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GEOLOGICAL SURVEY DIVISION

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RECONNAISSANCE OF THE GROUND-WATER
RESOURCES OF DELTA COUNTY, MICHIGAN

by
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*Prepared cooperatively by the
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ABSTRACT

Delta County is on the north shore of Lake Michigan in the south-central part of Michigan's Northern Peninsula. The county is sparsely inhabited, except for the Escanaba-Gladstone area along the west shore of Little Bay de Noc. Large areas of the county are forested.

The county is in the northwestern part of the Michigan basin, where Paleozoic rocks of Ordovician and Silurian age form the bedrock surface. During the Pleistocene epoch, a discontinuous mantle of glacial drift of varying thickness was deposited on the bedrock surface.

Most of the ground-water supplies of Delta County are derived from various bedrock aquifers. Several deep and relatively large-capacity wells tap the sandstones of the Munising and Au Train formations in the western part of the county. About half the wells in the county, however obtain small to moderate supplies at shallow depth from limestone of the Black River and Trenton formations. Shale of the Collingwood formation and the basal members of the Richmond group yield small amounts of highly saline water. Limestone and dolomite of the Richmond group locally are a source of fresh ground water on the Stonington Peninsula and northeastern part of the county. The Cataract formation yields small to moderate supplies of water to wells in the southeastern part of the county, but the water is very hard and has a high sulfate content. On the Garden Peninsula, the Burnt Bluff and Manistique formations are sources of hard to very hard water, which is otherwise of good chemical quality. In many parts of the county, the glacial drift is a source of small supplies. These deposits have considerable potential as a source of moderate to large supplies in the presently undeveloped northeastern part of the county.

Although adequate quantities of ground water are available throughout Delta County, adequate supplies of good quality may be difficult to obtain in various areas. Fresh-water aquifers tapped at depth must be protected from vertical leakage of saline water through uncased wells penetrating shales of the Richmond group and Collingwood formation or saline-water-bearing zones in other aquifers. Pumping from various parts of fresh-water aquifers may result in local changes in ground-water regimen and may cause migration of water of inferior chemical quality from adjacent aquifers. In this manner, water of high sulfate content from the Cataract formation has entered basal members of the Burnt Bluff formation. Lastly, the shallow limestone and dolomite aquifers of Delta County, which are readily recharged through fractures and crevices, are highly susceptible to contamination from surface sources.

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 to determine the general occurrence, availability, quantity, and quality of ground water. Basic ground-water information pertaining to this part of the State is needed for anticipated economic and population growth after completion of the St. Lawrence Seaway and the Mackinac Straits bridge.

This report is the fifth in the series of interim county-reconnaissance reports, and it summarizes the ground-water data obtained in Delta County during the 1958 field season. The first four reports of the series, describing in general the ground-water resources of the eastern part of the Northern Peninsula, have been published by the Michigan Geological Survey and are listed below. Pertinent data from those reports are used freely herein.

Progress report	County	Reference <u>1/</u>
17	Chippewa	Vanlier and Deutsch, 1958a
19	Mackinac	Vanlier and Deutsch, 1958b
21	Luce	Vanlier, 1959
22	Schoolcraft	Sinclair, 1959

1/ See "References Cited", at end of report.

Cooperative ground-water investigations in Michigan by the U. S. Geological Survey are directed jointly by P. E. LaMoreaux, chief of the Ground Water Branch, U. S. Geological Survey, Washington, D. C., and W. L. Daoust, State Geologist, Michigan Geological Survey, Lansing, Michigan, and are 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 Delta County are described in several 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 Leverett (1906), who also described the glacial features of the region and their significance (1929). A reconnaissance of the probable effects on ground-water levels of a Lake Superior-level canal from Munising, in Alger County, to Rapid River was made by the U. S. Geological Survey for the Corps of Engineers in 1949. Some of the data used in this report were collected during that survey, Hussey (1936, 1950, 1954) studied the Ordovician rocks underlying most of the county and Ehlers and Kesling

(1957) described the Silurian rocks of the Garden Peninsula and adjacent areas.

Acknowledgments

Special thanks are given to the residents of Delta County, to the well drillers of the region, particularly C. O. Rice of Escanaba, 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 Michigan Department of Health, who furnished 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 the well within the section. Thus, well 43N 23W 4-1 is well number 1 in section 4, Township 43 North, Range 23 West. The locations of wells to 40-acre tracts within the section are given in table 3. See also figure 13, which shows the distribution of -- and also serves as an index for -- Delta County well records, water-level information, logs, and chemical analyses referred to in the text and listed in tables 3, 4, and 5.

