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from the water-table part results in an actual dewatering of the unit, the transmissibility decreases as water is withdrawn.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.

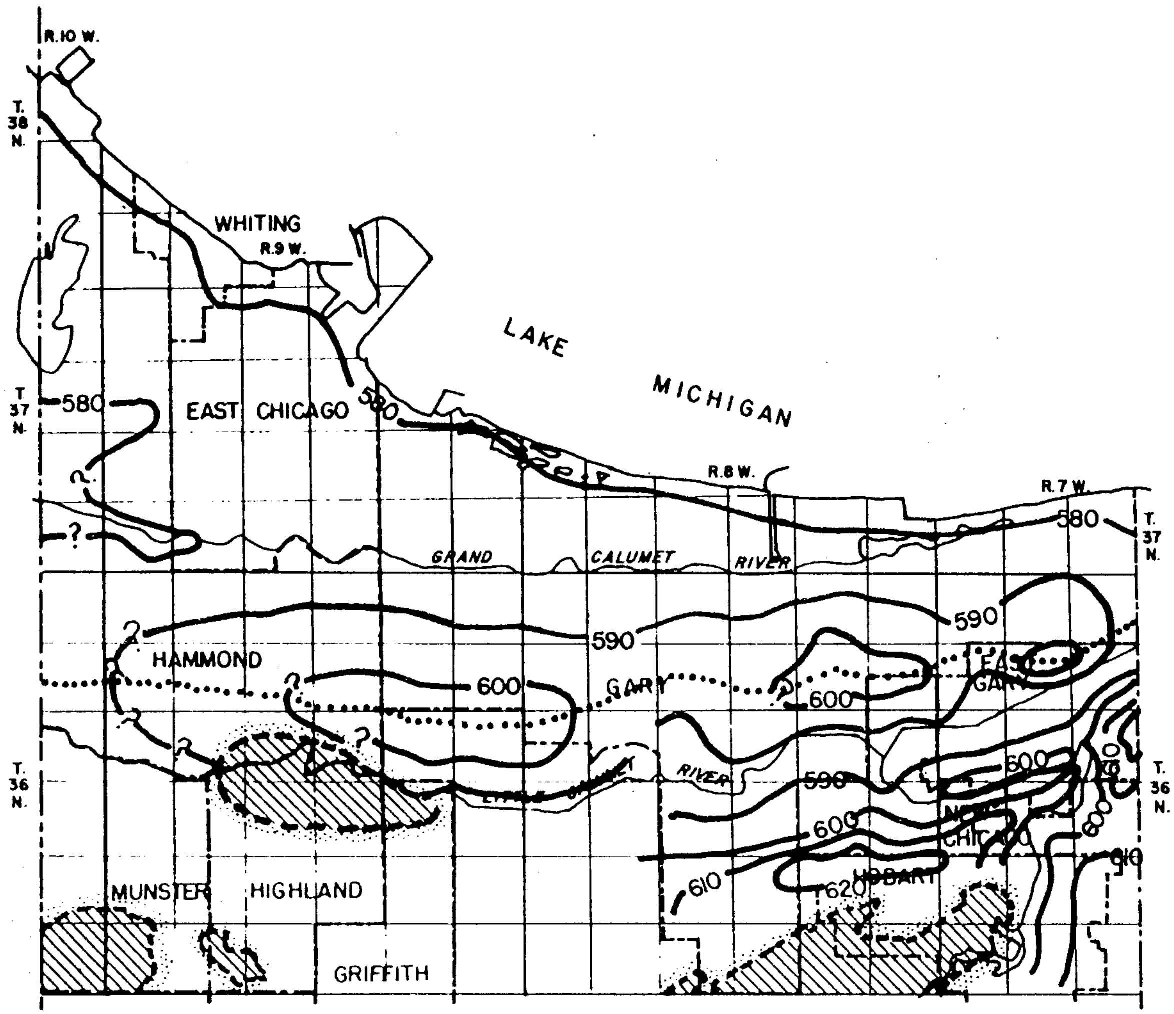
Direct evapotranspiration constitutes a major part of the discharge from the unit during spring and summer. Although the quantity of water discharged by this process has not been estimated, it must be considerably greater than the discharge from the unit to streams, ditches, and to Lake Michigan.

