Hydrology of the Alluvial Deposits in the Ohio River Valley in Kentucky

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1818

Prepared in cooperation with the Commonwealth of Kentucky, University of Kentucky, Kentucky Geological Survey, and the Kentucky Department of Commerce

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By JOHN T. GALLAHER *and* W. E. PRICE, JR.

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HYDROLOGY OF THE ALLUVIAL DEPOSITS IN THE OHIO RIVER VALLEY IN KENTUCKY

By JOHN T. GALLAHER and W. E. PRICE, JR.

ABSTRACT

In the Ohio River valley, water available for use is found in three interconnected and interrelated parts of the hydrologic system: on the surface, in the bedrock, and in the alluvial deposits. The alluvium is one of the major ground-water aquifers in the Central States, and future development of the area along the Ohio River will depend on the availability and quality of water from this source. Parts of the area are already heavily developed; others have an even greater potential, and a few have little potential or have problems related to quality or quantity of water.

Large quantities of water are available to wells drilled in the coarse basal alluvium. Saturated thickness of the alluvium increases downstream, from 35 feet near Ashland to about 110 feet in the Owensboro and Henderson areas. Yields of 200–800 gallons per minute from properly constructed drilled wells are not uncommon. Many high-discharge wells are located close to the Ohio River, where water movement between the river and the aquifer allows induced infiltration. Ground-water shortages can and do occur in some areas, in spite of this seeming abundance owing to heavy pumpage.

Quality, rather than quantity, of the ground-water supply will be the major controlling factor in the future. Under natural conditions the water is of the calcium bicarbonate type and contains varying amounts of sulfate; it is hard to very hard and has a high iron content. It also has a constant low temperature—a feature that makes it valuable for air conditioning and industrial cooling. As a result of man's activities in the valley, however, heating and chemical or organic pollution of the ground water occurs in varying degrees, and increased water usage may lead to greater problems of quality control.

Present and future development of ground-water supplies can best be done with foresight and an understanding of the hydrologic system as a whole. Users of large quantities of water should plan their well fields carefully and give adequate consideration to the problems of waste disposal. Pumpage should be inventoried more frequently, especially in areas where an increase in withdrawal may lower the water table excessively. To detect changes in quality of the ground-water supplies, a network of quality-of-water monitoring stations should be established throughout the Ohio River valley, especially in or near industrial and municipal areas.

INTRODUCTION

PURPOSE AND SCOPE

This report analyzes and interprets basic data on the ground-water resources of the alluvium of the Ohio River valley in Kentucky. It is intended to supplement a series of 14 hydrologic investigations atlases of the same area. The atlases consist of maps and sections which describe the geology and hydrology of the alluvium and the quality, availability, and occurrence of water within the hydrologic system. This report describes the hydrologic system and its function in the Ohio River valley and shows how the data presented in the atlases are applicable to further understanding and solution of some of the water problems of the valley.

The hydrologic investigations atlas series, as shown in figure 1, describes the geology and hydrology of the following areas, listed in downstream order:

HA–75, Catlettsburg to South Portsmouth,
HA–73, South Portsmouth to Manchester Islands,
HA–94, Manchester Islands to Silver Grove,
HA–98, Newport to Warsaw,
HA–97, Ethridge to Twelvemile Island,
HA–130, Prospect to southwestern Louisville,
HA–111, Southwestern Louisville to West Point,
HA–95, Wolf Creek to West Point,
HA–72, Hawesville to Cloverport,
HA–74, Lewisport to Owensboro,
HA–110, Stanley area,
HA–96, Spottsville to Reed,
HA–91, Henderson area,
HA–129, Uniontown area to Wickliffe.

WATER UTILIZATION AND WATER PROBLEMS

Municipalities and modern industry can thrive only on an adequate, dependable supply of water with moderately close quality tolerances. Supplies of raw water from rivers of the area sometimes fail to satisfy quality requirements owing to waste-water discharge, turbidity, and summer temperatures. Ground water, on the other hand, is uniform in chemical quality, free from turbidity, and cooler than surface-water supplies during the summer months. In some places ground water is the sole source of municipal or industrial supplies; elsewhere it may serve as a supplementary water source during low riverflow of the summer months or, because it is easily treated, as industrial-process water.

The alluvial deposits along the Ohio River constitute one of the principal sources of ground water in the Central States. E. H. Walker estimated (1957, p. 2) that a trillion gallons of water are in storage in the Ohio River valley alluvium. A perennial abundance is possible in many areas because of natural and induced infiltration of water from the river into the adjacent and underlying sand and gravel. Much development of the alluvial aquifer has already taken place, but the full potential of this source is far from being realized.

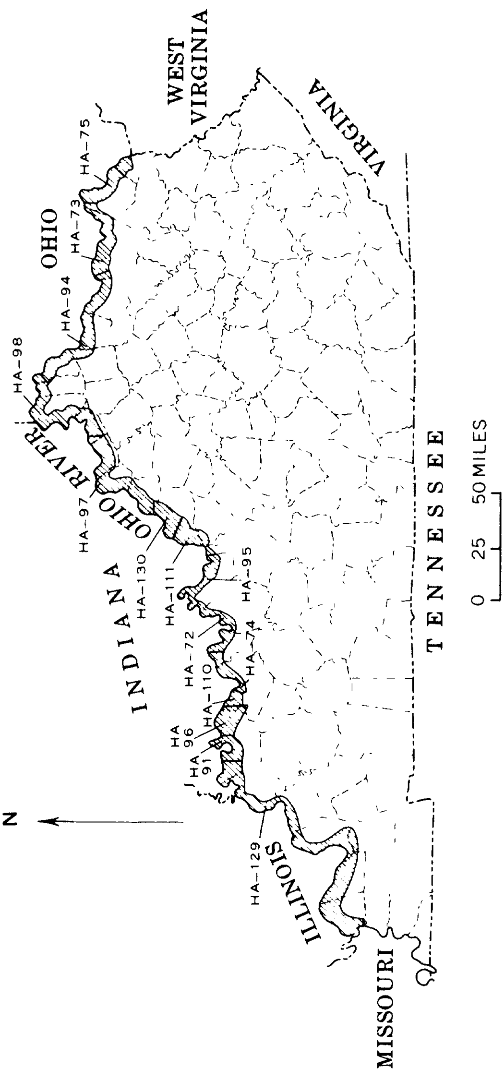

FIGURE 1.—Area covered by hydrologic investigations atlases of the Ohio River valley series, Kentucky.

Heavy pumping is currently confined to a few municipal and industrial areas, as Louisville and Ashland.

The adequacy and quality of the ground water in the Ohio River valley indicate that future progress, coupled with growing water-supply problems throughout the Nation, will lead to much greater use of this potential supply. Larger amounts will be needed for public and domestic supplies, industry, and agriculture.

Not only is the population of the area increasing, but so is the trend toward greater use of water per person. Automatic washing devices, garbage-disposal units, increased lawn care, and swimming pools all add to the quantity of water which is demanded from the available supplies.

In the petroleum industry, waterflooding, as a means of secondary recovery of crude oil from the oil-bearing formations, is becoming increasingly important. Three of the leading oil-producing counties in Kentucky are bordered on the north by the Ohio River, and at present about one-fourth to one-half of the production in these counties is by waterflooding methods (E. N. Wilson, Kentucky Geol. Survey, written commun., 1964). Eventually, most production will be by secondary-recovery methods, and water from the alluvium will probably be used wherever possible.

Annual precipitation is in excess of 40 inches per year. The time and rate of precipitation, however, do not necessarily coincide with the time of greatest need by crops. Many farmers are turning to irrigation as insurance against untimely dry periods. The increased yield and quality of irrigated crops, such as tobacco and vegetables, indicate that crop irrigation may be more extensively used in the future. A quantity of water sufficient for this purpose can be reached by driven or drilled wells in the alluvium in most areas of the flood plain.

Problems exist in the development of suitable ground-water supplies in some areas, and the increasing demands on the water system will probably create more and greater problems in the future. As the complexity of industrial and municipal development increases along the valley, the need for extensive cooperation and planning will also increase, so that the rights of all users will be protected. The surest way of protecting these rights, of course, is by the instigation and strict enforcement of wise legislation. The problem of quantity can be controlled by the proper spacing of wells in areas where the water-yielding properties of the alluvium are satisfactory for large developments. Quality control, however, is more complex; careful legislative regulation is necessary as a safeguard against factors that may degrade the quality of the ground-water supply.

PROCEDURES USED AND SUBJECTS COVERED

Fieldwork for this study was begun in 1955. Wells were inventoried to determine the depth, yield, depth to water, and the purpose for which the water is used. Wherever possible, pumping tests were made. Water samples were collected for chemical analysis, and samples of alluvium were tested for their hydrologic properties In addition, logs for thousands of water wells, oil wells, and test holes were collected from owners, drillers, and organizations concerned with oil-field activities.

The contact between the alluvium and the bedrock, as shown in atlases of the Ohio River valley series, was mapped either in the field or by the use of aerial photographs and topographic maps. The location of the contact between the Ohio River and the tributary alluvial deposits was approximated or was based on thickness and texture of deposits as recorded in well logs.

DESCRIPTION OF AREA

The Ohio River valley in Kentucky is approximately 666 miles long. It is a broad U-shaped rock-bottomed trough (fig. 2) partly filled with clay, silt, sand, gravel, and some deep lying boulders. The alluvial surface is relatively smooth and even and slopes gradually toward the river, except where it is broken by sloughs and remnants of alluvial terraces.

The Ohio River has cut through the upper part of the unconsolidated materials, and its winding course across the valley determines the width of the plain on either side of the river. On the Kentucky side of the river, the alluvium ranges in width from a few feet, in areas such as Greenup, to about 11 miles, near Stanley. The river in this area is now (January 1964) divided into pools by 18 navigation dams. Larger replacement structures, planned or under construction, will reduce this number to eight.

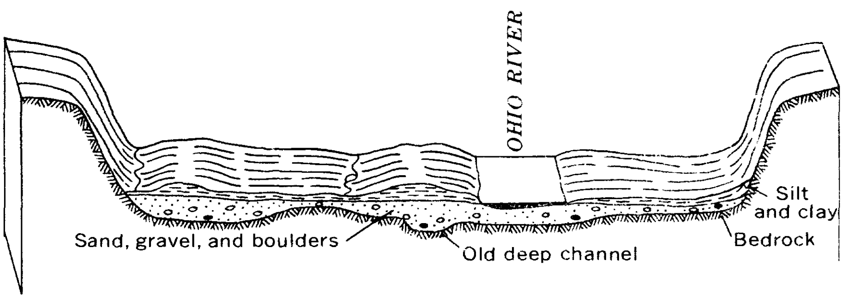

FIGURE 2.—Segment of the Ohio River valley (generalized).

Superimposed upon the valley floor are tributary streams and their deposits of fine-grained sediment. An indefinite boundary exists where these deposits merge with the coarser grained alluvium of the Ohio River.

The rich flood plain is used primarily for farming. Numerous oil fields have been developed in or near the flood plain in the western part of the State. Industry is concentrated in many areas along the valley, especially where the presence of coarse permeable alluvium allows the development of large water supplies and where dangers are minimal.

PREVIOUS INVESTIGATIONS

The deep channel, the alluvial deposits, and the geologic history of the Ohio River valley in Kentucky are described by E. H. Walker (1957). An atlas by Hendrickson (1958), which summarizes the occurrence of ground water in Kentucky, includes a section concerning the water of the alluvial deposits. These, and many other atlases and reports that give more localized information on the water resources of the valley, are included in the list of references.

ACKNOWLEDGMENTS

This report is one of a series published by the U.S. Geological Survey to describe the ground-water resources of Kentucky. The work was jointly financed by the U.S. Geological Survey and agencies of the Commonwealth of Kentucky; namely, the Kentucky Geological Survey and the Kentucky Department of Commerce.

The authors express their appreciation for the generous assistance of all those who contributed information or helped in the collection of data for this report. Data compiled by the late Otto Gutenson supplied valuable information concerning the geology of the Covington-Newport area. The Ashland Oil Co. and the Kentucky Geological Survey aided greatly by giving access to their well-log files. The Kentucky State Highway Department, the Illinois Central Railroad, the Louisville and Nashville Railroad, and the U.S. Army Corps of Engineers provided many useful logs of test holes. Leland Glidden and Joseph Valla of the Ranney Construction Co., Louisville, Robert Diehl and Charles Kelly of Diehl Pump & Supply Co., Louisville, and Fred Klaer, Jr., of Fred Klaer, Jr. & Associates, Columbus, Ohio, all contributed invaluable data in the form of well logs and pumping-test results.

HYDROLOGIC SYSTEM

The Ohio River valley may be thought of as a huge water container. Water is stored on or flows across the valley surface in the Ohio River and its tributaries, and even greater amounts of water are present beneath the land surface.

THE CONTAINER

The container is a trench which has been cut down into the bedrock and partly filled with water-deposited sediments.

During the ice age several glaciers, carrying rock particles, approached the area that is now the Ohio River valley. As one of the earlier lobes of glacial ice melted, torrents of water flowed out, carrying debris released from the ice. This waterborne debris, acting as an abrasive agent, scoured out the bedrock channel to its present size and shape. The erosion was accomplished in much the same way that the present river cuts its channel as it meanders across the valley.

The width and depth of the channel in any particular area were influenced largely by the hardness of the bedrock and its resistance to the cutting action of the waterborne debris. In areas of strong, resistant rocks, as at Madison, Ind. (fig. 3), the valley narrows, and the trench tends to have a smooth bottom and steep walls. The old deep channel occupies a relatively small part of the bedrock floor here, and its course coincides closely with that of the present river.

Where the rocks were generally less resistant the valley is wide and the valley walls are less abrupt. In these areas the meanders of the ancient river did not plane the floor of the trench to uniform smoothness. The deepest part of the buried channel meanders across the valley floor, and only by coincidence does it lie beneath the present stream channel. Buried bedrock hills, valleys, benches, and cusps lie beneath the valley alluvium. Good examples of many of these features are found in the Bon Harbor Hills region, west of Owensboro. The bedrock there rises as much as 140 feet above the surrounding valley

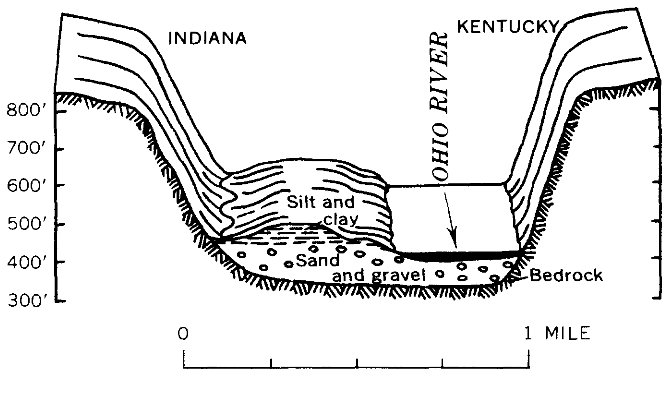

FIGURE 3.—Bedrock valley and alluvial fill in the Ohio River valley near Madison, Ind. (from Walker, E. H., 1957).

and 280 feet above the old deep bedrock channel, which splits and passes on either side of the hills. The presence of these channels and the existence of buried benches and hills are indicated ir well logs.

The fill material in the valley was deposited during the retreat of two later glaciers. Initially the great velocity and volume of the melt-water stream made possible the transport of all but the largest boulders. As the flow lessened so did the stream's ability to carry its load of heavy sediments. This caused the dropping out and deposition of fairly well-sorted glacial debris onto the valley floor.

The deposits can be divided into two somewhat heterogeneous but distinctly different types. The lower part, dropped by a fast-moving stream, is primarily composed of boulders, cobbles, gravel, and coarse sand (fig. 4). This coarse material forms a rather persistent layer atop the bedrock across the width of the valley. Some clay, silt, and fine-grained sand are also present, either mixed with the coarse material or in definite lenses. These finer materials represent periods of slack water or temporary ponding of the stream.

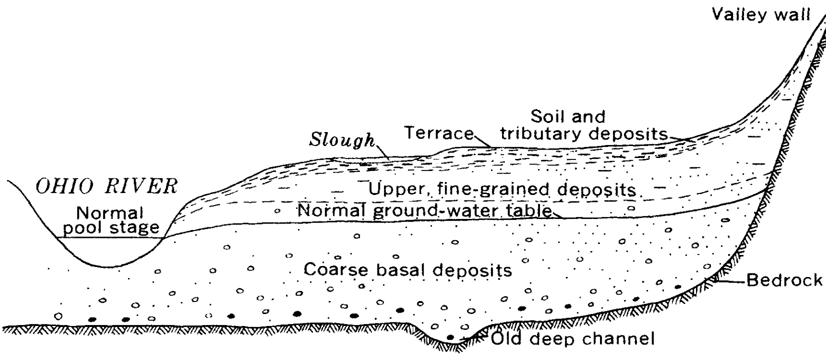

FIGURE 4.—Surface and subsurface features in the Ohio River valley (generalized).

The upper part of the valley deposits is composed mostly of finer grained material—clay, silt, and sand—deposited during the waning of the last glacier. Lenses of gravel and coarse sand are common, however, and represent periods of fast-moving water.

Initially, the total thickness of the valley deposits was as much as 180 feet, as indicated by remnants of the glacial sand and gravel far above the present valley floor.

Since the retreat of the last glacier, the Ohio River had meandered across the upper part of the alluvial fill, gradually cutting the valley surface down to its present level. In only a few places, as near Louisville, where it meandered over a buried rock bench, has the river eroded its way down to the bedrock. In many places along the valley as much as 140 feet of alluvium still remains.

Throughout this time the tributaries of the ancient Ohio River in Kentucky also were active, carrying their load of sediment into the valley. These streams deposited mostly clay, silt, and fine-grained sand. Where these lesser streams entered the main valley, an indefinite contact exists between valley and tributary sediments.

THE WATER

Precipitation is the source of essentially all water in the hydrologic system. It varies slightly in amount along the length of the valley; averages range from 40 to 46 inches annually. This amount is fairly evenly distributed throughout the year with only slightly more during the winter and early spring than throughout the rest of the year.

Water in the basin is in two major environments: on the surface, in stream channels; and underground, in the void spaces of the alluvium and bedrock. Surface water moves relatively rapidly through the area, but ground water moves so slowly that it can be considered as being in a form of storage. Water may move from one environment to another. Surface water, alluvial water, bedrock water, and the atmosphere are, therefore, all parts of one system.

Less than one-half of the precipitation is potentially available for use. In the study of a flood plain at Louisville, Rorabaugh (1946) calculated that of the 42.86 inches average annual precipitation for the area, nearly 23 inches returns to the atmosphere by evaporation, primarily during the warm months of the growing season (fig. 5). More than 8 inches of the remaining surplus flows directly over the ground to become part of the surface streams, and only 12 inches of the total moisture actually enters the ground. About 5 inches of this last amount is retained temporarily as soil moisture, to be lost later by evaporation and transpiration. After soil requirements are fulfilled, the remaining 7 inches percolates very slowly downward to become part of the ground-water system.

This precipitation study was made of a relatively undeveloped area, where the coarse basal alluvium is overlain by 5–40 feet of fine to very fine sand, silt, and clay, not atypical of the valley.

