STATE OF MICHIGAN
DEPARTMENT OF CONSERVATION
GEOLOGICAL SURVEY DIVISION

Progress Report Number 22
RECONNAISSANCE OF THE GROUND-WATER RESOURCES OF SCHOOLCRAFT COUNTY, MICHIGAN

by
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ABSTRACT

Schoolcraft County is on the north shore of Lake Michigan in the eastern part of Michigan's Northern Peninsula. The County is sparsely inhabited, most of the population being concentrated in the city of Manistique and other communities in the southern part of the county. The northern and central parts of the county are covered by forests and extensive swamps. The forest products and tourist industries are the backbone of the economy of the area.

The county is in the northern part of the Michigan basin, where Paleozoic rocks of Cambrian, Ordovician, and Silurian age form the bedrock surface. During the Pleistocene epoch, glacial ice, streams, and lakes deposited a wide variety of sediments over the bedrock surface. In some areas in the southern part of the county these sediments have been wholly or partly removed by erosion.

The best bedrock aquifers in the county are the sandstones of the Munising (Late Cambrian) and Hermansville (Late Cambrian and Early Ordovician) formations and the Manistique and Burnt Bluff formations of Niagara (Middle Silurian) age. Limestones and dolomites of the Richmond group and the Trenton and Black River limestones of Ordovician age may be sources of fresh water where they form the bedrock surface. These formations and the Cataract formation of Silurian age, however, commonly yield saline water, especially in areas where they are overlain by younger consolidated rocks.

Sand and gravel of glacial origin which mantle much of Schoolcraft County are important or potentially important aquifers. Glacial deposits consisting of silt and clay or sand and gravel containing significant amounts of clay are not important sources of ground water.

Adequate quantities of ground water of good quality are present in most of the county. However, various important aquifers containing water of good quality are covered or underlain by aquifers containing water of objectionable chemical quality. The glacial-drift aquifers generally yield soft or only moderately hard water of the calcium magnesium bicarbonate type. The sandstone aquifers yield water of good quality in the north, but the sodium and chloride content increases to an objectionable degree at the southern edge of the county. The Manistique and the upper member of the Burnt Bluff formation yield hard, but potable, water of the calcium magnesium bicarbonate type. Water in the Manistique and Gulliver areas, however, is subject to bacteriological contamination from surface sources, and the Burnt Bluff is hydraulically connected to the Cataract formation which contains water high in calcium and sulfate.

INTRODUCTION

Purpose and Scope of Study

A ground-water reconnaissance of the eastern part of the Northern Peninsula on a county-unit basis was begun in 1955 as part of the continuing cooperative investigation by the Michigan Department of Conservation and the U, S. Geological Survey. The objective of the reconnaissance is to determine the general occurrence, availability, quantity, and quality of ground water in the study area. This report is the fourth in the series of interim county-reconnaissance reports, and it summarizes the ground-water data obtained in Schoolcraft County during the 1957 field season. The first three reports of this series described the ground-water resources of Chippewa, Mackinac, and Luce Counties (Vanlier and Deutsch, 1958a and b; Vanlier, 1959). Pertinent data from those reports are used freely herein.

This ground-water investigation was directed jointly by A. N. Sayre, former chief, and P. E. LaMoreaux, present chief of the Ground Water Branch, U. S. Geological Survey, and W. L. Daoust, State Geologist, Michigan Department of Conservation, and was under the direct supervision of Morris Deutsch, District Geologist of the Federal Survey, in Lansing.

Previous Investigations

Various phases of the geology and hydrology of Schoolcraft County are described in a number of reports of investigations made in the Northern Peninsula of Michigan. An investigation of flowing-well districts in the eastern end of the Northern Peninsula was made by Frank Leverett in 1906. A detailed investigation of the glacial features of the county was made by S. G. Bergquist (1936). O. F. Poindexter outlined the geology of the county in an unpublished report prepared about 1933 which contained a number of chemical analyses of ground and surface water samples, and these are included herein. He later (1935, 1936) studied the geology and hydrology of Big Spring and associated features. A reconnaissance study of the probable effects on ground-water levels of a Lake Superior-level canal from Munising to Manistique was made by the U. S. Geological Survey for the Corps of Engineers in 1949. Many of the data used in this report were collected during that survey. Ehlers and Kesling (1957) described in considerable detail the Silurian rocks in Schoolcraft County and in adjacent areas of the Northern Peninsula.

Acknowledgments

Special thanks are given to the well drillers and residents of Schoolcraft County and to the State, county, and

municipal agencies whose cooperation made this report possible. Appreciation is expressed also to personnel of the Michigan Geological Survey and to members of the Michigan Basin Geological Society, who furnished much valuable data and assistance.

Well-Numbering System

The well-numbering system used in this report indicates the location of the wells within the rectangular subdivisions of the public lands, with reference to the Michigan meridian and base line. The first two segments of a well number designate the township and range; the third segment designates the section and the serial number assigned to each well within the section. Thus, well 47N 16W 9-1 is well number 1 in section 9, Township 47 North, Range 16 West. Wells plotted on maps are identified only by serial number where section lines are shown, or by section and serial number where only township and range lines are shown. The locations to 40-acre tracts within the section of wells described in this report are given in table 3.

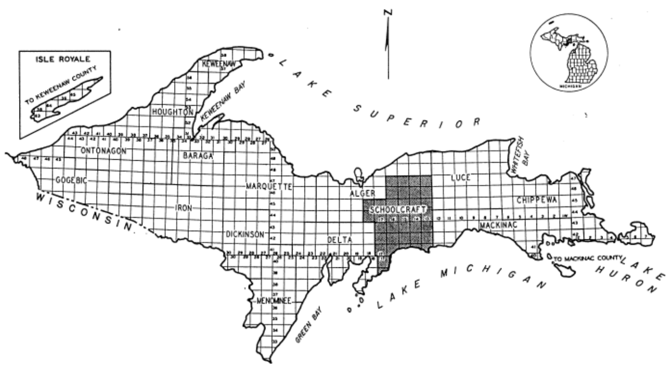

Figure 1. Index map showing location of Schoolcraft County, Mich.

GEOGRAPHY

Schoolcraft County is in the east-central part of the Northern Peninsula along the north shore of Lake Michigan (fig. 1). It is bordered on the west and north by Delta and Alger Counties and on the east by Luce and Mackinac Counties. It has an area of about 1,200 square miles, and a shoreline length along Lake Michigan of about 45 miles. Manistique, at the mouth of the Manistique River (fig. 2), is the county seat.

Population and Economic Development

The Michigan Economic Development Department estimated that the population of Schoolcraft County in 1957 was 8,620. Most of the inhabitants, including 4,780 persons in the city of Manistique, live in the southern part of the county; large areas in the northern part of the county are sparsely populated.

Industry in Schoolcraft County is closely related to the natural resources. Production of lumber, pulpwood, paper, and other forest products constitutes the major industry, which is almost equaled in dollar volume by the tourist business. Although commercial deposits of limestone may be present in Schoolcraft County, all the quarries previously worked have been abandoned in favor of high-quality deposits located in neighboring Mackinac County. Industrial expansion is anticipated as a result of completion of the St. Lawrence Seaway Project and the Mackinac Bridge.

Less than 5 percent of the total land area of the county is farmed, and most of the farmland is used for the production of dairy products. Nearly all the 250 farms are in the southern part of the county.

Transportation

The county is served by three railroads: the Duluth, South Shore & Atlantic; the Manistique & Lake Superior; and the Minneapolis, St. Paul & Sault Ste. Marie (fig. 2).

U. S. Highway 2 links the area with Sault Ste'. Marie and with the North-Central and Northwestern States. It also provides easy access to Michigan's Southern Peninsula via the Mackinac Bridge. State Routes M-28, 77, 94, 98, and 149 provide a network of hard-surfaced roads in the county.

The county is served by interstate bus and truck lines. The auto ferry from Frankfort in the Southern Peninsula, which is operated by the Ann Arbor Railroad, stops daily in the harbor at Manistique. Manistique Harbor is unique as the only harbor in the Northern Peninsula that remains open throughout the year; the discharge of the Manistique River prevents the harbor from becoming ice-bound.

Physiography and Relief

Schoolcraft County lies in an area that was glaciated during the Pleistocene epoch, and many of its physiographic features were formed during the period of glaciation (fig. 7). Extensive sandy plains mark areas where sediments were deposited in the glacial Great Lakes which inundated much of the county at the close of the glacial epoch. Highlands and ridges in the vicinity of Hiawatha, Steuben, Cooks, and Blaney Park occupy areas where rock debris (till) was deposited in the form of moraines directly by the glacial ice. These upland areas rise abruptly to elevations of 60 to 90 feet above the lake plains. Parts of the Kingston, Wetmore, and Boot Lake Plains in the northern and northwestern parts of the county (Bergquist) reach altitudes of about 1,000 feet above sea level. These plains are underlain by extensive deposits of sand and gravel outwash.

Because much of the drift was deposited in water and subjected to the currents and wave action of the glacial lakes, the relief is somewhat subdued and the distinguishing features of the various types of deposits are not easily recognized.

The lowest areas in the county are along the shoreline of Lake Michigan, which is at an altitude of about 580 feet.

