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GROUND WATER IN THE ALLUVIUM ALONG THE GREEN RIVER BETWEEN ITS MOUTH AND WOODBURY, KENTUCKY

By
Paul D. Ryder

WATER RESOURCES INVESTIGATIONS 53-73

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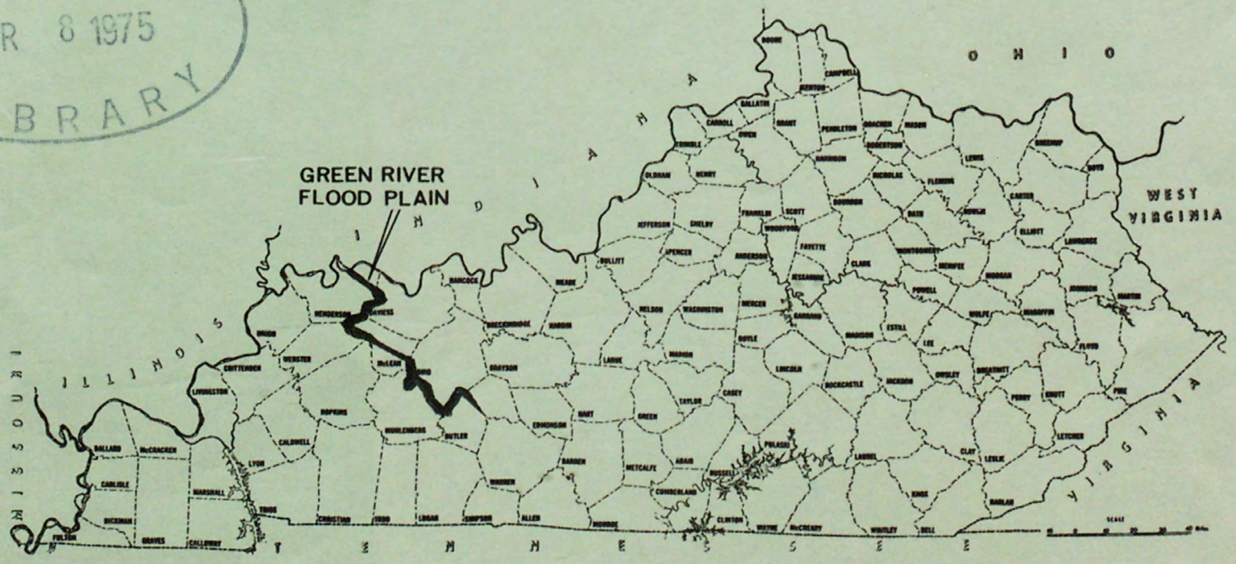

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GROUND WATER IN THE ALLUVIUM ALONG THE GREEN RIVER BETWEEN ITS MOUTH AND WOODBURY, KENTUCKY

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INTRODUCTION

The area of investigation is that part of the Green River flood plain which is in the Western Coal Field region of Kentucky. It extends from the mouth at the Ohio River to river-mile 149 (river-kilometer 240) at Woodbury, Ky. The flood plain varies in width from 0.4 mile (0.6 kilometer) to over 6 miles (9 kilometers). Total surface area is about 345 square miles (89,400 hectares). Navigational pools are maintained on this part of the Green River by a series of locks and dams.

Purpose

Recent public and industrial ground-water developments in the Green River alluvium, with well yields up to 0.44 cubic feet per second (ft^3/s) (0.012 cubic meters per second (m^3/s)) emphasize the need for a more intensive, quantitative investigation of this potentially valuable resource. The purpose of this study is to describe the geologic, hydrologic, and water-quality characteristics of the alluvial aquifer, and to analyze aquifer response to simulated pumping. This information will aid water users in the planning, location, and development of ground-water supplies in the area.