OHIO RIVER AND TRIBUTARIES

A large amount of water is carried through the valley by the Ohio River. As it passes, a considerable quantity of it is used by man, plants, and animals. Part of the water used is returned to the atmosphere by evapotranspiration, part becomes ground water, and part is returned to the river after use. At the same time the tributary

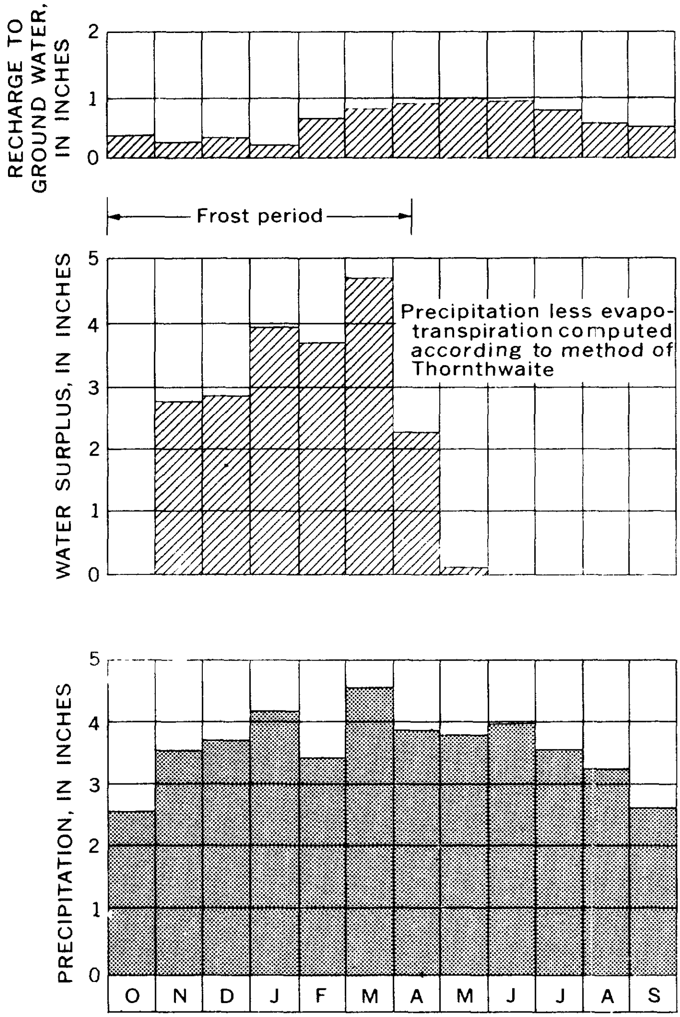

FIGURE 5.—Mean monthly precipitation, surplus water, and recharge to ground water, Louisville, Ky.

streams, overland runoff, and underground seepage add to the volume of the river. The flow of the Ohio River increases from an average of 50 billion gallons per day at Ashland, Ky., to three times that amount where the Ohio discharges into the Mississippi River.

GROUND WATER IN THE ALLUVIUM

Ground water occupies the open spaces between particles of sand and gravel, much as would water poured into a pan of dry sand (fig. 6).

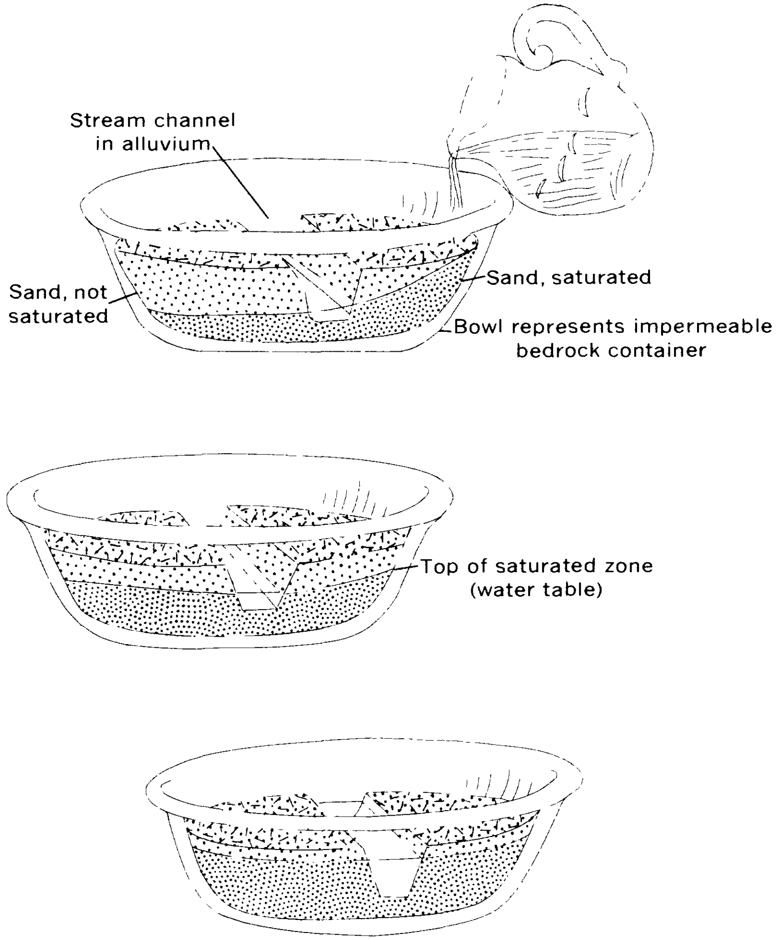

FIGURE 6.—Demonstration of the relation of the water table to the overlying unsaturated soil materials (adapted from Leopold and Langbein, 1960).

Water that enters the alluvium from precipitation percolates downward by gravity and follows the open spaces until it reaches either an impermeable barrier or the surface of the zone already saturated by water. The time necessary for this downward passage varies with the temperature and viscosity of the water, the perviousness of the material, and the distance to the ground-water surface. This may require several months under adverse conditions, such as those created by the presence of a thick impermeable clay layer.

The top of the saturated zone, known as the water table, is a free surface not confined by an overlying impermeable layer, and water in

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a well that penetrates such an aquifer will stand at the level of the water table. The water table is not flat, as is a body of surface water (fig. 7). The water-table level is highest near valley walls and lowest where it intersects channels of streams. This variance of level creates a gradient or slope which the water in the saturated zone follows laterally and downward until it intersects the river channel and becomes part of the surface water. The downgradient speed of ground water varies greatly within the saturated zone; it is fastest near the water table and decreases with depth in the basal parts.

Ground water that has no free surface but is confined by an overlying impermeable layer, such as clay, is known as artesian water. The overlying layer creates pressure on the aquifer and the water in a well penetrating such a zone will rise above the water table to an altitude known as the piezometric surface.

Two artesian conditions are fairly common along the Ohio River valley. Near the valley wall (fig. 7*A*) the more permeable materials are overlain by fine-grained less permeable deposits. Surface runoff and seepage from the bedrock area move downward and laterally through the coarser material along the ground-water gradient toward the river. If this lateral movement is blocked by overlying less permeable sediments, a pressure head is built up. Similar conditions prevail along the river (fig. 7*B*), where fine-grained stream deposits and clay slumping down along the riverbank may effectively block the flow of ground water into the stream. Also, high water in the stream may raise the water table in the alluvium near the river to such an extent that the water table is forced against an overlying impermeable clay layer. Under both conditions an artesian pressure head is created in the aquifer.

INTERRELATION BETWEEN AQUIFERS AND STREAMS

Water in the Ohio River and water in the alluvial aquifer are not separate entities. Rather, they are connected and interdependent parts of the water-supply system of the basin, and water can move from one environment to the other. Whatever affects the quantity or quality of one part, therefore, must also have an effect on the other.

Throughout most of the year ground water seeps into the stream channel (fig. 8, upper) and helps to maintain the volume of water in the river. Without this underground flow the Ohio River would be reduced to a trickle during times of drought. During floods, however, the situation is reversed (fig. 8, lower), and excess water in the river channel moves into and saturates the nearby alluvium or flows into the Mississippi River.

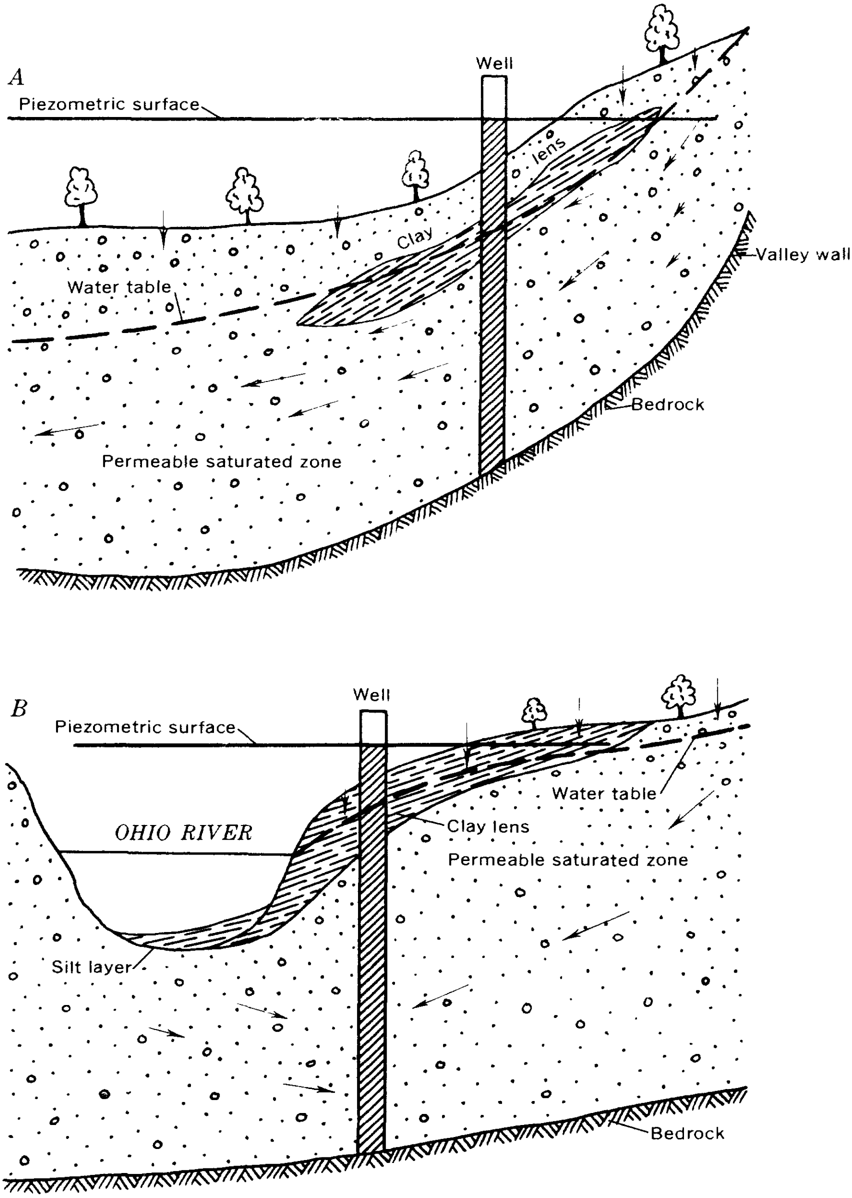

FIGURE 7.—Causes of some artesian conditions found in the Ohio River valley. *A*, Area near valley wall. *B*, Area near river. Arrows indicate direction of waterflow.

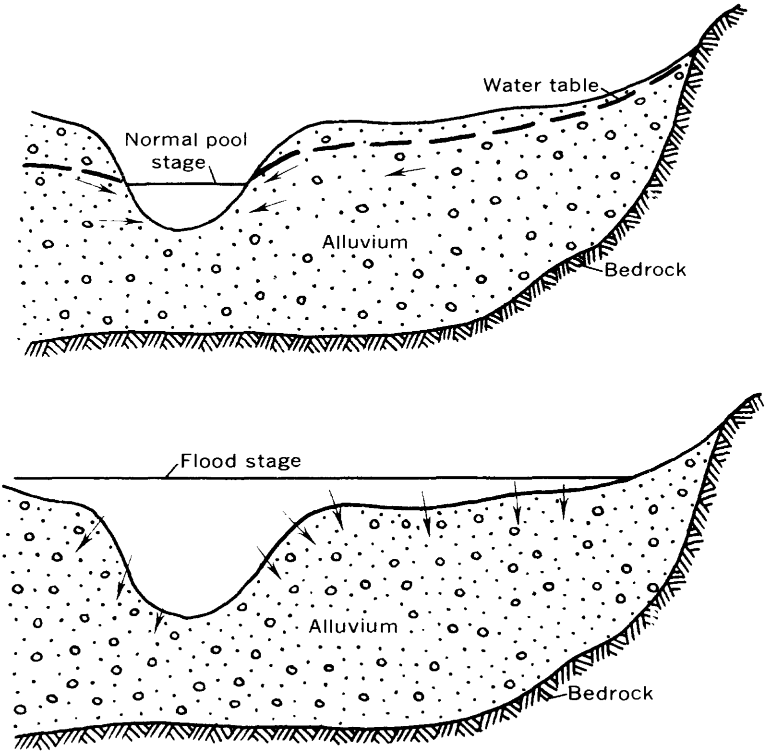

FIGURE 8.—Upper part: Ground-water drainage into stream channel. Lower part: Movement of surface water into aquifer during flood stage of river. Direction of waterflow is indicated by arrows in both parts.

CHANGES IN WATER AS IT MOVES THROUGH THE SYSTEM

Water enters the system as precipitation. This water is never entirely pure when it reaches the ground surface, for while it is still in the atmosphere it takes gases—notably carbon dioxide—into solution. Though dilute, this water is very slightly acidic and corrosive in nature. As the water moves downward through the soil and underlying alluvium, it dissolves a minute part of the minerals with which it comes in contact. These minerals are taken into solution in the form of charged particles called ions. The major positively charged ions (cations) generally found in ground water are calcium, magnesium, sodium, and potassium, and minor amounts of iron, manganese, and silica. The negative ions (anions) generally present are bicarbonate, sulfate, and chloride, and lesser amounts of carbonate, nitrate, and fluoride. The source and significance of charged ions are shown in table 1. These ions remain in solution unless they are precipitated by changes in temperature, pressure, or chemical environment.

TABLE 1.—*Source and significance of dissolved mineral constituents and physical properties of natural waters in the Ohio River valley alluvium*

[ppm, parts per million]

Constituent or physical property	Source or cause	Significance
Silica (SiO_2)	Dissolved from almost all rocks and soils, usually in small amounts from 1–30 ppm. High concentrations—as much as 100 ppm—generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from almost all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface water usually indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. Content of more than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. The U.S. Public Health Service (1962) recommends, in its water-quality standards, that iron and manganese together should not exceed 0.3 ppm; larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not as common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark-brown or black stain. Federal standards recommend that iron and manganese together should not exceed 0.3 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from almost all soils and rocks, especially limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Large quantities of magnesium are present in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Water with low calcium and magnesium contents desired for electroplating, tanning, dyeing, and textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from almost all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Federal standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage. Found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal standards recommend that chloride content should not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950).

TABLE 1.—*Source and significance of dissolved mineral constituents and physical properties of natural waters in the Ohio River valley alluvium*—Continued

[ppm, parts per million]

Constituent or physical property	Source or cause	Significance
Nitrate (NO_3)	Decaying organic matter, sewage, and soil nitrates.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 ppm of nitrate may cause a type of methemoglobinemia in infants, sometimes fatal. Water with high nitrate content should not be used in baby feeding (Maxcy, 1950). Nitrate has shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Federal standards recommend that dissolved solids should not exceed 500 ppm. Water becomes unsuitable for many purposes when it contains more than 1,000 ppm of dissolved solids.
Hardness as $CaCO_3$	Nearly all the hardness in most waters is due to calcium and magnesium. All metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–200 ppm, hard; more than 200 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water.	Specific conductance is a measure of the capacity of water to conduct an electric current; varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25°C.
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides and phosphates, silicates, and borates raise the pH.	pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. The pH is a measure of hydrogen-ion activity. The corrosive properties of water generally increase with decreasing pH; however, excessively alkaline water may also attack metals.
Temperature		Affects the usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground water from moderate depths usually is nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases on the average about 1°F with each 60-ft increment of depth. Seasonal fluctuations in temperatures of surface water are comparatively large—depending on the depth of water—but do not reach the extremes of air temperature.

Most water in the alluvium is more highly mineralized than is the water in the Ohio River. The concentration of dissolved solids in ground water averages slightly more than 400 ppm (parts per million) as compared with about 220 ppm in river water. The amount and type of mineralization in water depends on the availability of minerals with which the water can react and the time it takes for these reactions to come to equilibrium.

The temperature of ground water remains fairly constant throughout the year and generally approximates the average annual air temperature of about 57°F. Exceptions exist in shallow dug wells where the water is more exposed to changing air temperature.

Ground water under natural conditions is generally nonturbid, colorless, and usually pure bacteriologically. It has the further desirable characteristic of being fairly constant in quality throughout the year. River water varies greatly in composition both seasonally and from day to day. Its temperature during the year ranges from slightly over 32°F to about 87°F, it is often turbid and colored, and is affected by municipal and industrial wastes. Ground water may be used advantageously as process water because of its uniform chemical composition for it is more easily treated than surface water.

CONTROLLING FACTORS IN WATER-SUPPLY DEVELOPMENT

AVAILABILITY

Certain inherent factors determine the amount of ground water available to a well system. There must be a layer of water-saturated material with a source of recharge to replenish the water withdrawn from the system. Also, this material must be of such texture, thickness, and extent that it can yield water at a satisfactory rate. In areas where the physical properties of the aquifer are not conducive to yielding large supplies of water, it is necessary to be especially judicious in the choice of type, construction, and location of a well.

SATURATED THICKNESS

The saturated thickness of alluvium is the vertical distance between the water table and the underlying bedrock; it varies both in time and space along the Ohio River valley. The variation of the height of the water table determines the thickness of the saturated zone and represents the balance between water entering the alluvium by precipitation, flooding, and bedrock seepage and that leaving the alluvium by evapotranspiration, drainage, and withdrawal by pumping.

Most water that recharges the aquifer enters the ground during winter and early spring. Precipitation is slightly greater then, and the Ohio River is filled to overflowing as melting snows from upstream overload the tributary streams. The lowland areas along the Ohio Valley are inundated for long periods of time, and when the river recedes much of the land surface is waterlogged. Near the river where permeable formations are exposed, recharge to the aquifer may be very rapid. Throughout most of the valley bottom, however, the saturated upper part of the alluvium is relatively impermeable, and downward movement of the water to the water table may take months.

Though rainfall throughout the rest of the year averages from 3 to 3½ inches per month, it has little effect on ground-water levels, for very little of it gets below the soil level. High temperatures increase evaporation losses, and growing plants return much water to the atmosphere (fig. 9). During the growing season only a rain of unusual intensity and duration would contribute to the ground-water supply. Most ground water, therefore, is added to the system during the winter and early spring, and an unusually dry summer has no great immediate effect upon the saturated thickness of the aquifer.

In addition to the natural evapotranspiration losses, greater quantities of water are pumped during the summer months for cooling and irrigation purposes. Most of this water is not returned to the ground-water supply. Thus, after midsummer, water is removed from the zone of saturation by man and by natural seepage into stream channels at a rate that exceeds the rate of recharge to the aquifer.

Maximum thickness of the saturated zone increases downstream along the Ohio River valley from an average of 35–40 feet in the easternmost section to about 110 feet in the Owensboro and Henderson areas.

The saturated thickness also increases across the valley (fig. 9) toward the river. Near the valley wall, although water-table altitudes are much higher than those near the river, the alluvium has thinned to such an extent that the saturated thickness is greatly reduced. An exception to this occurs where the presence of the old deep channel in the valley adds several feet of thickness to the basal part of the saturated zone.

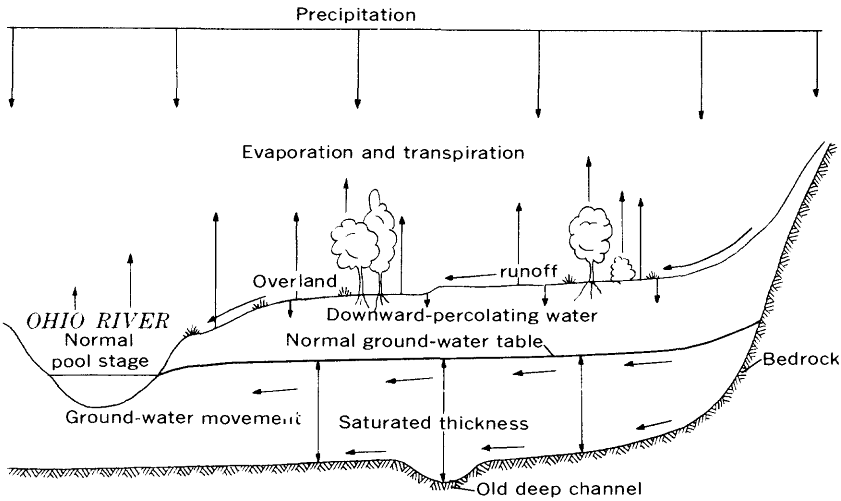

FIGURE 9.—Movement of water in the hydrologic system of the Ohio River valley.

A more favorable condition exists in the alluvium close to the river. Though the actual altitude of the water table is lower than that near the valley-wall area, it is perennially at or above stream level. Wells in this area, if they penetrate below the low-flow level of the Ohio River, will yield water throughout the year.