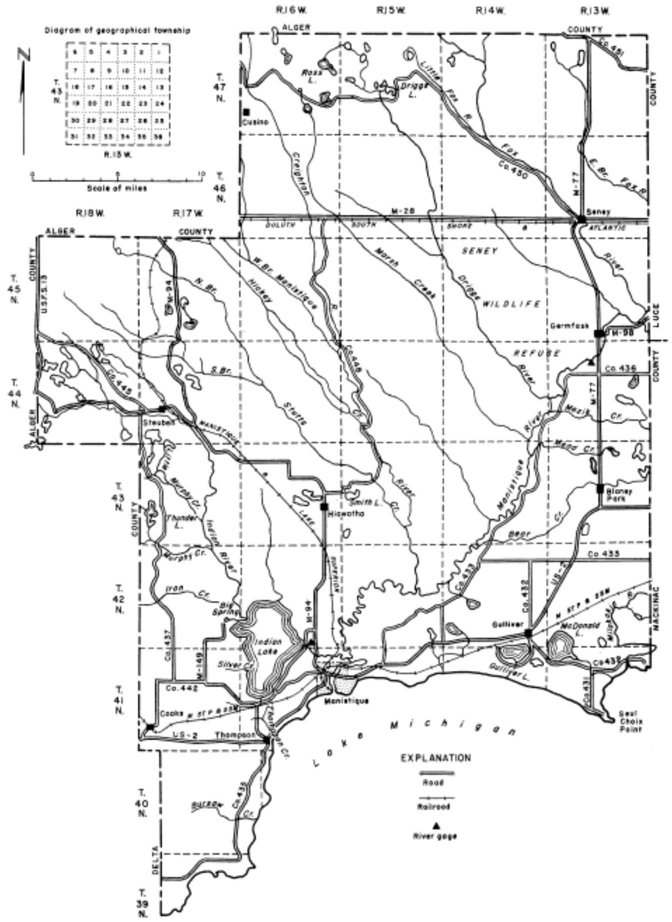

Figure 2. Map of Schoolcraft County.

The most prominent physiographic feature in the county, however, is related to the bedrock structure. This feature, the Niagara cuesta, is an asymmetrical ridge of resistant limestone and dolomite having a steep northern face, or scarp (fig. 3). It extends across the county in an arc about 10 miles inland and roughly parallel to the shore of Lake Michigan. In places the crest of the cuesta reaches a height of about 90 feet above the adjacent lake plains. South of the escarpment the topography reflects the bedrock surface, which slopes to the southeast at about 40 feet per mile. The cuesta is breached in the vicinity of Indian Lake along the trace of a preglacial valley. In some areas the topographic expression of the cuesta is obscured by a mantle of glacial drift.

Drainage

Nearly all of Schoolcraft County lies within the Manistique River Basin, which drains a total area of about 1,400 square miles. The Manistique River rises in Manistique Lake in Luce County and flows southwestward across Schoolcraft County from Germfask to Manistique, where it empties into Lake Michigan. Most of the major tributaries of the river flow southeastward across the county in roughly parallel courses until they join the main stream. The largest of these tributaries, the Indian River, flows into Indian Lake, and then to the Manistique River near Manistique (fig. 2).

The Manistique River flows at an average rate of about 1,700 cfs (cubic feet per second) or 760,000 gpm (gallons per minute). The maximum recorded flow was about 15,200 cfs and the minimum about 300 cfs.

South of the Niagara escarpment a total area of about 150 square miles is drained directly into Lake Michigan by the Milakokia River and by Thompson, Bursaw, and several other small creeks. The total length of all of the streams in Schoolcraft County exceeds 700 miles.

The 320 lakes, and the numerous sloughs and marshes in the county are evidence that the drainage is in a very early stage of development.

Climate

Records available from 1937 to the present indicate that Schoolcraft County receives an average precipitation of about 30 inches a year. Monthly precipitation totals at Germfask for the period 1953 through 1957 are shown in figure 11. Recorded temperatures range from a maximum of 97°F to a minimum of -35°F, and show an annual mean temperature of 41.7°F. The estimated average date of the last killing frost in the spring is June 15, and that of the first killing frost in the fall is August 27.

GEOLOGY

Schoolcraft County is underlain by sedimentary rocks of Paleozoic age which are mantled discontinuously by glacial deposits of Pleistocene age. The areal distribution of the Paleozoic rocks is shown in figure 3 and the surficial deposits in figure 7. The lithology and hydrology of the various rock units in the county are outlined in table 1 and are described in the section on Ground Water. Data concerning the depth, surface configuration, and nature of the Precambrian igneous and metamorphic rocks underlying Schoolcraft County are not available.

Summary of Geologic History

The Paleozoic rocks that underlie Schoolcraft County consist of limestone, dolomite, shale, sandstone, and gypsum. These rocks were deposited in the shallow seas which covered the Michigan basin during most of the Paleozoic era. The wide diversity of the sediments deposited is evidence of fluctuating sea levels, oscillating shorelines, and a variety of sediment sources.

During the estimated 200 million years between the Paleozoic era and the Pleistocene epoch, the Paleozoic rocks were uplifted and subjected to erosion, which resulted in the creation of some of the major physiographic features of Michigan. These features, later modified by Pleistocene glaciation, include the

Niagara escarpment and the major valleys which are now part of the basins of the Great Lakes.

A period of glaciation (the Pleistocene epoch) followed the long interval of erosion. During this epoch, ice migrated southward from accumulation centers in Canada. The glaciers scoured and abraded the surface and transported vast amounts of material torn from it. With melting of the ice sheets, this material was deposited over the eroded Paleozoic rocks (fig. 4).

At the close of the Pleistocene epoch a succession of glacial lakes covered nearly all of Schoolcraft County. Postglacial uplift of the landmass that had been depressed by the ice changed drainage patterns, lake elevations, and shoreline positions (Leverett and Taylor, 1915, chaps. 21-25, and Hough, 1958). The result of these changes was a succession of postglacial upper Great Lakes. Lakes Superior, Huron, and Michigan represent the modern stage of this succession. Bars, beaches, wave-cut terraces, and dunes throughout the county mark the shorelines of this succession of lakes. Another result of the uplift was enlargement of the Manistique River drainage basin and decrease of the size of basins draining to Lake Superior.

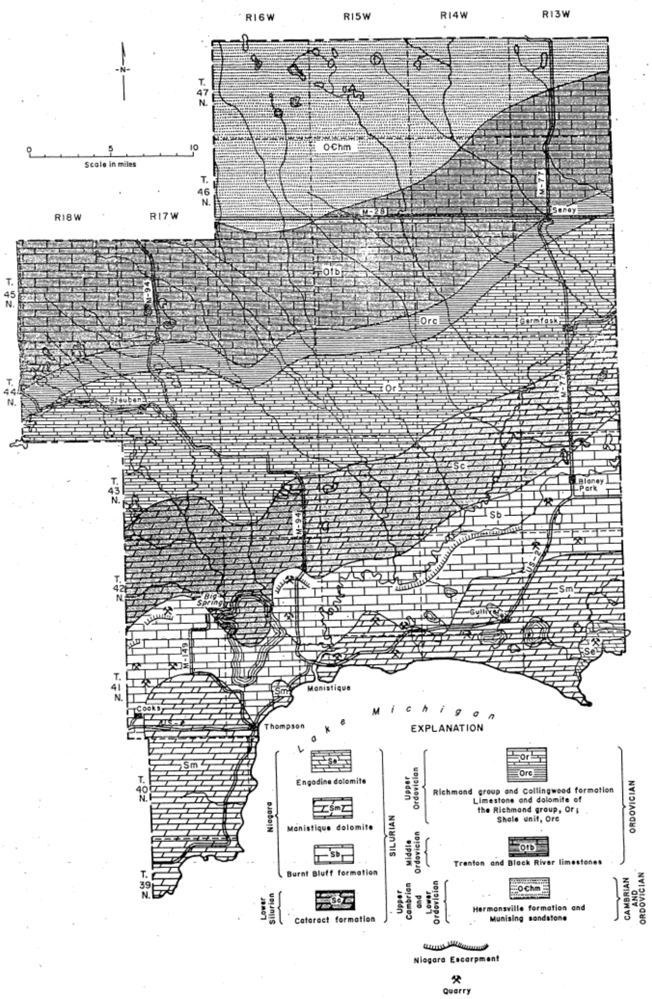

Figure 3. Bedrock geology of Schoolcraft County.

Bedrock Structure

The Precambrian surface upon which the sedimentary rocks of Schoolcraft County are deposited generally slopes southeastward toward the center of the Michigan basin. The Paleozoic rocks of the basin were deposited in nearly horizontal layers, but gradual subsidence and compaction of the beds, which was contemporaneous with deposition and greatest in the center of the basin, produced a bowl-shaped structure. The youngest beds are exposed at the surface in the central part of this structure in central Michigan, and the older formations crop out in roughly concentric bands. Schoolcraft County is near the northern edge of the basin, where older sedimentary rocks are exposed. The regional dip of these formations in the county is to the southeast at about 40 feet per mile (fig. 5). The formations tend to become thicker in that direction.

Although details concerning the structure of the Paleozoic rocks throughout the county are not known, at least one deformation in the regional structure has been studied (Ehlers and Kesling, 1957). This local structure is a northwest-southeast-trending fold (anticline) in the vicinity of Seul Choix Point.

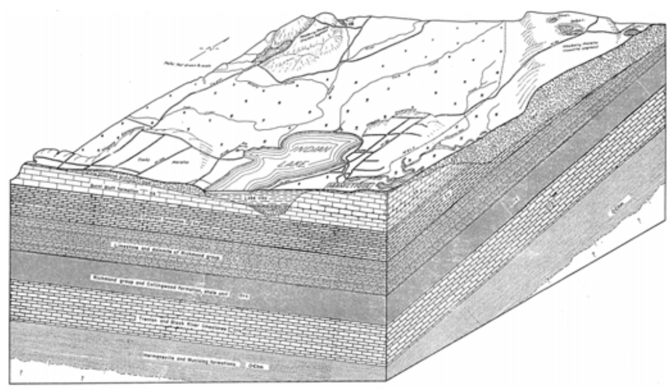

Figure 4. Block diagram showing surface features and geologic sections in part of southwestern Schoolcraft County.

