Ground-Water Conditions at Argonne National Laboratory, Illinois 1948-60

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-O

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By DOYLE B. KNOWLES, W. J. DRESCHER, *and* E. F. LEROUX

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GROUND-WATER CONDITIONS AT ARGONNE NATIONAL LABORATORY, ILLINOIS, 1948-60

By Doyle B. Knowles, W. J. Drescher, and E. F. LeRoux

ABSTRACT

The Argonne National Laboratory, a facility of the U.S. Atomic Energy Commission operated by the University of Chicago, is in southeastern Du Page County, Ill. The laboratory is about 16 miles southwest of downtown Chicago and about 1 mile north of the village of Lemont. It comprises an area of about 6 square miles.

The laboratory area is part of a plateau dissected into gently rolling hills. The Des Plaines River borders the southern part of the area. Saw Mill Creek and an unnamed stream, both emptying into the Des Plaines River, drain the laboratory area.

The laboratory is underlain by a basement complex of crystalline rocks of Precambrian age. The crystalline rocks have not been penetrated by wells in the laboratory area or in northeastern Illinois. Sedimentary rocks of Cambrian, Ordovician, and Silurian ages overlie the crystalline rocks. The rocks are divided, in ascending order, as follows: The Mt. Simon, Eau Claire, Galesville, and Franconia Sandstones of Cambrian age; the St. Peter Sandstone, Platteville Formation, Decorah Formation, Galena Dolomite, and Maquoketa Shale of Ordovician age; and the Niagara Dolomite of Silurian age. Unconsolidated deposits, largely of Pleistocene age and glacial origin, overlie the older rocks in most of the area.

The Mt. Simon Sandstone and the lower part of the Eau Claire Sandstone are separated from the Galesville Sandstone and younger rocks by relatively impermeable dolomite and shale strata in the upper part of the Eau Claire. The Mt. Simon Sandstone and the lower part of the Eau Claire Sandstone can be considered one aquifer. In the laboratory area, the water in the aquifer is of poor chemical quality.

The Galesville, Franconia, and St. Peter Sandstones are hydraulically connected and can be considered to form one aquifer. These units are heavily pumped in the Chicago region for public supply and industrial use. Water levels in wells tapping this aquifer have persistently declined as a result of the increasing withdrawal of water. The water-level decline in the laboratory area was about 500 feet from 1864, when the first deep well in the region was drilled at Chicago, to 1958. The water level in the deep supply well at the laboratory declined 103 feet in 1949–60.

The Niagara Dolomite is the chief source of water supply at the laboratory. The Platteville Formation, Decorah Formation, and Galena Dolomite, undifferentiated, and the Maquoketa Shale serve as an effective confining bed separating the Niagara Dolomite from the sandstones of Cambrian and Ordovician ages.

Rates of discharge of the laboratory's supply wells tapping the Niagara Dolomite range from 350 to 500 gpm (gallons per minute).

The deposits of Pleistocene and Recent ages are not a source of water supply at the laboratory, because their permeability is low. The deposits are important, however, because they supply most of the recharge to the Niagara Dolomite.

Recharge to the Niagara Dolomite at the laboratory is chiefly by infiltration of precipitation through the overlying deposits of Pleistocene age. Some water probably recharges from Saw Mill Creek, particularly in the lower reaches of the stream where the Niagara Dolomite crops out. Recharge at the laboratory is estimated at 3 to 4 inches per year. Natural discharge of water from the Niagara Dolomite is by seeps and springs along the base of the bluff that forms the edge of the Des Plaines River valley and along the Des Plaines River. Some water is also discharged by evapotranspiration in the valley where water levels in the Niagara are near the surface.

Withdrawal of water from wells tapping the Niagara Dolomite at the laboratory began during construction in 1948. It gradually increased to about 0.13 mgd (million gallons per day) in 1949, about 0.64 mgd in 1955, and about 0.93 mgd in 1960. The gradual increase in pumpage resulted in a gradual expansion of the cone of depression in the piezometric surface of water in the Niagara Dolomite at the laboratory. By 1960, the maximum decline in nonpumping water levels was 43 feet in the vicinity of the most heavily pumped wells. Water levels were at about the same stage in 1960 as in 1948 in the northern, western, and southern parts of the laboratory. In the eastern part, however, the water levels declined about 5 to 10 feet in 1948–60. The water pumped in 1948–60 from wells tapping the Niagara Dolomite at the laboratory is water that otherwise would have been discharged along the bluff at the edge of the Des Plaines River valley.

The coefficient of transmissibility of the Niagara Dolomite was determined by relating the pumpage to the shape of the piezometric surface; the coefficient of storage was estimated. The coefficients were verified by comparing computed water-level declines with actual declines. The differences in the computed and actual declines were small.

Probable declines in water levels that would occur if the 5 supply wells at the laboratory were pumped continuously for 5 years at 350 gpm each were computed, based on the coefficients of transmissibility and storage. The hypothetical combined pumping rate is about 2.5 mgd, or about 2½ times the average daily pumping rate at the laboratory in 1960. The computations indicate the decline in water levels would be more than 65 feet in the deepest part of the cone of depression. The decline in water levels would be about 45 to 50 feet along the northern boundary; no change in water levels would occur along the southern boundary.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Argonne National Laboratory is in southeastern Du Page County, Ill. (fig. 1). It is a facility of the U.S. Atomic Energy Commission and is operated by the University of Chicago. The laboratory is in a populous rural area about 16 miles southwest of downtown Chicago and about 1 mile north of the village of Lemont. The laboratory includes about 6 square miles within the area bounded on the west by Lemont Road, on the north by U.S. Highway 66, on the

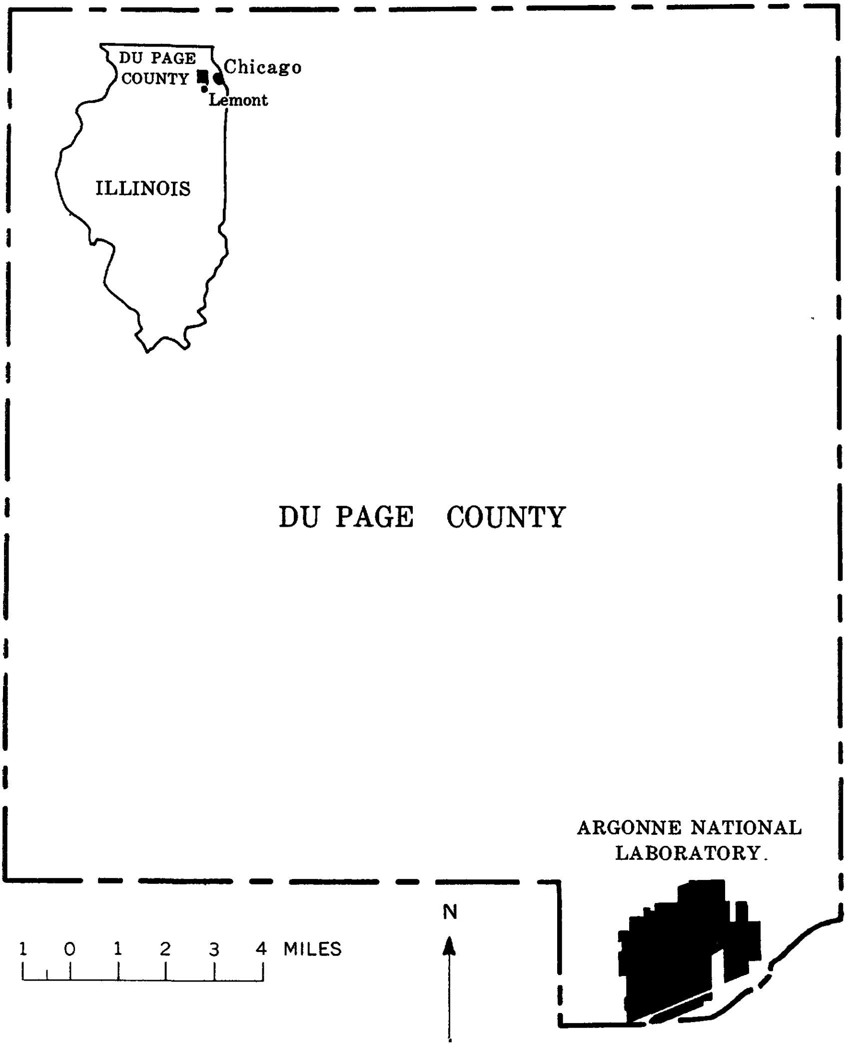

FIGURE 1.—Index map showing location of Argonne National Laboratory, Ill.

east by State Highway 83, and on the south by the Des Plaines River (fig. 2).

PURPOSE AND SCOPE OF INVESTIGATION

An adequate water supply is essential to the work of the laboratory. As no nearby public-water supply system is available, the U.S. Atomic Energy Commission, in 1948, requested the U.S. Geological Survey to make a study of the geology and ground-water resources of the laboratory area to assist in developing an adequate water supply.

The purpose of this investigation was as follows: To determine the thickness, character, and areal extent of the water-bearing beds underlying the site of the Argonne National Laboratory; to determine the capacity of the beds to absorb, store, transmit, and discharge water; and to determine the chemical character of the ground water. Special emphasis was placed on determining the occurrence and movement of water in the Niagara Dolomite of Silurian age and on evaluating the effect that ground-water withdrawals at the laboratory would have on supplies in adjacent areas.

This report is a progress report presenting information on ground-water conditions at the laboratory in 1948–60.

The investigation was made by the Geological Survey in cooperation with the U.S. Atomic Energy Commission. It was under the immediate supervision of F. C. Foley, W. J. Drescher, and C. L. R. Holt, Jr., successively district chief in charge of the Geological Survey's ground-water investigations in Wisconsin.

PREVIOUS INVESTIGATIONS

A detailed study of the geology and ground-water resources of the area in which Argonne National Laboratory is located had not been made prior to this investigation. General information, however, is contained in reports on the geology or ground-water resources of all or parts of northeastern Illinois by Alden (1902), Goldthwait (1909), Anderson (1919), Fisher (1925), Bretz (1939 and 1955), Thwaites (1927), Leighton, Ekblaw, and Horberg (1948), Bergstrom and others (1955), Hanson (1950), and Suter and others (1959).

The geology and ground-water resources of the Argonne National Laboratory area are described in U.S. Geological Survey open-file reports by Allen, Drescher, and Foley (1949) and by LeRoux and Drescher (1959). The results of the investigation contained in these open-file reports are included in the present report.

METHODS OF INVESTIGATION

The available data concerning more than 60 wells at the laboratory were collected and studied during the course of the investigation. The data on wells included (1) drillers' logs, (2) information on location, diameter, depth, water level, casing, and water-bearing formation tapped by each well, and (3) other pertinent facts related to the occurrence and availability of ground water. All the wells tapped the upper part of the Niagara Dolomite and yielded an adequate water supply for domestic and stock use. A few of the wells were reported to yield about 100 gpm (gallons per minute).

In 1948, all but 33 of the wells at the laboratory had been filled and abandoned. Pertinent data on these wells and on the laboratory's six supply wells are given in table 1. The locations of the wells are shown in figure 2.

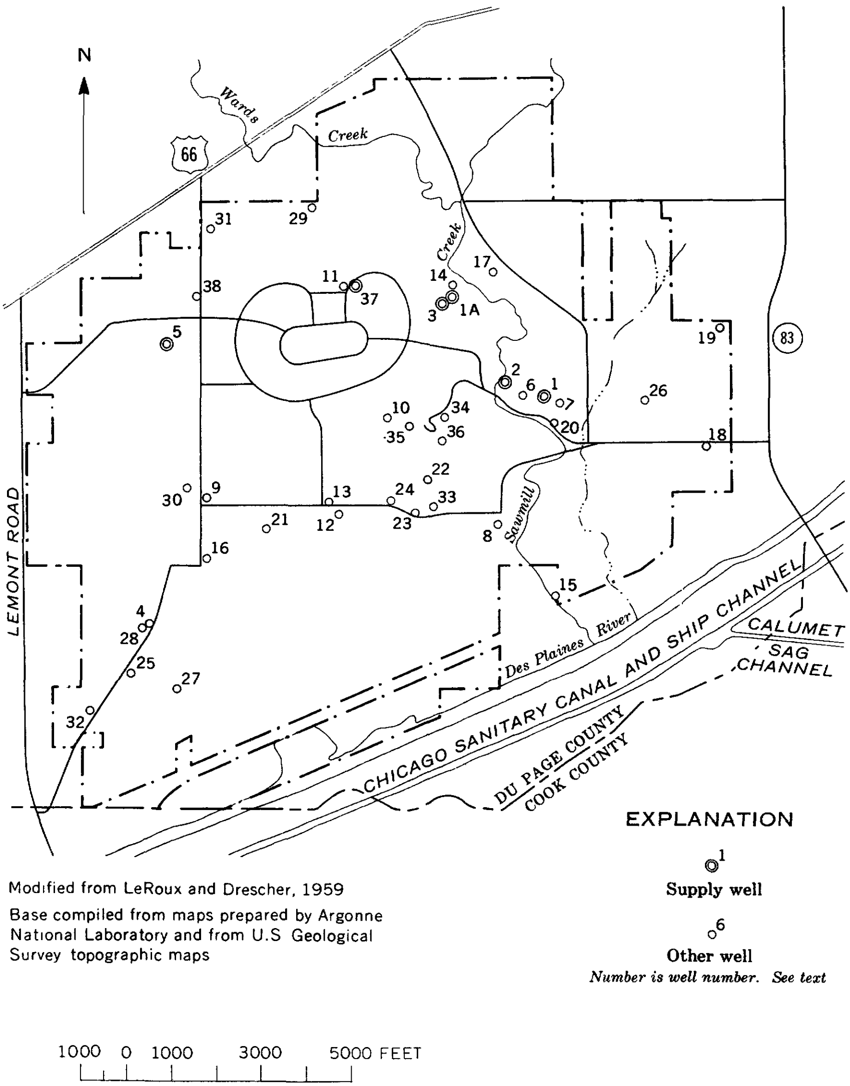

FIGURE 2.—Map showing location of wells at Argonne National Laboratory, Ill.