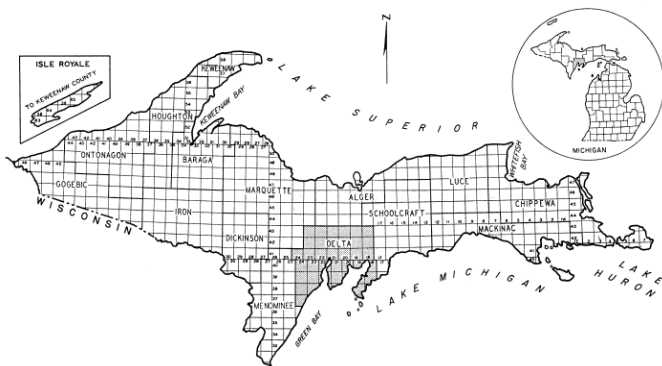


Figure 1. Index map showing location of Delta County, Mich.

GEOGRAPHY

Delta County is in the south-central part of the Northern Peninsula along the north shore of Green Bay (fig. 1). It is bordered on the west by Menominee and Marquette Counties, on the north by Marquette, Alger, and Schoolcraft Counties, and on the east by Schoolcraft County. It has an area of 1,180 square miles and a shoreline along Big Bay de Noc, Little Bay de Noc, and Lake Michigan about 200 miles long. Escanaba, on the west shore of Little Bay de Noc, is the county seat. The county includes a chain of small, uninhabited islands lying between Green Bay and Lake Michigan and extending from the tip of the Garden Peninsula toward

the Door Peninsula of Wisconsin (fig. 2). Two small islands are located in Big Bay de Noc.

Population and Economic Development

The population of Delta County in 1957 was 31,920, about two-thirds of whom reside in the Escanaba-Gladstone area. The city of Escanaba serves as the major center of State Government for the Northern Peninsula. Large areas of the county are sparsely populated.

One large manufacturer of industrial equipment and several smaller metalworking concerns are located in the Escanaba-Gladstone area. The tourist industry is of growing importance to the economy of the county. The remaining industry in Delta County is largely related to the county's natural resources; production of lumber, pulpwood, paper, and other forest products constitutes a major industry. Some of the limestone in Delta County is used for road metal and aggregate (Smith, 1916). Building stone has been quarried from the Manistique dolomite in the vicinity of Fairport. Sand and gravel for construction is produced from glacial deposits throughout the county.

Farms constitute 22 percent of the land area of the county, and most of the farmland is used for the production of dairy products. In 1954 there were about 900 farms in Delta County, most of which were in the western part of the county, but by 1960 the number of farms declined to about 600. The only known irrigator in the county is located on the Garden Peninsula and pumps water from Big Bay de Noc.

Transportation

The county is served by the Chicago and North Western; the Escanaba and Lake Superior; and the Minneapolis, St. Paul and Sault Ste. Marie Railroads (fig. 2).

U. S. Highway 2 links the area with Sault Ste. Marie and Michigan's Southern Peninsula by way of the Mackinac bridge. U. S. 2 and 41 provide access to Michigan's iron- and copper-mining regions and to the North-Central and Northwestern States. These roads, along with State Highway M-35, U. S. Forest Highway 13, and several county roads, provide a network of hard-surfaced roads in the county.

Delta County is served by North Central Airlines through the Escanaba Airport and by interstate bus and truck lines. The harbor at Escanaba is an important shipping point for iron ore and, along with docking facilities at Gladstone and Kipling, receives much of the petroleum, coal, and other products shipped to the area by way of the Great Lakes Waterways and St. Lawrence Seaway.

Physiography and Relief

The shoreline and much of the surface configuration of Delta County result from differences in resistance to erosion of the underlying bedrock formations, as

illustrated by figure 4. The formations crop out in roughly parallel bands trending southwest-northeast and dipping gently to the southeast.

