STATE OF INDIANA

DEPARTMENT OF NATURAL RESOURCES

John E. Mitchell, Director

BULLETIN NO. 31

OF THE

DIVISION OF WATER

GEOHYDROLOGY AND GROUND-WATER POTENTIAL OF LAKE COUNTY, INDIANA

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Prepared by the

GEOLOGICAL SURVEY

UNITED STATES DEPARTMENT OF THE INTERIOR

In cooperation with the

DIVISION OF WATER

DEPARTMENT OF NATURAL RESOURCES

1968

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OF LAKE COUNTY, INDIANA

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ABSTRACT

Lake County, in the extreme northwestern corner of Indiana, is underlain by a sequence of about 4,500 feet of sedimentary rocks ranging in age from Cambrian to Quaternary. Some ground water is produced from the rocks of each age represented in the sequence. The principal sources of ground water occur within the upper 350 to 400 feet of rocks. These rocks form a single but complex hydrologic system consisting of three aquifers and two confining layers. Recharge is derived from local precipitation. The system's potential yield is estimated to be 200 mgd (million gallons per day) of which about 7.5 mgd is currently being withdrawn.

The upper 100 feet of the dolomite of Silurian age forms the lowermost aquifer of the system. Recharge to this aquifer through its principal confining layer, unit 4-- clay till, is about 6 mgd under present hydrologic conditions. However, the estimated potential yield is 24 mgd. Natural discharge takes place locally by upward movement, where the head in the Silurian exceeds the head in the overlying rocks, and by downward movement into underlying rocks. Discharge by pumping is about 1.4 mgd, or about 18 percent of the ground water pumped.

Unit 3, a sand, forms the principal Pleistocene aquifer. The aquifer is partly artesian and partly water-table. Recharge to the artesian part is about 100,000 gpd per square mile or 30 mgd under present hydrologic conditions. The estimated potential yield is 60 mgd. Recharge to the water-table part is about 1.2 mgd per square mile and the estimated potential yield 100 mgd. Development of the potential of the water-table part is complicated by the continuing practice of ditching, which dewaters part of the aquifer, and by the aquifer's susceptibility to contamination by industrial and septic wastes.

Natural discharge from the unit takes place by effluent seepage to streams and ditches, evapotranspiration, and downward movement of water to the Silurian aquifer. An estimated 9,248 million gallons was discharged by evapotranspiration from the water-table part during the 1960 growing season. Pumpage from the unit is about 4 mgd, or about 53 percent of the ground water pumped.

Unit 2, a clay till, is the confining layer for the principal Pleistocene aquifer. The unit may have as much as 3 million acre-feet of water in storage. Production from the unit is limited to intertill sand and gravel zones and is estimated to be 100,000 gpd.

The hydrology of unit 2 is significant to both ground- and surface-water resources of the county. Under present hydrologic conditions the unit discharges an estimated 100 mgd of ground water to streams and ditches during the nongrowing season. Evapotranspiration decreases this discharge, and during the 1960 growing season an estimated 7,400 million gallons was discharged by this process.

Unit 1, a sand, is chiefly a water-table aquifer. Under present hydrologic conditions recharge is probably less than 600,000 gpd per square mile. The rate of recharge may have been decreased by more than 50 percent owing to extensive alteration of the unit's hydrology by industrial and urban development. Natural discharge takes place by evapotranspiration and by effluent seepage to streams, ditches, and Lake Michigan. Estimated pumpage from the unit is 1.9 million gpd, or about 25 percent of the ground water pumped. Under present hydrologic conditions the potential yield of the unit is about 30 to 40 million gpd. Development of this potential may be impeded by the unit's susceptibility to contamination by industrial and septic wastes.

INTRODUCTION

Purpose and Scope

A ground-water investigation is currently in progress in northwestern Indiana by the U. S. Geological Survey, in cooperation with the Division of Water Resources, Indiana Department of Conservation. Its purpose is to define the aquifers; their ground-water geology and hydrology and that of their associated beds; factors affecting and problems related to their development; and to estimate their current and potential yields. This report presents an evaluation of that part of the State underlying Lake County and provides information to serve as a guide for sound development and responsible management of the ground-water resources of the county. Standard methods of investigation were used.

Lake County lies adjacent to the heavily industrialized and intensely populated greater Chicago area (fig. 1). The county's industry and population should increase sharply within the next few decades as a result of economic growth of the greater Chicago area and the general economic development of the Great Lakes region. The rural nonfarm population has shown a rapid increase in the northwestern part of the county, particularly in the area adjacent to Illinois. The continued growth of the population southward from Lake Michigan and the potential for industrial development in the northern half of the county will increase greatly the demand for ground water. Interstate competition for ground water available in those sources that underlie both the county and the adjacent area in Illinois will be intensified in the future.

Previous Investigations

Detailed evaluation of the ground-water resources and geology of the county has not been previously published. Publications referring to Lake County are cited in various sections of the report and listed in the selected references.

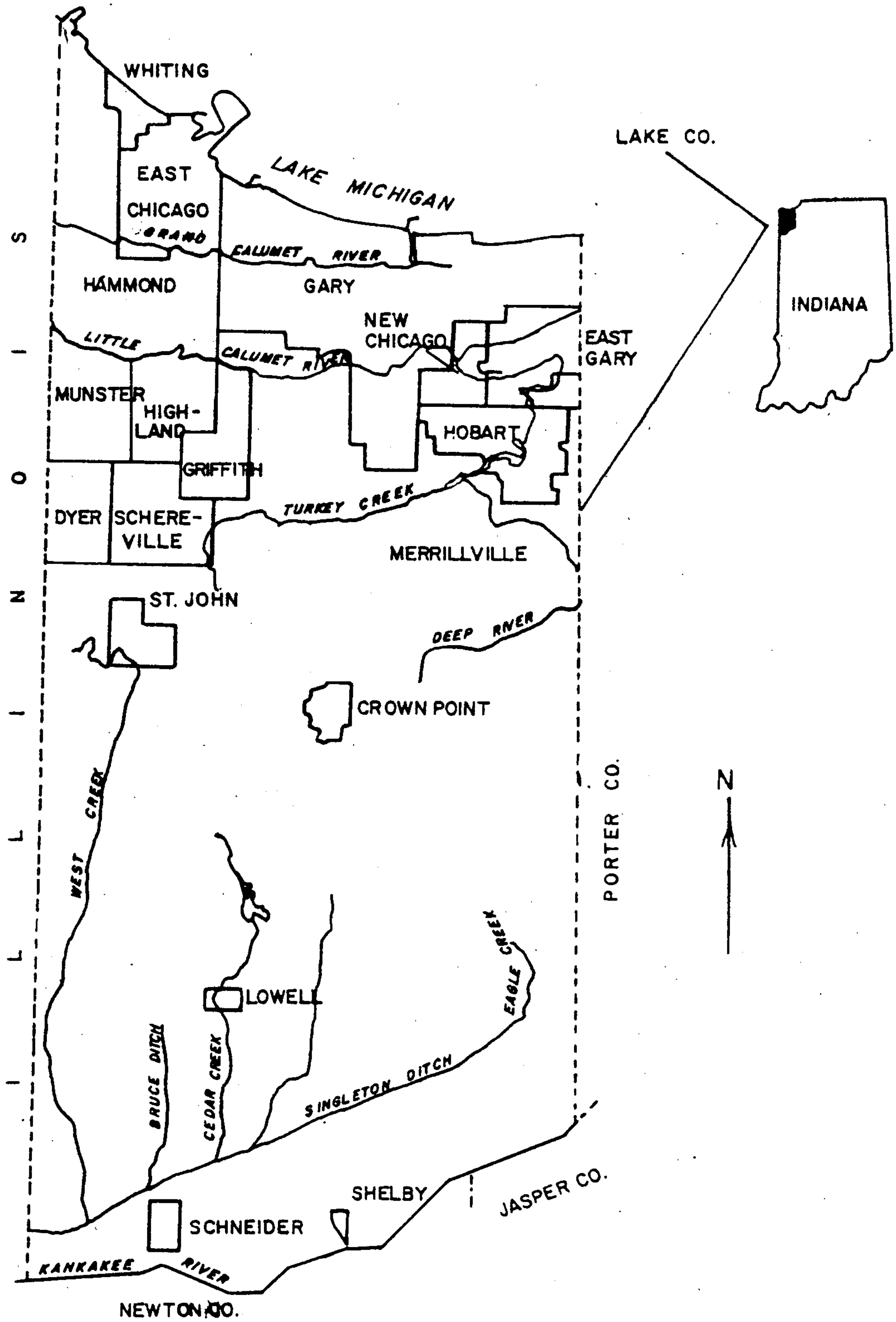


FIGURE I.-- Map of Indiana showing area covered by this report.

Well-Numbering System

Each well referred to in this report is assigned a number that indicates its location according to the official rectangular public-land survey. A comprehensive description of the well-number system is given in Rosenshein (1961, p. 4).

Acknowledgments

The authors thank all persons who contributed time, information, and assistance during the preparation of this report. The investigation was under the immediate supervision of C. M. Roberts, district geologist of the Ground Water Branch of the Geological Survey. J. E. Hackett of the Illinois Geological Survey provided information concerning the geology and hydrology of northeastern Illinois. R. J. Vig, formerly of the U. S. Geological Survey, collected and processed part of the data used in the preparation of the report and assisted in the geologic reconnaissance. Well drillers supplied logs and related information.

The authors also thank the following government agencies which provided information: Geological Survey, Indiana Department of Conservation; Divisions of Oil and Gas and Water Resources, Indiana Department of Conservation; Indiana State Highway Department; Indiana Toll Road Commission; and Indiana State Board of Health.

CLIMATE AND GEOGRAPHY

Climatic setting:--Lake County has a climate characteristic of the northern midcontinent region. The average annual precipitation is about 33 inches (fig. 2 and the average annual air temperature is about 52°F. at Whiting. Figure 3 shows monthly precipitation and temperature at Whiting from 1910 through 1961.

Topography and drainage:--The Valparaiso morainal system is the chief topographic feature of the county (pl. 3). It extends from west to east across the central three-quarters of the county. A principal drainage divide follows the crest of this morainal system and separates the St. Lawrence River basin from the Mississippi River basin. The maps in this report show the configuration of the principal streams and ditches. Courses of most streams have been straightened since the 1900's. Points of highest elevation are in the morainal system. The lowest elevation in the county is the shoreline of Lake Michigan. Maximum relief is about 210 feet.