Data shown in the hydrologic atlases can be used to determine the thickness of the saturated zone in many areas along the Ohio Valley. The difference between the land-surface altitude and the altitude of the bedrock (as shown by contours or by actual figures) represents the total thickness of alluvium in an area. The alluvium-thickness figure minus the figure that represents the depth to water equals the thickness of the saturated alluvium.

For example, a well is to be drilled in an area where the land surface is about 380 feet above sea level. The 260-foot bedrock contour in the hydrologic atlas passes close by the proposed location of the well. Subtraction (380−260) shows that the alluvium at this point is approximately 120 feet thick. The data for a nearby well shows 30 feet as the depth to water. The depth-to-water figure subtracted from the total-thickness figure (120−30) shows that there probably is 90 feet of saturated alluvium present. Deviations from the calculated saturated thickness are usually caused by the seasonal fluctuation of the water table.

OCCURRENCE OF WATER IN THE ALLUVIUM

Water in the zone of saturation occupies the space between the grains of alluvium. The percent of this void space in a given total volume of alluvium is called porosity; it governs the amount of water that can be stored in an aquifer. Porosity is dependent upon shape, arrangement, degree of compaction, and cementation of the particles. It is not, however, dependent upon grain size, so long as the size is uniform. A coarse graded gravel, for example, has no greater porosity than a silt or fine-grained sand of uniform size. Alluvium composed of a mixture of grain sizes is more compact and has a much smaller porosity than alluvium of a uniform grain size, because the smaller grains fill up the spaces between the larger grains.

Porosities of the alluvial deposits in the Ohio River valley are generally high. The sorting action of the streams has created deposits of relatively uniform grain size. A study of 66 samples of alluvium taken along the Ohio Valley in Kentucky showed an average porosity of 43.2 percent. The maximum porosity is 53.5 percent; the minimum, 27.7 percent. Most samples showing low porosity were collected from areas where Ohio River alluvium had been mixed with tributary alluvium. In those areas, owing to mixing, a greater variety of grain sizes exists. Physical characteristics of the Ohio River alluvium

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where mixing has not taken place are probably such that the overall porosities are higher than those shown by the tests.

WATER MOVEMENT

A high percentage of contained or stored water, however, is no guarantee that the water can move freely through the aquifer or that it can be readily pumped from a well. Movement requires that the material also must be pervious to the passage of water. This quality, called permeability, depends on the size and shape of the void spaces and upon the size, shape, and extent of the interconnections between these spaces. The openings in a coarse gravel of uniform size have good interconnections and readily permit movement of the contained water. In contrast, much water adheres to the containing particles in fine-grained alluvium and does not move freely. Such materials are relatively impermeable to the passage of water.

Quantitatively, perviousness is expressed as a factor known as the permeability coefficient. This is the rate of waterflow, in gallons per day, through a 1-foot-square cross section of aquifer under certain standard conditions. Permeabilities given in this report were determined by laboratory analysis of alluvial samples. Transmissibility, a measurement mentioned in the tables of some hydrologic atlas sheets of the area, is a measure of the capacity of the full thickness of an aquifer to transmit water at the prevailing water temperature and arbitrarily assumes the aquifer to be composed of uniform-sized material. Transmissibilities were computed from the results of pumping tests.

Table 2 presents, by atlas area, the data from permeability and transmissibility tests of alluvium along the Ohio Valley in Kentucky. Conditions that create the extremes of either exceptional or very poor water-supply potential tend to be somewhat localized.

Data concerning the previously mentioned porosity studies (p. 19) show that porosity does not necessarily indicate permeability. The highest porosities were those of a windblown silt (loess) which caps many hills in western Kentucky. Permeability coefficients of the loess samples, however, averaged only 1.6 gpd per sq ft (gallons per day per square foot) as compared with an overall average of 259 gpd per sq ft for all samples of the alluvial area. The highest permeabilities were found in uniformly sized medium-grained sand deposits. If gravel had been tested, the permeabilities would have been even higher.

It is believed that the average coarseness of the basal alluvium, and thus its perviousness, decreases downstream along the Ohio River valley. Nevertheless, in most areas downstream, lenses of gravel or even cobble-sized material exist, just overlying the bedrock. This

TABLE 2.—*Hydrologic characteristics of the alluvial deposits and specific capacities of wells along the Ohio River in Kentucky*

Area of Hydrologic Investigations Atlas	Permeabilities (gpd per sq ft)				Transmissibilities (gpd per ft)				Specific capacities (gpm per ft)			
	Number of samples	Maximum	Minimum	Median	Number of tests	Maximum	Minimum	Median	Number of tests	Maximum	Minimum	Median
HA-75, Catlettsburg-South Portsmouth	5	1,360	427	750	4	314,000	6,800	20,950	14	70	4	18
HA-73, South Portsmouth-Manchester Islands	3	120	1	60					4	83	5	15
HA-94, Manchester Islands-Silver Grove	1	280	280	280					13	82	8	34
HA-98, Newport-Warsaw					1	20,000	20,000	20,000	8	39	1	19
HA-97, Ethridge-Twelvemile Island	1	300	300	300	1	18,000	18,000	18,000	12	164	2	28.5
HA-130, Prospect-southwestern Louisville	32	1,700	120	480	6	121,000	18,000	84,000	71	500	6	40
HA-111, Southwestern Louisville-West Point	22	1,400	150	513	2	45,000	20,000	32,500	3	36	15	20
HA-95, Wolf Creek-West Point	4	3,000	960	2,800	4	185,000	49,000	124,000				
HA-72, Hawesville-Cloverport	1	310	310	310					1	29	29	29
HA-74, Lewisport-Owensboro	7	[1] 140,000	100	570	2	[1] 360,000	55,300	207,650	27	200	13	46
HA-110, Stanley									5	160	55	110
HA-96, Spottsville-Reed	4	750	70	380								
HA-91, Henderson									10	43	5	14
HA-129, Uniontown-Wickliffe	22	700	.005	180					5	120	9	26
All areas	102	[1] 140,000	.005	460	20	[1] 360,000	6,800	52,150	173	500	1	32

[1] Disturbed sample with fines removed during jetting of well.

is probably due to the presence of glacially fed tributaries during various periods of the ice age.

In some localities clay and silt deposits may be of such extent that they effectively hinder the movement of water within the alluvium. Areally extensive clay lenses at any depth effectively reduce the vertical passage of water that would otherwise move downward to recharge the more permeable basal material. Thick deposits of silt are also found locally, often near the mouths of sluggish tributary streams that empty into the Ohio River. In a few places they constitute almost the full thickness of the alluvial fill. Even where these fine-grained deposits are within the zone of saturation and are highly porous, they transmit water very slowly and are poor aquifers.

EFFECT OF PAVING OR FILL

The recharge of an alluvial aquifer by rainfall requires that the land surface be porous and permeable. In cities and heavily industrialized areas, much water available for aquifer recharge is rejected. Buildings, paved surfaces, and areas of dense artificial-fill material effectively block the downward passage of water and divert it to stormsewer systems which carry it to the streams. In the Louisville area, for example about 3.5 feet of rain falls yearly. This amounts to over 800 million gallons of water in a square-mile area. The loss of water by runoff in an urban area like Louisville would be at least 50–60 percent, as compared with 15–20 percent runoff in a rural area.

DEVELOPMENT OF GROUND-WATER SUPPLIES

TYPES OF WELLS

Water wells vary greatly in size and complexity of construction. The type used depends upon the water requirements, the characteristics of the aquifer, and the cost of installation and maintenance. A water well of modern design is constructed with a screen at the lower end which allows water to enter but filters out sand and silt from the water supply.

Many wells in the Ohio River valley are either dug or driven. They are simple in design (fig. 10) and are relatively inexpensive. Dug wells are constructed with no screen. The water flows through the bottom of the well, which is (most of the time) below the static water level of the area. Because these wells have relatively large storage capacities, they are especially useful for drawing water from aquifers of low permeability. The wells are, however, subject to contamination by surface seepage unless the well casings completely seal off the alluvium above the aquifer. With the exception of the Jackson Purchase region, most dug wells in the Ohio River valley have been sup-

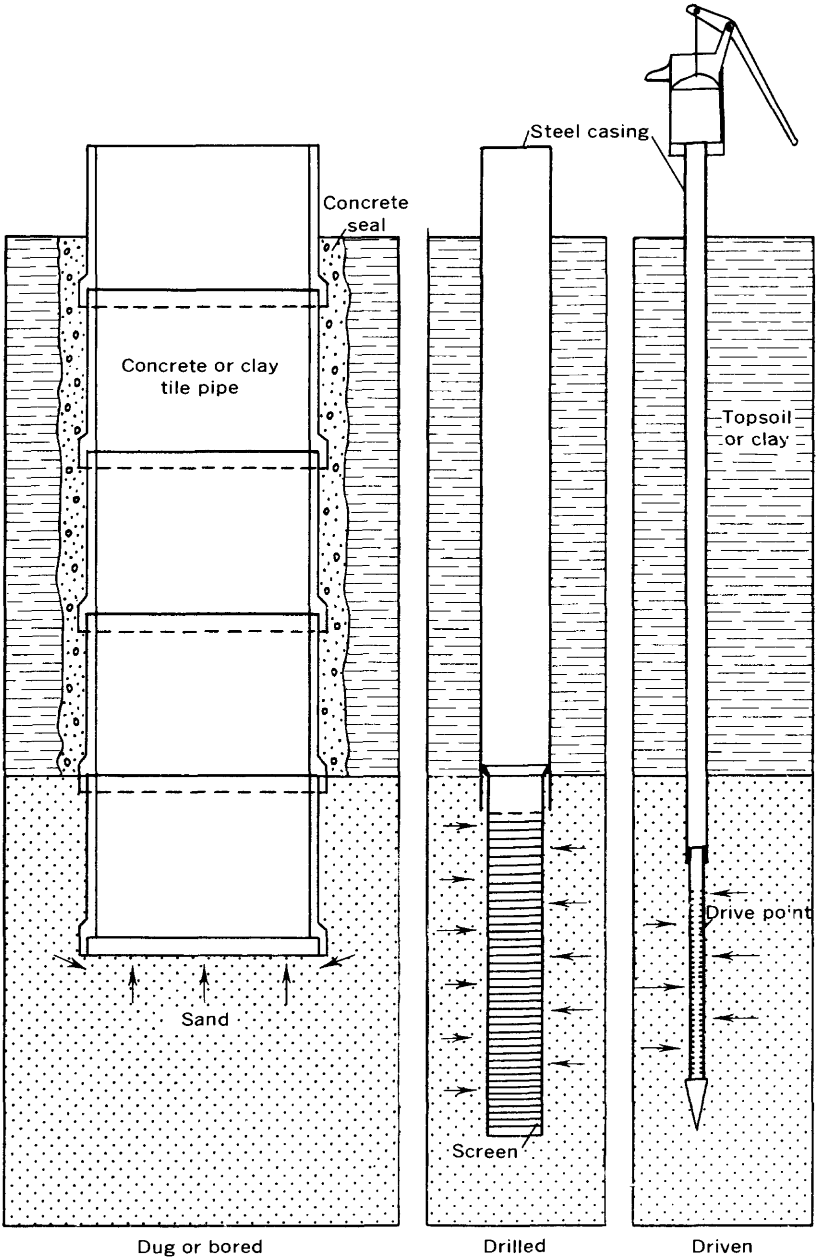


FIGURE 10.—Types of wells commonly constructed in alluvium.

planted by 1¼- or 2-inch-diameter driven wells. A driven well consists of a point and well screen that are driven down into the zone of saturation.

Both dug and driven wells generally furnish enough water for modern domestic supplies by use of power pump and pressure systems; however, many of these wells are restricted to pumping water from relatively shallow depths. Yields are normally less than 10 gpm (gallons per minute) primarily because of well depth and pump type rather than because of any deficiency in the aquifer. These low yields are exceeded in irrigated areas where two or more larger diameter (3- or 4-in.) driven wells are usually coupled or ganged together. Such systems commonly yield 200–500 gpm.

Most industrial- and municipal-supply wells in the Ohio River valley are drilled (fig. 10). Most of these wells are 6–18 inches in diameter, screened, and, where properly constructed, usually penetrate the entire thickness of the aquifer. Discharges of 1,000 gpm from such wells are not uncommon.

Radial-collector wells are more complex in construction (fig. 11) than the wells just described. The radial-collector wells are large in diameter and pump water through horizontal screened pipes that radiate outward, generally parallel to or beneath the river. The pipes extend as far as 200 feet into the surrounding alluvium. These wells are designed for large yields and withdraw water from the aquifer close to and below the river by induced infiltration. One of these wells can supply as much as 5,000 gpm if it is properly constructed in permeable material.

SPECIFIC CAPACITY

Specific capacity is the measurement commonly used for rating the yield of a well. Quantitatively, it is the discharge rate of a well per unit of drawdown, generally expressed as gallons per minute per foot of drawdown. It depends on the permeability of the aquifer, but it is also affected by the type and size of the well, the degree of screen incrustation, the size of the well-screen slots, and the duration of the pumping tests. Theoretically, doubling the discharge of a well doubles the drawdown; however, such a ratio applies only to the first few feet of water drawdown and does not make adjustment for the fact that such drawdown may expose some of the screen slots, thus reducing intake area.

Specific capacities of selected wells along the Ohio River valley (table 2) range from 1 to 500 gpm per ft and average 51 gpm per ft. The large range of values is primarily due to variations in the controlling factors mentioned above.

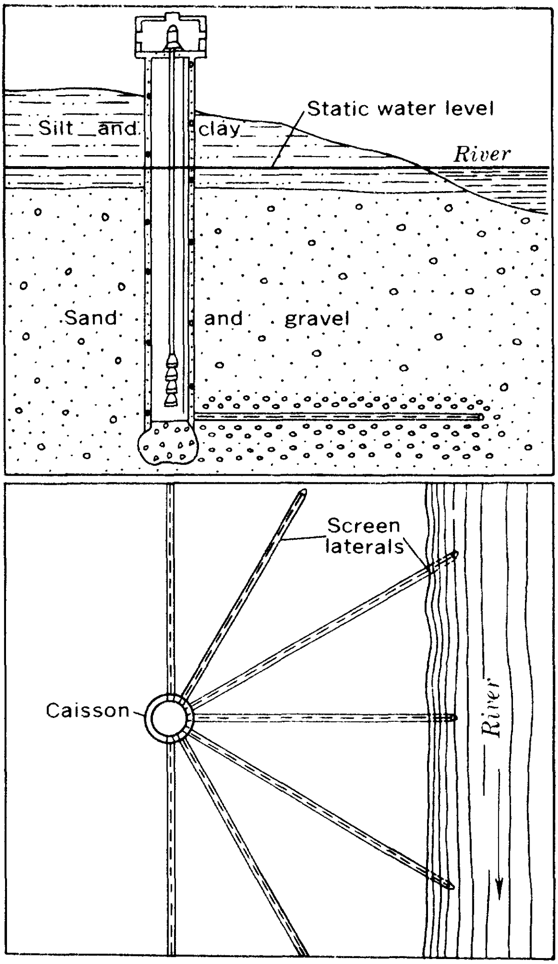


FIGURE 11.—Typical radial-collector well shown in section and plan.

CONES OF DEPRESSION

Under water-table conditions the water is an unpumped well stands at the height of the static level of the surrounding aquifer. The water in the formation moves through and around the well, following its normal path toward the point of discharge.

When pumping begins, however, the water level inside the well drops rapidly, and the water table near the well approximates the shape of a broad funnel with the well near its center (fig. 12). This funnel, or cone of depression, forms because of the difference in pressure between the water in the well and that in the aquifer. Water within the aquifer moves radially inward and downward along and beneath the slope of this newly created water surface toward the level of the water in the well. Water-level observation wells at various distances from the pumped well (fig. 12) show that the lowering of the water level in the aquifer decreases with distance from the discharging well. The

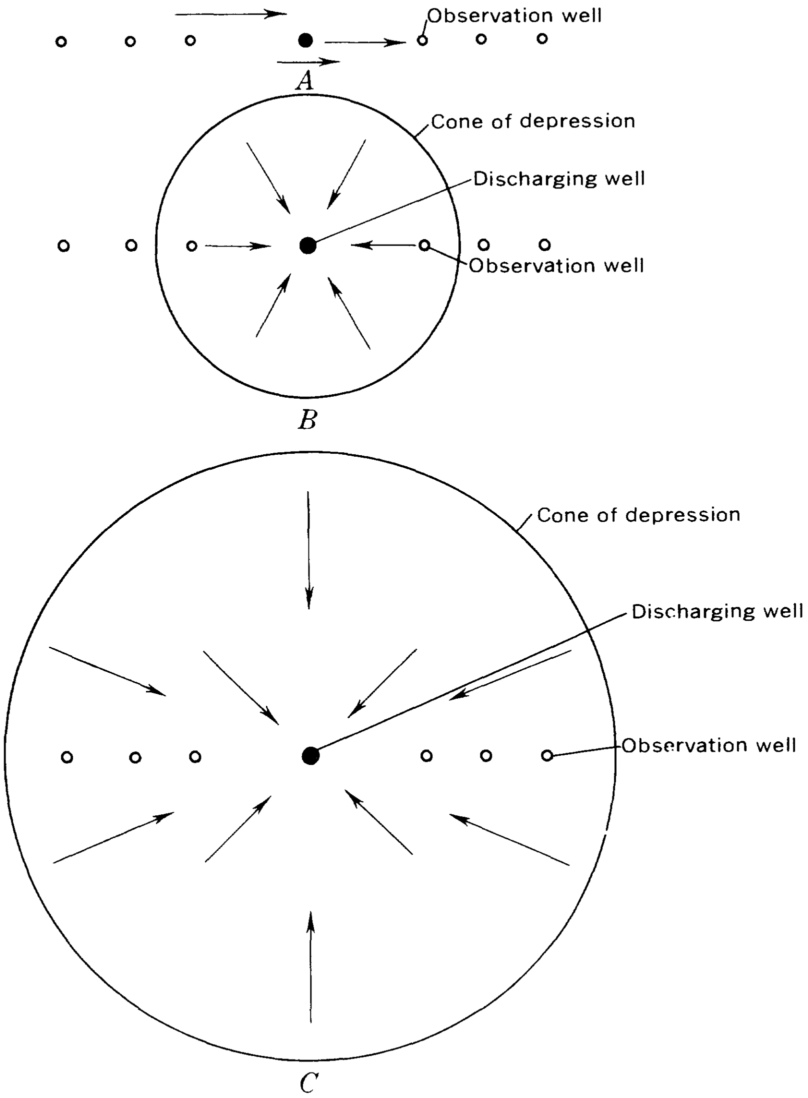
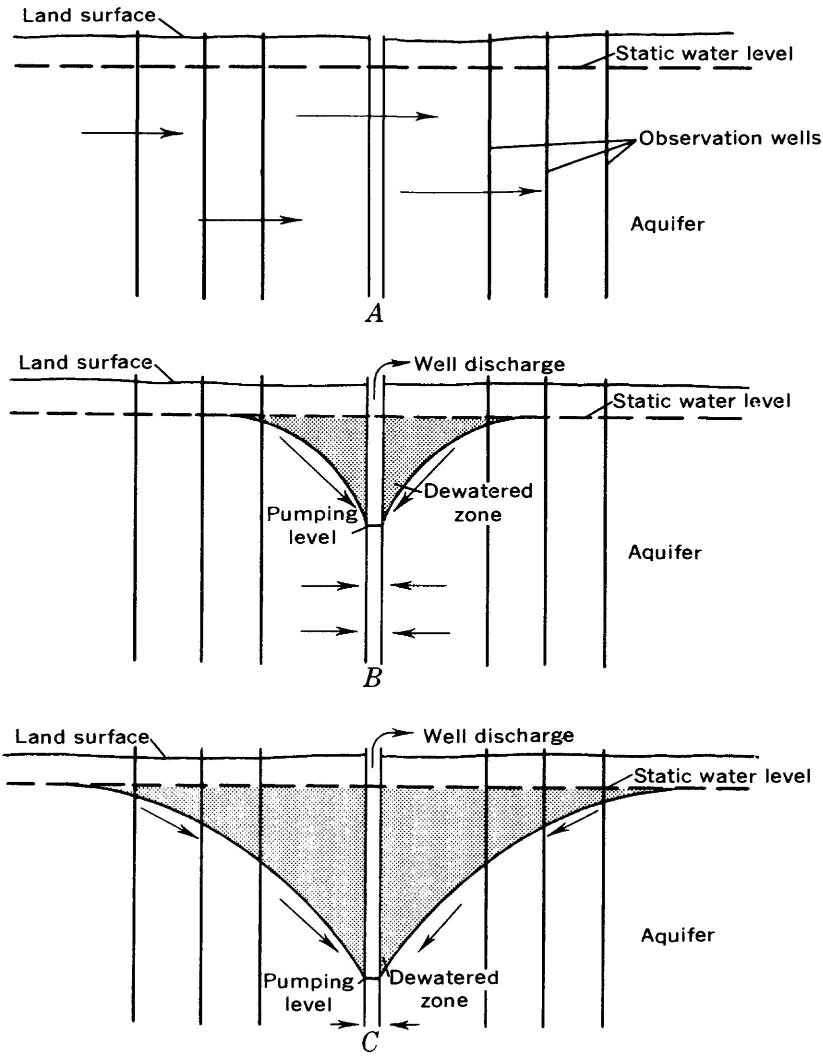


FIGURE 12.—The expansion of cone of depression when well is pumped, shown pumping. *B*, Cone forms when discharge exceeds rate at which water at which water enters area of influence of well.

volume of alluvium between the original static level and the new depressed level is dewatered according to the amount of well discharge.

