ANNOTATED BIBLIOGRAPHY OF SELECTED REFERENCES ON GROUND-WATER RESOURCES AND GEOHYDROLOGY OF THE LOUISVILLE AREA, KENTUCKY, 1944-93

By J. Jeffrey Starn and Donald S. Mull

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per second (ft/s)	0.305	meter per second
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liters per second
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot squared per second (ft^2/s)	0.0929	meter squared per second
gallon per day per square foot $(gal/d)/ft^2$	0.0408	meter per day

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Annotated bibliography of selected references on ground-water resources and geohydrology of the Louisville area, Kentucky, 1944-93

By J. Jeffrey Starn *and* Donald S. Mull

INTRODUCTION

Ground-water resources in the Louisville area have long been the subject of intense research and investigation. The earliest ground water assessment was recorded by Louisville's first historian, H. McMurtrie (1819) who reported "The well water of Louisville, which is found at various depth, from sixteen to forty feet, and which is the one commonly used by the inhabitants, is extremely bad, containing besides a considerable quantity of lime, a large portion of decomposed vegetable matter." McMurtrie would likely be amazed to learn that his assessment greatly understated the availability and quality of ground-water resources which have been a significant factor in the industrial development of Louisville. The vast alluvial aquifer that underlies much of Louisville is a dependable source of water for the industrial and commercial growth of the city of Louisville and the nearby area.

Because of the abundance of ground water and the need to properly develop and manage this resource, many investigations have produced reports that cover a variety of topics relative to the availability and use of ground water in the Louisville area. Many reports also include data about the quality of ground water, especially its temperature. This bibliography was prepared, in cooperation with the University of Louisville, because of continued interest in ground water in the Louisville area and the need for a single source of selected references published since 1944 but is not intended as a complete compilation of all references.

ORGANIZATION OF THE BIBLIOGRAPHY

The bibliography is arranged alphabetically by author. The arrangement is chronological where an author has more than one publication; if an author has more than one publication in a given year, a, b, c, and so on, are added. Each reference is followed by a brief summary of the data, analysis or findings of the report. In most cases, the summary includes a brief review of conditions or reasons for the investigation that led to the preparation of a particular report. Collateral studies, such as reports on surface water, paleontology, glacial geology, or stratigraphy of the Louisville area are not included. Geologic quadrangle maps are listed separately.

To avoid undue length, phrases such as "during the period of study" are not always included if the period of study is defined in the title of the reference. Thus, the statement "ground-water levels increased" in a report covering the period 1944-52 means that the increase in ground-water levels was only for the specified period. The ground-water resource in Louisville is changing continually, thus, the reader is cautioned to apply data only to the period for which it was intended. Also, subjective qualifiers such as "large supplies of ground water" or "poor quality ground water" are extracted from a particular reference and reflect the terminology used by the author. The reader should obtain the original reference to discern the author's intent in the use of such terms.

BIBLIOGRAPHY

Bell, E.A., 1962, The ground-water situation in the Louisville area, Kentucky, 1945-61: Kentucky Geological Survey, ser. 10, Information Circular 10, 24 p., 9 figs.

The most significant change in ground-water conditions during the study period was variation in ground-water storage. The report presents a water-level contour map which shows the altitude of water levels for January 1945, 1950, and 1961. Ground-water levels rose during the period 1945-49 and declined during 1950-61. Variations in recharge and ground-water withdrawals account for the changes in water levels. The ground-water potential of the Louisville area was estimated to be about 370 Mgal/d.

Bell, E.A., Kellogg, R.W., and Kulp, W.K., 1963, Progress report on the ground-water resources of the Louisville Area, Kentucky, 1949-55: U.S. Geological Survey Water-Supply Paper 1579, 49 p., 15 pls., 11 figs.

This report presents estimates of the yearly average ground-water withdrawals during 1937-55. Ground-water withdrawals were relatively constant from 1949 to 1955 and averaged about 30 Mgal/d. The total ground-water withdrawal for the undeveloped area southwest of the city was estimated to be about 1 Mgal/d which was used for irrigation, domestic, and public supply. High-yield limestone wells were identified in the west-central part of Louisville in an area that trends northeastward. One well in this area was reported to yield 1,500 gal/min.

The second highest flood of record occurred in 1945. This flood provided recharge to the aquifer in excess of the amount supplied in non-flood years. Artificial recharge of the local aquifer was attempted using recharge wells and pits. Many attempts at artificial recharge in previous years were not successful. Artificial recharge from 1944 to 1955 ranged from 0.6 to 1.6 Mgal/d.

Droughts occurred during 1952-55 in the Louisville area. Ground-water levels declined from 1948 to 1955 except in unpumped areas where water levels were unusually high. Ground-water withdrawal was reduced from 11 to 7 Mgal/d. Water levels in the downtown Louisville area fluctuated in response to changes in river stage and to seasonal withdrawals which were used for cooling office buildings. In the Distillery area, ground-water levels declined from 1953 to 1954 although the ground-water withdrawals were relatively constant. This indicates that recharge to the area was reduced or that local ground-water levels may have been affected by withdrawals in other areas.

Ground-water levels in the Rubbertown area, the most heavily pumped Louisville subarea, reached a record low in 1945. By 1948, the water levels were higher by 25 ft, however after 1949, the water levels again began to decline. Ground-water withdrawals in the Rubbertown area ranged from 13 to 16 Mgal/d during the period 1950-55.

The west-central subarea of Louisville, bounded by 10th street, 30th street, and Algonquin Parkway, seemed to have a poor hydraulic connection with the Ohio River. About 85 percent of all ground-water withdrawals from the limestone bedrock in the Louisville area was from wells in this area. From 1949 through 1955 the rate of pumping remained fairly constant at about 5 Mgal/d.

Ground-water withdrawals in the undeveloped southwestern part of the area were mainly from the expanding Louisville Extension Water District. Ground-water levels in this area are affected chiefly by natural recharge and discharge to the river and were at record highs during 1948-52 and at record lows in 1955.

Water-quality data presented in this report indicated that ground water in the alluvial aquifer is generally very hard with high concentrations of iron and sulfate. Dissolved-solids concentrations in

ground water are low near the Ohio River where river water containing low dissolved solids infiltrated the aquifer due to nearby ground-water withdrawals. Hardness, iron, and sulfate concentrations increased significantly during 1949-55 in areas of the alluvial aquifer which were underlain by limestone; probably because declining water levels in the alluvial aquifer created increased upward recharge from the underlying limestone. Concentrations of hardness, iron, and sulfate were less in water from wells underlain by shale. The quality of water from wells open to limestone and in wells open to sand and gravel overlying limestone was similar.

The average temperature of ground water in the Louisville area is about 58°F. Northeast of the city, along the river, the temperature of ground water ranged from 52°F to 66°F, with the coldest temperature being in the summer and the warmest in the winter. This is because of the period of time required for the water to move from the river to the wells.

Bell, E.A., 1966, Summary of the hydrologic conditions of the Louisville area, Kentucky: U.S. Geological Survey Water-Supply Paper 1819-C, 36 p., 6 pls., 6 figs.

This report presents a general description of the ground-water flow system based on data collected during the period 1943-62. Generalized geology and structure of the bedrock in Jefferson County is shown in a block diagram. Also, types of data available in previous reports are summarized in a table. The report contains a series of maps of Jefferson County including one that shows the thickness of sand and gravel beneath the flood plain and the distribution of ground-water withdrawals for 1962. Also, the map indicates alluvial areas underlain by limestone in which good water supplies were developed in previous years. Other maps show the altitude of the water table in 1962 and the degree of hydraulic connection between the Ohio River and the alluvial aquifer.