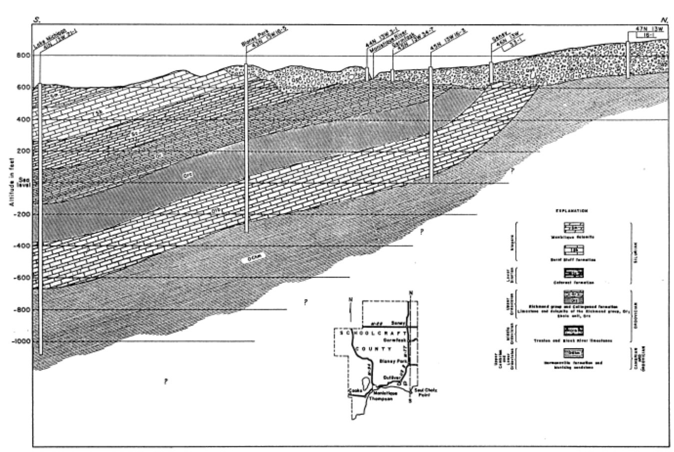

Figure 5. Geologic section through eastern Schoolcraft County.

GROUND WATER

Principles of Occurrence and Availability

A rock formation, part of a formation, or group of formations that yields water in usable quantities is called an aquifer. The imaginary surface consisting of all points to which water would rise in wells tapping an aquifer is called the piezometric surface. Aquifers may be classed as water-table or artesian. In a water-table aquifer, ground water is unconfined and the ground-water surface within the aquifer is termed the water table and may be considered the piezometric surface of that aquifer. The zone of saturation is that portion of the formation in which openings are filled with water. In an artesian aquifer, ground water is confined under pressure between relatively impermeable strata (strata through which water does not move readily). Under natural conditions, the water in a well that is finished in an artesian aquifer and tightly cased through the overlying confining bed will rise above the bottom of that bed, and therefore the piezometric surface is above the top of the aquifer. An artesian aquifer is full of water at all times, even when water is being removed from it. In topographically low areas wells tapping artesian aquifers may flow at the surface.

Porosity is the ratio of the volume of open spaces in a rock to the total volume of the rock. Porosity is generally described as primary or secondary. Primary porosity is porosity that is present in the rock when it is first formed. Secondary porosity is porosity that was developed by processes that affected the rocks after they were formed. In unconsolidated deposits the porosity is generally greatest where the deposits are well sorted and least where they are poorly sorted. In consolidated rocks cementation, fractures, and solution and deposition by ground water are generally the most important factors determining porosity.

The capacity of a material to transmit water under pressure is called permeability. The degree of permeability depends on the size and shape of the pores and the extent to which they are interconnected. The coefficient of permeability (P) as used herein is reported in Meinzer and is defined as the number of gallons of water per day that will move through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60°F. The field coefficient of permeability is the same except that it is measured at the prevailing temperature of the water. But the ability of the aquifer to yield water to a well is related also to the thickness and extent of these materials. A measure of the capacity of an aquifer as a whole to transmit water is called transmissibility. The coefficient of transmissibility (T) is defined as the number of gallons of water per day, at the prevailing temperature, that will move through a vertical strip of the aquifer 1 foot wide and of a height equal to the thickness of the aquifer under a hydraulic gradient of 100 percent, or 1 foot per foot. Hence, the transmissibility of an aquifer is the average field permeability of the rock materials multiplied by the thickness of the aquifer, in feet.

The yield of a well is a function of the transmissibility of the aquifer and the efficiency of the well. It is often expressed in terms of the specific capacity -- the yield of water in gallons per minute for each foot of drawdown in water level caused by pumping of the well. Table 2 lists the specific capacities of a number of wells tapping various .aquifers in Schoolcraft County.

The aquifers underlying Schoolcraft County consist of a variety of consolidated and unconsolidated rocks. The chief consolidated-rock aquifers are composed primarily of sandstone, limestone, or dolomite. In the sandstone aquifers water moves through primary openings between individual sand grains and through secondary openings along fractures and bedding planes. Water in the limestone and dolomite aquifers of the county moves predominantly through permeable zones which were developed by weathering and solution along such secondary openings.

Shales interbedded with layers of limestone and dolomite are of low permeability and yield very little water to wells. They are important, however, as confining beds in artesian systems.

Aquifers in the glacial drift are the most accessible source of water in much of the county. The water in drift aquifers is contained in the spaces between rock particles, and the permeability varies with the size, shape, and degree of sorting of the particles.

Well No.	Aquifer		Drawdown (feet)	Rate of discharge (gmp)	Duration of test (hours)	Specific capacity (gmp/ft.)
	Symbol [1/]	Lithology				
44N 13W 3-3	Or	Limestone, shaley	3.5	21	.5	6
23-2	Qg	Gravel	20	50	1	2.5
43N 13W 16-5	OЄhm	Sandstone	16	35	--	2.2
42N 17W 25-1	Qsg	Sand and gravel	10	15	12	1.5
42N 14W 33-6	Sm	Dolomite	17	20	6	1.2
35-4	Sm	do.	15	10	1	.67
41N 16W 3-4	Sb	do.	8	10	-	1.2
12-21	Sb	do.	3	50	1	17
12-24	OЄhm	Sandstone	81	1018	50	13
12-30	Sc	Dolomite	2	33	1	16
41N 15W 9-1	St	do.	21	14	1	.67
18-2	Sb	do.	12	100	--	8.3

[1/] See table 1.

Table 2. Specific capacities of wells in Schoolcraft County.

Ground Water in Consolidated Rocks

Precambrian Rocks

Precambrian igneous and metamorphic rocks underlie all of Schoolcraft County. However, neither the depth to the surface of these rocks nor their composition or physical characteristics have been determined at any location in the county. Well 41N 13W 21-1 (table 3) which was drilled to a depth of 1,710 feet, and is the deepest well in Schoolcraft County, did not reach the surface of the Precambrian rocks. (Fig. 14, which precedes tables 3, 4, and 5, is an index of available well records, water-level information, logs, and chemical analyses of ground water in Schoolcraft County, and shows the geographic distribution of these data). Future development of Precambrian rocks in the county as a source of water is very unlikely because of their depth and probable low permeability, and because the Precambrian rocks are overlain by moderately permeable sandstone aquifers.

Jacobsville sandstone of Precambrian or Cambrian age

The Jacobsville sandstone does not crop out in Schoolcraft County. Where it is present at the surface along the shore of Lake Superior in Alger County, it is composed of hard, resistant quartzitic sandstone. The formation extends southward and is presumed to overlie Precambrian rocks in the northern part of Schoolcraft County. Permeability of the formation probably is low, as the voids between grains have been filled with cement and a secondary-growth of the quartz crystals that form the sand grains. Joints and other fractures, which are present near the surface, probably are not well developed at depth (Vanlier, 1959). Because of the factors outlined, the formation is considered to have little potential as a source of water in the county.

Munising Sandstone of Late Cambrian Age and Hermansville Formations of Late Cambrian and Early Ordovician Age

The Munising sandstone of Late Cambrian age is the deepest and oldest formation in Schoolcraft County that may be considered a dependable source of ground water. I t is composed of medium-grained white to gray sandstone. Locally, shale or slightly dolomitic sandstone layers are present (table 4, log 41N 13W 21-1).

The Munising sandstone is overlain by the Hermansville formation of Late Cambrian and Early Ordovician age. The Hermansville is a rather dense sandy dolomite with layers of clean, well-sorted sandstone. Logs of wells in the Northern Peninsula indicate that the dolomite concentration within the formation increases toward the west. Because of the similar lithologic properties of the sandstones in the Munising and Hermansville it is difficult to distinguish between the formations in drill cuttings and hence they are not differentiated in figures 3, 4, and 5. They are generally similar also in hydrologic characteristics and are treated herein as a single hydrologic unit.

A particle-size analysis of a typical sample of sandstone from an outcrop of the Munising in Alger County (Al 1, fig. 6) shows that about 90 percent of the sample is fine and medium sand. The coefficient of permeability normal to the bedding plane of this sample was 52 gpd per square foot.

Particle-size analysis of a sample of sandstone from the Hermansville formation in Luce County (Lu 9, fig- 6) shows that this formation also is a fine- to medium-grained sandstone. The interstices between sand grains in some of the beds of the Hermansville formation, however, are filled with dolomitic cement, which reduces the permeability of the formation considerably. The permeability normal to the bedding plane of sample Lu 9 was 0.04 gpd per square foot, and the permeability parallel to the bedding plane was 0.07 gpd per square foot. The low permeability of sample Lu 9 is undoubtedly due to the presence of the dolomitic cement. However, the dolomitic beds will probably yield appreciable quantities of water, as most of the water in the well-cemented parts of the formation moves along fractures and bedding planes. Laboratory determinations can indicate permeability along primary but not secondary openings in sandstone samples. Aquifer testing in the field is required to determine the total water-bearing characteristics of fractured sandstone formations.

A sample of the Hermansville formation from an outcrop in Chippewa County (Ch 10, fig. 6) revealed that it too was very similar in particle-size distribution and lithology to the Munising sandstone. This sample, however, appeared to contain much less cementing material than sample Lu 9. The sample had a permeability of 34 gpd per square foot parallel to the bedding plane.

The Hermansville and Munising formations are a source of fresh water throughout most of the county. In the northern part of the county they form the bedrock surface, but to the south they dip beneath the younger consolidated rocks (figs. 4 and 5). Along Lake Michigan the top of the aquifer is about 1,200 feet below the land surface. The mineral content of the water in the aquifer increases basinward, and may reach objectionable concentrations at the southern edge of the county, although samples analyzed for chemical content (table 5) are believed to be mixtures of water from these sandstones and overlying formations which, in this area, generally yield saline water.

Water in this aquifer is held under artesian pressure by overlying shale beds and, in most parts of the county, will flow at the surface. A water level of 28 feet above land surface was reported for well 41N 16W 12-24 in the city of Manistique in 1942 and 80 feet above land surface for well 41N 13W 21-1 near Seul Choix Point in 1921.