The water level in a well drops and the cone of depression, or influence, expands outward and downward until the rate at which water moves through the aquifer toward the well is virtually equal to the



in plans and sections. Arrows indicate direction of waterflow. *A*, Before enters area of influence of well. *C*, Cone stabilizes when discharge equals rate

rate of well discharge. If the pumping rate is steady and does not exceed the available recharge, the system reaches an equilibrium. An increase in the pumping rate causes the lowering of water in the well and the lowering of the cone of depression until recharge to the well's area of influence again virtually equals the discharge of the well.

In many areas the cone of depression cannot extend indefinitely in all directions. If the discharging well is near a bedrock area or an impermeable layer of alluvium, as in figure 13, the expansion of the cone in that direction may be stopped. The cone must then develop in other directions to dewater an area that has enough recharge to balance the discharge. When pumpage exceeds recharge to the same area for prolonged periods and the cone of depression cannot expand farther, the water levels continue to decline, and the well "goes dry."

Where pumping wells are too closely spaced, (fig. 14) the cones of depression overlap and wells compete for the supply of available water. Drawdowns may then be excessive, and none of the wells yield as much as they could without the interference from adjoining wells.

Extensive cones of depression exist in some areas along the Ohio River valley, such as Ashland, southwestern Louisville, and Owensboro, where there is much competition for available ground water from relatively confined areas. In some locations the wells are too close together, and the rate of withdrawal of water greatly exceeds the natural recharge of the aquifer. The result is a spreading and lowering of the cones of depression and, consequently, a great reduction in thickness of the zone of saturation.

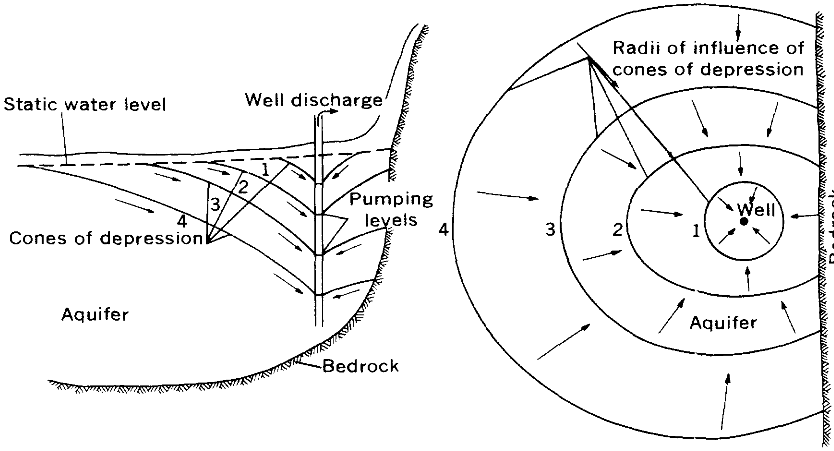


FIGURE 13—Increased drawdowns and spread of cones of depression resulting from increased or prolonged pumpage near an impermeable barrier. Arrows show direction of ground-water movement.

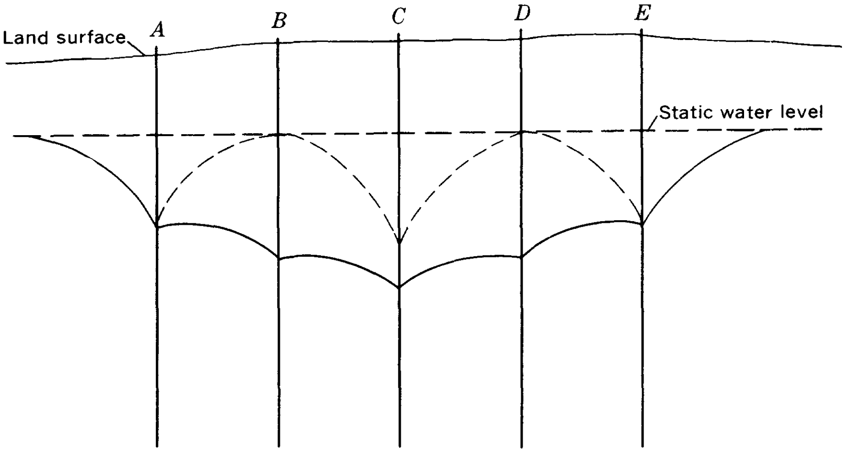


FIGURE 14.—Effect of too-close spacing of wells. Dashed line represents the cones of depression that resulted when alternate wells (*B* and *D*) were not pumped.

INDUCED INFILTRATION

When a cone of depression reaches the water of a perennial stream (fig. 15), the normal ground-water gradient is reversed, water moves from the stream into the alluvium, and conditions result that are favorable for large yields. When this happens the pumping level and the cone of depression soon become stabilized and remain so until the rate of discharge is changed. This principle, known as induced infiltration, is used to advantage in many areas of heavy pumpage

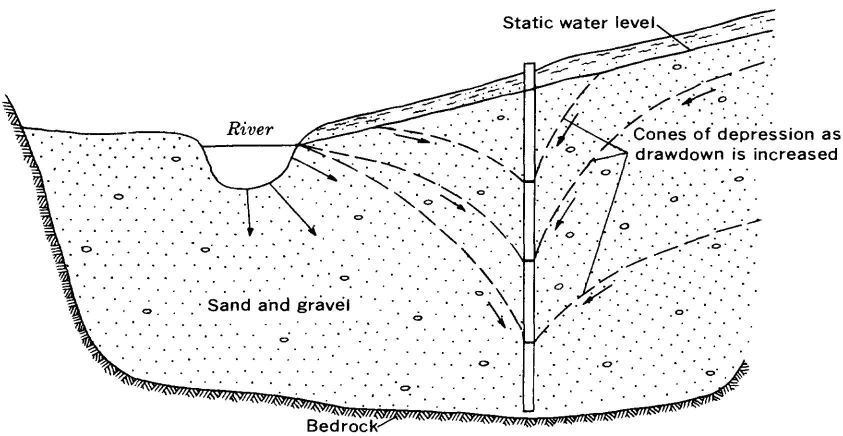


FIGURE 15.—Cones of depression where recharge is induced from a perennial stream. Arrows indicate direction of waterflow.

along the Ohio River valley, as at Ashland, Louisville, Brandenburg, and Owensboro.

Wells are placed in permeable material close to the river, and infiltration of the river water into the alluvium is thereby induced. Such wells yield a mixture of ground water and river water; however, passage through the intervening alluvium also provides a filtering action to the stream water and removes suspended material, color, and bacteria to a degree that makes the water suitable for many uses. Sustained yields of nearly 1,000 gpm from these wells are not unusual.

Two conditions (fig. 16) reduce induced infiltration of river water in some areas. In one condition, once-horizontal clay layers are undercut by the stream so that the clay collapses over the surface of the more permeable alluvium. In the other condition, the floor of the river channel is covered with fine-grained silt, by either the natural cut-and-fill processes of the river currents or disturbances such as dredging. The results for both are the same. The fine-grained materials of low permeability effectively slow the passage of water into the more permeable deposits and greatly reduce the rate of recharge to the aquifer.

WELL LOCATION

One major problem in water-supply development is the lack of detailed information regarding the geology and hydrology of certain areas in the Ohio Valley. Hence, for many areas only generalities or comparisons with similar or nearby sites can be made.

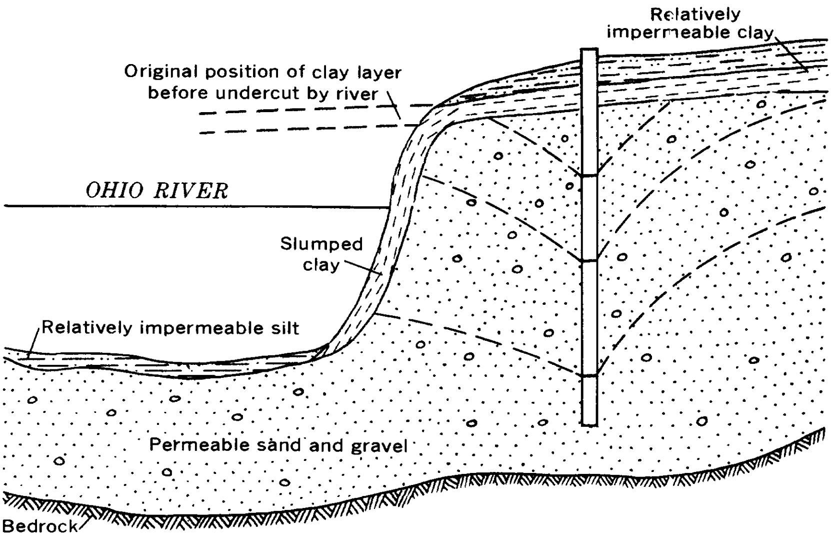


FIGURE 16.—Relatively impermeable layers that reduce the rate at which Ohio River water moves into the more permeable sand and gravel.

Drilling for industrial and municipal water supplies should therefore be preceded by a carefully planned test-well program when economically feasible. Properly spaced exploration holes will help to determine the location of the permeable parts of the aquifer in the proposed area. Preliminary pumping tests of the more promising sections of the aquifer will furnish data on the transmissibility, drawdowns, and yields that can be expected. The spacing of wells can be predetermined to avoid overlap of the cones of depression within the well field. In general, large overall yields along the Ohio River valley can be expected from well fields that extend in a line parallel to the Ohio River (fig. 17) and, thus, are perpendicular to the direction of underground water movement. Positioning of wells in this manner exposes the entire well field to recharge and helps to reduce drawdown in the aquifer.

WELL CONSTRUCTION AND DEVELOPMENT

Certain conditions are conducive to high yields regardless of well type. The deeper the well, the farther it penetrates into the water-saturated zone and the greater will be its allowable drawdown and yield. In most places along the Ohio Valley, the aquifer is more permeable at greater depths and will transmit water more readily to the well system. Wells in the valley area, ideally, should penetrate the full thickness of permeable alluvium. This, of course, is not generally practicable for dug or driven wells.

Proper development upon completion of a well is also essential. A certain amount of fine material is generally present in the coarser alluvium surrounding the well; this material reduces the permeability of the aquifer and is objectionable if it is pumped into the water-supply system. During well development much of the fine material adjacent to the well is removed by surging, backwashing, or overpumping (fig. 18). An alternate method of removal is to place a layer of specially graded gravel (fig. 19) between the well screen and the aquifer. All these methods increase the effective diameter of the well, help prevent the entrance of fine sand particles, and provide a more uniform and permeable material surrounding the well. Drawdown is reduced, specific capacity is increased, and there is less sand in the water from the well. The effectiveness of proper development can be noted from the results of the permeability analyses of alluvial samples collected from a well in Owensboro. This well was drilled by a jetting process which removed most of the fine material from the borehole in a manner similar to that used to remove fines from the aquifer close to the well during development. Laboratory analyses of these samples showed permeabilities as high as 140,000 gpd per

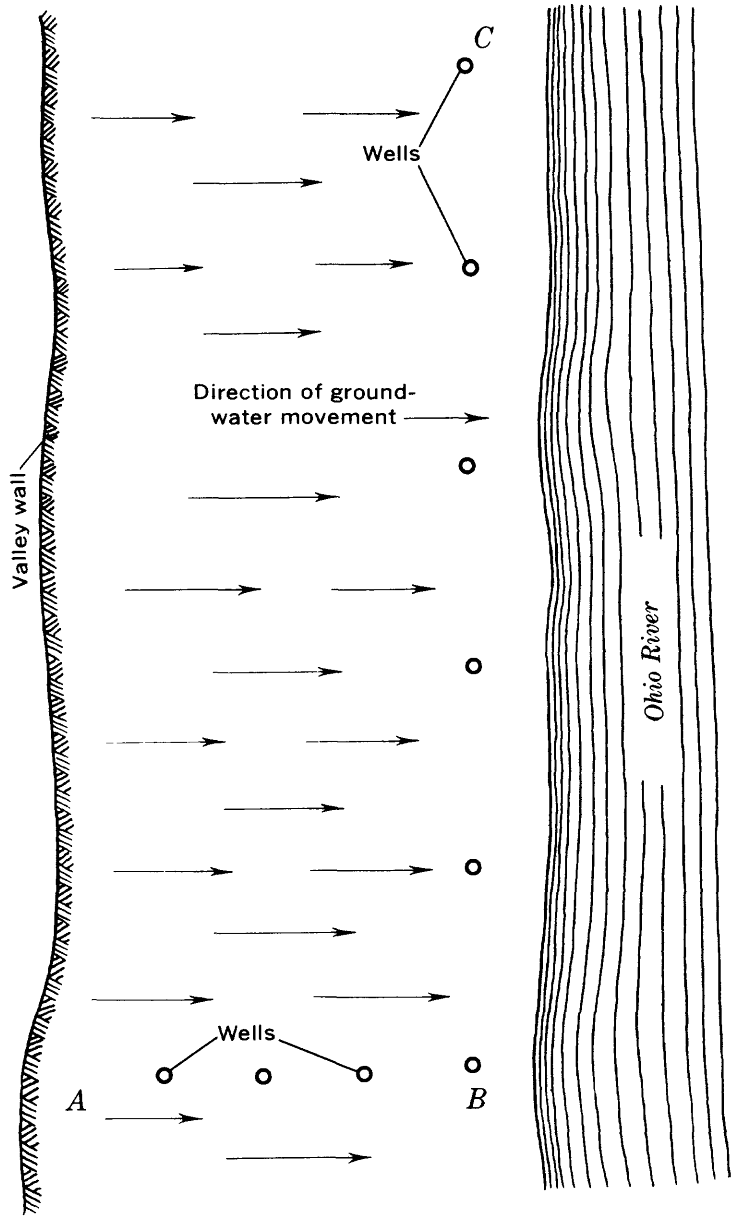


FIGURE 17.—The advantage of placing line of wells perpendicular to direction of ground-water movement. Wells in line *B–C* intercept more ground water than wells in line *A–B*.

sq ft as opposed to the average of 544 gpd per sq ft for the Ohio River valley.

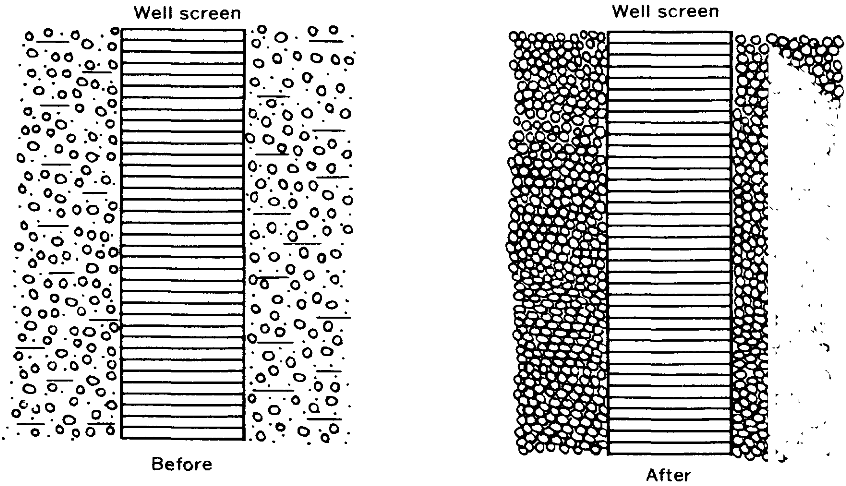


FIGURE 18.—Effect of well development on the aquifer.

QUALITY OF WATER

RANGE AND GENERAL CHARACTER

The quality of available water governs its usefulness. In water-suppy development along the Ohio River valley, quality is a far more critical factor than quantity.

The chemical and physical character of ground water varies widely throughout the length of the valley. Quality is related to depth, composition of alluvium, type and amount of mineralization derived from the bedrock container, and effects of man's activities. Bar diagrams of chemical analyses on sheet 1 of the 14 hydrologic atlases describing the ground-water resources of the Ohio River valley in Kentucky show hardness, in parts per million, and major chemical constituents, in equivalents per million. The water ranges from the more common calcium bicarbonate type to the calcium magnesium bicarbonate type; varying amounts of sulfate are present.

Figure 20 shows the average hardness and sulfate content of both the Ohio River water and the ground water at numerous locations along the river. The noticeable buildup in concentration of these (and other) substances in the areas of industrial and municipal development is undoubtedly due to man's effect upon these two water environments.

EXISTING WATER-QUALITY CONDITIONS

In areas that have not been affected by man's activities, the ground water is hard to very hard and contains large amounts of calcium, bicarbonate, and iron. Large amounts of sulfate and magnesium may

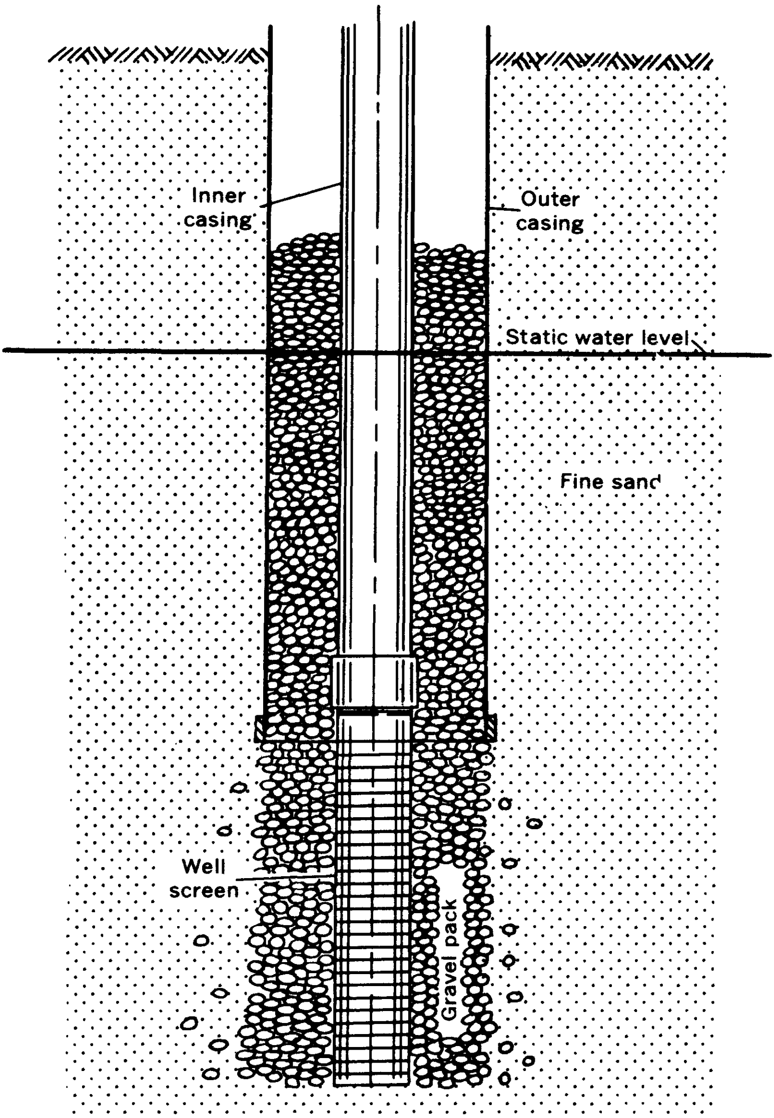


FIGURE 19.—Construction of a gravel-packed well.

also be present. Water is clear and colorless owing to the natural filtering action of the fine-grained particles, which, together with the oxygen present in the upper, unsaturated zone of alluvium, removes or destroys most harmful bacteria before they can move downward to the water table.