TABLE 1.—*Records of wells at Argonne National Laboratory, Ill.*

[The geologic source of water for all wells is the Niagara Dolomite of Silurian age, except well 1A whose geologic sources of water are the St. Peter Sandstone of Ordovician age and rocks of Cambrian age. Water level: Water levels shown in feet are reported; those in feet and tenths are measured. Use: De, destroyed; In, industrial; P, public supply; U, unused]

Well	Depth of well (feet)	Diameter of well (inches)	Altitude of land surface (feet)	Water level: Below land surface (feet)	Water level: Date of measurement	Use
1A	1,595	18, 12	670	387 490	12- 5-49 11-16-60	P, In
1	284	12	670	23 55.0	9- 3-48 6-14-60	P, In
2	300	12	662	16.7 57.5	9-10-48 6-15-60	P, In
3	318	12	688	50 51.7	8-23-55 6-15-60	P, In
4	181	6	748	130	12- -56	In
5	345	15, 12	749	105.7 103.8	9-14-48 6- 2-60	P, In
6	95	4	669	21 40.0	3- 3-48 6- 2-60	U
7	111	4	673	27.8	9-10-48	De
8	95	4	664	71.7 69.0	9-15-48 6- 3-60	U
9	140	4	733	91.5 92.7	9-15-48 6- 2-60	U
10	198	10	705	59.0 74.9	10-24-48 6- 2-60	U
11	141	4	716	68.0 81.7	10-24-48 6- 3-59	U
12	120	4	735	66.8	10-11-48	De
13	141	4	746	106.0 110.8	10-24-48 6- 2-60	U
14	112	8, 6	663	18.2	10-19-48	De
15	----------	----------	610	22.4 16.3	11- 5-48 5-22-57	U
16	155	6	744	105	3-22-49	U
17	104	6	688	39.9 50.1	3-17-49 6- 2-60	U
18	185	4	715	124.6 123.6	3-17-49 6- 2-60	U
19	174	6	703	66.9 73.4	5-18-49 5-26-59	U
20	168	6	663	35.6 35.6	8-14-52 6- 3-60	U
21	162	4	753	118.0	8-13-52	U
22	238	6	720	65.5 67.7	8-14-52 5-26-59	De
23	134	4	715	----------	----------	U
24	130	6	712	79.5	6- 2-60	U
25	150	6	736	126.7 124.4	10- 7-53 6- 2-60	U
26	104	4	686	48.1 59.9	3-17-49 6- 2-60	U
27	149	4	725	116.2 117.8	4-15-53 10-23-57	U
28	151	6	747	130.4 128.7	4-15-53 5-22-57	U
29	123	6	728	84.0 88.1	4-15-53 5-26-59	U
30	152	4	748	106.0 106.4	10- 7-53 6- 2-60	U
31	162	4	752	109.4 107.3	10- 7-53 6- 2-60	U
32	129	4	690	85.2 84.5	7- 7-54 6- 2-60	U
33	122	6	710	73.8 69.5	7- 7-54 5-26-59	U
34	150	8	----------	51.7 52.1	7- 8-54 6- 2-60	U
35	183	4	----------	81.4 88.6	4-21-55 6- 2-60	U
36	202	6	----------	77.0 77.5	10-20-55 6- 2-60	U
37	340	14	710	81.4 86.0	7-15-59 6-12-60	P, In
38	173	4	735	88.4	5-26-59	U

During the construction of the laboratory in 1948 and 1949, about 200 test holes were drilled for foundation purposes. The test holes ranged in depth from about 25 to 140 feet; about 20 of the test holes were drilled through the deposits of Pleistocene age to the top of, or a short distance into, the Niagara Dolomite—the bedrock in the area. Samples of material were collected so that the physical properties of the material cound be studied in detail. Measurements were made of the depth to water in selected test holes. Samples of water for chemical analysis were collected from some of the test holes that penetrated the Niagara Dolomite.

Periodic measurements of the depths to water have been made since 1948–49 in about 20 observation wells tapping the Niagara Dolomite at the Argonne National Laboratory. Recording gages are maintained on five key wells.

A series of short-term aquifer tests were made in 1949 and 1955 to determine the hydraulic characteristics of the Niagara Dolomite.

ACKNOWLEDGMENTS

The writers wish to thank the many persons who have contributed information and assistance during the field investigation and during the preparation of this report. In particular, thanks are expressed to J. A. Lieberman and J. A. Armstrong of the U.S. Atomic Energy Commission and to A. W. R. Oswald, Benjamin Evans, U. K. Sick, A. F. Stehney, R. M. Monson, R. Puricelli, L. L. Liebfried, and H. Werth of the Argonne National Laboratory. Acknowledgment is also made to the Illinois State Water Survey for analysis of water samples and to the Illinois State Geological Survey and Wisconsin Geological and Natural History Survey for describing rock samples from the supply wells at the laboratory and for supplying other information. F. C. Foley, State geologist and director, Kansas Geological Survey, and formerly district geologist, U.S. Geological Survey, Madison, Wis., contributed much to the early phases of the investigation. C. B. Tanner, Soils Department, University of Wisconsin, gave advice on determining characteristics of surficial materials.

PHYSICAL FEATURES

TOPOGRAPHY AND DRAINAGE

The Argonne National Laboratory area is in the Great Lakes section of the Central Lowland physiographic province of Fenneman (1938). The Great Lakes section was divided by Leighton and others (1948, p. 17) into the Wheaton Morainal Country and the Chicago Lake Plain. The area of this report is in the Wheaton Morainal Country.

The topography of the laboratory area is characterized by a plateau with gently rolling hills. The Des Plaines River borders the southern part of the area. The Chicago Sanitary Canal and Ship Channel is approximately parallel to and about 1,000 feet south of the Des Plaines River. A bluff ranging in height from 25 to 75 feet extends along the edge of the Des Plaines River valley. Altitudes range from about 600 feet above mean sea level along the Des Plaines River to more than 750 feet on some of the higher hills in the western part of the area. Saw Mill Creek drains the western two-thirds of the area and empties into the Des Plaines River (fig. 2). An unnamed stream drains the eastern third and also empties into the Des Plaines River.

CLIMATE

The climate of the area is characterized by warm summers and cold winters. The average annual air temperature at Midway Airport, Chicago, Ill., about 13 miles northeast of Argonne National Laboratory, was 49.8° F in 1905–60. The average monthly temperature ranged from 25.0° F in January to 73.7° F in July. The average monthly temperature for 1948–60 is shown in figure 3.

The average annual precipitation at Midway Airport during the period 1905–60 was 33.03 inches. The annual precipitation ranged from 22.23 inches in 1956 to 44.29 inches in 1957. June had the greatest precipitation, with an average of 3.66 inches; February had the least, with an average of 1.87 inches. The monthly precipitation for 1948–60 is shown in figure 3.

ROCK UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The rocks underlying the Argonne National Laboratory range in age from Precambrian to Quaternary. A stratigraphic outline and summary of the water-bearing characteristics of the rocks is given in table 2. Sample logs (logs compiled from examination of well cuttings) of supply wells 1A and 37 at the laboratory are given in table 3.

PRECAMBRIAN ROCKS

The laboratory is underlain by a basement complex of Precambrian crystalline rocks. The crystalline rocks have not been penetrated by wells in the laboratory area or in northeastern Illinois. The depth to the Precambrian rocks in the vicinity of the laboratory is estimated to be about 3,500 to 4,000 feet below land surface. The crystalline rocks are relatively impermeable and are not a source of water supply in areas of southern Wisconsin and northern Illinois were they have been penetrated by wells.

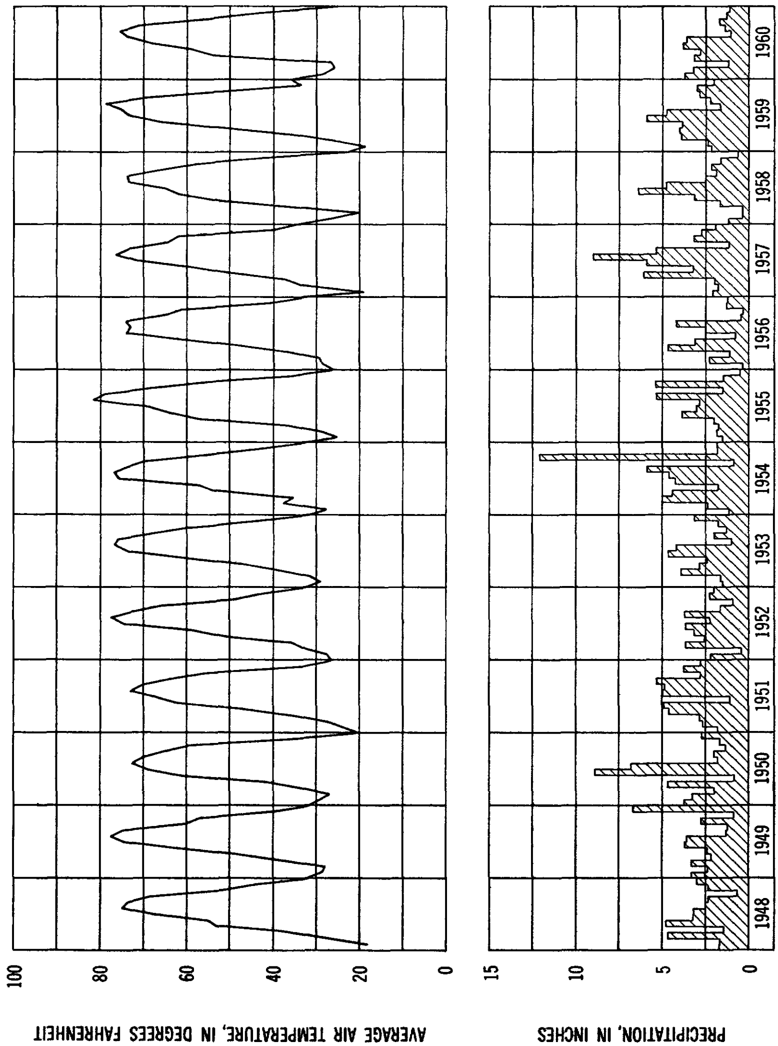

FIGURE 3.—Average monthly temperature and monthly precipitation at Midway Airport, Chicago, Ill., 1948–60.

TABLE 2.—*Stratigraphic outline and summary of water-bearing characteristics of rocks underlying Argonne National Laboratory, Ill.*

System	Rock unit		Maximum thickness (feet)[1]	Lithology	Water-bearing characteristics
Quaternary	Pleistocene deposits		180	Unstratified till and stratified clay, silt, sand, and gravel.	Not important as aquifers. Generally yield only small quantities of water.
Silurian	Niagara Dolomite		225	Dolomite, light- to dark-gray, fine- to medium-grained, thin- to massive-bedded, calcareous. Some white chert. Shaly near base at some places.	Yields moderate to large quantities of water from solutionally enlarged openings along joints and bedding planes. Some springs issue from aquifer near edge of Des Plaines River valley.
Ordovician	Maquoketa Shale		165	Shale, brownish-gray to green, dolomitic, compact, soft. Some thin dolomite beds.	Not important as an aquifer. Very low permeability.
	Galena Dolomite Decorah Formation Platteville Formation		347	Dolomite, buff—and in some places, brown and gray—very fine to medium-grained, massive-bedded. Some chert and sand. Few thin limestone beds.	Not important as aquifers. Yield only very small quantities of water.
	St. Peter Sandstone		498	Sandstone, white to gray, fine- to medium-grained, loosely cemented, locally dolomitic. Silty or clayey in places. Some thin shale and dolomite beds.	Yields moderate quantities of water.
Cambrian	Franconia Sandstone		82	Sandstone, dolomitic, glauconitic. Few thin beds of glauconitic dolomite.	Yields moderate to large quantities of water depending on permeability and thickness penetrated. Galesville Sandstone reported to be most productive. Water is probably highly mineralized in Mt. Simon Sandstone. Part of Eau Claire Sandstone acts as hydrologic barrier between water in the underlying Mt. Simon Sandstone and in overlying Galesville and Franconia Sandstones.
	Dresbach Group	Galesville Sandstone	179	Sandstone, white, fine- to coarse-grained, dolomitic. Some thin dolomite beds.	
		Eau Claire Sandstone	[2] 350	Shale, sandstone, and dolomite.	
		Mt. Simon Sandstone	[2] 1,500–2,000	Sandstone, pink, yellow, and white, fine- to coarse-grained.	
Precambrian			Unknown	Crystalline rocks.	Virtually impermeable. Yield little or no water.