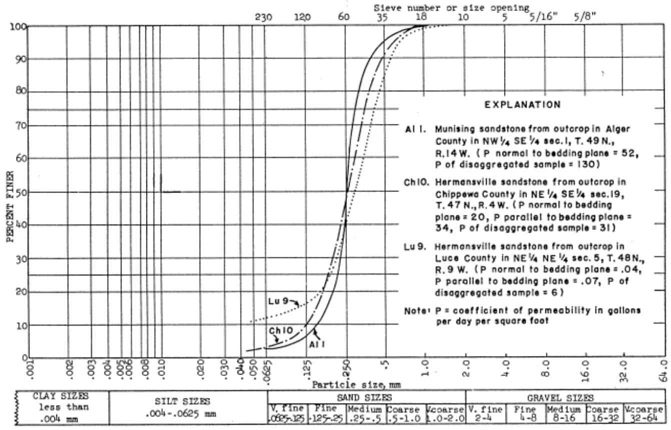

Figure 6. Particle-size-distribution curves of sandstone samples from the Munising and Hermansville formations in Alger, Chippewa, and Luce Counties.

Black River and Trenton Limestones of Middle Ordovician Age

The Black River and Trenton limestones are lithologically similar and no attempt is made herein to differentiate between them. They consist of brown and gray dolomites and limestones with a few layers of soft green, brown, or black shale. Well records indicate that these formations have an aggregate thickness of 250 to 300 feet in Schoolcraft County (table 4).

Where these rocks form the bedrock surface (fig. 3), they are everywhere mantled by glacial drift deposits. Although they may be a source of fresh water in this area, the overlying glacial drift provides a more accessible source of water of good quality. In the southern two-thirds of the county these formations are covered by younger consolidated rocks (figs. 3 and 5). In this area the Black River and Trenton limestones yield moderate supplies of water under artesian pressure, but the water is generally highly mineralized and unsatisfactory for most uses. Artesian pressure in this aquifer sufficient to raise water 9.5 feet above the land surface was reported when well 43N 13W 16-5 was drilled in 1949 (table 3). Mineral-water zones within these rocks should be sealed off in wells drilled through them, to avoid contamination of fresh water both in the underlying sandstones and in the overlying rocks.

Collingwood Formation and Richmond Group of Late Ordovician Age

<u>Shale unit</u>. A sequence of shale strata of the Collingwood formation and of the basal units of the Richmond group overlies the Trenton rocks. The Collingwood formation, at .the bottom of the sequence, is composed of about 20 feet of dark-gray to black bituminous shale. The basal units of the Richmond group are composed primarily of gray shale and include layers of dolomitic shale. The total thickness of the shale unit in the southern part of the county is reported to range from about 200 to 260 feet (table 4). These shales are of low permeability and are not a source of water to wells in Schoolcraft County.

<u>Limestone and dolomite of the Richmond group</u>. The upper units of the Richmond group consist of about 300 feet of dolomite, limestone, and shaly or sandy dolomite or limestone strata interbedded with shale. The log of well 43N 13W 16-5 (table 4) at Blaney Park also reveals the presence of streaks of gypsum in these strata. These rocks range in color from gray to brown. Rocks of the Richmond group are not known to crop out in Schoolcraft County.

Several wells in the county obtain water from Richmond rocks. The water occurs along fractures and bedding planes, which probably have been enlarged by solutional activity of ground water. Where overlain by the Cataract formation the water is confined under sufficient artesian pressure to cause it to flow at the surface in many places. In these areas the water is generally high in calcium and sulfate. Water of good quality might be obtained from these rocks where they form the bedrock surface (fig. 3). In this area, however, extensive development of the formation is unlikely, as the overlying glacial drift is a more accessible aquifer.

Cataract Formation of Early Silurian Age

The Cataract formation is composed of buff to gray, dense, shaly dolomite with layers of gypsum and greenish-gray shale (Ehlers and Kesling, p. 5-7). This formation ranges in thickness from about 150 to 200 feet. The Cataract is permeable as a result of solution openings which have been formed by leaching of the gypsum beds. This aquifer has been tapped for water at Blaney Park, at Manistique, and in the vicinity of Indian Lake, but in these areas it generally yields saline water (table 5). Generally, fresh water cannot be obtained from this aquifer anywhere in Schoolcraft County because of the soluble gypsum present in the formation. Where the formation is overlain by fresh-water aquifers, drilling into the Cataract should be avoided in order to insure a supply of fresh water and to prevent contamination of the overlying aquifers.

Niagara Series of Middle Silurian Age

Limestone and dolomite rock strata of the Niagara series which form the bedrock surface along the southern part of Schoolcraft County are an important source of water. In much of this area the glacial drift mantle is thin, and the Niagara rocks are exposed at the surface in numerous places. The Burnt Bluff and Manistique formations are important aquifers because they are present in the area where most of the population of the county is concentrated. The Engadine dolomite, however, is present only in a few square miles in the southeastern corner of the county, along the Lake Michigan shore.

Wells drilled into these rocks obtain water from openings formed largely by solution and weathering when the rocks were exposed at the surface, and from permeable zones developed at depth through solutional activity of percolating ground water. Study of the Niagara rocks in Mackinac County (Vanlier and Deutsch, 1958b) revealed that the permeable zones are areally extensive, and it is probable that such zones are extensive in Schoolcraft County also. Not all of the soluble beds have been made permeable by solutional activity, however, as the development of solution voids in some strata probably was blocked by initial impermeability of the bed, or by restriction of ground-water flow through adjacent strata of low permeability.

Generally, permeable zones in the Niagara rocks are thin and are separated by relatively thick beds of low permeability. Thus, the yield of a well tapping one permeable zone in these formations will not increase significantly until the next permeable zone is reached. By contrast, in a well tapping a formation of uniform permeability, the yield will increase approximately in proportion to the thickness of the formation penetrated.

<u>Burnt Bluff formation</u>. The Burnt Bluff formation is composed of about 250 feet of thin-bedded to massive light-gray to buff dolomite and dolomitic limestone. Some of the upper strata of the formation are beds of high calcium limestone, which is especially soluble. Caves have been formed by solution of portions of the high-calcium limestone members in adjacent areas in Mackinac County.

Water in the formation is generally confined under sufficient artesian pressure to cause it to rise to within a few feet of the land surface. A number of the wells tapping this formation flow at the land surface (table 3). The Burnt Bluff formation is the most important aquifer in the county, as it is the source of water to most of the wells in the populated areas. Generally, moderate supplies of fresh water can be obtained from it, and locally the formation will yield large water supplies.

<u>Manistique dolomite</u>. The Manistique dolomite is a thin-bedded to massive light-buff to brown or gray cherty dolomite. Chert nodules are common in the upper layers of the formation. The Manistique has a maximum thickness of about 150 feet in the vicinity of Seul Choix Point where it is overlain by the Engadine dolomite.

The Manistique is an important source of water where it is present in sufficient thickness, principally along the Lake Michigan shore. A number of wells that tap this aquifer in the Gulliver area flow.

<u>Engadine dolomite</u>. The Engadine dolomite is a massive hard bluish-white dolomite which is an extensive and important aquifer in Mackinac and Chippewa Counties. In Schoolcraft County, however, only a thin remnant of the basal portion of the formation is present in a small area in the southeastern corner of the county along the Lake Michigan shore. No wells in the county are known to tap the Engadine for a water supply, and the formation has little potential for development as an aquifer because of its limited areal extent and thickness.

Ground Water in Unconsolidated Sediments

The mantle of unconsolidated rock material that covers most of Schoolcraft County (fig. 7) was deposited by glacial action during the Pleistocene epoch. This material was plucked from the surface by moving ice and redeposited as till, outwash, lake sediments, and dunes. Glacial deposits are differentiated on the basis of their mode of deposition. Till is generally unstratified material that has been deposited directly from the ice, water playing a minimum part in the process of deposition. Outwash is stratified rock material that has been deposited by meltwater draining from the glacier. Glacial-lake sediments are stratified fine-grained materials laid down in glacial lakes. The general term used to describe all these deposits is glacial drift. Dunes are composed of well-sorted sand deposited by wind.

The physical, and hence hydraulic, characteristics of the drift deposits vary also according to the type of material from which the drift was derived. The sandy drift, which is the predominant type in the county, especially in the northern part, was derived mainly from the Cambrian and Ordovician sandstone formations, and to a lesser extent from the Precambrian igneous rocks in the Lake Superior region. This is illustrated by comparison of figure 8, in which the particle-size analyses of several samples of till and one sample of dune sand are plotted, with figure 6, in which the particle-size distribution of samples of sandstone from the Hermansville and Munising formations are shown. It is apparent that the till and dune sand were derived almost entirely from the sandstone. The composition of the deposits sampled reflects primarily the source of the rock particles rather than the mode of deposition.

Clayey drift deposits such as the clayey till in the moraines in the southern half of the county were derived from the Ordovician and Silurian limestone, dolomite, and shale formations described above. Figure 9 shows the particle-size analyses of several samples of till from the southern half of the county.

The permeability of the drift deposits varies with the size of individual grains and with the degree of sorting. The most permeable drift sediments are the outwash deposits, which are composed of larger particles of rock and are relatively well sorted. Sandy or gravelly till which contains only minor amounts of clay and silt is generally of moderate permeability. Clayey till, however, is of low permeability. Dune sands and lake-deposited sands, which are well sorted although relatively fine grained, also are of moderate permeability. Lake-deposited silts and clays, or silty, clayey sands, are generally of low permeability.

The drift mantle of Schoolcraft County varies greatly in thickness. Where valleys or channels were cut into the underlying bedrock and subsequently filled with glacial sediments, the drift is known to be as much as 200 feet thick. In the southern part of the county which is underlain by resistant Niagara rocks, the drift is generally thin or discontinuous.

Well records and surface evidence indicate that a pre-Pleistocene valley which connected the Lake Superior and Lake Michigan basins was cut into the bedrock formations underlying Schoolcraft County. This channel is believed to extend northward from the Lake Michigan shore between Thompson and Manistique through Indian Lake (fig. 4). The extent of this channel north of the Indian Lake region is not known, but is believed to be almost due north through T. 47 N., R. 16 W., and into Alger County. The reentrants in the bedrock formations along the trace of this inferred valley that are shown on figure 3 are based largely on surface evidence. The bottom of the valley contains permeable deposits of sand and gravel which are overlain by thick lake-clay deposits. The sand and gravel is the source of water to the many flowing wells near Indian Lake (table 3). Although data concerning this buried channel are incomplete, the channel deposits are believed to have considerable potential as a source of ground water of good quality.