In areas of Jefferson County beyond the Ohio River floodplain, most small streams and many wells are dry during summers. Stream discharge data are presented for the Ohio River and several smaller streams. In the northeastern part of the alluvial aquifer, near Zorn Avenue, surface water recharged the alluvial aquifer and flowed southwesterly toward a cone of depression in the downtown Louisville area. This cone of depression lies along a northeastern trend of a larger and deeper cone of depression centered further to the southwest near the Rubbertown area. Surface water recharged the alluvial aquifer near the Rubbertown area because large ground-water withdrawals induced infiltration from the river. In the undeveloped southwestern part of the alluvial aquifer, ground-water flow was toward the Ohio River except during periods of minor floods.

It was reported that the total withdrawals from the alluvial aquifer should not exceed 370 Mgal/d, assuming that recharge from the Ohio River would supply much of the water. Otherwise, the alluvial aquifer system could not meet increased demands. The total ground water stored in the aquifer was estimated to be nearly 100 billion gal.

Deep fractures in the bedrock aquifer can supply water to the overlying alluvial aquifer. At the Falls of the Ohio, where open bedrock fractures intercept the riverbed, water may move into the alluvial aquifer toward the cones of depression in the downtown and west-central areas of Louisville.

Davis, R.W., and Matthews, E.W., 1983, Chloroform contamination in part of the alluvial aquifer, southwest Louisville, Kentucky: U.S. Geological Water-Supply Paper 2202, 25 p., 20 figs.

This report describes the effects of contamination and subsurface movement of chloroform in the ground-water flow system near the Rubbertown area of Louisville. The probably source of the chloroform was a spill of 5,000 gal of chloroform in 1970, due to a break in an underground pipeline that delivered industrial chloroform. This investigation was intended to determine the extent of contamination and the possible movement of contaminants under different pumping scenarios. Data indicated that the chloroform was mainly retained in the unsaturated, fine-grained material overlying the bedrock aquifer and did not enter the ground-water flow system as an aqueous phase product.

The study reported that the spilled chloroform was probably adsorbed, primarily in clay layers, within the zone that was unsaturated at the time of the spill. The chloroform seemed to have migrated, perhaps in the gaseous phase, in a north-south direction parallel to the Ohio River. The direction of migration seemed to be related to the paleo-channel depositional environment and character of the aquifer material.

A rise in ground-water levels occurred throughout the 1970's that caused the water table to contact the contaminated material. The water-table rise in this area was reported to be 16 ft. Chloroform and chloride concentrations in a pumped well correlated closely with water levels in a nearby observation well. It was unknown at the time of this investigation whether the chloroform had migrated downward through the clay zone or whether it was entirely bound in clay layers by sorption to silicate minerals. Data from the flood of December 1978 supported the hypothesis that the concentration of the contaminant was related to ground-water levels because high water levels resulted in increased average concentration of chloroform in the saturated part of the aquifer.

Faust, R.J., and Lyverse, M.A., 1987, Ground-water levels in the alluvial aquifer at Louisville, Kentucky, 1982-87: U.S. Geological Survey Water-Resources Investigations Report 87-4197, 18 p., 12 figs.

This report cites renewed interest in using ground water for heating and cooling, especially in the downtown Louisville area where withdrawals resumed in 1985 after a prolonged period of no withdrawals. Several new wells were constructed in the downtown area to provide data for this report. Water levels had been stable since 1980. Generally, ground-water flow was toward the Ohio River in all areas except near Rubbertown where industrial withdrawals occurred and when the stage of the Ohio River was high. Water-table altitude maps presented in this report for October 1984, October 1986, and April 1987 indicate that pumping had caused a water-level decline of 2 to 4 ft in the downtown area. Also, detailed water-table altitude maps of the downtown area indicated a water-table trough in the area of the Humana building and a cone of depression at the Heyburn building.

Faust, R.J., and Lyons, B.E., 1989, Ground-water levels in the alluvial aquifer at Louisville, Kentucky, 1987-88: U.S. Geological Survey Water-Resources Investigations Report 89-4119, 15 p., 8 figs.

Water levels in the western and southwestern areas of Louisville were stable from 1980 to 1986, but declined in 1987. The decrease in ground-water levels ranged from 1 to 3 ft near the Ohio River and from 3 to 6 ft from the river. This was attributed to below normal precipitation between 1985-88. A water-table altitude map for October 1988 indicated a general pattern of ground-water flow toward the river and a water-table trough near the Rubbertown area. Ground-water levels in the downtown area were reported to have declined from 3 to 5 ft during 1985-88. This was attributed to below normal precipitation and gradually increasing ground-water withdrawals. The altitude of the water table in cones of depression near the Humana building and the Galt House was lower than the river stage most of the time. Generally, water-level declines had stabilized, and induced infiltration was probably in equilibrium with ground-water withdrawals. Ground-water withdrawal data for several downtown locations are included in the report.

Gallaher, J.T., and Price, W.E., Jr., 1966, Hydrology of the alluvial deposits in the Ohio River Valley in Kentucky: U.S. Geological Survey Water-Supply Paper 1818, 80 p., 21 figs.

This report summarizes the Ohio River valley alluvial aquifer Hydrologic Atlas series and contains generalized diagrams of the river valley and conceptual models of the Ohio River alluvial aquifer systems. Transmissivity and permeability values are summarized from the Hydrologic Atlas series. Permeability values in the alluvial aquifer generally decrease in the downstream direction. However, at any place along the Ohio River, a zone of boulders or cobbles may be present immediately above the bedrock as indicated by increased permeability values. These deposits are thought to be the result of the movement of sediments from tributaries to the Ohio River during Pleistocene deglaciation. Thick deposits of silt and clay are sometimes present where modern, sluggish tributaries enter the river.

The report cites the most favorable areas for future development of large quantities of potable ground water are near the Ohio River where induced infiltration can best be utilized. Two areas near Louisville that utilize ground water and induced infiltration from the river are in southwestern Louisville, and in northeastern Louisville from Zorn Avenue to Harrods Creek.

Grubb, H.F., 1970, Effects of a concentrated acid on water chemistry and water use in a Pleistocene outwash aquifer: Ground Water, v. 8, no. 5, p. 4-7, 9 figs.

This report describes the effects of a pipeline break at an industrial facility in the Louisville area, Kentucky, which resulted in a spill of concentrated hydrochloric acid into the aquifer in March 1967. The spill occurred near the Rubbertown area where water was being induced to wells from the Ohio River. The subsequent reaction of the acid with the aquifer material formed a zone of highly mineralized water. The sodium to potassium ratio for natural ground water in this area is 4 to 1, but in the area of the spill the ratio was 1 to 1. In addition, chloride concentrations in excess of 30,000 milligrams per liter (mg/L) were detected in water samples from a well.

Time of travel estimates were presented in this report. Rorabaugh (1946) reported a travel time of 5 ft/d for this area based on transmissivity values determined from aquifer tests. However, an analysis of peak arrival times indicated a travel time of 12 ft/d for the reported acid spill. One possible reason for the difference between the two travel times was that ground water may have migrated through a thin zone of highly permeable material. Also, the stage of the Ohio River at the time of the spill may have effected travel times of the contaminant. During a period of high stage on the Ohio River, the estimated travel time of the contaminant was 36 ft/d. A cone of depression existed near the area of the spill and probably effected travel times to some extent. Other factors which may have affected travel times of the contaminant were the density of the contaminant and the slope of the bedrock surface.

______1975, Simulated drawdown for selected well fields in the Ohio River alluvial aquifer: U.S. Geological Survey Water-Resources Investigations Report 2-74, 45 p., 24 figs.

