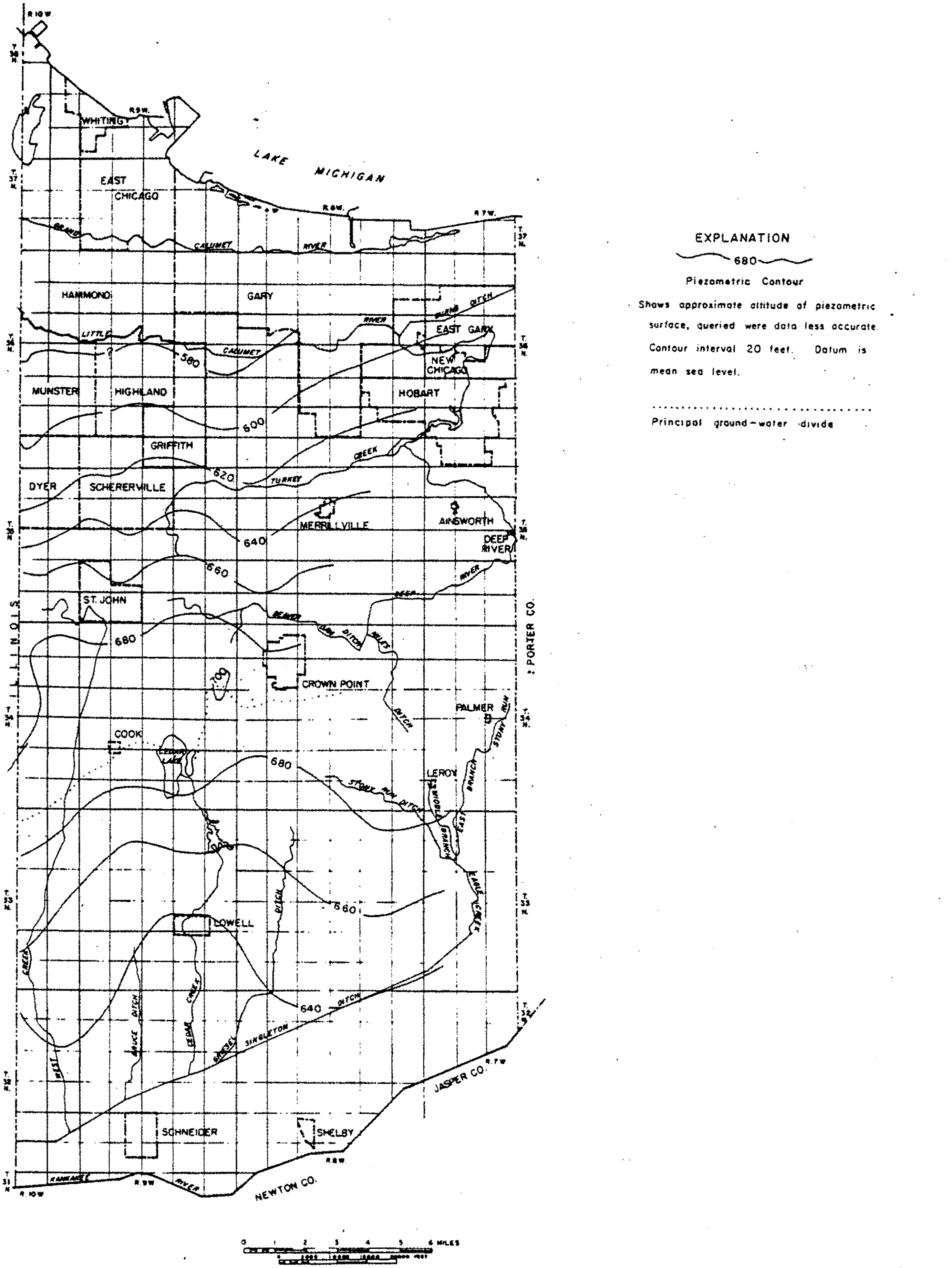


FIGURE 5-- Map showing configuration of the piezometric surface of the Silurian aquifer, Lake County, January 1960. Modified from Rosenshein (1963).

