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GROUND-WATER RESOURCES OF NOBLE COUNTY, INDIANA

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GROUND-WATER RESOURCES OF NOBLE COUNTY, INDIANA

By Robert W. Stallman and Fred H. Klaer, Jr.

ABSTRACT

This report describes the glacial geology and ground-water resources of Noble County, in northeastern Indiana. The area includes 13 civil townships and covers an area of about 420 square miles. The largest city in the county is Kendallville, a small industrial community. Ligonier and Albion also have several small industries; the remaining towns and villages in the county are primarily agricultural centers. The average annual temperature at Albion, the county seat, from 1917 to 1947, inclusive, was 49.2° F., and the average annual precipitation was 30.48 inches, the major portion falling during the spring, summer, and autumn months.

The bedrock formations of Noble County are buried beneath a thick mantle of glacial drift, which ranges in thickness from about 165 to more than 475 feet and has a probable average thickness of about 350 feet. The bedrock formations are sedimentary rocks of Devonian and Mississippian age. Ample water supplies have been obtained from wells in the glacial drift, and few wells have been drilled to bedrock for water. Therefore little is known about the ground-water resources of the bedrock.

The glacial history of Noble County is complex and the geology and topography have been modified by the advances of the ice sheets during the Wisconsin glacial stage. Noble County lies in the interlobate area between the Saginaw and Huron-Erie ice lobes. In the southeastern part of the county the glacial deposits are primarily boulder clay with interbedded outwash deposits of sand and gravel. In the northwestern part of the county sand and gravel outwash is widespread, although buried strata of clay are

found in many places. The water-bearing characteristics of the glacial deposits in each township are discussed in detail.

Ground-water levels in Noble County during the past 12 years have shown a close correlation with trends in rainfall. During this period ground-water levels in the county have shown little or no decline, except in areas of heavy pumping.

It is estimated that during 1947 about 1,500 million gallons of water was pumped from wells in the county for all uses. About 500 million gallons was pumped for municipal and industrial use. Five cities and towns in the county are served by public water-supply systems, all using water from wells.

Detailed pumping tests in Kendallville indicate that the shallow gravels near the municipal well field offer the best opportunity for further development. Although it has been shown by pumping tests that the Bixler Lake bottom is not hydraulically open to the shallow gravels along its shore, detailed studies of lake-level changes from the lake to the shallow gravels indicate that recharge probably occurs in large quantities.

The average daily recharge to the water-bearing formations of Noble County has been estimated at about 150 million gallons. It is apparent that as the total pumpage of ground water from wells is probably not more than 5 million gallons a day, the ground-water supplies of Noble County are not overdeveloped, and new supplies may be developed, particularly in outwash valleys in the western part of the county. The records of wells, well logs, and chemical analyses in tabular form are included in the report, together with maps showing the general surface topography, surficial geology, well locations, and elevations of water levels.

INTRODUCTION

The importance of ground water as a valuable natural resource has become rather generally recognized by the public during the last 10 years. The increased demands on water supplies for municipal, industrial, and agricultural use have raised many questions as to the adequacy of the present sources of water supply and have encouraged the development of new sources. In response to the public need for additional information on the water resources of the State, the Indiana Department of Conservation and the United States Geological Survey in 1943 expanded their cooperative water-resources studies on streams, lakes, and ground water to include detailed investigations on an areal or county basis.

The purpose of these investigations is to provide the basic information on the quantity and quality of ground water available for beneficial use by the citizens of Indiana. Such information will be valuable in the municipal, industrial, and agricultural development of the State. More than 80 per cent of the municipalities in Indiana served by public water-supply systems are dependent on ground water. The rapid modernization of homes, the increasing use of water-cooled equipment in industry, and the widespread use of water for air conditioning have caused a great increase in the demand for ground water. The growing trend toward decentralization of industry and the realization of the value of supplemental irrigation may require the development of large ground-water supplies in rural areas heretofore only sparsely populated. The increased use of water on the farm requires the development of additional ground-water supplies. The information obtained by present ground-water investigations will provide the basis for adequate planning and proper development of the ground-water resources of Indiana.

This report is the third of the current series of reports on the ground-water resources of Indiana and will be followed by other county or areal reports. The locations of the areas previously studied and on which reports are available are shown in figure 1. The area described in this report was selected for study because of the need for additional municipal water supply in the county and its proximity to the Fort Wayne industrial area. Many parts of the county are underlain by muck soils and are cultivated for special crops. In these areas the use of ground water for irrigation may become important.

The present investigation was started in March 1945 in cooperation with the City of Kendallville, Eugene V. Carteaux, mayor. The work has been carried on under the general administrative supervision of Charles H. Bechert, director, Division of Water Resources, Indiana Department of Conservation, and Don M. Corbett, district engineer, United States Geological Survey, Indianapolis; under the general supervision of O.E. Meinzer and A. N. Sayre, successive chiefs, Ground Water Branch, United States Geological Survey; and under the direct supervision of the junior author, as district geologist of the Ground Water Branch.

Previous Investigations

Previous studies relating to the ground-water resources of Noble County were limited largely to reconnaissance mapping of the glacial geology of Indiana. One of the earlier reports of C. R. Dryer (5)1/ contains a detailed description of the surface geology of Noble County, based on the results of careful field observation of topography and soils. Addition work was done by Frank Leverett and F. B. Taylor and described in their classic

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1/ See references at end of report.

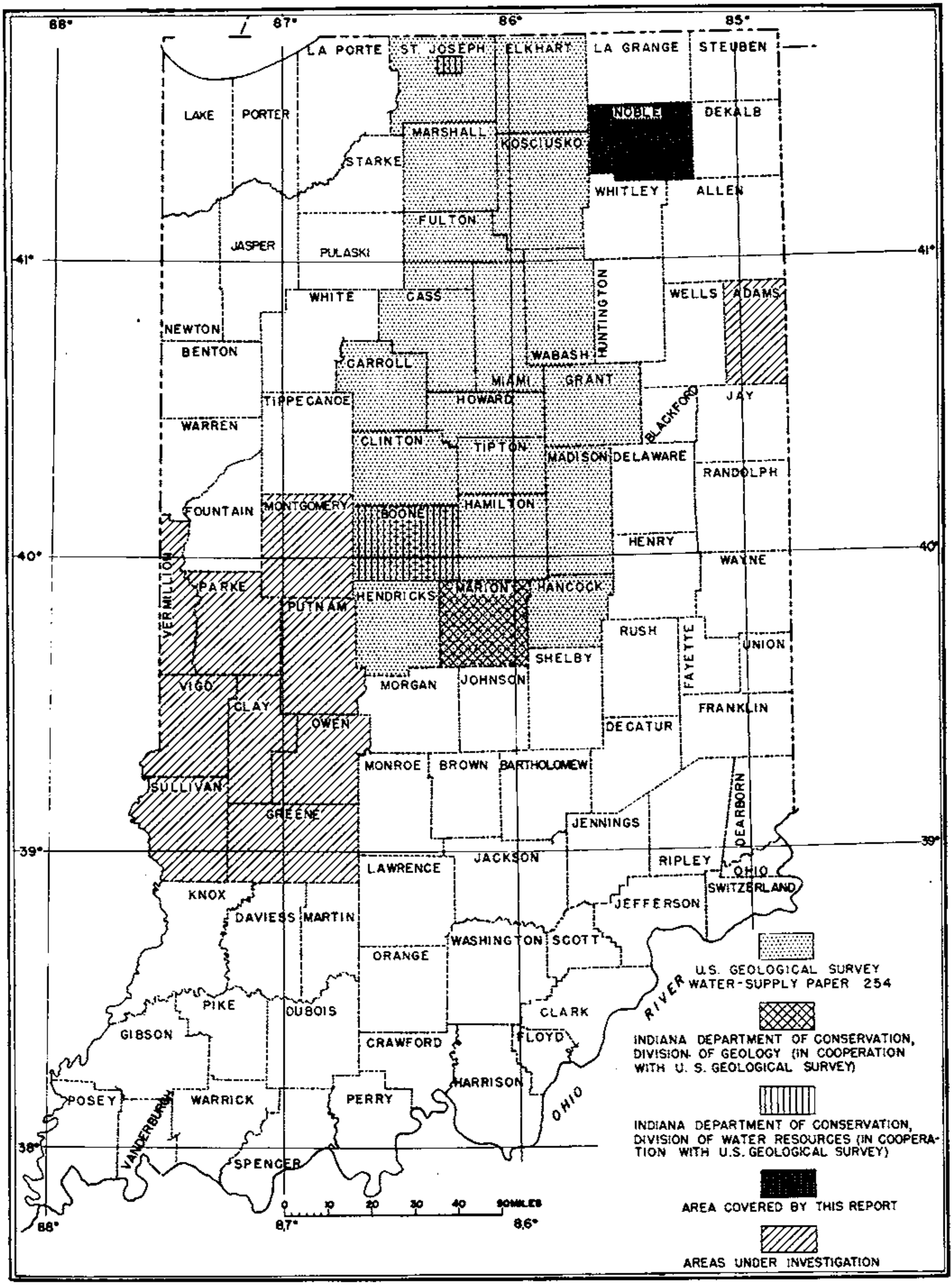

FIGURE I. MAP OF INDIANA SHOWING LOCATION OF AREAS ON WHICH REPORTS HAVE BEEN PUBLISHED, AREA DESCRIBED IN THIS REPORT, AND AREAS UNDER INVESTIGATION.

report on the Pleistocene geology of Indiana and Michigan (11). Leverett and Taylor, however, were concerned with the glacial geology of a very broad area and consequently gave little detail of the geologic conditions within any particular county. Logs of a few wells penetrating the drift and underlying bedrock are published in their reports (10,11). Logs of several wells in Noble County that were drilled in the search for oil and gas have been given by W. N. Logan (14). A brief discussion of the ground-water resources of Noble County was given by M. A. Harrell (8, pp. 378-382). Some of the data presented in the published reports are given and discussed in another section of this report. Other reports on the geology and lakes of Noble County include those by Blatchley and Ashley, Dryer, and Leverett.

A preliminary study involving several days' field work, from April 24 to 27, 1945, was made by the junior author in the Kendallville area, preceding the investigation covered by this report. Logs of wells in Kendallville were collected, and a short memorandum (9) was prepared. The preliminary investigation was made as a basic step in evaluating quantitatively the ground-water resources in the Kendallville area. A detailed investigation of water resources was proposed to determine the yield of the water-bearing formations in the Kendallville area and vicinity. This project was later expanded to include the entire area of Noble County.

Description of the Present Investigation

Purpose and Scope

It has been assumed by many that ground-water supplies are inexhaustible. Actually, the quantity of water that can be withdrawn perennially from the ground in a given area is dependent on the rate at which water is recharged or replenished to the natural water-bearing formations and on the ability of these formations to transmit and store water, and the ground-water supply of any area can be depleted by withdrawing water at too great a rate. The natural formations that serve as ground-water reservoirs in Noble County are glacial deposits of sand and gravel, whose areal extent and thickness, hydraulic characteristics, and recharge potentialities must be known before a detailed estimate of available ground water can be made.

The investigation of the ground-water resources of Noble County included a detailed study of the areal geology, the areal extent and thickness of the water-bearing and non-water-bearing formations, the localities where supplies of ground water may be obtained, the quantities of water that can be obtained from wells, and the general hydrology of the county. The work was based largely on records of existing wells and other data obtained by field study.

Well Inventory

Available information on existing wells was collected by frequent interviews with well drillers in the county, and by a house-to-house canvass of well owners. Information collected for each well included its depth, diameter, and yield; depth to water in the well; the types and thicknesses of the materials penetrated at the well site; and the quantity and use of the water pumped. This information is given in the well tables in appendies A and B at the end of this report, and the locations of the wells are shown on plate 3.

In order to facilitate reference, each well is given a number, composed of at least four parts, having a geographic significance, such as NoF20-2. The first part is a two-letter symbol designating the county in which the well is located, such as No for Noble County. The second part is a single letter designating the township or part of township as established by the Public Lands Survey (See figure 2). The townships of the

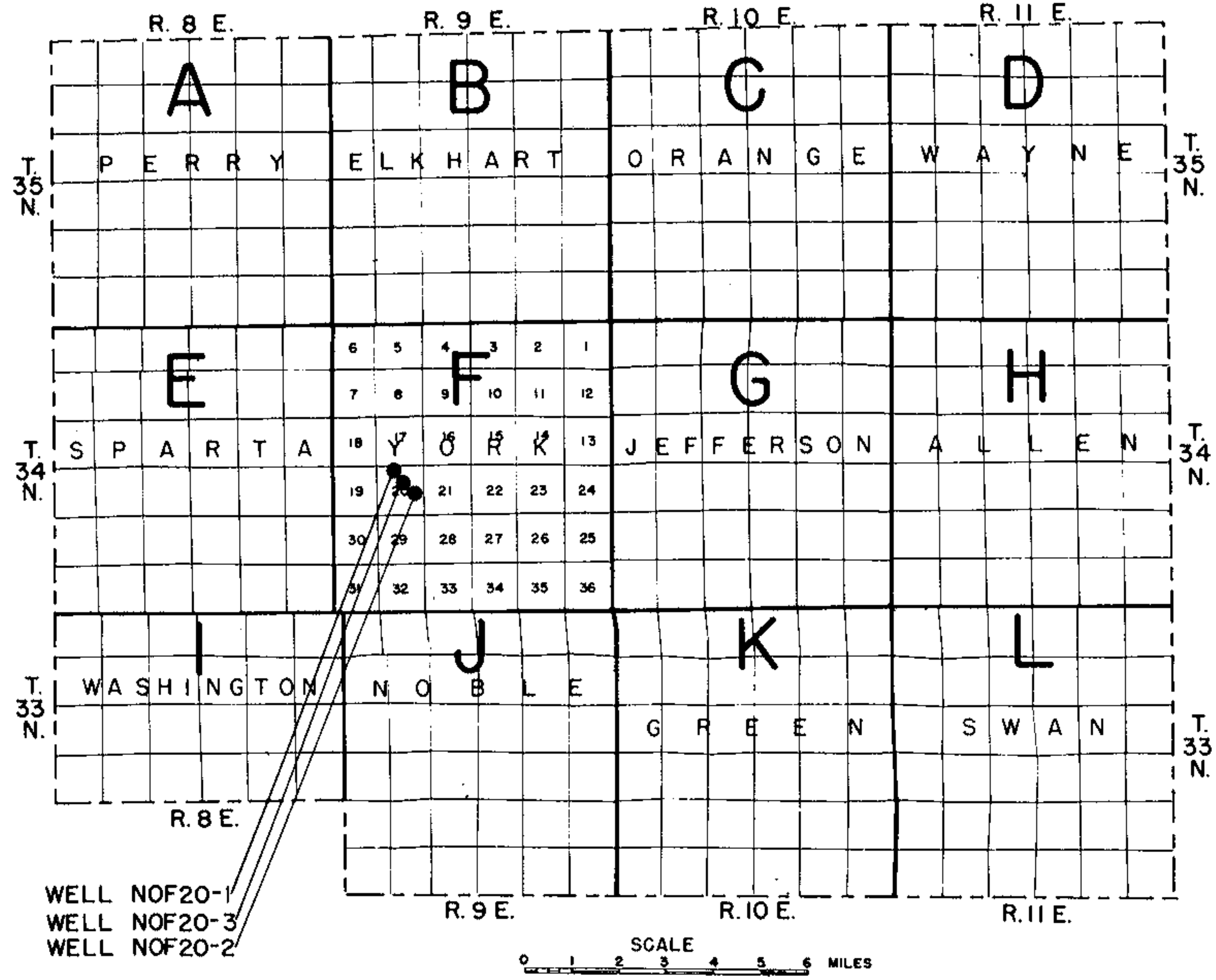

FIGURE 2. MAP OF NOBLE COUNTY, SHOWING WELL-NUMBERING SYSTEM.