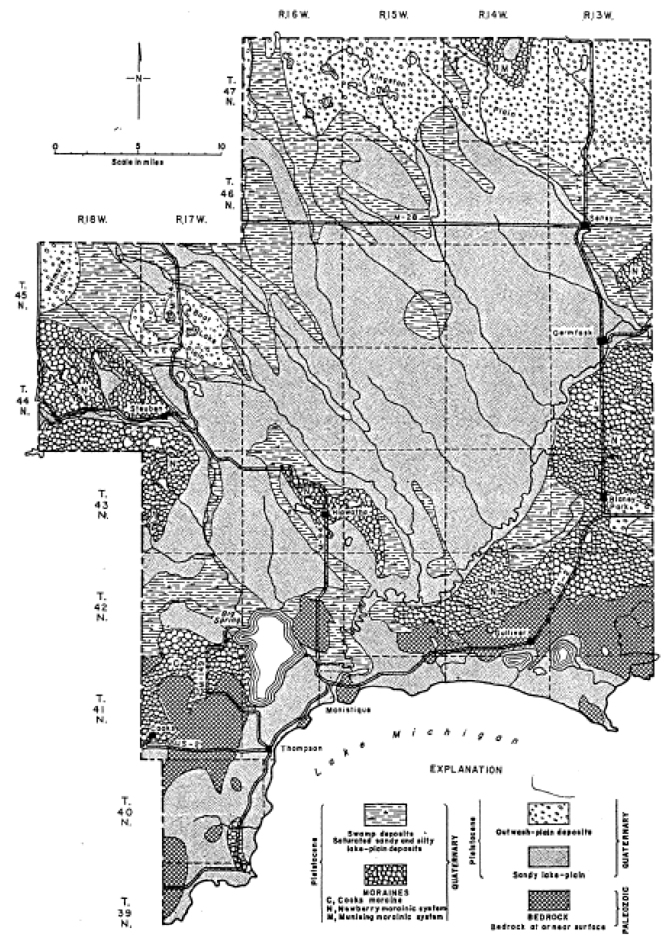

Figure 7. Surface geology of Schoolcraft County (adapted from Bergquist, 1936.)

Morainic Deposits

Moraines are ridges composed predominantly of glacial till deposited along the relatively static front of a glacier. The morainal till in Schoolcraft County is composed of unsorted rock particles ranging in size from clay to boulders, but the composition of the till varies with the bedrock sources from which it was derived. Areas in the county that are covered by moraines were mapped by Bergquist (fig. 7) who delineated them into the Cooks moraine and the Newberry and Munising morainic systems.

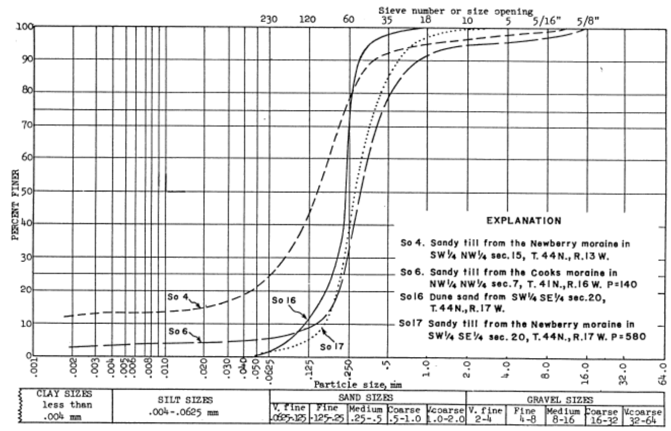

Figure 8. Particle-size-distribution curves of sandy till and dune-sand samples from Schoolcraft County.

During periods of rapid recession of the ice the drift material was deposited in undulating sheets known as till plains or ground moraine.

Most of the till of the moraines in the county was deposited in the waters of the glacial Great Lakes. The relief of the moraines has been greatly subdued by the washing action of the glacial lakes, which has also stratified and sorted the till deposits to some extent.

Parts of the moraines and much of the clay and silt originally present in exposed portions of the moraines were subsequently removed by the currents and waves of the various postglacial lakes. This is demonstrated by the virtual absence of clay and silt in samples So 3 and So 19, each taken from a depth of 2 feet (fig. 9). The removal of fine-grained sediments in some places has greatly increased the permeability of the till deposit. Sample So 19, taken from a remnant of a wave-washed moraine, is composed primarily of gravel and has a permeability of 2,600 gpd per square foot (fig. 9). The particle-size-distribution curve of sample So 13, taken from a depth of ^ feet, is similar to that of sample So 19, but the sample contains about 18 percent silt and clay. The permeability of sample So 13 is only 220 gpd per square foot.

Cooks moraine. The Cooks moraine, the oldest moraine in Schoolcraft County, is a knob of clayey till overlying a bedrock highland northeast of the village of Cooks (fig. 7). The average thickness of this till deposit is about 50 feet. All of the Cooks moraine except the high knob half a mile northeast of Cooks has been subjected to the wave and current action of the highest postglacial lake. Sample So 7 (fig. 9) was taken from a depth of 10 feet from the Cooks moraine at a level above the glacial lakes. The almost complete lack of sorting and the presence of about 40 percent of silt and clay in the sample indicates that the till has not been washed or reworked by the waters of the lake. The permeability of this material is low, and it would be difficult to develop a water supply from the glacial drift in this area. Low portions of the moraine from which clay and silt have been removed by water are fairly permeable and may yield amounts of water adequate for domestic purposes.

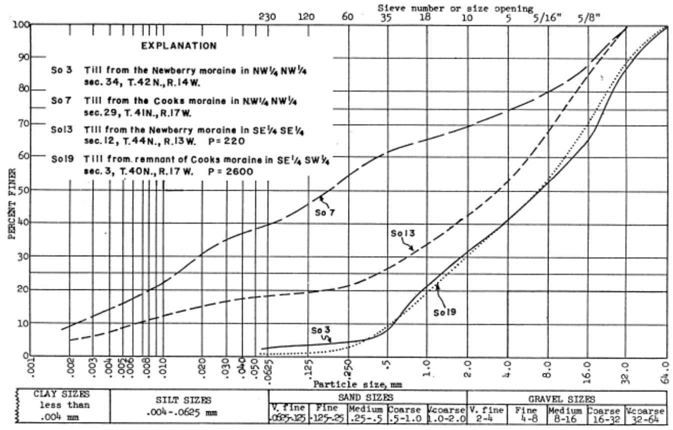

Figure 9. Particle-size-distribution curves of till samples from moraines in Schoolcraft County.

<u>Newberry morainic system</u>. The Newberry moraine is the most extensive of the till deposits in Schoolcraft County. It extends in an east-west arc across the county (fig. 7), but has been dissected into three distinct segments: the Blaney, Hiawatha, and Steuben segments (Bergquist).

The Blaney segment overlies the Niagara cuesta along the Manistique River south of Germfask. In the Germfask-Blaney Park area north of the cuesta, the till is more than 100 feet thick in places, and locally is an important source of water. Yields are generally small, however, since the Blaney segment is composed primarily of poorly sorted boulder till with a comparatively high content of silt and clay, such as is represented by sample So 13 (fig. 9). In the area north and west of Gulliver, the moraine is thin and discontinuous and is not shown in detail on figure 7. In this area the morainal material generally is not a source of ground water.

The Hiawatha segment of the Newberry moraine forms a highland rising abruptly to an elevation of about 60 feet above the lake plains and separates the Manistique and Indian River basins. The till underlying this segment of the moraine is composed principally of sand, but includes small pockets of boulder clay, and is about 200 feet thick in the vicinity of Hiawatha. A number of wells there obtain water from the sandy till, although some difficulty has been encountered in screening out fine sand.

The Steuben segment has a basin and knob type of topography and reaches an elevation of about 900 feet. It is similar in composition to the Hiawatha segment. Although data concerning the thickness of the drift deposits composing the Steuben segment are not available, the thickness in this area is probably about 200 feet. These deposits presently are tapped by only a few wells of small capacity.

<u>Munising morainic system</u>. A small part of the Munising morainic system extends from the main body of the moraine in Alger County into the northern part of Schoolcraft County (fig. 7). The moraine is composed largely of sandy till and forms part of the highland area along the northern tier of townships. The morainal deposit is permeable and is a potential source of water, although the area presently is uninhabited and undeveloped.

Outwash

Outwash plains are underlain by stratified sand and gravel which have been deposited by glacial melt-water streams. These deposits commonly are very permeable, and are a good potential source of ground water.

Large deposits of outwash materials occur in the northern part of the county. The Kingston Plain (Bergquist, p. 86) across the northern tier of townships is underlain by outwash carried by melt water from the glacial ice standing on the Munising moraine, as are Wetmore and Boot Lake outwash plains north of Steuben.

The only extensive outwash plain in the southern part of the county is east of Blaney Park. Although other small outwash deposits may be present, they are too small to be shown on figure 7.

The outwash deposits are tapped by only a few wells, as the deposits are located in sparsely inhabited areas.

Glacial-Lake Deposits

Lowlands in about two-thirds of Schoolcraft County are underlain by sand, silt, and clay deposited in the glacial Great Lakes. The surficial lake sediments are composed predominantly of sand, and hence the lake-plain areas shown on figure 7 are mapped as "sandy lake plain".

Figure 10 shows particle-size-distribution curves of three samples taken from the sandy lake plains. Samples So 14 and So 15, taken from depths of 2 and 3 feet, contain very little silt and clay and have permeabilities of 680 and 540 gpd per square foot. The permeability of sample So 5, taken from a depth of 25 feet, is only 170 gpd per square foot. All three samples are predominantly well-sorted sand, but sample So 5 is composed of slightly smaller particles and contains 10 percent more silt and clay, differences which, though scarcely noticeable to the eye, reduces the permeability of sample So 5 to about one-third of that of the other samples. These permeabilities indicate that the sandy lake deposits are potentially good sources of water in areas where they are relatively thick. Little information is available concerning the thickness and nature of the subsurface lake sediments throughout most of School-craft County. In much of the county, however, the lake sands may consist merely of a veneer over the bedrock surface or other glacial deposits.