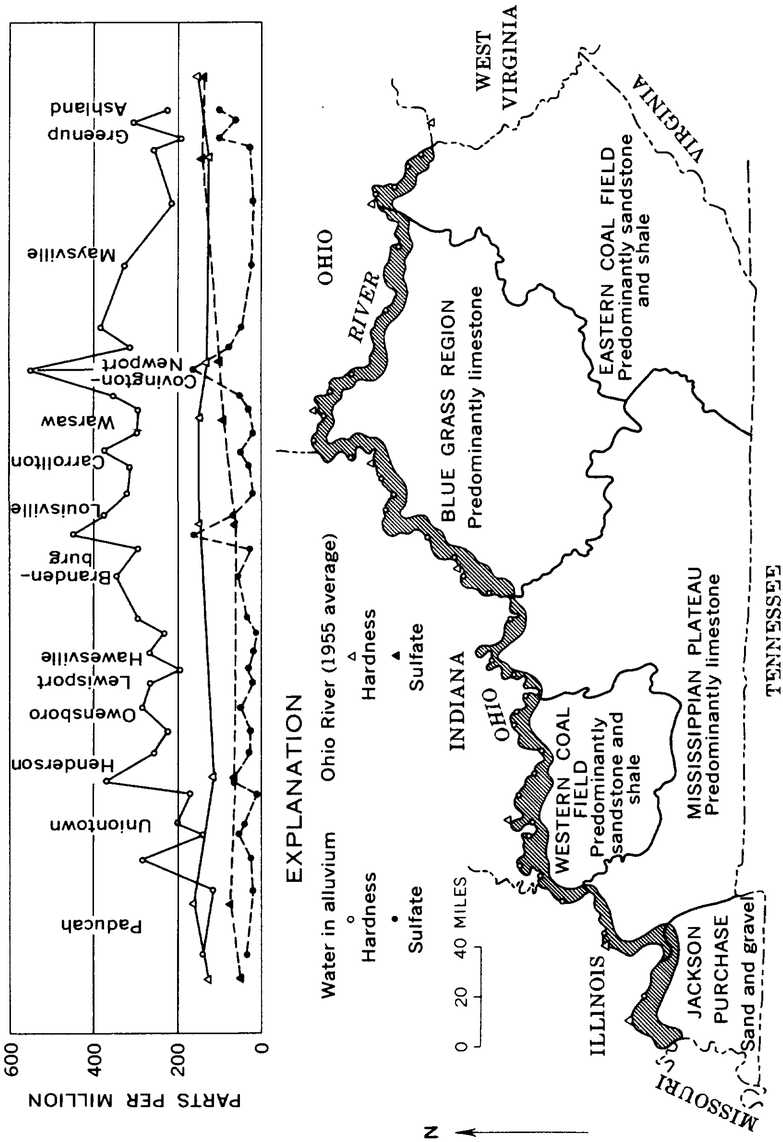


FIGURE 20.—Average hardness and sulfate content of water in the Ohio River valley. Shading indicates area of report.

The chemical quality and temperature (55°–58°F) of ground water are very stable. Most changes in quality are the result of heavy withdrawal or contamination due to poor waste-handling practices, either of which may upset the natural chemical balance of the water supply.

EFFECTS OF RECHARGE

Water enters the alluvial aquifer by precipitation, seepage from the bedrock, and addition of used water. Used water may be in the form of industrial waste, sewage, heated waste water, or waste with a high iron content.

As previously stated (p. 14), precipitation is relatively dilute but takes minerals into solution as it moves through the alluvium. The type and degree of water mineralization depend primarily on the chemical composition of the alluvium and on the depth, rate of movement, and temperature of the ground water.

Seepage from bedrock.—Ground water moves between the alluvium and the underlying or adjacent bedrock. The water from bedrock is, in many places, more highly mineralized than is the water from alluvium, and it contains objectionable amounts of iron, chloride, and sulfates and carbonates of calcium and magnesium. The type of mineralization varies with the rock type. Most limestone and dolomite, for example, yield water that is high in calcium, magnesium, bicarbonate, and carbonate (table 1).

Water movement is mainly from the bedrock into the basal alluvium, and the effects of this movement are very noticeable in some areas of the valley. In Louisville, for example, the water from alluvium overlying soluble limestone is much higher in hardness and sulfate content than is water from nearby alluvium which overlies a relatively dense chemically inactive shale. This condition is greatly intensified in areas where the water table has been lowered by excessive pumping, causing the more highly mineralized bedrock water to be drawn into the alluvial aquifer.

Industrial waste.—Industrial waste is composed of many types of organic or mineral compounds. Most waste is treated and discharged into the Ohio River, where it is rapidly diluted. Waste discharged onto the land surface, however, may reach the water table and affect the ground-water supply. Waste in liquid form may percolate downward to become part of the aquifer recharge. This is often a potential source of pollution in oil-field areas, where brines are pumped onto the ground or into poorly constructed disposal pits. Waste in a solid or semisolid state is subject to leaching and solution by rainwater that may transport the minerals downward to the saturated zone. Because water moves very slowly through the aquifer, early detection of pollutants is necessary to avert cumulative, long-term damage to the water supply.

Sewage disposal by septic tanks and cesspools.—Most sewage containing both bacterial and chemical pollutants is disposed of at or fairly near to the land surface. Bacteria are largely destroyed by oxidation or removed by the filtering action of fine-grained materials in the zone of aeration above the water table. Therefore, if the point of sewage discharge is well above the water table, little bacterial contamination of the ground water is likely to occur. The chemical part of the sewage, however, such as sodium, potassium, magnesium, calcium, nitrogen, chloride, and synthetic detergents, migrates farther and tends to accumulate and cause a gradual increase in the mineral content of the ground-water supply. Such accumulation is probably the cause of the locally high mineralization shown in figure 20.

Heated waste water.—A large and increasing percentage of ground water is used for air conditioning and industrial cooling. Little, if any, chemical change is involved in the process, but the temperature of the water is raised considerably. Most of the water so used is currently discharged into streams which dilute the water and carry it from the area. In Louisville, however, much of the heated water is pumped back into the aquifer, either to stabilize the water table or to avoid payment of the sewer-use tax. This practice raises the temperature of the ground water locally and makes the water less suitable for cooling purposes by subsequent users. In practice an effort should be made to return heated water to the aquifer downgradient, and at a considerable distance, from the discharge wells.

EFFECTS OF FLOODING

Flooding has a far greater effect on the quality of surface water than on the quality of ground-water supplies. The peak volume of riverflow ranges from about 20 to 90 times the low-flow volume; hence, the dilution is very great. During floods this dilution causes a diminishing of concentration of many constituents—calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, hardness, and total dissolved solids. There is, however, an increase in color, turbidity, silica, iron, organic compounds, and coliform bacteria. The greatest increase is in the number of coliform bacteria, probably because of the flushing out of surface or near-surface sewerage systems.

Though the floodwaters penetrate the alluvium, the overall effect on the quality of the ground-water supply appears minimal. Coliform bacteria, color, and turbidity disappear naturally soon after the recession of floodwaters. The other constituents are present in less concentration than is normally found in alluvium, so they do not constitute a means of degarding the ground-water supply.

SCREEN INCRUSTATION

Incrustation is the formation by precipitation of cementlike deposits on well screens and in the surrounding aquifer material. Most of these deposits consist of carbonates of calcium and magnesium—the same minerals that cause temporary hardness of water. The amounts present in ground water are variable and depend on carbon dioxide content, temperature, and water pressure. Water that enters the area of influence of a pumping well loses pressure. The pressure loss causes some of the carbon dioxide to be released from the water. Reduction of the carbon dioxide content causes the precipitation of hard carbonate minerals, both on the well screen and in the surrounding aquifer. These deposits may eventually accumulate to such a degree that the intake area of the well is effectively blocked.

Nothing completely halts this process, but it can be retarded by the use of screens whose openings are large enough to permit the entrance of water into the well while offering the least possible resistance, and also by reduction of the pumping rate, which decreases the drawdown and the resulting pressure change. It also diminishes the yield of individual wells and necessitates the use of a greater number of smaller diameter wells.

AVAILABILITY AND QUALITY OF GROUND WATER IN DEVELOPED AREAS

Ground-water conditions are generally good throughout the length of the Ohio River valley. Ground water has been extensively developed in some areas, and has good potential for future development in many other areas; ground-water development in a few areas, however, has little potential, mainly because of problems of yield, quality, or susceptibility to flooding.

The occurrence and availability of ground water is summarized for areas of extensive ground-water development. Areas that have good potential for future development or that have poor potential or special problems are discussed in later sections.

ASHLAND AREA

LOCATION

The Ashland area, included in Hydrologic Investigations Atlas 75 (Price, 1964), lies at the extreme east end of the Ohio River valley in Kentucky and has the heaviest concentration of industry in the eastern part of the State. The city of Ashland occupies the entire large southeast-northwest-trending bottom in the central part of the area. The southern part of the area is a narrow alluvial plain on which lies the community of Normal, and the northwestern section is a small bottom occupied almost entirely by the extensive plants of the Armco Steel Corp.

GEOLOGY AND SATURATED THICKNESS

The ancient bedrock valley of the Ashland area has steep, sloping sides and a very flat bottom. Alluvium fills most of the valley to a depth of about 70 feet, except along the northeast margin of the area where the river has cut a deep trench in the alluvium. There the river either removed the alluvium entirely or has left only a few feet of sand and gravel on top of the bedrock. (See Price, 1964, HA-75, sheet 2, section C–C^1.)

The alluvium is in two layers: a fine-grained upper layer and a coarse-grained lower layer that generally comprises more than half the total thickness. The upper layer, which consists of clay, silt, and fine sand, is irregular in thickness owing to surface erosion. The lower layer consists of lenses and beds of sand, gravel, or both in varying proportions. However, silt and clay may be mixed with the sand and gravel in significant amounts. Boulders are present just above the bedrock in a few places, as near the southeast end of the Armco plant. In other places there is a gravelly layer 5–10 feet thick, distinctly coarser than the sand and gravel below, immediately beneath the fine-grained alluvium, as in the test wells drilled on the property of the old Ashland water plant near Normal. Near the riverbanks the coarse alluvium thins abruptly and, in a few places, only a few feet is present beneath the river. Charts of the Ohio River, prepared by the U.S. Army Corps of Engineers before the locks and dams were constructed, indicate several places where the coarse alluvium is absent and the river flows over bare rock.

Along the riverbank a layer of fine-grained alluvium covers the lower sand and gravel. This fine-grained layer extends below the river level and, except for a relatively thin zone just above the bedrock, seals the sand and gravel off from the river. In places, as at the north end of the bottom occupied by the Armco Steel Corp. plants, a layer of silt several feet thick covers the sand and gravel that lies beneath the riverbed. Both of these fine-grained layers are relatively impermeable and reduce the rate at which pumping of wells near the river will induce infiltration from the river into the alluvium (fig. 16). In most places along the Ohio River near Ashland, however, water can move freely between the river and exposures of sand and gravel in the river bottom. For this reason, the surface of the water in the river and in the ground near the river are at about the same level.

The water levels of the area, both in the Ohio River and in the alluvium, have recently changed. Until 1961 dam 29, across the Ohio

River near Normal, kept the minimum water level in the river above the dam at an altitude of 498 feet. Below dam 29 the river level was maintained at a minimum altitude of 490 feet by dam 30, some distance down river at Lloyd. Because the floor of the old bedrock channel beneath the Ashland area is about 470–480 feet above mean sea level, 10–20 feet of the basal sand and gravel was saturated.

The new Greenup Dam was put into operation in 1961 to eliminate bottlenecks in river traffic caused by inadequate lockage and to improve flood control. It now replaces dams 29 and 30. Greenup Dam keeps the upstream river level at a minimum altitude of 515 feet; thus, it has raised the water level in the alluvium of the area below former dam 29 an additional 25 feet and above it, 17 feet. In most parts of the area about 35–45 feet of the alluvium is probably now saturated. The material newly filled with water is mostly the lower coarse-grained layer of alluvium. The newly saturated part is probably less permeable than the material in the original zone of saturation, but it extends over a slightly larger area.

YIELDS OF WELLS

Cable-tool rigs are used in the Ashland area to drill wells for public, commercial, or industrial purposes. The holes are kept open by 6- to 12-inch casing, and most holes are drilled through the entire thickness of alluvium to bedrock. Well screens 4–15 feet long are placed directly on or a short distance above the bedrock in beds of sand and gravel.

Of the 63 wells inventoried in the area, most were drilled for water to be used in the manufacture of ice, leather goods, and chemicals. Water is also pumped for air conditioning and for milk processing. Sixteen of these wells are test wells that were drilled at the site of the old city of Ashland waterworks near Normal and at the Armco plant northwest of Ashland.

The reported yields of 28 of the wells, inventoried before Greenup Dam was put into operation, ranged from 20 to 300 gpm with a median of 140 gpm. Only a few reports of yield were based on careful measurements, however. Some of the low yields were due to small demands; others were possibly the result of screen incrustation. The low yield of the test wells drilled on the riverbank at the Armco plant, on the other hand, was due to the thinness and low permeability of the aquifer. The low yields of the old, now abandoned, wells at the northwest end of the plant were due to excessive withdrawals of water from a small area and (or) incrustation of the well screens. A well in the basement of the Second National Bank Building was also reportedly abandoned because it supplied insufficient water after a new well nearby was pumped heavily.

Four wells in the area reportedly yielded 200 gpm or more. One well, at the Kentucky Power Co. in the central part of Ashland, reportedly yielded 300 gpm. Two wells south of Ashland at the Semet-Solvay Division of Allied Chemical and Dye Corp. reportedly yielded 275 and 200–220 gpm. A well at the Ashland Home Ice Co. plant near the southeast end of the Ashland bottom reportedly yielded 200 gpm.

A more accurate evaluation of the quantity of water that wells are capable of yielding can be obtained from tests of specific capacity and of aquifer performance. A specific-capacity test made on one of the Semet-Solvay Division wells indicated 38 gpm per foot of drawdown after pumping for 2 hours. If the water level in the well were pumped down to the top of the screen, a distance of 10 feet, the well should have yielded about 380 gpm. However, the test was short, and under sustained pumping the well was probably not capable of yielding this much.

Aquifer-performance tests on two groups of wells at the Armco plant were conducted (1958) by Ranney, Inc., to determine whether a ground-water supply utilizing induced river infiltration could be developed at the plant site. The yields of the test wells drilled on the riverbank were very low: 25 and 47 gpm. Transmissibilities also were low: 12,000 gpd per ft in the first test, and 6,800 gpd per ft in the second. The corresponding permeabilities also were rather low: 750 and 427 gpd per sq ft, respectively.

When Greenup Dam was finished (1961) and the water level in the river was raised, the thickness of the saturated part of the alluvium in the deepest part of the old bedrock channel was more than doubled in the area below former dam 29 and approximately doubled above. As a result, the transmissibility of the alluvium was doubled in most parts of the area, thereby roughly doubling the potential yield of wells.

QUALITY OF WATER

Most water in the alluvium of the Ashland area is of the calcium magnesium bicarbonate or sulfate type. Chloride, however, is present in relatively large amounts in some of the water. Analyses of four water samples from the Ohio River showed that the river water is also of the calcium magnesium sulfate type, contains significant amounts of chloride, and is similar in most respects to the water in the alluvium of the Ashland area. Analyses of water from wells in bedrock near the Ashland area indicated that the water from the bedrock is generally of different character than that from either the alluvium or the river. This evidence suggests that the Ohio River may be a prime source of recharge to the ground water in the alluvium of the Ashland area.

Chemical analyses of water from 11 representative wells showed that the ground water is suitable for most domestic and industrial purposes but is generally hard to very hard and contains noticeable amounts of iron. Bicarbonate content of the water ranged from 54 to 270 ppm; sulfate, from 42 to 160 ppm; chloride, from 17 to 128 ppm; and nitrate, from negligible amounts to 27 ppm. The water in almost all the wells sampled at Ashland contained more than 10 ppm nitrate, but water from wells in the small alluvial areas just upstream and downstream contained only very small amounts of nitrate. Hardness of the water sample ranged from 144 to 332 ppm.

The iron content of the water ranged from 0.04 to 6.3 ppm. However, highly mineralized water from two other wells, not included in the representative group, contained 47 and 206 ppm iron. These wells, now abandoned, are at the northwest end of the Armco plant. W. F. Guyton and D. K. Hamilton (written commun., 1944) suggested that the high iron content and high mineralization may have been due to slag and other iron-waste material that had been dumped at or near the well sites. The highest iron contents were found in water from wells drilled through this material; the lowest iron contents in wells farthest from it.

Temperatures of the water in 15 drilled wells, measured at different times of the year, ranged from 57° to 62°F. The average temperature was 59°F.

CONCLUSIONS

All data pertaining to the water wells of the area were collected prior to 1961 when the new Greenup Dam was put into operation. Before this dam was built, the yield of most large wells in the area was about 150 gpm, and the maximum possible sustained yield was about 350 gpm. Since then, the water level in the river has raised, and the maximum possible yield may be doubled.

The poorest area for the development of ground-water supplies is close to the valley wall, where nearly all the alluvium is fine grained and the saturated zone is thin. Also, wells close to the valley wall will yield less when the cones of depression intersect the valley wall.

A relatively unfavorable area for the development of infiltration supplies is along the riverbank to the northwest of Ashland. Exploratory drilling and aquifer tests showed that the deposits next to the river generally have low permeability and a small saturated thickness. Little information is available on the character of the alluvial deposits along the riverbank southeast of Ashland; however, there are indications that conditions may be more favorable in this area.

Probably the best areas for ground-water development are the central riverward part of the Ashland bottom and the area immediately to the south as far upstream as Normal. The saturated thickness probably diminishes both upstream and downstream from this section.

The quality of ground water is satisfactory for most uses and is generally similar to that of river water; however, the range in temperature fluctuation of the ground water is much less. Ground-water quality may be poor in areas where wells are drilled through or near industrial-waste fill.

COVINGTON-NEWPORT AREA

LOCATION

The Covington-Newport area, shown in Hydrologic Investigations Atlas 98 (Price, 1964), is made up of two alluvial areas across the Ohio River from metropolitan Cincinnati, Ohio. The larger of the two areas, which is divided into two parts by the Licking River, is occupied by the cities of Covington, Newport, Bellevue, and Dayton. The smaller valley flat is about a mile downstream in the Ludlow-Bromley area. E. H. Walker (1953) described the ground-water resources of the area.

Because the cities of Covington and Newport obtain water from the Ohio River for their own use and for supply to other nearby towns, little well water is used for public purposes in the area. However, two wells in alluvium provide the Bromley Sanitary Water District No. 1 with water for washing in their sewage-treatment plant. Approximately three-fourths of the ground water pumped for industrial purposes in the area is used in the brewing and distilling industries. Lesser quantities of ground water are pumped for use in air conditioning, food processing, and other industrial purposes.

GEOLOGY AND SATURATED THICKNESS

The maximum known thickness of alluvium in the area overlies the ancient deep channel of the Ohio River, which passes beneath parts of the cities of Bellevue, Newport, and Covington. Alluvium above this channel is about 150 feet thick.

The upper part of the alluvium is, for the most part, silt and clay; the lower part, sand and gravel. The upper silt and clay section of the alluvium is exposed in cuts and banks in the area and has been noted in nearly all well logs. It consists mainly of fine silt and varying quantities of clay, generally enough to make the material somewhat plastic in character. Some well logs indicate layers of sand within the silt or clay, but these beds are probably lenses of limited areal extent.

The change from the overlying silt and clay to the sand and gravel is fairly abrupt. The basal deposits are coarser from top to bottom;

sand is generally penetrated first, then sand with increasing quantities of gravel. Just above bedrock much of the gravel is very coarse and some contains small boulders. These coarser basal deposits rise gradually in places toward the bedrock valley wall but wedge out beneath the silt and clay. In the southern part of the area, these deposits merge with the fine-grained alluvial deposits of the Licking River and thin to a few feet in thickness immediately above the bedrock floor. Beneath the Ohio River the coarse deposits form all (or nearly all) of the alluvium.

As a rule the water-deposited sands are clean and sharp edged and consist mainly of quartz grains. Most sand of the old deep channel is coarse, the grains ranging in diameter from 0.5 to 1.0 mm. The gravel is well rounded and consists mostly of hard rocks, such as sandstone, granite, and quartzite, although fragments of limestone are common. Toward the edge of the Ohio River valley, especially at the junction with the Licking River valley, silt and clay make up a larger percentage of the gravel beds, and drillers have reported finding dirty or muddy gravel.