Public Lands Survey are generally square and are six miles on a side. They are numbered north and south from a base line, which, in Indiana, runs through southern Orange, Washington, and Clark Counties and east and west from a principal meridian which passes through western St. Joseph County south to central Crawford County. In the well number a single letter replaces the township and range designation. The letters are assigned to townships or parts of townships within the county, starting in the northwest corner of the county and lettering consecutively across the northern tier of townships (see figure 2). Each township is divided into 36 sections, each approximately one square mile in area. These are numbered as shown on figure 2. The third part of the number indicates the section within the township in which the well is located. The fourth part, which follows a dash, refers to the well owner and was assigned as information on the well was obtained in the field.

In addition to the four basic parts described, the letter G preceding the entire number indicates that the well was drilled for gas or oil. A number following the fourth basic part (the number of the owner within the section) refers to an individual well of the owner's well field. The letter T following the entire well number indicates that the well was a test well drilled as a part of an exploratory program.

At the close of the well inventory, altitudes of the well sites were determined by means of a surveying aneroid. Altitudes at many points on the surface drainage system also were obtained to determine the relation between surface- and ground-water levels.

Geologic Studies

A reconnaissance survey of the surficial geology of Noble County was made in 1946 by W. D. Thornbury, of Indiana University, and by E. A.

Brown and the junior author, of the United States Geological Survey. The field information was correlated with an interpretation, by the junior author, of an unpublished soils map prepared by the Purdue University Agricultural Experiment Station and the United States Department of Agriculture. The data presented on the map of surficial geology (pl. 2) was correlated with information on the subsurface geology obtained from well logs.

Water-Level Observation Program

Measurements of depths to water in three unused wells were made for a considerable time prior to the present investigation as a part of the State-wide observation-well program. An unused well in the Kendallville municipal well field, observation well Noble 1 (city well 21 or NoD33-1-21; see figs. 5 and 6) was measured intermittently from November 1, 1935, until March 15, 1945. On April 24, 1945, an automatic water-stage recorder was installed in the well, and was operated continuously during the investigation. In May 1946 this well was put back into service and the recorder was transferred to city well 23, known as Noble 6 in the State-wide water-level program.

Noble 2, a dug well on the county line about 1½ miles south of Merriam, owned by James Bodley, was measured twice a month from December 2, 1935, to April 15, 1944. Measurements were discontinued when the well was filled with rubbish in April 1944.

Well Noble 3, owned by Arthur McClellan, is about a mile northwest of Merriam along U. S. Highway 33. Measurements of depth to water in this well were made twice a month from December 2, 1935, to January 1, 1946, after which they were made weekly. This well was destroyed in July 1947 and was replaced by observation well Noble 7, located near Noble 3.

Noble 5, a dug well about 3 miles southwest of Kendallville, is owned by Rolla Becker. Measurements of water level in this well were made twice a month from May 1, 1942, through the close of the investigation. Water-level measurements are to be continued in wells Noble 5, 6, and 7 as a part of the State-wide program of ground-water-level observations. Water levels were measured in 26 other domestic wells at the time the well inventory was made.

Pumping Tests

A series of pumping tests were made in the municipal well field at Kendallville in 1945 and 1946 to determine the water-bearing characteristics of the several formations used as a source of supply in that area. A description of the tests and an analysis of the test data are given later in this report.

Acknowledgments

The authors are indebted to the many well drillers now operating in and near Noble County for their cooperative spirit in supplying information on wells. They are: T. M. Bair, Columbia City; O. A. Billman, Ligonier; Arthur Bonar, Albion; Charles Croy, Laotto; Dwight Gard, Cromwell; Merritt Gard, Kendallville; Walter Gordon, Churubusco; Glenn Hire, Wolf Lake; Ted. Peppinger, Albion; and Melvin Wheeler, Columbia City. Retired or semiretired drillers who supplied information for this report are Charles Brumbaugh, Albion; William Reinbolt, Kendallville; Harry Tucker, Rome City; and Ad. Wilson, Wolf Lake. Thanks are due also to the many well owners who provided information on their wells.

The observers who measured water levels in the observation wells are: Keith Becker, James Bodley, Don S. Deibele, Owen M. Leek, and Arthur McClellan. Their contribution in the collection of data is greatly appreciated.

The cooperation, during the work in the Kendallville area, of the Kendallville city officials, Eugene V. Carteaux, formerly mayor of Kendallville; Robert Moses, present mayor of Kendallville; Harold B. Hanes, Kendallville city engineer; S. R. Ludlow, superintendent of the Kendallville Water and Light Department; and Don Deibele, formerly chief engineer at the Kendallville powerhouse, is gratefully acknowledged.

GEOGRAPHY

Location

Noble County is in the northeast part of Indiana and is the second county south and west of the State lines. It is approximately rectangular and is bounded by Lagrange County on the north, Dekalb County on the east, Allen and Whitley Counties on the south, and Kosciusko and Elkhart Counties on the west. Noble County comprises about 420 square miles. The south line of the county is approximately 14 miles north of Fort Wayne and is within the Fort Wayne metropolitan area.

The county includes 13 civil townships, corresponding in general to the townships of the United States Public Lands Survey. Albion Township is made up of secs. 13 and 24 of T. 34 N., R. 9 E., and secs. 18 and 19 of T. 34 N., R. 10 E., and contains the City of Albion, the county seat. The relative positions of the civil townships are shown in table 1, northernmost townships being at the top of the list, reading west to east from left to right.

Table 1.-Civil townships in Noble County and corresponding designations of United States Land Survey and well-numbering system

	R. 8 E.	R. 9 E.	R. 10 E.	R. 11 E.
T. 35 N.	Perry (A)	Elkhart (B)	Orange (C)	Wayne (D)
T. 34 N.	Sparta (E)	York (F) (Albion)	Jefferson (G)	Allen (H)
T. 33 N.	Washington (I)	Noble (J)	Green (K)	Swan (L)

Culture

Kendallville, located in the northeastern part of Noble County, is the largest city in the county. Population of the incorporated towns and villages for the years 1920, 1930, 1940, and 1947 is given in table 2.

Table 2.-Population in Noble County, Ind.

Incorporated city or town	1947a/	1940	1930	1920
Kendallville	6,019	5,431	5,439	5,273
Ligonier	2,178	2,178	2,064	2,037
Albion	1,300	1,234	1,108	1,142
Avilla	534	534	559	537
Cromwell	425	399	371	420
Laotto	300	---	---	---
Wolcottville total	---	612	646	666
In Noble County	---	319	308	321
County total	----	22,776	22,404	22,470

a/ Estimate by the Indiana State Chamber of Commerce.

The population data for 1947 are estimates by the Indiana State Chamber of Commerce, and the earlier data are those reported by the United States Census Bureau. On the whole, the population of the county increased very little from 1920 to 1940, the increase being only about 1½ per cent of the total population in 1920, compared with an increase of about 5 per cent for the entire State during the same period. Kendallville was the only city in the county that showed a substantial increase in population as a result of the influx of industrial workers through the later war years. This increase in population and the acquisition of industry have considerably increased the demands for ground water in Kendallville.

In 1940, York Township contained the smallest number of persons per square mile (22.6), whereas Wayne Township contained the largest number (156).

The major industrial center of the county is Kendallville, which is served by the New York Central and Pennsylvania Railroads. The industrial products of Kendallville include iron castings produced by several foundries; windmills and towers for pumps, water-supply systems, and steel tanks manufactured by the Flint and Walling Manufacturing Co.; commercial refrigerator equipment manufactured by the McCray Refrigerator Co.; and juvenile-vehicle wheels and invalid-chair wheels manufactured by the Wheel Works, Inc.

At Ligonier the principal manufacturers are the Wirk Garment Corp., manufacturers of clothing, and the Essex Wire Corp., which produces automobile wiring. Corrugated metal pipe and aluminum castings also are manufactured in the Ligonier area. Clothing is manufactured by another Wirk Garment Corp. plant at Albion, and novelty furniture is manufactured by the Albion Manufacturing Co.

The smaller towns and villages of Cromwell, Avilla, Laotto, Wolcottville, Rome City, Kimmell, Merriam, Wolf Lake, Lisbon, and Wawaka are primarily agricultural centers.

Climate

Records of precipitation and temperature have been kept at the United States Weather Bureau Station at Albion from 1917 to date. The average monthly precipitation for the period of record through 1947 is given in table 3.

Table 3.-Average monthly precipitation, in inches, at Albion, Ind., 1917 to 1947 incl.

Winter		Spring		Summer		Autumn	
December	2.02	March	2.30	June	3.51	September	3.20
January	1.80	April	2.57	July	2.71	October	2.67
February	1.23	May	3.15	August	2.90	November	2.43
Seasonal total	5.05		8.02		9.12		8.30

The average annual precipitation for the period of record is 30.49

inches, compared to an average over the entire State for the same period of 39.16 inches. Of the total average annual precipitation at Albion, 57.2 per cent occurred in the summer and autumn, and only 42.8 per cent during the winter and spring. Monthly precipitation at Albion from 1936 through 1947 is shown in figure 3.

The air temperatures recorded at Albion have ranged from 21° F. below zero on January 12, 1911, to 111° F., recorded on July 22, 1934. January is the coldest month, according to the monthly average temperatures given in table 4, and July has the highest average temperature. The average annual air temperature at Albion is 49.2° F.; the average annual temperature for the entire State is 53.1° F.

Table 4.-Average monthly temperature, in degrees
Fahrenheit, at Albion, Ind., 1917 to 1947, incl.

January	24.4	April	47.6	July	72.9	October	52.5
February	26.7	May	58.5	August	70.9	November	39.1
March	36.5	June	68.6	September	64.3	December	27.9

Drainage

Divides between the major streams draining Noble County were located by examination of aerial photographs made available by the Indiana State Highway Commission. The positions of the major drainage divides are shown on plate 1.

Most of the area is drained by the Elkhart River, which flows westward out of the county at a point $1\frac{1}{4}$ miles south of the northwest corner of Perry Township. From the west border of Noble County the river flows generally northwestward and joins the St. Joseph River at Elkhart. The area south of the divide in Washington and Noble Townships is drained by the Tippecanoe River, which flows southwestward and joins the Wabash River about 7 miles downstream from Delphi. The area south of the drainage divide in Noble and Green Townships forms the headwaters of the Eel River. The Eel River flows southwestward and joins the Wabash River at Logansport. East of the divide shown in Swan, Green, Allen, and Wayne Townships, the surface drainage is to Cedar Creek, which empties into the St. Joseph River of the Maumee Basin at Cedarville. The St. Joseph River flows southward into the Maumee River at Fort Wayne, and the combined stream ultimately flows into Lake Erie.

A small area in the north part of Wayne Township is drained by Turkey Creek. Parts of Perry and Elkhart Townships are drained by the Little Elkhart River. The flow of Turkey Creek and the Little Elkhart River empties into the St. Joseph River of the Lake Michigan drainage basin, the mouth of which is at St. Joseph, Mich., on the Lake Michigan shore. The areas of the parts of the major drainage basins within Noble County are shown in table 5.

Table 5.-Areas of Noble County, Ind.,
drained by major streams

Drainage basin	Drainage area in square miles
Elkhart River	315
Cedar Creek	60.8
Tippecanoe River	18.9
Eel River	18.0
Little Elkhart River	6.2
Turkey Creek	1.1

Topography

Generalized contours of the land surface shown on plate 1 are based on altitudes of approximately 115 United States Coast and Geodetic and Geological Survey bench marks and on altitudes determined by means of a surveying aneroid. Aneroid readings were taken on about 375 well sites and at approximately 250 locations on streams, lakes, and ditches.

The maximum local relief in Noble County is on the south slope of a hill north of Diamond Lake. The hilltop, only a quarter of a mile north of the lake, is more than 100 feet above the base of the hill. Altitudes of land surface in Noble County range from 1,047 feet above mean sea level, just south of Lisbon, to 841 feet above mean sea level where Black and Willow Creeks cross the county line at the southeast corner of the county. At the west county line, the altitude of Solomon Creek is 857 feet above mean sea level. The water surface in the Elkhart River at the west county line is about 853 feet above mean sea level.