Previous Investigations

A series of related reports (Maxwell and Devaul, 1962a, b, c, d and Devaul and Maxwell, 1962a, b) describe the geology and availability of ground water in the Western Coal Field region, Kentucky. These studies were of a brief, reconnaissance nature, and little information was available with which to evaluate the potential of the alluvial aquifers in the Western Coal Field other than the Ohio River alluvium. A later report by Hopkins (1966) has a contour map showing the altitude of the base of fresh water in the area.

Method of Investigation

Water wells in the area were inventoried, and test drilling was done at several sites. These records, together with the logs of bridge and dam borings and coal, oil, and gas test holes, were used to construct a hydrogeologic map which shows the general extent, thickness, and character of the alluvial aquifer. Water samples were collected for chemical analyses.

A pair of 1½-inch (3.8-centimeter) observation wells were installed and screened in the alluvium at each of four sites. Continuous water-level data were collected at the wells; these data were analyzed by computer, using methods developed by Pinder, Bredehoeft, and Cooper (1969) and Bredehoeft and Pinder (1970).

Acknowledgments

This report was prepared as part of a Statewide program of water-resources investigations, conducted in cooperation with the Kentucky Geological Survey. The Kentucky Geological Survey's field office in Owensboro was particularly helpful in furnishing well-log data. The Tennessee Valley Authority was cooperative in furnishing hydrologic data.

GEOLOGY

Alluvium

The Green River, like other streams in the Western Coal Field, has a relatively wide, flat-bottomed, alluvium-filled valley. The extensive widening of the valley has been attributed to erosion of weak Pennsylvanian shales. The unusually great thickness of alluvium in this unglaciated area was caused, in part, by the ponding of the Green River during the Pleistocene Ice Age. The ponding, in turn, was caused by the aggrading of the Ohio River valley by glacial flood waters. The Green River bedrock valley thus was filled with sediment brought in by the stream system, and by material brought in by glacial backwater from the Ohio River (McFarlan, 1950, p. 165). Thickness and lithologic characteristics of the alluvium are shown graphically on the map by strip logs of 39 holes drilled for various purposes. A brief summary of the data from these 39 holes is as follows:

	Depth to bedrock (feet)	Thickness of surficial clay and silt (feet)	Aquifer thickness (feet)
Mean	80	46	34
Range	24 to 146	10 to 90	0 to 80

The upper part of the alluvium generally consists of clay and silt. Coarser grained deposits ranging from fine sand to gravel are found in the lower part of the alluvium, but the character and thickness of these deposits vary considerably from one place to another over the study area. The alluvium generally becomes thinner in the upstream direction. However, it can be seen from the map that many very shallow holes with little or no sand and gravel are found in the alluvium between site B and site C.

Generalized geologic sections (figs. 1-4) of sites A, B, C, and D show aquifer depth and thickness, ground-water levels with the Green River at pool stage, and the positions of the observation wells with respect to the Green River and the bedrock valley walls.

Bedrock

The alluvium-bedrock contact and the thickness of alluvium at numerous sites are shown on the map. The rocks in contact with the alluvium in the study area are mainly shale, siltstone, and sandstone of Pennsylvanian age. The areal distribution, lithology, hydrology, and water quality of each formation are described in reports by Maxwell and Devaul (1962a, b, c, d) and Devaul and Maxwell (1962a, b). In general, these rocks yield very little water; however, certain sandstone aquifers of limited areal extent reportedly yield water to wells at rates of up to 0.56 ft^3/s (0.016 m^3/s). The depth at which fresh water can be found is limited; a map by Hopkins (1966) shows that the altitude of the base of fresh water in the study area varies from about 200 feet (61 meters) above mean sea level at the junction of the Green and Ohio Rivers to about 300 feet (91 meters) below mean sea level in the vicinity of Rochester, Ky.

HYDROLOGY

Occurrence and Movement of Water in the Alluvium

Water occurs in the intergranular spaces in the alluvium and is derived from three principal sources: direct precipitation, underflow from bedrock, and the Green River during high stages.