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	Quaternary	Unit3	Max.	>7.5	40.08	6.89	59	12.80	9.99	4.62	>2,000	2,000
U. S. Geological Survey	4			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	Silurian		Max.	5.0	14.81	21.22	95	10.88	6.77	26.85	1,740	740
U. S. Geological Survey	6			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

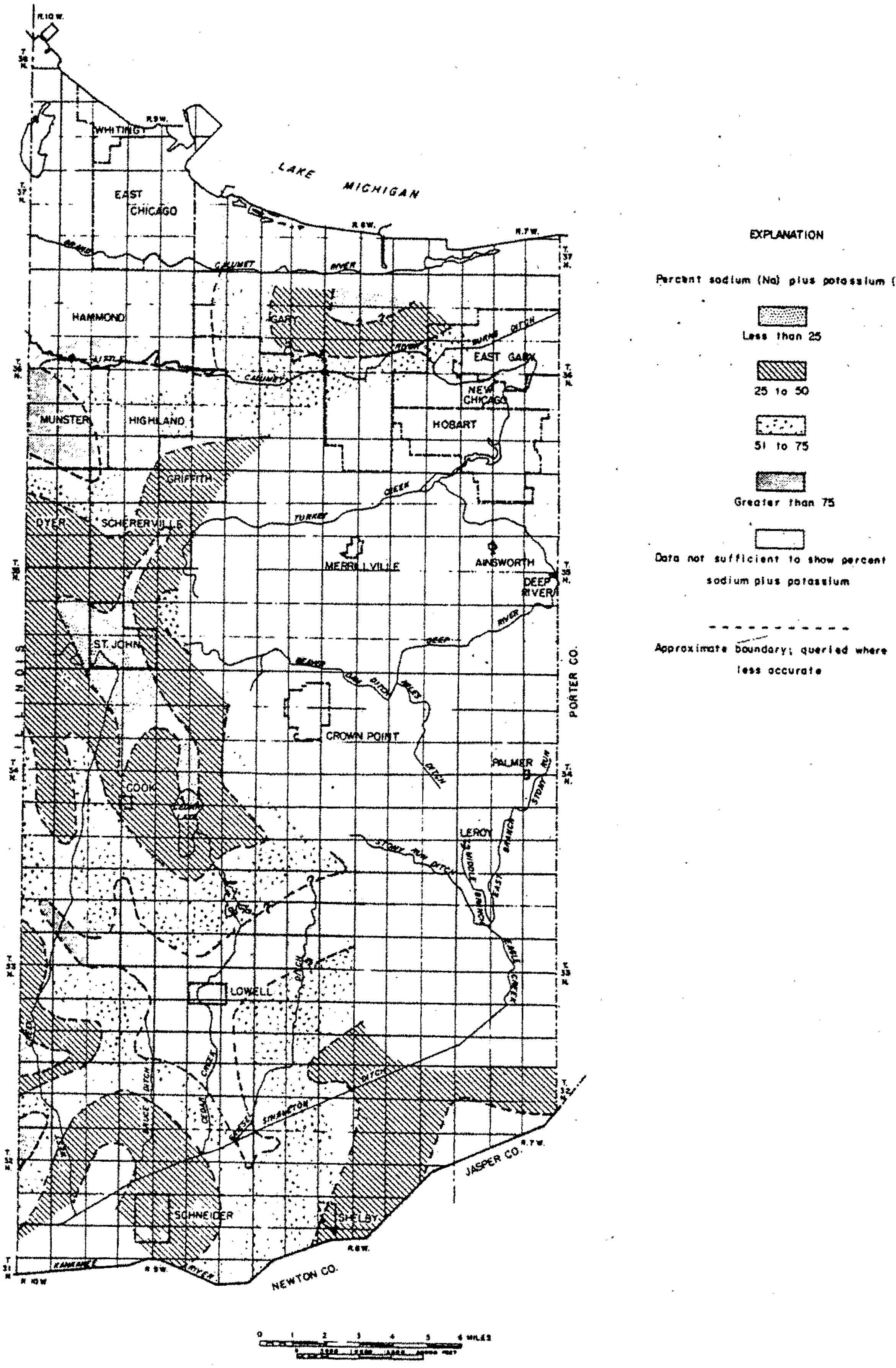


FIGURE 6 --Map of Lake County showing distribution of percent sodium (Na) plus potassium (K) in water of the Silurian aquifer.