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



EXPLANATION

600

Piezometric Contour

Shows approximate altitude of piezometric surface, queried were less accurate. Contour interval 10 feet. Datum is mean sea level.

Boundary of unit; hatched where unit absent.

Principal ground-water divide

0 1 2 3 4 5 6 MILES

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

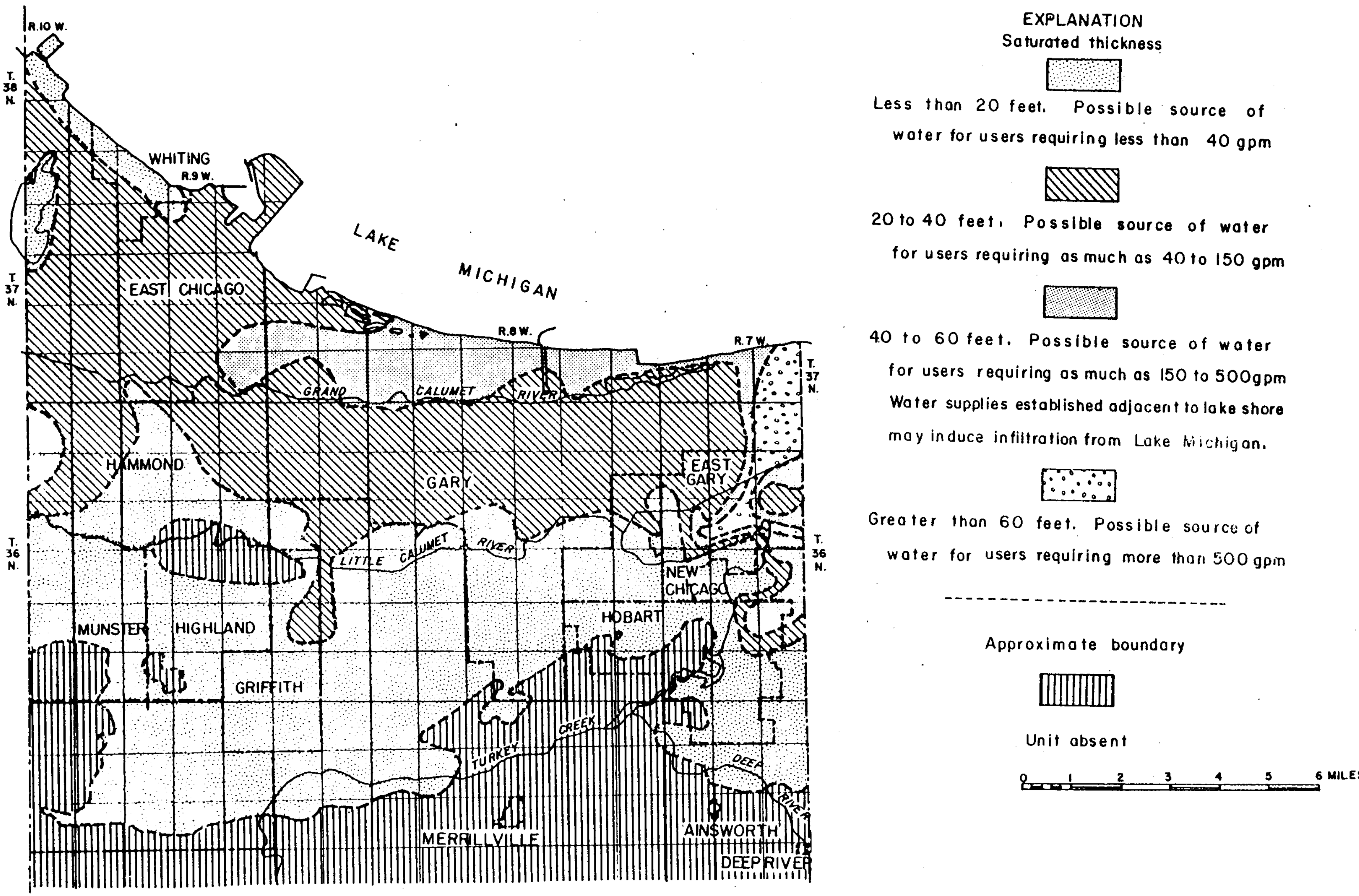


FIGURE 12.--Map showing saturated thickness and possible yields of wells, Unit I, Lake County.

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

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UNITED STATES DEPARTMENT OF THE INTERIOR
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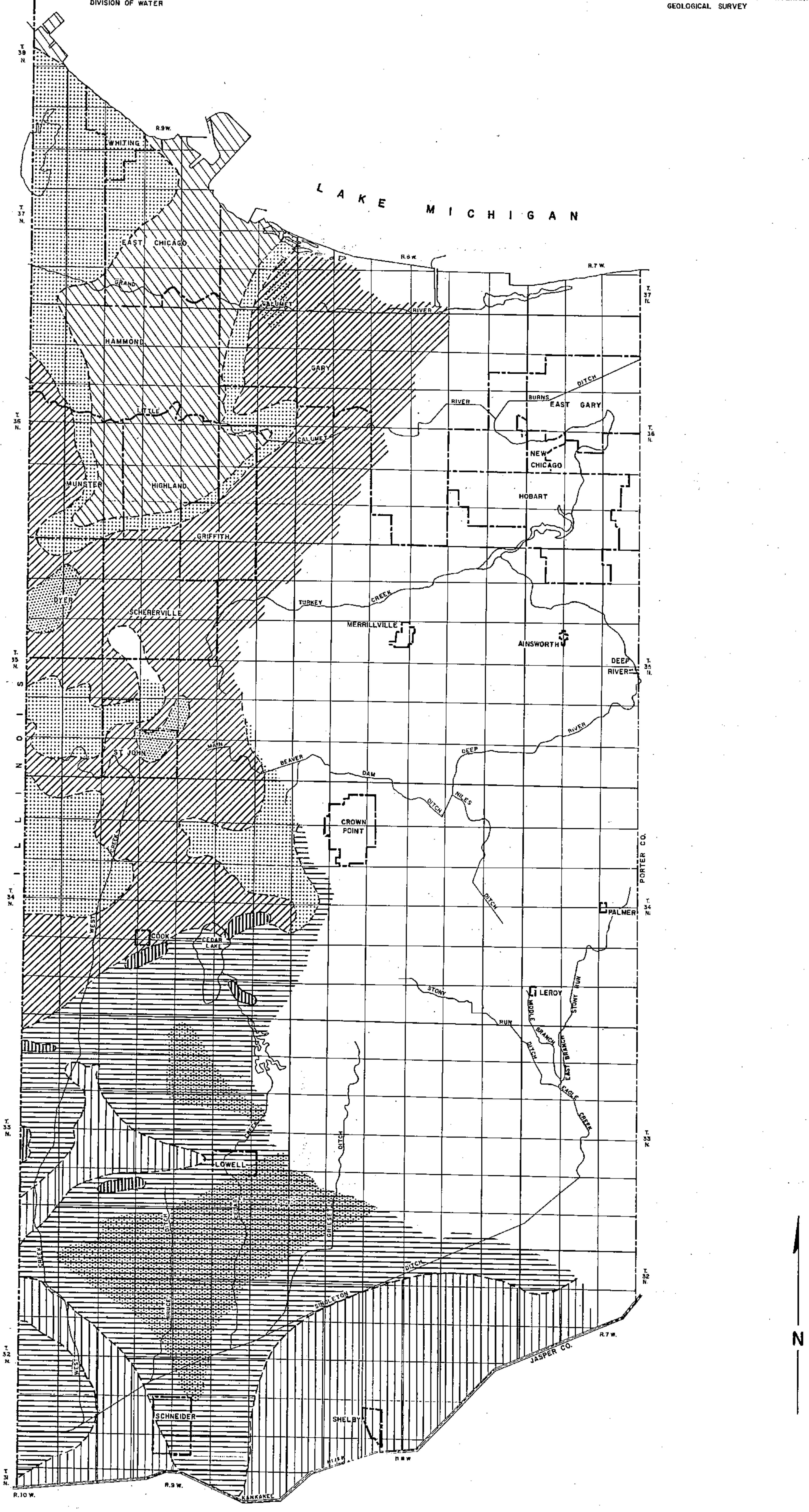
BULLETIN 31
PLATE 1