[1] Based on well logs.
[2] Estimated.

TABLE 3.—*Sample logs of materials penetrated by representative wells at Argonne National Laboratory, Ill.*

	Thickness (feet)	Depth (feet)
Well 1A (laboratory deep well 1)		
[Samples described by Illinois State Geol. Survey]		
Quaternary System:		
Pleistocene deposits:		
Drift	64	64
Silurian System:		
Niagara Dolomite:		
Dolomite, gray, very fine, cherty	26	90
Dolomite, gray, very fine	45	135
Dolomite, buff, very fine	20	155
Dolomite, light-grav to medium-gray and pink	30	185
Dolomite, white to light-gray, very fine	10	195
Dolomite, slightlv glauconitic; shale	5	200
Dolomite, buff; some gray dolomite	15	215
Dolomite, grayish-buff, slightly glauconitic	20	235
Dolomite, grayish-buff, partly cherty	25	260
Dolomite, sandy, slightlv glauconitic	10	270
Dolomite, light-buff to brown, very fine	5	275
Ordovician System:		
Maquoketa Shale:		
Shale, green, dolomitic; lenses of dolomite	50	325
Shale, dolomitic, brown to green; dolomite	20	345
Dolomite, brownish-gray; shale, dolomitic	15	360
Shale, brownish,gray, partlv dolomitic	80	440
Galena Dolomite, Decorah Formation, and Platteville Formation:		
Dolomite, buff, fine to medium	180	620
Limestone, dolomitic, buff	20	640
Dolomite, buff, cherty	20	660
Limestone, buff to brown, partly dolomitic	25	685
Limestone and dolomite, brown, buff, and gray	95	780
Dolomite, buff, very fine, partly sandy	7	787
St. Peter Sandstone:		
Sandstone, fine to medium, partly silty	83	870
Sandstone, fine to medium, clayey, silty	40	910
Sandstone fine to medium, clayey, silty; shale, gray	5	915
Sandstone, fine to medium, clavey, silty	60	975
Sandstone, fine to medium, clayev, silty; shale, gray, silty	45	1, 020
Sandstone, fine to medium, partly silty	170	1, 190
Sandstone; shale, partly sandy; chert pebbles	35	1, 225
Dolomite and chert pebbles; shale; sandstone	25	1, 250
Shale, purple and green; sandstone and dolomite pebbles	35	1, 285
Cambrian System:		
Franconia Sandstone:		
Sandstone, partly dolomitic, glaucontitic	30	1, 315
Dolomite, buff, very fine	5	1, 320
Sandstone, very fine, dolomitic, glauconitic	35	1, 355
Dolomite, fine, partly sandy, glauconitic	12	1, 367
Galesville Sandstone:		
Sandstone, white, coarse	8	1, 375
Sandstone, white, coarse, partly dolomitic	10	1, 385
Sandstone, white; streaks of dolomite	140	1, 525
Sandstone, white, fine to coarse, dolomitic	5	1, 530
Sandstone, white, medium to coarse	16	1, 546

TABLE 3.—*Sample logs of materials penetrated by representative wells at Argonne National Laboratory, Ill.* —Continued

	Thickness (feet)	Depth (feet)
Well 1A (laboratory deep well 1)—Continued		
[Samples described by Illinois State Geol. Survey]		
Cambrian System—Continued		
Eau Claire Sandstone:		
Dolomite, brown, very fine, slightly sandy	4	1, 550
Dolomite, brown, very fine, slightly sandy; sandstone, gray, medium to coarse	10	1, 560
Dolomite, sandy, glauconitic	10	1, 570
Sandstone, dolomitic	9	1, 579
Shale, silty, glauconitic	16	1, 595
Well 37 (laboratory shallow well 4)		
[Samples described by Wisconsin Geol. and Natural History Survey]		
Quaternary System:		
Pleistocene deposits:		
Soil, black, much organic material	5	5
Till, brown, much clay with some sand and stones, dolomitic	15	20
Till, medium-gray, much clay with some sand and stones, dolomitic	10	30
Till, brown, much clay with some sand and stones, dolomitic	10	40
Till, medium-gray, much clay with some sand and stones, dolomitic	75	115
Silurian System:		
Niagara Dolomite:		
Dolomite, light-medium-gray	45	160
Dolomite, light-gray; some white chert from 185 to 195 ft	40	200
Dolomite, light-medium-gray, vuggy from 210 to 215 ft	15	215
Dolomite, pale-red-gray to light-gray	5	220
Dolomite, light-medium-gray	45	265
Dolomite, light-gray; some white chert	25	290
Dolomite, light-medium-gray	20	310
Dolomite, light-gray; much medium-gray shaly dolomite	3	313
Ordovician System:		
Maquoketa Shale:		
Shale, green-gray to medium-gray, dolomitic	27	340

CAMBRIAN AND ORDOVICIAN SYSTEMS

DESCRIPTION

Sedimentary rocks of Late Cambrian age unconformably overlie the crystalline rocks of Precambrian age and are in turn overlain by younger formations. The rocks of Cambrian age underlying the laboratory are, in ascending order, the Mt. Simon, Eau Claire, and Galesville Sandstones of the Dresbach Group and the Franconia Sandstone. The Trempealeau Formation, the uppermost unit of

Cambrian age in northeastern Illinois, is not present in well 1A at the laboratory; it probably was deposited and later removed by erosion prior to the deposition of younger rocks.

No information is available on the thickness and character of the Mt. Simon Sandstone in the vicinity of the laboratory. In the Chicago region, which includes the laboratory area, the Mt. Simon consists of pink, yellow, and white fine- to coarse-grained sandstone, and at some places red to green shale beds occur near the base (Suter and others, 1959, p. 19). The Mt. Simon Sandstone is estimated to be 1,500 to 2,000 feet thick in the vicinity of the laboratory.

The Eau Claire Sandstone conformably overlies the Mt. Simon Sandstone and consists of sandstone, dolomite, and shale. It is estimated to be about 350 feet thick in the vicinity of the laboratory. The upper part of the Eau Claire was penetrated by well 1A (laboratory deep well 1) and consists chiefly of dolomite and shale (table 3).

The Galesville Sandstone conformably overlies the Eau Claire Sandstone. At the laboratory it consists of about 180 feet of white fine- to coarse-grained sandstone and some thin beds of dolomite.

The Franconia Sandstone conformably overlies the Galesville Sandstone. It is about 80 feet thick at the laboratory and consists of dolomitic, glauconitic sandstone and a few thin beds of glauconitic dolomite.

The rocks of Ordovician age unconformably overlie the rocks of Late Cambrian age. The rocks of Ordovician age underlying the laboratory, in ascending order, are as follows: The St. Peter Sandstone; the Platteville Formation, Decorah Formation, and Galena Dolomite, undifferentiated; and the Maquoketa Shale. The Prairie du Chien Group, the basal unit of Ordovician age farther to the south, is not present in the vicinity of the laboratory, as it was removed by erosion prior to the deposition of the St. Peter Sandstone.

The St. Peter Sandstone unconformably overlies the Franconia Sandstone at the laboratory and consists of about 500 feet of white to gray, fine- to medium-grained sandstone and a few thin beds of shale and dolomite. Some of the sandstone beds are silty, clayey, or dolomitic.

The Platteville Formation, Decorah Formation, and Galena Dolomite, called the Platteville-Galena unit in this report, have not been differentiated in the laboratory area. The Platteville-Galena unit consists of about 350 feet of buff very fine- to medium-grained massive-bedded dolomite. Some thin beds of limestone occur in the lower part of the unit.

The Maquoketa Shale conformably overlies the Platteville-Galena unit and consists of about 165 feet of brownish-gray to green dolomitic compact soft shale. The Maquoketa is nearly impermeable.

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WATER-BEARING CHARACTERISICS

The Mt. Simon Sandstone and the lower part of the Eau Claire Sandstone were considered by Suter and others (1959, p. 19) to form a single aquifer, separated from the Galesville Sandstone and younger rocks by relatively impermeable dolomite and shale strata in the middle and upper parts of the Eau Claire. Water occurs in the Mt. Simon Sandstone and lower part of the Eau Claire Sandstone in openings along fractures and bedding planes and in interstices between the sand grains. The water is of poor chemical quality.

The Galesville and Franconia Sandstones of Late Cambrian age and the St. Peter Sandstone of Ordovician age are hydraulically connected and can be considered to form a single aquifer. Ground water occurs in the sandstone in openings along fractures and bedding planes and in interstices between the sand grains. The permeability of the aquifer is variable, especially in a vertical direction, because of changes in the sorting of the sand and the presence of dolomite and shale strata in the Franconia and the St. Peter. The lower part of the St. Peter Sandstone is shaly and commonly is cased off in wells to prevent caving. The Galesville Sandstone probably has the greatest permeability and is the most productive. The Galesville, Franconia, and St. Peter Sandstones are heavily pumped in the Chicago region as a source of water for public supply and industrial use.

Recharge to the sandstone units of Cambrian and Ordovician ages is chiefly by infiltration of precipitation in the area about 35 to 40 miles west of the laboratory. In that area, which is immediately west of the border of the Maquoketa Shale, the water probably percolates downward to the sandstones through the Pleistocene and Recent deposits and the Platteville-Galena unit. There is also some recharge to the sandstones by downward leakage through the Maquoketa Shale. Walton (1960, p. 25) estimated that the amount of this leakage in 1958 was equivalent to about 11 percent of the water pumped from deep wells in the part of the Chicago region where the Maquoketa is present.

The Platteville-Galena unit may supply some water to wells in the laboratory area from openings along joints and bedding planes in the dolomite. The contribution of this unit is probably very small where it is overlain by the Maquoketa Shale, although the unit is fairly permeable in those areas where the Maquoketa is not present. At the laboratory, the Platteville-Galena unit and the overlying Maquoketa Shale serve as an effective confining bed between the Niagara Dolomite of Silurian age above and the sandstones of Ordovician and Cambrian ages below.

Deep well 1A at the laboratory taps water in the St. Peter, Franconia, Galesville, and the upper part of the Eau Claire Sandstones. The lower part of the St. Peter and the upper part of the Franconia are cased from 1,160 to 1,335 feet below land surface to prevent caving. The well was drilled to a depth of 1,595 feet and probably obtains most of its water supply from the St. Peter and Galesville Sandstones. Well 1A was test pumped in December 1949 for 21 hours at a rate of 500 gpm and had a drawdown in water level of 167 feet, indicating a specific capacity of 3 gpm per ft of drawdown.

From December 1949 to November 1960 the water level in well 1A declined from 387 to 490 feet below land surface, a decline of 103 feet in 11 years. A large decline in water levels in deep wells has occurred throughout northeastern Illinois as a result of the increasing withdrawals of water for public supply and industrial use in the Chicago region. From 1864, when the first deep well in the region was drilled at Chicago, to 1958, the decline in water level in the vicinity of the laboratory was about 500 feet (Suter and others, 1959, fig. 40).

The sandstones of Cambrian and Ordovician ages are not considered an important source of water at the laboratory, because an adequate water supply for all present and foreseeable future needs, except for cooling, is available from the shallow Niagara Dolomite of Silurian age. Well 1A has been used chiefly as a standby well since it was drilled in 1949.

SILURIAN SYSTEM

NIAGARA DOLOMITE

DESCRIPTION

The Niagara Dolomite unconformably overlies the relatively impermeable Maquoketa Shale, which, together with the Platteville-Galena unit, acts as an effective seal between the Niagara and the underlying sandstones of Ordovician and Cambrian ages. The Niagara is in turn overlain by a varying thickness of Pleistocene and Recent deposits.

The upper part of the Niagara Dolomite crops out along the bluffs adjacent to the Des Plaines River valley and along Saw Mill Creek (fig. 4). At these localities the Niagara is a weathered thin-bedded buff-yellow dolomite that is cherty and calcareous. Two well-formed, almost vertical joint systems were observed in the exposures of the Niagara Dolomite. In general, the joints trend north eastward and northwestward.