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).

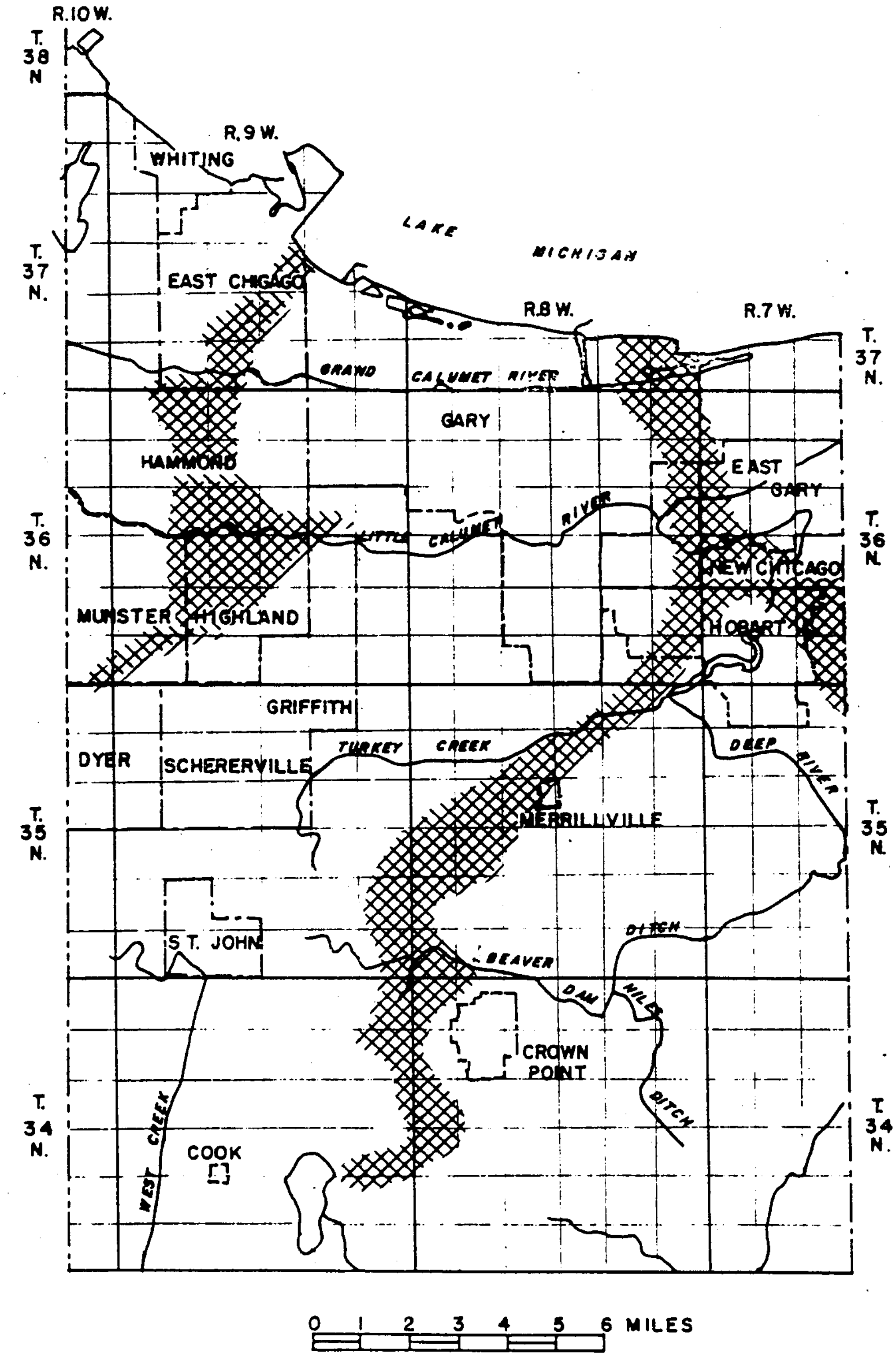


FIGURE 7. --Map showing areas of potential production from sand and gravel in basal part (crosshatched pattern) of Unit 4.