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.

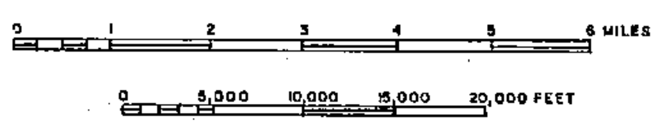
Estimated transmissibilities generally range from 1,000 to 10,000 gpd/ft.
Specific capacities of wells estimated to range from about 0.6 to 5 gpm per foot of drawdown
Possible source of water for users requiring as much as 30 to 250 gpm.
Dotted pattern indicates probable areas of lower transmissibility.

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.

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



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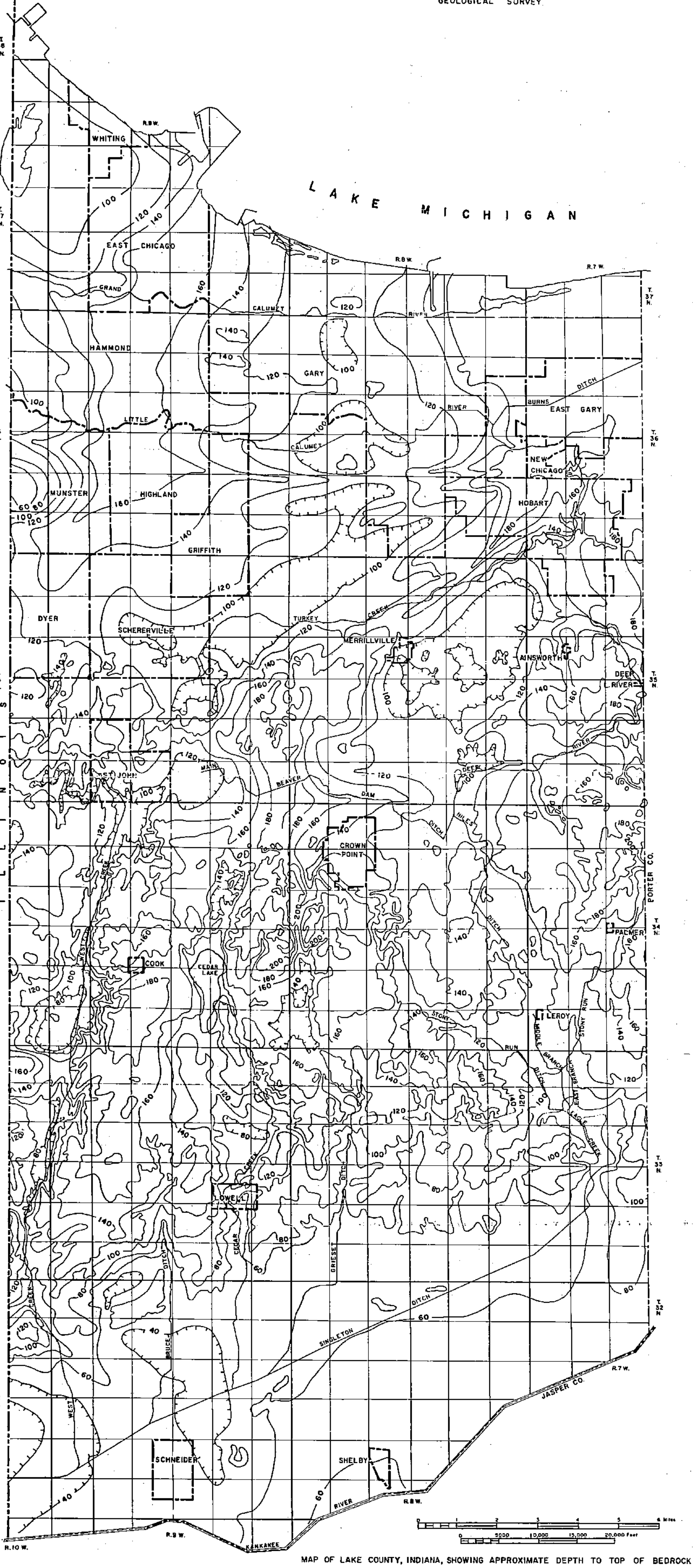