In some parts of the county, silty or clayey lake sediments underlie the sandy lake deposits. This is illustrated by the log of well 46N 13W 33-1 near Seney (table 4), which shows 60 feet of lake-deposited sand overlying 40 feet of blue lake clay.

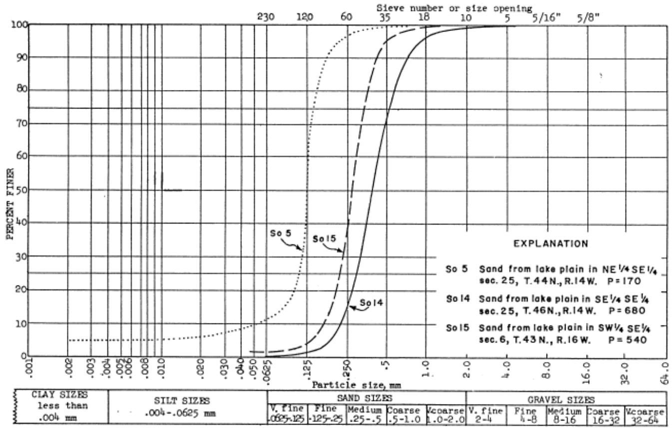

Figure 10. Particle-size-distribution curves of lake-deposited sand samples from Schoolcraft County.

Dune Sand

Areas of windblown sand are prevalent in parts of the county. Although very permeable, these deposits are above the water table in most areas and cannot be considered a source of water; however, they are important recharge areas. The individual dunes are relatively small, and hence are not shown on figure 7.

Ground-Water Phase of the Hydrologic Cycle

Source and Recharge Areas

The initial source of all fresh ground water in the aquifers of Schoolcraft County is precipitation, and the average annual precipitation over the county is about 30 inches. Most of the precipitation, however, does not enter the ground-water reservoirs, but is lost by evaporation, transpiration, and direct runoff.

The amount of precipitation that does enter the ground-water reservoirs is influenced by a number of factors including the duration, intensity, and type of precipitation, the density and types of vegetation, the topography, and the porosity and permeability of the soil, subsoil, and underlying rock formations. Also, an aquifer that is already full to overflowing obviously cannot receive additional water.

Conditions for recharge are favorable in the part of the county that is underlain by permeable sandy glacial sediments (fig. 7). In large areas in the southern part of the county, permeable limestones and dolomites at or near the surface have large infiltration capacities. Small areas of the county are underlain by clayey sediments, which impede infiltration of precipitation into the ground-water reservoirs.

Movement

The movement of water underground is similar to movement in surface streams, which is by gravity from high to low levels. Percolation of water through the interstices between rock particles below the surface involves a great amount of friction and hence is much slower than the flow of water upon the surface. Rates of ground-water movement range widely from a few feet per year to many feet per day. Water may travel considerable distances underground from recharge areas to areas down-gradient, where it may once more reach the land surface and appear as a seep or spring, join the flow of streams, enter a lake, or escape to the atmosphere by evaporation and transpiration. Where undisturbed by manmade diversions, the piezometric surface of an aquifer near the surface conforms generally to the configuration of the overlying land surface. In the deeper artesian aquifers, however, the shape of the piezometric surface may differ considerably from that of the land surface. Where more than one aquifer underlies the same area, water will migrate or leak from an aquifer of high head to an overlying or underlying one of lower head.

Discharge

Water is discharged from ground-water reservoirs by evaporation and transpiration and through wells, springs, and drains. Because much of the county is covered by dense growths of forest and swamp vegetation, the amount lost by evapotranspiration is presumed to represent a large percentage of the total discharge. It is likely, also, that large amounts of ground water are discharged at depth directly to Lake Michigan.

The greatest discharge by wells is that from flowing and pumped wells in the Manistique-Indian Lake area. Several flowing wells in the Blaney-Germfask area discharge water from the Cambrian and Ordovician sandstones. A considerable amount of water is discharged also by springs. Several springs are located along the west shore of Indian Lake. Big Spring or Kitchi-ti-ki-pi, which was described in detail by Poindexter (1935 and 1936), is the largest and best known of these. The discharge of Big Spring fluctuates between 20 and 40 cubic feet per second.

Water Level Fluctuations

Effects of Climate

Fluctuations of the water level in well 45N 13W 16-1 (fig. 11), which taps the limestones of the Richmond group near Germfask, have been observed since 1952 (Giroux, 1957). Since the beginning of record, through 1957, the maximum range in water levels has been slightly more than 1 foot. Analysis of the record on this well reveals that the water level fluctuates primarily in response to climatic conditions. This is indicated graphically in figure 11 by correlation of the graphs of monthly precipitation, water levels, and discharge of the Manistique River for the period 1953-57. In 1956 and 1957 precipitation was below the average for the period, and so, therefore, were water levels and streamflow. During the three years prior to 1956, precipitation was above the period average, and this also is illustrated by the curves showing cumulative departures of water levels and streamflow from the monthly averages. The streamflow data were obtained from a gaging station operated by the U. S. Geological Survey on the Manistique River about a mile south of Germfask. The river at this point drains an area of 341 square miles to the north and east, including the Seney Wildlife Refuge.

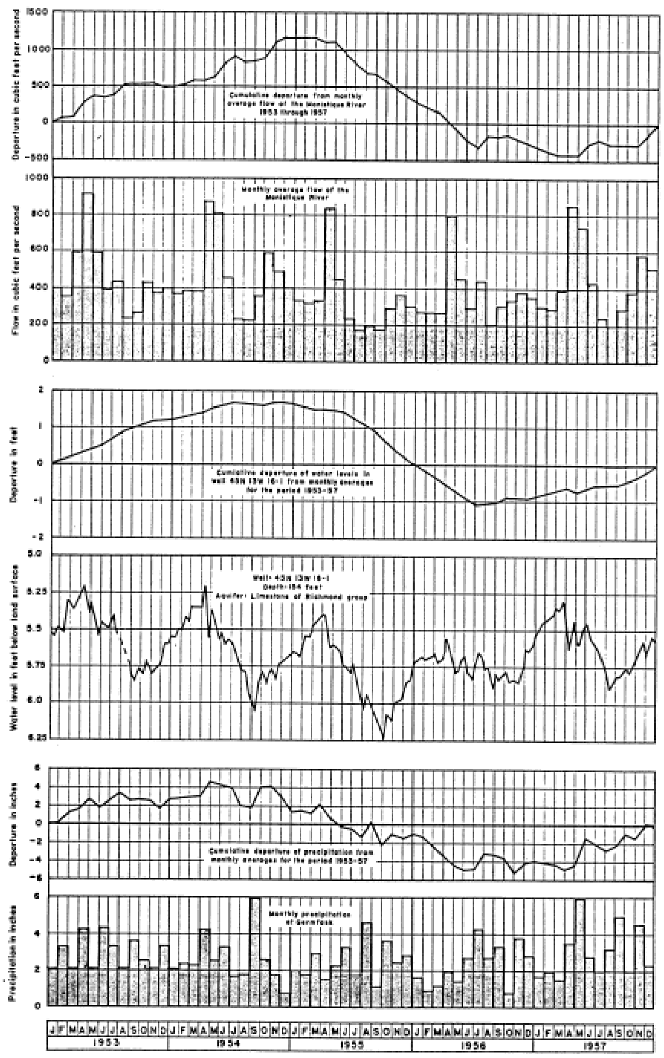

Figure 11. Graphs showing effects of precipitation on water levels in well 45N 13W 16-1 and discharge of the Manistique River near Germfask.

Water levels respond also to seasonal changes in climate. Precipitation in the form of snow has little effect on water levels or streamflow until the spring thaw permits runoff and infiltration. As shown in figure 11, the peaks in streamflow and recharge are reached between the spring thaw and the summer growing season. During the growing season, evaporation and transpiration of water by the dense vegetation use most of the available precipitation, thereby causing declines of water levels and stream discharge. Toward autumn, as the temperature falls and vegetation becomes dormant, precipitation is again available for ground-water recharge and surface discharge.

Effects of Discharging Wells

Generally, ground water is a renewable natural resource because it is replenished directly or indirectly by precipitation. Under natural conditions an aquifer is in a state of equilibrium with respect to recharge and discharge. When water is withdrawn from an aquifer by a well, a temporary increase in the total discharge from the aquifer results. This discharge by the well causes a cone-shaped depression in the water table or piezometric surface around the discharging well. Continued discharge expands the cone until the resultant lowering of the piezometric surface causes a decrease in natural discharge from the aquifer or an increase in recharge, which may restore the aquifer to a state of equilibrium. If the discharge from a well, or group of wells, exceeds the total available recharge, the water level will continue to decline as long as the discharge is maintained.

A lowering of the piezometric surface always results from the discharge of water from a well. Where a number of wells are pumped or allowed to flow, a composite cone of depression is formed which may extend over a large area. Water levels in wells within the cone of depression caused by discharge of other wells are thus lowered. A lowering of the piezometric surface is inevitable in the development of an aquifer. This principle was illustrated in the city of Manistique where artesian pressures in several wells were reported to have dropped at the time flowing well 42N 16W 12-24 was installed. Waste of water, however, as from unrestricted flowing wells or by underground leakage from poorly constructed wells or deteriorated well casings results in unnecessary lowering of the piezometric surface, which may cause some wells to cease flowing, decrease yields, and increase the cost of producing water.

Declines in artesian pressure due to pumping have been noticeable only in the vicinity of Indian Lake and in the city of Manistique. In most of Schoolcraft County withdrawals of water have had a negligible effect on water-level fluctuations, as the amount of pumpage is but an insignificant percentage of the available recharge.