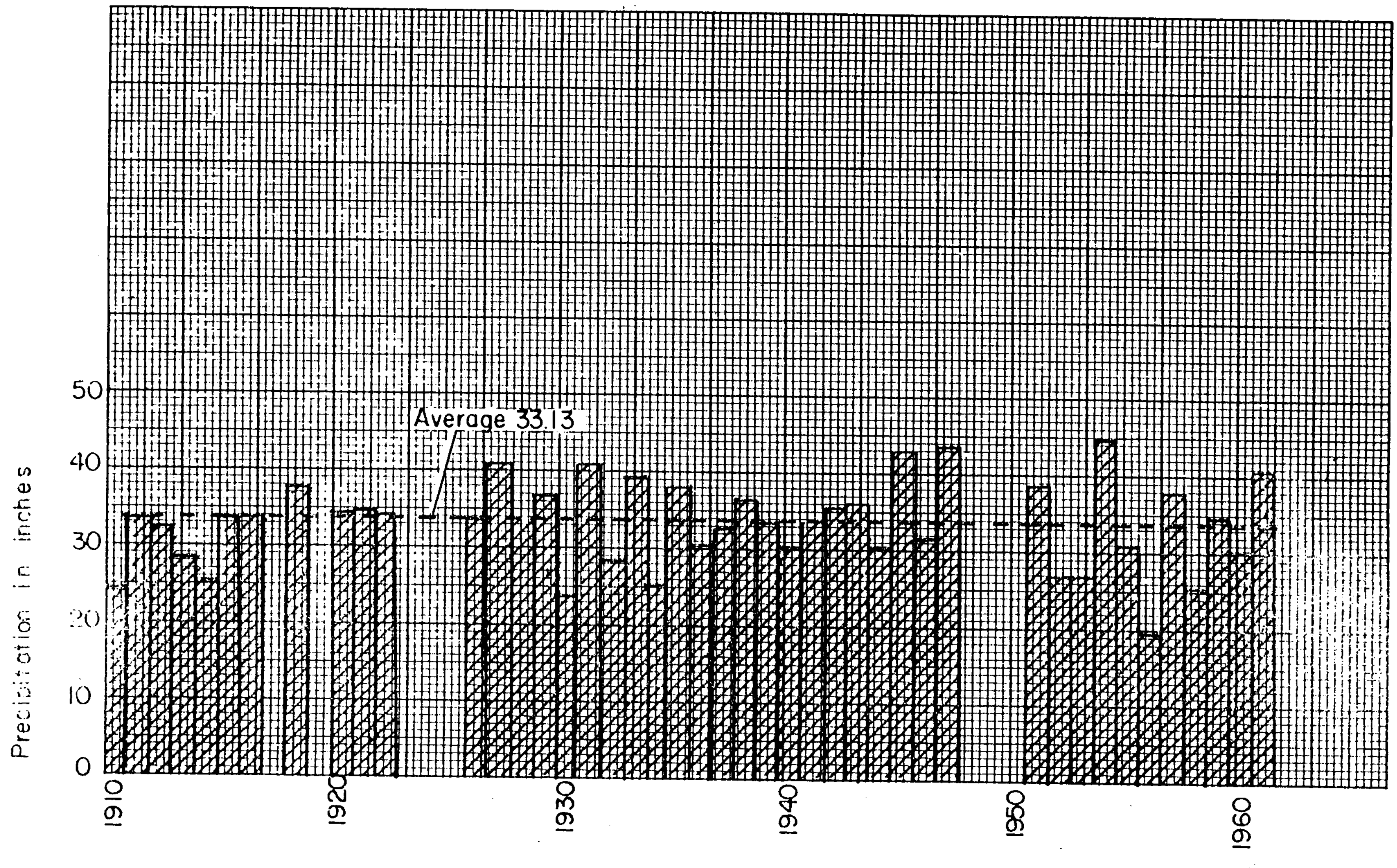


FIGURE 2.-- Annual precipitation at Whiting, Ind: available records, 1910-1961

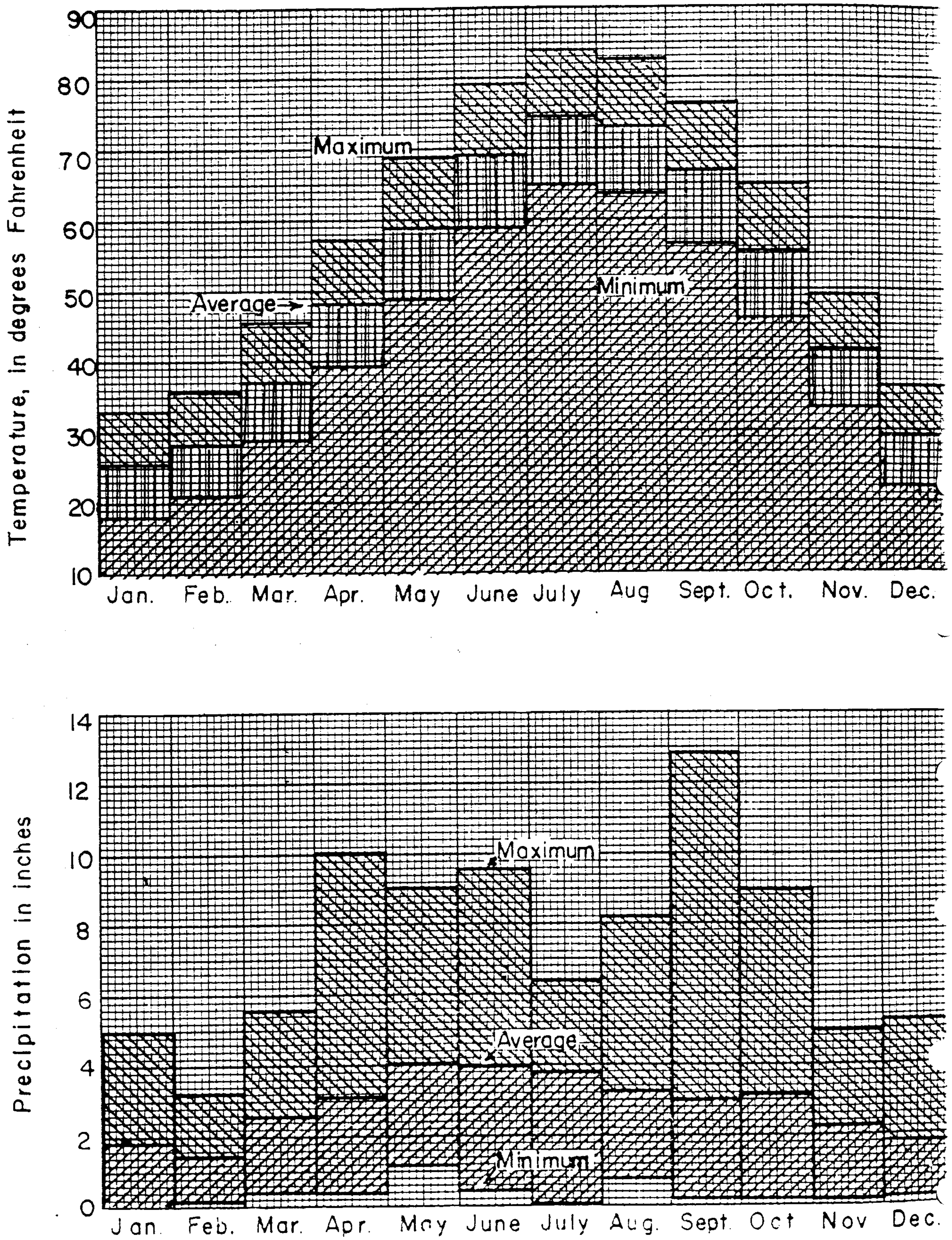


FIGURE 3.-- Monthly temperature and precipitation at Whiting, Ind.: available records, 1931 to 1959

GEOHYDROLOGY OF THE PRINCIPAL ROCK UNITS

Lake County is underlain by a sequence of about 4,500 feet of sedimentary rocks, which range in age from Cambrian to Quaternary. The stratigraphy and geohydrologic properties of these rocks are summarized in table 1. Some ground water is produced from the rocks of each geologic age in the sequence. The rocks in the upper 350 to 400 feet are used extensively as a source of water and have the greatest potential for future water supply development. These rocks are principally of Silurian and Quaternary ages and form a single but complex hydrologic system underlying the county.

Cambrian and Ordovician Systems

Water-bearing characteristics:--The sandstone and related dolomite of Cambrian and Ordovician ages (table 1) form a deep aquifer that is used extensively in northeastern Illinois. In northwestern Indiana the estimated production is less than 40,000 gpd; all of which is pumped by industrial wells. Walton and Csallany (1962, figs. 14 and 15, p. 21 and 22) have shown that the specific capacities (definition, p. 33) of wells tapping the aquifer in Illinois decrease eastward toward Indiana. This evaluation and limited information available in Indiana indicate that specific capacities of about 1 gpm per foot of drawdown or less can be expected from wells tapping this source in Lake County.

Table 1.-- Summary of stratigraphic section and water bearing properties of rock units, Lake County, Indiana

System	Series	Stratigraphic Unit	Thickness (feet) Range	Thickness (feet) Average	Character and distribution	Geohydrologic properties and significance	Remarks
Quaternary	Recent and Pleistocene	Unit 1	0-80	32	Sand, generally fine to medium, somewhat silty, slightly to moderately calcareous, grains generally subrounded; interbedded with zones of beach gravel, silt, and clay; locally organically rich; contains small areas of thinly laminated silt and clay as much as 30 feet thick; underlies about 140 square miles of northern part of county.	Second most utilized aquifer in county; possible source of water for users requiring less than 50 to more than 500 gpm; contributes to base flow of streams. Estimate of average hydraulic properties; permeability, about 450 gpd per square foot; transmissibility, about 15,000 gpd per foot; coefficient of storage, about 0.12.	Geohydrology and topographic expression extensively modified as result of industrial and urban growth in northern part of county.
		Unit 2	0-100+	45	Till; clay, silty, sandy, moderately to highly calcareous, containing some small pebbles; generally olive-gray in lower part, yellowish-gray or pale-to-dark-yellowish-gray in upper part; contains discontinuous lenses of sand and gravel of small areal extent; underlies about 300 square miles of central part of county.	Discontinuous sand and gravel lenses utilized locally as a source of water by some domestic and farm supplies; forms confining layer of unit 3; contributes significantly to base flow of streams. Estimated average vertical permeability, 0.007 gpd per square foot.	Forms dissected ground moraine and terminal moraine of the Valparaiso morainal system; hydrology markedly altered by extensive drainage of upper part of unit. Commonly described by drillers as yellow or brown in upper part and gray to bluish-gray in lower part.
		Unit 3	0-100	40	Sand, generally medium to coarse, somewhat pebbly, silty and clayey, calcareous, grains subrounded to rounded; composed of fragments of shale, quartz, dolomite, limestone, and igneous and metamorphic rocks; contains pyrite fragments and crystals; locally contains thick clays of distinctly limited areal extent; underlies about 370 square miles of southern part of county.	Principal Pleistocene aquifer; possible source of water for users requiring less than 50 to about 700 gpm; contributes to base flow of streams. Estimate of average hydraulic properties of artesian part: permeability, about 600 gpd per square foot; transmissibility, about 24,000 gpd per foot; coefficient of storage, about 0.003: of water-table part; permeability, about 600 gpd per square foot; transmissibility, about 15,000 gpd per foot; coefficient of storage about 0.12.	Exposed at surface in lower part of county.
		Unit 4	0-150	55	Till; clay, silty, sandy, pebbly, slightly to moderately calcareous, locally hard and compact, olive-gray to greenish-gray; contains some relatively thin, discontinuous, intertill sand and gravel zones; in northern part of county contains a relatively thin basal sand and gravel; underlies about 500 square miles of county.	Intertill sand and gravel zones utilized locally as source of water by some domestic and farm supplies; basal sand and gravel, an untapped potential source of water for relatively small supplies; forms confining layer of Silurian aquifer. Estimated average vertical permeability, 0.003 gpd per square foot.	

Table 1.-- Summary of stratigraphic section and water bearing properties of rock units, Lake County, Indiana.--Continued

System	Series	Stratigraphic Unit	Thickness (feet) Range	Thickness (feet) Average	Character and distribution	Geohydrologic properties and significance	Remarks
Devonian	Upper Devonian	New Albany Shale	0-110	20	Shale, somewhat silty, bituminous, sporiferous, thinly laminated, soft in upper part, grayish-black to brownish-black; contains finely disseminated pyrite crystals; underlies about 80 square miles of the eastern part of the county; present locally in the rest of the county as erosional remnants.	Minor source of water for domestic and farm supplies.	Forms upper part of bedrock surface in east-central part of county.
	Middle Devonian	Undifferentiated	0-150	—	Dolomitic limestone and some dolomite; underlies about 150 square miles of the county.	----do----	
Silurian	Middle Silurian	----do----	400-600	500	Dolomite, generally very fine- to medium-grained, calcitic, slightly to highly argillaceous, yellowish- or light-olive gray to olive- or greenish-gray; contains small pyrite crystals and carbonaceous flakes disseminated throughout; locally contains chert and zones of thinly-bedded dolomitic shale; argillaceous material generally concentrated in interstitial spaces between dolomite grains; underlies entire county.	Third most utilized aquifer in county; generally possible source of water for users requiring less than 10 to about 200 gpm; only upper 100 feet of dolomite sufficiently permeable to be considered part of the aquifer. Estimate of average hydraulic properties; permeability, 55 gpd per square foot; transmissibility, 5,500 gpd per foot; coefficient of storage, 0.0008.	Forms upper part of bedrock surface in much of county. Commonly described by drillers as "lime rock, rock, or limestone".
Ordovician	Upper	----do----	400-670	—	Shale and dolomitic shale in upper part; dolomite in lower part; underlies entire county.	Not a source of water in county.	
	Middle	----do----	50-250	100	Sandstone, fine- to coarse-grained; underlies the entire county.	Minor source of water in county.	
Ordovician and Cambrian	Lower Ordovician and Upper Cambrian	----do----	300-700	~ 500	Dolomite, cherty, and sandstone; underlies the entire county.	----do----	
Cambrian	Upper Cambrian	----do----	———	2,600	Sandstone, shale, and dolomite in upper 600 feet; chiefly fine- to coarse-grained sandstone in lower part; underlies the entire county.	----do----	Deposited on basement complex.

Quality of water:--Water from this aquifer in Indiana is of poor chemical quality for general use. The concentration of dissolved solids ranges from 2,000 to 3,500 ppm (parts per million). The water has a high concentration of sodium, calcium, chloride, and sulfate, a moderate concentration of magnesium and bicarbonate, and is very hard. The concentrations of iron, magnesium, sulfate, chloride, fluoride, and dissolved solids generally greatly exceed the recommended drinking-water standards of the U. S. Public Health Service (1962)

Development and potential:--The rocks of Cambrian and Ordovician ages will probably never become a significant source of water in the county. Well yield are small and construction and pumping costs are high compared with those of wells tapping the available shallower and more productive aquifers.

Water temperature is higher and mineral content much greater than that in the shallower sources. Water quality poses economic problems with respect to treatment and effect upon equipment. Safeguards, such as special well construction and proper treatment or disposal of waste water, are needed to prevent contamination of less mineralized water in the shallower aquifers. These limitations show that extensive use of water from this aquifer is generally no economically feasible.

Silurian System

The rocks of Silurian age consist chiefly of dolomite. This dolomite form the principal bedrock aquifer and the basal member of the complex hydrologic system underlying the county. It is not exposed at the surface in Lake County Its lithology, distribution, and general stratigraphic relations are summarized in table 1.

Water-Bearing Characteristics

The porosity (definition, p. 33) of the dolomite, as estimated from well cuttings, is about 5 to 10 percent. This porosity indicates that the rock has a moderate capacity to store fluid. The pores are generally small, many being pinpoint size or smaller, and apparently are not greatly inter-connected. The properties indicate that the natural permeability (definition, p. 33) of the rock is relatively small. This permeability has been increased by exposure of the upper part to chemical and physical weathering during pre-Pleistocene time

The permeability of the dolomite decreases significantly with depth and only the upper 100 feet of rock is sufficiently permeable to be considered par of the aquifer. Coefficients of transmissibility (definition, p. 33) of this upper part range from about 100 to about 50,000 gpd per foot, and the regional value of transmissibility is estimated to be 5,500 gpd per foot. This regiona value is somewhat similar to that obtained by Watkins and Rosenshein (1963) fo the Silurian in north-central Indiana.

The areas of high transmissibility in the rock occur generally on the uplands and upper part of the valley walls of the preglacial bedrock surface. The areas of low transmissibility coincide with deeper parts of the bedrock valleys. The control of water-bearing characteristics of the Silurian by preglacial weathering and erosion is also reported by Watkins and Rosenshein (1963) and Watkins and Ward (1962) in other parts of Indiana. This relationship was used in part to delineate the areas of transmissibility shown on plate 1.

The coefficient of storage (definition, p. 33) for the Silurian aquifer is estimated to average 0.0008. This estimate should be sufficiently accurate for evaluating regional characteristics of the dolomite in the county.

Recharge and Discharge

Fluctuations of the water level in the aquifer owing to seasonal variations in recharge and discharge are shown on figure 4. Recharge to the Silurian aquifer is derived from precipitation. The configuration of the piezometric surface (fig. 5) shows that this recharge occurs locally within the county. Ground water flows north and south from the aquifer's principal divide to points of discharge within the county and locally west and east to points of discharge outside the county. Down gradient from this divide recharge is added, chiefly by percolation through the overlying clayey till (unit 4, p. 21). Rosenshein (1963) has estimated that under present hydrologic conditions this recharge averages about 20,000 gpd per square mile.

Natural discharge takes place by upward movement of water from the Silurian where its head exceeds the head in the overlying rocks and by downward movement into the older rocks. Direct discharge by evapotranspiration can occur only in the extreme southwestern part of the county.

The estimated discharge of wells tapping the aquifer is 1.4 mgd or about 18 percent of the ground water pumped in the county. Of this amount 0.7 mgd is pumped for domestic and farm use, 0.6 mgd for municipal use, and 0.1 mgd for industrial and commercial use. Of the amount pumped by communities for municipal use, Dyer pumps 0.16 mgd, Lowell 0.21 mgd, St. John 0.02 mgd, Schererville 0.17 mgd, and Schneider 0.02 mgd.

Quality of Water

Water in the Silurian aquifer is generally hard although not as hard as that in the overlying drift. The dissolved ions consist chiefly of sodium, calcium, magnesium, and bicarbonate. Concentrations of the dissolved constituents and their significance are summarized in tables 2 and 3.

Geohydrologic control:--Recharge to the aquifer percolates through as much as 250 feet of unconsolidated rock. The water has lost much of its ability to dissolve dolomite by the time it reaches the Silurian. As a result, the properties of the water in the Silurian are not greatly influenced by the chemical composition of the rock composing the aquifer. Therefore, the water's chemical characteristics are determined to a large extent by the chemical characteristics of recharge derived from unit 4. As shown by table 2 all of the determined constituents except sodium and a small amount of chloride, are present in equal or greater amount in the water of the overlying principal Pleistocene aquifer, unit 3. Slightly higher concentration of chloride in water from the Silurian has no apparent significance.

