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Report on a Pumping Test at Evansville, Indiana

By

Fred C. Mikels and Porter E. Ward
Engineer Geologist
U. S. Geological Survey

Prepared in Cooperation with the

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REPORT ON A PUMPING TEST AT EVANSVILLE, INDIANA

By Fred C. Mikels and Porter E. Ward

Introduction

Purpose of the test

The City of Evansville, Ind. has utilized the Ohio River as a source of municipal water supply for many years. The average daily pumpage for the city in 1950 was reported to be about 10.5 million gallons. Because of the extreme variability in the quality of the river water and the extensive treatment necessary, the city considered the possibility of developing a ground-water supply to supplement its present surface-water supply.

In February, 1951 Mr. Oliver W. Summers, General Superintendent, Evansville Waterworks Department, in a letter to C. H. Bechert, Director, Division of Water Resources, Indiana Department of Conservation, requested the assistance of the Department of Conservation and the United States Geological Survey in conducting a pumping test to determine the hydraulic characteristics of the water-bearing formations in the area.

In view of the importance of Evansville as an industrial center and realizing the need for quantitative information in such an area, it was decided that the test should be a part of the State-wide investigation of the ground-water resources now being made by the U. S. Geological Survey in cooperation with the Indiana Department of Conservation.

This memorandum describes the procedure used in making the test and the results obtained from the test.

Acknowledgments

The writers wish to acknowledge the cooperation extended them by Mr. Oliver W. Summers, General Superintendent, and Mr. Lawrence J. Killian, Superintendent of Filtration, Evansville Waterworks Department. They also wish to thank Mr. Charles W. Pfeiffer, Mr. Charles Straeffer, Diehl Pump &

Supply Co., and employees of that company and of the Evansville Waterworks for their assistance in conducting the test.

General description and geology of the area

The city of Evansville is on the north bank of the Ohio River in south-central Vanderburgh County. The river bottom land or flood plain of the river is from 2 to 6 miles wide. In the vicinity of the test site, which is approximately 1 mile south of the heart of Evansville and in sec. 31, T. 6 S., R. 10 W., the alluvium-filled valley is about 5 miles wide. The test wells are roughly 2 miles northeast of its center.

The broad valley has been cut into the underlying rocks of Paleozoic age, to depths locally of at least 150 feet. This deep downcutting was done during a period when there existed a river that carried a much larger volume of water than that of today.

With the exception of a small area in the northwestern corner of the county, no evidence of glaciation has been recognized in Vanderburgh County. Although the glacial ice did not reach the vicinity of Evansville, streams carrying great volumes of water from the melting of the ice did.

The large quantity of meltwater that flowed down the Ohio River valley carried vast quantities of gravel, sand, and clay. Large amounts of this material were deposited along the course of the river on top of previously water-deposited unconsolidated materials. Deposition has continued and the ancient valley is now filled with a considerable thickness of materials consisting of older glacial gravel, sand and clay, and younger river alluvium of sand, silt, and clay.

After the retreat of the ice from the area the volume of water decreased and today we find the present river meandering over a wider valley than it could possibly have made.

As indicated by the well logs in figure 1, the sand and gravel is overlain by an impermeable layer of clay, which probably represents a flood-stage sediment. It appears that the river has cut below this confining clay layer, at least in places, and that there is a hydraulic interconnection between the river and the water-bearing sand and gravel. These water-bearing sediments, which are approximately 74 feet thick, constitute a rather large underground reservoir in which great quantities of water are stored.

Although lenses of clay were encountered at various depths within the water-bearing zone, they apparently do not extend sufficiently far in any one direction to form a substantial confining layer. Below the water-bearing formation, bedrock is encountered at an average depth of 100 feet or at an elevation of 280 feet above mean sea level.

Description of wells

The pumped well, the location of which is shown on plate 1, is a 16-inch gravel-packed well, 103 feet deep. At 63 to 103 feet it is screened with 16-inch shop screen. The log of this well is shown in figure 1. This well was equipped with a turbine pump and gasoline-power unit capable of discharging 2,000 gallons per minute. Provisions were made for measuring the water-level fluctuations in the pumped well by installing an air line and pressure gage. The discharge was measured by the orifice method.

Twelve observation wells were used in the test, the locations of which are shown on plate 1 and the descriptive data are given in table 1. The pumped well and observation wells P-1 through P-7 were drilled especially for this test by the Diehl Pump & Supply Co. of Evansville, Indiana. Wells T-1 through T-4 were drilled in September 1950 by the same company to determine the possibility of developing a ground-water supply in this area. Wells M-1 and M-2 were drilled for exploratory purposes in 1942 by the Heldt-Monroe Co.

of Evansville, Indiana.