Altitudes of the water surfaces in several large lakes in Noble County were determined by the Surface Water Branch of the United State Geological Survey as a part of a lake-level stabilization program in cooperation with the Indiana Department of Conservation, Division of Water Resources. Additional lake-level altitudes were obtained from the aneroid survey. These data are given in table 6. The altitudes given to tenths of feet are those determined by instrumental leveling.

Table 6.-Altitudes of the water surfaces in lakes,
Noble County, Ind. June 1948

Lake	Location	Altitude, in feet above mean sea level
Bixler Lake	At Kendallville	963.8
Cree Lake	4 miles N. of Kendallville	948
Crooked Lake	2 miles W. and 1½ miles S. of Merriam	905.7
Eagle Lake	2 miles S. and 3 miles W. of Wawaka	874.8
Engle Lake	2 miles S. of Ligonier	878
High Lake	2 miles SW. of Wolf Lake	905
Horseshoe Lake	1½ miles S. of Washington Center	901.9
Round Lake	½ mile NE. of Kendallville	960
Sackrider Lake	3 miles W. of Kendallville	962
Sand Lake	2½ miles E. of Burr Oak	895
Skinner Lake	3 miles E. of Albion	927.2
Smalley Lake	1 mile S. and 1 mile E. of Washington Center	882.1
Sparta Lake	½ mile W. of Kimmel	878.9
Summit Lake	2 miles NE. of Green Center	929

Table 6.-Altitudes of the water surfaces in lakes,
Noble County, Ind. June 1948 (Cont'd)

Lake	Location	Altitude, in feet above mean sea level
Sylvan Lake	At Rome City	916.3
Tamarack Lake	3½ miles E. of Wolcottville	942
Upper Long Lake	3 miles SW. of Albion	895
Waldron Lake	2 miles W. of Rome City	885

The topography of the county shows many variations. The Elkhart River flows in a flat lowland that contains many lakes. The edges of the valley of the main stream and its tributaries are marked by eroded hillsides and the bordering uplands are hummocky near the streams. The uplands between the North and South Branches of the Elkhart River are comparatively flat between Wawaka and Skinner Lake but become more hilly between Skinner Lake and Lisbon. The major parts of Wayne, Allen, Green, and Washington Townships are relatively hummocky and the remainder of the county is rather flat and level.

GEOLOGY

Introduction

The occurrence of ground water in a given area is controlled largely by the type and character of the rocks and soils. The rocks underlying Noble County may be divided into two general types: the consolidated bedrock formations of shale and sandstone, and the thick deposits of glacial drift. The bedrock formations are buried beneath a mantle of glacial drift, the thickness of which probably averages about 350 feet (2, p. 481). The quantity and quality of ground water that can be obtained from each type is quite different.

Bedrock Formations

The character of the underlying bedrock formations in Noble County is not known in detail, because few wells have been drilled through the thick glacial drift. It is known, however, that these formations are sediments of Carboniferous (Mississippian) and Devonian age, mainly shale and sandstone, that were deposited in an extensive inland sea. These deposits, in turn, are underlain by limestone, dolomite, and shale of Devonian, Silurian, and Ordovician age. (See log of well G-NoG18-1.)

Although many of these formations are water bearing in other parts of the State and provide ample supplies of potable water to many wells, it is believed that in Noble County the water in these formations is likely to be too mineralized for most uses. Ample supplies of water have generally been obtained from the glacial deposits in the county and, so far as is known, no attempt has been made to develop ground-water supplies from the bedrock formations. At the present time, they may not be considered as potential sources of potable water.

Glacial Deposits

Glacial deposits, often called glacial drift, may be divided into two general types, till and outwash. Glacial till generally is a mixture, composed primarily of clay but containing also angular fragments of rocks in varying proportions. It is unsorted and unstratified and represents material that was more or less dumped in place as the ice melted. Glacial outwash, on the other hand, is primarily sand and gravel, with small quantities of clay. This material has been sorted and stratified by water from the melting ice front, although in some deposits the sorting and stratification is poor. Lenticular beds of clay are often associated with outwash deposits.

Where the ice front remained in the same position for a considerable period of time, a ridge of till, often containing sand and gravel, was deposited, marking the position of the ice front. This type of ridge is called a moraine, and is long in comparison to its width and height.

Where the ice melted as a fairly uniform rate, the material carried within the ice was deposited as a sheet of till of more or less uniform thickness, called ground moraine. Many of the ground-moraine deposits contain thin beds of sand and gravel.

The sand and gravel washed away from the ice front was deposited in broad fan-shaped outwash plains and terraces, which may be large in areal extent. Sand and gravel filling crevasses or channels within the ice remain as eskers (long narrow ridges of sand and gravel) or as kames (generally round, steep-sided hills of small areal extent).

Thickness of glacial drift

The full thickness of the glacial drift in Noble County has been penetrated in a few wells that were drilled for gas during the 1890's.

Reported thicknesses are given in table 7.

Table 7.-Thickness of glacial drift and altitude of bedrock surface in Noble County, Ind.

Location	Thickness of drift (feet)	Altitude of rock surface (feet above mean sea level)
Ligonier	169	710±
Albion	375	551
Kendallville	475±	505±
Laotto	230	645±
Wawaka	354	538

The only available detailed record of the full thickness of the drift in the county is that given by W. B. VanGorder (Dryer 4, p. 30). He observed the drilling of well G-NoG18-1 and reported the log given in appendix B. At the location of the well the drift is composed mainly of sand and gravel. The drift in the Kendallville gas well was reported to be similar; although later drilling in Kendallville, near the same locality, revealed a thick deposit (about 350 feet) of clay in the northern part of the city.

Glacial History

The glacial history of Noble County as presented in this report is based in part on the published reports of Dryer (4,5), Leverett (11), and Malott (15); on an interpretation by F. H. Klaer, Jr., of an unpublished soils map of the county, prepared by Purdue University and the United States Department of Agriculture; on field reconnaissance by W. D. Thornbury, of Indiana University, and E. A. Brown and F. H. Klaer, Jr., of the U.S. Geological Survey; and on information obtained from the logs of about 250 wells. Many of the well records are comparatively generalized as only a few of the logs (about 15 per cent) had been written down within a few weeks of the actual drilling of the well and the remainder were recorded from memory by the driller.

Noble County was covered by several ice sheets or continental glaciers. The earliest glaciation that is known to have covered Noble County was the Illinoian ice sheet that covered about two-thirds of Indiana, reaching nearly to the Ohio River in the southwestern and southeastern parts of the State. The deposits of this ice sheet are exposed in a broad belt in southern Indiana, but in Noble County are buried by later deposits of the Wisconsin ice sheets. The Illinoian glacial stage was followed by the Sangamon interglacial stage, during which the ice front retreated northward, probably beyond the limits of Indiana. During the interglacial stage, the climate was probably somewhat similar to that of modern times and the Illinoian glacial deposits were exposed to weathering and erosion.

After the Sangamon interglacial stage, a second accumulation of ice caused ice sheets to move southward during the Wisconsin stage of glaciation. This glaciation is characterized by at least three major advances and retreats of the ice front, two of which caused important changes in Noble County.

During early Wisconsin time the ice sheet covered Indiana as far south as a line running roughly from Terre Haute on the west through Rockville, Greencastle, Columbus, Connersville, and Brookville on the east. As the ice front retreated northward it became separated into several sections or lobes, which acted more or less as individual units. The two lobes of major importance in Noble County are the Saginaw lobe, flowing southward through the basin of Saginaw Bay, and the Huron-Erie lobe, moving westward and southwestward through the present basins of Lakes Huron and Erie.

The retreat of the early Wisconsin ice front was halted temporarily and a series of moraines were formed by the several ice lobes. The extent of the Saginaw lobe at this stage is indicated by the massive Packerton moraine, extending from central Noble County southwestward to

Logansport and the Maxinkuckee moraine, extending northward from Logansport to South Bend. The position of the Huron-Erie lobe is marked by the relatively small Union City moraine on the south and probably by the Packerton moraine on the north and west. The materials of the Packerton moraine are believed to have been deposited mainly by ice of the Saginaw lobe, but deposits of the Huron-Erie ice doubtless occur along the southeastern flank. The Packerton moraine is shown on plate 2 as a massive hummocky moraine in Washington, York, and Noble Townships, extending about to Albion. The line of demarcation between the deposits of the two lobes is indeterminate, as the materials deposited by the lobes are similar.

The front of the Huron-Erie lobe apparently did not remain in the same position as long as that of the Saginaw lobe, as shown by the comparatively small Huron-Erie moraines. The retreat of the Saginaw ice front was comparatively slow and not as continuous as that of the Huron-Erie ice, as is shown by the formation of a number of recessional moraines. These moraines, the Bremen, New Paris, Topeka, Middlebury, Lagrange, and Sturgis moraines, mark temporary halts in the retreat of the ice front.

The New Paris moraine covers a large area in Washington and Sparta Townships, joining the Mississinewa moraine west of High Lake. The southern tip of the Lagrange moraine lies northwest of Ligonier in Perry and Elkhart Townships. The till deposits of these moraines are 40 to 60 feet thick and overlie sand and gravel outwash.

As the ice melted back, the sand, gravel, and clay carried in the meltwater were deposited in broad outwash plains that covered nearly all of Washington, Sparta, and Perry Townships. Most of the wells in western Noble County obtain water from sand and gravel outwash of the Saginaw ice deposited during the later phases of the early Wisconsin glaciation.

During middle Wisconsin time shifting centers of ice accumulation, probably due to climatic changes, caused the Huron-Erie lobe to advance into

Noble County, whereas the Saginaw lobe stopped north of the Indiana northern boundary. The glacial deposits of middle Widconsin age in Noble County were derived entirely from the Huron-Erie lobe. According to Flint (7, p. 250), the farthest advance of the ice is shown by the position of the Mississinewa moraine, the northern limb of which extends northeast from Wabash through the eastern half of Noble County, including the major parts of Green, Jefferson, Orange, and Wayne Townships. While the ice front was halted at the Mississinewa moraine, much of the previously deposited drift of the Saginaw lobe was removed by meltwater or covered by outwash from the Huron-Erie lobe. The thick clay deposits and glacial till of the Mississinewa moraine overlie the buried outwash of the Saginaw lobe.

The retreat of the middle Wisconsin ice front was again halted temporarily and the Salamonie moraine was deposited. Although Leverett (11, pl. 5) and Malott (15, p. 111) indicate the Salamonie moraine as covering just the southeast corner of Noble County, it is believed, on the basis of a recent soils map (16), that most of the till deposits in Swan Township and in the southern half of Allen Township are part of the Salamonie moraine.

Several thick, partly buried channels in Noble County are filled with coarse sand and gravel outwash and are important as sources of groundwater supply. One such channel is exposed east of Swan in Swan Township along the east county line. This channel, covered by till of the Salamonie moraine, curves northwestward through the northwest corner of Swan Township, where it is joined by a similar channel passing through Avilla. The channel continues westward along the valley of the South Branch of Elkhart River to Wolf Lake, where at least 122 feet of outwash was reported in well NoJ9-2. It continues northwestward from Wolf Lake to join the valley of Solomon Creek in sec. 26, Sparta Township.

A complex series of outwash-filled channels, which may be in part kame and esker deposits, occur in northern Allen, Wayne, and eastern Orange Townships (pl. 2). These channels curve gently to the northwest, one passing through Lisbon, one through Round and Long Lakes north of Kendallville, and one through the northern part of Wayne Township, joining the gravel deposits in the valley now containing the North Branch of the Elkhart River. Other buried deposits of this type are found at Albion and probably continue westward to the Solomon Creek area.

Extensive outwash deposits, laid down in Swan and Allen Townships and in the eastern half of Orange and the northern half of Jefferson Townships, are now buried by later till deposits. The buried outwash deposits are used as a source of water supply for most wells in those areas.

Water-Bearing Formations

Introduction

The occurrence of ground water in Noble County is controlled largely by the glacial geology of the county, which is shown in plate 2. The map is based mainly on field studies of the surficial materials correlated with records of wells obtained from well drillers, well owners, and others. For the purposes of correlation and comparison in this report, the water-bearing formations are discussed according to the altitudes above sea level at which they are encountered in drilling. By using an accurate topographic map showing altitudes of the land surface, the depth to which wells must be drilled to obtain an adequate water supply may be estimated for various parts of the county. The map showing generalized contours of the land surface, plate 1, can be used for estimating the depths of wells.

At the present time, topographic maps of Noble County and adjacent areas are being made by the United States Geological Survey in cooperation with the Indiana Department of Conservation, and detailed maps of the several quadrangles within the county should be available within a few years. When these maps are available they can be used with the information in this report in more detail than is possible at the present time.

Well depths and the altitudes at which the formations are screened are shown in plate 4. Unless otherwise designated by an X, the lowest altitude given is that of the bottom of the well. If followed by an X, it indicates the bottom of the formation. Most of the wells shown in plate 4 have been supplying water in sufficient quantity for farm use for at least several years. They therefore indicate water-bearing formations from which water supplies for domestic and farm use may be obtained.

Perry Township (T. 35 N., R. 8 E.)

The deposits of sand and gravel underlying Perry Township, in the northwest corner of the county, appear to be potentially the most productive water-bearing formations in the county because of their thickness, areal extent, and permeability. Deposits of sand and gravel are found at the surface throughout nearly two-thirds of the township and are continuous with the deeper water-bearing formations. Recharge from precipitation therefore reaches the deeper formations rapidly in large quantities. The Elkhart River and Solomon Creek are potential sources of recharge to the deeper formations should the water table be lowered below the stream levels by heavy pumping of large ground-water developments. These sands and gravels also act as an outlet for some of the ground water draining from the morainal materials in the eastern part of the county.