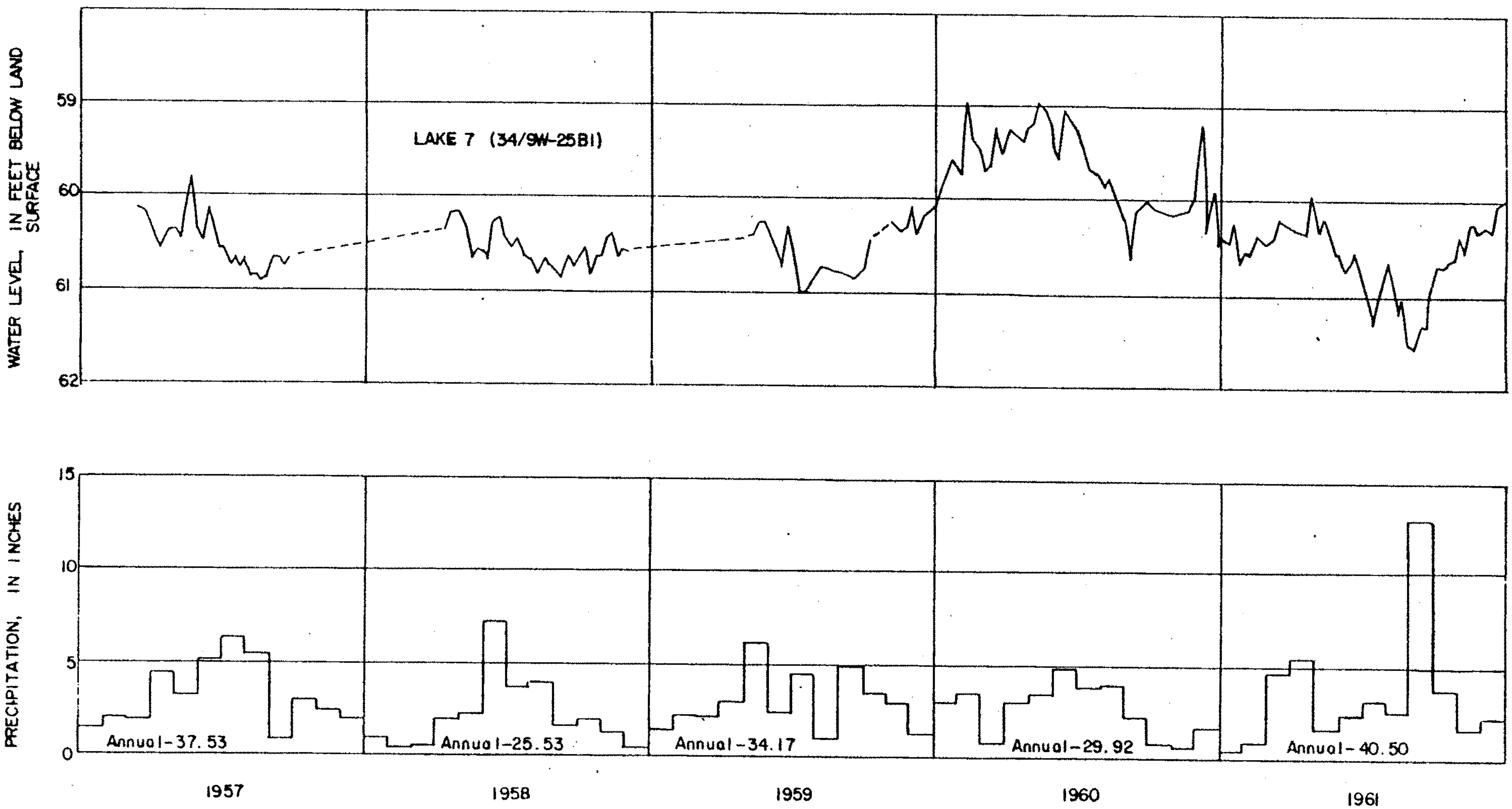


FIGURE 4.--Fluctuation of water level in observation well Lake 7 (34/9W-25B1) in Silurian aquifer and monthly precipitation at Whiting, Ind.

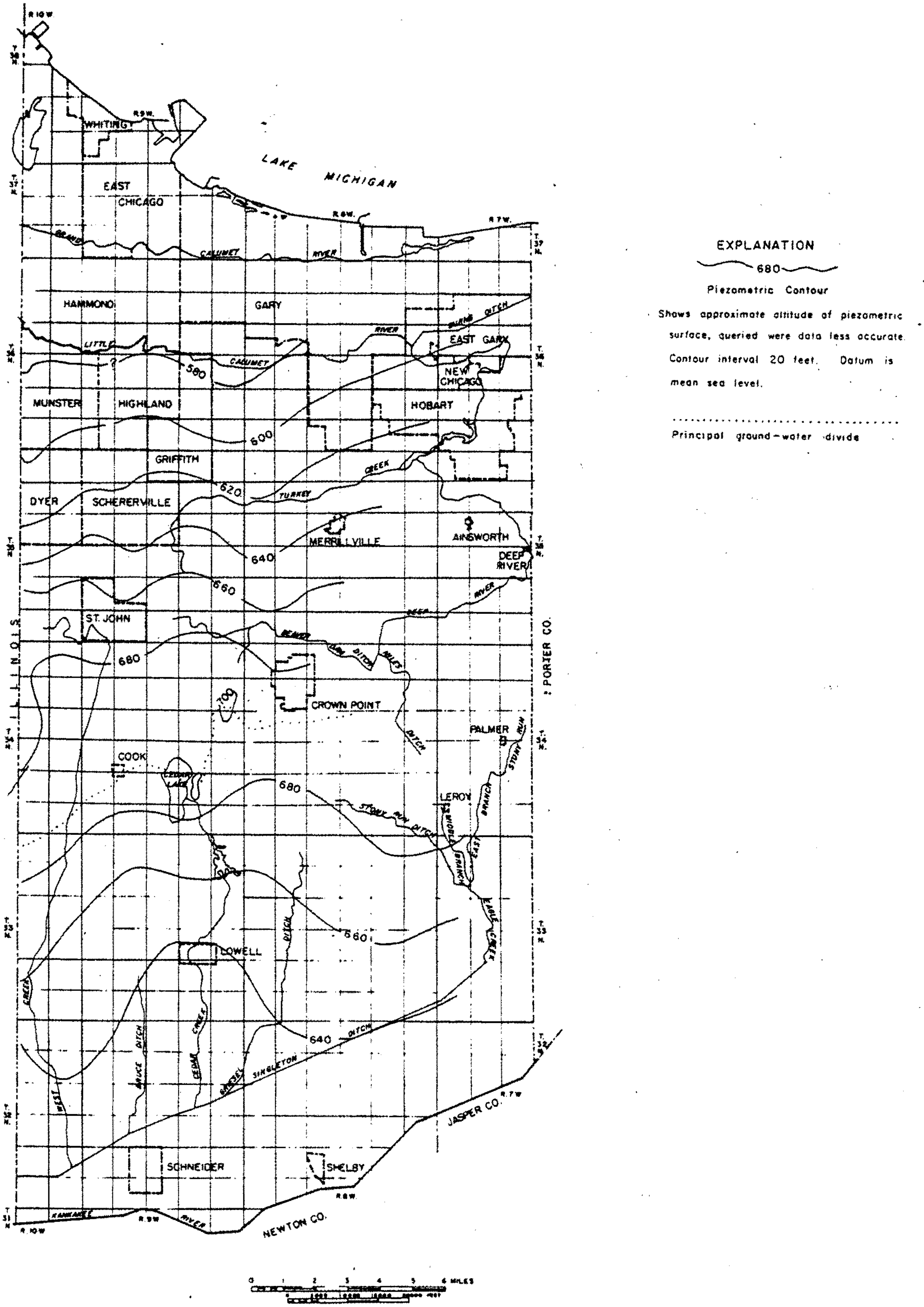


FIGURE 5-- Map showing configuration of the piezometric surface of the Silurian aquifer, Lake County, January 1960. Modified from Rosenshein (1963).

Table 2. -- Summary of water quality in Lake County, Indiana

Independent laboratories: Dearborn Chemical Co., and unknown.
Partial analyses determined in the field office of the U. S. Geological Survey.
Sodium plus Potassium for all partial analyses estimated by subtracting hardness as epm Ca + Mg from epm HCO_3 + epm SO_4 + epm Cl, the acid radicals; (Collins, p. 260 - 261, 1928.)
Total dissolved solids for all partial analyses estimated by the formula: $HCO_3 - 1/6\ HCO_3 + SO_4 + 0.4\ SO_4 + CL + 0.6\ Cl$ (Collins, p. 260, 1928.)
Abbreviations: epm, equivalents per million; ppm, parts per million.

Analyst	Number of samples				Iron (Fe) (ppm)	Calcium (Ca) + Magnesium (Mg) (epm)	Sodium (Na) + Potassium (K)	Percent Sodium (Na) + Potassium (K)	Total Alkalinity as Bicarbonate (HCO_3) (emp)	Sulfate (SO_4) (emp)	Chloride (Cl) (emp)	Total Dissolved Solids (ppm)	Hardness as Calcium Carbonate ($CaCO_3$) (ppm)
Partial analyses	2	Quaternary	Unit 1	Max.	0.8	6.56	0.42	9	3.84	1.37	0.73	278	328
U. S. Geological Survey	1			Min.	.0?	3.36	.17	4.	1.40	.86	.11	210	168
Indiana State Board of Health	3			Mode	--	----	----	-	----	----	----	---	---
Independent laboratories	0			Avg.	.3	4.39	.35	7	2.82	1.17	.39	267	220

Partial analyses	18		Unit2	Max.	7.5	17.76	3.24	28	11.20	7.81	3.83	1,100	888
U. S. Geological Survey	1			Min.	<.1	4.32	.58	5	3.92	.37	.03	330	216
Indiana State Board of Health	0			Mode	1.8	9.89	1.70	12	8.50	1.29	.34	575	494
Independent laboratories	0			Avg.	1.9	9.97	1.60	15	8.38	2.68	.51	634	498
Partial analyses	122		Unit3	Max.	>7.5	40.08	6.89	59	12.80	9.99	4.62	>2,000	2,000
U. S. Geological Survey	4	Quaternary		Min.	<.1	3.04	.37	4	2.68	.10	.06	263	152
Indiana State Board of Health	3			Mode	1.3	7.89	1.60	17	8.56	1.69	.29	560	394
Independent laboratories	1			Avg.	2.1	9.04	1.69	18	7.80	2.17	.40	548	452
Partial analyses	6		Unit4	Max.	5.0	9.76	4.34	50	10.96	1.71	.34	644	488
U. S. Geological Survey	1			Min.	.1	2.64	.56	1	3.76	.10	.11	204	132
Indiana State Board of Health	0			Mode	---	---	---	--	----	---	---	---	---
Independent laboratories	0			Avg.	1.7	6.52	2.10	26	7.85	.53	.22	447	326
Partial analyses	84			Max.	5.0	14.81	21.22	95	10.88	6.77	26.85	1,740	740
U. S. Geological Survey	6	Silurian		Min.	.1	.59	.71	15	3.88	.09	.06	264	29
Indiana State Board of Health	4			Mode	.2	3.41	3.58	35	6.52	.24	.34	570	170
Independent laboratories	3			Avg.	.6	5.34	4.57	44	7.78	.74	1.08	564	267

Table 3.--Significance of selected dissolved mineral constituents and properties of ground water [a/]

Constituent or property	Significance
Iron (Fe)--------------------------	Oxidizes to reddish-brown sediment upon exposure to air. More than about 0.3 ppm stains laundry and utensils reddish-brown. More than 0.5 to 1.0 ppm imparts objectionable taste to water. Larger quantities favor growth of iron bacteria. Objectionable for food processing, textile processing, beverages, ice manufacturing, brewing, and other purposes.
Calcium (Ca) and Magnesium (Mg)-----	Cause most of the hardness and scale-forming properties of water; soap consuming. See hardness. Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and Potassium (K)-------	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate (HCO_3)-----------------	Bicarbonate in conjunction with carbonate (CO_3) produces alkalinity. Bicarbonate of calcium and magnesium decomposes in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas.
Sulfate (SO_4)----------------------	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Public Health Service drinking-water standards recommend that the sulfate content should not exceed 250 ppm. b/

a/ Adapted in part from Palmquist and Hall (1961), p. 34-36

b/ U. S. Public Health Service (1962)

Table 3.--Significance of selected dissolved mineral constituents and properties of ground water[a] --Cont.

Constituent or property	Significance
Chloride (Cl)---------------------	Gives salty taste to drinking water when present in large amounts in combination with sodium. Increases the corrosiveness of water when present in large amounts. Public Health Service drinking-water standards recommend that the chloride b/ content should not exceed 250 ppm.
Dissolved solids-----------------	Public Health Service drinking-water b/ standards recommend that the dissolved solids should not exceed 500 ppm. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$ (Calcium and magnesium)------------------------	Hard water increases amount of soap to make lather. Forms scale in boilers water heaters, and pipes. Leaves curdy film on bathtubs and other fixtures and on materials washed in the water.

b/ U. S. Public Health Service (1962)

The higher concentrations of sodium plus potassium and the lower concentrations of calcium plus magnesium are caused by natural softening, occuring principally in the confining layer, unit 4, overlying the aquifer (table 2). Iron is removed from solution by the same process. In general, the percent sodium plus potassium is higher and iron concentration lower in areas where the hydraulic head in the Silurian is lower than the head in the principal Pleistocene aquifer. The areal distribution of percent sodium plus potassium is shown in figure 6.

Sulfate and bicarbonate concentrations are generally high in the Silurian aquifer wherever they are relatively high in the overlying drift. Some sulfate is removed from the water, possibly before it enters the Silurian. No relationship is apparent between its concentration and head difference.

Development and Potential

Plate 1 shows estimated transmissibilities and relates these transmissibilities to specific capacities and possible yields that can reasonably be expected from properly constructed wells penetrating the full thickness of the aquifer. The specific capacities are those to be expected for a 12-inch well at the end of one day's pumping. The possible yields of wells are estimated from the specific capacities, using a drawdown limited to 80 feet in

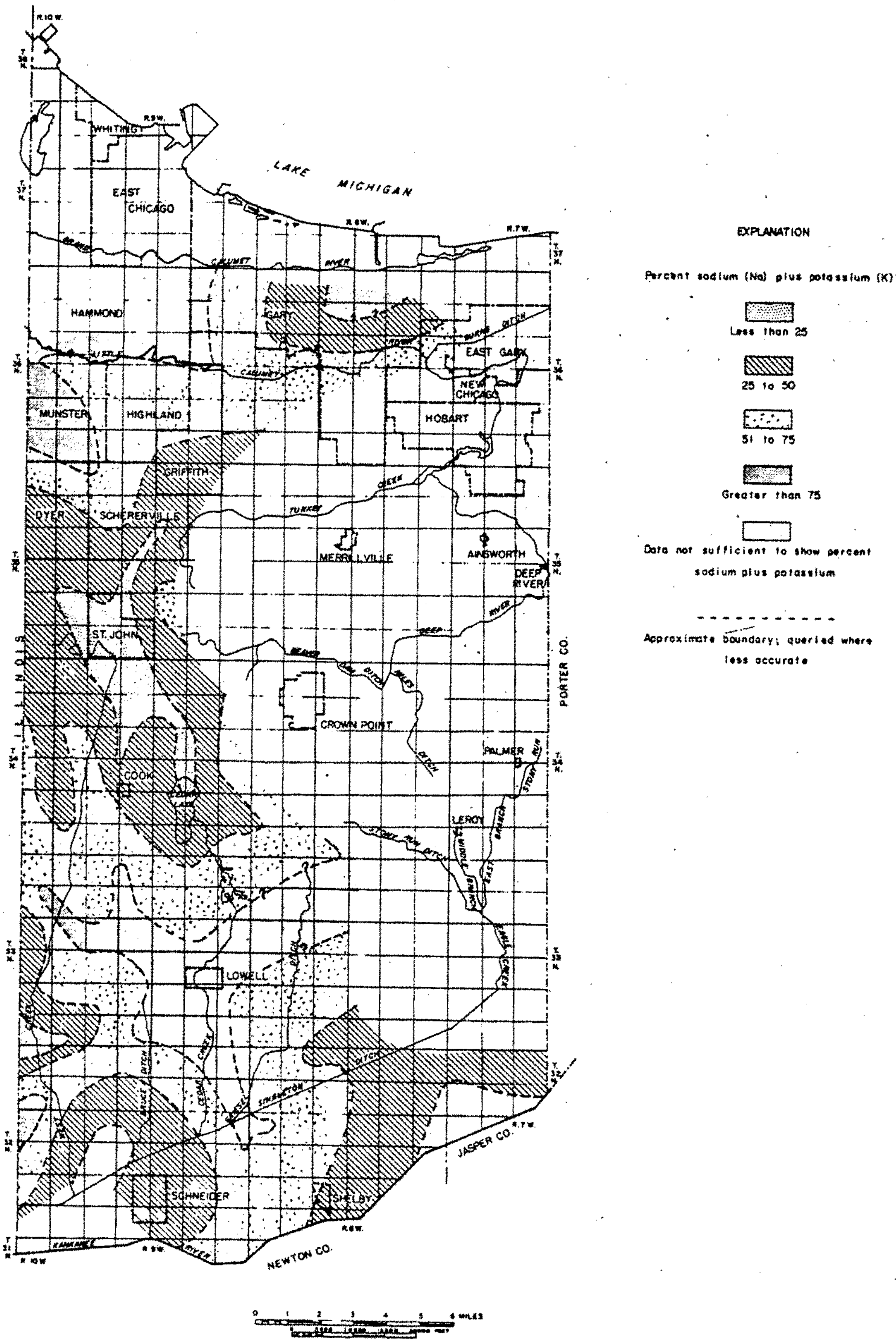


FIGURE 6 --Map of Lake County showing distribution of percent sodium (Na) plus potassium (K) in water of the Silurian aquifer.

the area approximately to the north and 50 feet in the area approximately to the south of the aquifer's principal divide (fig. 5). The yield for a specified drawdown will be greater for a larger diameter well than for a smaller diameter well. This relation also applies to longer or shorter pumping times. Because of these and other limitations, such as well efficiency, the map gives only an approximation of the capability of the aquifer as a source of water.