The partly plugged condition of wells M-1, M-2, T-1, T-2, and T-3 was determined by pouring water into the wells and noting the time required for them to return to their original levels, therefore measurements made in these wells were not used in the analysis.

In Figure 1 the log of well T-4 is shown. This well was not available during the test since it has been previously destroyed.

Table 1. Description of observation wells

Well number	Diameter (inches)	Depth of well below measuring point (feet)	Altitude of measuring point (feet above msl)	Screen	Condition of well at time of test	Distance from pumped well (feet)
P-1	1½	64.0	364.42	30" well point	Excellent	160
P-2	1½	54.7	364.48	do	do	180
P-3	1½	64.4	366.33	do	do	62
P-4	1½	60.4	364.34	do	do	180
P-5	1½	50.1	363.39	do	do	107
P-6	1½	60.8	363.04	do	do	60
P-7	1½	85.0	363.70	do	do	60
M-1	2	118.5	381.42	unknown	partly plugged	380
M-2	2½	84.6	361.36	do	do	166
T-1	6	79.8	379.18	none	do	1400
T-2	6	68.5	365.58	do	do	15
T-3	6	91.2	392.05	do	do	490

Test procedure

The pumping well was started at 8:03 a. m., April 6, 1951 and was continued until 8:03 a. m., April 7. A constant pumping rate of 1,500 gallons per minute was maintained until 10:00 p. m., April 6. At this time a light rain started and the pumping rate dropped to about 1,400 gallons per minute, owing to the slipping of the wet belts connecting the power unit to the pump. For the remainder of the test period the pumping rate varied between 1,300 and 1,600 gallons per minute.

The water level in all observation wells, except T-1 and T-2, was measured by the wetted-tape method at frequent intervals throughout the test period. Measurements were made by personnel of the U. S. Geological Survey and the Indiana Department of Conservation.

Samples of the discharge water were taken at 6-hour intervals and temperature measurements were made at 2-hour intervals during the test.

Water-level fluctuations

The water-level fluctuations in the observation wells are shown in hydrograph form in figures 2 to 5. Also shown in figure 5 is a hydrograph of the Ohio River stage during the test.

As indicated by the hydrographs, all observation wells showed a natural rising trend prior to the time pumping began. This trend closely paralleled the rising trend of the Ohio River, suggesting that a hydraulic connection exists between the water-bearing formation and the river.

The water levels in all observation wells were well above the top of the formation throughout the test period. Water-bearing formations of this type in which the water levels remain at a stage above the top of the formation are termed artesian. The point to which the water level rises is defined as a point on the piezometric surface. Plate 1 shows a contour map and cross section of the piezometric surface before pumping began. These contours and cross section show a hydraulic gradient away from the river, indicating flow from the river into the formation. At the time the test was run the river stage was very high, about 23 feet above normal pool stage. At times of normal pool stage the hydraulic gradient is reversed and ground-water flow is from the formation to the river.

When the pumping was begun, all wells responded almost immediately to the pumping and the water levels began to decline. They continued to decline throughout the test period. When the pumped well was shut off the water levels returned to their original position and trend. Plate 2 shows a contour map and cross section of the piezometric surface after 24 hours of pumping an average of 1,500 gallons per minute.

Partial penetration

When a pumping well does not completely penetrate the water-bearing formation, it is necessary to adjust the drawdowns observed in nearby observation wells. Because of the convergence of the flow lines as they approach the well face, the loss of head along the top of the formation is different from that along the bottom.

In this test, the pumping well penetrated the bottom 55 percent of the formation. The observed drawdowns along the bottom of the formation were larger than those for a completely penetrating well while the observed drawdowns along the top of the formation were smaller. Consequently, corrections had to be applied to the observed drawdowns before any analysis of the data could be made. These corrections were made according to the method developed by Jacob. 1/

1/ Jacob, C. E., Adjustments for partial penetration of a pumping well: U. S. Geol. Survey mimeographed report, August 1945.

Analysis and results of test

When a well is pumped, the piezometric surface is drawn down in the vicinity of the well in the approximate shape of an inverted cone, with its apex at the pumping well. From the measurements of the rate of decline of this surface, it is possible to determine the hydraulic characteristics which define the specific rate at which water is transmitted by the formation under a given hydraulic gradient.

The rate at which a formation will transmit water is proportional to its "coefficient of transmissibility," which is defined as the volume of water that will flow in a unit of time under a unit hydraulic gradient through a vertical strip of water-bearing material of unit width extending the full saturated thickness of the formation. The rate at which water is yielded from storage by a formation is proportional to its "coefficient of storage," which is defined as the volume of water which a unit decline in head releases from storage in a vertical prism of unit cross-sectional area whose height equals the thickness of the formation.