In the subsurface the Niagara Dolomite consists of thin- to massive-bedded light- to dark-gray dolomite that is fine to medium grained and calcareous and contains some white chert. At some places the Niagara is shaly near the base of the formation. The Niagara ranges in thickness from 198 to 225 feet in the 6 supply wells at the laboratory.

By the beginning of glaciation in Pleistocene time, the surface of the Niagara Dolomite was probably dissected by erosion and characterized by deeply incised stream valleys. Although the bedrock surface was modified by glaciation, it probably has about the same configuration as existed immediately prior to glaciation.

The general character and dominant features of the topography of the Niagara Dolomite at the laboratory are shown in figure 4. The

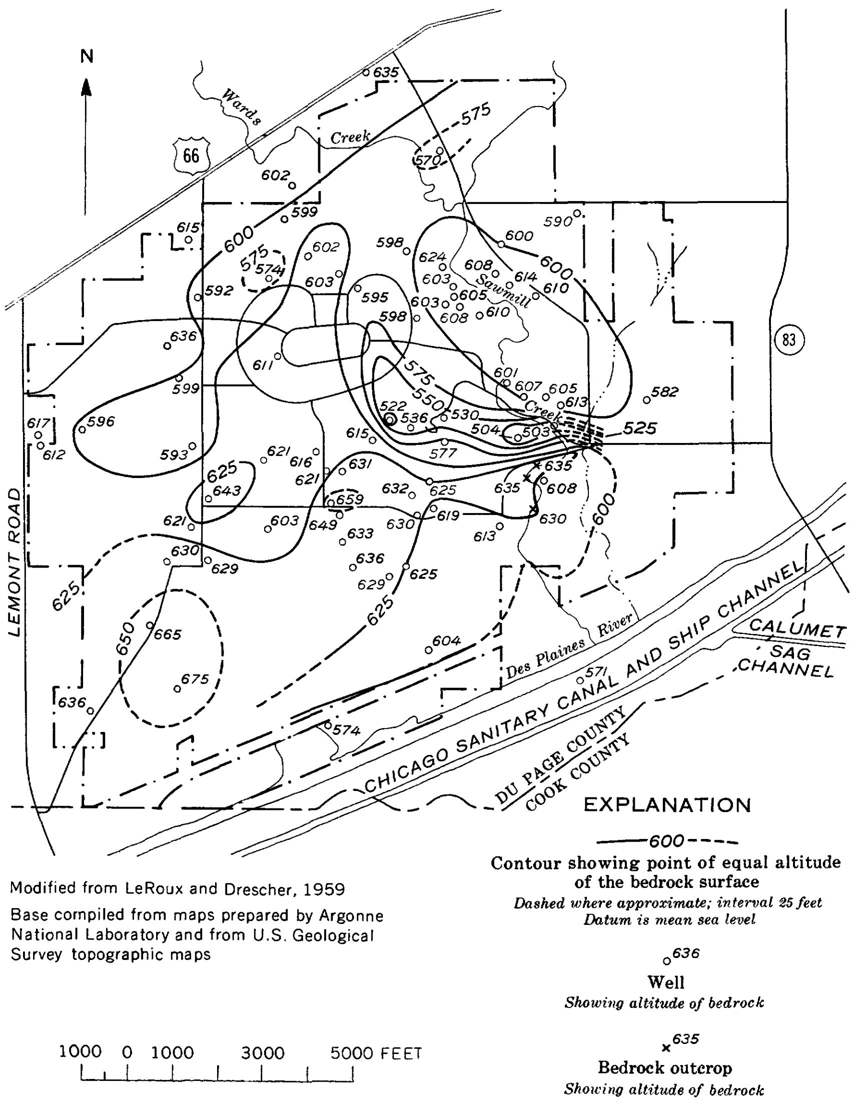

FIGURE 4.—Map showing approximate altitude of the top of Niagara Dolomite at Argonne National Laboratory, Ill.

topography is based on data from logs of the domestic and stock wells, test holes drilled for foundation purposes, and supply wells at the laboratory.

The surface of the Niagara is characterized by a stream valley with a relief of about 100 feet in the central part of the laboratory. The valley probably represents the course of a pre-Pleistocene stream that drained into the ancestral Des Plaines River.

WATER-BEARING CHARACTERISTICS

Ground water occurs in the Niagara Dolomite at the laboratory in solutionally enlarged openings along joints and bedding planes.

The rates of discharge of the laboratory supply wells tapping the Niagara Dolomite when they were test pumped on their completion or during short-term aquifer tests ranged from 350 to 925 gpm (table 4). The wells are normally pumped at rates ranging from 350 to 500 gpm. Wells yielding 300 gpm or more probably can be developed throughout the laboratory area.

TABLE 4.—*Rates of discharge and specific capacities of supply wells tapping the Niagara Dolomite at Argonne National Laboratory, Ill.*

Well	Normal rate of discharge (gpm)	Rate of discharge during test (gpm)	Draw-down during test (feet)	Specific capacity (gpm per ft)	Length of test (hours)	Date of test	Laboratory shallow well
1	350						1
2	350	350	11	32	38	Aug. 22-23, 1955	2
3	500	925	46	20	24	do	3
Do	do	500	19	26	24	Aug. 23-24, 1955	
5[1]	500	740	11.5	64	48	Sept. 2-4, 1948	5
37	500	550	32	17	17	Mar. 17-18, 1959	4

[1] Not connected to laboratory distribution system in 1948-60.

The relation between the rate of discharge and the resultant drawdown in water level in a pumped well is known as the specific capacity, which is generally expressed in gallons per minute per foot of drawdown. For example, if a well is pumped at a rate of 500 gpm and the water level is lowered 50 feet, the specific capacity of the well is 10 gpm per ft of drawdown. In a like manner, if the specific capacity of a well is 10 gpm per ft of drawdown, the implication is that, within certain limits, the discharge of the well will be increased 10 gpm for each foot of increased drawdown.

The specific capacity of a well depends both on the hydraulic characteristics of the aquifer and on the construction and development of the well. Specific capacities that were determined for the supply wells at the laboratory ranged from 17 to 64 gpm per ft of drawdown (table 4). The locations of the wells are shown in figure 2.

The withdrawal of water from a well causes a decline in the water level at the well and creates a hydraulic gradient that increases in slope toward the well. The hydraulic gradient forms an inverted cone centered at the well, known as the cone of depression. The cone becomes larger as the discharge from the well continues. Other factors being equal, the quantity of water moving toward a well is proportional to the gradient of the cone of depression. Two or more wells in the same area may compete for the available water if they are closely spaced and their cones of depression overlap. Mutual interference between the supply wells at the laboratory is relatively small.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT DEPOSITS

DESCRIPTION

Unconsolidated deposits of Pleistocene and Recent ages overlie the Niagara Dolomite in most of the laboratory area. These deposits, largely of Pleistocene age and glacial orgin, consist of unstratified till and stratified clay, silt, sand, and gravel.

Till is an unstratified and unsorted mixture of sediments. The till covers most of the laboratory area and forms a complex arrangement of hills and depressions known as the Valparaiso moraine, after its expression in the vicinity of Valparaiso, Ind. The till has been removed by erosion at a few places along Saw Mill Creek and along the bluffs that border the Des Plaines River valley. At the laboratory, the till ranges in thickness from a thin veneer to about 180 feet.

Logs of test holes drilled for foundation purposes indicate that the till consists of silt, sand, pebbles, cobbles, and boulders that are intermixed heterogeneously in a matrix of clay. The upper 10 to 20 feet of till is, in general, a partly oxidized blue and yellow silty clay with varying amounts of rock fragments, chiefly dolomite. A soft blue, gray, and yellow silty clay or clayey silt with varying amounts of sand, gravel, and rock fragments underlies the oxidized zone. At a few places thin beds of sand or silt occur within the till. Sample logs of two representative test holes completely penetrating the till at the laboratory are given in table 5.

Stratified deposits of Pleistocene and Recent ages are present in the Des Plaines River valley. They consist chiefly of sand and gravel and are generally only a few feet thick.

WATER-BEARING CHARACTERISTICS

The till is not important as a source of water supply in the laboratory area, because it has a very low permeability. In most of the area the till probably would not supply an adequate amount of water to wells, even for domestic and stock use, although—locally—thin beds of silt or sand might supply small amounts of water. The till is important in the laboratory area, because it confines the water in the Niagara Dolomite and supplies most of the recharge to the Niagara. Recharge to the till in the laboratory area is from local precipitation.

TABLE 5.—*Sample logs of two representative test holes penetrating deposits of Pleistocene age at Argonne National Laboratory, Ill.*

	Thickness (feet)	Depth (feet)
Test hole S-14		
[Located about 400 ft northwest of well 14 (fig. 2)]		
Quaternary System:		
Pleistocene deposits:		
Soil, black	1	1
Clay, yellow, silty; rock fragments	16	17
Sand, brown, fine-grained, silty with small amounts of clay	6	23
Clay, brown, silty, sandy; boulder at 47 ft	25	48
Silt, gray, sandy; rock fragments	5	53
Sand and rock fragments	7	60
Silurian System:		
Niagara Dolomite:		
Dolomite; weathered at top	23	83
Test hole 304G		
[Located about 1,500 ft northeast of well 9 (fig. 2)]		
Quaternary System:		
Pleistocene deposits:		
Soil, black	6	6
Silt, gray, soft; some clay	11	17
Clay, blue, silty; some rock fragments	30	47
Clay, brown, silty; broken rock and boulders	17	64
Silt, brown, clayey; some rock fragments	3	67
Clay, brown, silty; broken rock	6	73
Clay, gray, very silty	3	76
Silt, brown, sandy; broken rock; some coarse gravel at 90 ft	22	98
Silt, gray, sandy; broken rock	12	110
Silurian System:		
Niagara Dolomite:		
Dolomite; weathered at top	25	135

Data are not available on the water-bearing characteristics of the stratified deposits in the Des Plaines River valley, but small quantities of water might be obtained from wells tapping the beds of sand and gravel. Recharge to the stratified deposits is from local precipitation.

In 1952, Drescher made detailed field studies of the movement of water in the till in a test area about 1,000 feet west of well 13. As a part of these studies, a series of 19 test holes were installed. They were constructed by boring a 12-inch-diameter hole with a power auger to depths ranging from 12 to 19 feet. A 2-inch-diameter hole was then augered a short distance below the bottom of the 12-inch-diameter hole, and a 2-inch-diameter pipe was installed that extended from the bottom of the hole to about 2 feet above land surface. The annular space between the side of the 12-inch-diameter hole and the 2-inch pipe was carefully backfilled and the fill material tamped in place. A 1¼-inch hole was then augered to a depth of about 2 feet below the bottom of the pipe, and a 2-foot length of 1¼-inch perforated stainless steel pipe was installed to serve as a well screen. The test holes were then developed by jetting and bailing.

Each test hole was bailed or a small quantity of water, generally 1 gallon, was injected into the hole. Measurements of the rise or decline in water level in each test hole were made at frequent intervals of time for periods ranging from 4 to 42 days. The change in water level in each test hole was analyzed to determine the coefficient of permeability of the till by a formula described by Luthin and Kirkham (1949).

The coefficient of permeability may be expressed as the rate of flow of water, at the prevailing temperature, in gallons per day, through a cross sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot, or 100 percent. The coefficients of permeability of the till in the test area, obtained by analyzing the water-level data for the 19 test holes, ranged from 0.004 to 0.03 gpd (gallons per day) per sq ft and averaged about 0.01 gpd per sq ft.

Drescher computed the downward rate of movement of water through the till in the test area to be 0.1 inch per day. The saturated thickness of the till in the test area averaged about 95 feet. Thus, about 30 years would be required for water to move from the top of the zone of saturation in the till to the top of the Niagara Dolomite.

HYDROLOGY OF NIAGARA DOLOMITE

RECHARGE AND NATURAL DISCHARGE

Recharge to the Niagara Dolomite in the laboratory area is chiefly from local precipitation. Water enters the Niagara through the overlying deposits of Pleistocene age, which consist chiefly of till. The Pleistocene deposits have a very low permeability, but water that falls as precipitation moves through them to recharge the Niagara Dolomite, because the piezometric surface of water in the dolomite is at a lower altitude than the piezometric surface in the Pleistocene deposits. Some recharge is probably also from Saw Mill Creek, particularly in the lower reaches of the stream where the Niagara Dolomite crops out.

Drescher determined that the permeability of the Pleistocene deposits averaged about 0.01 gpd per sq ft in an area about a thousand feet west of well 13. At the laboratory, the saturated thickness of the Pleistocene deposits averages about 100 feet, and the piezometric surface of water in the Pleistocene deposits averages about 75 feet higher than the piezometric surface in the Niagara Dolomite. The recharge to the Niagara Dolomite, therefore, can be roughly computed by a variant of Darcy's Law,

$$Q_d = P'IA,$$

where

Q_d=discharge in gallons per day,
P'=coefficient of vertical permeability, in gallons per day per square foot,
I=hydraulic gradient, in feet per foot, and
A=area through which percolation occurs, in square feet.