The Silurian aquifer will generally yield less than 200 gpm to properly constructed wells. Yields can possibly be increased by acidizing. Because the dolomite is argillaceous, some mud results from drilling. This mud should be removed to obtain the maximum yield. Removal may be aided by the use of polyphosphates.

The pumping level in a well should not be lowered below the top of the aquifer where the more permeable zones occur. Intermittent or continuous lowering of the water level below these zones can result in excessive precipitation of the dissolved solids from the water. The precipitation in the immediate vicinity of the well can cause a large decrease in well yield.

The depth to the top of the aquifer can be estimated from plate 2 for the western, northeastern, and southeastern parts of the county, where the Silurian forms the bedrock surface. This depth can be used in conjunction with plate 1 to estimate the depth to which a well must be drilled in order to develop a water supply. The thickness of the aquifer to be penetrated depends on the desired yield. The full thickness should be penetrated in areas of low transmissibility to obtain the largest yield. In areas of high transmissibility only the upper 25 feet or less need be penetrated for a domestic or farm supply.

The quantity of water potentially available for development from the Silurian is dependent upon its rate of recharge. This rate is controlled to a large extent by the geohydrologic properties of its confining layer. Recharge to the aquifer is currently estimated to be about 6 mgd. Rosenshein (1963) has shown that the rate of recharge will increase as the aquifer is extensively developed and estimates that its potential yield is about 24 mgd. The present pumpage is about 5 percent of this potential yield.

Devonian System

Middle Devonian Series

The dolomitic limestone and dolomite of Middle Devonian is not used extensively as a source of water. The estimated pumpage from this rock is about 10,000 gpd. Detailed information is lacking about its physical properties and its water-bearing characteristics. However, the information in the table below indicates that the limestone and dolomite is a potential source of only small quantities of water.

Well	Estimated coefficient of transmissibility (gpd per foot)	Thickness of aquifer penetrated (ft.)	Estimated coefficient of permeability (gpd per square foot)
34/8W-7L3	1,400	12	120
13A1	200	62	3
34/9W-24H2	2,100	1	190

Upper Devonian Series

The shale of Late Devonian age is used locally as a source of water for domestic and farm supplies. Pumpage from this rock is estimated to be about 30,000 gpd. The information listed in the table below shows that the shale is a possible source for supplies requiring less than 25 gpm. Specific capacities of about 1 gpm per foot of drawdown can generally be expected from wells tapping this rock.

Well	Estimated coefficient of transmissibility (gpd per foot)	Thickness of aquifer penetrated (ft.)	Estimated coefficient of permeability (gpd per square foot)
33/8W-4L1	5,200	62	80
33/9W-12B2	1,700	20	90
12G6	2,600	11	240
34/8W-6Q1	830	14	60
7K1	4,000	23	170
20M5	7,100	18	390
29D2	4,700	15	310
35/8W-32Q2	1,600	14	110
36/9W-14A1	600	4	150

Quaternary System

The bedrock is overlain by unconsolidated rocks of Quaternary age which locally are more than 250 feet thick (pl. 2). These rocks were deposited chiefly as a result of glaciation during Pleistocene time. Their geology is described to some extent by Blatchley (1897), Leverett and Taylor (1915), and others. A more comprehensive description of the surficial expression and the subsurface geology of the rocks is given in a thesis titled, "Geology of the Unconsolidated Deposits of Lake County, Indiana", by R. J. Vig (1962), University of North Dakota. Rosenshein (1962) subdivided the rocks into the four lithologic units used in this report. All of the units are exposed at the surface and their areal extent and geologic character are shown on plate 3. Their stratigraphy and geohydrologic characteristics are summarized in table 1. These rocks in conjunction with the Silurian aquifer form a single but complex hydrologic system. The Quaternary units are discussed in ascending order on the following pages.

Unit 4

Water-bearing characteristics:--Unit 4 consists mainly of clay till that forms the principal confining layer overlying the dolomite of Silurian age. Recharge to the underlying rock occurs by downward movement of water through the till. The quantity of water passing through the unit depends in part on its vertical permeability. This permeability is estimated to average 0.003 gpd per square foot (Rosenshein, 1963).

The storage capacity is dependent upon porosity. The original porosity of the clay may have been as much as 50 to 60 percent. This porosity has been reduced by compaction since deposition and may now be 30 to 40 percent. Based on this porosity the unit may have as much as 6 million acre-feet of water in storage.

Development and potential:--The permeability of the clay is small, and it does not yield water readily to wells. Production from the unit is limited to discontinuous zones of intertill sand and gravel. These zones are used locally for domestic and farm supplies. Pumpage from the sand and gravel is estimated to be 100,000 gpd.

The basal part of the unit contains a relatively thin sand and gravel zone that fills the deeper parts of several preglacial valleys (fig. 7). The basal sand and gravel is generally less than 15 feet thick. It is a potential source of water for small supplies and has not been tapped to date.

Unit 3

Water-bearing characteristics

Unit 3 consists chiefly of sand (table 1) and forms the principal Pleistocene aquifer in the county. The aquifer is composed of an artesian and a water-table part. Its permeability ranges from less than 200 to more than 1,000 gpd per square foot and is estimated to average 600 gpd per square foot. The transmissibility ranges from less than 10,000 to more than 50,000 gpd per foot. The regional value is estimated to be 24,000 gpd per foot for the artesian part and 15,000 gpd per foot for the water-table part.

The coefficient of storage for the artesian part is estimated to average 0.003. In the southern part of the county, where the unit is water table, the coefficient of storage is estimated to average 0.12. These estimates should be sufficiently accurate to evaluate regional characteristics of the aquifer.

Recharge and discharge

Fluctuations of the water level in the aquifer owing to seasonal variations of recharge and discharge are shown on figure 8. Recharge to the unit is derived from local precipitation as shown by the configuration of the aquifer's piezometric surface (fig. 9).

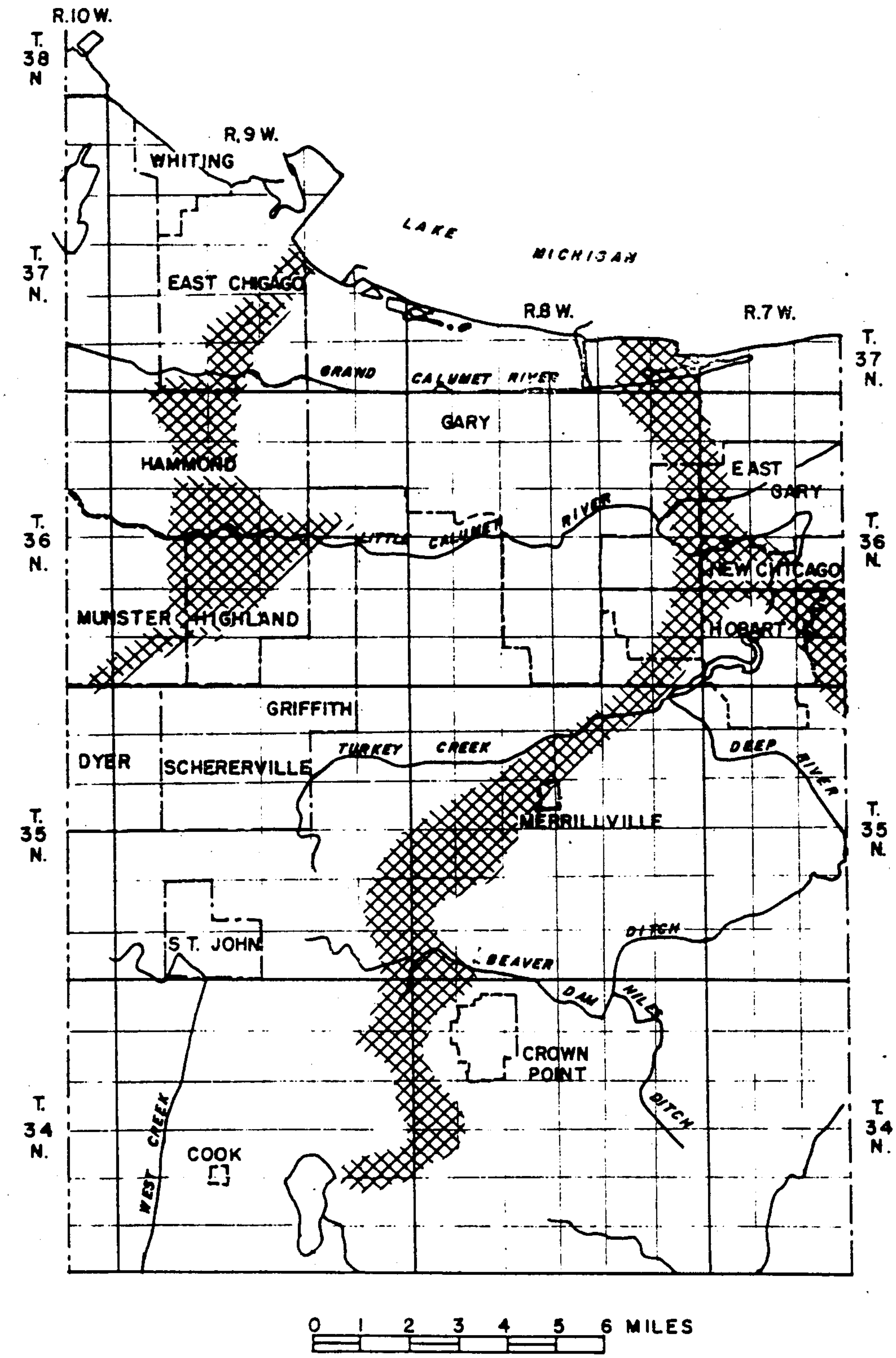


FIGURE 7. --Map showing areas of potential production from sand and gravel in basal part (crosshatched pattern) of Unit 4.

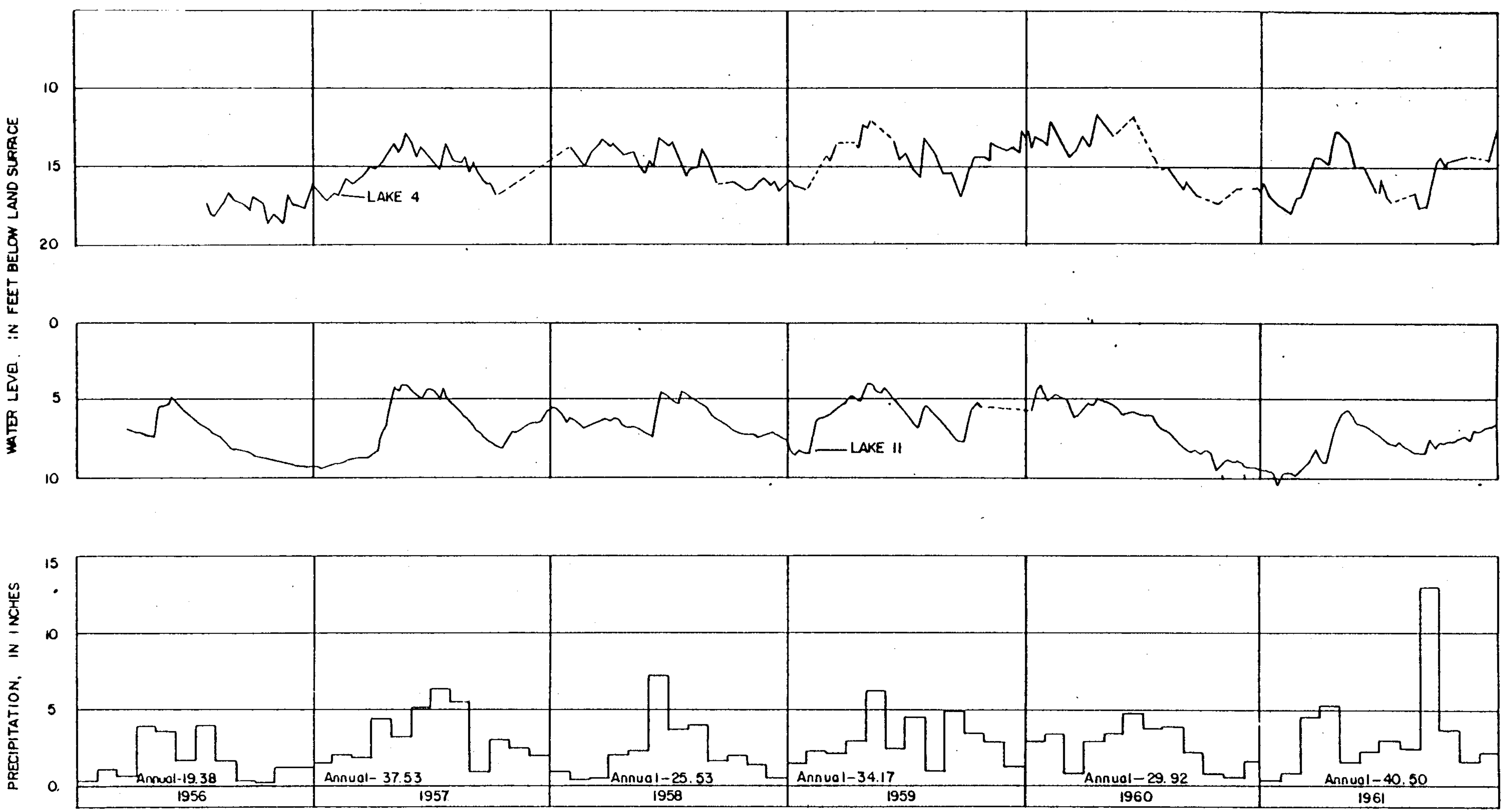


FIGURE 8. -- Fluctuations of water levels in observation wells Lake 4 (35/9W-2J1) in artesian part and Lake 11 (32/8W-28F1) in water-table part of unit 3 and monthly precipitation at Whiting, Ind.