Utilization of Ground Water

The city of Manistique has a small number of wells which are used for water supply, but the water of Indian River is its main source of supply. The rest of the county is supplied by privately owned wells or springs.

Stock and domestic use, including the use of water by the tourist industry, accounts for most of the county's use of ground water. Only a small amount of ground water is used by industry in general. The total amount of ground water used in the county is but a small fraction of the total available resource.

QUALITY OF WATER

Ground Water

The minerals present in ground water are acquired primarily by solution of minerals in the rock or soil through which the water percolates. In general, the degree of mineralization of the water is determined by the composition and solubility of the rock or soil; the duration of contact; and other factors such as pressure, temperature, and the amount of mixing, if any, with connate water (water entrapped at the time the sediment was deposited). Water that contains more than 1,000 parts per million (ppm) of dissolved mineral matter is herein considered saline regardless of composition.

Table 5 lists the chemical analyses of ground-water samples collected in Schoolcraft County. Geochemical interpretation of these analyses is aided by the diagrams in figure 12. The diagrams are drawn by plotting in equivalents per million (epm) the concentrations of six important ions and connecting the points plotted according to a technique devised by Stiff (1951). The diagrams are useful in determining the source of the sampled water, the general chemical character of the aquifer, and variations in the chemical quality of water within a given aquifer.

The sandstones of the Hermansville and Munising formations yield water of good quality throughout most of the county. The hardness of water sampled from these formations ranged from 100 to 201 ppm except for the sample taken from well 41N 1W 2-1 near Seul Choix Point, which had a hardness of 351 ppm. The hardness of water (expressed as CaCCU, in parts per million) is classified by the Michigan Department of Health (1948) as follows:

Class of water	Hardness (Parts per million)
Very soft	Less than 50
Soft	50-100
Moderately hard	100-200
Hard	200-300
Very hard	More than 300

The term "grains per gallon" is sometimes used to express hardness. One grain per gallon equals 17.1 ppm.

The sodium and chloride content of water in these formations increases toward the south (table 5), but the content throughout the county has not been determined. It is believed that part of the chloride present in some of the deeper wells tapping these sandstones represents leakage from other formations. Concentrations of chloride in excess of 250 ppm are considered to be objectionable for drinking water. The diagram of the sample from well 41N 16W 12-24 (fig. 12) is different in shape from diagrams of other samples taken from the sandstones. The presence of 360 ppm of sulphate indicates that this sample is a mixture of waters from the Hermansville and Munising formations and the Black River and Trenton limestones. Sulfate concentrations greater than 250 ppm also are considered objectionable for drinking water. Although only a few wells in the county have produced water from the Black River and Trenton limestones, data from wells in adjacent areas indicate that these formations are generally not a source of fresh water where they are overlain by younger consolidated rocks. They may be a source of fresh water where they form the bedrock surface as in adjacent areas of Alger County. Wells tapping these formations at depth in Delta and Mackinac Counties yielded water containing objectionable amounts of sodium and chloride. The only sample of water taken from the Black River and Trenton limestones in Schoolcraft County contained 1,300 ppm of sulfate.

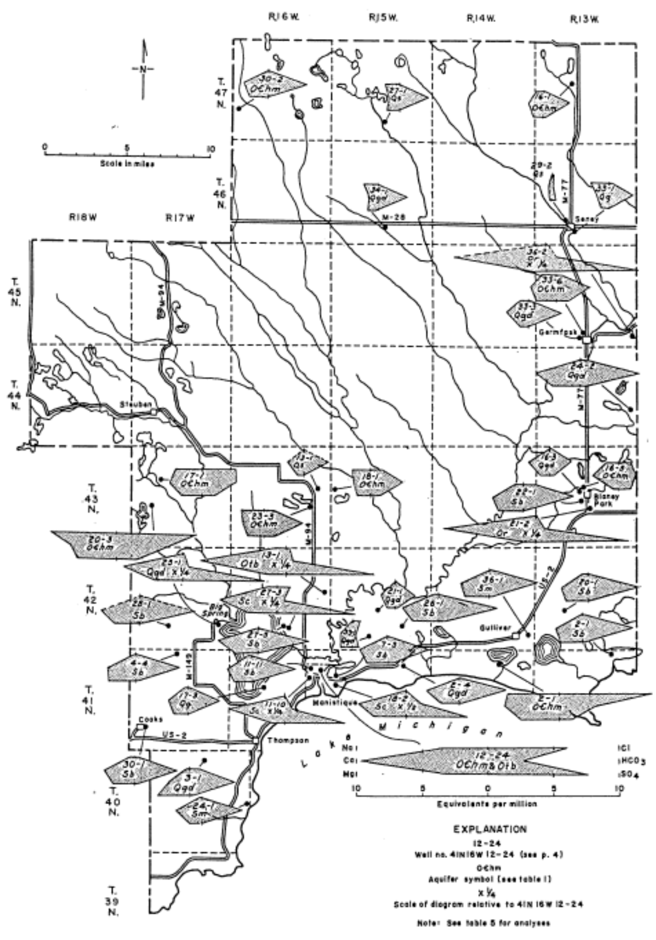

Figure 12. Selected diagrams showing variations in chemical quality of ground water in Schoolcraft County.

The limestones and dolomites of the Richmond group generally yield saline water. Water from well 45N 13W 36-2 (table 5) had a hardness of 1,750 ppm. However, these rocks are a source of fresh water in the area where they form the bedrock surface in Luce County.

Locally, where they form the bedrock surface in Schoolcraft County, they may also be a source of fresh water.

The Cataract formation is not a source of fresh water in the county. It includes beds of gypsum which are readily dissolved by percolating ground water. Hence, the water contained in this aquifer is high in calcium and sulfate, the sulfate generally amounting to more than 1,000 ppm. The presence of large amounts of calcium in the water makes it very hard, even in places where the sulfate content may be comparatively low (see 42N 16W 27-4, table 5).

Water from the Burnt Bluff formation generally is moderately hard or hard. The hardness results from the presence of calcium and magnesium ions leached from the limestones and dolomites. Most of the wells in the city of Manistique are finished in this aquifer at a depth of about 200 feet (table 3). The water produced from some of these wells, however, contains large quantities of calcium and sulfate which is not characteristic of the Burnt Bluff formation. Apparently the water yielded by these wells is contaminated by upward leakage of calcium sulfate waters from the underlying Cataract formation. Some of the wells may be bottomed in the upper part of the Cataract formation, and derive water from both aquifers. Migration of calcium sulfate water from the Cataract formation apparently has been caused by discharging of water by pumping or by unrestricted flow from wells tapping the basal part of the Burnt Bluff formation. The water from wells tapping shallower permeable zones in the Burnt Bluff has not been high in calcium and sulfate.

The Manistique dolomite yields water similar in chemical quality to that of the Burnt Bluff (fig. 12). In most areas where the Manistique is present, it is at or near the surface and contamination by organic wastes is a constant hazard due to the free circulation of water through solutionally enlarged fractures at the surface of the formation. Thus, the water contained in this aquifer is generally of good chemical quality but, in many cases, of poor bacteriological quality.

The quality of water from the glacial-drift aquifers of the county varies considerably. The mineral content of the water is determined by the composition of the glacial drift and by the quality of water in aquifers 'hydraulically connected with the drift aquifers. The glacial drift aquifers, however, generally yield water low in dissolved mineral content. One notable exception is the large concentration of calcium and sulfate in the sample taken from well 42N 17W 25-1 (table 5) near Big Spring. The analysis of this sample indicates that the water has migrated through the gypsiferous Cataract formation or has been mixed with water from that aquifer. Drift aquifers in other areas underlain by gypsiferous rocks may also yield water containing significant amounts of calcium and sulfate.

The temperature of water from most wells in Schoolcraft County ranges from about 44° to 48°F (table 5). That of water from several deep wells tapping the Munising and Hermansville formations ranges from about 46° to 55°F.

Surface Water

Chemical analyses of water from lakes, streams, and springs in Schoolcraft County are listed in table 6 and diagrammed in figure 13. Figure 13 shows the relative uniformity in chemical content of surface water from various sources throughout Schoolcraft County. Water from the Manistique River drainage basin, much of which represents ground-water discharge, is predominantly of the calcium magnesium bicarbonate type. Variations in quality are small as the rapid flow of surface water permits rather thorough mixing of water from different sources. Spring water taken at or near the point of discharge, however, such as at Big Spring and Hoholik's Spring (fig. 13), closely reflects the chemical quality of ground water in the source aquifers.

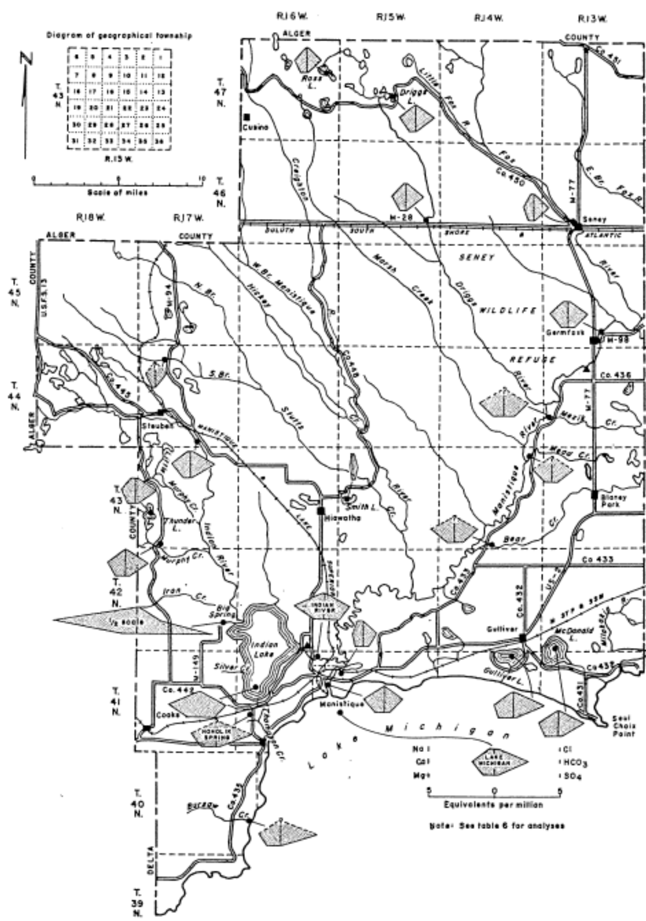

Figure 13. Diagrams showing chemical quality of surface water in Schoolcraft County.