Thus, through a 1-square-mile area of the Pleistocene deposits, the computed recharge is

$$Q_d = 0.01 \times \frac{75}{100} \times 5{,}280 \times 5{,}280 = 200{,}000 \text{ gpd},$$

or for the 6-square-mile area of the laboratory, the computed recharge is 1.2 mgd (million gallons per day). The computed recharge is equivalent to about 4 inches per year, or about one-eighth of the average annual precipitation of 33 inches. It was assumed in the computations that the coefficient of vertical permeability of the till was equal to the average horizontal(?) coefficient of permeability as determined by Drescher and that the computed value of this coefficient was representative of the Pleistocene deposits throughout the laboratory area.

Computations by LeRoux and Drescher (1959), based on the extent of the cone of depression in 1958 and the amount of pumpage at the laboratory in 1948–58, indicate that the recharge to the Niagara Dolomite at the laboratory averages about 3 inches per year.

The amount of recharge to the Niagara Dolomite at the laboratory computed by the two independent methods agrees closely, and the recharge to the Niagara in the laboratory area probably averages 3 to 4 inches per year.

Many small springs and seeps issue from the Niagara Dolomite near the base of the bluff that forms the edge of the Des Plaines River valley. Natural discharge of ground water from the Niagara also occurs in the Des Plaines River valley by evapotranspiration where water levels are near the surface, such as in marshy areas, and by spring flow and seepage into the Des Plaines River.

PUMPAGE

Large ground-water withdrawals from wells tapping the Niagara Dolomite at the laboratory began during construction of the facilities in 1948. Pumping of ground water for public supply, general laboratory use, and cooling has gradually increased. The average monthly withdrawals from the Niagara Dolomite at the laboratory from August 1948 to December 1960 are shown in figure 5. Withdrawals of water averaged about 0.13 mgd in 1949, about 0.64 mgd in 1955, and

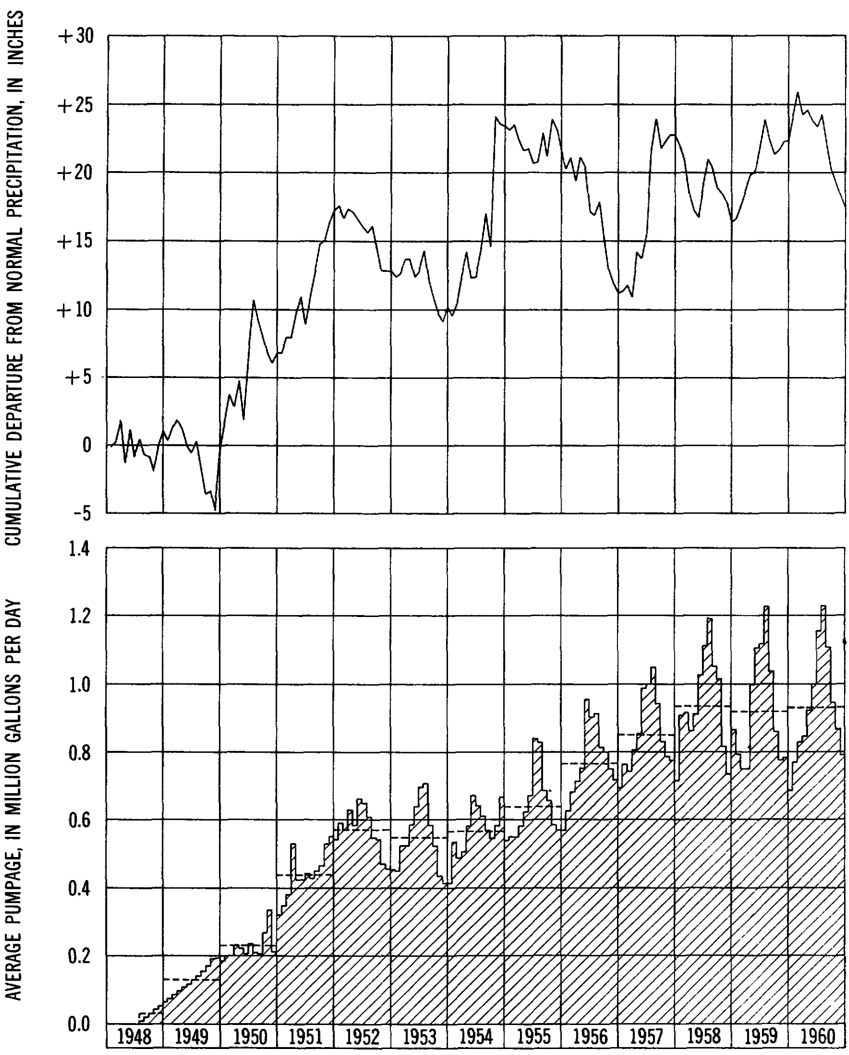

FIGURE 5.—Above, cumulative departure from the normal precipitation of 1921–50 at Midway Airport, Chicago, Ill., 1948–60; below, pumpage at Argonne National Laboratory, Ill., 1948–60.

about 0.93 mgd in 1960. The increase in air temperature in late spring and summer results in increased withdrawals of ground water, particularly for cooling. Similarly, the decrease in air temperature in the fall, winter, and early spring causes a decrease in the amount of pumpage. For example, the withdrawals in 1960 ranged from an

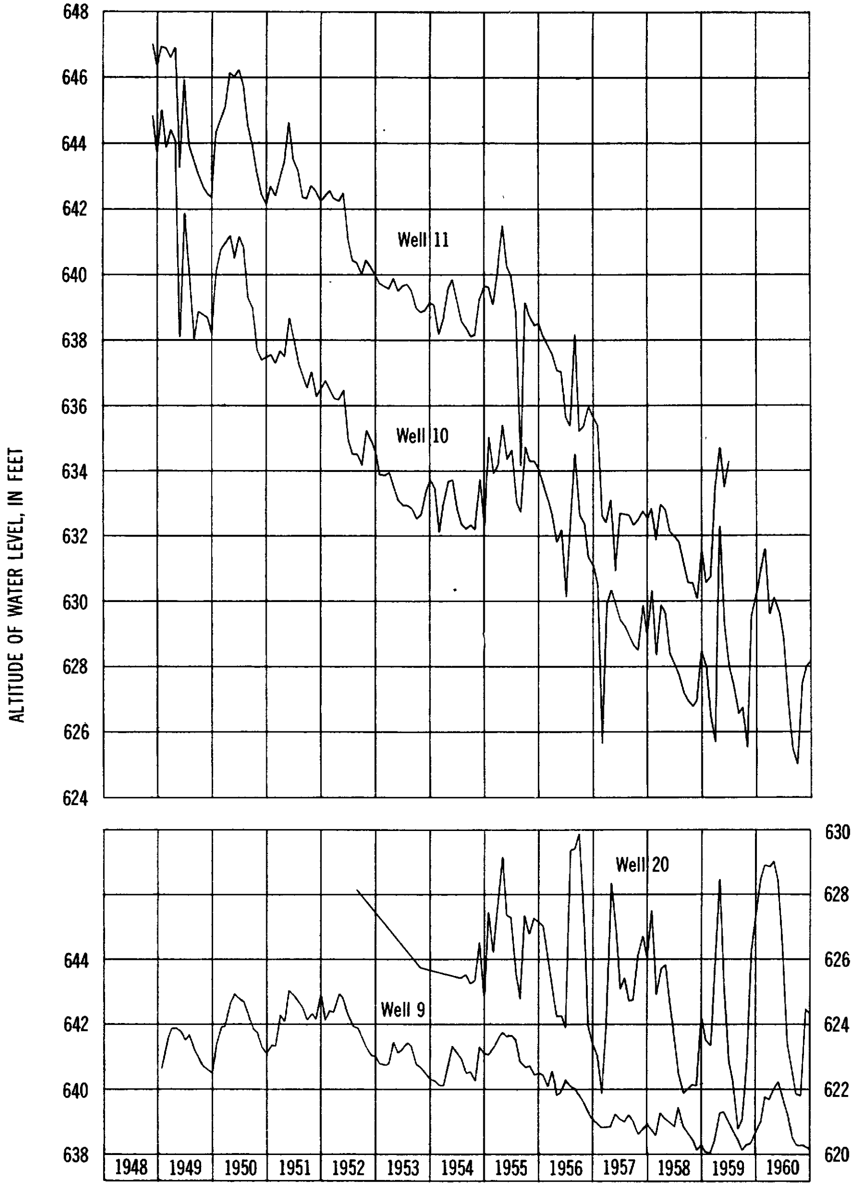

FIGURE 6.—Hydrographs of wells 9, 10, 11, and 20, for the period 1948–60.

average of 0.68 mgd in January to 1.23 mgd in August. The maximum weekly rate of pumping (1.43 mgd) occurred on August 29 to September 4, 1960.

WATER-LEVEL FLUCTUATIONS AND THEIR SIGNIFICANCE

A fluctuation of water level in a well indicates that the ground-water reservoir is adjusting to changes in storage because of variations in recharge and discharge. When recharge exceeds discharge, water levels in wells rise, and when discharge exceeds recharge, water levels decline. A knowledge of these fluctuations is necessary to determine water-level trends and changes in ground-water storage. Other factors that affect water levels—such as changes in atmospheric pressure, earthquakes, earth and ocean tides, and changes in surface loading—generally have only a temporary effect and change only slightly the actual quantity of water stored in the ground-water reservoir.

Periodic measurements of depths to water have been made since 1948–49 in about 20 wells tapping the Niagara Dolomite at the laboratory. Recording gages are operated on five key wells to provide continuous records of the fluctuations in water levels. Hydrographs for wells 9, 10, 11, and 20 are shown in figure 6. The graphs show the lowest water level each month for the periods of record, as determined from charts from recording gages. The recording gage installed on well 11 was removed in June 1959 when well 37 (laboratory shallow well 4), located a short distance from well 11, was placed in operation. The gage was installed at well 38 in the western part of the laboratory area. In October 1960 a recording gage was installed on well 32, near the southwestern corner of the laboratory, to detect changes in water level caused by pumping at the laboratory or in the adjacent area.

Wells 10, 11, and 20 are relatively near the laboratory supply wells, and their levels fluctuate chiefly in response to withdrawals of water at the laboratory. The hydrographs show gradually declining water levels to 1958 owing to the gradually increasing withdrawals of water (fig. 6). The levels also show fluctuations in response to seasonal variations in the rates of pumping. In 1958–60, the average pumpage was relatively uniform, and the trend of declining water levels was halted, although the levels continued to fluctuate seasonally in response to seasonal changes in the pumping rates.

Well 9 is about 1–1½ miles from the laboratory supply wells. From 1949 to the spring of 1952, the water level apparently was not affected by pumping at the laboratory and fluctuated seasonally, chiefly in response to changes in rates of recharge through the overlying Pleistocene deposits. During this period the trend of the fluctuations in water level was about the same as that of the cumulative departure from normal precipitation (fig. 5). Although the level in well 9 continued to fluctuate seasonally, in the spring of 1952 it began a persistent downward trend that continued until early in 1959. The decline in 1952–59, however, amounted to only about 5 feet. The water level fluctuated seasonally in 1959–60 and was at about the same stage in late 1960 as in early 1959.

