

STATE OF MICHIGAN
DEPARTMENT OF CONSERVATION
GEOLOGICAL SURVEY DIVISION

Progress Report Number 21
RECONNAISSANCE OF THE GROUND-WATER
RESOURCES OF LUCE COUNTY, MICHIGAN

by
Kenneth E. Vanlier
Geologist

*Prepared cooperatively by the
Geological Survey
United States Department of the Interior*

1959

Glacial-Lake Deposits.....	11
Dune Sand.....	11
<i>Permeability and Particle-Size Distribution of Selected Samples of Consolidated and Unconsolidated Sediments</i>	<i>11</i>
<i>Ground-Water Phase of the Hydrologic Cycle</i>	<i>13</i>
Source and Recharge Areas	13
Movement.....	13
Discharge.....	13
<i>Fluctuations of the Water Table</i>	<i>14</i>
Climatic Influences	14
Fluctuations Due to Discharge from Wells	14
<i>Chemical Quality of the Water</i>	<i>14</i>
Fresh Ground Water.....	15
Saline Ground Water	15
<i>Utilization of Ground Water</i>	<i>16</i>

SUMMARY AND CONCLUSIONS.....	16
-------------------------------------	-----------

REFERENCES CITED	17
-------------------------------	-----------

Contents

ABSTRACT.....	1
INTRODUCTION.....	2
<i>Purpose and Scope of Study.....</i>	<i>2</i>
<i>Previous Investigations.....</i>	<i>2</i>
<i>Acknowledgments</i>	<i>3</i>
<i>Well-Numbering System.....</i>	<i>3</i>
GEOGRAPHY	3
<i>Location and Extent of Luce County</i>	<i>3</i>
<i>Population and Economic Development</i>	<i>3</i>
<i>Physiography.....</i>	<i>3</i>
<i>Relief.....</i>	<i>4</i>
<i>Drainage</i>	<i>5</i>
<i>Climate.....</i>	<i>5</i>
GEOLOGY	5
<i>Summary of Geologic History.....</i>	<i>5</i>
<i>Bedrock Structure.....</i>	<i>5</i>
GROUND WATER	6
<i>Principles of Occurrence and Availability</i>	<i>6</i>
<i>Ground Water in Consolidated Rocks</i>	<i>7</i>
Precambrian Rocks.....	7
Jacobsville Sandstone of Early and Middle Cambrian Age	7
Munising Sandstone of Late Cambrian Age	7
Hermansville Formation of Middle Ordovician Age ..	8
Trenton and Black River Formations of Middle Ordovician Age	8
Collingwood Formation and Richmond Group of late Ordovician Age	8
Cataract Formation of Early Silurian Age	9
Burnt Bluff Formation of Middle Silurian Age.....	9
<i>Ground Water in Unconsolidated Rocks</i>	<i>9</i>
Morainic Deposits	10
Deposits of the Newberry morainic system	10
Deposits of the Munising morainic system	10
Deposits of the Crisp Point morainic system	10
Outwash Deposits.....	10

Illustrations

Plates

Plate 1. Geologic map of Luce County, Mich., showing bedrock formations beneath surficial deposits.	7
Plate 2. Map of the surficial deposits in Luce County.	9
Plate 3. Map of Luce County showing hydrologic, geologic, and quality-of-water data.	16

Figures

Figure 1. Index map showing location of Luce County.	3
Figure 2. Map of Luce County.	4
Figure 3. Map of the upper Great Lakes region showing areas of deposition in extinct glacial lakes.	4
Figure 4. Map of Luce, Chippewa, and Mackinac Counties showing major drainage basins and drainage areas tributary to the Great Lakes.	5
Figure 5. Generalized north-south geologic section through Luce County.	6
Figure 6. Diagram showing several types of rock interstices and the relation of rock texture to porosity.	6
Figure 7. Particle-size distribution curves of samples of sandy till from Luce County and sandstone from Alger, Luce, and Chippewa Counties.	12
Figure 8. Particle-size distribution curves of samples of glacial sediments from Luce County.....	12
Figure 9. Particle-size distribution curves of samples of fine- grained glacial sediments from Luce and Chippewa Counties.	13
Figure 10. Graphs of air temperature, precipitation, ground- water levels, and discharge of the Tahquamenon River. 14	
Figure 11. Chemical composition of ground water in Luce County.....	14

Tables

Table 1. *Lithology and hydrology of rocks underlying Luce County*..... 19

Table 2. *Reported specific capacities of 20 wells in Luce County*..... 19

ABSTRACT

Luce County is in the eastern part of the Northern Peninsula of Michigan. The northern two-thirds of the county is covered by forests and forested swamps and is largely undeveloped and relatively inaccessible. Most of the inhabitants reside in the southern part of the county. Lumbering and the tourist industry are the backbone of the county's economy.

The entire county is underlain by bedrock formations of Paleozoic age. These formations, consisting of sandstone, shale, limestone, and dolomite, are mantled throughout most of the county by Pleistocene glacial deposits composed predominantly of sand.

Although tapped by only a few wells, the Jacobsville sandstone of Early and Middle Cambrian age, the Munising sandstone of Late Cambrian age, and the Hermansville formation of Middle Ordovician age are important potential sources of potable water throughout the county. The water is contained in openings along joints and bedding planes, where the rocks are fully cemented, and also in voids between sand grains where they are uncemented or only partially cemented. These formations are near the surface in the northern part of the county but dip southward to a depth of 1,000 feet, or a little more.

The Black River and Trenton formations of Middle Ordovician age, the Richmond group of Late Ordovician age, the Cataract formation of Early Silurian age, and the Burnt Bluff formation of Middle Silurian age are tapped by wells where they are near the surface. Water in these formations is contained mainly in solution openings along joints and bedding planes. Generally the water is hard and, where readily soluble minerals such as gypsum or halite are present in the rocks, is highly mineralized. Where these rocks occur at depth or where solution openings have not been developed they are of low permeability, and the ground water contained in them generally is high in mineral content.

The glacial drift is the most important aquifer in Luce County, and also has the greatest potential for future development. Both the surficial and buried deposits of glacial outwash and sandy till in the drift are sources of large supplies of water. However, in some places in the county the drift consists wholly of clayey till, which yields only meager amounts of water to wells, and in a few places the drift is missing or is too thin to be a source of supply. All the large-capacity wells in the county tap glacial drift, and probably the drift would yield large supplies of water in the parts of the county not yet developed.

Ground water of good quality is present throughout nearly all of the county. The ground water is predominantly of the calcium magnesium bicarbonate and calcium sulfate types. The sandstone and glacial-drift aquifers generally yield soft or only moderately hard water of good chemical quality. These aquifers, however, may yield water of poorer quality where they are connected hydraulically to other aquifers containing very hard or saline water. Locally, gypsum-bearing strata of the Richmond group and of the Cataract formation yield water high in calcium and sulfate. Well 45N 10W 9-4, which tapped rocks of the Richmond group, yielded water containing appreciable quantities of sodium and chloride.

Although all the water used in the county is obtained from wells, the amount is only a small fraction of the available ground-water supply.

INTRODUCTION

Purpose and Scope of Study

A ground-water reconnaissance of the eastern part of the Northern Peninsula of Michigan on a county-unit basis was begun in 1955 as part of the continuing cooperative agreement between the Michigan Department of Conservation and the U. S. Geological Survey. The objective of the reconnaissance was to determine the general occurrence, availability, quantity, and quality of ground water in the study area. To make the results available to the public with the least possible delay, progress reports are to be released upon completion of the reconnaissance in each county. This report is the third of the series of reconnaissance reports, and it summarizes the ground-water data obtained in Luce County. The first progress report of this series (Vanlier and Deutsch, 1958a) described the ground-water resources of Chippewa County and the second (Vanlier and Deutsch, 1958b) contained similar information for Mackinac County. Pertinent data from those reports are used freely herein.

The cooperative ground-water investigations in Michigan are directed jointly by A. N. Sayre, Chief, Ground Water Branch, U. S. Geological Survey, Washington, D. C., and W. L. Daoust, State Geologist, Michigan Department of Conservation, Lansing, Mich., and are under the direct supervision of Morris Deutsch, District Geologist, U. S. Geological Survey.

Previous Investigations

Many years prior to the investigation being discussed in this report -- in fact, in the early part of the century -- an investigation of flowing-well districts in the eastern end of the Northern Peninsula was made by Leverett (1906). Detailed investigations of the surface geology of Luce County were made several decades later, by Bergquist (1933, 1936). During the period 1934 through 1936, the Michigan Department of Conservation, in cooperation

with the Civilian Conservation Corps, delineated areas of shallow ground-water supplies that might be tapped by fire-control wells. Some of the data gathered during that project have been included in this report. In 1949, J. G. Ferris, L. A. Wood, and E. A. Moulder of the U. S. Geological Survey made a reconnaissance to determine the probable effect that a canal at the level of Lake Superior and extending through the eastern part of the Peninsula would have on adjacent ground-water levels. Many of the data collected during that survey are contained in this report. A study of the Cambrian sandstones in the Northern Peninsula of Michigan by Hamblin (1958) revealed stratigraphic information pertinent to ground-water studies. Various phases of the geology and hydrology of the Northern Peninsula are described in numerous other reports. A rather comprehensive bibliography of these works, which date back to 1821, is included in the report on Chippewa County by Vanlier and Deutsch (1958a). Further pertinent information on Luce County is contained in the publication entitled "An Index of Michigan Geology" by Martin and Straight (1956).

Acknowledgments

Special thanks are given to the well drillers and residents of Luce 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 advice and assistance.

Well-Numbering System

The well-numbering system used in the report indicates the location of wells within the rectangular subdivisions of the public lands, with reference to the Michigan meridian and base line. The first two segments designate the township and range; the third segment designates both the section and the number assigned to the well within the section. Thus, well 50N 9W 25-1 is well number 1 in section 25, Township 50 North, Range 9 West. The 40-acre tract in which the well is located is shown for each well listed in the well records (table 3).

GEOGRAPHY

Location and Extent of Luce County

Luce County is in the eastern part of the Northern Peninsula of Michigan (fig. 1). The county is roughly square and is bounded on the north by Lake Superior, on the east by Chippewa County, on the south by Mackinac County, and on the west by Schoolcraft and Alger Counties. It has an area of about 900 square miles. The shoreline along Lake Superior has a length of about 31 miles.