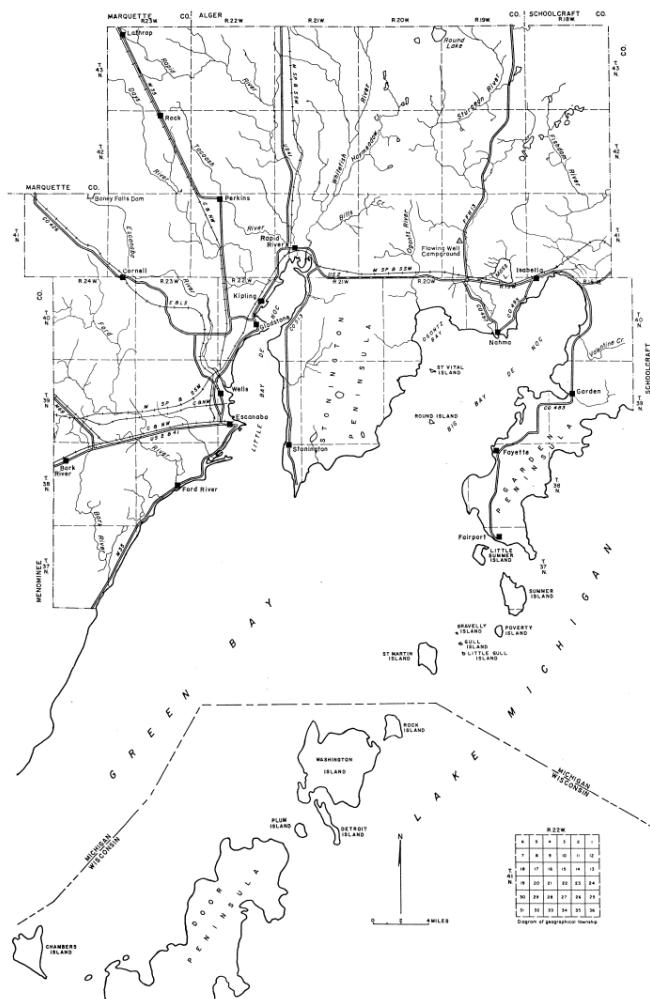


Figure 2. Map of Delta County, Mich.

The bluffs, which form the west shore of Garden Peninsula and outlying islands, are part of the prominent Niagara Escarpment, a major physiographic feature which may be traced across the northern rim of the Michigan basin, from the type locality at Niagara Falls, N. Y., to the Door Peninsula of Wisconsin. The bluffs and islands are composed of hard, resistant limestone and dolomite formations of the Niagara series. The soft gypsum and shaly dolomite members of the Cataract formation, which have been eroded to about 100 feet below lake level, form the trough occupied by Big Bay de Noc. The Stonington Peninsula is formed by a resistant limestone ridge of the Richmond group. The limestones of the Richmond group are underlain by shale, which also has been eroded to about 100 feet below Lake Michigan level and forms the trough occupied by Little Bay de Noc. West of Little Bay de Noc, the limestone and dolomite of the Black River and Trenton formations form the bedrock surface, which rises rather evenly toward the northwest and attains an elevation of 1,000 feet above sea level (420 feet above Lake Michigan) in

the vicinity of Lathrop in the northwest corner of the county.

Delta County was glaciated during the Pleistocene epoch -- a time when many of its physiographic features were formed. In the northeastern part of the county, glacial deposits form highlands and ridges of considerable relief. West of the valley of the Whitefish River, the land surface generally reflects the configuration of the underlying bedrock and is more subdued. Extensive swamps cover much of the lowlands of the county as well as poorly drained areas in the uplands. A large part of the county was covered by the waters of early glacial lakes, as indicated by lake plains, beaches, and sand dunes, which are important physiographic features in some areas.

Drainage

The surface drainage of Delta County is divided into several narrow watersheds all draining to Lake Michigan by way of Big Bay and Little Bay de Noc. Natural drainage in much of the county, however, is in an early stage of development, as indicated by numerous and extensive swamps. The drainage divides in some areas are obscured by low relief and the extensive swamps. In the western part of the county, the streams follow the dip slope of the underlying bedrock, but the Whitefish, Sturgeon, and other rivers to the east flow along old glacial drainageways.

Climate

Delta County receives an average of 29.2 inches of precipitation a year. Temperature ranges and precipitation totals at Escanaba for 5-day periods from July 1958 through December 1959 are shown in figure 9. The annual mean temperature is 41.9°F. Recorded temperature extremes range from -31°F to 100°F. The average date of the last killing frost in the spring is estimated to be May 12, and that of the first killing frost in the fall, October 5.

GEOLOGY

The sedimentary rocks of Paleozoic age including the Jacobsville sandstone of possible Precambrian age that underlie Delta County rest upon Precambrian igneous, metamorphic, and sedimentary rocks and are mantled discontinuously by glacial deposits of Pleistocene age. The areal distribution of the Paleozoic rocks is shown in figure 3 and that of the glacial deposits in figure 5. The lithology and hydrology of the various rock units underlying the county are outlined in table 1 and are described in the section on ground water.

Summary of Geologic History

The Paleozoic rocks that underlie Delta County consist of limestone, dolomite, shale, sandstone, and gypsum. These rocks were deposited in the shallow seas that

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 Mesozoic and most of the Cenozoic eras, the Paleozoic sediments were 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 now largely occupied by 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 during the course of at least four major glacial stages. The glaciers scoured and abraded the surface and transported vast amounts of material plucked from the surface. With melting of the ice sheets, this material was deposited over the eroded Paleozoic rocks.