The piezometric surface of water in the Niagara Dolomite at the laboratory in October 1948, October 1954, and June 1960 is shown in figures 7, 8, and 9. The piezometric maps show the position and areal

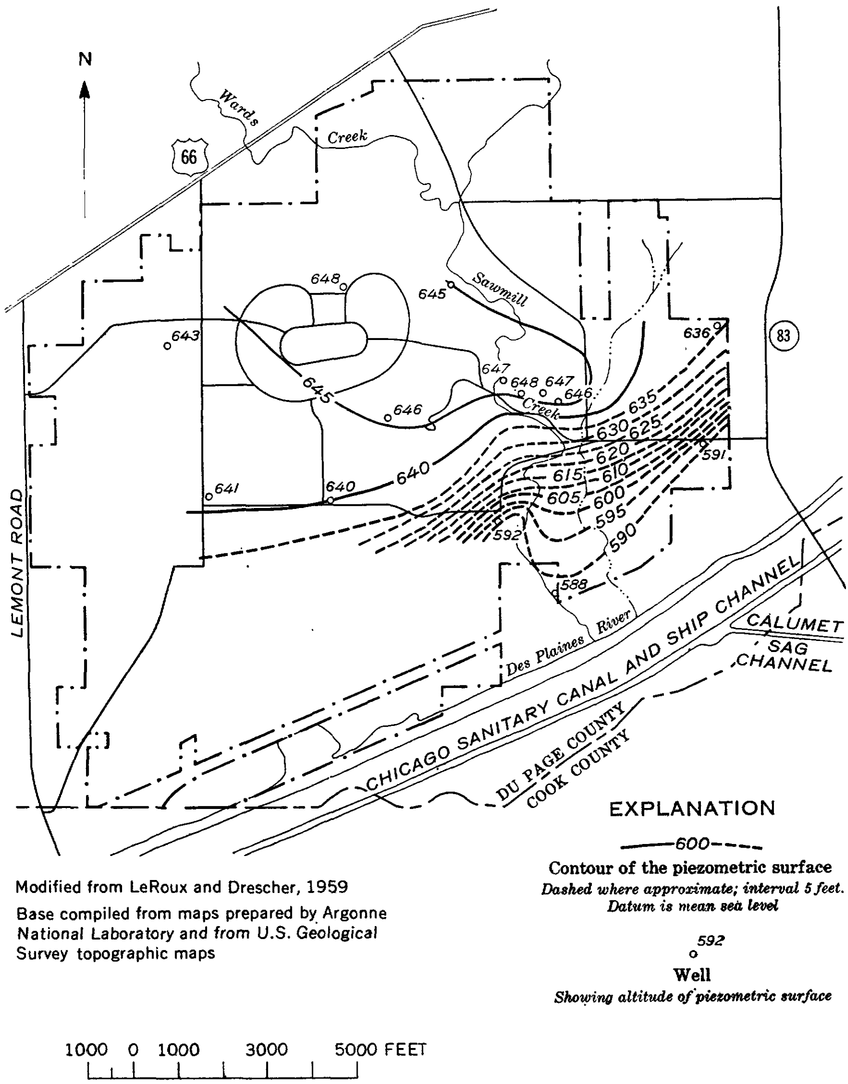

FIGURE 7.—Piezometric surface of water in the Niagara Dolomite at Argonne National Laboratory, Ill. October 1948.

extent of the cone of depression as it existed at the indicated times and the altitudes of water levels in wells tapping the Niagara Dolomite. The maps show also the direction of movement of water, which is approximately normal to the contour lines.

Figure 7 is a map of the piezometric surface about 2 months after withdrawals from the Niagara Dolomite began at the laboratory. It represents natural, undisturbed conditions. The movement of water

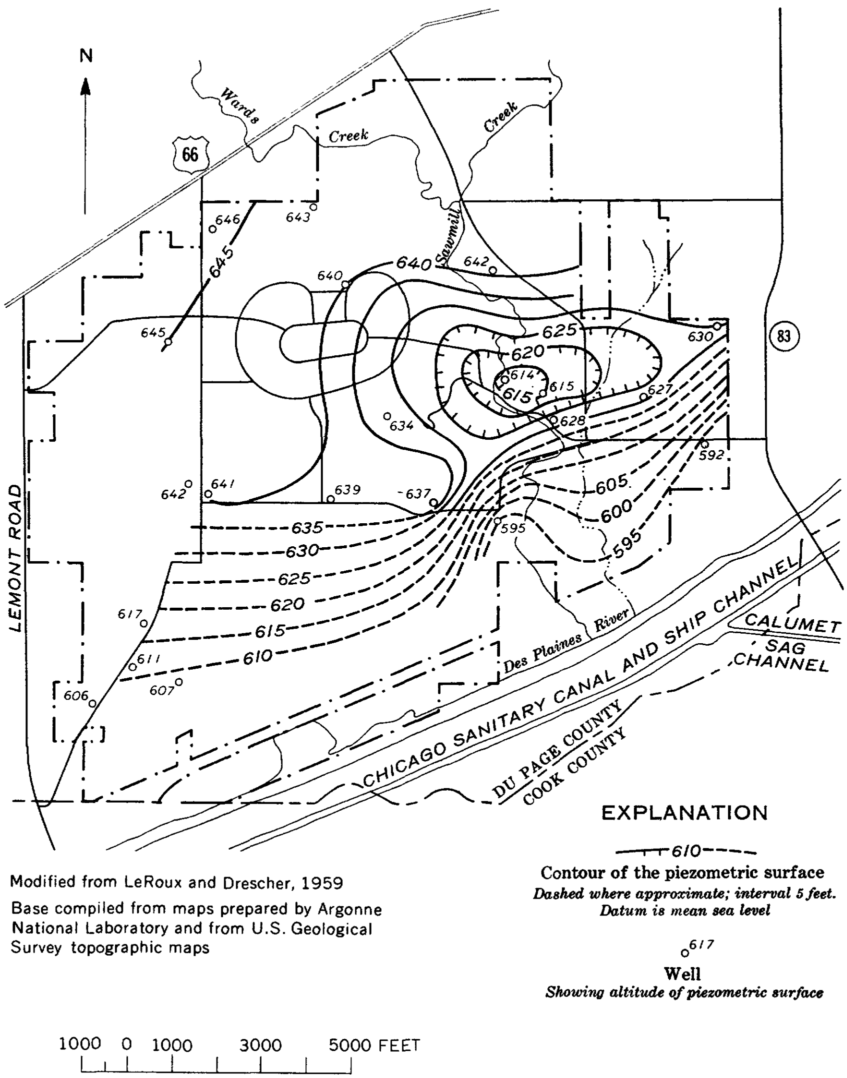

FIGURE 8.—Piezometric surface of water in the Niagara Dolomite at Argonne National Laboratory, Ill., October 21, 1954.

in the area was chiefly to the southeast toward the discharge area at the edge of the Des Plaines River valley.

By October 1954, the pumping of wells 1 and 2 (the source of water supply from the Niagara Dolomite at the laboratory in 1948–54) had created a relatively small cone of depression in the piezometric surface (fig. 8). The cone had a relief of about 10 feet, with its center located at wells 1 and 2. The pumping formed a ground-water divide in the

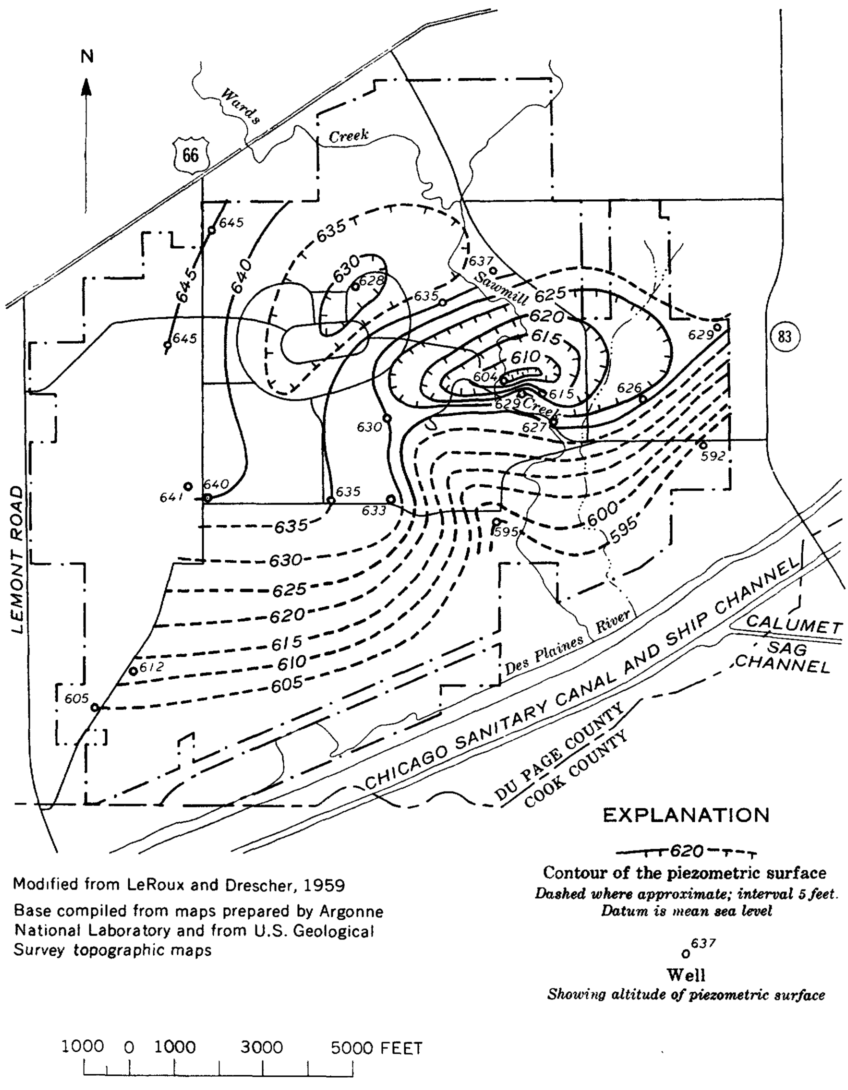

FIGURE 9.—Piezometric surface of water in the Niagara Dolomite at Argonne National Laboratory, Ill., June 2-3, 1960.

vicinity of well 20, about a quarter of a mile southeast of the cone. The divide was about a mile in length and roughly parallel to the cone of depression. North of the divide, water was moving toward the cone of depression. South of the divide and in the areas east and west of the cone of depression and of the divide, water was moving toward the discharge area at the edge of the Des Plaines River valley.

Between October 1954 and June 1960, water levels continued to decline in response to the continually increasing pumping of water from the Niagara Dolomite. Pumping began from well 3 in 1955 and from well 37 (laboratory shallow well 4) in 1959. The main cone of depression was centered at wells 1 and 2 and, in June 1960, had a relief of about 25 feet (fig. 9). Owing to the redistribution of pumping, by 1960 the ground-water divide of 1954 (fig. 8) had migrated northward toward the cone centered about wells 1 and 2. South of this divide, water was moving southeastward toward the discharge area. A shallow cone of depression, with a relief of almost 10 feet, was centered at well 37. This cone is separated from the main cone by a ground-water divide. Both east and west of the cones of 1960, water was moving also toward the discharge area. If the 1960 rate of pumping is maintained or increased and the distribution of pumping does not change significantly, the two cones of depression in the piezometric surface in 1960 will probably merge and form a single large cone.

The approximate decline in water levels in the Niagara Dolomite from October 1948 to June 1960 is shown in figure 10. The maximum decline, 43 feet, was recorded at well 2 near the center of the main cone of depression in 1960. Water levels were at about the same stage in 1960 as in 1948 in the western and southern parts of the laboratory. Although water-level data are not available in the northern part of the laboratory, it is estimated that water levels were at about the same stage in 1960 as in 1948. In the eastern part, however, water levels declined 5 to 10 feet in 1948–60.

The maps showing the shape of the piezometric surface (figs. 7–9) and the map showing the decline in water levels in 1948–60 (fig.10) indicate that the water pumped in 1948–60 from wells tapping the Niagara Dolomite at the laboratory is water that otherwise would have been discharged along the base of the bluff at the edge of the Des Plaines River valley.

HYDRAULIC CHARACTERISTICS

The amount of water that can be withdrawn perennially from a ground-water reservoir depends chiefly upon the capacity of the aquifer to transmit water from the areas of recharge to the points of withdrawal, the amount of water available in the areas of recharge to replace the water that moves to points of withdrawal, and the amount of water available from storage as the water level declines.