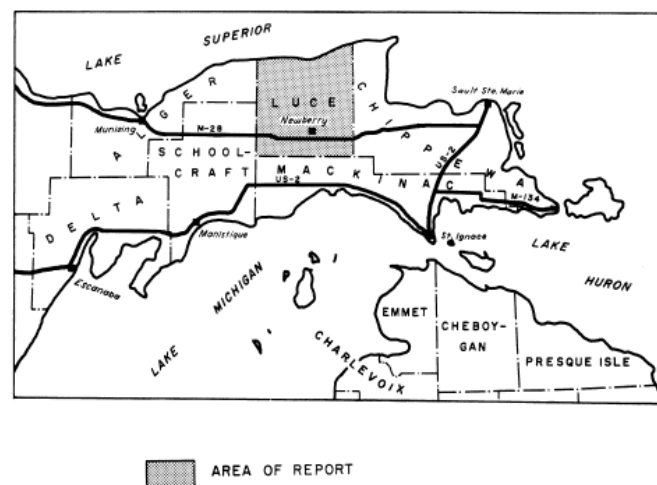


Figure 1. Index map showing location of Luce County.

Population and Economic Development

The population of the county in 1955 was estimated by the Michigan State Health Department to be 7,420; in 1950 it was 8,147 and in 1940 it was 7,423 according to the Bureau of the Census. The population for the City of Newberry for the same years was 2,610, 2,802, and 2,732, respectively.

The economy of Luce County is related primarily to its natural resources. The production of timber and timber products is the main industry. Two small dolomite quarries have been operated intermittently, and a number of sand and gravel pits are also worked as a source of aggregate or road metal. The natural scenic beauty, the inland lakes, and the wildlife of the county provide for a thriving tourist industry. The Newberry State Hospital provides employment for a number of people in the area.

The county is served by State Highways 28, 98, 117, and 135, and by the Duluth, South Shore and Atlantic Railroad (fig. 2).

Physiography

Luce County lies in the area that was once covered by the waters of glacial Lake Algonquin and other extinct glacial lakes (fig. 3). Its main physiographic features are the rather level lake plains formed by deposits of glacial-

lake sediments and the extensive ridges or hills of the Newberry, Munising, and Crisp Point morainic systems (Bergquist, 1936). The moraines were deposited in glacial Lake Algonquin and other extinct glacial lakes and were modified somewhat by the wave action of the lakes.

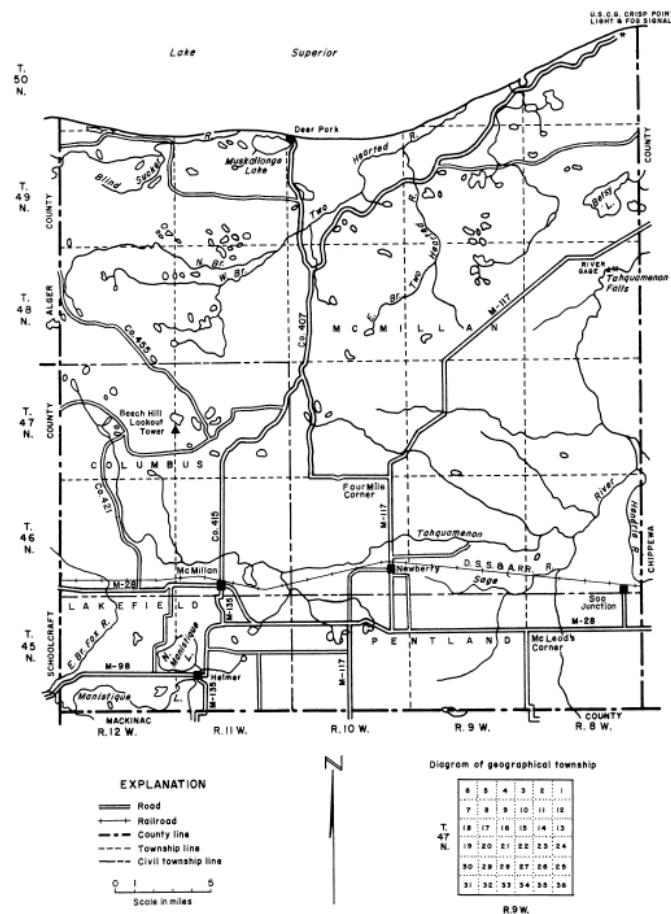


Figure 2. Map of Luce County.

Within Luce County, the Newberry moraine consists of a series of rough and irregular hills which extends from Manistique Lake to a point about 6 miles southeast of Newberry. The Munising morainic system is an undulating highland belt which crosses the central part of the county in a rough east-west arc (pl. 2). This belt of highlands is broken into a larger western segment and a smaller eastern segment. The western segment extends from the southern part of the boundary common to Alger and Luce Counties to a point a few miles north of Newberry, and the eastern segment is in T. 48N., Rs. 8 and 9 W. The Munising morainic system lies north of the Tahquamenon River except in the eastern part of the county, where it is breached by the river. The Crisp Point morainic system forms a broken belt of hills across the northern part of the county. This belt of hills is not as rough and distinct as the highlands of the other morainic systems.

Other highlands are formed by drift covered cuestas, or bedrock ridges in the southern part of the county. Rocks of the Burnt Bluff formation form a prominent cuesta in adjacent areas of Mackinac County. The escarpment of

this cuesta extends into Luce County and forms a prominent topographic feature along the southern boundary of the county in T. 45 N., Rs. 8 and 9 W. A smaller cuesta is formed by resistant dolomite in the lower part of the Cataract formation. This cuesta forms a highland of low relief in T. 45 N., R. 8 W. Elsewhere the cuesta is buried by morainal and associated glacial deposits.

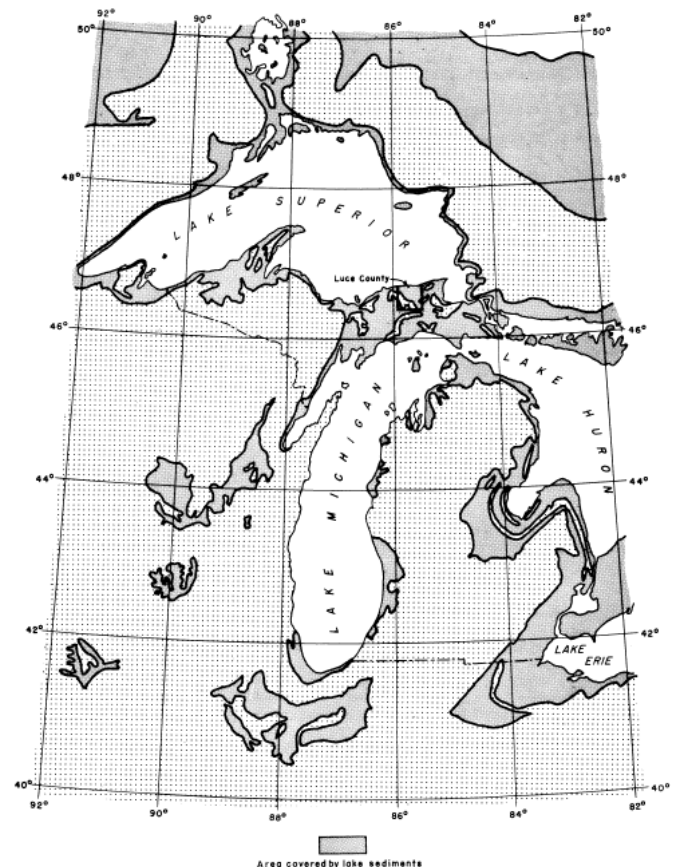


Figure 3. Map of the upper Great Lakes region showing areas of deposition in extinct glacial lakes.

Rather level lake plains and other minor features associated with glacial Lake Algonquin and post-Algonquin lakes characterize most of the remainder of the county. Extensive swamps and marshes occupy poorly drained segments of the lake plains.

Large areas of sand dunes lie along the Lake Superior shoreline. Locally, wave action has cut bluffs in the dunes.

Relief

The highest points in Luce County are two knobs on the Munising Moraine in the western part of the county. One of the knobs is in the southwestern part of T. 48 N., R. 12 W., the other is at Beech Hill Lookout Tower (fig. 2). The maximum altitudes of these knobs is slightly less than 1,200 feet. The highest points on the Newberry Moraine are south of McMillan, and reach altitudes slightly greater than 1,050 feet. The lowest areas in the

county are along the shore of Lake Superior at an altitude of about 600 feet.

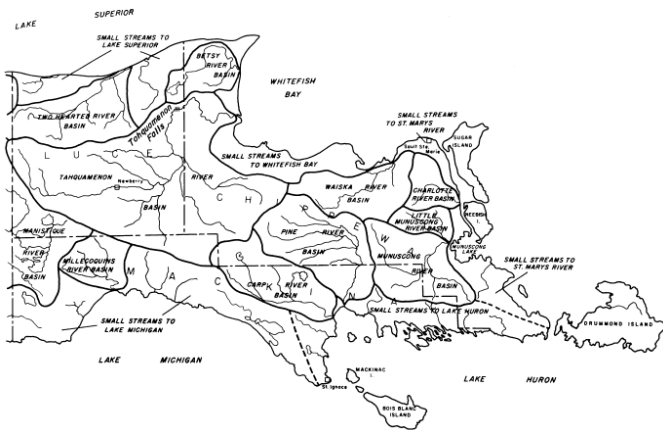


Figure 4. Map of Luce, Chippewa, and Mackinac Counties showing major drainage basins and drainage areas tributary to the Great Lakes.

Drainage

Nearly all of the county is drained by streams tributary to Lake Superior (fig. 4). A small area in the southwest corner of the county, including North Manistique Lake (fig. 2), is tributary to the Manistique drainage system, which empties into Lake Michigan, and a small part of T. 45 N., R. 10 W. drains to Lake Michigan through the Millecoquins River. The Tahquamenon River, which empties into Whitefish Bay of Lake Superior, is the largest stream in the county. At the Tahquamenon River Falls (fig. 2) near the Chippewa County line the river plunges over a 40-foot ledge of Cambrian sandstone. The Two Hearted River and several smaller streams flow directly into Lake Superior. The discharge of the Tahquamenon River for the period 1954 and 1955 is shown by a graph in figure 10.