Precipitation, which averages about 44 inches (112 centimeters) per year in this area, falls directly on the alluvium and may percolate downward under favorable conditions to become part of the ground water. Notable factors that influence the amount of percolation include topography, type of surficial material, soil-moisture content, temperature and humidity, and the type and amount of vegetation present. It is probable that direct precipitation accounts for only a very small part of the total recharge to ground water in the study area because of the almost universal presence of a thick surficial layer of clay and silt.

Water flowing through bedrock aquifers may enter the alluvium at the bedrock-alluvium interface. However, recharge from this source is small because of the fine-grained nature of the bedrock in the area. At two sites in the alluvium, sites C and B, recharge from bedrock ranged from negligible to only 0.016 foot per day (0.0049 meter per day).

The largest source of recharge to the alluvium, where hydraulic connection exists between alluvium and river, is the Green River. At times of low river stage, normally during the summer and fall months, the slope of the potentiometric surface is toward the river, and water discharges from the alluvial aquifer to the river. Induced infiltration of river water may occur when the water level in the aquifer falls below river stage in response to ground-water pumpage. During times of high river stages, mainly in the winter and spring, water flows from the river into the alluvium.

Ground-Water Use and Well Yields

Withdrawal of water supplies from the alluvial aquifer is often preferable to withdrawing water directly from the Green River because of the relatively high cost of intake construction and maintenance associated with the latter source. During times of greater streamflow and higher stages, the river-water intakes become clogged with silt and debris; frequent cleaning is thus necessitated. Other advantages of a ground-water supply include a more uniform quality and temperature, little or no turbidity, and a virtual absence of bacteria. These advantages are maintained even when the ground-water supply is recharged from the river via induced infiltration (Rorabaugh, 1963, p. 50).

The alluvium along the Green River has been the source of water for a few small-diameter drilled wells and for dug wells. These wells yield several gallons per minute and are usually adequate for modern domestic supplies. However, in recent years one city and two industrial operations have turned to the Green River alluvium as the source of relatively large water supplies. The city of Island, in McLean County, has a recently completed water system in which two gravel-packed tubular wells reportedly yield water at the rate of 0.44 ft^3/s (0.012 m^3/s) each. A waterflood well for Ashland Oil Company's North Euterpe unit was completed in the alluvium in Henderson County about 2 miles (3 kilometers) north of Delaware, Ky. This well has a reported potential yield of about 0.39 ft^3/s (0.011 m^3/s). Two wells finished in the alluvium 1.5 miles (2.4 kilometers) west of Calhoun supply water for the secondary recovery of oil at Har-Ken Oil Company's Guffie unit. The combined yield of the two wells has been reported at 0.62 ft^3/s (0.018 m^3/s).

Aquifer Characteristics

Two terms that define the hydraulic characteristics of an aquifer are transmissivity and storage coefficient. Transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient, and is given in feet squared per day. The storage coefficient (S) is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. When T, S, and boundary conditions are known, the drawdown can be predicted for any time after the start of pumping, at any distance from the pumped well, and for any given rate and distribution of pumping. Kunkel (1960) discusses time-distance-drawdown relationships when T and S are known or assumed.

A pumping test is the most frequently used method for determining the aquifer characteristics T and S. However, no properly conducted pumping tests have been made in the Green River alluvium. A relatively inexpensive method for determining the diffusivity, the ratio of the transmissivity to the storage coefficient (T/S), from the responses in the aquifer to fluctuations in river stage is described by Pinder, Bredehoeft, and Cooper (1969). This method, the Flood Wave Response Model, was used at four sites labeled A, B, C, and D on the map. At each site a 1½-inch (3.8-centimeter) observation well was placed very close to the river's edge and screened near the base of the alluvium. A second observation well was placed about 1,000 feet (305 meters) back from the first well, and in a line perpendicular (or nearly so) to the length of the river. A flood wave in the river induces water-level changes in the first observation well. These changes are recorded continuously. The responding water-level changes in the second well are also recorded; these changes are dependent upon the geometry and hydrologic characteristics of the aquifer. Water-level data from the first well, known geometric data, and several estimated T/S values are used in the Flood Wave Response Model to generate theoretical type curves. The curve that best matches the plot of the observed data at the second well (a trial-and-error process) gives a value from which the diffusivity can be computed. (See Pinder, Bredehoeft, and Cooper (1969) for the theoretical development and a more complete discussion of this method.) The diffusivity provides a rational basis for estimating T when S is known or assumed or vice versa, and time-distance-drawdown relationships can then be computed.