The rate at which water is transmitted depends on the coefficient of transmissibility of the aquifer and the hydraulic gradient. The coefficient of transmissibility may be expressed as the rate of flow of water, at the prevailing temperature, in gallons per day, through a vertical section of the aquifer 1 mile wide extending the full saturated

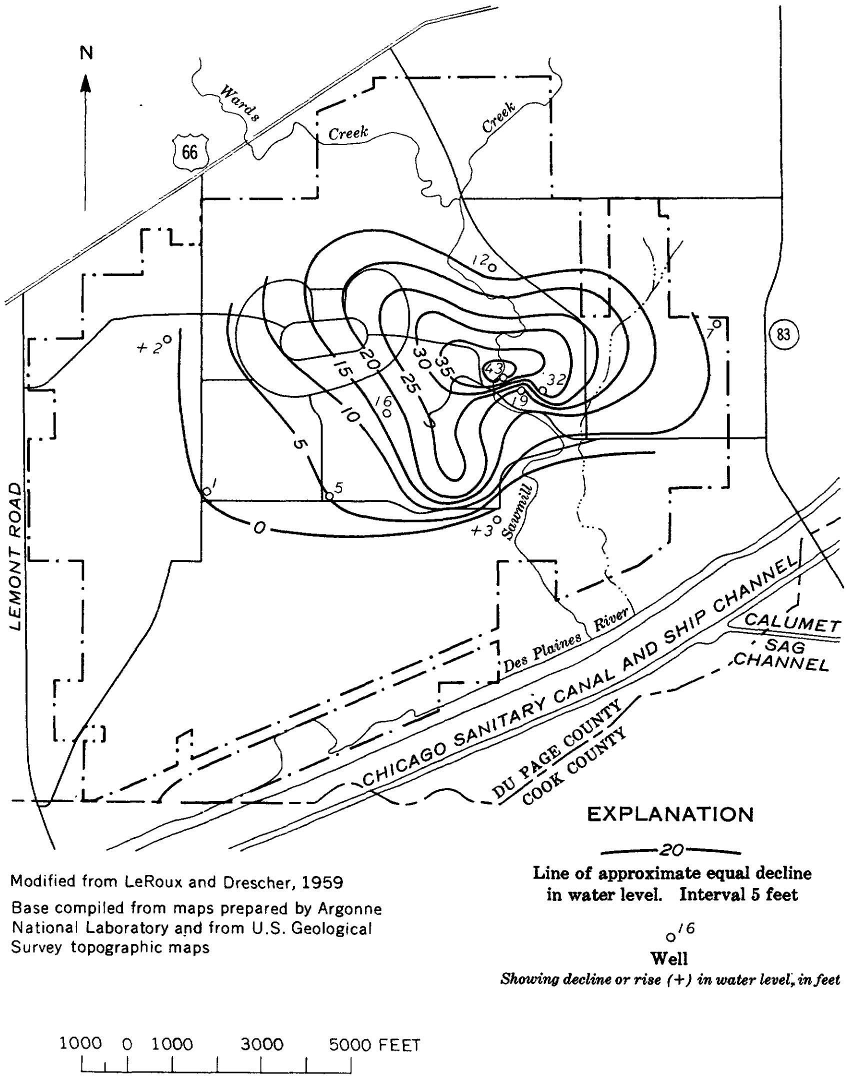

FIGURE 10.—Map showing approximate decline in water levels in the Niagara Dolomite at Argonne National Laboratory, Ill., October 1948 to June 1960.

height of the aquifer under a hydraulic gradient of 1 foot per mile. It may be expressed also as the number of gallons of water per day moving through a vertical strip of the aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot, or 100 percent. The volume of water that will flow each day through a mile-wide section of the aquifer, therefore, is the product of the hydraulic gradient, in feet per mile, and the coefficient of transmissibility.

The amount of water available from storage as the water level declines depends on the coefficient of storage. The coefficient of storage of an aquifer is the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

If geologic and hydrologic conditions are favorable, the coefficients of transmissibility and storage can be used to estimate the rate and amount of lowering in water levels to be expected at various rates and distribution of pumping.

SHORT-TERM AQUIFER TESTS

Short-term aquifer tests were made at the laboratory in 1949 and 1955 to determine the coefficients of transmissibility and storage of the Niagara Dolomite. Each test consisted of pumping a well at a uniform rate of discharge and either observing the amount and rate of drawdown or stopping the pump and observing the amount and rate of recovery in the pumped well and in each of several observation wells. The results of the tests were analyzed by the nonequilibrium formula (Theis, 1935).

The nonequilibrium formula is based on the assumptions that the aquifer is infinite in areal extent, that the aquifer is homogeneous and isotropic (transmits water in all directions with equal facility), that the aquifer's coefficients of transmissibility and storage are constant, that the aquifer is confined between impermeable beds, that the discharging well penetrates the entire thickness of the aquifer, and that the discharged water is released instantaneously from storage with decline in head. None of these conditions are fully met in nature, and considerable judgment is necessary to decide the extent to which they apply in any particular area. Despite the restrictive assumptions on which it is based, however, the nonequilibrium formula has been successfully applied to many problems of ground-water flow.

The apparent coefficients of transmissibility and storage obtained from the short-term aquifer tests at the laboratory are given in table 6. The apparent coefficient of transmissibility ranged from about 10,000 to 70,000 gpd per ft, and the coefficient of storage ranged from 0.00002 to 0.0009.

TABLE 6.—*Coefficients of transmissibility and storage of Niagara Dolomite determined from short-term aquifer tests at Argonne National Laboratory, Ill.*

Date	Pumped well	Observation well	Distance from pumped well to observation well (feet)	Coefficient of trans-missibility (gpd per ft)	Coefficient of storage
May 24-25, 1949	1 off	7	280	10,000	0.0009
		10	3,560	15,000	.00002
		11	5,120	25,000	.00006
		13	5,360	50,000	.00004
Aug. 22-23, 1955	3 on	10	2,815	65,000	.00003
		11	2,300	50,000	.00007
	3 off	10	2,815	70,000	.00004
		11	2,300	50,000	.00009

One of the assumptions upon which the nonequilibrium formula is based is that the aquifer is homogeneous and isotropic. Homogeneity and isotropy are relative terms with respect to time and space. For example, after allowing for the distances involved, if the slightly meandering path of water as it moves toward a well may be described statistically as conforming to the concept of radial flow, the nonequilibrium formula will provide a sound analysis. Conversely, when the flow field is significantly distorted in the area of observation, the assumption of homogeneity is incorrect. At the laboratory, the openings along joints and bedding planes in the Niagara Dolomite are not uniformly disseminated, and in the area sampled by an aquifer test of a few hours or a few days duration, the flow field is probably greatly distorted. Thus, it is concluded that the nonequilibrium formula, or any other method based upon the concept of radial flow, is not applicable to the analysis of data from short-term aquifer tests of the Niagara Dolomite at the laboratory.

The apparent coefficient of transmissibility of the Niagra Dolomite is generally greater and the coefficient of storage is smaller at increased distances from the pumped well. (See table 6.) The apparent changes in the coefficients with the distance from the pumped well are probably caused by distortion of the flow field in the area sampled by the tests. The possible lack of hydraulic connection of the openings in a vertical direction may contribute to the distortion of the flow field because the observation wells for the short-term aquifer tests tap only the upper part of the Niagara Dolomite, whereas the pumped wells penetrate the complete thickness.

LONG-TERM AQUIFER TESTS

ANALYSIS OF PIEZOMETRIC MAPS

The most effective means of determining the hydraulic characteristics of an aquifer is by analysis of records of past pumping and water levels. The shape of the piezometric surface can be used in conjuction with Darcy's law to determine the coefficient of transmissibility of an aquifer, if relatively complete records of pumpage in an area are available.

Darcy's law may be expressed

$$Q=PIA,$$

where

Q=discharge, in gallons per day,

P=coefficient of permeability, in gallons per day per square foot,

I=hydraulic gradient, in feet per foot, and

A=cross-sectional area through which discharge occurs, in square feet.

For many ground-water problems, the formula can be more convienty written

$$Q=TIL,$$

in which Q and I are defined as above, T is the coefficient of transmissibility in gallons per day per foot, and L is the width, in feet, of the cross section of the aquifer through which the discharge occurs. It may be expressed also

$$T=\frac{Q}{IL}.$$

The formula $T=Q/IL$ was applied to the data shown on the piezometric map in figure 8 to determine the coefficient of transmissibility of the Niagara Dolomite. There were no significant changes in water levels from September to October 1954 (fig. 6); this fact indicates that little or no water was being taken from or added to storage and that all or almost all the water pumped at the laboratory was being transmitted from beyond the closed contour lines. The average pumping rate, Q, at the laboratory in October 1954 was 0.554 mgd; the average hydraulic gradient, I, between the 625- and 615-foot contours was 0.009 feet per foot; and the average length of the area between the contours, L, was 8,000 feet. Substitution in the aforementioned formula gives a value for the coefficient of transmissibility of about 8,000 gpd per ft. The formula was applied also to data for August 1952, October 1955, and October 1958 in the same manner as it was applied to the data on the piezometric map for October 1954 in figure 8. The fact that no significant changes in water levels occurred for 1 to 2 months preceding these dates (fig. 6) indicates that little or no water was being taken from or added to storage. The results of the computations are given in table 7.

The average coefficient of transmissibility, as determined from the long-term aquifer tests, is about 8,000 gallons per day per foot. Sufficient data were not available to determine the coefficient of storage. Le Rouxand Drescher (1959), however, estimated the coefficient of storage at about 0.002, based on data from the short-term aquifer tests and long-term declines in water levels.

TABLE 7.—*Coefficients of transmissibility of Niagara Dolomite determined from long-term aquifer tests at Argonne National Laboratory, Ill.*

Date of piezometric map	*Coefficient of transmissibility (gpd per ft)*
August 1952	7, 000
October 1954	8, 000
October 1955	8, 000
October 1958	9, 000
Average	8, 000

APPLICATION OF RESULTS

The principal use of the coefficients of transmissibility and storage is in estimating the amount of lowering of water levels to be expected in an area as a result of any given distribution of pumping from wells. It is desirable, therefore, to check the values of the coefficients obtained from aquifer tests against long-term records of pumpage and water levels.

The theoretical decline in water levels in the Niagara Dolomite at the laboratory from October 1948 to October 1958 was computed by applying the nonequilibrium formula to the pumpage data shown in figure 5. The coefficients of transmissibility and storage of 8, 000 gpd per ft and 0.002, respectively, were used in the computations. The average rate of pumping was 380 gpm in 1948–58. For the purpose of the computations it was assumed that the water was pumped from a single well at a center of pumpage located about midway between laboratory supply wells 1 and 3. It was further assumed that the distribution of pumping was constant in 1948-58.

The computed decline in water levels, less the effect of recharge, should be equal to the actual decline in 1948–58. The maps showing the piezometric surface of water in the Niagara Dolomite (figs. 7–9) indicate that a boundary occurs in the southern part of the laboratory area. The boundary can be considered a recharge boundary, because the supply wells at the laboratory intercept a part of the water in the Niagara that was formerly discharged by seeps and springs along the base of the bluff at the edge of the Des Plaines River valley. For the purposes of the computations, it was assumed that the recharge boundary was a straight line roughly parallel to and near the top of the bluff (figs. 11 and 12). Some recharge, however, probably occurs to the Niagara along Saw Mill Creek, particularly where the dolomite crops out. Thus, the effective recharge boundary may be a few thousand feet north of the location shown in figures 11 and 12.

The effect of recharge was computed by using the method of images. That is, the effect of recharge on the decline in water level produced by a pumping well is the same as though the aquifer were infinite in extent and a recharging well were located on a line perpendicular to the pumping well and at an equal distance on the opposite side of the recharge boundary. The imaginary recharging well operates simultaneously with the pumped well and returns water to the aquifer at the same rate it is withdrawn by the pumped well.

The net theoretical decline in water levels at the laboratory in 1948–58 is shown by the lines of equal decline in figure 11. The observed decline in water levels in several observation wells is also

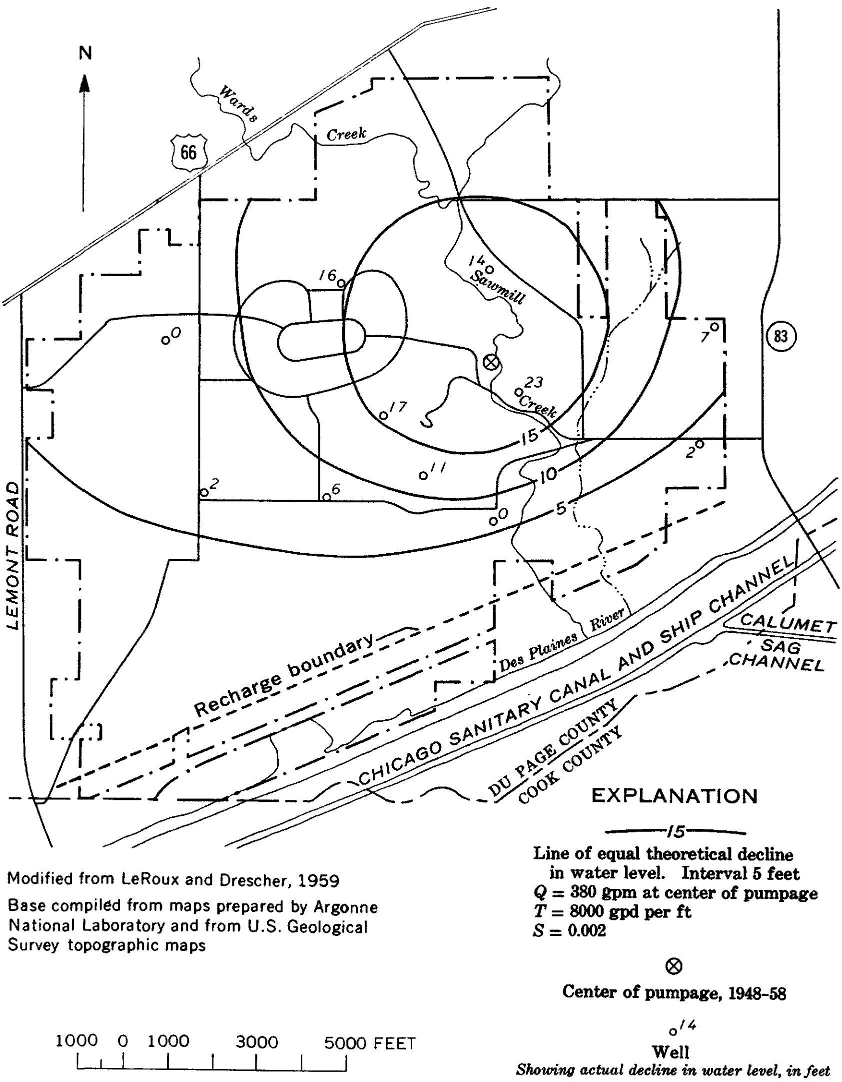

FIGURE 11.—Map showing theoretical and actual decline in water levels in the Niagara Dolomite at Argonne National Laboratory, Ill., October 1948 to October 1958.

shown in figure 11. The differences in the computed and actual declines are relatively small, except at wells 5 and 8 where there was no change in the water level. The lack of decline in wells 5 and 8 may be due to above-average transmissibility or to local recharge. The specific capacity of well 5 is 2 to 4 times greater than the specific capacities of the other laboratory supply wells (table 4); this fact indicates that the transmissibility of the Niagara Dolomite in the vicinity of well 5 is probably much greater than the average. Well 8 is only about 500 feet from a Niagara Dolomite outcrop, and recharge from Saw Mill Creek was probably adequate to prevent a decline in water level.