Recharge to the artesian part takes place by slow percolation through the aquifer's confining layer, the overlying clay till (unit 2, p. 28). Rosenshein (1963) has estimated that, under present hydrologic conditions, this recharge averages 100,000 gpd per square mile.

Recharge to the water-table part occurs chiefly by direct percolation of precipitation through the upper part of the unit which crops out in the southern part of the county (plate 3). This recharge is estimated to average 1.2 mgd per square mile.

Much natural discharge from the artesian part occurs along the unit's northern edge as leakage upward through the confining layer. This discharge contributes to conditions causing marshes. Some natural discharge takes place by evapotranspiration. The quantity discharge directly by this process is relatively small and occurs mostly where the confining layer is less than 20 feet thick. Discharge to many of the streams can take place only by upward movement of water from the artesian part where its hydraulic head exceeds the hydraulic head in unit 2. Discharge from both the artesian and water-table parts also occurs by downward movement through unit 4 to the Silurian aquifer.

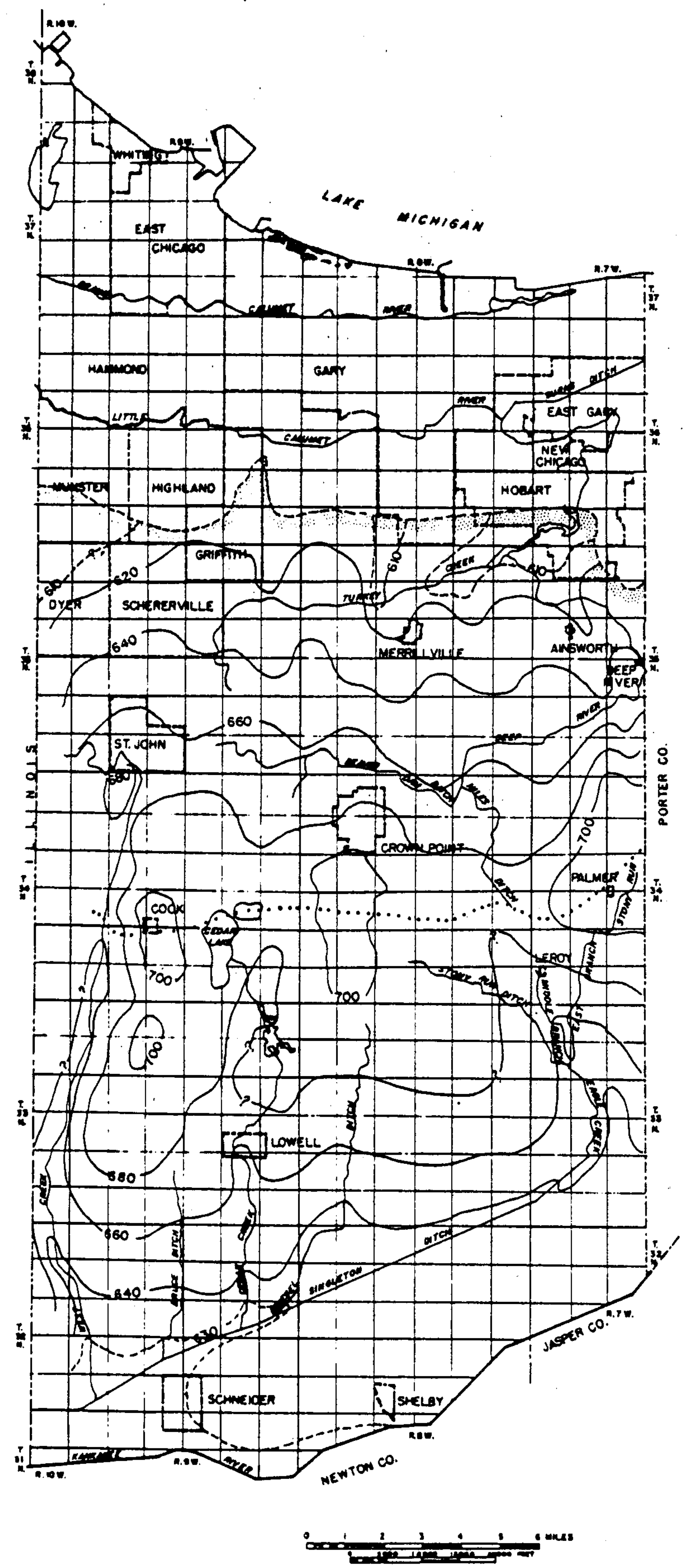
Natural discharge from the water-table part occurs chiefly as effluent seepage (definition, p. 33) to the ditches and streams that penetrate the unit and as direct evapotranspiration. Effluent seepage constitutes most of the discharge from the water-table part in the non-growing season and only a small part in the growing season. However, this discharge makes up much of the flow of the streams and ditches in the low flow period from July through September.

An estimated 9,250 million gallons was discharged by direct evapotranspiration from the water-table part during May through September, 1960. Estimates of the average daily and monthly discharge by evapotranspiration are listed in the table below.

Month	Estimated average daily discharge by evapotranspiration (in million gallons)	Estimated monthly discharge by evapotranspiration (in million gallons)
May	38	1,178
June	38	1,140
July	38	1,178
August	82	2,542
September	107	3,210

These estimates were obtained by evaluating the aquifer's contribution to the base flow of Singleton Ditch at Schneider, and by obtaining the average differences between the contribution during the non-growing season and the contribution for each month of the growing season.

Wells tapping the unit discharge an estimated 4mgd. This discharge accounts for 53 percent of the ground water used in the county and is pumped mostly from the artesian part of the aquifer. Of this amount 2.6 mgd is pumped for domestic and farm use, 0.7 mgd for municipal use by Crown Point, and 0.7 mgd for industrial and commercial use.



EXPLANATION

660
Piezometric contour
Shows approximate altitude of piezometric surface; queried where data less accurate. Contour interval 20 feet; dashed lines represent half-interval contours. Datum is mean sea level.

Approximate boundary of unit 3

Principal ground-water divide

FIGURE 9.--Map showing configuration of the piezometric surface of the principal Pleistocene aquifer, Lake County, January 1960. Modified from Rosenshein (1963).

Quality of water

The artesian part of unit 3 and its confining layer, unit 2, contain the most highly-mineralized water of all the Pleistocene deposits underlying the county (table 2). The ions in solution are principally bicarbonate, calcium, and magnesium. Locally sulfate is a major constituent. Concentrations of the dissolved constituents and their significance are summarized in tables 2 and 3.

Geohydrologic control:--Recharge to the artesian part of the aquifer must percolate through unit 2, a clay till which contains finely-divided calcareous particles. The particles expose a relatively large surface area per unit volume of material to react with the water. As a result, water from unit 3 contains high concentrations of bicarbonate, calcium, and magnesium derived from unit 2. Distribution of bicarbonates in the artesian part of the aquifer may be caused by differences from place to place in the amount of calcareous material in the overlying till. Percolating ground water has slowly dissolved this material since deposition of the till, and the amount of calcareous material dissolved depends on the amount of water that has passed through the till. Wherever much of the calcareous material in the till has been dissolved in the past, the concentration of bicarbonate in the water presently in the underlying aquifer should be relatively low. The factors controlling the amount of water passing through the till in a given amount of time are the thickness and permeability of the till and the difference in hydraulic head between the till and the underlying aquifer.

Bicarbonate concentration (pl. 4) is generally highest in the aquifer where the till is thickest. The calcium and magnesium are associated with bicarbonate and sulfate. Thickness of till apparently is not related to the concentration of sulfate (fig. 10), which may be derived from several sources. As a result the calcium and magnesium concentrations are not as directly related to thickness of till as is the concentration of bicarbonate. Sulfate, iron, and chloride concentrations are often relatively high in poorly drained areas where organic decay takes place.

Development and potential

Plate 5 shows estimated transmissibilities and relates these to specific capacities and possible yields obtainable from properly constructed wells that are screened the full thickness of the aquifer. The specific capacities are those to be expected for a 12-inch well, at the end of one day's pumping. The possible yields of wells tapping the artesian part are estimated from the specific capacities using a drawdown limited to 20 feet. This map is subject to limitations similar to those described on page 19 for the Silurian aquifer.

The artesian part of the unit is a possible source in much of the county for supplies that require 300 gpm or more. However, without proper construction actual yields of wells may be considerably less than those indicated on plate 5. Proper construction requires careful choice of well diameter, screen diameter and length, and slot size of screen openings. Wells tapping the unit require development to remove the clay, silt, and very fine sand from the immediate vicinity of the screen.

The depth to the artesian part of the aquifer can be estimated from plate 6 which can be used in conjunction with information on plate 5 to estimate the depth to which a well need be drilled to develop a water supply. For supplies requiring maximum possible yield, the full thickness of the aquifer should be

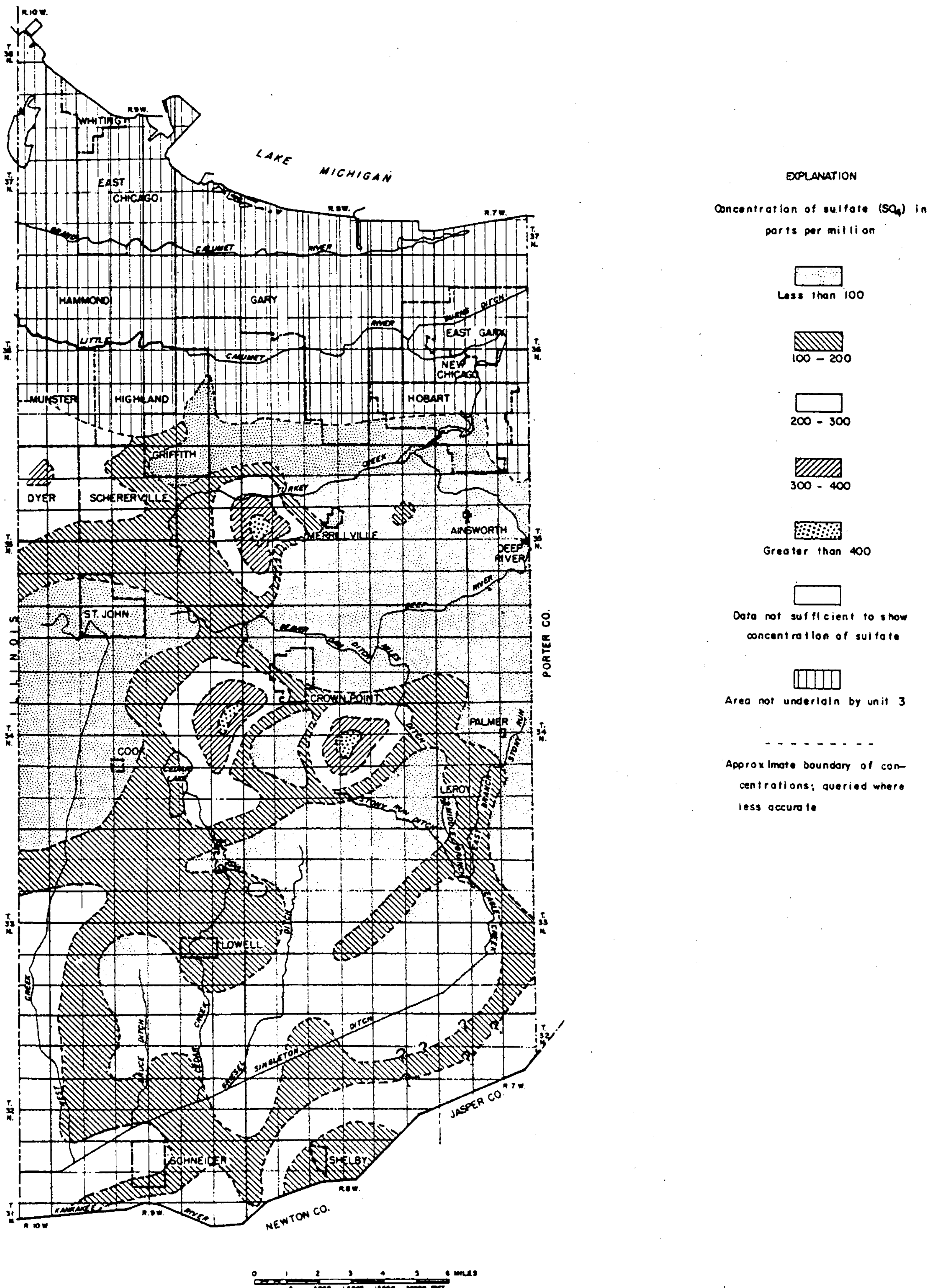


FIGURE 10.--Map of Lake County showing distribution of sulfate (SO_4) in water of unit 3.

penetrated and as much screened as is economically feasible. For domestic or farm supplies only the upper 10 to 15 feet need be penetrated and a short, small diameter screen used.

The quantity of water potentially available for development from the artesian part depends on its rate of recharge. This rate is controlled to a large extent by the geohydrologic properties of its confining layer. Recharge to this part of the aquifer is currently estimated to be 30 million gpd. Rosenshein (1963) has shown that the rate of recharge will increase as the artesian part is extensively developed and estimates that its potential yield is 60 mgd. Present pumpage is about 7 percent of the water potentially available for use.

Development of water supplies within the water-table part is complicated by many factors. The saturated thickness of the unit is relatively thin and varies seasonally by about five feet (fig. 8). Because pumping from the water-table part results in an actual dewatering of the unit, the transmissibility decreases as water is withdrawn. Estimates of the specific capacities and possible yields (pl. 5) of this part of the aquifer have been adjusted for the above factors.

The potential yield of the water-table part is estimated to be 100 million gpd. The small-diameter tubular wells currently used in the area are capable of tapping only a very small part of this potential. However, where economically feasible, exceptionally large-diameter vertical wells and horizontal infiltration galleries and collectors could utilize a much larger part of this yield, particularly where the transmissibilities exceed 10,000 gpd per foot.

The use of land and the susceptibility to contamination are factors that also complicate possible development. The land in the southern portion of the county is used chiefly for farming. As a result, it is continually being ditched-- a practice that decreases the average saturated thickness, thereby permanently dewatering a part of the aquifer and decreasing its potential for development. Because the aquifer is readily susceptible to contamination, the user should guard against downward leakage of undesirable waste products that could deteriorate the quality of water and thereby impede the use and development of the aquifer.

Unit 2

Water-bearing characteristics

Unit 2 consists chiefly of clay till (table 1) which forms the confining layer for the artesian part of unit 3. The amount of recharge to the underlying aquifer depends in part on unit 2's vertical permeability. This permeability is estimated to average 0.007 gpd per square foot (Rosenshein, 1963).