This report describes a finite difference ground-water flow model for four sites in the Ohio River alluvial aquifer; one site is in the Louisville area. Transmissivity values and storage coefficients determined in the model were based on the diffusivity values calculated by Grubb and Zehner (1973). Data from the aquifer test conducted by Rorabaugh (1946b) were used to calibrate the model and values of streambed permeability were varied in an attempt to refine the model. The hydraulic conductivity of the streambed material was calculated to be 7.5×10^{-6} ft/s on the basis of the hydraulic conductivity value of 2.4×10^{-3} ft/s for the underlying aquifer. The storage coefficient value used in the model simulation was 0.02.

Grubb, H.F., and Zehner, H.H., 1973, Aquifer diffusivity of the Ohio River alluvial aquifer by the flood wave response method: U.S. Geological Survey Journal of Research, v. 1., no. 5, p. 597-601, 6 figs.

In this report, the flood response was used to determine the aquifer diffusivity (the ratio of transmissivity to the storage coefficient) in areas of recent ground-water development. This technique did not assume full penetration of the river into the underlying aquifer or a complete hydraulic connection between the river and the aquifer. Presented in the report are calculated aquifer diffusivity values for two sites in the Louisville area using two different methods. At one site at the Louisville Water Company on Zorn Avenue, the diffusivity values was reported to be 10.29 ft^2/s using the flood-response technique. The aquifer diffusivity value was estimated to be 760 ft^2/s using the transmissivity and storage coefficient values reported by Rorabaugh (1948). One reason for the different values may be that during the aquifer test by Rorabaugh (1948), recharge into the aquifer was replaced by infiltration from the river in a very short time, 0.01 days. The flood peak analyzed in this report lasted for 20 days. Re-analysis of Rorabaugh's data using the flood-response method, resulted in a diffusivity value of 13.4 ft^2/s. Tests at the second site located at Lee's Lane resulted in a diffusivity value of 0.40 ft^2/s, compared to 0.35 ft^2/s from the aquifer-test data by Rorabaugh (1946b).

Guyton, W.F., 1944, Artificial recharge of ground-water reservoir with water from city's surface water supply at Louisville, Kentucky: U.S. Geological Survey Open-File Report, 6 p., 1 fig.

Distilleries required large quantities of cool ground water for the production of alcohol during World War II. As a consequence of large withdrawals, ground-water levels declined such that ground water was no longer a dependable source of water for this industry. Because the source of water for the public supply, the Ohio River, was too warm in summer, the distilleries were threatened with curtailed production. This was avoided by discontinuing ground-water withdrawals in the winter when water from the public supply was cool. During the winter, cool water was recharged to the aquifer for later use in the summer months. Due to this artificial recharge, ground-water levels rose. The high water levels resulting from the artificial recharge were reported to be consistent with the predictions of the U.S. Geological Survey.

______1946, Artificial recharge of glacial sand and gravel with filtered river water at Louisville, Kentucky: Economic Geology, v. 41, no. 6, p. 644-658, 5 figs.

This report cites two areas in Louisville as having the largest quantities of ground-water withdrawals; one was near the Rubbertown area and the other near the Distillery area. Ground-water withdrawals during summer months were 20 to 30 percent higher than the yearly average because much of the ground water was used for consumptive purposes including ice making and air conditioning. Also, the report stated that values for specific capacity for 70 industrial wells ranged from 8 to 410 (gal/min)/ft and averaged about 60 (gal/min)/ft.

The report stated that the potential for the development of additional ground-water supplies is best in the northeastern and southwestern areas of the alluvial aquifer. Areas suitable for induced infiltration from the Ohio River are in the areas from Third Street northeastward and from Bells Lane southwestward. The report further stated that artificial recharge should be designed so that most of the water recharged will remain in the aquifer because it is separated from flow toward the Ohio River by tributary valleys incised on the bedrock surface. Artificial ground-water recharge during 1944 occurred through wells at the National Distilleries plant and at the Seagram Company through a Ranney collector well. The report suggested that a recharge basin could be constructed by excavating surficial deposits (5 to 30 ft thick) from the land surface and flooding the pits with untreated water from the Ohio River.

Guyton, W.F., Stuart, W.T., and Maxey, G.B., 1944, Progress report on the ground-water resources of the Louisville area, Kentucky: U.S. Geological Survey Open-File Report, 20 p., 14 figs.

This report describes the alluvial aquifer which consists of poorly-sorted gravel and coarse- to fine-grained sand in interbedded lenses. Gravel or coarse-grained sand is the dominant material in these lenses. Sand lenses vary from 5 to 20 ft in thickness. Some lenses contained well-sorted and medium- to fine-grained sand, but well-sorted gravel was rare. Other lenses contained sparse, fine-grained sand and silt; however, silt and clay lenses were seldom present.

A flood on the Ohio River in 1937 caused flooding in basements and sewers in the Louisville area due to increased ground-water levels. The ground-water levels remained high for a period of time, but declined throughout the aquifer after ground-water storage in the alluvial aquifer dissipated.

During 1939, war-related industrial expansion resulted in significant increases in ground-water withdrawals. Consequently, some areas reported decreased water levels and ground-water availability. At that time, the U.S. Geological Survey established an observation well network of 130 wells. Water-level data from these wells was used to construct a water-table altitude map. This map indicated that water infiltrated the alluvial aquifer from the Ohio River northeast of Louisville and flowed southwesterly toward large cones of depression in the Distillery and Rubbertown areas. The ground-water budget was estimated to consist of: (1) 60 Mgal/d of ground-water withdrawals, (2) 30 to 40 Mgal/d recharged to the aquifer, and (3) 20 to 30 Mgal/d withdrawals from storage in the aquifer.

Guyton, W.F., and Sublett, H.E., 1944, Conservation of ground water in the Louisville area, Kentucky: U.S. Geological Survey Open-File Report, 4 p., 7 figs.

This report represents the beginning of ground-water investigations by the U.S. Geological Survey in the Louisville area and Jefferson County, Kentucky. The study was initiated because of concerns that there may have been damage to foundations, basements, and sewers caused by extremely high ground-water levels during the 1937 flood. The study was extended because of record low ground-water levels following 1937, due in part to heavy industrial ground-water withdrawals during World War II. This report also documented conservation measures undertaken to reduce ground-water level declines.

Haggerty, D.J., and Lippert, K., 1982, Rising groundwater-problem or resource?: Ground Water, v. 2, no. 20, March-April 1982, p. 217-223, 7 figs.

This article supported the concept that changes in pumping rates and natural precipitation are the principal causes for increased ground-water levels in the Louisville area, during 1966-80. Average ground-water levels were plotted against a cumulative departure in withdrawals and a cumulative departure in precipitation. A linear regression equation developed from these data indicated a coefficient of variation of $r = 0.996$.

A series of aquifer tests were planned in the central, urban areas of Louisville to evaluate a method to control or reduce rising ground-water levels. The tests were to be the preliminary steps in a study to utilize ground water to cool buildings in central Louisville, then recharge the local aquifer system with the coolant water. However, the tests were not performed because the Louisville sewers were devastated by a hexane explosion on February 13, 1981.

Hamilton, D.K., 1944, Ground Water in the bedrock beneath the glacial outwash in the Louisville area, Kentucky: U.S. Geological Survey Open-File Report, 21 p., 4 figs.

This report identified limestones that subcrop beneath the alluvial aquifer in Jefferson County that are considered to be a significant source of ground water to the overlying alluvium. Shale beds were not considered to be hydrologically significant except as confining units. About 50 wells were drilled through the alluvial aquifer and completed in bedrock. Two-thirds of the wells yielded only a small quantity of water, but one-third of the wells yielded more than 200 gal/min.