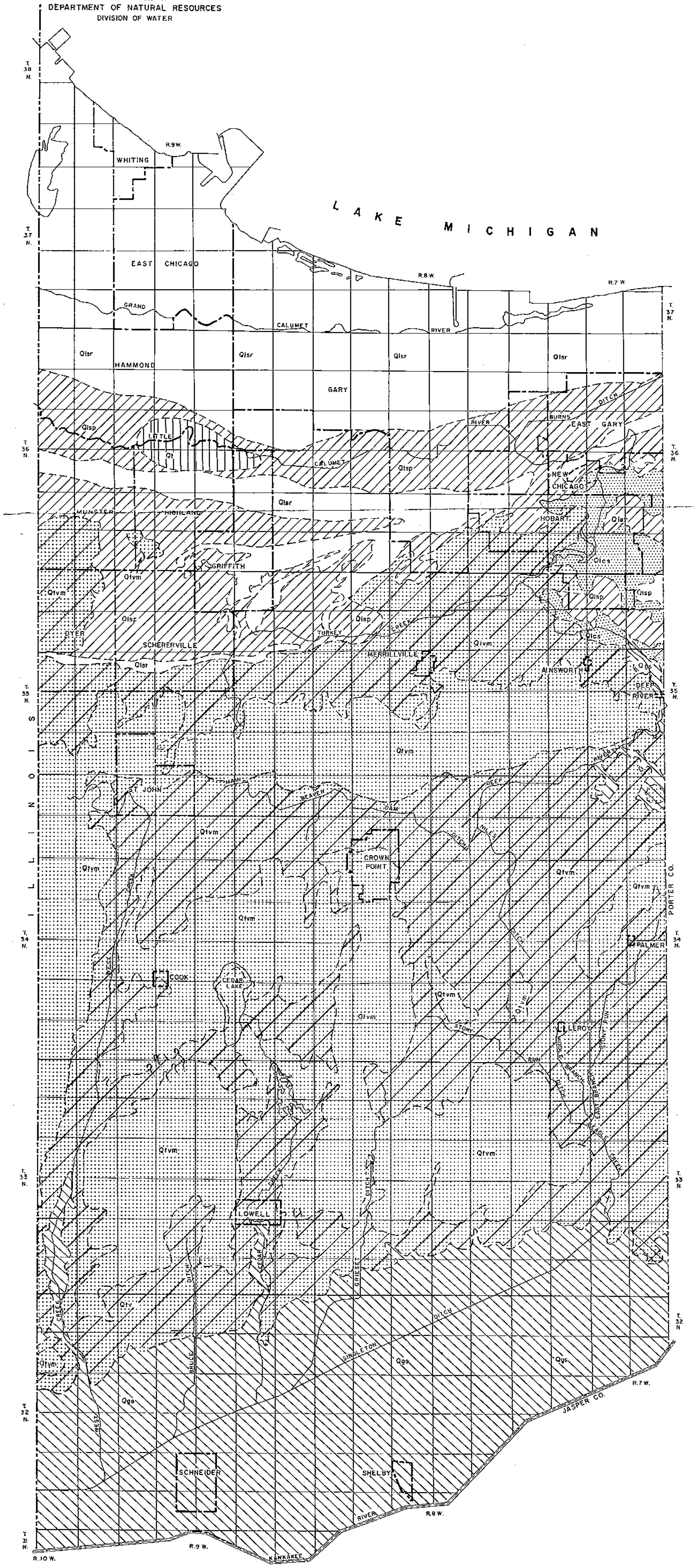
EXPLANATION

100

Contour shows approximate depth to top of bedrock. 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 