Natural drainage is in an early stage of development as shown by the presence of extensive swamps and a great many (571) inland lakes. Drainage features are poorly developed in areas underlain by sandy soils because little surface runoff occurs. Drainage features are best developed in the topographically high areas underlain by clayey soils of low permeability.

Climate

Compared with that of other interior continental areas in the same latitude, the climate of Luce County is less rigorous because of the tempering effect of the Great Lakes. Average annual precipitation at Newberry State Hospital is about 28 inches and average annual temperature is 40.1° F. The average growing season is about 110 days, extending from the average date of the last killing frost, June 2, to that of the first killing frost, September 20.

GEOLOGY

Luce County is underlain by sedimentary rocks of Paleozoic age which, except for outcrops which are too small to be shown on plate 2, are mantled everywhere by glacial deposits of Pleistocene age. The areal distribution of the Paleozoic rocks is shown on plate 1. The lithologic and hydrologic properties of the various rock units underlying the county are described briefly in table 1, and more fully in the section on Ground Water. Plate 3 is an index to the location of the hydrologic, geologic and quality of water data.

Summary of Geologic History

Sandstone, shale, limestone, and dolomite, which were deposited in shallow seas that covered the Michigan basin during the Paleozoic era, underlie all of Luce County. During the Mesozoic and most of the Cenozoic eras the Paleozoic rocks were above sea level and were eroded by wind and running water. The erosion resulted in the basic topographic configuration of the present bedrock surface.

During the Pleistocene (glacial) epoch, which followed the long interval of erosion, the Michigan basin was buried at least four times under glacial ice that flowed southward from accumulation centers in Canada. The physiographic features formed during Mesozoic and early Cenozoic time were greatly modified by the advancing glaciers. The ice sheets transported vast amounts of a wide variety of rock material torn from the surface over which they moved, and when they melted, this material was deposited on the eroded Paleozoic rock surface.

At the close of the Pleistocene epoch, glacial Lake Algonquin covered nearly all of Luce County (fig. 3). Postglacial uplift of the land mass, which had been depressed by the ice, resulted in changes in drainage patterns, lake elevations, and shoreline positions. The result of these changes was a succession of postglacial upper Great Lakes, of which Lakes Superior, Michigan, and Huron represent the modern stage (Leverett and Taylor, 1915, chaps. 21-25). Inland bars, beaches, wave-cut benches, and dunes mark the shorelines of these successive lakes.

Bedrock Structure

Little is known of the configuration of the Precambrian rock surface upon which the Paleozoic sediments of Luce County were deposited. Although the Paleozoic sediments of the Michigan basin were deposited in nearly horizontal layers, gradual subsidence and compaction of the beds, which were contemporaneous with deposition and were 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 rock units crop out in roughly concentric bands. Luce County is at the north edge of the structure where the oldest sedimentary

rock units are exposed (fig. 5). The regional dip of these units here is southward at about 40 to 60 feet per mile. The units thicken toward the center of the basin.

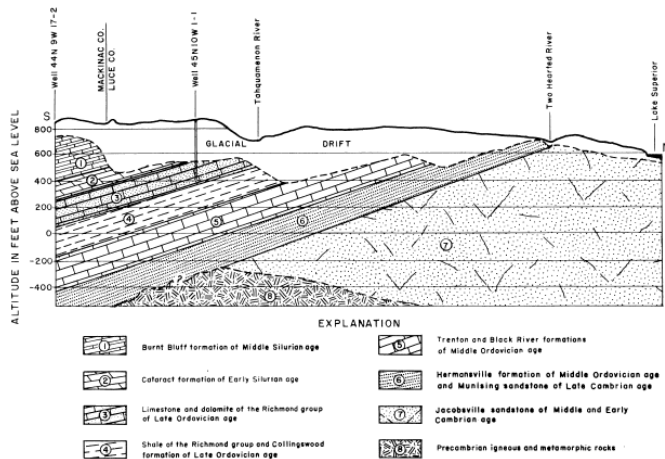


Figure 5. Generalized north-south geologic section through Luce County along line N-S as shown on Plate 1.

GROUND WATER

Principles of Occurrence and Availability

A water-bearing formation that yields water in usable quantities is termed an "aquifer". In areas where ground water is difficult to obtain, a formation yielding less than a gallon per minute (gpm) to wells may be classified as an aquifer. In other areas, where wells may yield many gallons per minute, a rock from which wells obtain only a few gallons per minute might not be classified as an aquifer.

The capacity of a water-bearing material to transmit water under pressure is termed "permeability." The coefficient of permeability as used herein is reported in meinzers (Meinzer's units). The meinzer is defined as the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60°F. The coefficient of permeability varies greatly, the variance depending in general upon the degree of assortment and the arrangement and size of the particles. Coefficients of permeability of most important water-bearing materials are greater than 10 meinzers. The permeability of the deposits of sand and gravel tapped by the large capacity wells in Luce County probably range from 200 to 1500 meinzers.

The specific capacity of a well is defined as the yield of water in gallons per minute for each foot of drawdown in water level caused by pumping of the well. It is a function of the permeability and thickness of the aquifer and of the efficiency of the well. The specific capacities of 20 wells tapping various aquifers in Luce County are listed in table 2.

Ground water is the water in the zone of saturation, the zone in which all voids are filled with water under

atmospheric or greater pressure. On the basis of water occurrence, aquifers may be classified as water-table or artesian. In a water-table aquifer, ground water is unconfined and its surface within the aquifer is termed the "water table". 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 finished in an artesian aquifer and tightly cased through the overlying confining bed (aquiclude) will rise above the bottom of that bed. An artesian aquifer is full of water at all times, even while water is being removed from it. In time, however, enough water may be pumped to draw the water level below the bottom of the overlying confining bed, thus creating water-table conditions locally. The imaginary surface connecting all points to which water would rise in wells tapping an artesian aquifer is called the "piezometric surface". In topographically low areas the piezometric surface may be higher than the land surface, and wells tapping artesian aquifers in these areas will flow.

Meinzer (1923) showed that the hydrologic properties (permeability and porosity) of aquifers are determined basically by the character of the interstices between grains, or open spaces within the rocks, that form the aquifers (fig. 6). Interstices in rocks can be grouped into two main classes -- the original interstices which were formed when the rocks came into existence and the secondary interstices (joints, fissures, solution passages) which were developed later. The amount of water available to a well is governed by regional and local hydrologic and lithologic characteristics of the aquifer and by the climatic conditions and the hydraulic properties of the soils and subsurface rocks in the recharge areas.

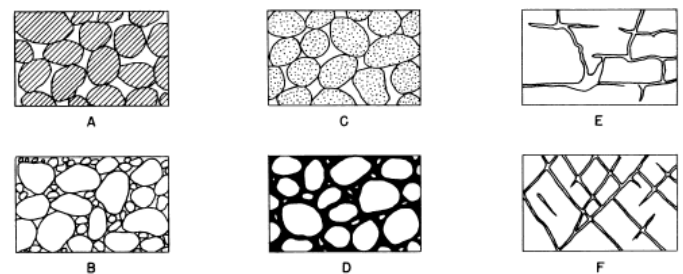


Figure 6. Diagram showing several types of rock interstices and the relation of rock texture to porosity. A, Well-sorted sedimentary deposit having high porosity; B, poorly sorted sedimentary deposit having low porosity; C, well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; D, well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; E, rock rendered porous by solution; F, rock rendered porous by fracturing. (From Meinzer, 1923, p. 3).

The aquifers underlying Luce County consist of a variety of consolidated and unconsolidated rocks. The consolidated-rock aquifers are composed primarily of sandstone, limestone, or dolomite. In a sandstone aquifer water moves through interstices between individual sand grains and along joints, other fractures,

and bedding planes. Movement of water in limestone and dolomite aquifers is predominantly through permeable zones which were developed by weathering and solution in areas where these rocks were exposed at the surface during preglacial time. Layers of shale interbedded with layers of limestone and dolomite are of low permeability and yield little water to wells. They are significant in the hydrologic system, however, because they impede vertical movement of ground water, and hence retard solution in underlying soluble rocks, and also act as confining beds in artesian systems. The unconsolidated aquifers are composed of glacial drift and in general are the most accessible source of water to wells in the county. The water in these aquifers is contained in the interstices between rock particles. The drift aquifers have the greatest potential for future development, but in those places in Luce County where the mantle of unconsolidated sediments is thin or lacks permeable zones, the consolidated-rock aquifers are the only source of ground water.

Ground Water in Consolidated Rocks

Precambrian Rocks

Precambrian rocks underlie all of Luce 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. Future development of Precambrian rocks as a source of water supply is very unlikely because of their depth and probable low permeability, and because in most of the county the Precambrian rocks are overlain by three formations which constitute an aquifer of moderate permeability.

Jacobsville Sandstone of Early and Middle Cambrian Age

The Jacobsville sandstone is the oldest Paleozoic sedimentary-rock unit in the county. Its maximum thickness is more than 19000 feet. It is a hard, resistant quartzitic sandstone, the interstices between the sand grains being largely filled with silica cement and with a secondary growth of the fragment of crystalline quartz which form the individual sand grains. The formation is jointed. The sandstone is predominantly red but is mottled and streaked with white. This rather unique coloration is characteristic of the formation. The Jacobsville sandstone underlies nearly all of the county but is nearest the surface in the northern part, where it is mantled only by glacial drift. (See pl. 1). In this part of the county the sandstone and drift, where saturated, constitute essentially a single aquifer. However, the area is largely undeveloped and none of the few wells present is known to have been drilled into the Jacobsville sandstone. Data from wells in adjacent Chippewa and Alger Counties indicate that the permeability of the Jacobsville sandstone is the result of jointing and weathering and decreases with depth.