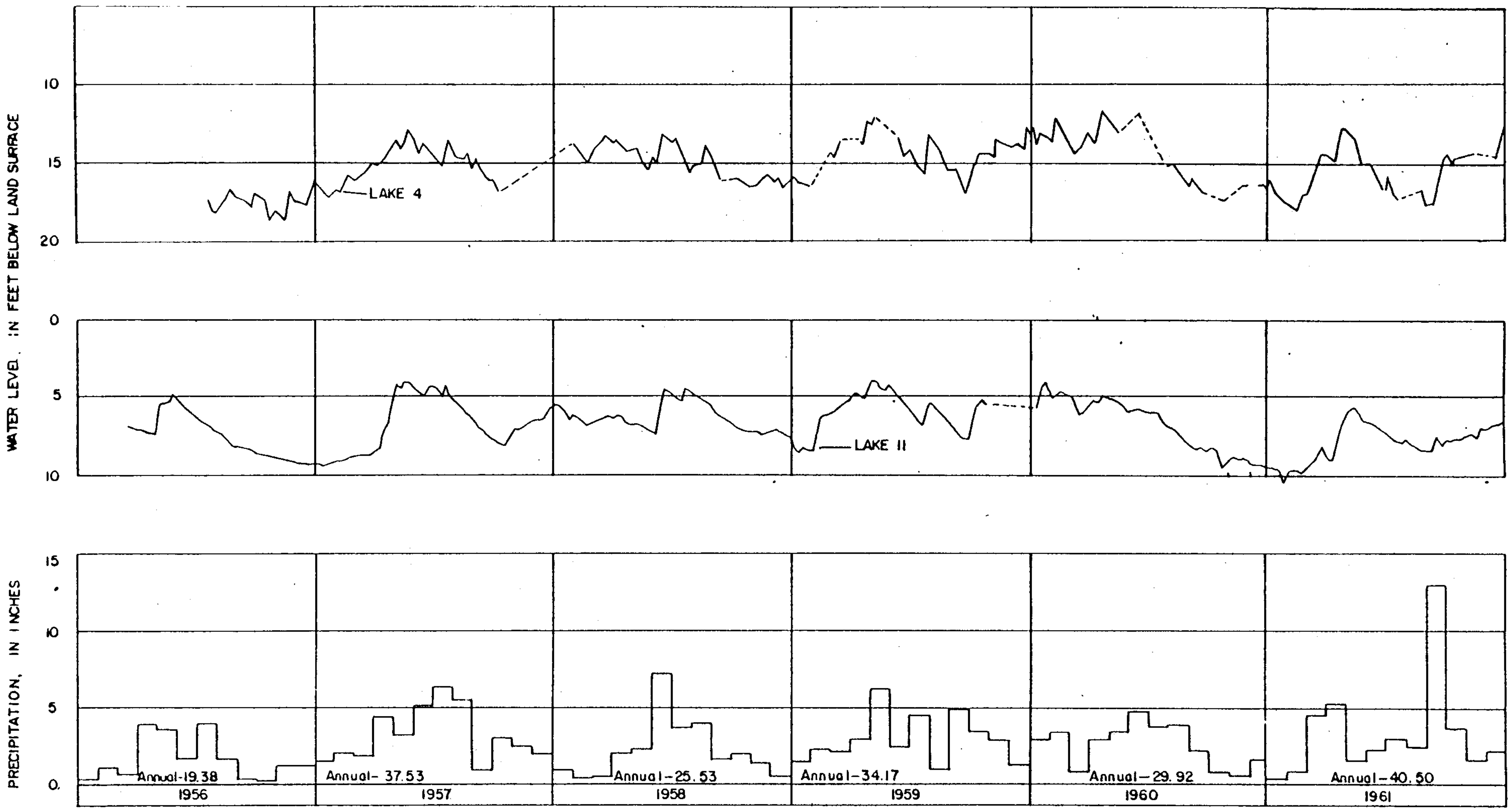


FIGURE 8. -- Fluctuations of water levels in observation wells Lake 4 (35/9W-2J1) in artesian part and Lake 11 (32/8W-28F1) in water-table part of unit 3 and monthly precipitation at Whiting, Ind.