Wells drilled in the areas shown as moraines (pl. 2) penetrated blue clay before striking the water-bearing gravel. Clays in the center of the moraine northeast of Ligonier are reported to be 40 to 60 feet thick, although they become considerably thinner near the edge of the moraine. The kame and esker deposits in secs. 23 and 24, east of Ligonier, supply water to shallow wells and are continuous under the moraine lying to the north and west. The top of the water-bearing sands along the southeastern side of the moraine lies at an altitude of 910 feet. In sec. 2, gravel is found at about 900 feet above mean sea level on the western edge of the Lagrange moraine, and in secs. 14, 15, 20, and 21, on the eastern edge, gravel is first penetrated at about 870 feet above mean sea level.

Wells in secs. 4, 5, and 6 must be drilled to depths of about 90 to 120 feet to obtain a water supply as a considerable thickness of clay overlies the principal water-bearing formation in that area (see record of well NoA5-1 in Appendix A).

In the remainder of the township, water can be obtained from wells 20 to 30 feet deep. The continuation of the Topeka moraine, extending toward the northwest from sec. 29, is thin. Wells in this moraine penetrate about 40 feet of clay before striking sand and gravel.

Well records indicate that the deposits of sand and gravel in the Solomon Creek and Elkhart River Valleys are very thick. The Ligonier municipal wells were drilled through at least 130 feet of coarse sand and gravel. (See log, well NoA27-1.) Drillers penetrated about 200 feet of sand and gravel on the Virgil Bobeck farm in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, Turkey Creek Township (T. 34 N., R. 7 E.), in Kosciusko County, a mile west of the southwest corner of section 31 in Perry Township. At that site the water table was only 8 feet below land surface. Wells drilled in such formations may produce as much as several thousand gallons a minute, and may provide an adequate supply for large industries.

It is probable that these thick deposits of gravel extend some distance upstream along the Solomon Creek Valley. Similar formations probably exist downstream from the confluence of the North and South Branches of the Elkhart River.

Sparta (T. 34 N., R. 8 E.) and Washington (T. 33 N., R. 8 E.) Townships

Sparta and Washington Townships, south of Perry Township in western Noble County, are underlain by thick and continuous beds of sand and gravel. In general, thick beds of sand and gravel lie beneath the outwash plain in the northern and eastern parts of Sparta Township.

North and east of U. S. Highway 33, in the area shown as being covered with kame, esker, and morainal deposits, the few available well logs show no consistency in structure of the water-bearing gravels. It is likely that the sands supplying water to wells are lenticular, and are imbedded in a buried moraine. Wells drilled at Kimmell, less than half a mile from these deposits, have reportedly penetrated at least 80 feet of sand and gravel.

The surface of the buried outwash plain under the New Paris moraine, lying northwest of sec. 12 in Washington Township, is remarkably flat. Northwest of sec. 35 in Sparta Township, the top of the water-bearing sand and gravel is encountered at about 870 feet above mean sea level. Its altitude ranges from about 900 feet above mean sea level in the north half of sec. 36 in Sparta Township to about 860 feet above mean sea level beneath the western edge of the New Paris moraine in Washington Township. Gravel is found at about 860 feet above sea level beneath the moraine in western Washington Township.

Driven wells 20 to 30 feet deep obtain water from shallow gravel in secs. 19 and 20 in Washington Township. Most of the wells in the township are screened at about 850 feet above sea level.

Noble (T. 33 N., R. 9 E.) and Green (T. 33 N., R. 10 E.) Townships

Wells in Noble and Green Townships range greatly in depth. The deepest well now in use in the county is well K29-1, which is 327 feet deep. Beds of sand and gravel buried in the moraine covering these townships are lenticular and are not extensive over broad areas. This is especially true of the area lying south of the group of lakes north of Burr Oak along the tributary to the South Branch of the Elkhart River.

Wells drilled along the east shore of Big Lake penetrate over 200 feet of very fine sand, which often contains lenses of gravel at depths of about 90 feet. One well, however, was drilled through 231 feet of fine sand without penetrating gravel, and in another well gravel was encountered at a depth of 265 feet. (See logs of wells NoJ33-1, 2, and 3 in Appendix A.)

Wells in the western part of Noble Township obtain water from deposits of sand and gravel at altitudes of 830 to 850 feet above sea level. At Wolf Lake, water is obtained at shallow depths, many of the wells being 20 to 30 feet deep. The gravel at Wolf Lake is at least 122 feet thick.

Northwest of Merriam, the outwash deposits are thin and do not generally provide adequate water supplies. The more successful wells are about 190 feet deep, although in some wells a fine sand 50 to 60 feet below the surface is used as a source of water. Many 60-foot wells at Merriam have failed, probably because of the difficulties in screening the fine sand.

The coarse outwash deposits near the north line of Noble Township are thick. Wells drilled in that area penetrate deposits of sand and gravel which are continuous vertically from the land surface to below the water table. In the moraine north of this area wells encounter sand and gravel 860 to 870 feet above sea level.

In the center of sec. 3, Green Township, the surface of the sand and gravel deposit rises abruptly, attaining an altitude of 941 feet above sea level (NoK2-2) in the northwest corner of sec. 2. However, the upper part of the gravel is dry because the water levels in that area are about 910 feet above sea level. Wells in secs. 11, 12, 13, and 14, in Green Township, are drilled to about 840 feet above mean sea level, and are 100 to 140 feet deep. At Green Center, wells generally are less than 100 feet deep and tap small lenses of sand buried in glacial till. Wells in the southeastern quarter of the township generally strike a satisfactory water-bearing material between 860 and 870 feet above mean sea level.

York Township (T. 34 N., R. 9 E.)

In the northeast quarter of York Township water-bearing gravel is encountered at about 870 feet above sea level. Wells range in depth from

40 to 120 feet because of differences in surface altitude. In the low ground in the northwest quarter of the township, wells less than 25 feet deep will provide sufficient water for farm use. However, in the vicinity of Eagle and Diamond Lakes the surface material is marl or clayey sand and there are no shallow aquifers.

It appears probable that the sand beneath the till in York Township was deposited by a stream of meltwater flowing westward from a point east of Albion. The surface of the outwash forms a hill, its crest being along a line extending westward through Albion. The plain slopes toward the south, its surface being 870 feet above sea level in the northwest corner of sec. 36. South of this location, along the South Branch of the Elkhart River, the outwash plain drops to an altitude of about 800 feet above sea level. In the area south and west of Albion, wells from 40 to 70 feet deep generally penetrate water-bearing formations that provide an adequate supply for all farm and domestic purposes.

The sand and gravel at Albion is coarse and thick. The municipal wells (NoF24-1-1 and 2) yielded 1,000 gallons a minute with a drawdown of only 13 feet in 1926. Data on the present operation of the wells are not available, but there seems to have been little, if any, reduction in capacity of the wells since 1926.

Jefferson Township (T. 34 N., R. 10 E.)

In general the beds of gravel supplying water to wells in Jefferson Township are encountered at about 900 feet above sea level, particularly in the north half of the township. However, discontinuities in the formation appear at Skinner Lake in sec. 16, in sec. 18 east of Albion, and between wells G21-1 and G16-1. Gravel was reported below 906 feet in well G18-1, whereas in well G18-2 gravel was first penetrated at about 842 feet above sea level. Wells along the south line of sec. 16 encounter gravel 860 feet above sea level.

No gravel was reported in well G13-1 above an altitude of 760 feet. Thick clayey till is reported in wells east and southeast of sec. 13. Wells in the remainder of the township are generally less than 100 feet deep. Data collected during the investigation indicate that the deposits of gravel probably are not continuous horizontally in the south half of the township.

Elkhart (T. 35 N., R. 9 E.) and Orange (T. 35 N., R. 10 E.) Townships

The formations in Elkhart and Orange Townships are very favorable for supplying water in moderate quantity. In most of the area, water can be obtained either from shallow driven wells 40 to 50 feet deep, in which the water table is near the land surface, or from flowing wells 100 to 135 feet deep in the lowlands of the Elkhart River and its tributary streams. At some places near Rome City, shallow wells drilled near the base of kame and esker or moraine deposits may flow. Thin extensive beds of hardpan or clay partly confine vertical movement of ground water in that region. Consequently, pressures nearly equal to the static water level on the uplands may exist beneath the layers of hardpan or clay. Shallow flowing wells can be obtained in the lowlands where hardpan layers extend horizontally under the uplands. The most pronounced example of this type of structure is found at the Kneipp Sanitarium north of Rome City, where several shallow wells (which are locally called springs) flow perenially under the influence of the pressures transmitted from the uplands lying north of the sanitarium.

The moraine near Wolcottville, north of Sylvan Lake, is composed primarily of clay. However, water-bearing gravel is found at shallow depths (25 to 50 feet). Wells in the outwash, kame and esker, and patchy moraines in the northeastern part of Orange Township are shallow, and are drilled through alternate lenses of clay and sandy gravel. The deposits around Sylvan Lake are primarily sand and gravel, which yield large quantities of water to small wells.

Wells drilled through the moraine on the upland area east of Wawaka and south of Sylvan Lake encounter water-bearing gravel 890 to 900 feet above mean sea level. At Wawaka domestic water supplies are obtained from wells less than 35 feet deep. Another gravel at Wawaka, frequently used as a source of supply, is found at depths of 90 to 100 feet. Wells drilled into the deeper formation (such as well GNoB29-1) in the depression occupied by Huston Ditch, flow above land surface.

Shallow driven wells 15 to 25 feet deep are in general use on the outwash terraces in Elkhart Township. Beds of water-bearing gravel are found 900 feet above mean sea level in secs. 5, 6, and 7, under the Lagrange moraine. The kame and esker deposits lying along a line through secs. 3 and 18 provide water to wells less than 35 feet deep. Wells on Diamond Hill in sec. 31, drilled through the heterogeneous kame and esker material, range considerably in depth.

An extensive permeable artesian formation is found in the central and northeastern parts of Elkhart Township and the western part of Orange Township. The buried outwash deposit crops out south and west of Rome City and slopes westward. Its surface lies 823 feet above sea level in well C18-1, 780 feet above sea level in wells B15-1, B15-2, and B10-1, and about 800 feet above sea level in wells B11-2, B14-1, and B27-1. Wells B4-1 and B11-1 were driven into gravel at 844 feet above sea level. The top of the outwash was lowest, 756 feet above sea level, at well B30-1.

The area of outcrop of the formation is large and constitutes an intake area for recharge to the buried gravels. It is probable that 2 to 3 million gallons of water a day could be taken from the artesian formation perennially. Should the withdrawal be increased to that amount it is likely that many wells in the area would cease flowing.

Wayne Township (T. 35 N., R. 11 E.)

The glacial features of Wayne Township are principally moraine deposits of boulder clay and associated deposits of unstratified coarse sand and gravel that may be, in part, kame and eskers or coarse outwash deposits close to the ice front. The coarse sand and gravel deposits lie along definite lines that trend westward at the east county line, curve northward, and cross the North Branch of Elkhart River at right angles. Along these channels the sand and gravel deposits are thick, as shown by the fact that 71 feet of sand and gravel was penetrated in well D11-1. Water-bearing sand and gravel is found at moderate depths except where the land is high.

Wells in the township are generally less than 100 feet deep and the screens are set at various elevations. North of Kendallville the deposits of sand and gravel are apparently discontinuous lenses. In sec. 12 and near the NE corner sec. 10, wells obtain water from a gravel lens that may extend northward and eastward at an altitude of about 900 feet above sea level. In and near the N$\frac{1}{2}$ sec. 19, coarse water-bearing gravel is found 870 above sea level. Wells D27-2, D26-1, and D36-1 were drilled through clay to depths considerably below the level at which water-bearing materials are found in surrounding areas.

At Kendallville, coarse outwash material was deposited by meltwater from the glacial ice in a narrow band along a north-south line. This deposit is shown on plate 2. The area is apparently underlain at shallow depths by thick beds of sand and gravel. In Kendallville, in the NW$\frac{1}{4}$ sec. 4, Allen Township, these materials supply water to many domestic wells. The Kendallville municipal wells also pump water from this deposit. Most of the remaining area of the town is covered with clay that contains few lenses of sand or gravel capable of supplying large quantities of water. Experience of well owners in the city indicates that the most permeable water-bearing formations are generally found less than 75 feet below land surface. It is believed that the area deserving most attention in future exploratory programs for large ground-water developments in the Kendallville area is the E½ sec. 33, Wayne Township, and the NW¼ sec. 4, Allen Township.

Allen Township (T. 34 N., R. 11 E.)

Allen Township is underlain by buried outwash deposits at depths of about 70 to 130 feet below land surface. However, at those depths the outwash is very thin or missing in some places. Wells are 200 feet or more deep in the NW¼ sec. 4, near the SW corner of sec. 12, and in sec. 18.

A chain of partly buried outwash deposits passing south of Sackrider Lake continues through sec. 6 and the north part of sec. 9. Well records indicate that the outwash deposits may continue for a short distance southeastward from Lisbon, parallel with State Road 3 (see record of well H15-1 in appendix A). At well H6-1, the top of the outwash deposit is reported to be 951 feet above sea level. The gravel crops out in the N½ sec. 9, at an altitude of about 1,000 feet above sea level. Gravel 70 feet thick is found below an altitude of 995 feet above sea level in well H9-1. Outwash deposits sloping away from the crest of the moraine have been penetrated in neighboring wells. At wells H7-2 and H8-1 gravel is found about 930 feet above sea level. The water-bearing materials occur somewhat above an altitude of 920 feet in well H16-1 and slope toward the southwest to an altitude of about 880 feet above sea level in wells H28-2 and H30-1.

Wells in the eastern half of the township are screened in formations lying between 870 and 930 feet above sea level, most of the screens, especially in the southeast quarter of the township, being set at the 870-foot level.