As stated in this report, natural recharge to the alluvial aquifer from the underlying bedrock was estimated to be 15 to 20 Mgal/d. Recharge to the bedrock occurred through openings along enlarged vertical joints and bedding planes in outcrop areas. Horizontal joints in outcrops were observed to be less well developed than vertical joints. It was suggested that if this pattern persisted where bedrock subcrops beneath the alluvium, then water pumped from bedrock can flow to the open-hole section of the well through vertical joints from the overlying alluvium.

The report includes a geologic map of the subcrop area with contours showing the altitude of the top of the bedrock surface. Bedrock units of Silurian age include, in order of increasing age, Louisville Limestone, Waldron Shale, and Laurel Dolomite. The Louisville Limestone comprises most of the subcrop in the Louisville area and is a thickly-bedded, fine-grained limestone 40 to 90 ft thick. The Waldron Shale consists of about 12 ft of nodular, gray shale and separates the Laurel Dolomite from the overlying Louisville Limestone. The Waldron shale is probably a leaky confining unit that can supply a small quantity of water to adjacent carbonate rocks. The Laurel Dolomite subcrops in the northeastern part of the aquifer and is relatively well jointed. The Laurel Dolomite is less than 40 ft thick and consists of beds of dolomitic limestone, each about 1 ft thick. The Jeffersonville and Sellersburg Limestones of Devonian age are relatively thin where they subcrop southwest of the Distillery area. The combined thickness of the Silurian and Devonian age limestone is about 100 ft. A large amount of recharge probably enters the alluvial aquifer through these formations at the eastern wall of the bedrock valley. The New Albany Shale of Devonian age and the New Providence Shale of the Borden Group of Mississippian age overlie the limestone. Although these units probably yield a small quantity of water, they are not considered significant sources of ground water.

Kernodle, J.M., and Whitesides, D.V., 1977, Rising ground-water level in downtown Louisville, Kentucky, 1972-1977: U.S. Geological Survey Water-Resources Investigations Report 77-92, 24 p., 9 figs.

The brief descriptions of the Louisville ground-water conditions by McMurtrie (1819) are the basis for several conclusions concerning the hydrology of the alluvial aquifer discussed in this report. Select water-level measurements made during 1819-36 are summarized in the report. Also, hydrographs for three wells are presented that indicate a seasonal fluctuation of water levels.

In the mid to late 1960's, it was noted that the amplitude of annual water-level peaks had decreased. By 1972-73, these peaks had virtually disappeared, probably due to a reduction in the use of ground-water for cooling purposes. During 1972-77, there was a nearly linear trend of rising water levels. Reasons suggested for the increase in water levels included (1) a decrease in ground-water withdrawals and (2) human-related sources of recharge in the downtown area such as leaking water mains, recharge wells, and sewers.

During this investigation, water levels in the downtown area increased as much as 32 ft. An additional rise of 20 ft was predicted by projecting the trend of observed data to the year 1982. To further substantiate and predict ground-water level trends, a technique was needed to estimate recharge from precipitation and from leaking pipes in the downtown area. Also, present measures to protect against damage from high ground-water levels were discussed.

MacCary, L.M., 1955, Map of the Louisville Area, Kentucky, showing contours on the bedrock surface: U.S. Geological Survey Hydrologic Investigations Atlas HA-5, 1 sheet.

This Hydrologic Atlas presents a single map with locations of drilled wells, test borings, exposures, and soundings in the Louisville area. Contours depict the configuration of the altitude of the bedrock surface beneath the alluvium.

______1956, Availability of ground water for domestic use in Jefferson County, Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-8, 5 p., 1 pl., 2 figs.

This Hydrologic Atlas includes a map of Jefferson County, subdivided into five areas, according to ground-water availability to drilled wells. The well depth and depth to water are included for most drilled wells. Records of wells and springs in Jefferson County are tabulated, except for large industrial wells in the Louisville alluvial area. Bar diagrams indicate the quality of ground water by geologic formation in Jefferson County. Also, chemical analyses of water from wells and springs in the study area are tabulated.

McMurtrie, H., 1819, Sketches of Louisville and its environs; including, among a great variety of miscellaneous matter, a Florula Louisvillensis: Louisville, Kentucky, reprinted 1969, G.R. Clark Press, Louisville, Kentucky, 255 p., 1 pl.

This report describes the earliest accounts of Louisville and contains a brief description of ground-water resources, surface streams, and geology of the area. A reprinted edition presents a 6-page Epilogue which includes a brief biographical sketch of McMurtrie and the events leading to the publication of his book.

Patterson, G.M., and Jones, D.J., 1944, Chemical analyses of water from wells in the Louisville area, Kentucky: Kentucky Geological Survey, Geological Division, unnumbered report, 5 p.

This report consists of tables which list well depth, identifies the water-yielding formations, and chemical analyses of water from 58 wells in the Louisville area. A map shows the location of the wells sampled. The analyses were released without interpretation or illustration except for the well location map.

______1945, Driller's logs of wells and test borings in the Louisville area, Kentucky: Kentucky Department of Mines and Minerals, Geological Division, unnumbered report, 70 p.

This report contains driller's logs for 170 wells which list owners name, location, altitude of the land surface, generalized geologic description of the material penetrated by each well, thickness of each geologic unit, and total depth of each well. The location of these wells are indicated on a map of the Louisville area which included Jeffersonville and New Albany, Ind. Text is not included.

Price, W.E., Jr., 1964a, Geology and hydrology of alluvial deposits along the Ohio River between Prospect and southwestern Louisville, Kentucky: U.S. Geological Survey Hydrologic Atlas HA-130, 2 pls.

This Hydrologic Atlas presents structural fence diagrams of the study area and maps of the altitude of the top of the bedrock surface, water-quality data, and tables showing permeability and transmissivity values. Text is not included. Transmissivity values from five aquifer tests ranged from 62,000 to 121,000 (gal/d)/ft. The median transmissivity was 93,000 (gal/d)/ft. The median value of hydraulic conductivity determined from laboratory tests ranged from 120 to 1,700 (gal/d)/ft^2. The median values were determined from 10 to 17 samples in each of 16 wells. The median values of each hydraulic conductivity were sorted and ranked and it was determined that this median value was 320 (gal/d)/ft^2.

______1964b, Geology and hydrology of alluvial deposits along the Ohio River between southwestern Louisville and West Point, Kentucky: U.S. Geological Survey Hydrologic Atlas HA-111, 2 pls.

This Hydrologic Atlas presents structural fence diagrams of the study area, maps of the altitude of the bedrock surface, water-quality data, and tables of permeability and transmissivity values. Text is not included. A calculated transmissivity value from one aquifer test was 20,000 (gal/d)/ft. The test included

a line of observation wells extending toward the Ohio River. A transmissivity value calculated from another aquifer test was 45,000 (gal/d)/ft. This test included a line of observation wells extending away from the river. The median value of hydraulic conductivity determined from laboratory tests ranged from 150 to 1,400 (gal/d)/ft^2. The median values were determined from 4 to 20 samples in each of 22 wells. The median values of hydraulic conductivity were sorted and ranked, and it was determined that this median value was 510 (gal/d)/ft^2.

Rorabaugh, M.I., 1946a, Inventory of water wells, Louisville area: U.S. Geological Survey Open-File Report, prepared in cooperation with city of Louisville and Jefferson County, 37 p., 1 fig.

This report lists the owner, location, and construction details for hundreds of wells in the Louisville area. The altitude of the land surface and bedrock, and water-level and withdrawal data are included for selected wells. Wells are located on a map of the Louisville area, which included Jeffersonville and New Albany, Ind.