The glacial features of Delta County resulted largely from the Green Bay lobe of the last of the major continental ice sheets (Wisconsin glacier) that covered the Northern Peninsula. The Green Bay lobe invaded the area now occupied by Delta County along a general north-south axis marked by the valleys of the Au Train (in Alger County) and Whitefish Rivers. During periods of relative stability while the Green Bay lobe was melting, large moraines were deposited in the county along the ice front. Most of the moraines are segments of the Marquette and Sturgeon morainic systems (Martin, 1957), although not enough field work has been done to distinguish between them in Delta County. A portion of the Newberry moraine that extends into Delta County from Schoolcraft County (Sinclair, 1959) probably is correlative with the Sturgeon moraine.

At the close of the Pleistocene epoch, a succession of glacial lakes covered much of Delta County, and at one stage water flowed directly into the Lake Michigan Basin from the Lake Superior Basin along valleys presently occupied by the Au Train and Whitefish Rivers. Uplift of the land which had been depressed by the ice, changed drainage patterns, lake elevations, and shoreline positions (Leverett and Taylor, 1915, and Hough, 1958). The result of these changes was a succession of glacial upper Great Lakes. Lakes Superior, Huron, and Michigan represent the modern stage of this succession. Bars, beaches, wave-cut terraces, and dunes, which are present throughout the county, mark various shorelines of this succession of lakes.

Bedrock Structure

The Precambrian surface upon which the sedimentary rocks of Delta County are deposited slopes generally 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 the center of the Southern Peninsula, and the older formations crop out in roughly concentric bands. Delta County is near the northwest edge of the basin, where the oldest sedimentary rocks are exposed. The regional dip of the formations in Delta County is to the southeast at about 40 feet per mile. The formations tend to become thicker toward the center of the basin.

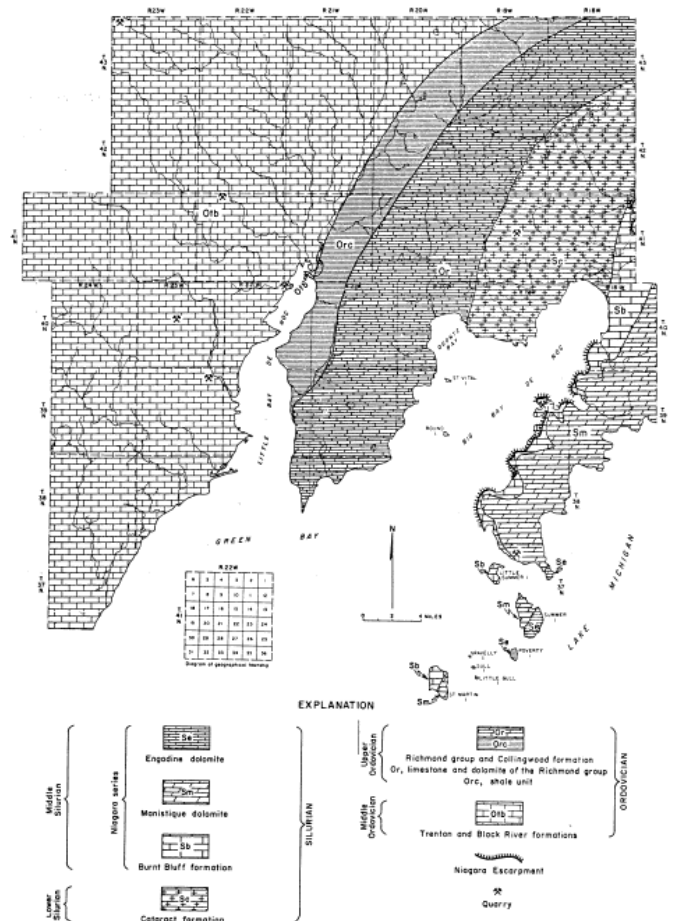


Figure 3. Bedrock geology of Delta County.

Although the structure of the Paleozoic rocks throughout the county has not been studied in detail, Hussey (1950, 1952) described several small east-west-trending anticlines in the Stonington Peninsula.

GROUND WATER

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; its surface is termed the "water table" and may be considered to be 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. Under natural conditions, the water in a well that is finished in an artesian aquifer and is 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. In topographically low areas, wells tapping artesian aquifers may flow at the surface. An artesian aquifer is full of water at all times, even when water is being removed from it, although an artesian aquifer may be dewatered locally by heavy pumping.

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 that present in rocks when they are first formed. Secondary porosity is developed by processes that affect rocks after they are formed. The porosity of unconsolidated deposits is generally greatest where they are well sorted, and least where they are poorly sorted. In consolidated rocks, the extent of fracturing and solutional openings and the degree of cementation and mineral encrustation around primary and secondary openings are generally the most important factors determining porosity.