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.

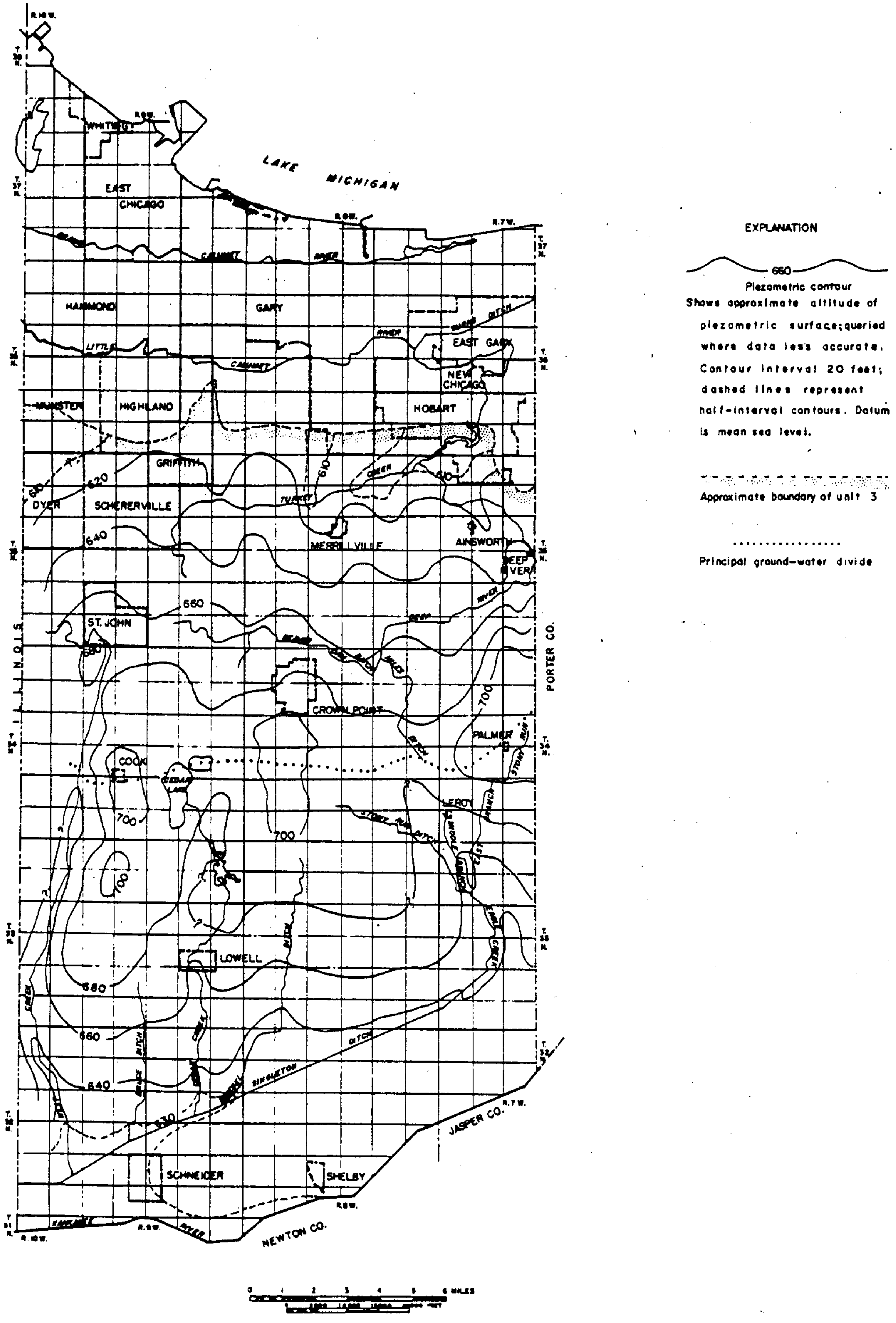
Natural discharge from the water-table part occurs chiefly as effluent seepage (definition, p. 33) to the ditches and streams that penetrate the unit and as direct evapotranspiration. Effluent seepage constitutes most of the discharge from the water-table part in the non-growing season and only a small 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