Plots of observed flood-wave data at sites B and C and the best-fitting theoretical type curves are on figures 5 and 6. Computed diffusivities are shown on each graph. The observed data could not be matched by calculated type curves at sites A and D. Significant inhomogeneity of the aquifer material is assumed to be the major cause. Absence of diffusivity values and permeability distribution data at these two sites precludes aquifer evaluation by digital modeling, which is discussed in the next section for sites B and C.

Aquifer Evaluation by Digital Modeling

The T/S ratio obtained from the Flood Wave Response Model at each site can be divided into reasonable values of T and S by using a rule-of-thumb method proposed by Lohman (1972, p. 53) to estimate S at each site. These parameters, together with streambed thickness and hydraulic conductivity, water-level elevations in streams, and location of bedrock valley walls, are used in an iterative digital model developed by Bredehoeft and Pinder (1970). This model simulates the response of an aquifer to pumping or fluctuations in stream stage by solving the two-dimensional ground-water flow equations. A complete description and procedure in the use of the model is given by Pinder (1970).

Each variable parameter in the model is adjusted until the model can be said to be verified. In the case of the sites in this study, verification was assumed when the digital model closely simulated the observed response in the aquifer to a sharp rise and fall of stream stage. Figures 7 and 8 show the observed and simulated response to stream-stage fluctuations that were used to verify the digital models of sites B and C. The parameters T, S, and streambed hydraulic conductivity (K_S) are shown for each site.

The two sites have similar geologic characteristics. Both sites have a relatively thin aquifer, approximately 30 feet (9 meters) thick, composed of very fine to medium grained sand and overlain by a thick layer of clay and silt. Calculated respective transmissivities at sites B and C (1,600 ft^2/day (150 m^2/day) and 1,000 ft^2/day (90 m^2/day)) and storage coefficients (8×10^{-5} and 3×10^{-5}) seem to be reasonable values. The resultant hydraulic conductivities at the two sites fall within the expected range for fine to medium sand.

There are two significant differences between the two sites. No source of recharge to the aquifer at site C other than the Green River was indicated. However, at site B a small amount of recharge to the aquifer, 0.016 ft/day (0.005 m/day), from the bedrock valley wall had to be added in order to simulate the correct aquifer response. Another difference is readily apparent from the geologic sections. The stream channel at site B penetrates the aquifer, but at site C about 15 feet (4.6 meters) of silt separates the channel bottom from the aquifer. This probably accounts for the hydraulic conductivity of the streambed at site B being more than 32 times greater than at site C, 5.2×10^{-3} ft/day (1.6×10^{-3} m/day) and 1.6×10^{-4} ft/day (4.9×10^{-5} m/day), respectively.

With the models verified, pumping can be simulated at the two sites. Various pumping rates may be selected and the pumping wells may be placed at any desired location within the site. Hydraulic head changes are generated in the aquifer in response to pumping; by analyzing these head changes, the most feasible location and pumping rates of wells can be determined.

During pumping simulation, the Green River is always kept at normal pool stage at each of the sites. (Normal pool stage is the minimum elevation of the pool surface that is maintained behind each dam.) The average discharge at Calhoun (river-mile 63.2) (river-kilometer 101.7) for 41 years is 10,570 ft^3/s (299 m^3/s), and river stages exceeding normal pool can be expected to occur often during a typical year. However, it is desirable to observe the aquifer response under the most adverse conditions, that is, the low stream stage at normal pool. Generally, a minimum flow of 400 ft^3/s (11 m^3/s) is maintained at Calhoun by releases from four large reservoirs in the basin, and it is unlikely that any foreseeable development of water resources in the basin will have any significant lowering effect on normal pool stages in the Green River.