______1946b, Ground-water resources of the southwestern part of the Louisville Area, Kentucky: U.S. Geological Survey Open-File Report, prepared in cooperation with Rubber Reserve Co., city of Louisville, and Jefferson County, 39 p., 15 figs.

The investigation that led to this report was a cooperative effort between the U.S. Geological Survey and the Rubber Reserve Company, a war-time Federal agency. The purpose of the investigation was to assess the potential for additional ground-water supplies in the Rubbertown area. A map showing the altitude of the bedrock surface was drawn using data from boreholes and an electrical resistivity survey. Previous studies in this area have described the alluvium overlying bedrock as mainly composed of gravel and sand with insignificant silt and clay lenses. A geologic unit not previously described, which overlies sand and gravel in the northeastern part of the alluvial aquifer and the bedrock high in western Louisville, was identified as the "blue shale" in this study.

This report also includes geologic sections that show significant channel infill of clay and sand in the southwestern part of the alluvial aquifer. It was reported that in this area a fault with a vertical displacement of 20 to 30 ft may exist in the bedrock. In the study area, none of the wells completed in shale bedrock yield significant quantities of water. A surficial layer of fine-grained sand, silt, and clay extends into the riverbed at Bell's Lane and Lee's Lane in southwestern Louisville. About 160 ft from the river's edge, this unit decreases to zero thickness and the riverbed consists of sand and gravel.

This report summarizes data from 45 test wells and includes owner, location, well-construction details and a water-level measurement made at the time the well was drilled. Permeability values determined in the laboratory were listed on a map for each 5-ft interval of depth at each of the test wells. Grain-size analyses for each sample were also reported. Water-quality data indicated that ground-water in areas of the alluvial aquifer underlain by limestone was characterized by greater hardness than where the alluvium was underlain by shale. Water from wells closer to the Ohio River was less hard than at other locations in the aquifer. The temperature of ground water near the river fluctuated more than elsewhere, especially during periods when ground-water withdrawals were relatively high.

At the time of this investigation, the U.S. Geological Survey observation-well network in the Louisville area included 118 wells. Water-table altitude maps were constructed for selected periods during 1945 and 1946. Hydrographs were constructed to illustrate the three main factors that affect altitude of the water-table. These factors were fluctuations in (1) ground-water withdrawals, significant near major industrial and commercial areas, (2) river stage, significant at a distance of 2 mi from the Ohio River, and (3) precipitation, as measured in undeveloped, rural parts of the area.

An aquifer test at Lee's Lane was used to calculate various aquifer properties. The calculated specific yield was 20 percent. The calculated values of transmissivity were 20,000 (gal/d)/ft near the Ohio River and 45,000 (gal/d)/ft farther from the river. The difference in the transmissivity values was attributed to the effects of a surficial clay layer that impedes flow from the river. The water budget of the alluvial aquifer in the study area included ground-water flow across the bedrock valley wall [20 (gal/d)/ft], recharge from precipitation (estimated to be 6 inches per year, or 12 percent of yearly total precipitation), and natural flow to the river in undeveloped areas (estimated to be 800,000 gal/d per mile of river).

The efficiency of the hydraulic connection between the river and the aquifer at various locations was evaluated by comparing the response of ground-water levels during periods of floods from wells at varying distances from the river. The hydraulic connection of the river and the aquifer at Lee's Lane is less than at other locations. The best hydraulic connection is at Cane Run, where scouring action may have removed the silt accumulation along the riverbed and banks.

______1948, Ground-water resources of the northeastern part of the Louisville area, Kentucky: U.S. Geological Survey Open-File Report, prepared in cooperation with Louisville Water Company, 77 p., 42 figs. Report published as U.S. Geological Survey Water-Supply Paper 1360-B. See Rorabaugh, 1956.

______1949, Progress report on the ground-water resources of the Louisville area, Kentucky, 1945-49: U.S. Geological Survey Open-File Report, prepared in cooperation with city of Louisville and Jefferson County, 64 p., 17 figs.

This report presents the results of analysis of data from the observation-well network in the Louisville area and preliminary results from the U.S. Geological Survey research study of the Ranney collector well at Bell's Lane. The Ranney collector well was installed in 1945 and had an average yield of about 2,600 gal/min. The minimum yield of the well was estimated to be 1,600 gal/min. The most transmissive layer within the aquifer at this site is a vertical interval 18 ft thick which has a transmissivity of 18,000 (gal/d)/ft. At the time of this report, no siltation of the riverbed had been observed. Total ground-water withdrawals from the Ranney collector well had been decreasing since 1945.

The Louisville Water Extension District opened a new well field about 8 mi southwest of Rubbertown during the period of this investigation. Ground-water withdrawals from this well field totaled 1,500 gal/min.

Ground-water withdrawals from wells completed in bedrock increased from 10 to 20 percent during 1945-46. Of wells completed in bedrock, 50 percent yielded more than 200 gal/min. This report proposed the concept that solution channels in the limestones were better developed in the subsurface due to the active circulation of ground water. In one well, the water level in the bedrock was 1 ft above the level in the sand and gravel, indicating upward flow into the alluvium. Ground-water withdrawals from the bedrock aquifer probably cause the normal upward flow to reverse. A concept was proposed stating that a possible recharge area of some of the ground water in the bedrock aquifer was where the Ohio River flows over the limestone at the Falls of the Ohio. The most productive bedrock wells occur along a prominent joint set that trends north 30° west from the Falls of the Ohio. A map showing the altitude of the contact between the shale and limestone bedrock was presented in this report.

Recharge from the Ohio River into the bedrock aquifer is not significant in the area between the McAlpine Dam and Bell's Lane on the river. In the northern part of this area, the limestone crops out at an elevation above the normal elevation of pool; however, the river is not in contact with the alluvium. In the western part of this area, a surficial-clay layer extends into the riverbed and impedes infiltration of surface water into the aquifer.

Significant floods can provide natural recharge to the alluvial aquifer. For example, the flood of 1945 was estimated to have recharged about 5 billion gal of water to the aquifer. Recharge from rainfall in a year of average precipitation is estimated to be about 4 inches per year.

The report cites several attempts by local businesses to inject ground water withdrawn and used for air conditioning back into the aquifer. This artificial recharge was successful in areas of the limestone aquifer and in other areas where large-capacity injection wells were developed in the alluvium. At many other locations, attempts at artificial recharge failed because of interference with production-well water temperature or clogging of the well screen either by silt or by the precipitation of dissolved solids caused by pressure and temperature changes in the recharge water.

Maps are presented that show the yearly altitude of the ground water for the period 1942-48. In general, water levels recovered from wartime lows in the Rubbertown and the Distillery areas, but continued to decline in the downtown Louisville area.

Increased hardness and concentration of sulfate in ground water was probably caused by increased flow into the sand and gravel from the limestone bedrock. Generally, the concentration of chloride in water from the bedrock aquifer was high. Near Zorn Avenue, the average yearly temperature of ground water ranged from 51°F to 65°F. Ground-water temperatures were observed to lag about 6 to 8 months behind seasonal changes in ambient air temperature.

______1951, Stream bed percolation in development of water supplies: Brussels, International Association of Hydrology, p. 165-174, 1 fig.

This report presents the results of the study of the Ranney collector well at Bell's Lane, in southwestern Louisville. A surficial clay and silt layer extends for about 160 ft from the Ohio River's edge into the riverbed. Sand and gravel underlie the river in its deepest parts, where the aquifer is about 20 ft thick. The aquifer is generally unconfined, except where the hydraulic head is higher than the base of the surficial clay and silt layer near the river, in which case, the aquifer is unconfined. Lateral well screens extend 300 ft from the Ranney collector-well caisson in all directions, except under the river, where they extend 175 ft. Data collected during pumping indicated that there is a connection between the well and the river and that there is a time lag of several days in water-level response in laterals. Also, surface-water floods increase the specific capacity of the well. Finally, viscosity changes, due to the temperature of water in the river, affect the specific capacity of the well, seasonally.