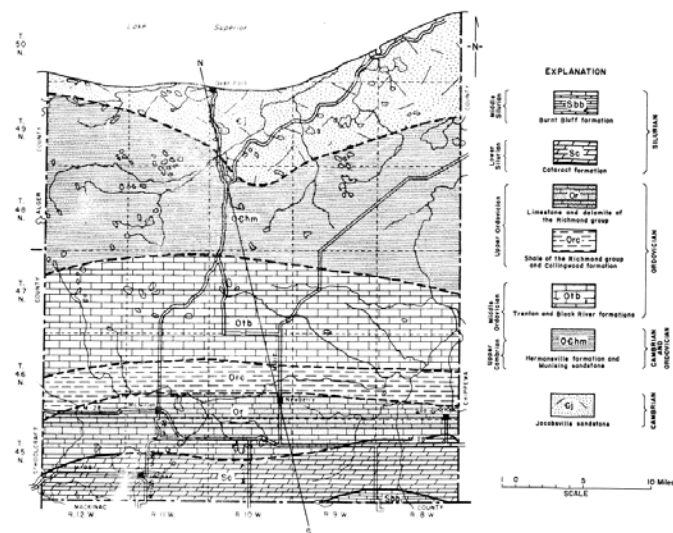


Plate 1. Geologic map of Luce County showing bedrock formations beneath surficial deposits.

Munising Sandstone of Late Cambrian Age

The Munising sandstone is a white to gray fine- to medium-grained sandstone. Parts of the formation are pink but can be readily distinguished from the red Jacobsville sandstone (Cohee, 1945). The formation is not as well cemented and therefore is less competent than either the underlying Jacobsville sandstone or the sandstone members of the overlying Hermansville limestone. In Alger County, a thin bed of conglomerate forms the basal member of the Munising (Hamblin, 1958), but it is not known whether the conglomerate extends into Luce County.

The Munising sandstone crops out at several places in the eastern part of the Northern Peninsula and in adjacent areas in Canada. The sandstone forms the famed pictured rocks and many of the waterfalls in Alger County. The only extensive exposures of the Munising in Luce County are at the falls of the Tahquamenon River and along the Two Hearted River for a distance of more than a mile upstream from the bridge across county road 407 (fig. 2). The Munising has not been completely penetrated in the drilling of any well in Luce County, and therefore the thickness of the formation is not known. Data from wells in other counties in the eastern part of the Northern Peninsula indicate that the sandstone is about 200 feet thick in Luce County where it is overlain by younger consolidated rocks. Where it forms the bedrock surface, it ranges in thickness from about 200 feet along its boundary with the Hermansville formation to a feathered edge along its boundary with the Jacobsville sandstone (pl. 1). It is not possible, however, to delineate the boundary between the Munising and Hermansville on plate 1 because of the lack of subsurface data, and because these formations crop out in so few places in the county. The only well in Luce County known to tap the Munising sandstone where it is mantled by younger consolidated rocks is well 45N 12W 21-2. In the area where the Munising forms

the bedrock surface, it is tapped by a few wells ranging in depth from 11 to 86 feet (table 3).

Hermansville Formation of Middle Ordovician Age⁽¹⁾

In the eastern part of the Northern Peninsula the Hermansville formation consists of beds of white and gray fine- to medium-grained sandstone, dolomitic sandstone, and sandy dolomite. Apparently, the amount of dolomite in the formation decreases from west to east, dolomitic strata being common in Alger County but not in Chippewa County. Within Luce County, the formation is believed to contain appreciable quantities of dolomitic cement. This is indicated in the vicinity of the Tahquamenon Falls, where the caprock at the falls is the competent, well-cemented basal layer of the Hermansville and the underlying, loosely cemented Munising sandstone has been cut away. Some of the sandstone layers in the Hermansville are lithologically similar to the Munising sandstone but can be distinguished from them because they differ in fossil content (Hamblin, 1958).

Well 45N 12W 21-2 is the only well in Luce County known to tap the Hermansville formation. Although a log of this well is not available, the depth of 850 feet indicates that it taps both the Munising sandstone and beds of sandstone in the Hermansville formation, which form a single aquifer. The artesian pressure in this well and also in several wells in adjacent areas in Mackinac and Schoolcraft Counties that tap the same aquifer is great enough to cause water to flow at the land surface. In all of southern Luce County, where the aquifer is overlain by younger consolidated rocks, the water in this aquifer is confined under considerable artesian pressure and in much of this part of the county the piezometric surface is near or above the land surface.

The Munising sandstone and Hermansville formation in Luce County are believed to have considerable potential for future development. Wherever present within the county these formations probably are capable of yielding moderate supplies of potable water.

⁽¹⁾ The use of the term "Hermansville formation" in this report does not imply that the Michigan Geological Survey discredits the work done by Wm. Kenneth Hamblin resulting in Publication 51 "Cambrian Sandstones of Northern Michigan." The present work was too near completion to be revised when the above paper was published. (Editor's note)

Trenton and Black River Formations of Middle Ordovician Age

The Trenton and Black River formations overlie the Hermansville formation in the southern part of Luce County. Where they form the bedrock surface (pl. 1) they are everywhere mantled by deposits of glacial drift. Outcrops of the formations in several places in Chippewa, Alger, and Delta Counties consist of a series of limestones, dolomites, and dolomitic shales (Hussey, 1936). Because they are similar in lithologic and

hydrologic characteristics, the Trenton and Black River formations are treated as a single unit in this report.

In preglacial time these formations are believed to have been eroded to form a cuesta (Black River cuesta, Thwaites, 1946, p. 20), having a northward-facing escarpment and a gentle southward dip slope. This cuesta which is buried under glacial drift in Luce County, trends in a general east-west direction.

No wells in Luce County are known to tap the Trenton and Black River formations, but because these formations yield fresh water to several wells in Chippewa County, they probably would be a source of fresh water in Luce County also. In Chippewa County the water is contained in solution openings along fractures and bedding planes where these formations form the bedrock surface. As solution must have been greatest in the upper limestone and dolomite strata, the permeability of the rocks probably decreases with depth. The basal layers of the Black River formation form the aquiclude capping the Munising and Hermansville formations.

Well 44N 9W 17-2 in Mackinac County, about 10 miles south of Newberry, produced saline water from the Trenton and Black River formations (Vanlier and Deutsch, 1958b). It is believed that wells tapping these rocks in the southern part of Luce County where the formations are overlain by younger consolidated rocks would also produce saline water. These formations are not important as potential sources of water in the county because in the areas where they might produce fresh water, they are overlain generally by shallower and more prolific glacial-drift aquifers.

Collingwood Formation and Richmond Group of late Ordovician Age

Shales of the Collingwood formation and Richmond group.-- A sequence of black bituminous shale, the Collingwood formation and gray dolomitic shale of the basal unit of the Richmond group, overlies the rocks of Middle Ordovician age. This shale is nearly impermeable and therefore is not a source of water to wells in Luce County. The thickness of the sequence along the southern boundary of the county is believed to be about 200 feet.

Limestone and dolomite of the Richmond group.-- The upper units of the Richmond group consist of limestone, dolomite and of shaly or sandy dolomite interbedded with layers of shale. The log of well 43N 13W 16-5 in Schoolcraft County indicates the presence of streaks of gypsum in these strata. The color of the dolomite ranges from gray to dark brown, whereas the shale is bluish-gray or black (see logs 45N 10W 1-1 and 9-4 in table 4). Where overlain by the Cataract formation in Luce County, these rocks are about 200 feet thick. Rocks of the Richmond group are not believed to crop out in Luce County.

The Richmond group is a source of water to a number of wells in the part of the county where these rocks form

the bedrock surface (pl. 1). In places, water-bearing, permeable glacial drift overlies and is hydraulically connected with the Richmond and a well completed in one of the aquifers, may produce water from both aquifers. Several wells in the Newberry area and one well (45N 11W 8-2) near McMillan obtain fresh water from these rocks although well 45N 10W 9-4, which tapped the same aquifer, produced saline water.

Cataract Formation of Early Silurian Age

The Cataract formation is composed chiefly of dolomite and shale interbedded with thin layers of gypsum. The dolomite generally is gray to dark gray, but cuttings brought to the surface when wells are drilled into it often are somewhat blue when wet, and for this reason the formation is sometimes referred to as the "blue rock" by water-well drillers. The shale generally is dark gray, but green shale has been reported (Ehlers and Kesling, 1957, p. 5-7). The maximum thickness of the Cataract formation in Luce County is about 200 feet. The formation crops out in T. 45 N., R. 12 W., on the shore of Manistique Lake, and also in T. 45 N., R. 8 W.

The Cataract formation is a source of water to several wells in the southern part of the county where it forms the bedrock surface. Apparently, the water moves principally through solution openings along joints and bedding planes. It is believed that the Cataract formation will yield water to wells throughout the area where it forms the bedrock surface. Generally, however, water from the formation is very hard, and locally it is too highly mineralized for most uses.

Burnt Bluff Formation of Middle Silurian Age

A small, undeveloped area in southeastern Luce County is underlain by light gray to gray thinly bedded to massive limestones of the Burnt Bluff formation (pl. 1). The strata of the formation are hard and resistant. Some beds are dolomitic, but others are high in calcium content. Although no wells in Luce County are known to tap these rocks, the formation is a source of water to many wells in Mackinac County and where present in Luce County probably would yield water to wells,

Ground Water in Unconsolidated Rocks

Nearly all of Luce County is mantled by unconsolidated rocks of various types deposited during the Pleistocene epoch. These deposits are referred to collectively as "glacial drift". The types of drift (till, outwash, glacial-lake sediments, and dunes) are differentiated on the basis of their mode of deposition. Till is generally unstratified drift that was deposited directly by the ice, water playing a minimum part in the process of deposition. Outwash is stratified drift that was deposited by melt water flowing from the glacier. Glacial-lake sediments are stratified fine-grained rock materials that were deposited in glacial lakes. Dunes are composed of well-sorted sand

deposited by wind action, principally during the glacial epoch.

The drift deposits differ not only in their mode of deposition but also in the source of the material. Although some of the material that makes up the drift was transported a great distance, most of the material was derived from nearby sources. Flint (1947, p. 114) states that "the average distance traveled by a rock fragment from the time it is picked up by the glacier until it is deposited is only a few miles". The glaciers moved in a southerly direction across Luce County, and much of the material plucked and scoured from the bedrock surface was deposited a few miles to the south when the glacier melted. Thus, the drift of Luce County is closely related to the bedrock formations of the county.

The drift in and immediately south of the area where the Jacobsville, Munising, and Hermansville formations compose the bedrock surface is made up predominantly of sand derived from these formations. Locally, in the southern part of the county, limestone fragments and clay derived from limestones and shales of Ordovician and Silurian age make up a large part of the drift mantle. However, most of the drift in Luce County is composed principally of quartz sand.