Figures 9 through 13 are a series of maps showing contours of water-level drawdowns generated in response to simulated pumping from the alluvial aquifer at site B. The drawdown maps provide information on the potential of the aquifer; they also show the results of optional schemes of well-field design, and clearly illustrate some of the basic principles involved in the optimal development of ground-water supplies. It should be noted that well losses at and near pumping wells are not taken into account in the digital model. These losses may amount to many feet and be of considerable importance in the planning and design of a well or well field. Well losses in a given aquifer vary according to the size, type, and construction of the well and to the rate at which the well is pumped.

DEVELOPMENT OF GROUND-WATER SUPPLIES

Test Drilling

The first and most important phase in the development of water supplies from the alluvial aquifer is test drilling. The geologic logs clearly show how the alluvial materials vary greatly from one location to another. The logs also show that in some areas the alluvium is only a few feet thick in places where topographic location would suggest an alluvial thickness many times as great. Thus a good test-drilling program, with proper geologic sampling and logging, is necessary in order to define the vertical and areal extent of the aquifer and to gain insight into the probable range and distribution of the hydraulic conductivity of the aquifer material.

Well Location

Proper well location is critical in the development of water supplies from the alluvium where induced infiltration from a large stream is an important factor. The following criteria should be met in order to obtain optimum development. (1) Wells must be located where the aquifer is sufficiently thick; a thin aquifer could be dewatered before enough hydraulic gradient is generated to induce infiltration from the river. (2) Wells should be located where hydraulic connection exists between river and aquifer. When there is no such connection, the relatively thin and narrow alluvial aquifer is quickly dewatered under moderate to heavy pumping. This is shown by simulated pumping at site B. The drawdowns in figure 9 stabilize because of induced infiltration; under identical conditions, except that river infiltration has been removed, the three wells go dry in less than 12 hours as shown in figure 10. (3) Wells should be located as near as possible to the river to induce maximum river infiltration in the shortest possible time. Figure 11 shows predicted water-level drawdowns at site B after pumping from a well only 100 feet (30 meters) from the river. The much greater drawdowns in figure 12, where all factors are identical to those in figure 11 except that the well has been moved 1,000 feet (305 meters) away from the river, illustrate the importance of locating wells as near as possible to the river. (4) Wells in a well field should be spaced far enough apart to minimize interference effects. Figure 9 shows three wells at site B spaced 1,800 feet (549 meters) apart. Drawdowns in figure 9 stabilize after about 10 days of pumping. The effects of well interference are obvious in figure 13 where the well field is identical except that the spacing between wells has been reduced to 500 feet (152 meters). The three centers of drawdown in figure 9 now appear more as one center of drawdown. Drawdowns are greater and more concentrated in the immediate vicinity of the three wells, and the middle well goes dry after about 10 days of pumping.

Well Design and Construction

The relatively fine-grained nature and low hydraulic conductivity of the Green River alluvial aquifer present a problem to water users. For very small requirements, a dug or small-diameter driven well may be adequate. Most of the large-yielding wells (0.44 ft^3/s (0.012 m^3/s) range) in the Green River alluvium are 10-inch (25-centimeter) diameter drilled wells. Setting the screen the full length of the aquifer should increase yields. The fine-grained nature of the aquifer material along the Green River tends to favor gravel-pack construction. This method, which increases the effective diameter and hence the yield of a well, may well be worth the additional cost.

Test Pumping

The hydraulic characteristics of an aquifer can be determined by properly conducted aquifer tests. Water-level changes induced by a pumping well are recorded in nearby observation wells. The data are analyzed using appropriate equations, and the aquifer characteristics are determined. Water levels resulting from theoretical pumping can then be predicted, as shown by Kunkel (1960), and various well-field designs can be evaluated. A rapid, accurate, and economical means of utilizing aquifer-test results is to incorporate them into a digital model for aquifer evaluation, such as the one used in this report.