The porosity of the unit may be about 40 percent. Under existing conditions the saturated thickness is estimated to average 38 feet. Based on these estimates the unit may have as much as 3 million acre-feet of water in storage. However, because of its small permeability direct production from the unit is limited to relatively thin, discontinuous, intertill sand and gravel zones. The pumpage from these zones for domestic and farm supplies is estimated to be 100,000 gpd.

Hydrology with respect to water resources

Unit 2 is the most extensive geologic unit exposed at the surface. The flow of many streams and ditches is determined to a large extent by the ground-water discharge and run-off characteristics of this unit. During the nongrowing season it may contribute as much as 80 to 90 percent of the base flow of streams such as West Creek (fig. 1). This contribution decreases sharply during the growing season and may amount to less than 20 percent owing to evapotranspiration.

Ground-water discharge from the unit to streams and ditches was estimated to average 400,000 gpd per square mile or about 0.6 cubic feet per second per square mile in the nongrowing season of the 1960 water year. Based on this estimate the unit currently discharges about 110 mgd to the streams draining the county in the nongrowing season.

An estimated 7,400 million gallons was discharged by direct evapotranspiration from the unit in May through September, 1960. Estimates of the average daily and monthly discharge by evapotranspiration are listed in the table below.

Month	Estimated average daily discharge by evapotranspiration (in million gallons)	Estimated monthly discharge by evapotranspiration (in million gallons)
May	20	600
June	20	600
July	60	1,900
August	70	2,200
September	70	2,100

The hydrology of unit 2 has been appreciably altered within the last 60 years. Prior to the 1900's large sections of the county, underlain by unit 2, were imperfectly drained, and many parts of the unit were nearly or completely saturated during much of the year. Since the 1900's agricultural development and the increase in the rural nonfarm population has caused extensive ditching of the unit. Drainage of its upper part has resulted in a probable average dewatering of 5 to 7 feet. An improved drainage system has also resulted in a more rapid runoff. These effects will be intensified with continued growth of the county's rural nonfarm population.

Unit 1

Water-bearing characteristics

Unit 1 consists chiefly of sand (table 1) whose transmissibility ranges from less than 5,000 to about 30,000 gpd per foot. The permeability ranges from about 60 to about 1,000 gpd per square foot and averages about 450 gpd per square foot. Based on the average permeability and average saturated thickness of the unit, the regional value of transmissibility is about 15,000 gpd per foot.

The coefficient of storage of the unit is estimated to be 0.12. This estimate should be sufficiently accurate for evaluating regional characteristics of the aquifer.

Recharge and discharge

Recharge to the unit is derived from local precipitation and may originally have been equivalent to that estimated for the water-table part of unit 3. However, the hydrology has been markedly altered since the 1890's by extensive ditching of a large part of the area underlain by the unit, owing to industrial and urban development. The ditching straightened and deepened channels and increased their gradients. New drainages were established, and locally the flow of streams was reversed. As a result ground-water gradients to streams were increased, the upper part of the unit was dewatered, and many marshy areas were drained. Recharge has also been decreased somewhat by storm sewers, pavements, and buildings in heavily populated areas. Therefore, the potential rate of recharge to the unit may have been decreased by more than 50 percent, and is probably less than 600,000 gpd per square mile.

The principal ground-water divide (fig. 11) for the unit coincides with the areas overlain by sand dunes and beach ridges (pl. 3). Ground water moves downgradient from this divide to points of discharge chiefly within the county. Under natural conditions prior to the 1890's, the piezometric surface in much of the aquifer sloped gently toward Lake Michigan. This gentle slope was depressed somewhat where channels of shallow meandering streams penetrated the unit. A relatively small part of the flow of the aquifer was discharged into the streams. Part of the flow passed under the streams to be discharged along the northern edge of the unit in the vicinity of Lake Michigan by evapotranspiration or as effluent seepage to the lake. Under present conditions a much larger part of this flow is now discharged directly to the streams draining the area.

Direct evapotranspiration constitutes a major part of the discharge from the unit during spring and summer. Although the quantity of water discharged by this process has not been estimated, it must be considerably greater than the discharge from the unit to streams, ditches, and to Lake Michigan.

The estimated discharge of wells tapping the unit is 1.9 mgd. This withdrawal accounts for about 25 percent of the ground water pumped in the county. Of this amount 0.2 mgd is pumped for domestic use, 1.0 mgd for municipal use, and 0.7 mgd for industrial and commercial use. Of the amount pumped for municipal use, East Gary pumps about 0.6 mgd and New Chicago about 0.4 mgd.

Development and potential

Figure 12 shows the saturated thickness and possible yields obtainable from wells that tap the aquifer. The transmissibility in a specified area can be estimated by multiplying the saturated thickness by its average permeability (p. 29)

Development of the unit is complicated by factors similar to those affecting the water-table part of unit 3 (p. 28). Where the saturated thickness is less than 20 feet the unit will not be extensively developed except possibly

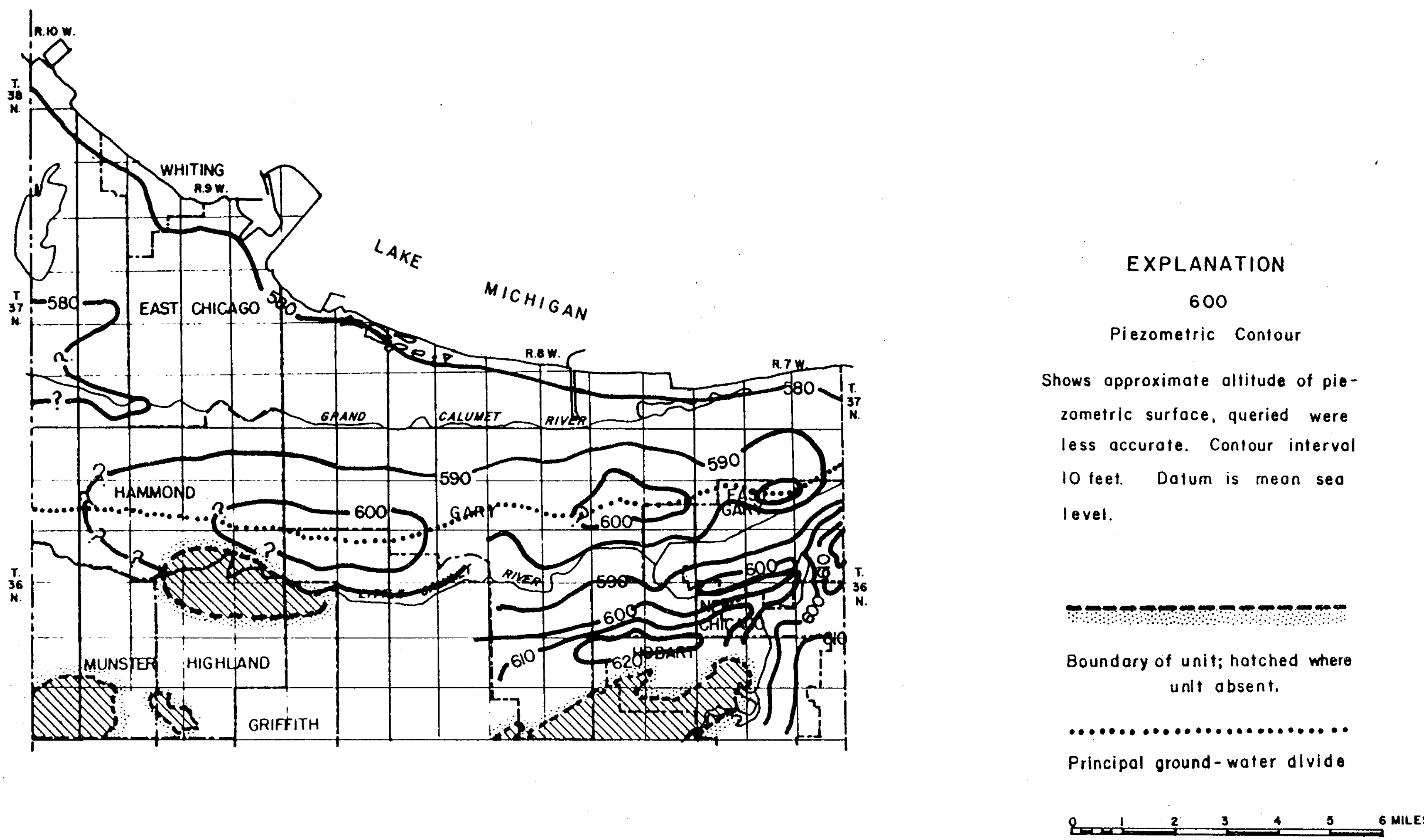


FIGURE 11.--Map Showing configuration of the piezometric surface of unit 1, Lake County, January, 1960.

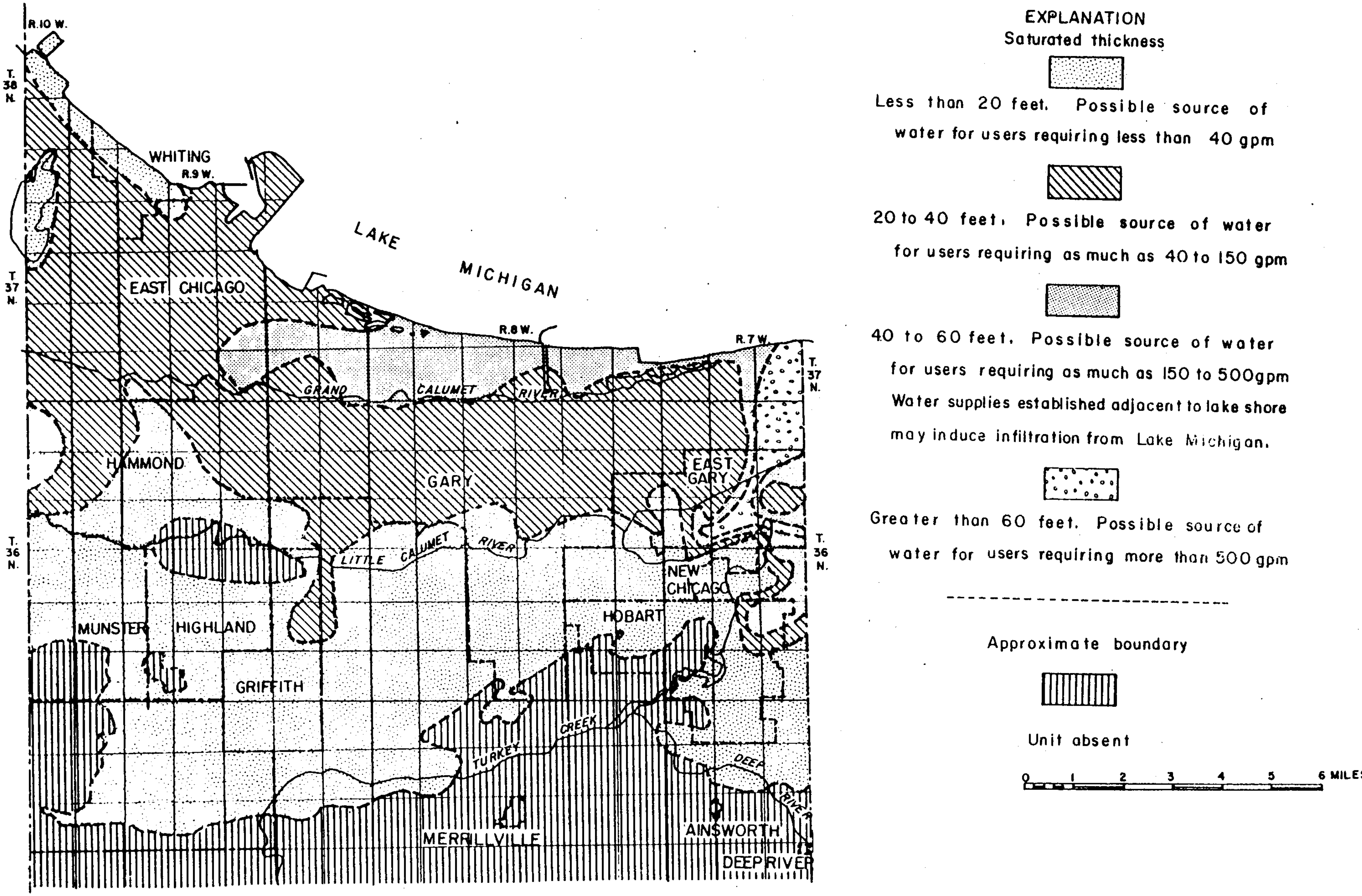


FIGURE 12.--Map showing saturated thickness and possible yields of wells, Unit I, Lake County.

for domestic use. To develop even a small part of the unit's potential will require types of wells different from those commonly used. Properly constructed horizontal infiltration galleries and collectors or extremely large-diameter wells could obtain large quantities of water, particularly in the area adjacent to Lake Michigan, where the aquifer is relatively thick and infiltration could be induced from the lake.

Susceptibility to contamination may impede development. Because of the slow movement of water through the aquifer areas of concentrated contamination can easily form within it. Contamination in unit 1 has been reported in the vicinity of Garyton.

A small part of the potential yield of the aquifer is being utilized. Under present conditions of recharge, the potential yield may be in excess of 30 to 40 mgd. This potential will decrease somewhat as industrial and urban growth continues. However, in spite of the feasibility of using the unit as a source for moderately large commercial or industrial supplies, development will be slow because of the accessibility of Lake Michigan as a source of water.

SUMMARY

General summary:--The principal sources of ground water occur within the upper 350 to 400 feet of rocks. The other rocks are only a minor source. The upper rocks form a single but complex hydrologic system that consists of three aquifers and two confining layers. The system's potential yield is estimated to be 200 mgd of which about 7.5 mgd or 4 percent is currently being withdrawn.

The quantity of ground water that is available for development should be adequate to satisfy the needs of the county for the next few decades. However, to tap a major part of the potential yield of the aquifers will require sound practices of development and responsible management of water resources based on the available geohydrologic facts.

Geohydrology of rock units:--Sandstone and dolomite of Cambrian and Ordovician ages form a deep aquifer of minor significance in the county from which about 40,000 gpd (gallons per day) is pumped by industrial wells. Other minor sources of water are the dolomitic limestone, dolomite and shale of Devonian age. The pumpage from these rocks is about 40,000 gpd. The shale has a coefficient of transmissibility that ranges from about 600 to 7,000 gpd per foot, and is a potential source of water for supplies requiring less than 10 gpm (gallons per minute).

The upper 100 feet of the dolomite of Silurian age forms the lowermost aquifer, and its coefficient of transmissibility ranges from about 100 to 50,000 gpd per foot. The regional value of coefficient of transmissibility is estimated to be 5,500 gpd per foot and that of the coefficient of storage about 0.0008. Recharge to the unit through its principal confining layer is about 6 mgd under present hydrologic conditions. However, the estimated potential yield is 24 mgd.

The dissolved constituents in the water from the Silurian consist mainly of bicarbonate, calcium, magnesium, and sodium. Concentration of dissolved solids averages about 560 ppm. The constituents are derived chiefly from the recharge percolating through unit 4.