The capacity of a material to transmit water under pressure is called its permeability. The degree of permeability depends on the size and shape of the openings and the extent to which they are interconnected. The coefficient of permeability (P), as used herein, is reported in meinzers 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. Coefficients of permeability of most important water-bearing materials are greater than 10 meinzers. The permeability of some sand and gravel samples collected in Delta County was as high as 5,000 meinzers (fig. 8).

The ability of the aquifer to yield water to a well is related also to its thickness and extent. A measure of the capacity of a given aquifer to transmit water is called its 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 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 commonly 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. The specific

capacities of 14 wells tapping some of the bedrock aquifers in the county are given in table 2.

The aquifers underlying Delta County consist of a variety of consolidated and unconsolidated rocks. The chief consolidated rock aquifers are composed of strata of sandstone, limestone, or dolomite. In sandstone aquifers, water may move through both primary openings between individual sand grains and secondary openings along fractures and bedding planes. Water in limestone and dolomite aquifers moves predominantly along fractures and bedding planes and other permeable zones developed by weathering and solution.

Shale interbedded with limestone and dolomite commonly is of low permeability and yields very little water to wells. Shale is important, however, as a confining bed in an artesian system and because the contact zones between beds of shale and limestone or dolomite commonly are paths of ground-water movement.

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

Well number	Formation ^{1/}	Lithology	Drawdown (feet)	Rate of discharge (gpm)	Duration of test (hours)	Specific capacity (gpm/ft)
42N 23W 31-1	Otb	Limestone	45	2.5	--	0.06
41N 22W 23-1	Oat	Sandstone	100	165	36	1.65
40N 22W 22-2	Em	do.	180	400	720	2.2
40N 18W 4-3	Sc	Limestone	25	20	1	.8
39N 22W 6-5	Otb	do.	35	8	12	.2
6-7	Otb	do.	5	10	.1	2.0
29-1	Em	Sandstone	100	300	--	3.0
30-2	Em	do.	12	660	--	^{2/} 5.5
30-3	Em	do.	230	560	--	2.4
31-3	Em	do.	160	590	--	3.7
39N 18W 7-6	Sc.	Limestone	5	17	5	3.4
38N 23W 14-1	Otb	do.	21	10	1	.5
16-2	Em	Sandstone	150	42	--	.3
16-2	Em	do.	90	26	--	.3

^{1/} See table 1.

^{2/} Average of several tests.

Table 2. Specific capacities reported for wells in Delta County.

Ground Water in Consolidated Rocks

Precambrian Rocks

Precambrian igneous, metamorphic, and sedimentary rocks underlie all of Delta County but are everywhere mantled by consolidated Paleozoic sedimentary rocks of varying thickness. (See figs. 3 and 4.) The depth to the Precambrian rocks near the village of Rock in the northwestern part of the county was logged at 610 feet in well 43N 23W 35-1 (table 4), but well 41N 19W 20-1, at the Flowing Well Campground in the eastern part of the county, drilled to a depth of 1,160 feet, failed to reach the Precambrian rocks. There is little doubt, however, that the total range in depth to these rocks in Delta County is greater than indicated by the above information.

The composition of these rocks is known only at a few scattered areas where test holes for iron ore have been drilled. Future development of Precambrian rocks in the county as a source of water is unlikely because of their depth and probable low permeability and because they lie beneath two relatively permeable sandstone formations.

Jacobsville Sandstone of Precambrian or Cambrian Age

The Jacobsville sandstone is a red and white quartzose sandstone, which overlies the Precambrian rocks along the south shore of Lake Superior. Although the Jacobsville sandstone attains a thickness of more than 1,000 feet in Alger County, it thins rapidly to the south and has not been identified in any wells in Delta County. Hamblin (1958, fig. 2) shows the formation pinching out along the northern boundary of the county. Hence, the Jacobsville sandstone cannot be an important potential source of water in Delta County, although it is tapped as a source of supply in Alger and Marquette Counties.

Munising Sandstone of Late Cambrian Age and Au Train Formation of Early and Middle Ordovician Age

The Munising sandstone and Au Train formation form extensive aquifers and are potential sources of fresh water throughout Delta County. Because they have similar lithologic characteristics and in some areas may be hydraulically connected, and because subsurface data necessary to distinguish between them is sparse, they are treated herein as a single aquifer. The Munising is composed of fine- to medium-grained white to gray sandstone and includes some lenses of shale and siltstone. The sandstone commonly is cemented with silica. The Munising ranges in thickness from 50 to 200 feet in the county.

A 300-foot sequence of thin- to medium-bedded sandy dolomite and dolomitic sandstone with lenses of quartz sand overlies the Munising sandstone. Van Hise and Bayley (1900) proposed the term "Hermansville" for this

sequence of rocks. More recently, Hamblin (1958, p. 115) suggested that this term be abandoned and replaced by the term "Au Train", as the thickest sections and best exposures known are at Au Train Falls in Alger County and because no type section for the "Hermansville" was given by Van Hise and Bayley. The name Au Train formation is therefore accepted for use in this and subsequent reports of this series of studies and hence supersedes the term "Hermansville" used in previous reports of the series.