The coefficients of transmissibility and storage were computed by the Theis 2/ nonequilibrium formula from the changes in water levels in each of the

2/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., vol. 16, pp. 519-524, 1935.

observation wells. A summary of results is given in table 2.

Table 2. Summary of coefficients of transmissibility and storage.

Well number	Coefficient of transmissibility (gallons per day per foot)	Coefficient of storage
P-1	191,000	1.45×10^{-3}
P-2	187,000	1.46×10^{-3}
P-3	183,000	1.52×10^{-3}
P-4	184,000	1.40×10^{-3}
P-5	181,000	1.40×10^{-3}
P-6	180,000	1.37×10^{-3}
P-7	185,000	1.24×10^{-3}

In the analysis of the test data, it was found that after pumping had been in progress for about 2 hours the observed changes in water level in the observation well began to depart from the theoretical changes computed by the nonequilibrium formula. These departures were in a positive direction, that is, less observed change than computed change, which indicates a positive or recharge boundary for the formation. Using the method of image wells, as described by Ferris, 3/ these departures were analyzed and a recharge boundary

3/ Ferris, J. G., Ground-water hydraulics as a geophysical aid: Michigan Department Cons., Geol. Survey Div. Tech. Rept. 1, 12 pp., 1948.

was found to exist about 1,200 feet west of the pumped well (shown by the dashed line in plate 1). The significance of this recharge boundary is that a free hydraulic connection exists between the formation and the Ohio River at this point and that by pumping a well to induce a favorable hydraulic gradient, it is possible to induce water from the river into the formation.

Quality and temperature

A total of five water samples were collected at the discharge pipe during the test. Table 3 gives the chemical analyses of the samples, in parts per million, as determined by the Indiana State Board of Health.

Table 3. Chemical analyses of water samples from the test well

Sample No.	1	2	3	4	5
Date	4/6/51	4/6/51	4/6/51	4/7/51	4/7/51
Hour	6:30 a.m.	2:20 p.m.	8:15 p.m.	2:00 a.m.	7:45 a.m.
Color	10	10	10	10	10
Sediment	Slight	Slight	Slight	Slight	Slight
Turbidity	27	27	27	27	27
pH	7.5	7.5	7.5	7.5	7.5
Alkalinity (Methyl Orange)	300	300	300	300	300
Total hardness	430	440	458	458	458
Total iron (Fe)	3.0	3.0	3.0	3.0	3.0
Chloride (Cl)	9	10	9	9	10
Fluoride (F)	0	0	0	0	0
Nitrate (N)	Less than 1	Less than 1	Less than 1	Less than 1	Less than 1
Manganese	0.3	0.5	0.5	0.5	0.5

As indicated from the above analyses, the ground water in the area is fairly hard and contains sufficient iron (3 p.p.m.) to make it unsuitable for most uses unless treated. The standards of the U. S. Public Health Service specify that iron plus manganese should not exceed 0.3 p.p.m. in water used for public consumption. 1/

1/ Code of Federal Regulations of the United States of America, 1946 Supplement, Title 42 - Public Health, p. 216.

The temperature of the discharge water remained constant at 56° F. throughout the test. The temperature of the river water during this same period varied between 50° and 51° F.

Summary and conclusions

The sand and gravel in the vicinity of the test site represent only a small part of the unconsolidated sediments that now fill the valley of the preglacial Ohio River. This valley constitutes a rather large underground reservoir in which large quantities of water are stored.

The test proved conclusively that the water-bearing formation is interconnected with the Ohio River in the vicinity of the test site. The test showed that initially the water pumped is derived from storage, and as pumping progresses a condition of steady-state flow is approximated, when much of the water that is pumped is replaced by infiltrated river water and the drawdown in the well becomes stable. Negligible increments of drawdown were observed in all observation wells near the end of the 72-hour pumping period, indicating that a condition of approximate equilibrium was established. Thus nearly all the water pumped has infiltrated into the formation from the Ohio River.

On the basis of the large storage capacity of the formation, the relatively high coefficient of transmissibility, and the fact that river infiltration is available in sufficient quantity to insure ample recharge to the formation, it appears that substantial ground-water development is possible in this area through properly constructed and spaced wells.

In another area along the Ohio River quite similar to the one tested (Charleston area, Ind.), a ground-water supply dependent on river infiltration has yielded an average of about 10 million gallons per day over a 4-year period.[5]

5/ Kazmann, R. G., River infiltration as a source of ground-water supply: Am. Soc. Civil Eng. Proc., vol. 73, no. 6, pp. 837-853, June 1947.