The permeability of the drift is governed by the size of the individual grains and by the degree of sorting. The most permeable drift sediments are the outwash deposits, which are composed of larger particles of rock debris and are relatively well sorted. Sandy and gravelly till containing only minor amounts of clay and silt is moderately permeable. Clayey till, however, is relatively impermeable. Dune sands and lake-deposited sands that are well sorted, even if relatively fine, also are moderately permeable, but lake-deposited silt, clay, and silty, clayey sand are generally of low permeability.

Plate 2 shows the areal distribution of the surficial glacial deposits. Because the surficial deposits may be underlain by glacial deposits of other types, the map should not be considered to indicate the presence of the same type of material throughout the drift section. Thus, the map can be used only as a general aid in locating ground-water supplies.

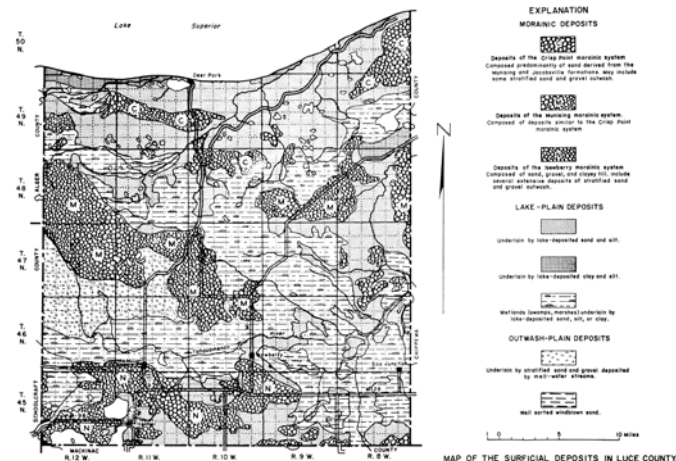


Plate 2. Map of the surficial deposits in Luce County.

Morainic Deposits

Moraines are ridges composed predominantly of glacial till deposited along the relatively static front of a glacier. Three extensive morainic systems in Luce County have been described (Bergquist, 1933, 1936). The composition of the till in the three moraines is related to the bedrock sources from which the morainal deposits were derived. All the moraines, however, are composed largely of sandy till, most of which was deposited in and beneath the waters of Lake Algonquin. Three small areas of land-laid moraine were mapped by Bergquist (1936, fig. 12). The till deposited in water tends to be somewhat better sorted and stratified than till deposited on land.

Deposits of the Newberry morainic system. The Newberry moraine is the southernmost and the oldest of the morainic systems in Luce County. This ridge of glacial till can be traced from a point southeast of Newberry to the southwest corner of Luce County (pl. 2). The topography of the moraine is generally rough and is characterized by knobs and basins. The lower part of the moraine was modified by the wave action of Lake Algonquin and by sediment deposition in the lake.

Bergquist (1936, p. 74) described the drift of the Newberry moraine in Luce County as follows:

The glacial drift which constitutes the moraine is largely sandy, with local admixtures of clayey material. The soil of the sandy areas is loose textured, porous and open, and allows good drainage. The heavier phases are more compact and firm and tend to retain a greater amount of water. The more important areas of clayey drift are found in the vicinity of the Manistique lakes and south of McMillan. Foreign boulders and limestone slabs of local origin are abundantly scattered through the glacial drift, especially in the more strongly developed inner portions of the moraine. In the weaker outer borders, the drift is sandy to gravelly in texture and erratics are generally quite scarce.

The thickness of the drift in this moraine differs considerably from place to place. The greatest known thickness is at well 45N 10W 1-1, which penetrates 320 feet of unconsolidated rock. The drift of the Newberry moraine is thinnest in those areas in which the Cataract formation crops out, in T. 45 N., R. 12 W.

The sandy till of the moraine is permeable and is a source of water to many wells throughout the area mapped as Newberry moraine (pl. 2). Most wells tapping this sandy till produce small to moderate supplies of water. However, wells tapping stratified sand and gravel outwash incorporated within the till of the Newberry moraine produce large supplies of water. All the large-capacity wells in the county (table 2), except well 47N 8W 24-1, produce water from sand and gravel deposits within or adjacent to the Newberry moraine. Logs of wells (table 4), and also the large quantities of gravel removed from pits throughout the moraine,

indicate that a considerable amount of sand and gravel outwash is incorporated within the morainal material.

Deposits of the Munising morainic system. The Munising morainic system crosses the central part of Luce County and is broken into two major segments (pl. 2). The moraine was described by Bergquist (1936, p. 79-80) as follows:

Upon entering Luce County, the Munising morainic system takes a definite swing to the southeast and breaks off into the Tahquamenon swamp a few miles north of Dollarville. Like its counterpart south of the swamp (Newberry moraine), this moraine is not separable into distinct ridges but stands as a mass of undulating drift.

On its inner border, the moraine here stands at an altitude of 750 to 800 feet and presents a strongly developed relief. The topography is generally quite undulating and in places broken by numerous basins which are hemmed in by knobs of varying heights. The drift is predominantly sandy and is locally interspersed with admixtures of gravel and clay. Erratics and occasional slabs of limestone are scattered through the section but not in such large quantity as in the moraine to the south. The limestone makes up a relatively small proportion of the drift but is conspicuous in the shore bluff which marks the northern margin of the moraine, south of Cold Spring in sec. 6, T. 47 N., R. 10 W. This shore feature marks the northern limit of limestone drift in Luce County. . . .

The area occupied by the Munising moraine in Luce County is largely undeveloped, and only a few small-capacity wells have been drilled into the morainic deposits. These wells tap lenses of coarse sand or fine gravel. Most of the wells are completed at depths less than 100 feet.

Deposits of the Crisp Point morainic system. The Crisp Point moraine is a rather poorly defined ridge of glacial drift which crosses the northern part of Luce County. The moraine is formed predominantly by sand derived from the underlying bedrock, but contains scattered patches of gravel and a few lenses of clay.

Few data other than records of the shallow fire-control test holes (table 3), are available concerning the water-bearing characteristics of ground-water potential of the drift in the area mapped as the Crisp Point moraine. Because the moraines and associated materials in this area are composed largely of sand, it is believed that they would yield moderate supplies of water to properly constructed wells.

Outwash Deposits

Outwash plains are underlain by stratified sand and gravel deposited by glacial melt-water streams. In Luce County the deposits are closely related to and in places are incorporated within the moraines. Only one major outwash plain was mapped in the county (pl. 2). The

outwash was deposited in glacial lakes and tends to be deltaic. This outwash plain extends into the western part of Luce County from Schoolcraft and Alger Counties and was described by Bergquist (1936, p. 87) as follows:

The eastern extension of the plain, continuing into Luce County, and especially that portion situated directly across the swamp from the village of McMillan, seems to have formed in the wake of a rapidly retreating ice-border. Near its inner edge, the plain is generally smooth and unbroken. It contains coarse cobbly and gravelly material interspersed with occasional boulders which protude through from the underlying till. To the south, however, the surface of the apron is deeply trenched and pitted and presents a relief sufficiently rugged to be easily mistaken for a morainic feature. Superficial boulders are relatively rare in this area but may be encountered within a few feet of the surface as evidenced in the deeper skidding trails and along the floors of streams which have trenched their channels through the overwash.

Only a few shallow fire-control test holes have been drilled into this deposit of outwash, and little is known of the thickness of the deposit or of its water-yielding capacity. Outwash deposits, however, are the most permeable sediments within the glacial drift, and hence it is probable that moderate to large water supplies could be obtained from this deposit.

Glacial-Lake Deposits

Glacial lake plains, underlain by sand, silt, and clay deposited in the waters of Lake Algonquin, cover much of Luce County (fig. 3). In the northern tier of townships the lake sediments are composed predominantly of sand. Elsewhere, the lake deposits may be sandy or clayey, but in the large areas covered by swamps, the surficial lake sediments have not been differentiated (pl. 2). Well logs, however, indicate that extensive areas of the county may be underlain by clayey lake deposits.

Although the lake clays are not a source of water to wells and the lake-deposited sands generally will yield only small supplies of water, these lake deposits commonly mantle drift that is highly permeable. Locally, large supplies of water can be obtained from aquifers covered by lake deposits. Well 47N 8W 24-1 is reported by the owner to have flowed about 400 gpm from coarse gravel mantled by about 55 feet of lake-deposited clay, silt, and sand. The city of Newberry obtains large supplies of water from wells tapping sand and gravel in an area mantled by lake-deposited sand. Flowing wells in some of the swamp areas indicate that these swamps must be underlain by a relatively impermeable layer of silt and clay that is the upper confining layer in an artesian system.

Dune Sand

Extensive sand dunes are prominent features along the Lake Superior shore and in a large area north of the Tahquamenon Falls in Luce County. Numerous smaller dunes, which are not delineated on plate 2, are scattered over the lake plains throughout the county. A few of the dunes are being moved inland by winds blowing from Lake Superior. The dunes are composed of very well sorted windblown sand. Locally, saturated zones in these deposits may yield small supplies of water to properly constructed shallow wells, but in general the dunes are a poor potential source of water because they are above the water table. They have a high infiltration capacity, however, and provide an important avenue of recharge to underlying aquifers.

Permeability and Particle-Size Distribution of Selected Samples of Consolidated and Unconsolidated Sediments

Three samples of sandstone and ten of glacial drift were collected in and near Luce County for particle-size analysis and permeability determination in the Hydrologic Laboratory of the U. S. Geological Survey at Denver, Colo. The results of the tests were used as an aid in determining the origin of various glacial-drift deposits, the relative permeability of sandstone and drift deposits, and the relation of particle-size distribution to permeability.

If the permeability of a sample is typical of that of the aquifer in the vicinity of the sampling point and if the thickness of the aquifer is known, then the coefficient of transmissibility can be computed. The coefficient of transmissibility 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 full thickness of the aquifer, under a hydraulic gradient of 100 percent, or 1 foot per foot (gpd per foot); it is equal to the average field coefficient of permeability multiplied by the thickness of the aquifer, in feet. A rough approximation of the specific capacity of a 100-percent efficient 6-inch well penetrating the entire aquifer can then be made by dividing the transmissibility by 2,000. This calculation is based on an equation devised by Thiem (1906). For example, the laboratory determination of the coefficient of permeability of a sample of the Munising sandstone (Al 1) was 52 gpd per square foot, and the thickness of the formation is known to be about 200 feet. Hence, the transmissibility is estimated to be 10,000 gpd per foot, and the specific capacity of an efficient well open to the full thickness of the aquifer would be about 5 gpm per foot of drawdown. The laboratory measurement of permeability was made at right angles to the bedding planes in the sandstone, and the permeability is probably a minimum value, as sedimentary rocks commonly are more permeable along than across the bedding.