The Avilla municipal wells are probably at the east edge of an eskerlike mound lying along an east-west line through Avilla. The top of this buried mound of gravel is 960 feet above sea level in the SW corner sec. 28, and is 905 feet above sea level in the NW corner sec. 34. It may be part of a buried chain of eskers that crops out in sec. 3, Green Township, and continues buried under till through the NW corner sec. 2, through sec. 36, Jefferson Township, and along the north line sec. 31 in Allen Township.

Wells drilled along the south line of Allen Township are screened from 880 to 890 feet above sea level. Thick beds of sand and gravel are reported to lie along the south line of sec. 34. Along the east line of sec. 36, in the lowlands, wells are drilled to an altitude of 825 feet above sea level to obtain a satisfactory supply of water, although shallow wells, 15 to 25 feet deep, obtain water from beds of sand at altitudes of 880 to 890 feet.

Swan Township (T. 33 N., R. 11 E.)

Swan Township is crossed by a chain of outwash channels extending from sec. 13 through sec. 16 and curving northwestward to sec. 6. Extensive outwash was deposited north and south of the channel. In the southeastern part of the county beds of water-bearing sands or gravel are usually found 820 to 830 feet above sea level. However, at several places along the south line of the township, the sand has proved unsatisfactory for farm and domestic water supplies and many wells have been drilled deeper to a formation about 790 feet above sea level.

In and near the SE¼ sec. 19, and within a half-mile radius of the

SE corner sec. 6, wells are drilled to an altitude of about 835 feet above sea level before striking water-bearing materials. In the remainder of the northwest corner of the township, water-bearing sand is found at an altitude of 880 to 890 feet above sea level. The buried surface of the outwash slopes east and south from the northwest part of the township to the lower altitudes along the south and east lines mentioned above.

HYDROLOGY

Introduction

The water falling on the earth's surface as precipitation is dispersed in several different ways. Some of it runs off directly over the land surface to the surface streams; another part percolates downward through the soils and is stored, more or less temporarily, in the small openings in the underlying materials; some of this water is retained in the soil, later to be removed by evaporation and plant use, or transpiration.

The formations underlying the earth's surface generally contain small openings of various sizes and shapes. The characteristics of the openings depend mainly on the type of material in the formation and the manner in which it was formed or deposited. In fragmental materials, such as sand, gravel, and clay, small openings between individual fragments of material are more or less evenly distributed throughout the rocks and in some places occur in a definite pattern or in definite zones. The openings are interconnected so that water can move slowly through the materials, except where the openings are so small that water is held in them by molecular forces.

The ability of a formation to act as a reservoir is a function of its <u>porosity</u> or the ratio of the volume of open space to its total volume. However, the ability of a formation to yield water is somewhat smaller than its porosity and is measured by its <u>specific yield</u> or <u>coefficient of storage</u>. Not all the water in storage is released by a lowering of the water table or artesian head, as part is retained in the smaller openings by capillarity, which counteracts the force of gravity. The <u>specific yield</u> of a formation is defined as the ratio of the volume of water that will drain by gravity from a given volume of material to the total volume, and is often expressed as a percentage.

In an artesian formation, in which the hydrostatic pressure causes water levels in wells to rise above the top of the formation, the quantity of water that can be released from storage as the artesian pressure declines is indicated by its coefficient of storage. This is defined as the quantity of water, in cubic feet, that is released from each vertical prism of the formation having a base 1 square foot in cross-sectional area when the hydrostatic or artesian pressure is lowered 1 foot. The specific yield of a bed of gravel under water-table conditions is many times greater than its coefficient of storage.

The ability of a formation to transmit water or to allow water to pass through it is measured by its coefficient of permeability. Little water can pass through fine-grained materials, such as clay, under the normal hydraulic gradients found in nature because of the high friction loss caused by the very small openings between the particles of clay. Formations composed of sand and gravel which ordinarily have relatively large openings, are much more permeable than clay and will permit greater quantities of water to pass through them under similar hydraulic gradients. The coefficient of permeability, as used in most ground-water studies, is expressed as the quantity of water, in gallons a day, that will pass through a cross-sectional area of 1 square foot of material under a hydraulic gradient of 1 foot per foot at a temperature of 60° F.

Most aquifers are heterogeneous and the permeability unit is therefore inadequate to describe the water-bearing capacity of the formation as a whole. The coefficient of transmissibility, which is approximately equal to the product of the average permeability and thickness of the aquifer, serves this purpose. The coefficient of transmissibility usually is expressed as the number of gallons a day that will pass through a 1-foot width of the aquifer under a hydraulic gradient of 1 foot per foot, and is generally determined by pumping tests.

Water Table and Piezometric Surface

The water that seeps into the ground tends to percolate downward through openings in the soil and rocks, including interstices between individual fragments of rock and cracks and fissures in hard rocks, to reach the zone of saturation, in which the rock openings are filled with water. The upper surface of the zone of saturation, except where formed by an impermeable body, is the water table, and its position is shown in a general way by the water levels in wells.

In areas where porous and permeable formations are present at the surface and water from percipitation can reach the zone of saturation by direct downward percolation, water is said to occur under water-table conditions. Where, however, the water-bearing formations are overlain by relatively impermeable formations and the water in the aquifers is confined under hydrostatic pressure, artesian conditions exist, and the water levels in wells will rise above the bottom of the confining layer. Under artesian conditions, the water levels in wells tapping the confined aquifers will show the position of the pressure-indicating or piezometric surface.

The water table and piezometric surface in Noble County are generally less than 40 feet below the land surface. The shape of the piezometric surface is similar to the topography of the land surface, although the depth to water on hills is generally greater than in the lowland areas.

Altitudes of the water surface in wells are shown on plate 5. The contours of the water table and piezometric surface for the principal water-bearing outwash deposits of the county are shown where possible. Although the thick till deposits in the northeastern part of the county contain numerous lenses of sand and gravel of relatively small areal extent that yield water to wells, the deposits of sand and gravel do not act as a unit but contain water under a wide range of hydrostatic pressures. It is therefore impracticable to show contours of the water table and piezometric surface in most of the area covered by thick till deposits.

The piezometric surface in the deeper formations slopes gently westward from the eastern and southeastern parts of the county at a fairly constant rate of about 2 feet to the mile from an elevation of about 930 feet above sea level along the limits of the Elkhart River drainage basin to an elevation of about 880 feet in the Solomon Creek Valley. East of sec. 26, Perry Township, the clays that confine the water under artesian pressure have been cut away by later glacial drainage through the Elkhart and Solomon Creek Valleys. Thick deposits of sand and gravel outwash have filled these glacial sluiceways and now serve as conduits for the transmission of water escaping from the artesian zones.

A large area in which flowing wells may be obtained extends along the valley of the North Branch of the Elkhart River from a point several miles upstream from Ligonier to Rome City. The approximate limits of this area are shown on plate 5. The formations that supply water to the flowing wells are at an altitude of about 800 feet above mean sea level in Perry, Elkhart, Orange, and York Townships. It is believed that the artesian head is maintained largely by recharge to the formations in the higher morainal land north, east, and south of the area.

Water-level altitudes in wells in the eastern part of the county indicate that water is continually entering the deep beds of sand and gravel at altitudes of about 830 to 880 feet by slow percolation downward through the overlying clayey till. It is evident that some water is reaching the flowing-well area from the higher moraines to the east.

In southwest Sparta and Washington Townships, a combination of shallow relief, high permeability, and efficient surface drainage allows ground water to discharge naturally into the streams.

Some wells may flow because of local physiographic and geologic conditions of small areal extent. Such flowing wells are common in Orange Township along the valley of the North Branch of the Elkhart River west and north of Rome City. Many flowing wells obtain water at shallow depths at the Kneipp Sanitarium north of Rome City. Well NoC20-1-2, south of Rome City, also flows because of local conditions. The head causing well NoJ1-1, in Noble Township, to flow is produced by local conditions extending to the higher land in sec. 6 of Green Township.

In the lowland along the Elkhart River, many marshy areas indicate a very shallow water table throughout a large part of the year. The water in the shallow formations apparently drains naturally into the surface streams, particularly where the surface streams have cut channels considerably below the general lowland level.

Fluctuations of Water Levels

Many people have been alarmed for a number of years by the reports of a continued decline of the water table. In areas where large quantities of water are removed from the ground, a decline has occurred. In a few of these areas, the decline in the water table may be classified as a serious problem requiring solution. In Noble County there has been no serious general decline in the water table. Measurements of depth to water have been made in four observation wells in the county for nearly 10 years prior to the present investigation and have been continued where possible. Graphs of the data are shown on figure 3.

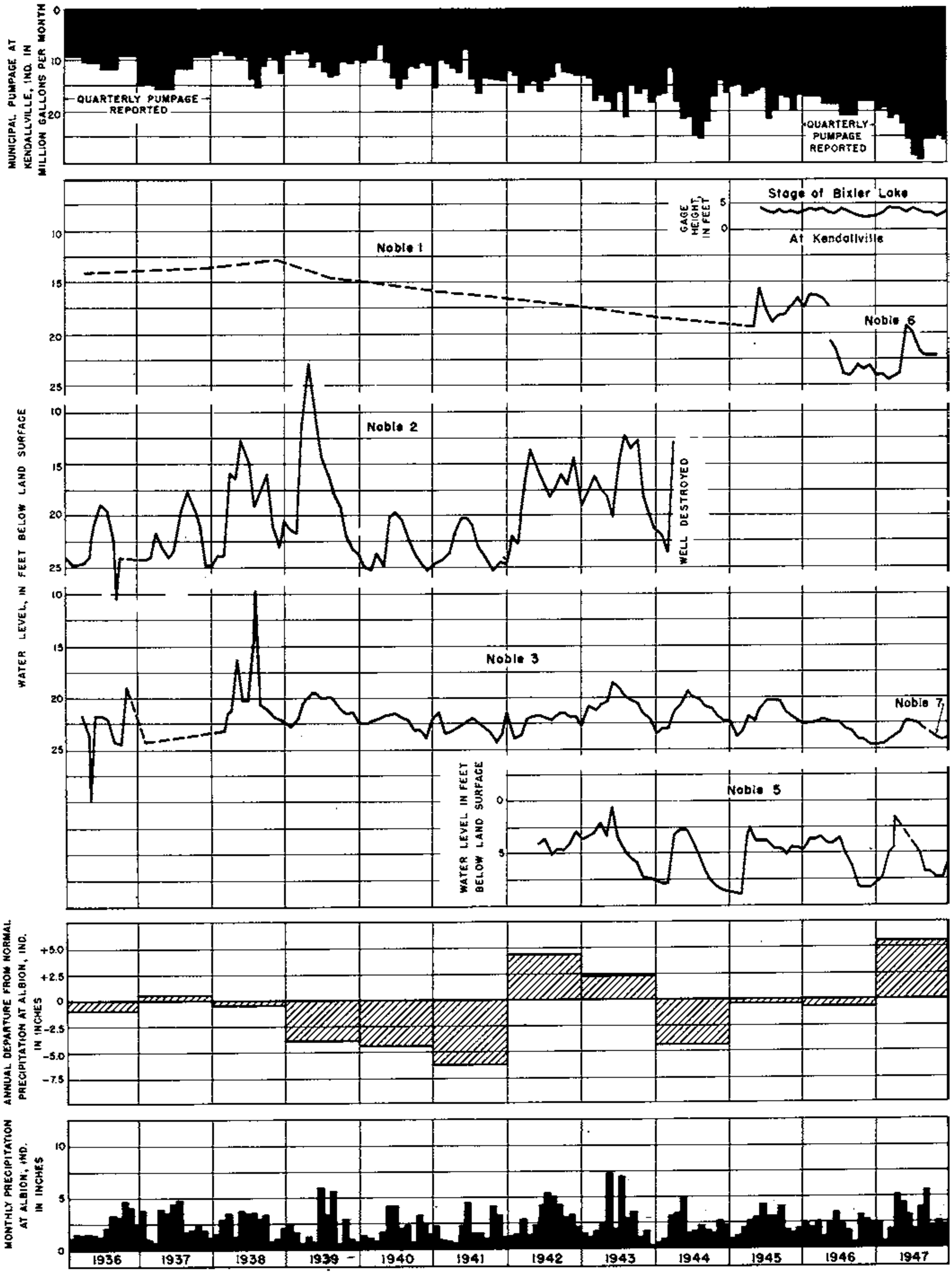

Figure 3. Graphs of water levels in observation wells in Noble County; water levels in Bixler Lake; municipal pumpage at Kendallville; and monthly precipitation and annual departure from normal precipitation at Albion, Indiana.

Water levels in wells Noble 1 and 6 (NoD33-1-21 and 23) are affected considerably by pumping in the Kendallville municipal well field. Wells Noble 2 and 5 (NoJ35-1 and ONoG13-1 were dug in clayey till. Well Noble 3 (ONoJ23-1) penetrates a thick bed of sand and gravel.

Water levels in the Kendallville municipal well field have declined about 7 feet since 1936 because of increased pumping. In the remaining observation wells in the county the net change in water levels is insignificant for the period covered by the measurements. Wells near ditches may have been affected by dredging, but there seems to be no noticeable widespread effect on water levels from these operations.

Leverett (10,11) in his work on the glacial geology of Indiana, obtained measurements of the water levels in several wells in the county. He reported altitudes of 930 feet at Rome City and 895 feet at Wawaka (in about 1910). In well NoC16-1, at Rome City, the altitude of the water level in the fall of 1946 was reported to be about 934 feet; in well NoB28-1, at Wawaka, it was 896 feet. From these figures it seems unlikely that the reports of a generally declining water table are founded on fact.

Water levels in the county seem to be affected more by the distribution of rainfall and other climatic conditions through a 1-year period than through a period of several years. For example, from 1937 to 1941 precipitation was much below normal each year, increasingly so as time progressed. However, during that same period, little decline in water levels was recorded. Similarly, excessive precipitation did not cause the water table to be maintained at a high level. Reasons for the lack of close correlation of water level trends with precipitation are found in a study of the precipitation data. In table 8, average monthly precipitation at Albion is shown by 5-year periods from 1937 to 1947, inclusive, together with the average monthly precipitation for the entire period of record.