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

----

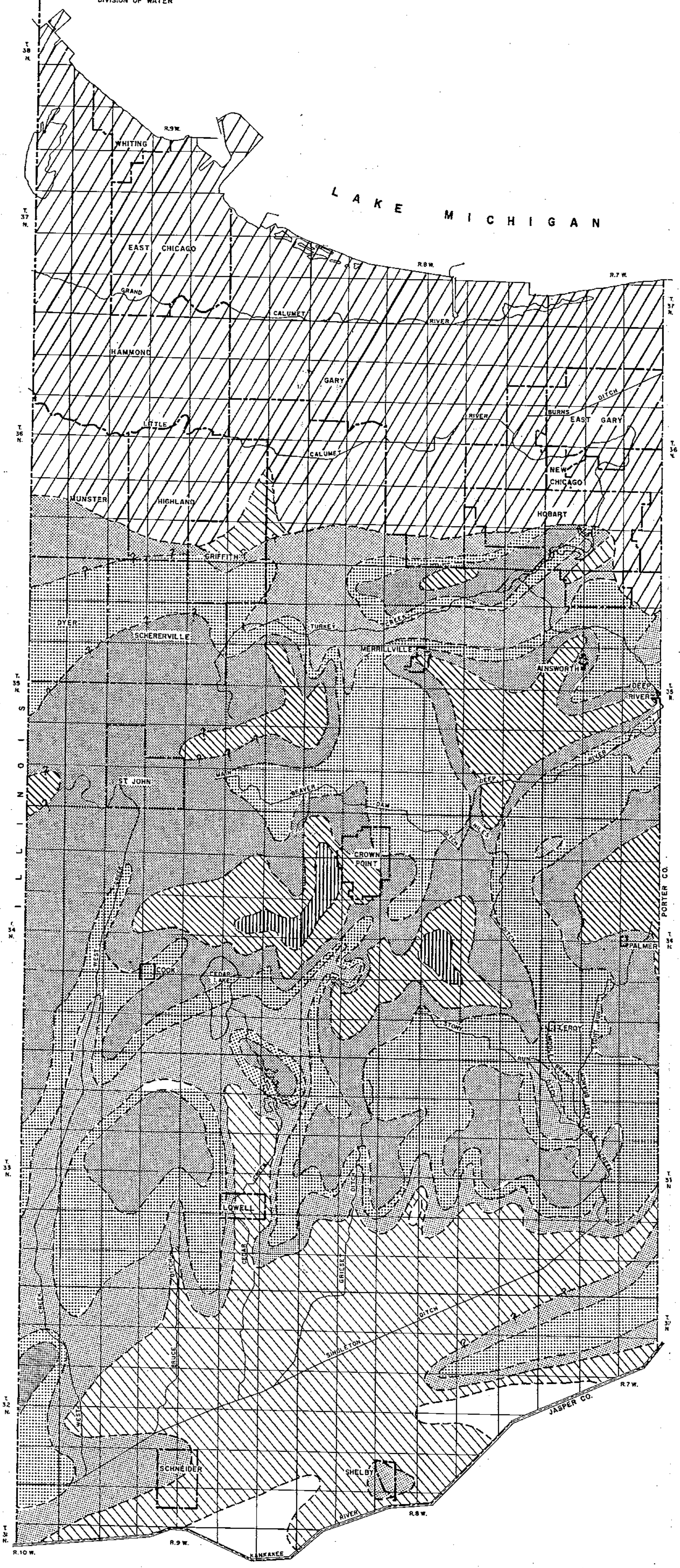
Approximate contact; queried where less accurate.