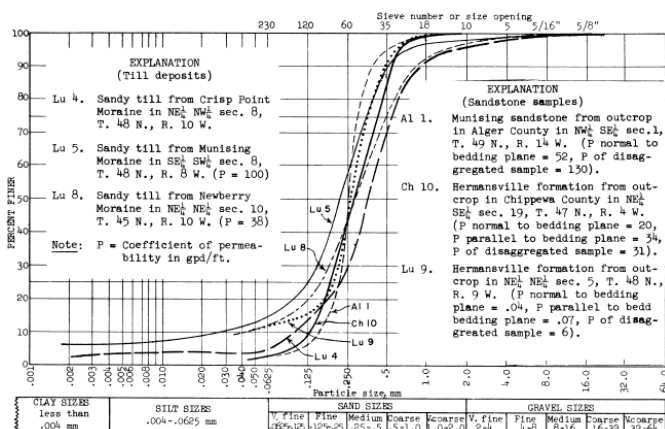


Figure 7. Particle-size distribution curves of samples of sandy till from Luce County and sandstone from Alger, Luce, and Chippewa Counties.

The Munising sandstone is poorly cemented, and secondary openings along fractures and bedding planes are uncommon. Most of the water contained in the formation is believed to move through the primary interstices between individual sand grains. A particle-size analysis of a typical sample of sandstone from the Munising sandstone in Alger County (Al 1, fig. 7) shows that the sandstone consists predominantly (more than 90 percent) of fine- and medium-grained sand.

The Hermansville formation is similar lithologically to the Munising sandstone. Particle-size analysis of a sample of sandstone from the Hermansville in Luce County (Lu 9, fig. 7) shows that this sandstone also is fine to medium grained. However, the interstices between sand grains in some of the beds of the Hermansville 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 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. This does not indicate, however, that the dolomitic beds will not yield appreciable quantities of water inasmuch as most of the water in the well-cemented portions of the formation moves along fractures and bedding planes. Aquifer testing in the field would be required to determine the capacity of the dolomitic beds to yield water.

Another sandstone sample from the Hermansville formation collected in Chippewa County (Ch 10, fig. 7), also was very similar to the sample from the Munising sandstone. This sample, however, appeared to contain much less cementing material than sample Lu 9; its coefficient of permeability was 20 gpd per square foot normal to the bedding plane and 34 gpd per square foot parallel to the bedding plane.

Figure 7 also shows the particle-size distribution of three samples of sandy till. The similarity of these curves to those representing the Munising sandstone and Hermansville formation suggests strongly that the sandy till was derived primarily from those formations. The

coefficients of permeability determined for samples Lu 5 and Lu 8 were 100 and 38 gpd per square foot, respectively. For purposes of comparison, the sandstone samples were disaggregated, and it was found that the coefficients of permeability of the two samples derived from the loosely cemented sandstones were nearly the same as those determined for the sandy till. Although disaggregation of the samples of loosely cemented sandstone did not increase their permeability appreciably, the disaggregation of the cemented sandstone sample (Lu 9) increased its permeability about 90 times.

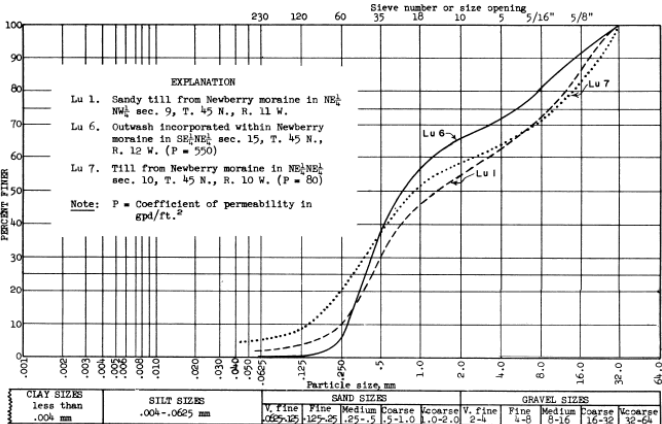


Figure 8. Particle-size distribution curves of samples of glacial sediments from Luce County.

The outwash sands and gravels are the most permeable deposits in the county, as shown by the results of tests on various wells to determine specific capacity (table 2). These sediments are the source of water to most of the large-capacity wells in the county. A particle-size analysis of a sample of outwash (Lu 6, fig. 8) shows that the outwash is very similar to till in nearby areas, except that it is somewhat better sorted. The coefficient of permeability of this sample, as determined in the laboratory, was 550 gpd per square foot, whereas that of a sample of till from the Newberry moraine (Lu 7, fig. 8) was 80 gpd per square foot. This difference in permeability may be attributed to the fact that the outwash contained less fine sand and practically no very fine sand, silt, or clay which would impede movement of water by clogging the interstices between the larger sand and gravel particles. A coefficient of permeability was not determined for sample Lu 1, but inspection of the particle-size-distribution curve (fig. 8) reveals that some till deposits may be very similar in composition to outwash deposits.

Particle-size analyses were made of two samples of fine-grained till from Luce County (Lu 2 and Lu 3, fig. 9). Although fine-grained till is commonly referred to as clay till, the analyses revealed that the material is composed largely of silt. The writer believes that the deposit from which the samples were taken was derived from glacial-lake sediments that were reworked and redeposited by later glacial action. Sample Lu 2 had a coefficient of permeability of 2 gpd per square foot, which is considerably greater than that of the sample of well-

cemented sandstone from the Hermansville formation (Lu 9, fig. 7). However, fine-grained till sampled in Chippewa County (Ch 3, fig. 9) was poorly sorted and contained 40 percent clay; it is assumed to have been less permeable than samples Lu 2 and Lu 3.

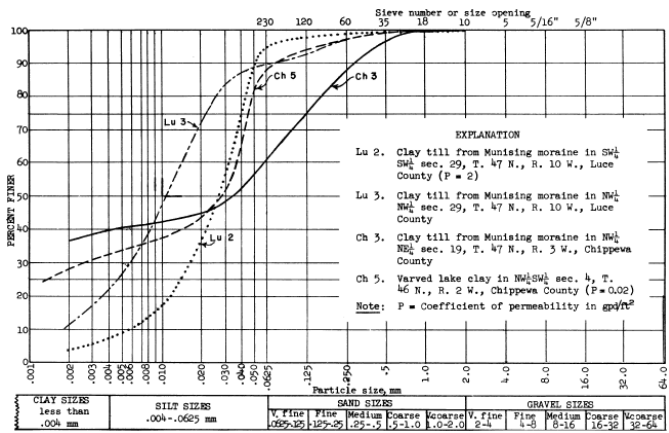


Figure 9. Particle-size distribution curves of samples of fine-grained glacial sediments from Luce and Chippewa Counties.

Samples of glacial-lake deposits were not collected in Luce County, but a particle-size analysis of a sample of a varved lake deposit in Chippewa County (Ch 5, fig. 9) showed it to contain about 33 percent clay and 55 percent silt; the coefficient of permeability of the same sample was only 0.02 gpd per square foot. The permeability of clayey lake or till deposits in Luce County probably is similarly low.

Ground-Water Phase of the Hydrologic Cycle

Source and Recharge Areas

Precipitation is the initial source of all ground water in the aquifers of Luce County, with the possible but negligible exception of a very small amount of juvenile water from deep-seated sources. If all the moisture that fell upon the county (an average of 28 inches per year) were to infiltrate to the aquifers of the county, a supply of ground water greatly in excess of all foreseeable needs, would be assured. However, only a small part of the precipitation reaches the ground-water reservoirs; the much greater part of it evaporates, is consumed by plant life, or runs off into streams and lakes.

The amount of precipitation that does enter the ground-water reservoirs is governed by a number of factors. Among these are the duration, intensity, and type of precipitation; the density and type of vegetation; the topography; the porosity and permeability of the soil; the permeability, thickness, and structure of the subsoil and underlying rock formations; and the extent to which the aquifer is already saturated.

Much of Luce County is underlain by sandy permeable soils and subsoils, and where these are above the regional water table conditions are favorable for infiltration of precipitation. In the areas underlain by clay

soils of low permeability, less water is able to infiltrate into the ground-water reservoirs.

Movement

The movement of water through the ground is similar to movement in surface streams in that the water moves by gravity from high to low levels. Ground water moves much more slowly than surface water, however, because of friction generated by the water as it percolates through the crevices and interstices in the earth's crust. Rates of ground-water movement range from a few feet per year to several feet or tens of feet per day. Water may travel great distances underground from recharge areas to areas downgradient, where it may once more reach the surface and join the flow of streams, appear as a seep or spring, enter a lake, escape directly to the atmosphere by evaporation or transpiration or be withdrawn from a well. Where undisturbed by manmade diversions, the water table of an unconfined aquifer 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 overlying land surface. Where more than one aquifer underlies the same area, water migrates or leaks from aquifers having a higher pressure head to those having lower head.

Discharge

Water is discharged from ground-water reservoirs by evaporation and transpiration, through wells, springs, and drains, and by flow into surface-water bodies. Because so much of the county is covered by dense forest and swamp vegetation, the amount of water discharged by transpiration represents a large percentage of the precipitation. Because the water table is shallow in much of the county, a substantial part of the water evaporated and transpired doubtless is ground water.

Considerable water is discharged from the shallow ground-water reservoirs through springs. Most of the springs in the county are along the edges of the moraines. Some of the ground water discharged in Luce County moves into the county from recharge areas in adjacent counties. Conversely, some of the precipitation which falls in Luce County becomes ground water and moves by underflow to be discharged outside of the county.

Discharge from wells is greatest in the vicinity of Newberry where several large-capacity wells are pumped and in the southern part of the county where most of the flowing wells are located. However, the total discharge of water from wells is small compared to total natural ground-water discharge.

Fluctuations of the Water Table

Climatic Influences

Although long-term water-level observations have not been made in Luce County, fluctuations of the water level in well 46N W 24-1 (fig. 10) in Chippewa County have been recorded for a number of years (Vanlier and Deutsch, 1958a). Because this well taps sand and gravel in an outwash deposit associated with the Munising morainic system, the water-level fluctuations in it are believed to be similar to those in wells tapping the glacial drift in Luce County.