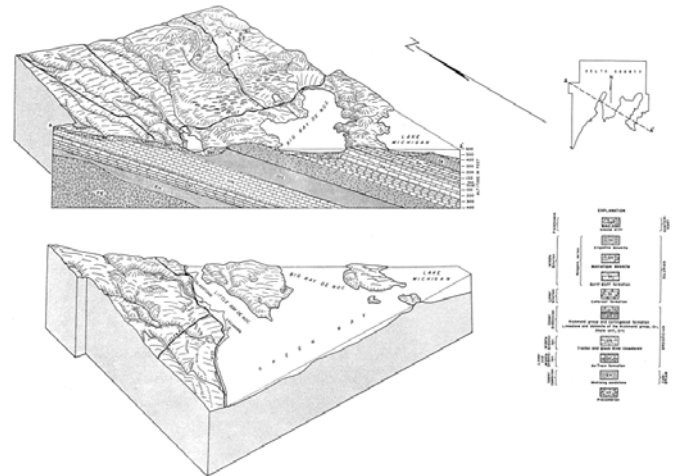


Figure 4. Split-block diagram of Delta County showing major physiographic features and a generalized geologic section.

The Munising and Au Train formations crop out in adjacent areas of Alger and Marquette Counties, at elevations of about 1,000 feet above sea level, but dip beneath the younger consolidated rocks in Delta County. In the Escanaba-Gladstone area, the top of the Au Train formation is about 275 feet below the level of Lake Michigan. Water in this aquifer is confined by overlying beds of dense dolomite and shale of the Black River limestone. In many parts of the county, wells tapping the sandstone flow at the surface, and yields as great as 250 gpm (gallons per minute) have been reported (table 3). The sandstone beds of both the Munising and the Au Train formations yield most of the water produced from this aquifer. However, fractures and solution openings in the dolomite beds of the Au Train may yield some water.

These formations are tapped by more than 60 wells in Delta County. Most are privately owned domestic wells in the western part of the county. Several public and industrial wells also tap this aquifer. The city of Escanaba obtained its main source of supply from this aquifer during and after World War II. Later, however, the city abandoned its ground-water supply system, because of inadequate yields, hardness, high iron content, and civil actions against the city by owners of wells finished in the Au Train formation at depths of 325 to 350 feet.

Black River and Trenton Limestones of Middle Ordovician Age

The Black River and Trenton formations overlie the Au Train formation and form the bedrock surface in Delta County west of Little Bay de Noc and the valley of the Whitefish River (fig. 3). These formations have been described in detail by Hussey (1936, 1950, 1952). Hussey differentiated between the Black River and the overlying Trenton limestone primarily on fossil evidence. However, the lithologic and hydrologic characteristics of the two formations are so similar that in this report no distinction is made between them.

The Black River and Trenton formations are composed of thin, irregular beds of gray to buff limestone and dolomite interbedded with thin layers and lenses of shale. The thickness of these rocks in Delta County ranges from 150 to 300 feet. Where the entire section is present (overlain by younger formations), it is about 300 feet.

These formations are the chief sources of water in the western part of the county, where the water is commonly obtained at moderate depth. A few wells in the eastern part of the county tap the Black River and Trenton limestones at depth, although most wells in this area tap overlying aquifers. The water moves almost exclusively in openings along bedding planes and joints or other fractures. These secondary openings have been enlarged through solutional activity of percolating ground water.

The specific capacity of wells tapping the Black River and Trenton formations is generally low (table 2), and, although the many wells tapping this aquifer are adequate for domestic and farm needs, in most places the rocks would not yield an adequate supply for large industrial users or irrigators.

Collingwood Formation and Richmond Group of Late Ordovician Age

Shale unit. A sequence of shale strata including the Collingwood formation and the basal members of the Richmond group overlies the Trenton rocks in the eastern half of Delta County. Where exposed, in the banks of Bills Creek and Haymeadow Creek and in the cliff that forms the east shore of Little Bay de Noc near Stonington, the shale is thinly bedded, fissile, and generally soft, although the sequence contains a few beds of hard shale as thick as 6 inches. The color varies from light gray to dark brown on fresh surfaces, which weather to a light blue. In many places the shale grades into a dark-brown limestone, which is moderately hard, coarsely crystalline, and, in some places, very fossiliferous. The thickness of the shale unit varies greatly; sections of 135 and 300 feet have been reported (wells 41N 19W 20-1 and 39N 21W 29-1, table 4).