______1956, Ground water in northeastern Louisville, Kentucky, with reference to induced infiltration: U.S. Geological Survey Water-Supply Paper 1360-B, p. 101-169, 17 pls., 24 figs.

In 1945, a cooperative study by the U.S. Geological Survey and the city of Louisville Water Company investigated the potential for large ground-water supplies in an area from Beargrass Creek to Harrod's Creek in northeastern Louisville. This study was undertaken because of the increasing difficulty of treating Ohio River water to remove the water-quality effects of upstream discharges. The bedrock valley is narrower in this area than in the southwestern part of the aquifer and is a U-shaped valley with a broad, flat bottom and steep walls. Wells completed below the Waldron Shale were expected to yield small quantities of water. Limestones of Silurian and Devonian age overlie the Waldron Shale and are moderately to well-jointed. Water in these formations flows down dip to the west from their outcrop areas, east of the alluvium, to a point where the bedrock valley wall is intersected. Recharge occurs across the bedrock valley wall into the alluvium.

For purposes of this study, 30 test wells were installed. The alluvium in the study area consists of sand and gravel with a surficial cover of silt, clay, and fine-grained sand. Geologic samples from wells drilled through the riverbed indicated that the surficial material was 15 to 30 ft thick. This layer was present in the riverbed where it slopes to the northwest 100 ft from the river's edge and decreases to zero thickness. Beyond this point, the river flows on sand and gravel, as in the southwestern part of the aquifer. Laboratory-determined permeabilities of samples taken at 5-ft vertical intervals are presented on a map of the study area.

It was noted that water levels in wells, as much as 2,400 ft from the river, responded to changes in river stage. At the time of this investigation, water levels in the area south of Wagner's Lane were declining because of heavy withdrawals in the downtown area. Water levels in wells also responded to precipitation. Water levels measured in one well, 2,000 ft from the river's edge, was reported to equalize with the stage of the Ohio River during dry summer months.

Specific yields ranged from 0.16 to 0.22. The water budget of the aquifer in the area northeast of Wagner's Lane, where flow was unaffected by withdrawals, was estimated to be composed of flow to the river (about 200,000 gal/d per mile of river) and recharge from precipitation (700,000 gal/d, or about 4.9 inches per year). The precipitation measured during this study was below normal.

Chemical analyses reflected the effect of river infiltration in areas where ground-water withdrawals were relatively high. Concentrations of hardness and sulfate in ground water were high near pumped wells which indicated that water was flowing from the bedrock to the wells. This can be compared to results in other areas underlain by limestone where concentrations of hardness and sulfate increased due to withdrawals from the alluvium.

In order to determine whether infiltration supplies were available and to what extent, the U.S. Geological Survey conducted a 14-day aquifer test. The test site was 300 ft downstream from the city of Louisville, Ohio River pumping plant. Prior to the test, temperature measurements were made at 5-ft vertical intervals in observation wells. The temperature of ground water was observed to lag behind ambient air temperature by about 3 months. A greater range of temperature fluctuation in ground water was observed near the water table than deeper in the aquifer. Temperature data collected during the aquifer test indicated that warm water, which had infiltrated a short distance beneath the riverbed during the summer, migrated toward the pumping well. The movement of the temperature front indicated that a zone within the aquifer had higher permeability and formed a preferential pathway for the movement of ground water. Temperature data also indicated that cool water was probably flowing upward from the bedrock near one observation well. This temperature effect was local.

During the aquifer test, drawdown data were corrected for changes in river stage, barometric pressure, and well-screen head losses. Induced recharge from the river occurred during the aquifer test within a very few minutes. Slight declines in the cone of depression on the valley-wall side of the pumped well continued past the end of the test. Analysis of the aquifer test data indicated that the distance from the pumped well to the effective source of the river infiltration was about 350 ft. This is approximately the distance from the well to the edge of the surficial-clay layer in the riverbed. Vertical permeability was observed to be much less than horizontal permeability. A conservative estimate of the amount of ground-water that could be obtained in this area was 280 Mgal/d. The storage coefficient was estimated to be 0.0003, and the transmissivity was estimated to be 120,000 (gal/d)/ft. Transmissivity was uniform over the study area based on the uniformity of results from the laboratory permeability tests. Rorabaugh's development of equations for induced infiltration, based on steady-state flow, are presented in this report.

Rorabaugh, M.I., Schrader, F.F., and Laird, L.B., 1953, Water resources of the Louisville area, Kentucky and Indiana: U.S. Geological Survey Circular 276, 49 p., 2 pls., 41 figs.

This report contains chapters on surface- and ground-water resources. A map of the altitude of the water table for 1952 is included.

Bedrock wells that intercept fractures in limestone usually produce large amounts of water, but wells that do not intercept fractures can be dry. At places where limestones are below the water table in sand and gravel, dissolution can be extensive. At places where limestones are overlain by the New Albany Shale, yields from the limestone are poor because water circulation, especially downward movement, can be impeded by shale. The normal rate of ground-water movement in the aquifer was estimated to be about 2 ft/d.

Water-level declines in the downtown area generally ceased in 1948; however, in the northern part of the Rubbertown area, water levels declined slightly. In the Distillery area, a rise of water levels continued. A large distillery continued to implement water conservation measures by attempting artificial recharge of the aquifer. Water-quality data reflected changes in the source of ground-water recharge. Water from the river contained low concentrations of hardness and total dissolved solids. Water from the bedrock contained high concentrations of hardness and total dissolved solids.

Total ground-water withdrawals from the Louisville Extension Water District well field in 1952 was 0.4 Mgal/d. The well field consisted of two wells located near Betheny Lane and Lower River Road. A summary of ground-water withdrawals gave yearly totals for the period 1937-52. The withdrawals were larger than previously reported. In 1952, total withdrawals and total recharge were balanced at 30 Mgal/d for each.

Walker, E.H., 1957a, The deep channel and alluvial deposits of the Ohio Valley in Kentucky: U.S. Geological Survey Water-Supply Paper 1411, 25 p., 6 pls., 2 figs.

This report describes the geologic history of the Ohio River valley and the alluvial aquifer, but does not discuss ground-water availability or well yields. In the preglacial Ohio River Basin, a large drainage area combined with structural uplifts caused the river to deepen and widen. During glaciation, the Illinoian ice sheet blocked flow of rivers south and east of Cincinnati. Water from these glacial reservoirs spilled over into the drainage basin of the Salt River, south of Louisville. Once the ice sheet melted, water flowed from the lake and removed Illinoian glacial deposits that had accumulated in the valley. Sea level was relatively low during the Wisconsinan glaciation. This resulted in the river-bed erosion and the further removal of valley-bottom Illinoian sediments. Melting of the ice lobe of the Tazwell substage filled the valleys with well-sorted, coarse-grained sediments in a relatively homogeneous mass that contained few intervening layers of fine-grained sediments. This deposition raised the valley floor above the bedrock upon which the river had been flowing. The irregular surface of the coarse-grained sediments probably resulted from erosion during subsequent interglacial stages. Post-Tazwell glaciation did not affect the Ohio River valley directly, but the rise in sea level following glacial melting, and the subsequent aggradation of the Mississippi River valley, led to lower velocities in the Ohio River and the consequent deposition of the fine-grained alluvium over the coarse-grained alluvium. The source of this material that flowed into the river was the normal sediment load from tributaries and not the glaciers. In post-glacial times, the river probably is not aggrading or degrading, but is meandering.