Water levels fluctuate with changes in the rate of recharge to and discharge from the ground-water reservoirs. During the spring thaw, water levels in wells in Luce County rise in response to the infiltration of rain and melting snow, and during the summer they decline because ground-water discharge exceeds the recharge. The graphs in figure 10 show that precipitation during the summer growing months had little effect on either the water level in well 46N W 24-1 or on the discharge of the Tahquamenon River; nearly all the precipitation was consumed by vegetation or was evaporated. After the growing season, evapotranspiration losses were reduced and precipitation again caused rises in water levels. In the fall of 1954 infiltrating rain added considerably to both ground water in storage and discharge of the Tahquamenon River, but subsequent snowfall had little effect on ground water levels or the discharge of the river until the spring thaw. The considerable time lag between the peak in the discharge of the river and the highest ground-water levels shows that aquifers do not respond as quickly to precipitation as do surface streams.

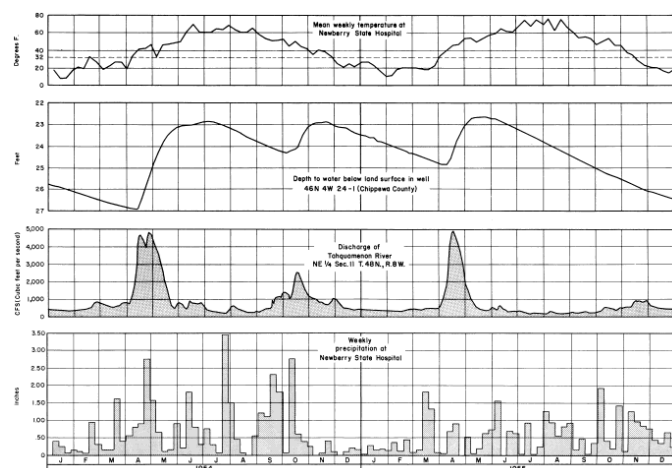


Figure 10. Graphs of air temperature, precipitation, ground-water levels, and discharge of the Tahquamenon River.

Fluctuations Due to Discharge from Wells

Generally, ground water is a renewable natural resource because it is replenished directly or indirectly by precipitation. If an aquifer is to be developed by means of wells so that a long-term yield can be obtained, the

average rate of recharge to the aquifer must balance the average rate of discharge from the aquifer. In any aquifer in its natural state (before it is tapped by wells) an approximate dynamic equilibrium exists between recharge and discharge. When water is withdrawn from an aquifer by a well, a temporary change in the total discharge from the aquifer results. The discharge by the well causes a cone-shaped depression in the water table or piezometric surface around the discharging well. With continued discharge by the well, the cone expands until the resultant lowering of the water level causes a decrease in discharge from the aquifer or an increase in recharge to the aquifer, or a combination of the two, which again restores 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 so long as the discharge continues.

Where a number of wells are pumped or allowed to flow, a composite cone of depression is formed and may extend over a large area. Water levels in wells within the cone of depression also are lowered even though the wells are not pumped. A lowering of the water table or piezometric surface, therefore, is a necessary result of the development of an aquifer. A good illustration of the above is provided by Leverett (1906, p. 41) who reported that flowing wells in the vicinity of the Newberry Lumber and Chemical Co. stopped flowing when the Company wells were pumped. Waste of water from unrestricted flowing wells or through underground leakage from poorly constructed wells or deteriorated well casings may result in sufficient lowering of the piezometric surface to cause some wells to stop flowing, decrease the discharge from others, and increase the cost of producing water.

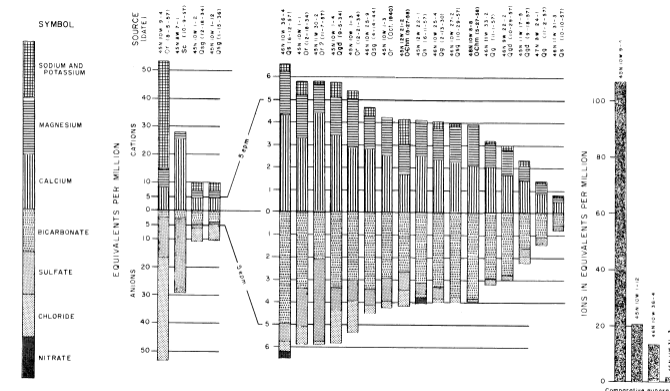


Figure 11. Chemical composition of ground water in Luce County.

Chemical Quality of the Water

Water percolating through soil and rocks dissolves some of the material with which it comes in contact. The amount and character of the dissolved mineral matter in ground water depend on the chemical and physical composition of the rocks through which the water moves, the duration of the contact, and other factors such as temperature, pressure, and amount of mixing, if any,

with highly mineralized connate water (water entrapped at the time the sediment was deposited). Figure 11 illustrates graphically the chemical composition of 21 water samples from wells in Luce County, and table 5 lists analyses of 30 samples from wells tapping the glacial drift and 9 samples from wells tapping the bedrock. In figure 11 the analyses are expressed in equivalents per million -- parts per million divided by the chemical equivalent weight of the constituent. The analyses in table 5 are given in parts per million.

The hardness of the water sampled in the county ranged from 24 to 1,750 parts per million (ppm). Hardness of water is due principally to salts of calcium and magnesium in solution. Limestone and dolomite strata and gypsum-bearing formations in the county are the major sources of calcium and magnesium ions in the ground water.

Water with respect to hardness is classified by the Michigan Department of Health (1948) as follows:

<u>Class</u>	<u>Hardness</u> (parts per million)
Very soft	less than 50
Soft	50-100
Moderately hard	100-200
Hard	200-300
Very hard	more than 300

Hardness is commonly computed also in grains per gallon. One grain per gallon equals 17.1 ppm.

Fresh Ground Water

The Jacobsville sandstone is not known to be the source of water to any of the wells in Luce County. Data from wells in Alger and Chippewa Counties indicate that this formation would yield moderately hard to hard water of the calcium bicarbonate type in Luce County.

Water in the Munising and Hermansville formations is also of the calcium magnesium bicarbonate type. The sample from well 48N 10W 8-8 which taps these formations in the northern part of the county where they form the bedrock surface had a hardness of 192 ppm and contained less than 1 ppm of chloride. The sample from well 45N 12W 21-2 which taps these formations where they are overlain by several hundred feet of younger consolidated rocks had a hardness of only 151 ppm, but contained 26 ppm of chloride. Data from Schoolcraft, Mackinac, and Chippewa Counties shows that the chloride content of water in these formations increases toward the center of the Michigan basin. However, the chloride content of the water in these rocks is relatively small throughout Luce County.

The limestone and dolomite of the Richmond group are a source of fresh water which also is predominantly of the calcium magnesium bicarbonate type. Locally, they contain significant amounts of chloride and sulfate. The chloride probably results from a mixing of fresh water with some of the saline water that also is present in

these rocks. The sulfate probably results from the migration of the water through gypsum-bearing strata, either in rocks of the Richmond group or in the overlying Cataract formation. The sulfate content of samples of water from these rocks ranged from 45 to 680 ppm and the chloride content from 10 to 1,300 ppm. Sulfate or chloride content of drinking water should not exceed 250 ppm.

The Cataract formation is a source of fresh water to several wells in the county, but the water generally is hard to very hard and is very high in sulfate. Gypsum present in the formation which has been leached by percolating ground water is the source of calcium sulfate in the water.

The chemical quality of water in the glacial-drift aquifers differs considerably from place to place in the county. The differences in the quality of the water in the drift reflect in part the composition of the drift and in part the underlying bedrock formations. In the northern part of the county the drift is composed mainly of quartz sand; and only minor amounts of soluble minerals are present. Thus, water from the drift in the northern part of the county is soft and low in dissolved solids. On the other hand, the drift in the southern part of the county contains a larger proportion of soluble rock fragments -- limestone, dolomite, and gypsum -- and thus most of the ground water is hard and contains higher concentrations of dissolved solids. Locally, however, shallow drift in the southern part of the county yields water low in dissolved solids, probably because the water passed through only a thin layer of material to reach the aquifer and has been in the aquifer only a relatively short time. The hardness of the water samples from the glacial drift ranged from 24 to 370 ppm. Half of the drift waters sampled were moderately hard. Six of the samples were in the soft or very soft class and nine were hard or very hard. The higher proportion of chloride present in the water from wells tapping the drift in the vicinity of the Newberry State Hospital probably reflects inflow of saline water from rocks of the Richmond group.

Saline Ground Water

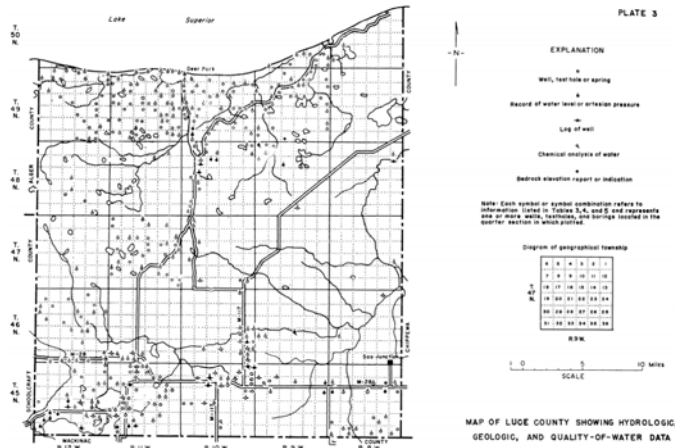
Some of the aquifers in Luce County contain saline water. The term "saline water" is used in this report to mean water that contains more than 1,000 ppm of dissolved solids, regardless of the composition of the solids; saline water is not necessarily a sodium chloride water.

Although the Trenton and Black River formations are not known to yield water in Luce County, data from wells in other places in the eastern part of the Northern Peninsula indicate that these formations probably contain saline water in Luce County.

Well 45N 10W 9-4, which taps the Richmond group, was the only well sampled that yielded water containing appreciable concentrations of sodium and chloride. The chloride in water from the Richmond group is the result of the mixing of fresh water with connate water or was

Samples of water from well 45N 12W 34-1 and spring 45N 8W 7-1, both tapping the Cataract formation, had concentrations of 1,250 and 1,240 ppm of sulfate, respectively, and correspondingly high concentrations of calcium and hence are considered saline.