Table 8.-Average monthly precipitation, in inches, at Albion, Ind.

Period	Jan.	Feb.	Mar.	Apr.	May	June	July
1937-1941	2.26	1.51	1.33	1.82	3.00	4.61	3.07
1942-1946	1.36	1.34	2.48	2.11	4.05	3.49	3.86
1917-1947	1.80	1.23	2.30	2.57	3.15	3.51	2.71

Period	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1937-1941	2.78	1.37	2.63	1.84	1.32	27.54
1942-1946	2.94	2.74	2.28	2.35	1.69	30.69
1917-1947	2.90	3.20	2.67	2.43	2.02	30.48

The period covered by the hydrographs is divided into two sections for comparison. The first, from 1937 to 1941, is marked by deficient precipitation, and the second, from 1942 to 1946, by slightly above-normal precipitation. The hydrographs show that the most favorable conditions for recharge exist in March, a month of moderate weather during which plants absorb little water from the ground. In table 8 it is noted that during the months of March and April in the years of drought precipitation was considerably below normal. However, during the growing season the precipitation was generally about equal to or much greater than normal, the months of greater precipitation being May, June, and July. Thus, little or no excessive demand for water from the zone of saturation was created during the years of drought, and water levels were not affected adversely, even though precipitation was deficient during the months favorable for recharge.

Recharge to the Ground-Water Reservoirs

The ground-water reservoirs are continually being recharged by water derived from precipitation and are depleted by drainage to nearby streams and by the use of water by vegetation. The natural drainage into surface streams is a measure of the rate of recharge into the water-bearing formations and, therefore, is an approximate measure of the quantity of water that could be salvaged perennially by properly located wells. During periods of no rainfall the flow of streams is maintained by the natural discharge or rejected recharge from the ground-water reservoirs. This natural discharge of ground water is called the base flow of a stream.

Computations of the base flow of the Elkhart River at Goshen were made by L. W. Furness, of the Surface Water Branch, United States Geological Survey, Indianapolis. The area drained by the Elkhart River upstream from Goshen includes about 315 square miles in Noble County (pl. 1), about 65 square miles in south-central Lagrange County, about 120 square miles in southeastern Elkhart County, and about 75 square miles in northeastern Kosciusko County, constituting a total area of 573 square miles. The average annual base flow at Goshen for the period 1940 through 1944 was 7.54 inches per year, equal to about 24 per cent of the total rainfall. This is equivalent to an average ground-water discharge of about 360,000 gallons per day per square mile.

The extensive marshy lands along the Elkhart River and its tributaries in Noble County provide conditions that are favorable for high evaporation and transpiration losses, and at least part of the ground-water discharge is lost by evapo-transpiration before reaching the stream. It is believed, therefore, that the average recharge in the Elkhart Basin above Goshen is at least 360,000 gallons a day per square mile or about 150 million gallons a day within Noble County.

GROUND-WATER CONDITIONS IN SPECIFIC AREAS

Introduction

Most of the wells in Noble County drilled for domestic water supply are tubular wells, 2 inches in diameter, which are generally constructed by jetting and driving a 2-inch casing to a water-bearing formation and inserting a suitable screen in the bottom of the well. In the shallow beds of gravel 1¼-inch wells are often constructed. A few 2½-, 3-, and 4-inch wells have been drilled where larger quantities of water are needed for supplying farm animals or for operating mint stills.

Use of Ground Water in Rural Areas

It is estimated that about 5,000 domestic and farm wells were in use in the county during 1948 of which about 2,500 wells were equipped with electric pumps. Domestic and farm use of water increases materially with the introduction of electrical pumping equipment because of the ease with which water can be obtained.

In the areas where flowing wells can be drilled there is a distinct tendency to waste water. Many of the flowing wells in the western part of the county produce as much as 30 to 60 gallons a minute and are allowed to flow continuously. Continuous discharge at 30 gallons a minute for 1 year, amounts to nearly 16 million gallons. If a well flowing at this rate supplies a herd of 40 head of cattle with as much as 10 gallons a day per head, the annual use of the herd is only 145,000 gallons, and more than 99 per cent of the flow from the well is wasted. Such a waste decreases the hydrostatic pressure in a flowing-well area and thereby reduces the area in which wells will flow.

It is estimated that the total annual pumpage of ground water in

Noble County, other than for municipal use, is about 1,000 million gallons. Of this amount about 250 million gallons is discharged annually from a comparatively small number of flowing wells in the northwestern part of the county.

Municipal-Supply Wells

Municipal-supply wells in the county are from 50 to 138 feet deep. The deepest municipal well is at Albion and the shallow wells are at Kendallville. Average daily municipal pumpage from 1915 through 1947 is shown in figure 4. The total of the municipal and industrial pumpage in the county was about 510 million gallons in 1947.

There has been small increase in the use of ground water at Albion, Ligonier, and Avilla, although their populations have not increased materially since 1920. At Kendallville the municipal pumpage has increased from an average of about 9.2 million gallons a month in 1917 to 20.4 million gallons a month in 1947.

Kendallville

History

The first well used as a source of water supply at Kendallville was a dug well of large diameter, located at the present site of the municipal power plant on East Diamond Street. It was constructed in 1887 primarily to supply water for fire protection. The public-supply system was rapidly expanded, and in 1892 a second well, 30 feet deep and 30 feet in diameter, was dug near the first. The dug wells were abandoned shortly after 1892 in favor of tubular wells.

According to fragmentary reports in the records of the city council the first tubular wells in the municipal well field probably were drilled in 1894. The locations of municipally and industrially owned tubular wells are

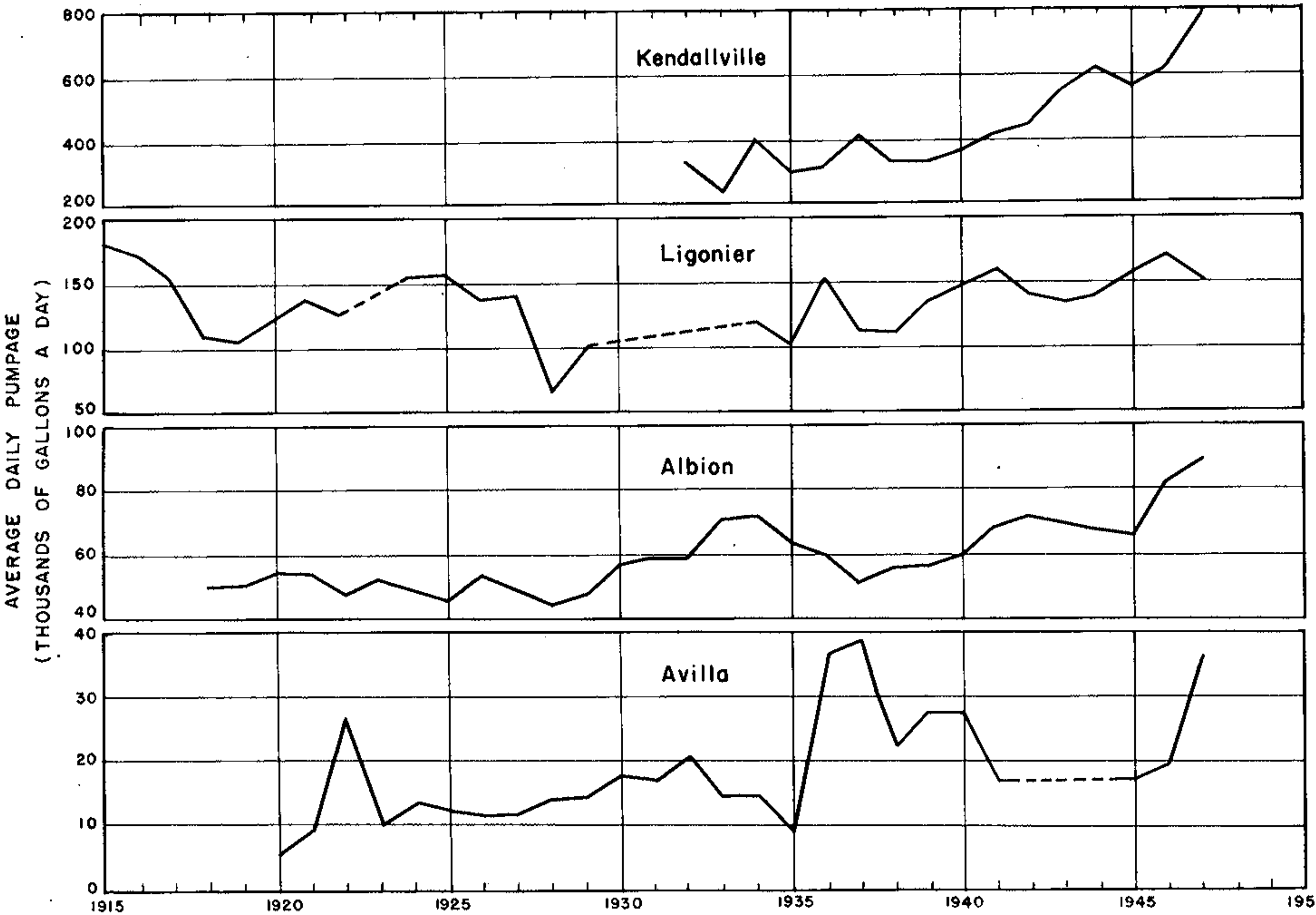

FIGURE 4. GRAPHS OF MUNICIPAL PUMPAGE OF GROUND WATER IN NOBLE COUNTY, INDIANA,

shown in figures 5 and 6. Six-inch wells from 35 to 62 feet deep were drilled along the west shore of Bixler Lake, north of the east end of Diamond Street. The wells were connected to a common header and pumped by suction. Additional 6-inch wells were added to the suction system as the demand for water increased and the older wells became inefficient. The last group of suction wells was drilled in 1927. A total of 27 wells were drilled, but a maximum of only 20 were operating in 1927, the older wells having been abandoned prior to that time. The maximum yield of the suction field, probably in 1927, was reported to be 700 gallons a minute. Incrustation of screens decreased the yield gradually. By 1946 the yield had declined to 180 gallons a minute. The wells were cleaned in May 1946, and the yield was thereby increased, but only for a short time.

The South well, NoH4-4, was drilled in 1928. Originally it was 99 feet deep and yielded 285 gallons a minute when pumped continuously. In 1933, after the yield had declined considerably, it was deepened to 105 feet and equipped with a screen 25 feet long and 12 inches in diameter. In 1946 this well yielded 125 gallons a minute under continuous operation.

The Park well, NoD33-1-31, was constructed in December 1940 to a depth of 113 feet to provide additional supply. The diameter of the outside casing is 38 inches and the well is equipped with a 10-foot length of 10-inch-diameter screen. This well originally produced 250 gallons a minute and now yields only about 180 gallons a minute under continuous operation.

A water shortage was foreseen for the summer of 1947, and three test wells were drilled north of the suction field in October 1946 for the purpose of locating sand and gravel that might supply additional water. City wells 3 and 5 (NoD33-1-38 and NoD33-1-39) were drilled by the Layne-Northern Co., Mishawaka, Ind., at the location of two of the test wells.