The longitudinal gradient of the bedrock surface is lower, north of the Falls of the Ohio, at Louisville, than between Louisville and the Mississippi River. The valley width reflects the effect of local geology. For example, the valley is relatively wide where it crosses the outcrop area of the New Albany Shale below the Falls of the Ohio, but the valley tends to be narrower where the river flows through more competent carbonate rocks. In most places, the bedrock valley is flat bottomed and steep sided and is often wider than deep. In reaches where the valley is broadest, incised troughs and benches are present beside the main channel.

Erosion of the alluvium by the river has exposed the river to the sand and gravel of the coarse-grained alluvium almost everywhere along the river profile. In some places, the fine-grained alluvium has been undercut by the river and now forms a blanket of low-permeability sediments that extends on the riverbed for some distance from the bank. At Louisville, cobbles up to 8 inches in diameter are reported in the deep parts of the bedrock valley. Most of the cobbles exceed 2.5 inches in diameter. The sand fraction is mostly quartz. The source of gravel and cobbles ranges from the igneous and metamorphic rocks of the Canadian shield to local limestones and sandstones.

The overlying fine-grained alluvium averages 25 to 30 ft in thickness. The river has, in most places, eroded below the base of the fine-grained alluvium. This material is usually a clayey silt with some sand. The fine-grained alluvium is yellow to gray where more clayey. In places, organic matter is abundant. Several years passed before water levels returned to normal after the 1937 flood due to the large amount of water stored in the fine-grained alluvium. In places, the fine-grained material may cause confined ground-water conditions to exist in the coarse-grained alluvium.

______1957b, An aquifer test in the southwestern part of the Louisville area, Kentucky: U.S. Geological Survey Open-File Report, 41 p., 13 figs.

An aquifer test was conducted in 1953 at the Stauffer Chemical site, southwest of Rubbertown near Bramer's Lane, and north of Lee's Lane. The aquifer is heterogeneous, with fine-grained sediment in the upper part, but responds as a homogeneous aquifer when pumped a sufficiently long period of time in order to dissipate slow drainage from the overlying fine-grained sediments. Changes from confined to unconfined conditions occurred during the early part of the test. Corrections were applied to drawdown for atmospheric pressure, seasonal recession of the water table, and an oil layer in the pumping well. The test resulted in a specific yield estimate of 0.22 and a transmissivity estimate of 80,000 (gal/d)/ft. Hydraulic conductivity was estimated to be 1,500 (gal/d)/ft^2, which the author stated is identical to the hydraulic conductivity determined for this area by Rorabaugh (1946b).

Ground water outflow to the river was estimated to be 1.6 Mgal/d per mile of river. Inflow from the valley wall was estimated to be 140,000 gal/d per mile of valley wall. Recharge from precipitation was estimated to be 5 inches per year for 1952; the annual precipitation was 37.58 inches. A geologic section of the study area is included.

Whallon, A.J., 1985, Aquifer test report Louisville Water Company, Zorn Avenue plant, Louisville, Kentucky: U.S. Geological Survey Open-File Report, 2 p.

This report documents an aquifer test conducted by the U.S. Geological Survey at the Louisville Water Company on Zorn Avenue near the study site of Rorabaugh (1948). The aquifer consists of 55 to 70 ft of fine- to medium-grained sand with sparse to abundant gravel. The gravel is overlain by a semi-confining layer composed of recent alluvial clay, silt, and some fine-grained sand. The layer is 0 to 45 ft thick. The pumped well was about 200 ft from the Ohio river. Analysis of the data indicated that the transmissivity values ranged from 9,000 to 11,000 ft^2/d and that storage was within the artesian range.

Whitesides, D.V., and Nichols, E.S., 1961, Water levels in observation wells in Jefferson County, Kentucky, 1935 through 1960: Kentucky Geological Survey, ser. 10, Information Circular 6, 75 p., 152 figs.

Hydrographs are presented for all observation wells in Jefferson County that have more than 3 years of water-level records. Also included are the owners name, local well-number, and well descriptions. The report includes two water-level contour maps that indicate the altitude of the water table for December 1950 and December 1960.

Whitesides, D.V., Kernodle, J.M., and Leist, D.W., 1978, Water levels in observation wells in Kentucky, 1935 through 1976: U.S. Geological Survey Open-File Report 78-129, 156 p., 196 figs.

Hydrographs from the U.S. Geological Survey state-wide network of observation wells, including 99 from the Louisville area, are presented in this report. The hydrographs present long-term trends of ground-water levels in addition to short-term water-level fluctuations. Also included are the owners name, local well-number, and well descriptions. An extensive bibliography of ground-water data reports, beginning in 1937, is also included.

Whitesides, D.V., Faust, R.J., and Zettwoch, D.D., 1983, Problems of rising ground-water levels in urban areas with special reference to the Louisville, Kentucky area: U.S. Geological Survey Water-Resources Investigations Report 83-4233, 26 p., 13 figs.

Causes of rising ground-water levels and potential damage in urban areas are discussed in this report. Damage from rising ground-water levels at Louisville would probably result from differential compaction of aquifer material caused by the wetting and drying of fine-grained sediments during periods of rising water levels.

By 1982, ground-water levels in Louisville had stabilized and the trend of rising water-levels ceased. However, stabilized ground-water levels still responded to seasonal fluctuations in recharge from precipitation. The highest water levels usually occur in May, and the lowest levels occur in December or January. Long-term hydrographs are presented in this report and the water-table altitude map for 1962 by Bell (1962) is presented in modified form. A water-table altitude map for 1982 is included. The altitude of the water table in 1962 and in 1983 for the downtown and Rubbertown areas is illustrated in two sections. These sections also indicate the shape of the bedrock valley at each location. Also, a contour map showing the change of water levels between 1962 and 1983 is presented.

Ground-water levels are correlated to river stage for paired wells near the Ohio River. Changes in water level are correlated with precipitation data. Precipitation records for the period 1873 to 1982 indicate that some periods of above-normal precipitation lasted longer than similar periods during 1969-79. The drought period of 1980-81 may have been only a temporary dry period, and the potential for water levels to rise higher than those measured in 1982 is discussed.

The rise in water level is discussed in relation to yearly total ground-water withdrawals and the cumulative departure from average normal precipitation. Cumulative departure data from 1873 to 1982 are presented in this report. A linear formula described by Hagerty and Lippert (1982) was used to predict average water levels on the basis of precipitation and withdrawals. Also, this report describes the limitations of such formulas and stresses the need for a digital model to predict ground-water levels based on precipitation.

Geologic Quadrangle Maps

The geologic quadrangle map series depicts the surficial geology, sections, structure, and economic geology of parts of the Louisville area. Each map covers an area of approximately 60 square miles. Only those rock units that are discussed in other reports as relevant to the hydrogeology of the alluvial aquifer are discussed below. To avoid repetition, geologic descriptions are not repeated after the first time a unit is discussed, unless differences are noted.

Kepferle, R.C., 1972, Geologic map of the Valley Station quadrangle and part of the Kosmosdale quadrangle, north-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-962, scale 1:24,000.