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.

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.

N

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

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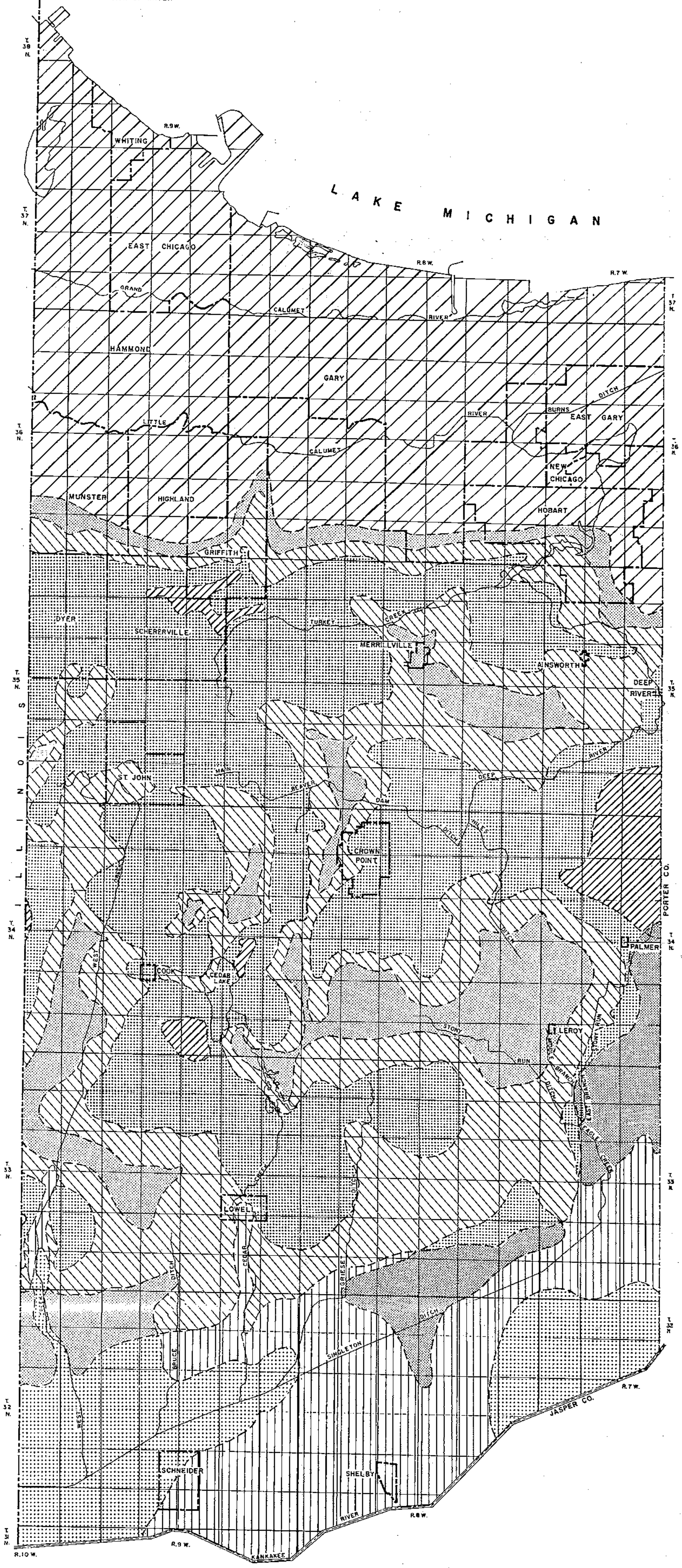