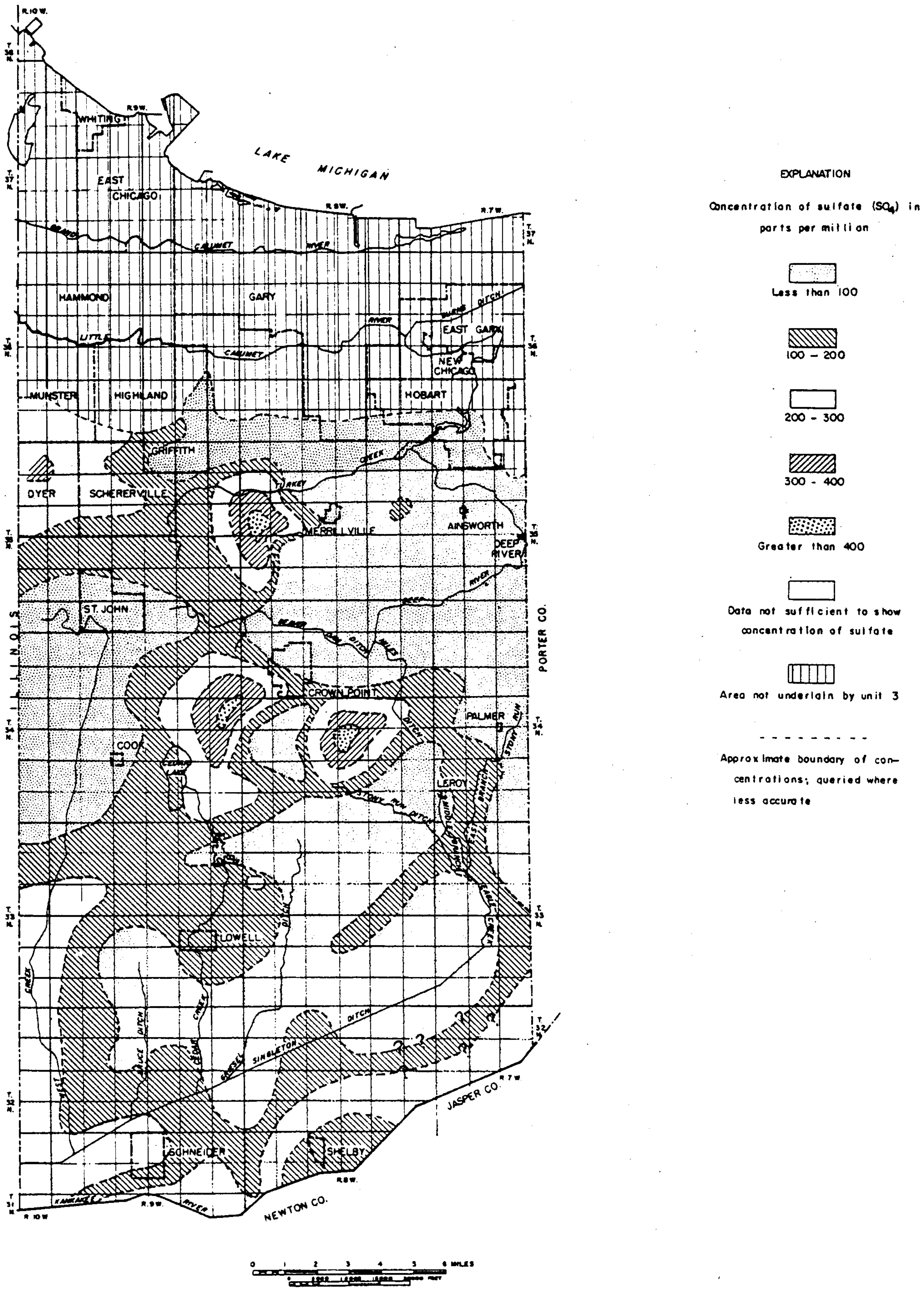


FIGURE 10.--Map of Lake County showing distribution of sulfate (SO_4) in water of unit 3.