In the Covington-Newport area, water probably moves between the Ohio River and the lower sand and gravel layer in most places. However, as E. H. Walker (1953) pointed out, water movement is slow, which may indicate the presence of a relatively impermeable mud or clay "lip" that extends down the bank and over part of the riverbed (fig. 16). This fine-grained blanket partially seals off the river water from the underlying coarse deposits.

Until 1963 the minimum water level of the Ohio River in this area was 441 feet above mean sea level; the level was controlled by dam 37 about 12 miles downstream. The ground-water table was at approximately the same altitude as the top of the basal sand and gravel, and in most places this layer was entirely saturated with water. In the thicker deposits overlying the old deep channel, as much as 75 feet of coarse alluvium was saturated. The thickness of the water-filled sand and gravel is less in areas outside the deep channel, either because the buried bedrock is higher or because the glacial deposits of the Ohio River valley were replaced by fine-grained tributary sediments, as in the southern part of the area near the Licking River valley.

The level of the river in the Covington-Newport area was raised 14 feet when the new, higher Markland Dam, about 60 miles downstream, was completed. Because the ground-water level was already near the top of the coarse alluvium, the ground-water buildup resulting from this increase is mostly in the upper, fine-grained alluvium.

YIELDS OF WELLS

Cable-tool rigs are used in the Covington-Newport area to drill wells for public, commercial, and industrial purposes. Most holes are drilled through the entire thickness of alluvium to bedrock and are kept open by 6- to 12-inch casing. Well screens, most of which are 10–20 feet in length, are placed in the sand and gravel just above the bedrock.

Records were obtained of 56 wells drilled into the Ohio River alluvium in the Covington-Newport area. Most records were from the previous study by E. H. Walker (1953). The yields of 40 of these wells, reported by the owners or well drillers, ranged from 30 to 666 gpm, with a median yield of 180 gpm. The yields were carefully measured for only a few wells, however. Some of the low yields merely indicate small water demands; others are the result of screen incrustation. Wells drilled near the valley walls generally yield only small amounts of water because the sand and gravel layer there is thin. Small yields are also reported from wells in the southern part of the area, near or in the tributary alluvium of the Licking River; there the yields of five drilled wells were 8, 16, 33, 40, and 60 gpm.

Four wells in the area reportedly yield 400 gpm or more. These wells are in the northern part of Newport and Covington and in Bromley. Three of these wells penetrate the thick sand and gravel deposits of the old deep channel, and the fourth is in sand and gravel near the river.

A more accurate idea of the quantity of water that wells in the area are capable of yielding can be obtained from specific-capacity and aquifer-performance tests. Specific capacities reported by owners of eight wells in the area ranged from 1.2 to 39 gpm per ft, with a median value of 19 gpm per ft—somewhat below average for the Ohio River valley. The yield of the sand and gravel aquifer at the site of the old City Ice & Fuel Co. well, at Second Street and Scott Boulevard in Covington, was estimated by use of hydrographs, pumpage data, and the results of pumping tests. The transmissibility of the aquifer was computed from these data to be about 20,000 gpd per ft (F. R. Hall, oral commun., 1957).

When the water level above Markland Dam was raised 14 feet, to a new altitude of 455 feet above mean sea-level, the alluvium above the original water table was newly saturated. In coarse-grained sections the transmissibility of the aquifer and the yields of wells increase by an amount dependent upon the permeability of the newly saturated sand and gravel. In sections where the alluvium is very fine grained and clayey, the principal result is an increase in head available for drawdown.

QUALITY OF WATER

Most water in the alluvium in the Covington-Newport area is of the calcium magnesium bicarbonate type. Analyses showed that water from the Ohio River is of the calcium magnesium sulfate type and is much less mineralized than the water in the alluvium. Analyses of water from wells in the bedrock south of Covington and Newport indicated that the water is generally of poor quality; the water is about as hard as is water from the alluvium and also may contain high concentrations of chloride, sulfate, nitrate, or iron. E. H. Walker (1953) found that the hardness and dissolved-solids content of water in the alluvium decreased from the valley wall toward the Ohio River. Evidently much water in the alluvium at the edge of the valley comes from the soil that overlies the bedrock of the valley wall. Most dilution of the dissolved constituents is by water seeping down from the land surface during ground-water movement toward the river; near the river there is further dilution by river-water infiltration.

Chemical analyses of water from 11 wells showed that the ground water is suitable for most domestic and industrial purposes, but that it is very hard and generally contains noticeable amounts of iron. Bicarbonate content ranged from 246 to 683 ppm; sulfate, from 37 to 388 ppm; chloride, from 35 to 204 ppm; and nitrate, from a trace to 61 ppm. Hardness ranged from 252 to 862 ppm; and iron content, from 0.18 to 11 ppm.

An analysis of water from a well in the alluvium of the Licking River valley suggests that the quality of ground water in the tributary alluvium may differ from that of water in the Ohio River alluvium. The analysis revealed that the water has more calcium and bicarbonate and less sodium, sulfate, and chloride than does the average well water in the Covington-Newport area. Dissolved solids and total hardness concentrations are also lower in the Licking River valley well. Another well in the Licking River valley alluvium contains 1,520 ppm dissolved solids. The sum of its sodium and potassium contents is 527 ppm, and the chloride concentration is 630 ppm. These concentrations were the highest found in any well in alluvium in the Covington-Newport area. E. H. Walker (1953) suggested that the character of the water and the high concentration of dissolved solids may indicate local ground-water pollution by industrial waste.

The temperature of water in 15 drilled wells, measured at different times of the year, ranged from 56° to 59°F, with an average of 57°F.

CONCLUSIONS

Most large wells in the area yield about 200 gpm, but the maximum possible sustained yields probably exceed 1,000 gpm.

The least favorable areas for the development of ground-water supplies are in the valley of the Licking River and near the walls of the Ohio River valley. The alluvium of the Licking River valley is fine grained and yields only small quantities of water to wells; the highest reported yield is 60 gpm. The chances of obtaining large supplies of water become progressively less closer to the valley walls, because the section of saturated alluvium becomes thinner and generally finer grained.

Probably the best areas for obtaining large ground-water supplies are where thick deposits of sand and gravel are present in the old deep channel of the Ohio River beneath the cities of Ludlow, Covington, Newport, and Bellevue.

In terms of water quality, the poorest areas for development are those close to the valley walls and near areas of known industrial contamination of water. The most favorable sites are near the bank of the Ohio River. Here the river water enters the sand and gravel and dilutes the hardness and dissolved solids of the ground water to less-than-average concentrations. Ground water in the Licking River valley seems to be less mineralized than that in most places in the Ohio Valley alluvium, but more analyses are needed to substantiate this conclusion.

LOUISVILLE AREA

LOCATION

The Louisville area is in a large alluvial bottom near the midpoint of the Ohio River valley in Kentucky. For convenience of discussion, the authors have divided the Louisville area into subareas (fig. 21) on the basis of ground-water pumpage and industrial usage.

More detailed study has been made of the geology, hydrology, and quality of water in this area than at any other place in the Ohio River valley. To date more than 25 atlases and written reports have been published concerning the area. The latest of these reports are Hydrologic Investigations Atlases 130 and 111 ("Geology and Hydrology of Alluvial Deposits along the Ohio River between Prospect and Southwestern Louisville, Kentucky," and "Geology and Hydrology of Alluvial Deposits along the Ohio River between Southwestern Louisville and West Point, Kentucky" (Price, 1964)) and Water-Supply Paper 1819–C ("Summary of Hydrologic Conditions of the Louisville Area, Kentucky" (E. A. Bell, 1966)). Other pertinent reports are included in the list of references at the end of this report. Because of the amount of detailed coverage, this section is intended to serve only as a brief summary of the hydrologic system of the area.

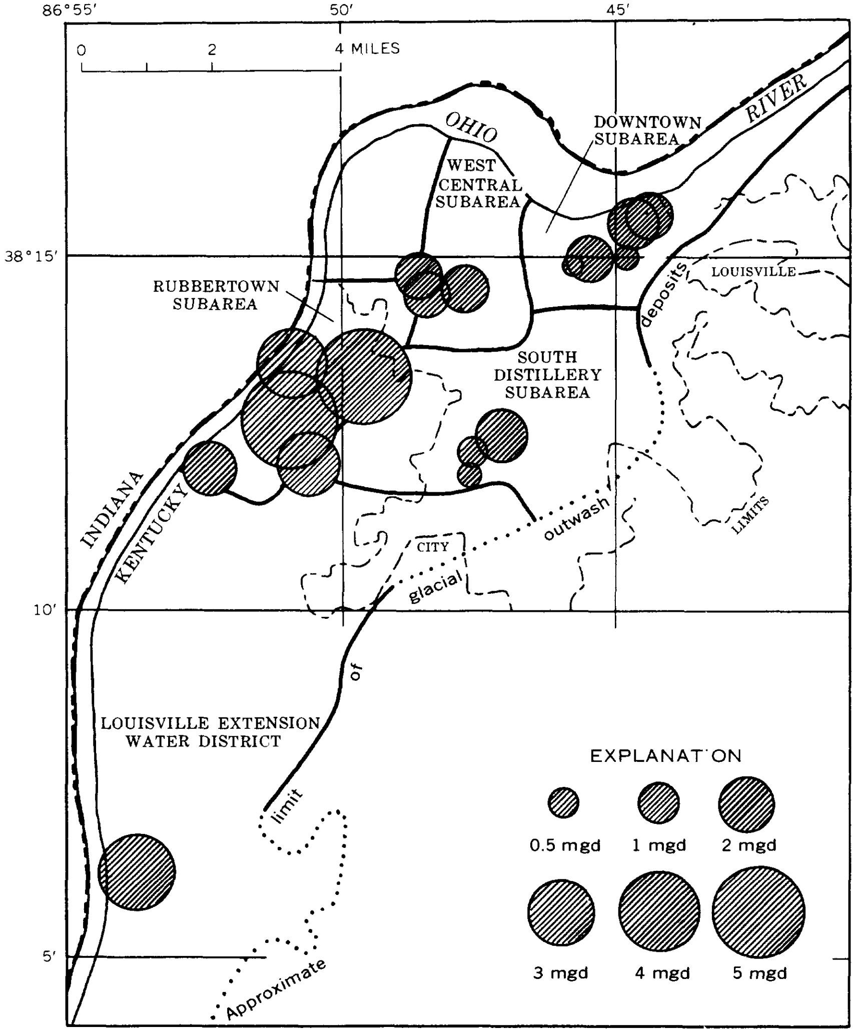


FIGURE 21.—Distribution of ground-water pumping in the Louisville area, 1962.

GEOLOGY AND SATURATED THICKNESS

The bedrock underlying the Ohio River alluvium of the area is made up primarily of limestones and shales of Silurian, Devonian, and Mississippian ages. The old deep channel, cut into these rocks down to an altitude of about 335 feet, trends southwest across the area from Towhead Island to a point south of the Rubbertown industrial subarea. Upstream and downstream from these points, the old channel approximately follows the present river channel.

The alluvial deposits in the Louisville area are mostly of glacial origin. Their thickness ranges from 0 to 150 feet, depending upon the altitude of the erosional surface of the underlying bedrock formations. The upper part of the unconsolidated deposits consists of 5–40 feet of relatively impermeable clay, silt, and fine sand. Beneath this layer are thick deposits of permeable sand and gravel. The general distribution of the alluvial deposits is shown in figure 22.

The saturated thickness of alluvium varies widely with local pumpage, but ranges from 0 to 80 feet. The water table (fig. 22), generally slopes toward the river, but heavy pumpage has created local cones of depression. Close to the river, pumping levels have been lowered to such a degree locally that the normal water-level gradient is reversed, and the water flows from the river toward pumped wells.

WATER SOURCE AND USE

More than 40 billion gallons of water is used annually (Kulp and Hopkins, 1960) in the Louisville area. Three-fourths of this is taken from the Ohio River for public supply; most of the remainder of the water comes from alluvium and is used by the Louisville Extension Water District for public supply and by most of the industries for manufacturing, air conditioning, and cooling purposes. Supplies of

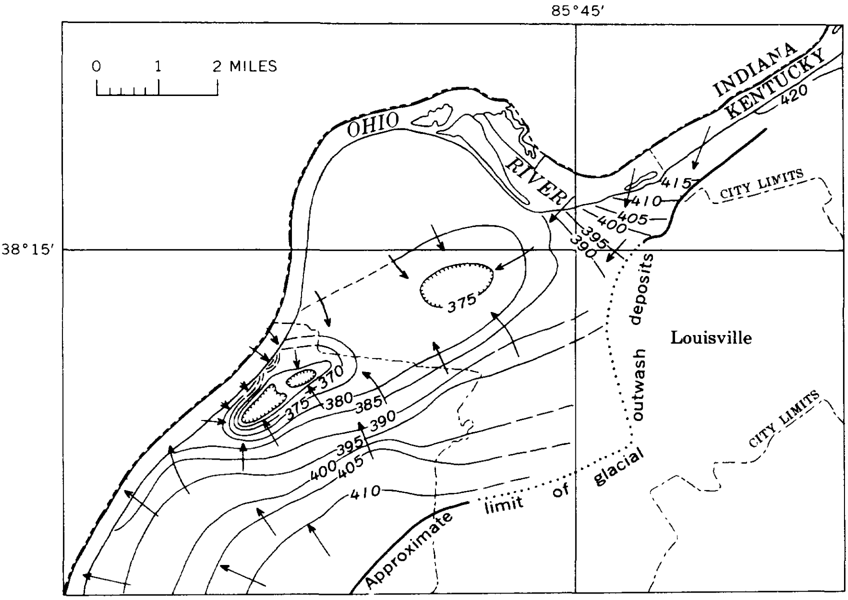


FIGURE 22.—Water-level contours in the Louisville area, December 1960 (from Whitesides and Nichols, 1961). Altitude given in feet above mean sea level. Contour interval, 5 feet. Arrows indicate direction of ground-water movement.

ground water in this area are obtained primarily from large-diameter drilled wells that penetrate the full thickness of the aquifer; exceptions are two radial-collector wells within a few hundred feet of the Ohio River. Some water used by local distilleries is pumped from the limestone aquifer underlying the alluvium.

Much water, especially that which has been used for cooling purposes, is returned to the aquifer by means of recharge wells. Though primarily a means of avoiding payment of sewer-rental taxes, this method of disposal helps to maintain an overall balance between the total withdrawal and the total recharge of the aquifer. From 1944 to 1960 the amount of water returned to the aquifer by artificial recharge ranged from 0.6 to 1.6 mgd (million gallons per day). There has been an apparent decline in this practice within the past several years, however, and the recharge amount reported by industry for 1962 was only 0.517 mgd.

WELL YIELDS AND AQUIFER TESTS

The average yield for all drilled wells in alluvium is probably about 200 gpm, but each of the better wells of the area produces 400–500 gpm, and a few yield 800–1,000 gpm. The two radial-collector wells reportedly pump 2,600 and 3,500 gpm. Specific capacities for wells in alluvium range from 6 to 500 gpm per ft, with a median of 38 gpm per ft. Permeabilities, determined on the basis of laboratory studies of alluvial samples, ranged from 120 to 1,700 gpd per sq ft, with a median of 500 gpd per sq ft. Transmissibilities, determined by pumping tests, ranged from 18,000 to 121,000 gpd per ft, with a median of 68,500 gpd per ft.

QUALITY OF WATER

Ground-water quality varies widely throughout the area; it changes according to location, type of underlying bedrock, and rate of withdrawal.

Water from wells in limestone is very highly mineralized. Hardness as $CaCO_3$ averages about 580 ppm, and sulfates average about 450 ppm.

Water in alluvium varies in quality but is generally very hard, high in bicarbonate and iron, and, in many places, high in sulfate. Average hardness of water from wells in alluvium in the part of Louisville included in Hydrologic Investigations Atlas 130 is 422 ppm and in Hydrologic Investigations Atlas 111, is 296 ppm. Sulfate content of water in these atlas areas averaged 162 and 26 ppm. The alluvium in the upstream part (HA–130) overlies limestone bedrock, from which it derives its high mineralization. Downstream, the underlying impermeable shale effectively prevents much of the mineralized limestone water from entering the alluvium.

There is also considerable variation in the quality of water, owing to variation in distance of wells from the Ohio River. Water in wells within a few hundred feet of the river is less mineralized than that in wells that are farther away. This reflects the diluting effect of river water that enters the alluvium during flood stage or is induced into the formation by infiltration.

A notable change in water quality has occurred in areas of heavy pumping. Large withdrawals have lowered the water table in some areas and thereby induced infiltration from the river; the pumped water is softer and of lower overall mineral content. Where heavy pumpage has not induced infiltration from the river, however, as in the West-Central subarea, wells in alluvium overlying the limestone bedrock are pumping increasing amounts of hard, highly mineralized water.

Average ground-water temperature in the area is 58°F. The range, from 47° to 66° F, depends largely on the temperature and quantity of river water induced by infiltration.

CONCLUSIONS

The most favorable areas for future development of large quantities of good-quality water are near the river, where induced infiltration makes perennially large supplies possible. This condition exists in southwestern Louisville, and in northeastern Louisville from the Louisville Gas & Electric plant to Harrods Creek. In the Rubbertown subarea, however, the opportunity for further development is very limited because the cone of depression there (fig. 22) has already been lowered to the maximum allowable for sustained yields. Wells near the river and in alluvium overlying shale bedrock produce the least mineralized water.

BRANDENBURG AREA

LOCATION

The alluvial area near Brandenburg, included in Hydrologic Investigations Atlas 95, is typical in size to many river bottoms along the Ohio Valley. It is a crescent-shaped bottom 6½ miles long about 37 river miles downstream from Louisville. Though narrow (about half a mile wide) it occupies the width of the Ohio River valley at this point. The land surface has been dissected by Doe Run and Flipping Creek and ranges in altitude from 400 feet above mean sea level at the riverbank to more than 460 feet along the valley wall and at the upstream and downstream ends of the bottom. Most of the land, however, is between 440 and 450 feet above mean sea level.

Present water usage is confined to municipal supplies at Brandenburg and to public and industrial supplies at the Olin-Mathieson chemical plant. Total daily ground-water use for the area averages in excess of 17 million gallons per day.

GEOLOGY AND SATURATED THICKNESS

The bedrock of the area is limestone of Mississippian age. It slopes beneath the alluvial fill from 350 feet above mean sea level at the valley wall to approximately 305 feet in the old deep channel, which is near the present Ohio River channel.

The thickness of alluvium varies widely in the area because of the land-surface relief and the steep slope of the underlying bedrock. Most of the alluvium is from 50 to 100 feet thick, but where the old deep channel crosses beneath the higher, western part of the bottom, the alluvium probably approaches 150 feet in thickness.

Texturally, the alluvial fill is in two layers. The upper layer is composed of fine-grained deposits of silt, clay, and sand and ranges from 0 to 60 feet in depth. The coarse basal layer of sand and gravel is in excess of 50 feet thick and, where the upper layer has been eroded, occupies the full thickness of the aquifer.

Static water levels in the area near the river range from 30 to 40 feet in depth below the land surface. No wells are known to have been drilled in the valley-wall area, but water levels there are probably considerably higher. The saturated thickness of alluvium depends on the altitude of the bedrock surface and ranges from about 50 to 70 feet along the river.

YIELDS OF WELLS

Water for the area is produced in two ways. The city of Brandenburg is supplied by two wells drilled to depths of 90 and 95 feet in alluvium and producing 200 and 265 gpm, respectively. Wells in the industrial area of the Olin-Mathieson plant are the radial-collector type and are 97 feet deep. They are rated at 5,000 gpm, and have pumping levels 85 feet below land surface. This indicates that much of their yield is the result of induced infiltration of Ohio River water. Test wells drilled prior to the construction of the collector wells yielded 300–500 gpm.

Aquifer-performance tests in the area showed permeabilities and transmissibilities that averaged 2,390 and 120,500 gpd per ft, both of which greatly exceed other averages for the Ohio River valley.

QUALITY OF WATER

Only three analyses were made of the water from the alluvium: one of a sample from a Brandenburg city well, and two of samples from wells at the Olin-Mathieson plant. The results were considerably different. One industrial well has relatively soft water of low mineralization; the other, about half a mile downstream and at the same depth, has a concentration of nearly 500 ppm hardness as $CaCO_3$ and a chloride content of 180 ppm. The water from the city well at Brandenburg is moderately hard (300 ppm hardness as $CaCO_3$) and heavily mineralized.