The shale beds are of low permeability, and the water contained in them is of poor quality. The yield of well 39N 22W 36-1 near Stonington, drilled to a depth of 300

feet and completed in the shale unit, was so small that the well was never used. It is unlikely that the shale unit is a potential source of fresh ground water at any place in Delta County.

Limestone and dolomite of the Richmond group. The upper 300 feet of the Richmond group is composed of numerous thin layers of shaly limestone and dolomite interbedded with thin layers of shale. A few of the limestone beds are massive, hard, and cherty. (Hussey, 1926, 1950). The beds range in color from light gray to dark brown, although many of the rocks turn bluish gray upon weathering. These rocks lie at or near the surface throughout most of the Stonington Peninsula, and form the bedrock surface in a band 6 to 8 miles wide that extends through the northeast corner of the county (fig. 3).

The permeability of these rocks is low compared to that of other beds of limestone and dolomite in the county. This is due in part to the numerous shale layers, which impede the movement of ground water. Secondary openings along bedding planes and joints or other fractures are not well developed in the soft shaly limestone and dolomite, as these rocks are not sufficiently competent to support such openings. Some water, however, does move through secondary openings in the few hard massive limestone and dolomite beds in this rock sequence.

Several dozen wells in the Stonington Peninsula and a few scattered wells to the northeast (table 3) obtain small supplies of water from the limestone and dolomite in the Richmond group. About half of these are dug wells of large diameter. Because of the low permeability, ground water in this aquifer moves into wells very slowly. Large dug wells may yield adequate supplies from such an aquifer because of their relatively great entrance areas and storage capacities. The Michigan Department of Health (Faust, 1937, p. 13), however, discourages the use of dug wells, primarily because they are especially susceptible to contamination from surface sources.

Cataract Formation of Early Silurian Age

The Cataract formation is composed of three members. The basal dolomite is gray to buff gray, massive to thinly bedded, and cherty in the upper part. It is overlain by a gray shale, which contains many thin beds of gypsum and dolomite. The upper member is a gray and buff cherty dolomite interbedded with layers of gypsum and shale (Ehlers and Kesling, 1957, p. 6). The Cataract formation is about 250 feet thick in eastern Delta County.

The basal dolomite probably does not crop out in the county. The shale is at or near the surface in the sandy plains north of Moss Lake. The upper dolomite member is at or near the surface in the area between Isabella and Nahma and forms the bluff along the east side of Moss Lake. The rocks of the Cataract formation dip gently toward the southeast beneath the rocks of the

Niagara series near the western shore of the Garden Peninsula.

Many of the wells near the northern end of Big Bay de Noc in the Nahma-Isabella area obtain water from the Cataract formation. The Cataract is permeable as a result of solution openings formed by leaching of the gypsum beds. The soluble gypsum in the formation is the source of calcium and sulfate, which commonly reach objectionable concentrations in water taken from the formation. (See "Quality of Water".)

Niagara Series of Middle Silurian Age

Rocks of the Niagara series form the prominent cliffs that line the western shore of the Garden Peninsula and form the bedrock surface throughout the Garden Peninsula and adjacent islands. The glacial drift in much of this area is thin and discontinuous.

The rocks of the Niagara series are predominantly hard, resistant limestones and dolomites. Wells drilled into them obtain water from permeable zones formed largely by solution and weathering at the surface and by solution activity of percolating ground water at depth. Solution probably was greatest along beds of limestone, which is more soluble than dolomite. Not all beds of limestone, however, have been made permeable by solution activity. Development of solution openings in some strata probably was blocked by the initial impermeability of the bed or by restriction of ground-water flow by 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 a permeable zone in these formations does not increase significantly until the next permeable zone is reached. This contrasts with the yield of a well tapping permeable glacial drift, which increases roughly with the amount of the formation penetrated.

Burnt Bluff formation. The Burnt Bluff formation is composed of about 250 feet of thinly bedded to massive light-gray to buff calcitic dolomite. More than 200 feet of these rocks is exposed in the cliffs at various places along the east shore of Big Bay de Noc. The formation is present in Delta County only in the Garden Peninsula and offshore islands and in a small area northeast of the head of Big Bay de Noc.

Generally, moderate supplies of fresh water can be obtained from this formation, and locally it will yield large water supplies. Most of the drilled wells on the Garden Peninsula tap the Burnt Bluff formation. Records available from the early 1900s indicate that artesian pressures in this aquifer were sufficiently high to produce flows above the land surface from wells along the shore of the bay. Data in table 4, however, indicate that the artesian pressure has declined considerably since that time.