Unit 4, a clay till, is the confining layer overlying the bedrock. Its vertical permeability is estimated to average 0.003 gpd per square foot. The unit may have as much as 6 million acre-feet of water in storage. The clay contains some discontinuous zones of intertill sand and gravel from which about 100,000 gpd is pumped. Its basal part contains a thin sand and gravel zone that is not used but is a potential source of water for small supplies.

Unit 3, a sand, forms the principal Pleistocene aquifer. Its coefficient of transmissibility ranges from less than 10,000 to more than 50,000 gpd per foot. The estimated regional value of transmissibility for the artesian part is 24,000 gpd per foot and for the water-table part 15,000 gpd per foot. The estimated regional value of the coefficient of storage for the artesian part is 0.003 and that for the water-table part 0.12. Recharge to the artesian part is about 30 mgd under present hydrologic conditions. However, the estimated potential yield is 60 mgd. Direct recharge to the water-table part is about 1.2 mgd per square mile, and the estimated potential yield is 100 mgd. Development of this potential will require types of wells different from those commonly used in the area.

The principal dissolved constituents in the water from Unit 3 are calcium, magnesium, and bicarbonate. The concentration of dissolved solids averages about 550 ppm. The constituents in the artesian part are derived mostly from the recharge percolating through unit 2 and their concentrations in the aquifer are controlled to a large extent by the thickness of the confining layer.

Unit 2, a clay till, is the confining layer for the principal Pleistocene aquifer. Its vertical permeability is estimated to average 0.007 gpd per square foot. The unit may have as much as 3 million acre-feet of water in storage. Production from the unit is limited to intertill sand and gravel zones and is estimated to be 100,000 gpd. It is the most extensive unit exposed at the surface, and its hydrology is significant to both the ground- and surface-water resources of the county. This hydrology has been altered since the 1900's as a result of agricultural development and increase in rural nonfarm population. Under present hydrologic conditions the ground-water discharge from the unit to streams and ditches is about 110 mgd during the nongrowing season.

Unit 1, a sand, is chiefly a water-table aquifer. Its coefficient of transmissibility ranges from less than 5,000 to about 30,000 gpd per foot. The estimated regional value of transmissibility is 15,000 gpd per foot and that of the coefficient of storage 0.12. The hydrology of the unit has been markedly altered by industrial and urban development. Under present hydrologic conditions recharge is probably less than 600,000 gpd per square mile and the potential yield about 30 to 40 mgd. Development of this potential will require types of well different from those commonly used in the area and may be impeded by the unit's susceptibility to contamination by industrial and septic wastes.

GLOSSARY

Hydraulic Coefficients (After Ferris and Others, 1962)

Permeability.--Measure of a material's capacity to transmit water; expressed as rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under hydraulic gradient of 1 foot per foot at prevailing temperature.

Storage.--Volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Transmissibility.--Rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot.

Miscellaneous Terms

Effluent seepage.--Discharge of ground water to surface bodies of water.

Equivalent per million (epm).--Weight concentration of ion divided by combining weight of that ion. (Hem, p. 32).

Porosity.--Volume of pore space expressed as a percentage of the total volume of the rock.

Specific capacity.--Yield of well in gallons per minute per foot of drawdown.

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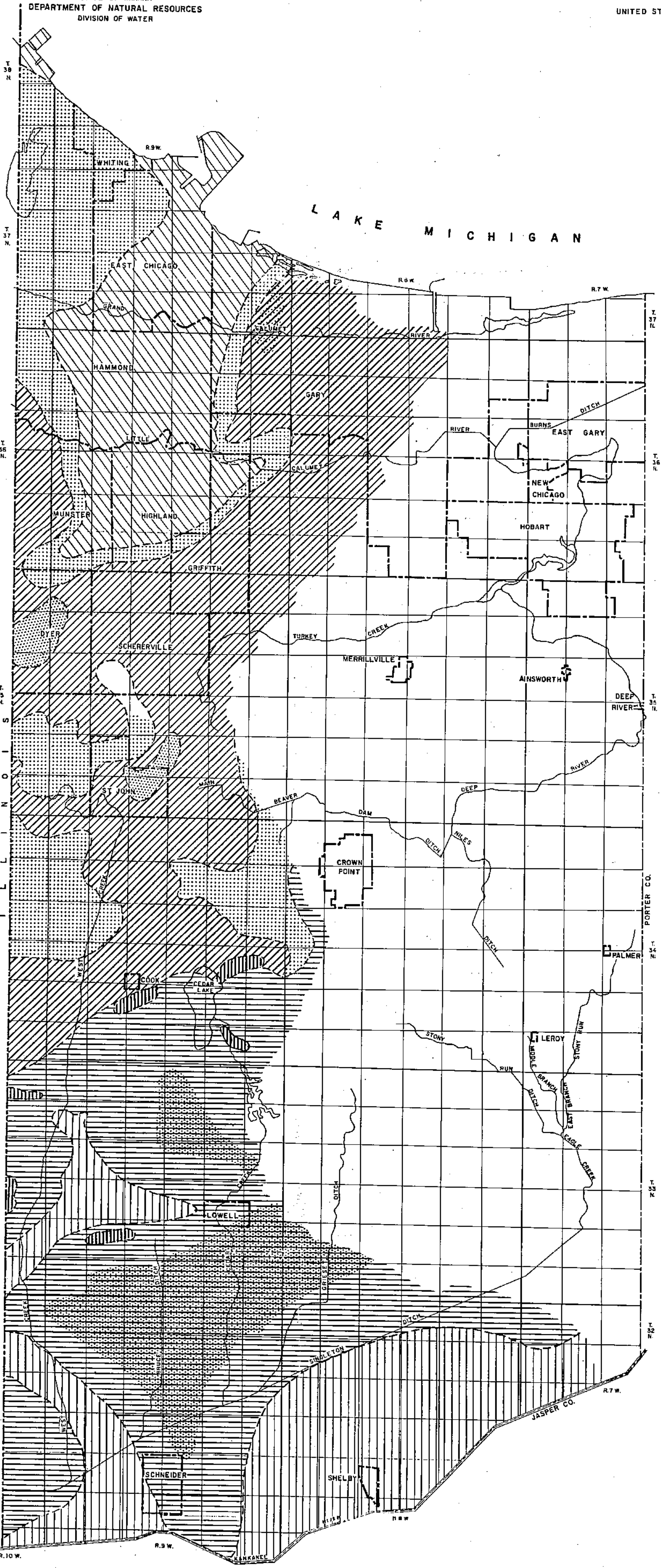
STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



EXPLANATION

Estimated transmissibilities generally less than 200 gpd/ft (gallons per day per foot).
Specific capacities of wells estimated to be less than 0.1 gpm (gallons per minute) per foot of drawdown.
For practical purposes considered only a marginal source of water for users requiring less than 10 gpm.

Estimated transmissibilities generally range from 200 to 1,000 gpd/ft.
Specific capacities of wells estimated to range from about 0.1 to 0.6 gpm per foot of drawdown.
Possible source of water for users requiring as much as 10 to 50 gpm.

Estimated transmissibilities generally range from 1,000 to 10,000 gpd/ft.
Specific capacities of wells estimated to range from about 0.6 to 5 gpm per foot of drawdown.
Possible source of water for users requiring as much as 60 to 400 gpm.

Estimated transmissibilities generally greater than 10,000 gpd/ft.
Specific capacities of wells estimated to be greater than 5 gpm per foot of drawdown.
Possible source of water for users requiring more than 400 gpm.

Estimated transmissibilities generally range from 200 to 1,000 gpd/ft.
Specific capacities of wells estimated to range from about 0.1 to 0.6 gpm per foot of drawdown.
Possible source of water for users requiring as much as 10 to 30 gpm.

Estimated transmissibilities generally range from 1,000 to 10,000 gpd/ft.
Specific capacities of wells estimated to range from about 0.6 to 5 gpm per foot of drawdown.
Possible source of water for users requiring as much as 30 to 250 gpm.
Dotted pattern indicates probable areas of lower transmissibility.

Estimated transmissibilities generally more than 10,000 gpd/ft.
Possible source of water for users requiring more than 250 gpm.

Approximate boundaries of areas; queried where less accurate.

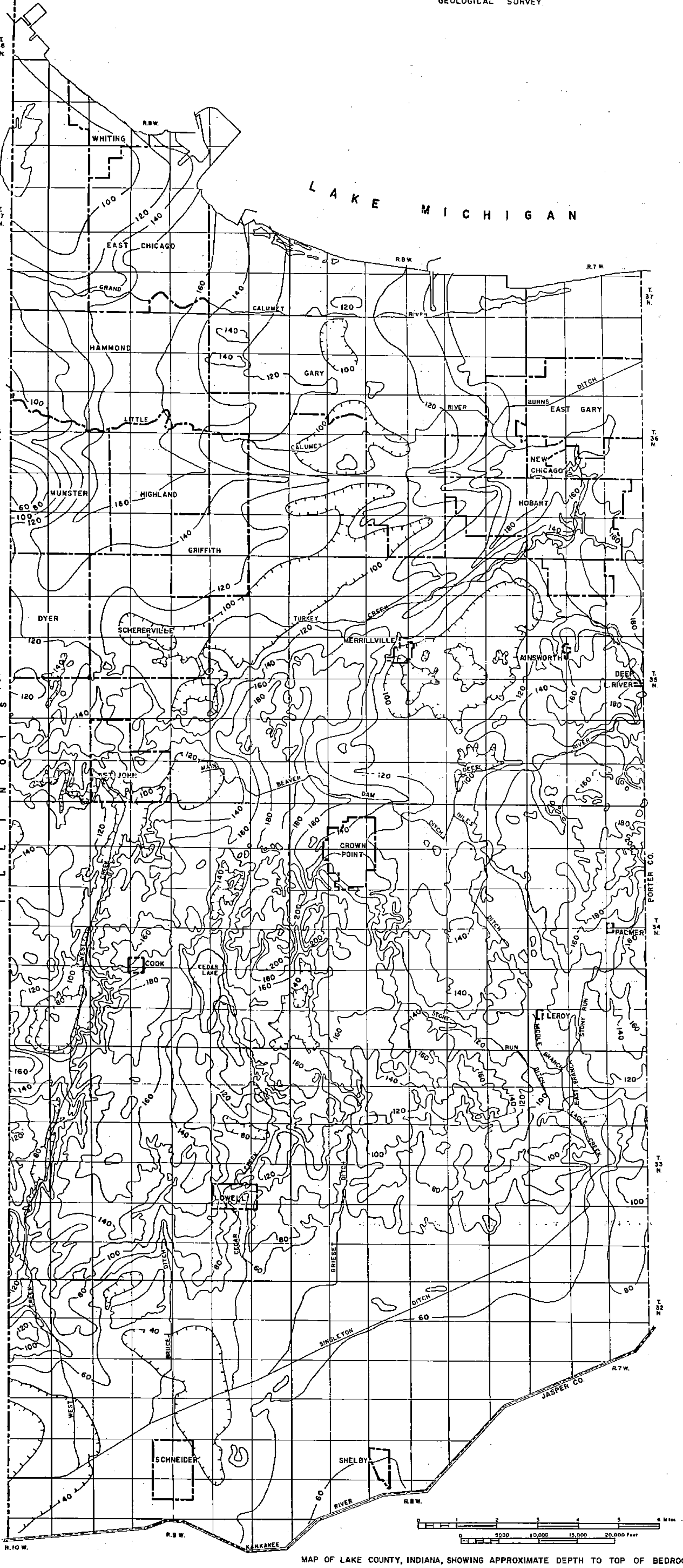
Base map from modified General Highway and Transportation Map revised to July, 1953.
Drainage and town boundaries in part from U.S. Geological Survey topographic maps.

N

MAP OF LAKE COUNTY, INDIANA, SHOWING CAPABILITY OF SILURIAN AQUIFER AS A SOURCE OF WATER

0 1 2 3 4 5 6 MILES

0 5,000 10,000 15,000 20,000 FEET



EXPLANATION

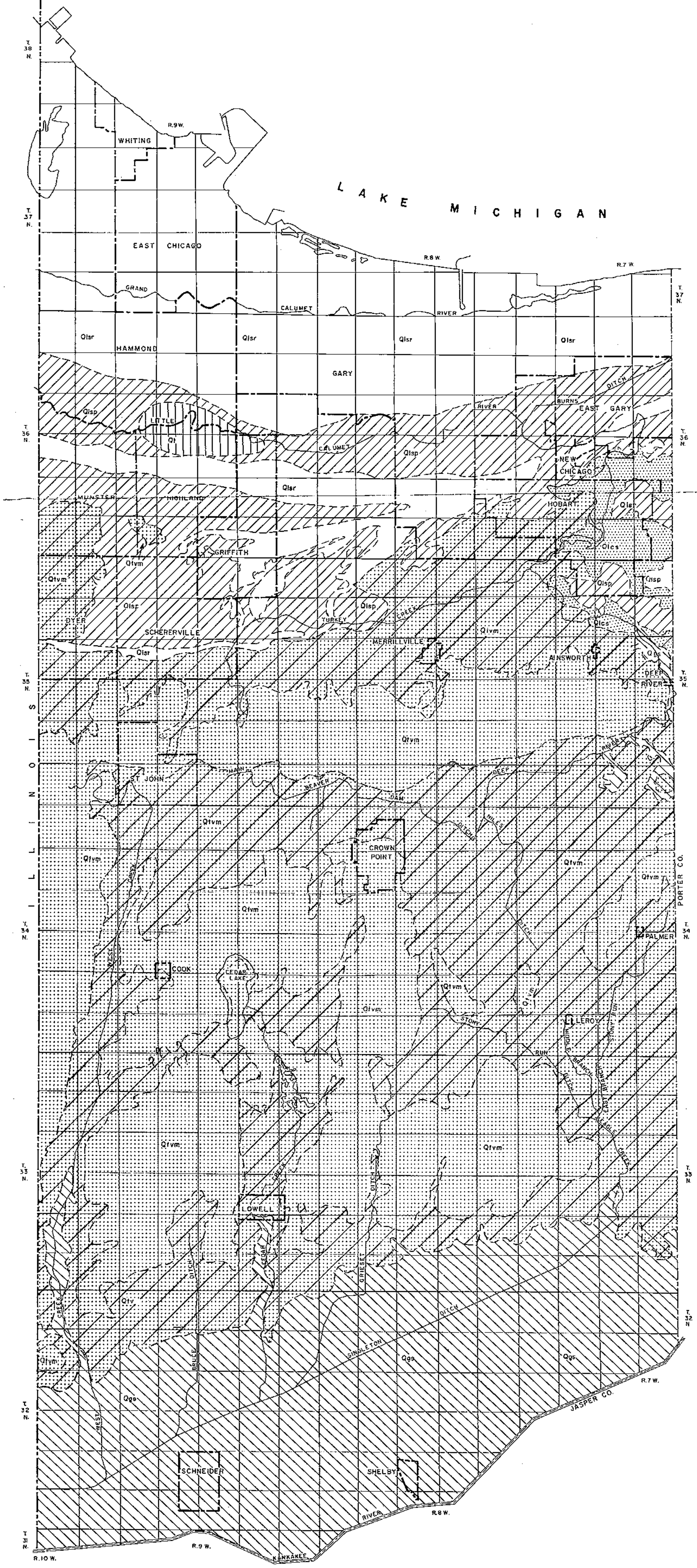
100

Contour shows approximate depth to top of bedrock. Contour interval 20 feet.