CONCLUSIONS

This area, like most other relatively small alluvial bottoms along the Ohio Valley, might have been bypassed or overlooked had it not been for exploratory drilling which revealed its potential. Most smaller bottoms are somewhat isolated and reportedly subject to excessive flood damage.

Transportation to the chemical plant was solved by the addition of a railroad spur that leads to the main line. Water supplies are protected from potential flood damage by setting the caissons of the wells so that they extend far above the land surface. The height of the greatest recorded flood (1937) was 446 feet above mean sea level, and much of the Brandenburg area is higher than this. Flood-control structures that have been built since 1937 have greatly reduced the likelihood of extremely high water, and additional structures are still being constructed or are in the planning stage.

OWENSBORO AREA

LOCATION

Owensboro is in the western part of Kentucky about 110 miles from Louisville. The municipal-industrial area extends 6½ river miles from the Dewey and Almy plant downstream to Bon Harbor Hills. The upstream half of this stretch is comparatively narrow; it ranges from about 1 to 2 miles in width. The downstream part of the bottom abruptly broadens to nearly 10 miles in width and includes part of the drainage system of Panther Creek. The geoloy and hydrology of the area are described in Hydrologic Investigations Atlas 74.

The flood-plain is relatively flat and ranges in altitude from 380 to 400 feet above mean sea level. Its evenness is interrupted by a northeast-southwest-trending natural levee which stands 25–30 feet above the surrounding valley and extends from one end of the area to the other. This feature is from 500 to 800 feet wide and has a maximum altitude of slightly more than 430 feet.

Owensboro is a progressive, industrialized city that ranks second in the State in its use of ground water. Ground-water usage averages about 10.7 mgd. Of this quantity 1.4 mgd is for domestic supply, and the balance, derived from both municipal and privately owned wells, is used by industry. Slightly more than half of the gross pumpage is used by five industries, which include three distilleries, a steel mill, and a meat-processing company. Municipal pumpage, from 22 deep wells, is 4.6 mgd.

GEOLOGY AND SATURATED THICKNESS

The bedrock underlying the alluvium of the area is mainly shale of Pennsylvanian age. In the 2-mile-wide strip adjoining the river, the bedrock surface is quite uneven as a result of dissection prior to deposition of the alluvial fill. Buried cusp-like remnants, separated by channels of ancient streams, rise to an altitude of 300 feet above mean sea level and project outward into the valley. (See HA–74.)

Less is known of the subsurface geology of the wide flood plain inland from the river, but much of it is probably dissected in a manner similar to the strip along the river. Logs of scattered wells indicate that the altitude of the bedrock floor averages about 280 feet in the middle of the valley and more than 350 feet near the valley wall.

The lowest points of the bedrock floor are on the west side of the city, where a branch of the old deep channel of the Ohio River passes southwest around Bon Harbor Hills at an altitude of 240 feet above mean sea level. Ancient tributaries to the deep channel eroded deeply into the bedrock and cut their valleys to between 240 and 280 feet above mean sea level.

The land surface is relatively smooth; hence, the variation in thickness of the alluvium is controlled primarily by the altitude of the concealed bedrock surface. An exception occurs, however, in the area of the natural levee, where the alluvium is thicker by 20–30 feet. In the area along the Ohio River, the thinnest alluvium overlies the buried bedrock highs and generally ranges from 90 to 110 feet in thickness. The deposits above the old deep channel west of town are nearly 150 feet thick. Most alluvium in the area, however, ranges from about 120 to 130 feet in thickness.

In the broad inland flood plain, most of the bedrock lies between 90 and 130 feet below the land surface; however, near the valley wall, the alluvium thins rapidly to only a few feet in thickness.

The texture of the alluvium gradually changes across the valley from mostly coarse deposits near the river to fine-grained deposits on the inland flood plain.

In the riverward part of the area, the thickness of the upper, fine-grained deposits is generally 30–50 feet. These deposits are underlain by a basal layer that ranges in texture from boulder-sized material, found in the municipal well field, to sand or sand and gravel, found throughout most of the area. An exception is in downtown Owensboro, where two extensive clay layers about 10 feet thick occur. One layer is at a depth of 35–65 feet; the other is deeper and lies immediately above the bedrock in most places.

Farther from the river the fine-grained layer thickens and becomes a mixture of Ohio River alluvium with increasing amounts of tributary alluvium. Here the coarse basal section is reduced in thickness to a few feet or may be missing entirely.

The thickness of the saturated zone is governed by the water level and the depth of the alluvium. In the heavily pumped area near the Ohio River, the water level ranges from 30 to 50 feet below land surface. The saturated thickness of alluvium ranges from 60 to 70 feet over the buried bedrock hills to 80 to 90 feet over most of the bedrock lows; however, in the area of the old deep channel, the saturated zone is about 100 feet thick.

Inland the water table is noticeably higher—from 10 to 15 feet below land surface—and the saturated zone ranges from 80 to more than 120 feet in thickness.

YIELDS OF WELLS

In the 2-mile-wide strip along the Ohio River, almost all the wells are drilled and are designed for high yields. The outward expansion of the municipal water system has eliminated much of the need for domestic wells except in rural areas.

All the municipal, industrial, and air-conditioning supply wells are in the heavily pumped section along the river. The most favorable depth for large yields in this area corresponds to the depth to bedrock, as this permits setting of well screens in the coarsest material and gives access to the greatest saturated thickness. Many older wells of the area are comparatively shallow; they range from 80–100 feet deep. Experience has proved the value of complete penetration of the water-bearing formation, however, and in the past 10 years most wells have been drilled down to bedrock. The depths of these wells vary with location and range from about 120 to 130 feet.

Well yields along the river generally range from 400 to 1,000 gpm; most wells are pumped at rates between 700 and 800 gpm. Drawdown at these pumping rates is not excessive. The specific capacities of 26 wells in this part of the Owensboro area range from 13 to 75 gpm per ft, with a median of 45 gpm per ft, which is well above the median (32 gpm per ft) for the entire Ohio River valley in Kentucky. Infiltration of surface water is apparently being induced in the areas of heavy pumping near the river. Most water from deep wells close to the riverbank is less mineralized than the ground water in the rest of the area; this indicates dilution by surface water of lower mineral content.

In the more rural areas, both along the river and on the inland flood plain, most water supplies are derived from small-diameter driven wells. These wells range from 50 to 105 feet in depth, and the low yields generally reflect the water needs rather than the potential of the aquifer. Where larger supplies are needed, drilled wells are customarily used. For example, the yield of a drilled well, 123 feet deep, at the Owensboro Country Club south of the city limits, has been measured at 725 gpm.

Very few tests have been made of the hydrologic properties of the aquifer underlying the Owensboro area. A single transmissibility test, conducted at the municipal well field, showed a transmissibility coefficient of 55,300 gpd per ft. This is slightly more than the median for the entire Ohio River valley.

The permeability of alluvial samples from two sites near the river was tested in the laboratory. Three undisturbed samples of sand, silt, and clay collected from various depths on the riverbank had permeability coefficients that averaged 525 gpd per sq. ft. Four disturbed samples of alluvium were collected at depths of 86–128 feet from a well jetted in the new municipal well field. Laboratory analyses of the samples showed permeabilities that ranged from 570 to 140,000 gpd per sq ft, which indicates that much of the fine-grained material was probably removed during the jetting process. Though these figures are, in part excessively high, they do indicate the potential that can be expected from properly developed wells in this area.

Logs of wells in the alluvium of tributary valleys indicate that low permeabilities and transmissibilities can be expected. The subsurface material is, in general, very fine grained, ranging from dense clay to mixtures of silt and fine-grained sand. Yields are not known, but the fact that wells in this area are either dug in alluvium or drilled into the underlying bedrock indicates the probability that the water-transmitting capacity of the alluvium is poor.

QUALITY OF WATER

The overall quality of ground water in this area equals or exceeds that of the valley as a whole, and the degree of mineralization is less than the average for the entire valley. There is, however, a noticeable difference between the quality of water from the alluvium within a few hundred feet of the river and that from the area farther inland. Water from the heavily pumped zone along the river is less mineralized and is of the calcium bicarbonate or calcium bicarbonate sulfate type, with a hardness of about 200 ppm. This may be the result of induced infiltration (as previously noted) which would cause the wells to yield a mixture of hard ground water and soft river water. Ground water inland from the river is much harder (300–400 ppm hardness as $CaCO_3$), and most is more mineralized.

Excessive iron content in the water is a problem throughout the area. The iron content generally ranges from 2 to 8 ppm, and only a very few of the wells that were sampled had water containing less than 0.5 ppm. The U.S. Public Health Service standards indicate that over 0.3 ppm of iron causes objectionable staining.

CONCLUSIONS

High yields of good water can be obtained throughout the 2-mile-wide strip adjoining the river. Deep wells within a few hundred feet of the riverbank produce the largest yields and the least mineralized water; however, part of this water is probably induced from the river by infiltration.

The alluvium farther inland is generally finer grained but may contain basal lenses of coarse sand or sand and gravel that could yield more than 500 gpm of water to drilled wells. Most water in this area is much harder than that from wells which are closer to the Ohio River.

AVAILABILITY AND QUALITY OF GROUND WATER IN RELATIVELY UNDEVELOPED AREAS

AREA BETWEEN OWENSBORO AND THE HAWESVILLE VICINITY

LOCATION

The alluvial area upstream from Owensboro (HA–74, HA–72) follows a winding course for about 35 miles from Yellow Creek, near the Dewey and Almy plant, to the Skillman bottoms. The valley wall closely parallels the present Ohio River channel and borders an alluvial bottom which averages 1½ miles in width. At Hawesville and upstream from Skillman, however, the valley narrows to less than 1,000 feet in width.

The area is sparsely populated, and water resources are relatively undeveloped. Land use is devoted mainly to farming and oil production. The development of large water supplies has been confined to the municipal well systems at Lewisport and Hawesville. The only manufacturer currently (1964) using ground water is the Murray Tile Co. at Lewisport; however, the Harvey Aluminum Co. is constructing a rolling mill near Lewisport and anticipates an eventual need of a 15,000-gpm water supply. Water is also being used for irrigation of high-cash-yield crops and for secondary recovery of oil by waterflood methods.

GEOLOGY AND SATURATED THICKNESS

Oil production is concentrated mostly in the Maceo part of the area, but much oil is also produced throughout the rest of this alluvial bottom. Drillers' well logs give a good picture of the subsurface geology. The bedrock immediately underlying the alluvium is shale of Pennsylvanian age, which generally lies 350 feet above mean sea level near the valley wall but only 240 feet above mean sea level in the old deep channel. Concealed cusp-shaped remnants of the original bedrock protrude into the valley as subsurface extensions of the existing valley wall. These remnants are separated by valleys that were eroded by ice-age tributary streams.

Most of the lowest points of the bedrock floor are in the old deep channel, which lies at an altitude of about 250 feet in the upstream segment of this area and at an altitude of about 240 feet between Lewisport and Owensboro. This buried channel follows a winding course but is on the Kentucky side of the valley throughout most of this reach of the Ohio River (sheet 1 of HA–72 and of HA–74). The bedrock surface near Maceo is at a relatively lower altitude, however. Drillers' well logs of this area show bedrock altitudes of 217–235 feet above mean sea level (HA–74, sheet 2, section *B–B′*). These altitudes are several feet below the known altitude of the old deep channel.

The valley surface is relatively flat; hence, variations in the thickness of alluvium are primarily governed by the altitude of the underlying bedrock floor. This thickness generally increases toward the river because of the general slope of the bedrock surface. The alluvial deposits overlying the old deep channel are nearly 155 feet thick; and in the area of the bedrock low near Maceo, the deposits are more than 160 feet thick. The alluvium is thinnest, ranging from 90 to 100 feet in thickness, near the valley wall and over the buried bedrock highs. In the Lewisport area, for example, these highs are extensive and cover most of the bottom area; thus, the thickness of the overlying sand and gravel is not as great as elsewhere.

Texture of most alluvium throughout the area ranges from coarse sand to sand and gravel. In many places the generally fine-grained upper layer is missing or is very thin, and only a coarse basal section more than 130 feet thick is present.

Clay is present mostly as lenses that range from 5 to 15 feet in thickness. These clay layers, though sparse throughout most of this 35-mile-long stretch, are mentioned in many drillers' logs of wells in the valley bottom northeast of Lewisport. These lenses are also mentioned in a few logs of wells in the Skillman area.

The coarse basal layer of alluvium is generally a mixture of sand and gravel. In some areas, however, as in the river bottom between Hawesville and Lewisport, this material is predominantly sand, and gravel is absent or very sparse.

There appears to be no noticeable change in texture of the alluvium across the valley except in areas near the mouths of tributary valleys. In such places the material is a fine-grained heterogeneous mixture of tributary and Ohio River alluvium.

In general the water table of the area slopes rather steeply across the valley. It is highest (often within 10–15 ft of the surface) in the valley-wall area and lowest at the river, where it ranges from 360 to 370 feet in altitude. At the river the altitude of the water table is influenced by the pool stage of the Ohio River, as well as by seasonal conditions.

In terms of depth, the water levels in the Skillman bottom, upstream from Hawesville, are farthest from the surface and range from 45 to 62 feet below land surface. This is primarily because of the generally higher land surface in the area. Water nearest the surface occurs close to the valley wall where water levels in shallow alluvial wells are within 10 feet of the land surface.

The saturated zone, mostly composed of coarse-grained material, is thick throughout the area. It is thinnest (less than 40 ft) in the area near the valley wall, where the buried bedrock slopes rapidly upward. Throughout most of the bottom, however, this saturated zone ranges from about 100 to 140 feet in thickness. An exception to this is in the Lewisport area, where thinner alluvial deposits reduce the average thickness of the water-bearing zone to less than 80 feet.

After the completion of the dam at Cannelton, Ind., the pool stage of the Ohio River in the Skillman area will be raised 25 feet to an altitude of 383 feet above mean sea level. A similar rise in the ground-water table will result from this, and the saturated thickness in parts of the Skillman bottom will increase to more than 150 feet.

YIELDS OF WELLS

More than half of the water supplies in the area is derived from 1¼-inch-diameter driven wells. The depth of most of these wells ranges from 45 to 60 feet, but many in use are more than 85 feet deep. The multiple systems of large-diameter driven wells used for irrigation in the Maceo-Waitman area are generally only 30–40 feet deep.

Drilled wells are used in nearly half of the water systems. Depths are generally 60–100 feet, but two wells have been drilled to 110 feet, and another is 144 feet deep.

There are only a few dug wells, most of which are in the areas of tributary alluvium. The large-diameter wells allow greater storage for the slow-moving ground water.

Nearly all wells in the area yield less than 10 gpm. Most wells, however, supply only domestic needs or water for livestock; hence the yields generally indicate the users' demands rather than the potential of the aquifer. The only large-yield well systems in the area are used for public supply or irrigation. The public-supply wells at Hawesville are 110 feet deep and yield 350 gpm. The valley is less than 800 feet wide at that point, and the saturated thickness is only 75 feet; therefore, these wells are probably inducing infiltration from the Ohio River, which is about 200 feet away. The municipal supply well at Lewisport was drilled to a depth of only 83 feet and yields 300 gpm. The shallow multiple-well systems commonly used for irrigation in the area have yields ranging from 300 to 400 gpm.

Few aquifer-performance tests have been made in this part of the valley bottom. One permeability test was performed in the Geological Survey Hydrologic Laboratory on an undisturbed sample of fine sand. This sample, taken at 10-foot depth near the mouth of a tributary valley, had a permeability of 310 gpd per sq ft.

The only transmissibility and specific-capacity data available are from the analysis of pumpage and drawdown measurements taken during a well test near Maceo. The well, pumped for only 1 hour, had a specific capacity of 200 gpm per ft. Transmissibility, from the same test, was computed at 360,000 gpd per ft.

A general comparison of the saturated thickness and texture of the alluvium in this section of the valley with similar sections of known performance indicates that yields in excess of 500 gpm may be obtained here from properly constructed wells.

Little is known about the water-bearing potential of the tributary alluvium. The authors noted, however, that most wells in or near the tributary valleys are dug wells in alluvium or are drilled wells penetrating the underlying bedrock aquifer. This suggests that low yields can be expected from the tributary alluvium in these areas.

QUALITY OF WATER

Ground water of the area is of the calcium bicarbonate type and is, in many respects, of about average quality for water in the Ohio River valley. In chemical analyses of most samples, the hardness as $CaCO_3$ ranged from 250 to 350 ppm, and two extremes, 55 and 570 ppm, were noted. Significant amounts of magnesium and sulfate were recorded in some water samples on which complete analyses were made.

Iron is present in large amounts in water throughout the area. Its presence is a troublesome factor to users. Water from many wells contains less than the U.S. Public Health Service's maximum recommended standard of 0.3 ppm iron, and nearly all has less than 1.0

ppm; but the iron content of water from some wells ranged from 5 to 10 ppm.

Most chloride and nitrate contents were less than the amounts considered unsafe for drinking purposes. Where the chloride and nitrate contents were high, the cause could generally be attributed to localized contamination by oil-well brine or by barnyard and fertilizer seepage moving into the alluvial water supply. An example of this was water from a well near the mouth of a tributary stream. Analysis of this water showed nitrate and chloride contents in excess of 100 ppm. The well is located in a barnyard and is only 200 feet from an oil well; consequently, these high concentrations are probably due to surface contaminants rather than to natural causes.

CONCLUSIONS

The availability and quality of ground water are such that the area seems to have good potential for industrial or municipal growth. The largest yields can be expected from wells that penetrate the full thickness of saturated alluvium near the river and in the area of the old deep channel.

Seasonal flooding is not likely to be a danger, except in the area of the minor tributary streams. Most land surface is above an altitude of 390 feet and therefore safely above the waters of even extreme floods.

The Skillman bottom, though virtually undeveloped, has certain geologic and hydrologic assets. The alluvium is generally coarse, and the old deep channel is present throughout the length of the bottom. Upon completion of the dam at Cannelton, Ind., the thickness of the saturated zone will increase from 130 feet to more than 150 feet; thus, the ground-water potential for the area will be greatly increased.

AREA FROM OWENSBORO TO SPOTTSVILLE

LOCATION

Downstream from Owensboro and terminating near the confluence of the Green and Ohio Rivers is one of the most extensive and least developed alluvial areas in the Ohio River valley. It is about 25 river miles in length and includes the Green River and Panther Creek drainage systems. In the Stanley–Bon Harbor Hills area the alluvium is approximately 11 miles wide. Downstream it gradually narrows to a few miles in width in the Spottsville area, at which point it wedges out abruptly to 1 mile in width at the mouth of the Green River. Most of this area is described in Hydrologic Investigations Atlases 9? and 110.

Throughout most of the area there is relatively little topographic relief; the land surface ranges in altitude from 370 feet above mean sea level near the Ohio River to 400 feet several miles inland. Two notable exceptions exist. One, the westward extension of the natural levee in the city of Owensboro, stands above the alluvial plain at an altitude of about 420 feet above mean sea level. The other is an outcropping remnant of rocks of Pennsylvanian age west of Owensboro. The largest of these outcrops is the Bon Harbor Hills area, which covers several square miles and rises more than 150 feet above the surrounding plain. Smaller bedrock remnants lie to the southwest of Bon Harbor Hills and rise to altitudes of 460–490 feet above mean sea level.

Development of water supplies is minimal. There are no public water systems; daily needs are supplied by private wells. The recently established Old Stanley Distillery is the only industry in the area.

Present land use is primarily for farming and oil production, but these activities are becoming progressively larger users of ground water. Irrigation of high-cash-yield crops, such as tobacco, vegetables, and berries, has increased rapidly during the past 15 years. This highly consumptive use is practiced most heavily during the season of fairly low ground-water levels, and most of the water thus used is lost from the ground-water system by evapotranspiration.

Use of waterflood methods for secondary oil recovery has also greatly increased in the area. Henderson and Daviess Counties rank first and second in Kentucky oil production, and, as previously noted, in 1962 one-fourth to one-half of this production was by waterflood methods. Thus far, most of the water used is from the deeper bedrock aquifers and is recirculated in closed systems. Present use from the alluvial supply thus is somewhat limited. In one of the larger flood projects near Reed, 25,600 gpd is used. This is the quantity pumped in 24 hours by a well yielding only 18 gpm. As natural pressure is lost in the oil pools, more and more production will be by waterflood methods, and part of this water will be derived from wells that terminate in the alluvium.