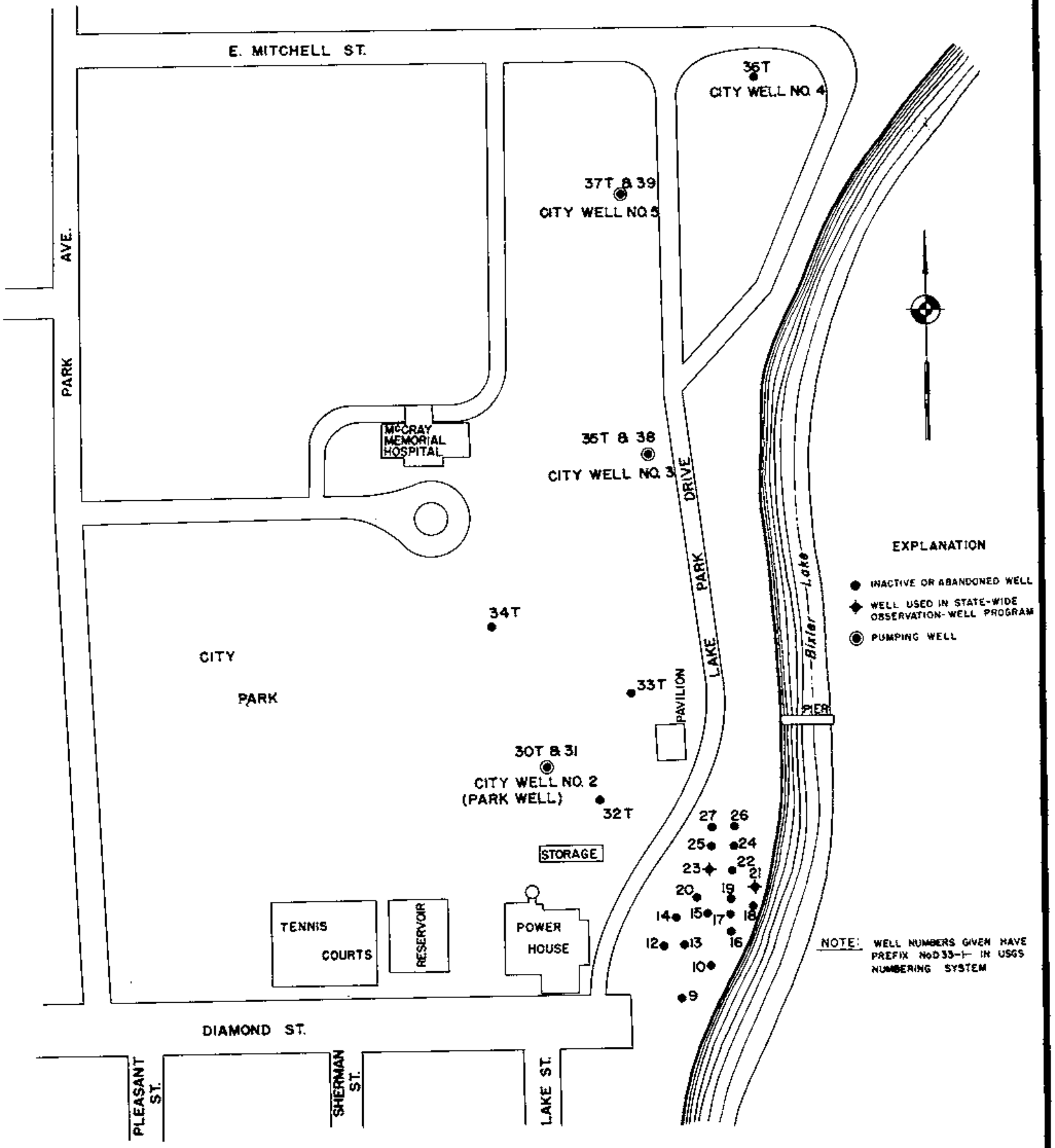

FIGURE 5.
MAP OF
CITY PARK, KENDALLVILLE, INDIANA
SHOWING
LOCATIONS OF MUNICIPAL WELLS

0 100 200 300 FEET
SCALE

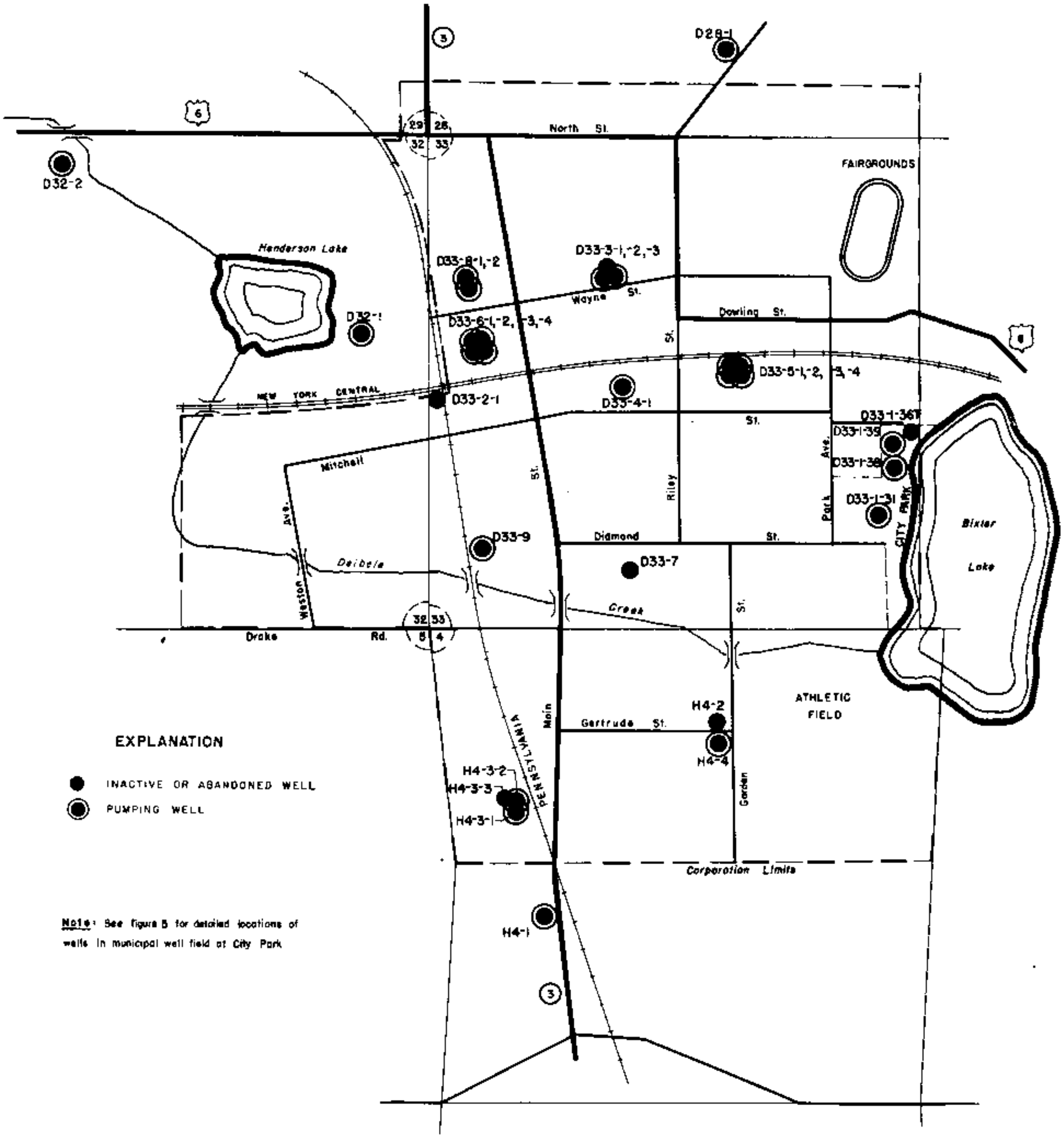

FIGURE 6.

MAP OF KENDALLVILLE, INDIANA

SHOWING LOCATIONS OF WELLS

0 1,000 2,000 3,000 4,000 5,000 Feet

SCALE

City well 3 and 5 are about 60 feet deep and are equipped with 15 feet of 30-inch-diameter screen. These were completed in January and February of 1947. In initial tests on February 3, 1947 well 3 produced 800 gallons a minute with a drawdown of 9.8 feet after pumping for 2.5 hours. Well 5 produced 800 gallons a minute for 2 hours with a drawdown of 16.25 feet on March 8, 1947.

Well 3 was operated at nearly full capacity for about 1 year. The yield declined steadily during that period because of incrustation of the well screen and formation, and the well required rehabilitation in the spring of 1948. It is believed that the high rate of incrustation was due in large part to the excessive rate of pumping from this well. Cleaning the well with acid treatment increased the yield to almost the original capacity. In 1947 after it became apparent that the new wells would supply the city with an adequate quantity of water, the suction wells were used for standby service only.

Water is pumped from the wells along the shore of Bixler Lake to an underground concrete storage reservoir which has a capacity of 584,000 gallons. The water is chlorinated and is pumped from storage to the mains through high-service pumps. Water from the South well is pumped directly into the mains without treatment.

Pumpage

The demand on the municipal ground-water supply in Kendallville increased from about 120 million gallons a year in 1936 to 288 million gallons a year in 1947, a net increase of 140 per cent. In the smaller communities the increase in demand through the same period was only 20 to 25 per cent. This great difference in trend is attributed to the influx of industry to Kendallville, which has required increasingly larger quantities of water from the municipal source. Both the expansion of industry and declines in the yields of industrially owned wells have been cited as causes of the increasing dependence on the municipal supply.

The quantity of ground water pumped in 1947 by industries in Kendallville, estimated from information supplied by the plant operators, is shown in table 9. Industrial pumpage in that year was about 39 per cent of the municipal pumpage, and probably was somewhat higher during the preceding war period.

Table 9.-Pumpage by industries,
Kendallville, Ind., 1947

Type of industry	Annual pumpage, in million gallons a year
Processing dairy products	47.0
Manufacture of metal products	44.0
Manufacture of ice	24.7
Total	115.7

Water Levels

Measurements of water level have been made in several wells in Kendallville during the present investigation. In the deep wells, water levels rise to approximately 930 feet above mean sea level, and in the shallow wells, less than 70 feet deep, they rise to about 955 feet above mean sea level, except in the area affected by pumping. In the municipal shallow suction well field, occasional measurements were made in well 21 (NoD33-1-21) during 1935, 1936, and 1937. The water level during this period was about 13½ feet below the land surface (see fig. 3). During 1945 and 1946 the water level ranged from 14.6 to 19.4 feet below the land surface, and averaged about 17 feet. It was reported that in 1926 the water level in the wells of the suction field was at an altitude of about 952 feet. In 1935 they were at about the same altitude and during 1945 and

1946 were about 4 feet lower. This lowering in water level has probably been caused largely by the increased pumping in the area. It has also been reported that the water level in the area of the municipal well field has dropped 14 feet since 1890.

In the South well (NoH4-4) the "static" water level has apparently declined about 10 feet during the period June 1928 to May 1946. A comparison with the original static level is somewhat inconclusive as the South well is not allowed to recover from pumping long enough for a true "static" water-level measurement to be made.

In general, the decline in ground-water levels in the Kendallville area has apparently been relatively small and has not been serious. At the municipal well field, the decline is the natural result of increased pumping from the water-bearing formations.

Pumping Tests

Pumping tests are conducted by changing the discharge of one or more wells and observing the effect on water levels in nearby idle wells. The purpose of a pumping test is to determine the coefficients of transmissibility and storage, or the hydraulic characteristics of the water-bearing formation, that are used in estimating the perennial yield of a well field, predicting interference effects between wells, and comparing the water-bearing qualities of different aquifers.

When a well is pumped, water moves from the surrounding area through the formation to the well screen. Flow through the interstices in the formation creates a hydraulic gradient toward the well, forming an inverted conelike depression in the water table near the pumping well. Water levels continue to decline in the vicinity of a well until recharge to the area exceeds or equals the discharge of the well. The amount of decline of the water level at any point on the cone of depression is called the <u>drawdown</u> at that point.

The coefficient of transmissibility can be determined from measurements of the decline of water levels caused by the pumping well. It is a measure of the ability of the formation to transmit water, approximately equals the product of the average permeability and thickness of the formation, and is generally expressed as the number of gallons a day that will pass through a vertical section of the formation 1 foot in width under a hydraulic gradient of 1 foot per foot.

The relationship among discharge of the pumping well, drawdown at any point on the cone of depression, distance from the pumping well to the point of the drawdown observation, time of pumping, and hydraulic characteristics of the formation is expressed mathematically by the Theis nonequilibrium formula (18). Several simplifying assumptions were made regarding the physical shape and hydraulic properties of the formation in development of the formula. It was assumed that: (1) the formation is of infinite areal extent and uniform thickness; (2) no recharge is added to the formation during the pumping period (i.e., all water pumped is removed from storage); (3) the formation is homogeneous and isotropic (transmits water with equal facility in all directions); (4) water is released from storage instantaneously with a lowering in hydrostatic pressure; and (5) water enters the well throughout the full thickness of the formation.

The Theis nonequilibrium formula is the most convenient tool available for analyzing pumping-test data. Hydraulic characteristics of formations can be determined from test periods of short duration, whereas long test periods are required to obtain data necessary for analysis by means of the steady-state or equilibrium formulas. In applying the flow formulas to ground-water hydraulics, the basic assumptions made in the development of the formulas must be kept in mind. Stringent specifications for the ideal formation are set by the basic assumptions made in development of the Theis formula. The formula can be used only for general comparison studies where the natural water-bearing formations are nonisotropic.

The Theis formula is as follows:

$$s = \frac{114.6Q}{T} W(u) \quad \ldots \ldots \quad (1)$$

Where the "well function of u"

$$W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{2 \cdot 2!} - \frac{0.577216}{4 \cdot 4!} \quad . \quad (2)$$

and

$$u = \frac{1.87r^2S}{Tt} \quad \ldots \ldots \quad (3)$$

Where: Q = discharge or change in discharge of pumped well, in gallons a minute
s = drawdown at observation well, in feet
T = coefficient of transmissibility, in gallons a day per foot under a hydraulic gradient of one foot per foot
r = distance from observation well to pumped well, in feet
S = coefficient of storage, as a ratio or decimal fraction
t = time well has been pumped, in days.

Values of W(u) and u are given by Wenzel (19). The W(u) and u are plotted on log paper to form a type curve used in analyzing pumping-test data. Drawdowns observed in an observation well are plotted on log paper against values of $\frac{r^2}{t}$. The plot of the observed data is superimposed on and matched with the type curve, keeping the axes of the two graphs parallel. Values of W(u), u, $\frac{r^2}{t}$, and s are taken from a convenient point common to the two graphs. Then equation (1) can be solved for T, and equation (3) is solved for S, to obtain the hydraulic characteristics of the formation tested.

A detailed discussion of pumping-test methods is beyond the scope of this report. Interested readers are referred to the work of Wenzel (19) and Ferris (6) for a more complete discussion.

The sand and gravel penetrated by the Park well, NoD33-1-31 (see app. B), between depths of 77 and 92 feet is thought to be a gravel correlative to that screened in the shallow suction wells (NoD33-1-1 to 27). Only 7 feet of sandy clay separates this gravel from the deeper sand and gravel screened in the Park well.

Several excavations in the suction-well area show the existence of a buried lake-clay about 12 feet thick which slopes eastward beneath the bed of Bixler Lake. Pumping tests were made in 1945 and 1946 to determine the extent of the clay penetrated near the bottom of the Park well, and the lake clay in the suction wells, as both materially affect the hydraulic features of the formations in the Bixler Lake area.

In November 1945, three wells (NoD33-1-32T to 34T) were put down in the shallow gravel for observation purposes. At 12:40 p.m. on December 15, 1945, pumping of the suction wells was discontinued after a long period of continuous pumping. At 3:03 p.m. on December 17, 1945, discharge was resumed. The pumping rate before and after the recovery period was about 180 gallons a minute. Water-level measurements were made in wells NoD33-1-9, -13, -21, -27, -32T, -33T, and -34T. A total of 13 wells were being pumped in the suction field. The Park well was idle for some time before December 11. The schedule of operation during the test is given in table 10.

Table 10.--Schedule of well operation at municipal well field, Kendallville, December 1945

Date	Time	Change in operation	Change in discharge of unit
11	2:50 p. m.	Park well (on)	+180 g.p.m.
15	12:40 p. m.	Suction wells (off)	-180 g.p.m.
17	3:03 p. m.	Suction wells (on)	+180 g.p.m.
19	12:48 p. m.	Park well (off)	-180 g.p.m.