The coefficients of transmissibility and storage and the location of the recharge boundary used in the computations may be applied with reasonable assurance to estimate, at least for periods of a few years, changes in water levels that will result from any given condition of pumping at the laboratory. The coefficients cannot be used to estimate changes in water levels that will occur for short periods of a few days or a few months owing to the distortion of the flow field in the vicinity of the pumping wells, as described under "Short-term aquifer tests" (p. 31).

The anticipated additional water requirements at the laboratory will be chiefly for cooling purposes and will be supplied from surface-water sources. The increase in laboratory facilities, however, will require an increase in withdrawals of water from the Niagara Dolomite for public supply and laboratory use. Wells 1, 2, 3, and 37 are the present supply wells. Well 5, which is equipped with a pump, is a standby well that will be connected to the supply system when it is needed. Figure 12 shows the computed decline in water levels that would occur if wells 1, 2, 3, 5, and 37 were pumped continuously for 5 years at 350 gpm each (a total of about 2.5 mgd, or about 2½ times the average daily pumpage in 1960). The map in figure 12 indicates that the decline in water levels would be more than 65 feet in the deepest part of the cone of depression. The decline in water levels would range from about 45–50 feet at the northern boundary of the laboratory to no change in water levels along the southern boundary.

CHEMICAL CHARACTER OF WATER

Water that falls as rain or snow contains only small quantities of dissolved mineral matter, but upon reaching the ground, it begins to dissolve minerals from the soil and rocks. The amount and kind of dissolved minerals in ground water varies greatly from place to place, depending upon such factors as the amount and type of organic material in the soil, the type of rocks through or over which the water moves, the length of time the water is in contact with the soil and rocks, and the temperature and pressure of the water. Water passing through or over rocks containing easily soluble minerals will become more mineralized than water passing through or over rocks consisting of relatively insoluble minerals. Calcium and magnesium are present in nearly all ground water, because they are dissolved easily from limestone, dolomite, and other rocks. Other constituents

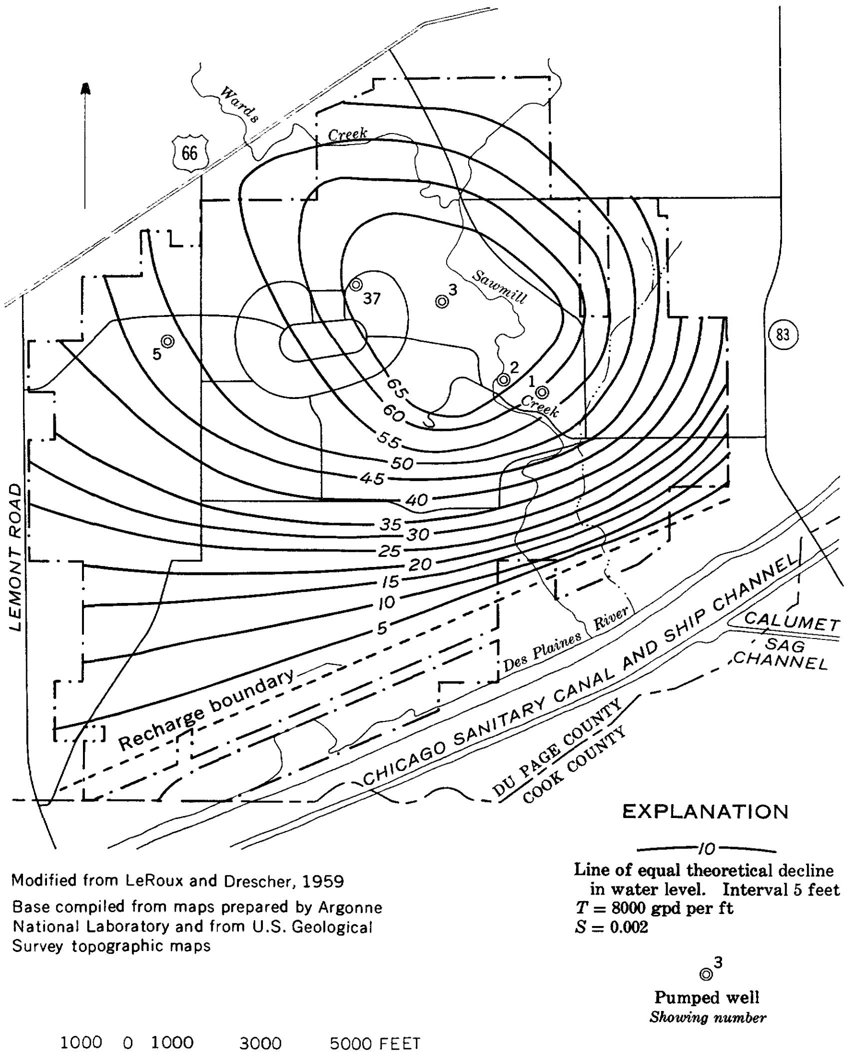

FIGURE 12.—Map showing theoretical decline in water levels in the Niagara Dolomite at Argonne National Laboratory, Ill., after pumping 5 wells at 350 gallons per minute each for 5 years.

commonly found in ground water are iron, manganese, sodium, potassium, silica, carbonate, bicarbonate, sulfate, chloride, and nitrate.

The chemical character of water may restrict its use for public supply, industrial use, and domestic and other purposes. Requirements vary greatly from one industry to another, and the requirements for some industrial applications are more rigid than those for public supplies. The chemical character of water for public supply is commonly judged on the basis of standards promulgated by the U.S. Public Health Service (1946) for water used by common carriers in interstate commerce. These standards for certain common constituents are as follows: Iron and manganese should not exceed 0.3 ppm (parts per million); magnesium should not exceed 125 ppm; chloride should not exceed 250 ppm; sulfate should not exceed 250 ppm; and dissolved solids preferable should not exceed 500 ppm, although, if such a water is not available, a dissolved-solids content of 1,000 ppm may be permitted.

The water in the Mt. Simon Sandstone and the lower part of the Eau Claire Sandstone is of poor chemical quality. A sample of water collected in 1915 at Lemont, about a mile south of the laboratory, from a well 2,284 feet deep was reported to contain 590 ppm of chloride and 1,300 ppm of dissolved solids (Hanson, 1950). The well penetrates to a depth of about 450 feet below the top of the Mt. Simon Sandstone.

Chemical analyses of water from well 1A at the laboratory and a public supply well at Lemont, which tap the upper part of the Eau Claire Sandstone, Galesville Sandstone, and Franconia Sandstone of Cambrian age and the St. Peter Sandstone of Ordovician age, are given in table 8. The hardness of the water is about 300 ppm, and the dissolved-solids content is about 450 ppm. Although the water is classified as very hard, it is not as hard as the water from the shallow Niagara Dolomite.

Chemical analyses of water from seven wells tapping the Niagara Dolomite at the laboratory are given in table 8. The calcium and magnesium contents range from 92 to 113 ppm and from 44 to 60 ppm, respectively, and average about 100 and 50 ppm. The sulfate content of the water ranges from 24 to 130 ppm and averages 70 ppm. The chloride content is low, averaging about 3 ppm. There are objectionable amounts of iron in the water from some wells. The iron content is extremely variable from well to well, ranging from 0.2 to 1.9 ppm and averaging 1.0 ppm.

The dissolved-solids content of water from wells tapping the Niagara Dolomite ranges from 451 to 577 ppm and averages about 500 ppm. The hardness of the water ranges from 425 to 519 ppm

TABLE 8.—*Chemical analyses of water from selected wells at Argonne National Laboratory, Ill.*

[Geologic source of water: Єu, Cambrian System, undifferentiated; Osp, St. Peter Sandstone; Sn, Niagra Dolomite; Q, deposits of Pleistocene Age. Analyses, in parts per million, by Illinois State Water Survey]

Well	Depth of well (feet)	Date of collection	Geologic source of water	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness (as $CaCO_3$)	Temperature (° F)
1A	1,595	12-10-49	Osp, Єu	13	1.1	83	29	40	93	28	0.4	444	327	57
1	284	9-16-48	Sn		.2	94	45	20	99	4.0	1.9	471	425	52
2	300	8-27-48	Sn		1.0	98	45	15	92	3.0	.1	477	434	52
5	345	9-5-48	Sn		.4	106	52	23	130	.6	3.6	548	481	52
6	95	11-2-48	Sn	17	1.3	113	48	27	130	6.0	.5	577	481	52
10	198	10-20-48	Sn	23	1.1	108	58	10	71	1.0	.4	546	510	57
11	141	do	Sn	27	1.2	108	60	16	67	3.0	.7	564	519	59
14	112	do	Sn	17		100	44	17	100	6.0	1.3	512	435	52
33	122	11-2-48	Sn	20	.7	92	51	8.3	49	2.0	.4	469	444	55
34	150	do	Sn	29	1.9	92	48	3.7	24	4.0	.7	451	425	55
Test hole 311A [1]	117	10-16-48	Sn, Q	24		106	59	79	80	4.0	0.2	593	510	
Test hole 316A [2]	114	11-2-48	Sn, Q	13		57	100	38	80	19	.6	667	557	59
Village of Lemont [3]	1,493	1-21-49	Osp, Єu	12	1.8	77	21	62	78	46	.3	472	277	55

[1] Located about 1,000 ft north of well 13.
[2] Located about 1,000 ft south of well 13.
[3] Located about a mile south of the laboratory.

and averages about 460 ppm. The average hardness is about 135 ppm greater than the hardness of water from deep well 1A.

Chemical analyses of water from two test holes tapping deposits of Pleistocene age and the Niagara Dolomite are given also in table 8. The water is similar in chemical character to the water from wells tapping only the Niagara Dolomite, although it contains a greater concentration of sodium and dissolved solids and is harder. The temperature of water from the Niagara Dolomite averages about 54° F.

The water used at the laboratory is treated before entering the distribution system. The treatment plant is capable of reducing the hardness of water from about 500 ppm to about 85 ppm and of removing or reducing the content of iron, manganese, and silica.

CONCLUSIONS

An adequate supply of water for all present and foreseeable future needs at the laboratory, except for cooling purposes, can be obtained from the Niagara Dolomite. A planned expansion of facilities at the laboratory may require large quantities of water for cooling purposes. This water will be obtained from the Chicago Sanitary Canal and Ship Channel or the Des Plaines River.

In 1958–60 the average yearly rate of withdrawals from the Niagara Dolomite was relatively constant at about 0.93 mgd. In 1959–60 water levels in wells tapping the Niagara had ceased declining or were declining only slightly. The rate of pumping in 1958–60 could probably be continued indefinitely with only small additional declines in water levels. If, however, the average rate of pumping from each of the 5 supply wells at the laboratory was increased by 350 gpm, or a total increase in withdrawals of about 2.5 mgd, after 5 years of pumping, the decline in water levels at the laboratory would range from less than 5 feet to more than 65 feet below the 1960 levels. If the rate of withdrawals remained constant, only small additional declines would occur after the 5 years of pumping.

Water levels were at about the same stage in 1960 as in 1948 in the northern, western, and southern parts of the laboratory. In the eastern part, however, the water levels declined about 5 to 10 feet in 1948–60.

The recharge to the Niagara Dolomite in the laboratory area is estimated to be about 3 to 4 inches per year. This amount of recharge is equivalent to about 0.15–0.20 mgd per sq mi.

Additional deep wells tapping sandstones of Cambrian and Ordovician ages would be tapping formations that are already heavily pumped in the Chicago region and would be subject to large drawdowns in water level and to considerable mutual interference between wells.

The nonpumping water level in the deep well at the laboratory was about 500 feet below land surface in 1960 and had declined at a rate of about 9 feet per year in 1949–60. The water levels in wells tapping the deep sandstones will continue to decline as long as the withdrawal continues to increase. At the laboratory, additional deep wells tapping the sandstones are not recommended.

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