CONCLUSIONS

The ground-water resources in Schoolcraft County are adequate for present needs and for considerable future development by municipalities, agriculture, and industry. North of the Niagara escarpment, small to moderate yields of water of good quality can be obtained from relatively shallow wells in the glacial drift or from deeper wells tapping the Hermansville and Munising formations. South of the escarpment, water of good quality can be obtained from the Manistique and Burnt Bluff formations and locally from permeable deposits of glacial drift. The Trenton and Black River limestones and the limestones and dolomites of the upper part of the Richmond group may yield water of good quality in areas where they form the bedrock surface, but for the most part these formations yield water of rather poor chemical quality. The Cataract formation is not a source of good water.

The development of the ground-water resources of Schoolcraft County will involve more problems of quality of water than of locating adequate quantities of water. In much of the county the Munising and Hermansville formations, which are a source of fresh water, are overlain by the Trenton and Black River rocks which yield saline water. Uncased wells drilled to the sandstones will produce a mixture of saline water from the Trenton and Black River and fresh water from the Munising and Hermansville. Thus, the Trenton and Black River must be sealed off in wells tapping the sandstones to prevent contamination by the saline water. In the area where the Cataract formation forms the bedrock surface (fig. 3), water supplies taken from the upper portions of the overlying drift mantle where possible or from the sandstones of the Munising and Hermansville at depth will insure water of good chemical quality. In the Manistique area, fresh water supplies can be obtained from the upper members of the Burnt Bluff formation. Penetration to the basal members of the formation or to the Cataract formation may result in migration of saline water from the Cataract. Restriction of flowing wells tapping the Burnt Bluff formation may be necessary to retain maximum pressure in the aquifer. The lowering of the piezometric surface, which always results from discharge by a well, probably has contributed to the contamination of the water in the basal strata of the Burnt Bluff formation by permitting upward migration of calcium sulfate water from the Cataract formation.

In the Manistique and Gulliver areas, sewage and septic tank effluent that has undergone little or no natural filtration is readily recharged to the creviced and fractured Burnt Bluff and Manistique formations, which are at or within a few feet of the land surface. In these areas a number of wells are reported to yield water of objectionable bacterial quality. To prevent entrance of sanitary wastes, the wells can be drilled to deeper permeable zones and the polluted zones near the surface sealed off to prevent leakage from above. Further contamination of ground water by sanitary wastes should be avoided.

Future ground-water research should include studies of the geochemistry of the aquifers in Schoolcraft County to be used as a guide for development of the fresh-water aquifers in a manner which will result in minimum contamination of those sources from saline-water aquifers. Further, study should be made also of the extent, depth, and water-bearing properties of glacial drift in the pre-Pleistocene valleys, as such deposits are potential sources of large quantities of ground water of good quality.

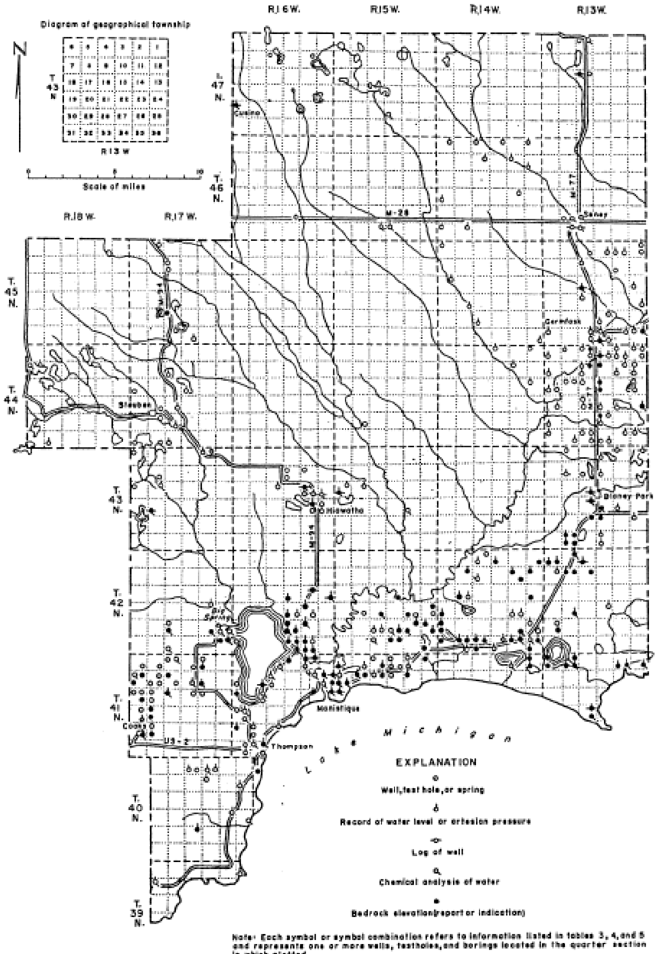

Figure 14. Index map of Schoolcraft County showing availability of hydrologic, geologic, and quality of water data.

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System	Series		NAMES AND SYMBOLS USED IN THIS REPORT LITHOLOGY	THICKNESS (Feet)	HYDROLOGY	NAMES USED BY MICHIGAN GEOLOGICAL SURVEY: SYSTEM	SERIES	GROUP	FORMATION
QUATERNARY	Pleistocene	Wisconsin stage	GLACIAL DRIFT UNDIFFERENTIATED (Qgd) SAND (Qs); GRAVEL (Qg) SAND AND GRAVEL (Qsg) Deposits of sand, gravel, and boulder-clay till; well-sorted lake deposited clay, silt, and sand; well-sorted sand and gravel outwash; and well-sorted dune sand.	0 to 200+	In the northern two thirds of the county, the drift is composed primarily of moderately permeable sand which will yield small to moderate supplies of water. Locally, the drift is composed of permeable sand and gravel which may yield large supplies of water. In large areas of the southern part of the county the drift is thin and discontinuous, and generally not a source of water.	QUATERNARY	GLACIAL DRIFT (Wisconsin)		
SILURIAN	Niagara		ENGADINE DOLOMITE (Se) Massive hard bluish-white dolomite.	10±	Not an important source of water because of its limited areal extent and thickness.	SILURIAN	NIAGARAN	LOCKPORT	ENGADINE
			MANISTIQUE DOLOMITE (Sm) Thinly bedded to massive, light-buff to brown and gray siliceous dolomite, with chert nodules; secondary openings enlarged by solution.	150+	Yields fresh water to a number of wells in the southern part of the county. Permeability of these strata is the result of solution openings formed along joints and bedding planes.				MANISTIQUE
			BURNT BLUFF FORMATION (Sb) Thinly bedded to massive, light-gray to buff dolomite and dolomitic limestones.	250±	Important aquifer in the populated southern part of the county. Generally yields small to moderate supplies of water. Locally may yield large supplies. The basal strata of this formation may be hydraulically connected with the underlying Cataract formation which yields water high in calcium and sulfate.			CLINTON	BURNT BLUFF
	Lower Silurian		CATARACT FORMATION (Sc) Buff to gray, dense, shaly dolomite with layers of greenish-gray shale and gypsum.	150 to 200	Generally yields moderate supplies of water containing large amounts of calcium and sulfate.		ALBION	CATARACT	MAYVILLE CABOT HEAD MANITOULIN
ORDOVICIAN	Upper Ordovician	Richmond group	LIMESTONE AND DOLOMITE (Or) Light-brown dolomite and dolomitic limestones with layers of greenish-gray shale and some gypsum.	300+	Generally yields rather mineralized water. Locally these rocks may yield fresh water in the area where they form the bedrock surface.	ORDOVICIAN	CINCINNATIAN	RICHMOND	QUEENSTOWN? BIG HILL STONINGTON BILLS CREEK

		Collingwood formation	SHALE UNIT (Orc) Gray to dark-brown and black bituminous shale interbedded with layers of dolomitic shale.	200+	Not a source of water				LORRAINE? UTICA? COLLINGWOOD
	Middle Ordovician		TRENTON AND BLACK RIVER LIMESTONES (Otb) Light-brown to gray dolomitic limestone, a few layers of greenish-brown shale.	250 to 300	Where these rocks form the bedrock surface they may be a source of fresh water. Where overlain by consolidated rocks they yield saline water.		MOHAWKIAN	TRENTON BLACK RIVER	TRENTON BLACK RIVER
	Lower Ordovician	<-----------OЄhm----------->	HERMANSVILLE FORMATION Dense sandy dolomite with layers of clean, well-sorted sandstone and a few lenses of sandy shale.	20 to 80	These rocks form a single aquifer which will yield moderate to large supplies of water of good quality in most of the country. The water is under considerable artesian pressure and in nearly all the county will flow from wells. Along the southern edge of the county the aquifer may yield water high in sodium and chloride				HERMANSVILLE
CAMBRIAN	Upper Cambrian		MUNISING SANDSTONE White to gray and some pink sandstone, slightly dolomitic, a few shale lenses.	400+		CAMBRIAN		LAKE SUPERIOR SANDSTONE	MUNISING
PRECAMBRIAN OR CAMBRIAN			JACOBSVILLE SANDSTONE (ЄpЄj) Red and white quartzitic sandstone.		Present in the northern part of the county; its southern extent is unknown. Permeability low. Not important as a source of water because mantled by water-bearing sandstones of the Hermansville and Munising formations.				JACOBSVILLE
PRECAMBRIAN			METAMORPHIC AND IGNEOUS ROCKS		Not a source of water.	PRECAMBRIAN			

Table 1. Lithology and hydrology of the rocks underlying Schoolcraft County.