All the present water supplies in the county come from ground-water sources, but the amount used represents only a small fraction of the total resource available. A supply of ground water exceeding all foreseeable needs is assured by the average annual precipitation (about 28 inches) and the favorable conditions for recharge that exist throughout most of the county.



Utilization of Ground Water

Most of the water used in Luce County is utilized for domestic purposes, but a small amount is used for stock watering and for industrial supply; one well (45N 10W 13-4) is used solely for irrigation. The total amount of ground water used in Luce County represents only a small fraction of the total resource available.

SUMMARY AND CONCLUSIONS

The glacial-drift aquifers, which are the most accessible and are the source of water to most of the wells in the county, are believed to offer the greatest potential for future development. All the large capacity wells in the county tap drift aquifers, and test drilling would

Wells, J. V. B., and others, 1958, Surface water supply of the United States, 1956, Pt. 4, St. Lawrence River basin: U. S. Geol. Survey Water-Supply Paper 1437.

REFERENCES CITED

- Bergquist, S. G., 1933, Surface geology of Luce County, Mich.: Michigan Acad. Sci. Papers, v. 14, p. 437-452.
- Bergquist, S. G., 1936, The Pleistocene history of the Tahquamenon and Manistique drainage region of the Northern Peninsula of Michigan: Michigan Geol. Survey Pub. 40, Geol. ser. 345 pt. 1, p. 7-148.
- Cohee, G. V., 1945, Sections and maps of Lower Ordovician and Cambrian rocks in the Michigan basin, Michigan and adjoining areas: U. S. Geol. Survey Oil and Gas Inv. Prelim. Chart 9.
- Ehlers, G. M., and Kesling, R. M., 1957, Silurian rocks of the Northern Peninsula of Michigan: Michigan Geol. Soc. Ann. Field Trip Guidebook.
- Flint, R. F., 1947, Glacial geology and the Pleistocene epoch: New York, John Wiley and Sons, Inc.
- Hamblin, W. K., 1958, The Cambrian sandstones of Northern Michigan: Michigan Geol. Survey Pub. 51.
- Hussey, R. C., 1936, The Trenton and Black River rocks of Michigan: Michigan Geol. Survey Pub. 40, Geol. ser. 34, pt. 3, p. 227-260.
- Leverett, Frank, 1906, Flowing-well districts in the eastern part of the Northern Peninsula of Michigan in Fuller, M. L., and others, Underground-water papers: U. S. Geol. Survey Water-Supply Paper 160, p. 29-53.
- Leverett, Frank, and Taylor, F. B., 1915, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U. S. Geol. Survey Mon. 53, 529 p., 32 pls.
- Martin, H. M., and Straight, M. T., 1956, An index of Michigan geology: Michigan Geol. Survey Pub. 50.
- Meinzer, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489.
- Michigan Department of Health, 1948, Chemical analyses and their interpretations Public water supplies in Michigan: Michigan Dept. Health, Eng. Bull. 4.
- Tague, G. C., 1938, An occurrence of nonwetting sand at Muskallonge Lake, Luce County, Mich.: Michigan Acad. Sci. Papers, v. 23, p. 497-502.
- Thiem, Gunter, 1906, Hydrologische methoden: Leipzig, J. M. Gebhardt.
- Thwaites, F. T., 1946, Outline of glacial geology: Madison, Wisc., F. T. Thwaites.
- Vanlier, K. E., and Deutsch, Morris, 1958a, Reconnaissance of the ground-water resources of Chippewa County, Mich.: Michigan Geol. Survey Prog. Rept. 17.
- Vanlier, K. E., and Deutsch, Morris, 1958b, Reconnaissance of the ground-water resources of Mackinac County, Mich.: Michigan Geol. Survey Prog. Rept. 19.
- Wells, J. V. B., and others, 1957a, Surface water supply of the United States, 1954, Pt. 4, St. Lawrence River basin: U. S. Geol. Survey Water-Supply Paper 1337.
- Wells, J. V. B., and others, 1957b, Surface water supply of the United States, 1955, Pt. 4, St. Lawrence River basin: U. S. Geol. Survey Water-Supply Paper 1387.



STATE OF MICHIGAN
DEPARTMENT OF CONSERVATION
Gerald E. Eddy, *Director*
GEOLOGICAL SURVEY DIVISION
William L. Daoust, *State Geologist*

AGE			NAMES AND SYMBOLS USED IN THIS REPORT LITHOLOGY	THICKNESS (feet)	HYDROLOGY	NAMES USED BY THE MICHIGAN GEOLOGICAL SURVEY		
						SERIES	GROUP	FORMATION
CENEZOIC	QUATERNARY	PLEISTOCENE	GLACIAL DRIFT, UNDIFFERENTIATED (Qgd) SAND (Qs); GRAVEL (Qg) SAND AND GRAVEL (Qsg) Heterogeneous assemblage of unsorted to slightly stratified clayey, sandy, and gravelly till, principally water-laid; stratified sand and gravel outwash; stratified clayey, silty, and sandy lake deposits; and wind-deposited sand.	0 to 320+	Principal aquifer in Luce County. Best yields from sand and gravel outwash deposits, many of which are incorporated within the morainic deposits. Small to moderate supplies from sandy and gravelly morainal till. Poor yields from clayey till. Small yields from lake-deposited sand. Moderate to large supplies from sand and gravel deposits overlain by lake-deposited silt, sand, and clay. Layers of lake-deposited clay and clay till are confining beds in some artesian system.	GLACIAL DRIFT		
PALEOZOIC	SILURIAN	MIDDLE	BURNT BLUFF FORMATION (Sbb) Hard, resistant light-gray to gray thinly bedded to massive limestone and dolomitic limestone; contains beds of high-calcium limestone.	200±	Not tapped by wells in Luce County but would yield water to wells in the small area in T. 45 N., Rs. 8 and 9 W.	NIAGARAN	CLINTON	BURNT BLUFF
		EARLY	CATARACT FORMATION (Sc) Hard, resistant gray dolomite interbedded with gray and greenish-gray shale and gypsum.	200±	A source of water to a number of wells in the southern part of the county. Permeable as a result of solution along joints, or other fractures, and bedding planes. Generally yields water too hard for most uses. Locally contains highly mineralized water.	ALBION	CATARACT	MAYVILLE CABOT HEAD MANITOU LON
	ORDOVICIAN	LATE	LIMESTONE AND DOLOMITE OF RICHMOND GROUP (Or) Gray to dark-brown dolomite and limestone interbedded with dark-colored shale.	200±	Yields water to several wells in the Newberry area and to one well south of McMillan. Generally yields hard water. Locally contains saline water.	CINCINNATIAN	RICHMOND	QUEENSTOWN? BIG HILL STONINGTON BILLS CREEK
			SHALE OF RICHMOND GROUP AND COLLINGWOOD FORMATION (Orc) Gray dolomite and black bituminous shale.	200±	Permeability low. Not a source of water to wells in Luce County.			COLLINGWOOD
		MIDDLE	TRENTON AND BLACK RIVER FORMATIONS (Otb) Hard gray and brown limestone and dolomite interbedded with shale and shaly limestone and dolomite.	200±	Not a source of water to wells at present. May yield fresh water from openings enlarged by solution where these strata form the bedrock surface. Probably contain saline water where overlain by younger consolidated rocks.	MOHAWKIAN	TRENTON AND BLACK RIVER	TRENTON AND BLACK RIVER
			HERMANSVILLE FORMATION (Oh) White to gray fine- to medium-grained sandstone, and sandy dolomite.	50	These two sandstone formations constitute a single aquifer which is presumed to be a source of fresh water wherever present in the county. Water contained in openings along joints and bedding planes in cemented parts of aquifer and in interstices between individual grains in non-cemented parts.			HERMANSVILLE
	CAMBRIAN	LATE	MUNISING SANDSTONE (Em) White to gray fine- to medium-grained sandstone.	200±		LAKE SUPERIOR		MUNISING

		EARLY AND MIDDLE	JACOBSVILLE SANDSTONE (Cj) Well-cemented quartzitic sandstone, red and pink with patches of white.	1,000±	Source of water to wells in Chippewa and Alger Counties and a potential source of water is here present in Luce County. Water contained in openings along joints and bedding planes; permeability decreases with depth.			JACOBSVILLE
PRECAMBRIAN	METAMORPHIC AND IGNEOUS ROCKS		?	Too deep to be an economical source of water supply. Permeability (probably) low.		PRECAMBRIAN, UNDIFFERENTIATED		

Table 1. Lithology and hydrology of rocks underlying Luce County.

Well number	Aquifer		Length of screen (feet)	Duration of test (hours)	Rate of discharge (gpm)	Drawdown (feet)	Specific capacity (gpm/per ft)
	Symbol	Lithology					
46N 11W 33-2	Qg	Gravel	--	--	350	20	17.5
46N 10W 24-4	Qsg	Sand and gravel	--	--	.25	4.5	.06
25-7	Qs	Sand, coarse	75	--	1,280	30	42
25-9	Qsg	Sand and gravel	20	23	715	29.5	24
36-4	Qs	Sand	6	--	100	6	17
36-5	Qsg	Sand and gravel	6	24	10	70	.14
45N 12W 22-1	Qs	Sand, coarse	5	--	15	18	.8
26-2	Qsg	Sand and gravel	3	--	14	10	1.4
45N 11W 4-3	Qs	Sand	5	6	5	8	.6
45N 10W 1-3	Or	Dolomite	--	--	170	42	4
1-7	Qg	Gravel	--	6	27.5	80	.35
1-8	Qsg	Sand and gravel	--	.5	300	84	3.6
1-9	Qsg	Do.	--	3	412	4.5	92
1-10	Qsg	Do.	10	--	540	68	8
1-12	Qsg	Do.	16	--	510	40	13
9-6	Or	Dolomite	--	2	10	21	.5
11-1	Qs	Sand, fine	--	--	1	5	.2
13-4	Qs	Sand, coarse	40	6	1,000	28	36
20-1	Qs	Sand, medium	6	5	10	15	.7
45N 8W 14-1	Sc	Dolomite	--	1	17	15	1.1

Table 2. Reported specific capacities of 20 wells in Luce County.