Bedrock in this quadrangle consists of limestones and shales of Mississippian age and does not yield appreciable quantities of water to wells except near outcrop areas. High-level terrace deposits of possible Illinoian age are present in tributary valleys. The terrace deposits consist of silt, clay, and sand and are from 0 to 20 ft thick. Silty to sandy loess from 0 to 30 ft thick mantles much of the area. Outwash of Wisconsin age consists of about 50 ft of cross-bedded sand, gravel, and cobbles overlain by silt and sand. This unit ranges from 0 to 110 ft thick. Soils developed on the outwash often have a hardpan layer that impedes drainage. Lacustrine deposits of clay, silt, sand, and gravel are found at lower elevations than the loess and terraces in tributary valleys. These deposits are from 0 to 50 ft thick and grade laterally into the outwash deposits. The youngest unit is silt and clay alluvium of recent origin. The unit ranges from 0 to 20 ft thick and forms the valley bottoms in tributary valleys.

Structure contours depict the configuration of the top of the New Albany Shale. An unnamed anticlinal structure, probably the plunging southern terminus of the Springdale Anticline, is present in the area. The New Albany Shale dips to the west on the west flank and to the southeast on the eastern flank of the anticlinal structure. A fault is present along the valley of Knob Creek, which is parallel to the trend of the anticline.

Natural gas was produced from the New Albany Shale around the turn of the century, near Kosmosdale, in the southwestern part of the area. Water is available from the glacial outwash deposits, from sand and gravel at the base of lacustrine deposits, and from Mississippian limestones. Water in shale units is sulfurous or saline. Clay and shale units tend to be plastic and unstable where slopes are oversteepened. The permeability of the outwash and lacustrine deposits is variable.

______1974a, Geologic Map of parts of the Jeffersonville, New Albany, and Charlestown quadrangles, Kentucky-Indiana: U.S. Geological Survey Geologic Quadrangle Map GQ-1211, scale 1:24,000.

The Louisville Limestone of Silurian age is a fine- to medium-grained crystalline dolomitic limestone. Beds are thin near the top and thicken near the base. Total thickness ranges from 45 to 75 ft. The overlying Jeffersonville Limestone contains numerous fossils in a thinly cross-bedded, fine-grained limestone matrix. It is typically more coarse grained than the Louisville Limestone. The Sellersburg Limestone, a fine-grained limestone containing some shale, chert, and fossils, is mapped with the Jeffersonville Limestone. The combined unit ranges in thickness from 35 to 50 ft. The Jeffersonville Limestone is overlain by the New Albany Shale, which is a carbonaceous, massive, dense, silty shale more than 80 ft thick.

The unconsolidated deposits in the area are similar to those discussed for the Valley Station quadrangle (Kepferle, 1972) except that terrace deposits are not present in this quadrangle. Loess ranges in thickness from 0 to 20 ft. The outwash ranges in thickness from 0 to 135 ft. An expanded discussion of the outwash is presented for this geologic quadrangle. The unit is composed of very fine- to coarse-grained sand and gravel, it is well to poorly sorted, and is commonly cross bedded. The outwash deposits are intermixed and interbedded with alluvial and lacustrine deposits at tributary mouths in bar or deltaic deposits. The lacustrine deposits interfinger headward in tributary valleys with recent alluvium and colluvium and are from 0 to 60 ft thick. Recent alluvium in this quadrangle ranges from 0 to 30 ft thick.

Structure contours depict the top of either the New Albany or the Waldron Shales. The New Albany Shale dips to the west beneath the McAlpine lock and dam. The Waldron Shale dips to the west on the west flank of the Springdale Anticline, a minor fold structure that runs through the southeastern corner of the quadrangle.

Ground water is the most important resource in the quadrangle and is principally available from the outwash deposits. Lesser amounts of ground water also are available from wells and springs near the base of each of the exposed carbonate units. Water in the limestone contains an average concentration of 580 mg/L calcium and 450 mg/L of sulfate. Water from the alluvium has average concentrations of calcium (422 mg/L) and sulfate (162 mg/L). No successful oil or gas wells have been drilled in this quadrangle. During the 1937 flood, water reached an altitude of 462.8 ft at Harrod's Creek, 458.2 ft at 9th Street and Broadway, and 458.2 ft in the southwestern part of the aquifer. Caverns and sinkholes exist in the limestone, particularly in the Beechwood Member of the Sellersburg Limestone at the contact with the overlying New Albany Shale. Topography on the surface of the Sellersburg Limestone, where it is covered by soil, commonly varies by about 10 ft.

______1974b, Geologic map of parts of the Louisville West and Lanesville quadrangles, Jefferson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1202, scale 1:24,000.

The bedrock in this quadrangle consists of New Albany Shale of Devonian age and shales and carbonates of Mississippian age. The unconsolidated units are similar to those described previously (Kepferle, 1974b). The outwash unit contains sand deposits that rise 5 to 15 ft above the outwash surface and were probably deposited as dunes or levees. The outwash ranges from 0 to 130 ft thick. The lacustrine deposits range from 0 to 50 ft thick, and recent alluvial deposits range from 0 to 30 ft thick.

Structure contours depict the top of the New Albany Shale. The Springdale anticline, a minor fold structure, parallels the eastern boundary of the alluvium. The surface of the New Albany Shale dips to the west on the west flank of the anticline and to the southeast on its eastern flank.

Limestone beneath the New Albany Shale has produced a show of oil but has not been developed commercially. Two wells were known to have produced natural gas in the quadrangle. Water from the New Albany Shale, or deeper, is usually saline or sulphurous, especially where wells are completed below stream level. The clays and shales in this area can be unstable. The permeability of the outwash and lacustrine deposits is variable, depending on the clay content.

______1974c, Geologic map of the Louisville East quadrangle, Jefferson County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1203, scale 1:24,000.

The bedrock is Waldron Shale and limestones of Silurian and Devonian age, the New Albany Shale of Devonian age, and the New Providence Shale of Mississippian age. The Louisville Limestone of Silurian age contains calcite-filled joints and vugs that trend N. 10° E. and extend upward into the Devonian limestones. The Louisville Limestone ranges from 65 to 85 ft thick. The Jeffersonville Limestone contains abundant whole fossils in this area and is more coarse grained than the Louisville Limestone. The Sellersburg Limestone is mapped together with the Jeffersonville Limestone. The total thickness of these units is 10 to 40 ft. The New Albany Shale ranges from 90 to 105 ft thick in this quadrangle.

The unconsolidated units are similar to those in other quadrangles in the Louisville area. The terrace and loess deposits range in thickness from 0 to 20 ft each; the outwash ranges in thickness from 0 to 125 ft. The lacustrine deposits range in thickness from 0 to 50 ft, and recent alluvium ranges from 0 to 20 ft thick.

Structure contours are drawn on the top of either the New Albany Shale or the Waldron Shale. The Springdale anticline, a minor fold structure, trends across the area from northeast to southwest. The New Albany Shale dips to the west on the western flank of the structure and to the south and southeast on the eastern flank toward the Lyndon syncline. The Lyndon syncline, a minor fold structure, lies parallel to the Springdale anticline about 3 mi southeast. In the eastern and northern parts of the quadrangle, the Waldron Shale dips to the west.

Ground water is readily available in large amounts from the outwash deposits. Lesser quantities of water can be obtained from the limestone and dolomite in the eastern part of Jefferson County. Springs are developed in the Sellersburg and Jeffersonville Limestones and locally from the upper part of the Louisville Limestone. Clay and shales in this area can be unstable. The permeability of the lacustrine and outwash deposits is variable depending on clay content. The water table in the lacustrine deposits reaches the land surface during wet periods. Caverns and sinkholes have developed in the limestone units. Where the Devonian limestones are overlain by soil, as much as 10 ft of relief exists on the bedrock surface. The Beechwood Member of the Sellersburg Limestone is the most susceptible to dissolution.

CO-AUTHOR INDEX

This index serves as a guide to the co-authors of the references included in this bibliography. The publication produced by the co-author is referenced according to the principal author of that publication.