GEOLOGY AND SATURATED THICKNESS

More is known about the subsurface geologic conditions here than in any other area of comparable size along the Ohio River valley. Much of the area, especially that near Reed and Stanley, has been extensively drilled and logged by companies in search of oil. This has provided much information on both the thickness and texture of the alluvium and on the composition of the underlying bedrock.

The bedrock immediately underlying the alluvium is shale of Pennsylvanian age. In contrast with the flat land surface of the area, the bedrock surface displays many erosional features and considerable relief. The erosion, which occurred prior to the deposition of the present valley fill, left a surface composed of benches, cusps, and terraced hills separated by glacial-age stream channels. The highest parts of the alluvial-covered bedrock in the area are at an altitude of 300 feet.

Less is known about the altitude of the bedrock surface in the area 5–11 miles from the river. However, logs from scattered wells indicate that the bedrock surface has less relief and rises gradually toward the valley wall.

The lowest bedrock altitudes in the area are found in the old deep channels. (See sheet 1 of HA–96 and of HA–110.) East of Bon Harbor Hills the deep channel is at an altitude of 240 feet above mean sea level. The channel forks at this point; one branch continues to follow the path of the present Ohio River, and the other branch passes south and then west around Bon Harbor Hills and then curves northwest to the Birk City area. The deep channel then takes a northerly course, passes just east of Newman, and rejoins the main branch. At this point the channels are at an altitude of 230 feet above mean sea level. Ancient streams tributary to the deep channel were entrenched to altitudes of 250 feet above mean sea level.

The land surface is relatively flat; hence, the thickness of the alluvium is governed primarily by the altitude of the surface of the underlying bedrock. This thickness averages 120 feet or less throughout the bottom.

The alluvium is 90 to 100 feet thick where the valley fill overlies the bedrock highs. Greatest depths of alluvium are found in the area of the old deep channel. Here the alluvium averages 140 feet in thickness and may be as much as 180 feet deep in the area of topographic highs, as on those points where the channel passes beneath the natural levee.

The size and texture of most alluvium readily allow movement of water to a well. The upper fine-grained layer is 30 feet deep or less, and the thick basal layer is predominantly gravel or sand and gravel and apparently lacks extensive clay layers. (See sheet 2 of HA–96 and of HA–110.)

The basal material is coarse throughout more than half the width of the valley. At an indefinite point inland from the river (5–7 miles inland in the wider parts of the valley), however, the basal material becomes progressively finer in texture and consists mostly of sand-sized material. Still farther from the river the material is largely a mixture of silt, clay, and fine sand, and little or no gravel is present. This is mostly tributary alluvium of Green River and Panther Creek.

Two other areas of fine-textured alluvium are found near the Ohio River. In the proximity of Bon Harbor Hills much alluvium is not only thin but very fine grained and includes may layers of clay or silt and clay mixtures. The other area of alluvium of poor texture is near the confluence of the Green and Ohio Rivers. Here, though the alluvium is thick, it is mostly sand, silt, and clay, and represents a mixture of the deposits of the two river systems.

Textures of alluvium in the Green River valley, inland several miles from its mouth, are somewhat unpredictable. Though much of the alluvium is fine grained, many extensive lenses of coarse gravel are found in the zone immediately overlying the bedrock.

The water table of the area slopes very gradually toward the river across the main part of the valley. The watertable is highest early in the growing season and lowest at the end of summer but is always above the Ohio River pool level. In the coarser more productive area within a few miles of the river, the water table is 15–25 feet below land surface. The water is generally 8–15 feet below land surface in the area of fine-grained alluvium away from the main stream. The thickness of the saturated zone ranges from 90 to 120 feet; it is determined primarily by the altitude of the underlying bedrock.

YIELDS OF WELLS

In this area wells are predominantly driven wells 1¼-inch in diameter which penetrate 25–35 feet of alluvium. Wells within a few hundred feet of the Ohio River, however, must be 45–50 feet deep, because the water table slopes steeply down to the low-pool stage in late summer. These small-diameter wells are primarily for domestic use and for watering livestock, for which purposes they are quite adequate. Reported or measured yields are normally 10 gpm or less, but this reflects user needs or the pump type rather than the potential of the aquifer.

Driven wells of larger diameter (4–6 in.) are used for irrigation. Yields of from 300 to 800 gpm are obtained by combining as many as four such wells into one system. The depth of these wells varies greatly; it depends on the owner, his needs, and the local conditions. The general range of depth is from 30 to 70 feet below land surface.

There are relatively few drilled wells in the area, mostly because of initial cost and lack of widespread need for large yields. Most are fairly shallow. They range from 35 to 80 feet in depth and do not penetrate the full thickness of the water-bearing formation. The deepest known wells in the area are two recently drilled 12-inch-diameter wells at the Old Stanley Distillery. These are about 122 feet deep and probably draw from the entire saturated thickness of the aquifer. Yields, when tested, were 200 and 394 gpm as compared with about 90 gpm for most of the area's shallower drilled wells.

The permeabilities of four undisturbed samples of fine-grained alluvium taken from shallow depths at one site on the bank of the Ohio River ranged from 70 to 750 gpd per sq ft. Specific capacities of six wells ranged from 9 to 160 gpm per ft and averaged 92 gpm per ft, which is nearly double the average for wells in the Ohio Valley in Kentucky.

The hydrology of the tributary alluvium in the area is largely unknown. Though most of the alluvium is fine grained, a few basal layers of gravel or sand and gravel are present which supply good yields. This is true along the Green River, where yields sufficient for use in waterflooding are being obtained from basal gravels.

The smallest yields in the area are obtained where the fine-grained tributary alluvium has mixed with coarser Ohio River valley alluvium, as near the mouth of the Green River and along the flood plain of Panther Creek, deep in the valley.

QUALITY OF WATER

The area's overall ground-water quality is about average for the Ohio River valley. The water is of the calcium bicarbonate type; it ranges from 100 to 350 ppm in hardness as $CaCO_3$—slightly less hard than the average along the valley.

Iron content in water tends to be a problem in many wells. Some wells tested had water that contained less than the U.S. Public Health Service recommended maximum limit of 0.3 ppm, but most wells yielded water that had an iron content ranging from 0.5 to 10 ppm.

Despite the large number of oil wells in the area, there is little chloride contamination from brine disposal. In one sample, from a water well near Carlingburg, the chloride content was about 200 ppm, which is well below U.S. Public Health Service recommended maximum limits.

Only one water sample tested showed nitrate as NO_3 in quantities above the U.S. Public Health Service recommended maximum limit of 45 ppm. This water had 60 ppm nitrate, probably owing to barnyard contamination.

CONCLUSIONS

The area seems entirely adequate for industrial expansion, especially for users who need large quantities of water. The largest yields are to be obtained in the area close to the Ohio River from deep wells that terminate in the basal gravel just above the bedrock floor. Where such wells also penetrate to the floor of the deep channel, the increase in saturated thickness will permit greater drawdowns in individual wells. Potential yields from properly constructed deep wells in this bottom should easily exceed 500 gpm.

The water is hard and is high in iron content, but the overall quality is better than the average for water in the Ohio River valley.

AREAS OF POOR POTENTIAL OR WITH SPECIAL PROBLEMS

Despite the good ground-water potential of the Ohio River valley as a whole, there are areas where quality or quantity of the alluvial water supply is substandard. In the Henderson area (HA–91), for example, most alluvium is so fine grained that even modest well yields are uncommon, and water supplies must be obtained from the Ohio River or from the bedrock aquifers. There are exceptions to this both upstream and downstream, but parts of these areas are residential or are subject to yearly flooding by the Ohio River and its tributary, Canoe Creek. The large bottom that extends downstream to Uniontown is underlain mainly by very permeable formations. Only one part of this area, a topographic high north of the community of Geneva, lies above the altitude of known flood waters, however.

The quality of ground water in the alluvium of the abandoned Ohio River meander in the Wolf Creek area of Meade County, Ky., is a potential problem. The nitrate content of water from domestic-supply wells is as much as 160 ppm—over four times the maximum recommended limit established by the U.S. Public Health Service. Contamination may stem from several sources, but because the greatest nitrate concentrations are all found in water from shallow dug wells, poor well construction coupled with barnyard seepage or leaching of nitrate fertilizers are seemingly the most probable causes

Frequent flooding by the Ohio River or its tributaries is a limiting factor in the development of many alluvial areas. Overflow of the riverbank seems more severe in the downstream part of the State. The volume of the river in this area is greater owing to the addition of water from many tributaries; also, land-surface altitudes are lower in comparison to the heights of flood crests than are the bottoms upstream. Flooding by the Ohio River may eventually be alleviated by the flood-control reservoirs that are being built or planned for many tributary streams.

Flooding also occurs near the mouths of tributary streams and often causes more property damage than the waters of the overflowing Ohio River. These smaller streams become clogged easily, and in the spring the melting snow and heavy precipitation cause them to overflow their banks.

FACTORS AFFECTING FUTURE GROUND-WATER QUALITY AND QUANTITY

The future quality and quantity of ground water in the Ohio River alluvium will be affected by a number of factors. Among these are increased withdrawal, changes in the chemistry, temperature, and radioactivity of Ohio River water, drainage problems associated with increased urbanization, new dams that create changes in pool stage, and changes in the amount or character of river sediment.

INCREASED WITHDRAWAL

Increase in withdrawal will come as the natural result of population increase, greater water use per capita, and industrial growth. Growth in the Ohio River valley during the next 15 years will probably be rapid. In the Evansville (Ind.)-Henderson-Owensboro (Ky.) area, for example, both population and employment are expected to double by 1980.[1] Modern plumbing, swimming pools, kitchen appliances, and greater use of ground water for industrial cooling and air conditioning will create greater demands. Local problems of quantity will probably arise, but as a whole, the area can supply many times the expected growth increase.

Irrigation is a consumptive water use—that is, almost all the water used is returned to the atmosphere by evaporation and transpiration. The practice of irrigation in the Ohio River valley is somewhat limited at present (1964), but it is profitable and is expected to increase greatly in the future. Most irrigation is done during the time of low ground-water levels; however, there is no other major water use in the rural areas, and no serious shortages are likely to occur there.

Use of waterflooding as a means of secondary recovery of oil also is rapidly increasing. The total pumpage of fresh water for oil recovery is, at the present time, moderate (generally averaging less than 100 gpm in a waterflood project), and even the expected increase in use will not noticeably affect the ground-water supply. Contamination of the fresh ground-water supply is a potential problem, but closed systems are generally used. These systems recirculate the waters of high chloride content and prevent their escape into the alluvial aquifer.

CHANGES IN CHEMISTRY, TEMPERATURE, AND RADIOACTIVITY OF OHIO RIVER WATER

Water moves rather freely between its surface and subsurface environments; therefore, that which affects the water at the surface also

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[1] Bramlett, G. A., and Pratt, W. J., 1964, Economic development in the Ohio River valley region: Spindletop Research, Inc., Lexington, Ky.

affects the water in the subsurface environment. The reverse is also true. This interrelation is most apparent in heavily industrialized areas close to the river, where much river water is induced into alluvial wells by infiltration. River-water contamination, highest during the time of greatest pumpage, could adversely affect the quality of water yielded by these wells.

Man's activities have caused numerous changes in the quality of the Ohio River water. Prior to the inception in 1948 of an eight-state organization, the Ohio River Valley Water Sanitation Commission (ORSANCO), the Ohio River was much like a cesspool in nature. Less than one-half percent of the population of the Ohio River valley lived in communities where sewage-treatment plants were in operation. By 1963, 98.5 percent of the valley's population lived where sewage treatment was practiced, and 85.6 percent of the industries that discharged waste directly into the Ohio River and tributaries met the minimum ORSANCO requirements. Only 12 plants did not treat their waste products at that time.

Dumping of oil-field brines onto the land surface and into tributary streams was a problem until recently. The practice made both surface- and ground-water supplies unfit for man's use and killed much of the fish population. Legislation has almost entirely eliminated this problem.

A large percentage of the ground water used by industry is for cooling purposes. After use this water is often returned to streams or pumped into the aquifer. It is chemically unchanged but much warmer. The increase in temperature makes the water less suitable for similar use in downstream areas.

Other problems are the pollution of the water by household detergents and by waste materials from plants that handle radioactive materials. Modifications are being made in the composition of detergents which will promote their decomposition and reduce the contaminating effect on surface- and ground-water supplies. High-level radioactive wastes, such as spent reactor-fuel elements and discarded radioisotopes, are presently stored and, except for human error, are not a potential source of ground-water contamination. Low-level wastes, including cooling and wash water used near reactors, may be stored at such depths that fresh-water supplies will not be affected.

The Ohio River water is reused many times before it discharges into the Mississippi. With the increase in number of ground-water users, greater quantities of river water will be induced into the alluvial aquifer by infiltration, and it may become necessary to develop new and more effective methods of water treatment and both increase and tighten the existing water-pollution controls.

DRAINAGE PROBLEMS ASSOCIATED WITH INCREASED URBANIZATION

Drainage problems will increase with the growth of cities and industry. Additional buildings and areas of asphalt will increase the amount of water carried off overland and by storm sewers and will reduce the amount of ground-water recharge. Increased runoff will create a greater peak load that must be borne by smaller streams of the area during high water, thereby causing local flooding in low areas. The increased runoff will reduce both recharge and the amount of ground water available to the streams during times of low flow.

HIGHER DAMS AND RESULTING CHANGES IN POOL STAGE

Larger navigation locks and dams are being constructed along the Ohio River to replace the present structures. New pool stages above these dams will be considerably higher than before, and a corresponding rise of the ground-water table in the adjacent alluvium will result. Thus, the amount of ground water in storage will be increased, and more water will be available for use. This rise may, however, put the water table at or above the level of existing septic tanks and cesspools in some areas, and cause contamination of both ground- and surface-water supplies. Also, some water logging of the upper part of the alluvium is expected during the period of excess water, as in the spring of the year.

CHANGES IN AMOUNT OR CHARACTER OF RIVER-BOTTOM SEDIMENT

Changes are also expected to occur in the amount and character of the sediment on the river bottom. Both dredging and the change in ponding created by the new dams will cause shifting of silt and clay deposits in the streambed. In some areas this may effectively reduce the amount of river water available to wells that formerly derived much of their water by induced infiltration; in other areas infiltration may be improved.

CONCLUSIONS

The alluvium and the ground water that is stored in and moves through the alluvium are parts of the whole hydrologic system of the Ohio River basin. Water in the ground, on the surface, and in the atmosphere are interrelated and interdependent parts of the system, and that which affects the quantity or quality of water in one environment can affect the whole system.

The quantity of water in the alluvial part of this system is large, and there is no problem of an "overall" shortage of supply in the foreseeable future. Yields of several hundred gallons per minute are available from properly constructed wells in permeable materials near the river, and amounts large enough for domestic needs, or for the requirements of small industries, are available in most areas along the valley.

Expansion of areas of industrial or municipal withdrawal or the development of new industrial sites should not create problems of quantity if care and intelligent management are used in the spacing and construction of wells. However, where industrial and public-supply wells already are heavily concentrated in relatively small areas, as in Ashland, southwestern Louisville, and Owensboro, greater caution must be exercised in the development of new supplies. In such areas withdrawal equals or exceeds the amount of water available by natural recharge. Extended periods of drought would cause further depression of the water table, thereby necessitating artificial recharge of the aquifer or the reduction of pumpage.

The problem of greatest concern in the area is the present and future quality of water. Water from the alluvium, though generally very hard and high in iron content, offers several advantages over that from other sources of supply because of its low temperature and constant quality. Increased growth and expansion in the Ohio River valley will, however, multiply the problems of waste disposal, water purification, and pollution of ground-water supplies. Because water may move in either direction between the surface streams and aquifers, the quality of all water in the basin must be safeguarded, and new methods of treatment must be developed.

Floods are a problem, especially in the development of new industrial sites, but the danger of flood damage may be lessened by future U.S. Army Corps of Engineers structures. A workable solution to the problem of industrial flooding is to elevate all facilities above the possible flood stage. An alternative might be to construct plant sites in the high bedrock area of the valley wall and pump ground water up to the factory from alluvial wells in the bottoms.

Such methods could involve the use of cheaper land for the factory site, access to better transportation, and less potential flood danger than exists in many areas now considered prime industrial sites.

RECOMMENDATIONS FOR FUTURE STUDY

DETAILED STUDIES OF PROBLEM AREAS

Additional detailed investigations are needed regarding the quality and quantity of available ground-water supplies throughout the Ohio River valley. Studies should include specific areas, such as Henderson and Wolf Creek, and the general problem areas of the entire valley.

Solution of problems must keep pace with the anticipated, as well as the existing, demands of industrial and municipal growth.

STUDY OF THE GEOLOGY AND HYDROLOGY OF SMALL BOTTOMS AND TRIBUTARY VALLEYS

Little or no information is available about the material underlying many of the smaller bottoms along the Ohio River valley. Exploratory-drilling programs should be conducted in such areas, especially in bottoms where the land surface is above flood stage and where transportation and labor requirements can be satisfied.

Studies should also be made of the alluvium and the ground water in tributary valleys, especially in areas near or adjacent to the Ohio Valley. Well yields from basal alluvium along the Green River, for example, range from 100 to 300 gpm—enough for many types of small industries. More detailed information concerning the extent and yield of such deposits and the quality of the contained water could be an economic asset to the entire Ohio River valley.

MONITORING STATIONS FOR GROUND-WATER QUALITY

As mentioned, control of water quality is expected to be the greatest problem in the future. Surface-water quality is now monitored at many points in the valley, both on the Ohio River and its tributaries. The quality of ground water, however, is monitored only in the heavily pumped Rubbertown subarea of Louisville. In the future a system of stations should be set up to periodically monitor the quality of ground water in and around cities, industrial sites, unpopulated areas, and tributary valleys.

GEOCHEMICAL STUDIES

More detailed geochemical studies should be made concerning specific areas or specific problems. Studies are already underway to determine how ground water is affected by acid mine drainage. Additional investigation should be made on the heating effect of recharge water, the high sulfate and hardness of ground water near cities (as in the Louisville and Covington-Newport areas), excessive nitrate (as in the Wolf Creek area), possible ground-water contamination resulting from the higher pool stages above the new dams, and many other existing or potential problems.

PERIODIC INVENTORY OF WATER USE

The U.S. Geological Survey periodically inventories the amount of water used for public, industrial, and municipal supplies. The time lapse between present inventorying periods is, however, sufficiently long to allow increased withdrawal to cause overdraft of the aquifer and lead to local water shortages. More frequent inventories and (or) better liaison with the State and municipal agencies in close contact with industrial development would provide early warning of major changes in pumpage and allow time to recommend and execute measures that might protect the aquifer.

Two relatively new water uses, irrigation and oil-field waterflooding, are rapidly increasing, and they should also be inventoried carefully. These withdrawals are normally from sparsely settled areas, so there is no conflict with other water users; such information, however, would add greatly to existing knowledge concerning the potential of the alluvial aquifer.

WATER-TABLE MAPS

Water-table maps show contours on the top of the zone of saturation. When such maps are made and periodically revised, it is possible to see the shift or development of cones of depression and to foresee overdraft of the aquifer. Water-table maps are available only for the Rubbertown subarea of southwestern Louisville, but such maps could provide valuable information in other heavily pumped areas in the Ohio River valley, such as Ashland and Owensboro.

These maps should also be made of the water levels in alluvial bottoms upstream from some of the proposed larger Ohio River dams. The higher pool stages of the river in these areas will raise the water table and may have both good and bad effects on the alluvial bottoms involved. For example, some benefit may be derived from the increase in saturated thickness, and some damage may result from waterlogging. Information obtained by observing the rate and degree of this ground-water buildup can be used to predict the effects of new pool stages in other areas. Such a project should be combined with an investigation of the changes in water quality, as mentioned in "Geochemical Studies" (p. 71).

ARTIFICIAL RECHARGE

Artificial recharge is the introduction of water into an aquifer by means of water spreading or by recharge wells. Both methods have been tested in Louisville, but only the latter has been successful. The practice of artificial recharge allows replenishment of the aquifer during times of surface-water excess and has also been used as a means for disposing of warmed water that had been used for cooling purposes.

Continued industrial and municipal growth will cause artificial recharge to become standard practice in heavily pumped areas. Before such time arrives, research should be done on the details of proper use of this method and on the effects that such use would have upon the aquifer.

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