N

Base Map from modified General Highway and Transportation Map revised to July, 1953. Drainage and town boundaries in part from U.S. Geological Survey topographic maps

MAP OF LAKE COUNTY, INDIANA, SHOWING APPROXIMATE DEPTH TO TOP OF BEDROCK



EXPLANATION

Pleistocene To Present

QUATERNARY

Qlsr

SAND, fine to medium, locally coarse, pebbly, and organically rich. Forms beach ridges and dunes that represent former strand lines. Includes manmade land along edge of Lake Michigan.

UNIT 1

Chiefly glaciolacustrine

Qlsp

SAND, fine to medium, silty, or clayey, locally organically rich. Forms relatively flat to slightly rolling plains between sand dunes and beach ridges.

Qlcs

CLAY, silty, maroon, alternating with layers of tan silt; thinly laminated. Locally contains calcareous concretions and some sand.

UNIT 2

Qtvm

TILL; silty clay, generally buff to tan in outcrop, somewhat sandy and pebbly. Forms upper part of the dissected ground moraine (hatched pattern) and the terminal moraines of the Valparaiso morainal system.

UNIT 3

Chiefly glaciofluvial

Qgs

SAND, fine to coarse, somewhat silty, clayey, and organically rich. Locally interbedded with layers of organically rich silt and clay of relatively small areal extent. Contains small sand dunes.

UNIT 4

Qt

TILL; hard, compact, gray clay with subangular to rounded pebbles

Approximate contact; queried where less accurate.

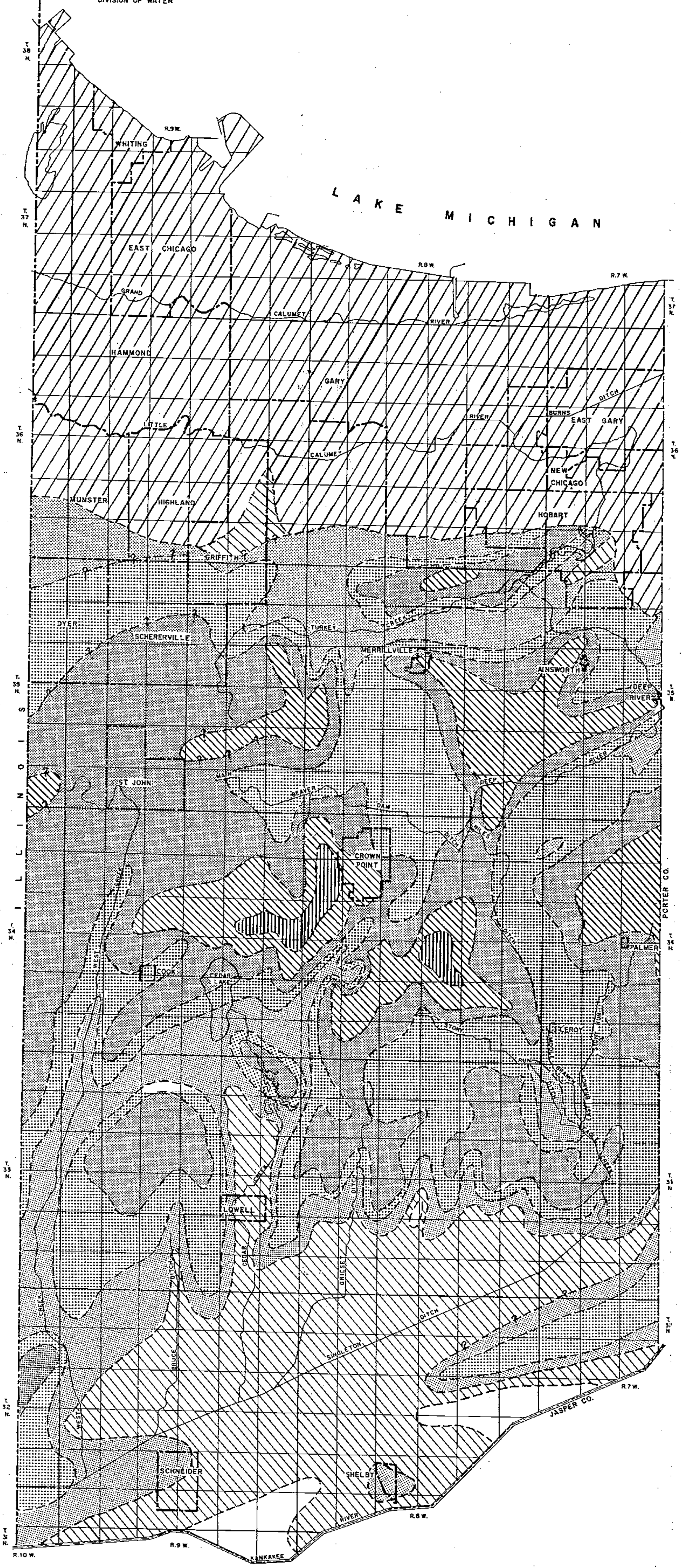
Base map from modified General Highway and Transportation Map revised to July, 1953. Drainage and town boundaries in part from U.S. Geological Survey topographic maps.

N

MAP OF LAKE COUNTY, INDIANA, SHOWING AREAL GEOLOGY

0 1 2 3 4 5 6 MILES

0 5000 10000 15000 20000 FEET



EXPLANATION

Concentration of bicarbonate (HCO_3)

in parts per million

100 – 200

201 – 300

301 – 400

401 – 500

501 – 600

601 – 700

Greater than 700

area not underlain by unit

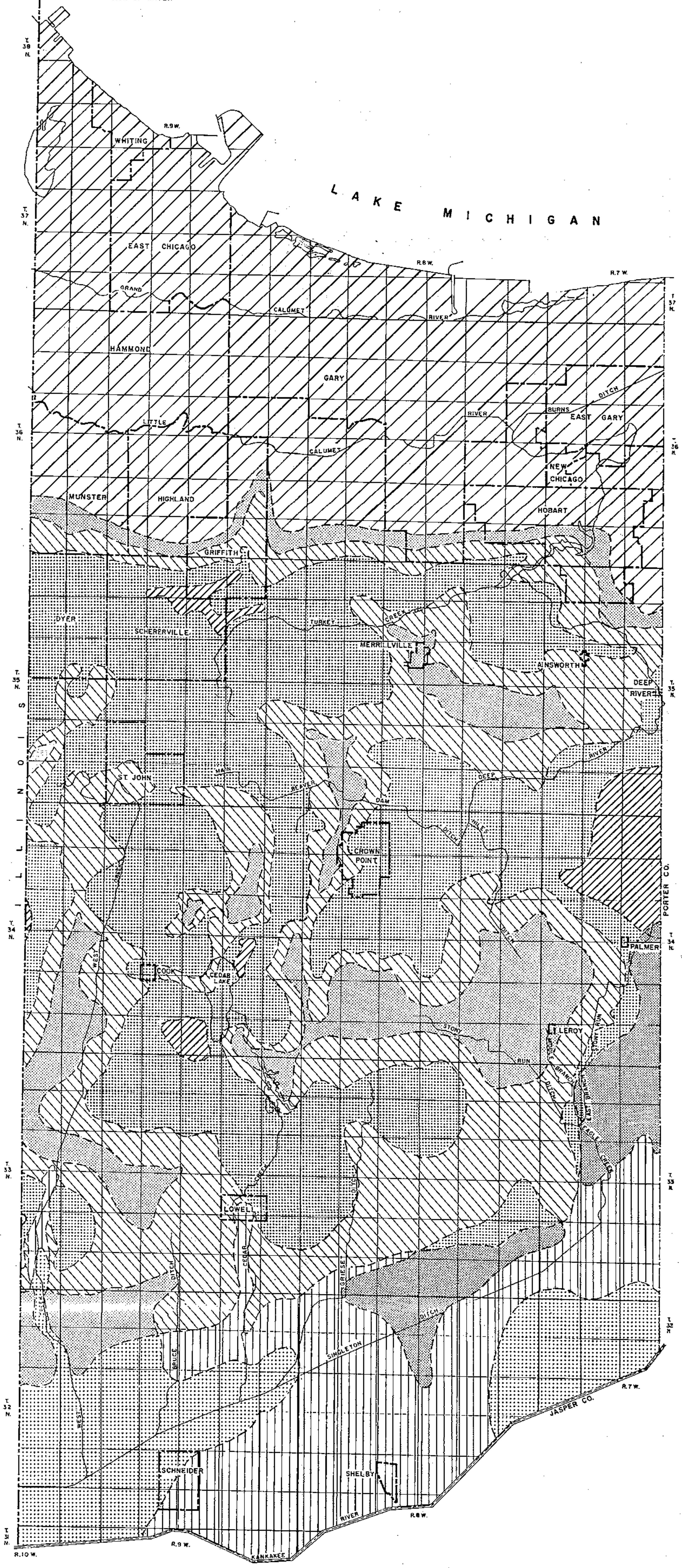
approximate boundary of concentration; queried where less accurate.

Base map from modified General Highway and Transportation Map revised to July, 1953. Drainage and town boundaries in part from U.S. Geological Survey topographic maps.

MAP OF LAKE COUNTY, INDIANA, SHOWING DISTRIBUTION OF BICARBONATE (HCO_3) IN WATER OF UNIT 3

0 1 2 3 4 5 6 MILES

0 5,000 10,000 15,000 20,000 FEET



EXPLANATION

Artesian Part

Estimated transmissibilities generally less than 10,000 gpd/ft (gallons per day per foot).
Specific capacities of wells estimated to be less than 6 gpm (gallons per minute) per foot of drawdown.
Possible source of water for users requiring less than 120 gpm.

Estimated transmissibilities generally range from 10,000 to 24,000 gpd/ft.
Specific capacities of wells estimated to range from 6 to 13 gpm per foot of drawdown.
Possible source of water for users requiring as much as 120 to 250 gpm.

Estimated transmissibilities generally range from 24,000 to 48,000 gpd/ft.
Specific capacities of wells estimated to range from 13 to 25 gpm per foot of drawdown.
Possible source of water for users requiring as much as 250 to 500 gpm.

Estimated transmissibilities generally greater than 48,000 gpd/ft.
Specific capacities of wells estimated to be more than 16 gpm per foot of drawdown.
Possible source of water for users requiring more than 500 gpm.

Water-Table Part

Estimated transmissibilities generally less than 10,000 gpd/ft.
Specific capacities of wells estimated to be less than 5 gpm per foot of drawdown.
Possible source of water for users requiring less than 25 gpm.

Estimated transmissibilities generally range from 10,000 to 24,000 gpd/ft.
Specific capacities of wells estimated to range from 3 to 10 gpm per foot of drawdown.
Possible source of water for users requiring as much as 15 to 180 gpm.

Estimated transmissibilities generally range from 24,000 to 48,000 gpd/ft.
Specific capacities of wells estimated to range from 10 to 19 gpm per foot of drawdown.
Possible source of water for users requiring as much as 180 to 700 gpm.

area not underlain by unit

Approximate boundary

Base map from modified General Highway and Transportation Map revised to July, 1953.
Drainage and town boundaries in part from U.S. Geological Survey topographic maps

MAP OF LAKE COUNTY, INDIANA, SHOWING CAPABILITY OF UNIT 3 AS SOURCE OF WATER

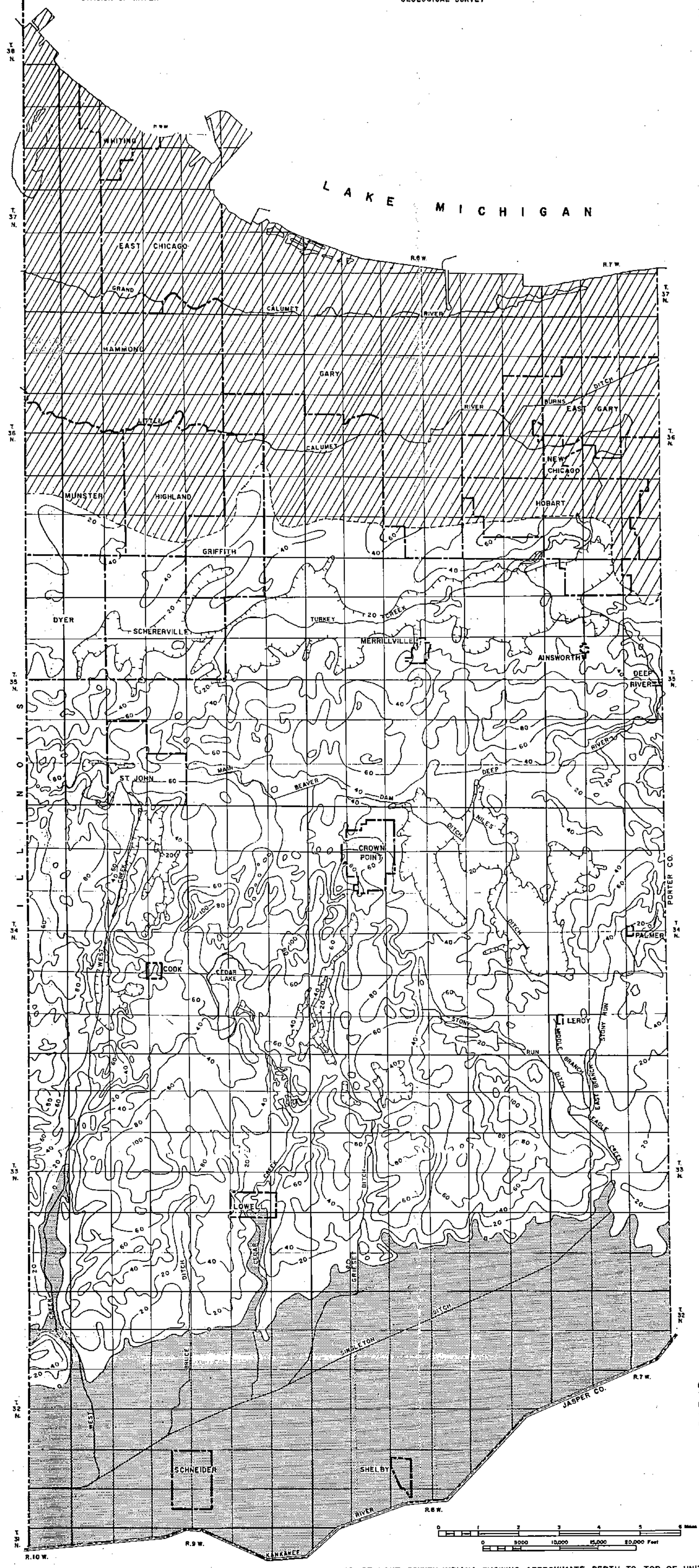
0 1 2 3 4 5 6 MILES

0 5,000 10,000 15,000 20,000 FEET

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

PREPARED BY
UNITED STATES DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY

BULLETIN 31
PLATE 6



EXPLANATION

Area not underlain by unit 3

Area where unit exposed at surface

20

Contour shows approximate depth to top of unit 3. Contour interval 20 feet.

Base Map from modified General Highway and Transportation Map revised to July, 1953. Drainage and town boundaries in part from U.S. Geological Survey topographic maps.

MAP OF LAKE COUNTY, INDIANA, SHOWING APPROXIMATE DEPTH TO TOP OF UNIT 3