Ferris and others (1962) state some conditions and limitations involved in aquifer tests. It is emphasized that a prior knowledge of the geology in the vicinity of the test site is very important in interpreting the test data. In the case of the alluvial aquifer of the Green River, it is essential that the river stage (preferably pool stage) remain practically constant for the duration of the pumping test. For good results, pumping tests must be properly planned and carefully conducted under controlled conditions. Much literature, for example Ferris and others (1962), Stallman (1971), Kruseman and DeRidder (1970), and Johnson (1966), is available to assist in planning and designing aquifer tests and interpreting the results.

QUALITY OF WATER

The table (on map) shows chemical analyses of water from seven wells in the alluvium. The water is predominantly a calcium magnesium sodium bicarbonate type. All of the water sampled from the alluvium has a very high iron content. The following limits are recommended by the U.S. Public Health Service (1962): *Iron*—amounts greater than 0.3 milligram per liter (mg/1) impart brownish color to laundered goods and cause objectionable taste; *Manganese*—amounts greater than 0.05 mg/1 impart same objections as for iron and interfere with water-quality control; *Sulfate*—amounts greater than 250 mg/1 impart an objectionable taste and somewhat larger concentrations may produce a laxative effect; *Chloride*—imparts objectionable taste in concentrations greater than 250 mg/1; *Fluoride*—maximum recommended limits vary with the annual average of maximum daily air temperatures; upper limits range from 0.8 mg/1 at 32.5°C to 1.7 mg/1 at 10.0°C; *Nitrate*—there is evidence that nitrate concentrations in excess of 45 mg/1 may cause methemoglobinemia in infants; *Dissolved solids*—the recommended upper limit of 500 mg/1 is influenced primarily by taste considerations.

Hardness values are not specified in the U.S. Public Health Service standards. Hardness usually refers to the soap-consuming capacity of a water resulting from cations that form insoluble compounds with soap, and also to the tendency of a water to form a scale or encrustation when heated. Hem (1970, p. 225-226) states that for ordinary domestic purposes hardness is not particularly objectionable below a level of about 100 mg/1. In excess of 200 or 300 mg/1, hardness becomes a problem and the problem increases in proportion to the concentration.

The table shows that iron concentrations greatly exceed the recommended limit, reaching a maximum of 31 mg/1, and that manganese concentrations equal or exceed the recommended limit for all samples. Commercial devices utilizing cation exchange or oxidation-precipitation processes are available for iron and manganese removal. A relatively inexpensive device for reducing iron concentrations can be constructed by domestic-supply users. Water containing iron in the reduced (ferrous) state is pumped from the well and allowed to drain by gravity over a bed of charcoal or some similar material. The resulting oxidized iron (ferric hydroxide) is practically insoluble and most of it will precipitate and adhere to the charcoal; the remainder can be filtered, or settled out in a holding basin. The charcoal must be renewed periodically. Iron concentrations can be reduced to less than 0.1 mg/1 by this method; however, iron chemistry is sometimes complex, and experimentation to ensure the feasibility of this method is advisable.

Sulfate, chloride, fluoride, and nitrate concentrations in all the samples are within the recommended limits. In all the samples but one, dissolved-solids concentrations are slightly below or slightly above the recommended limit of 500 mg/1.

Hardness values in all but one sample are very high. For most uses, including domestic supplies, treatment to soften the water would be desirable. Bar diagrams on the map readily show the areal distribution and the chemical constituents of the samples listed in the table.

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ENGLISH UNIT/METRIC UNIT CONVERSION TABLE

Common Measure	Metric Equivalent
Inch	2.54 Centimeters
Foot	0.3048 Meter
Mile	1.6093 Kilometer
Square inch	6.452 Square centimeters
Square foot	0.0929 Square meter
Square mile	259 Hectares
Cubic inch	16.39 Cubic centimeters
Cubic foot	0.0283 Cubic meter
Liquid quart, United States	0.9463 Liter

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