EXPLANATION

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

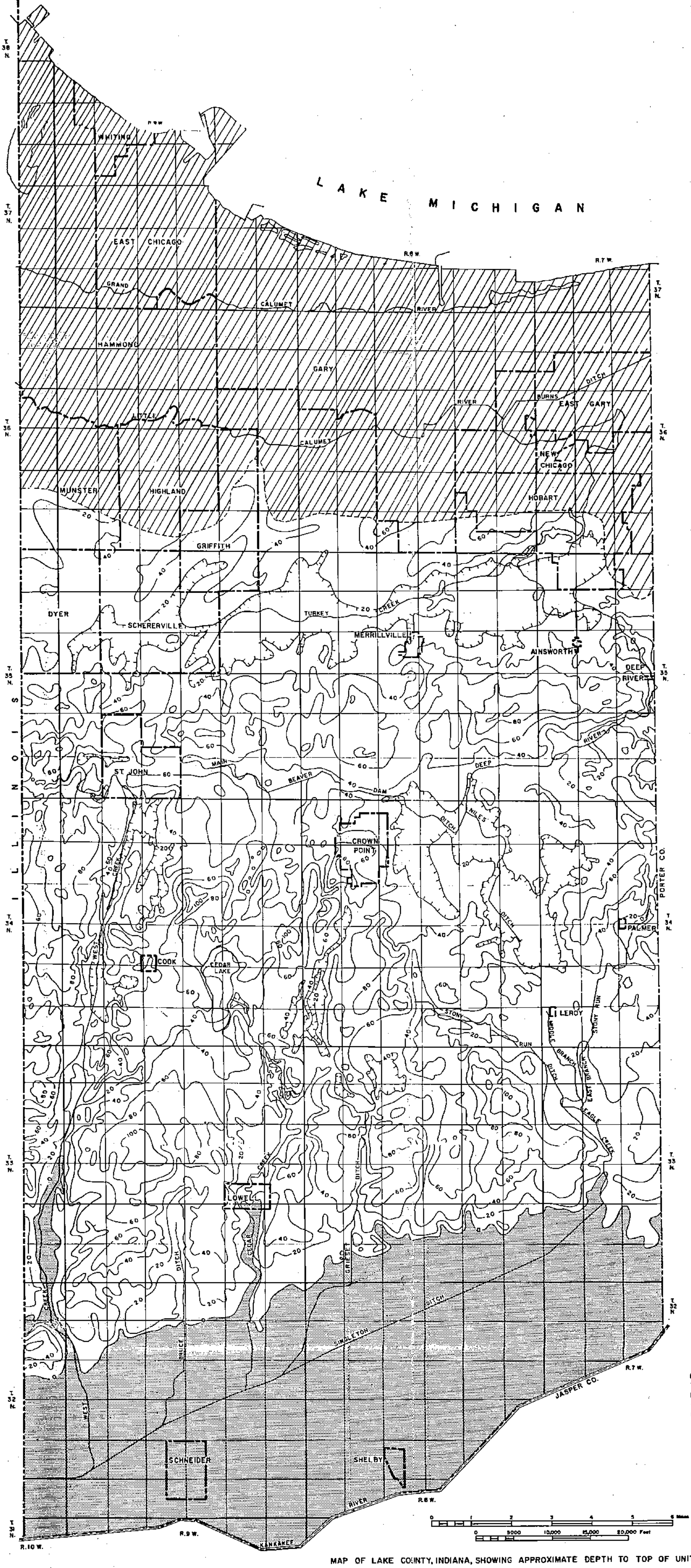
N

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 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



EXPLANATION

Area not underlain by unit 3

Area where unit exposed at surface

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