Graphs of water levels observed through the test period in wells 21, 32T, 33T, and 34T are shown in figure 7.

Since the Theis nonequilibrium formula takes into account the discharge changes in only a single well, the formula was necessarily modified. A compound type curve was constructed for each observation well (17), assuming the discharge of each of the suction wells to be equal. Using the compound type curves, the values of transmissibility and storage given in table 11 were computed from the data collected at each observation well.

Table 11.-Coefficients of transmissibility and storage of the shallow sand and gravel at municipal well field, Kendallville

Observation well	Coefficient of transmissibility (g.p.d./ft.)	Coefficient of storage
9	38,600	0.07
13	50,600	0.04
21	58,500	0.13
27	48,200	0.17
32T	45,200	0.05
33T	67,000	0.05
34T	75,000	0.08
Average	54,000	0.07

Values of the hydraulic characteristics at wells 33T and 34T are probably not sound. At that distance from the suction field, part of the ground-water flow is directed through the more clayey materials, increasing the vertical section of the flow toward the suction wells. Therefore the computed coefficients of transmissibility are probably too great, being based on a small drawdown at those points. The average of the coefficients of transmissibility determined at wells 9, 13, 21, 27, and 32T is 48,100 gallons a day per foot and the average coefficients of storage is 0.07.

The data imply that direct infiltration from the bottom of Bixler

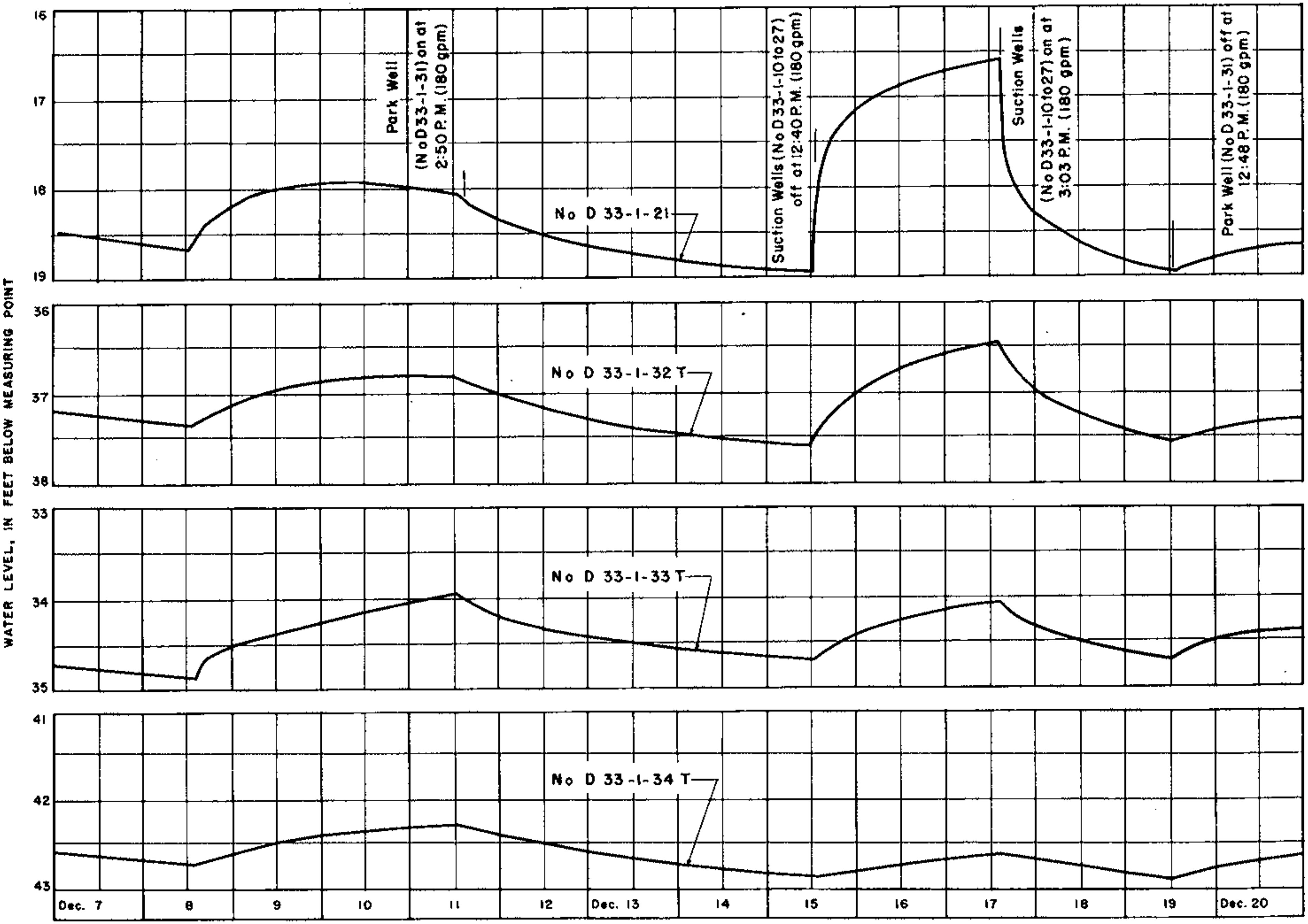

FIGURE 7. GRAPHS OF WATER LEVELS IN OBSERVATION WELLS IN KENDALLVILLE, INDIANA, MUNICIPAL WELL FIELD, DECEMBER 1945

Lake is not particularly effective as a source of recharge. However, the test reflects only those conditions within a radius of about 750 feet from the center of the suction field. Therefore, the possibility that the shallow gravel receives direct recharge or recharge at a low rate from Bixler Lake is not entirely eliminated. Present data on Bixler Lake levels indicate a high rate of loss from the lake, which is most sensibly explained as recharge to the shallow gravel (3).

The effect on ground water in the shallow gravel caused by pumping the Park well becomes less as the distance to the observation point increases, as shown in figure 5.

The character of the materials below the shallow gravel changes widely in the vicinity of the Park well, as shown by the logs of wells NoD33-1-30T, -31, -32T, -33T, and -34T (see app. B). Flow toward the Park well is therefore far from the idealized radial flow assumed in development of the Theis nonequilibrium formula.

In March 1946, wells NoD33-1-32T, -33T, and 34T were extended to a depth approximately level with the top of the screen in the Park well. Water-level measurements were made in wells NoD33-1-21, -27, -32T, -33T, and -34T from April 2 to 14, 1946. Changes in discharge during the second test are given in table 12. The Park well and the suction wells were operated continuously at a constant rate for a considerable time prior to April 2.

Table 12.-Schedule of well operation at municipal well field, Kendallville, April 1946

Date	Time	Change in operation	Change in discharge of unit
7	7:25 a. m.	Park well (off)	- 125 g.p.m.
8	6:45 a. m.	Park well (on)	+ 125 g.p.m.
13	11:09 p. m.	Suction wells (off)	- 140 g.p.m.

The drawdowns observed in wells NoD33-1-32T, -33T, and -34T were analyzed by means of the Theis nonequilibrium formula and the results are given in table 13. The extreme range in coefficients of transmissibility and storage is credited to the heterogeneous character of the formations at the Park well screen level.

Table 13.-Coefficients of transmissibility and storage of the sands and gravels tapped by the Park well, Kendallville

Observation well	Coefficient of transmissibility	Coefficient of storage
32T	7,950 g.p.d./ft.	1.7×10^{-1}
33T	18,400 g.p.d./ft.	2.4×10^{-3}
34T	1,670 g.p.d./ft.	2.4×10^{-4}

Graphs of water levels observed in wells NoD33-1-21, -32T, -33T, and -34T during the period April 2 to 14, 1946, are shown in figure 8.

The Kendallville South well (NoH4-4) was shut down at 12:45 a. m. April 13, 1946, after pumping about 123 gallons a minute continuously for a long time. At 2:30 p. m. the well began discharging at its former rate. The resulting recovery and drawdown of water levels were observed in the McReary well (NoH4-2), 184 feet north of the South well. The coefficient of transmissibility of the formation tapped by the South well was found to be 3,910 gallons a day per foot and the coefficient of storage is 4.1×10^{-4}.

Tests on city wells 3 and 5 in July 1947 show the coefficient of transmissibility of the shallow gravel at that location to be about 200,000 gallons a day per foot. However, it is not likely that gravel with such high transmissibility will be found over an extensive area.

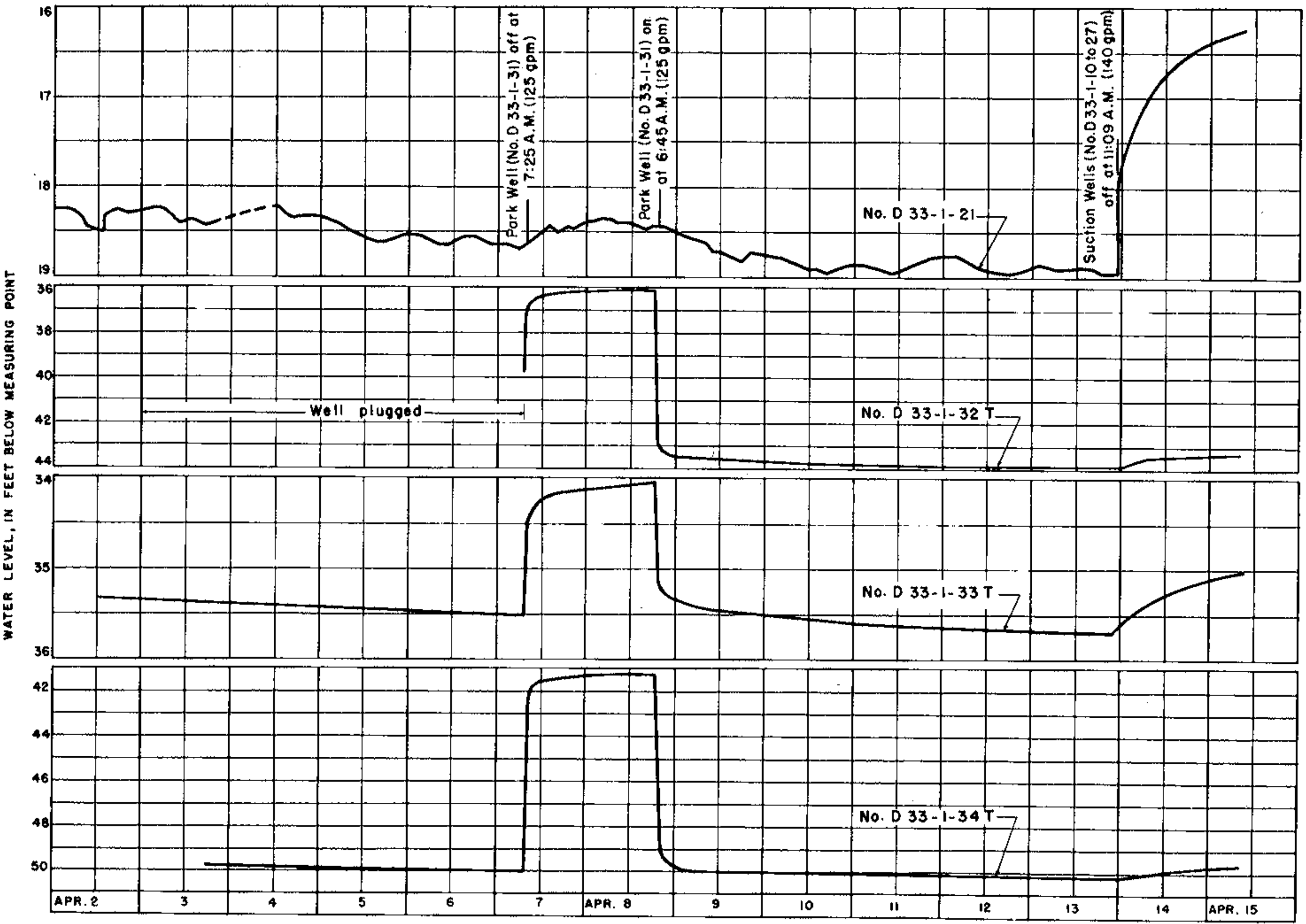

FIGURE 8. GRAPHS OF WATER LEVELS IN OBSERVATION WELLS IN KENDALLVILLE, INDIANA, MUNICIPAL WELL FIELD, APRIL 1946

Conclusions

Results of pumping tests indicate that (1) no direct infiltration from Bixler Lake occurs to the shallow sand and gravel within about 750 feet of the center of the suction-well system, (2) water pumped from the Park well originates in the shallow gravel and percolates generally downward through sandy clay to reach the Park well screen, and (3) the formation supplying the Park well is probably small in areal extent, the materials varying widely in character through short distances horizontally (also indicated by well logs). The shallow gravel in the municipal well field has the higher coefficient of transmissibility of the two known water-bearing formations in the area.

Ground-water levels in several wells in Kendallville are below the altitude of the water surfaces in Henderson and Bixler Lakes. Bixler Lake, Deibele ditch, Henderson, Round, and Long Lakes are potential sources of recharge in the Kendallville area. Some movement of water from Bixler, Round, and Long Lakes to the wells in Kendallville is possible at the present time. However, data are insufficient to show this conclusively, or to arrive at an estimate of the present rate of recharge from these sources.

Recent data on levels of Bixler Lake collected by the Surface Water Branch, United States Geological Survey, show that a large quantity of water is lost from the lake daily. During the period August 1 to 14, 1947, about 350,000 gallons a day was lost from the lake, in addition to losses by evaporation. Preliminary computations for later periods indicate that this loss may be continuous. The only known escape for this water is through the shallow sand and gravel to the city wells. A report on the hydrology of Bixler Lake is being prepared by the Surface Water Branch, U.S. Geological Survey, which will show in more detail the quantities of water