Well 39N 18W 17-1, owned by the village of Garden, penetrated the Burnt Bluff formation and was completed

in the underlying Cataract formation. The water obtained from this well is a mixture of water from both formations. As the quality of water from the Burnt Bluff formation is far superior to that from the Cataract, precautions should be taken to avoid complete penetration of the Burnt Bluff when drilling for water, (See "Quality of Water".)

Manistique dolomite. The Manistique dolomite is a thin-bedded to massive light-buff to brown or gray cherty dolomite. In Delta County it is present only on the Garden Peninsula and offshore islands. The formation is thickest (possibly as much as 150 feet) on the extreme south tip of the Garden Peninsula and on Summer Island, where it is overlain by the Engadine dolomite. On the west edge of the Garden Peninsula, all but a thin remnant of the formation has been removed by erosion. This remnant lies above the regional water table. The Manistique dolomite is of significant thickness and of potential importance as an aquifer only in the presently undeveloped areas along the Lake Michigan side of the peninsula. Hence, the formation is a source of supply for only a few wells in the county. These wells tap the relatively large interconnected secondary openings that are characteristic of the formation from Delta County to Mackinac County.

Engadine dolomite. The Engadine is a massive hard bluish-white dolomite and is an extensive and important aquifer in the eastern part of the Northern Peninsula. In Delta County, however, only a thin remnant of the basal part of the formation is present on the southeast tip of Garden Peninsula, Poverty Island, and part of Summer Island. No wells in the county are known to tap the Engadine. It has little potential for development as an aquifer in Delta County, because it is thin and small in areal extent.

Ground Water in Unconsolidated Sediments

The mantle of unconsolidated rock material that covers much of Delta County (fig. 5) was deposited by the Green Bay lobe of the Wisconsin ice sheet, which pushed down the valleys now occupied by the Au Train and Whitefish Rivers during the Pleistocene epoch. This material was plucked from the surface by moving ice and redeposited as till, outwash, glacial-lake sediments, and dunes. These deposits are differentiated on the basis of their mode of deposition. Till is generally unstratified drift that was deposited directly from the ice, with water playing a minimum part in the process. Outwash is stratified rock material deposited by meltwater draining from the glacier. Glacial-lake sediments are stratified fine-grained materials laid down in glacial lakes. Dunes are composed of well-sorted sand deposited by wind. Most of the dunes in Delta County are associated with the glacial epoch. The general term used to describe all these unconsolidated sediments is glacial drift.

The physical and, hence, hydraulic characteristics of the drift deposits vary also with the type of material from which the drift was derived. The sandy drift, which is

predominant in the southeastern part of the county, was derived mainly from the Cambrian and Ordovician sandstone formations and to a lesser extent from the Precambrian igneous rock in the Lake Superior region.

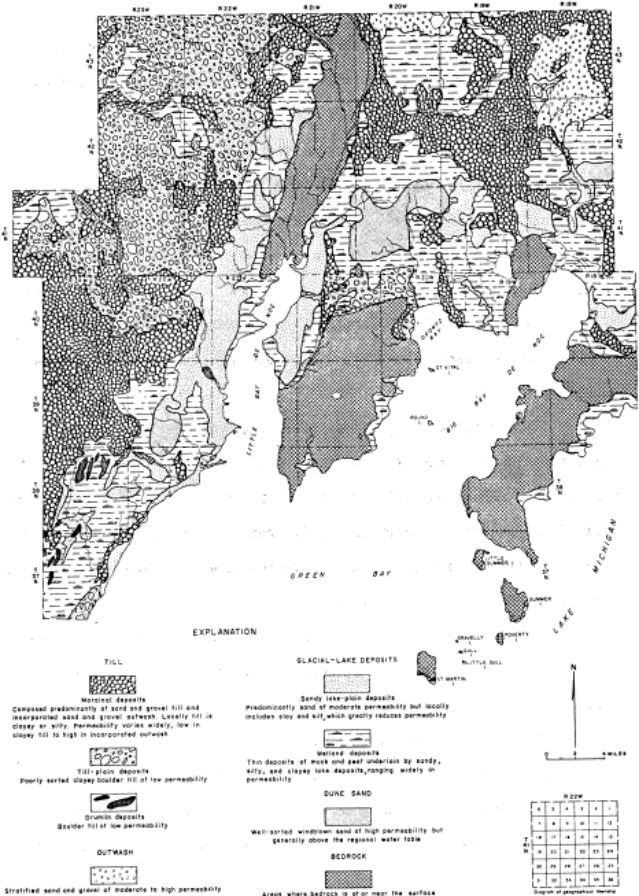


Figure 5. Surface geology of Delta County.

Clayey drift deposits, such as the clayey till in the western part of the county, were derived largely from the Ordovician limestone, dolomite, and shale formations described above and perhaps from clay deposits in the Lake Superior Basin.

The permeability of the drift deposits varies with the size of the 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 and gravelly till that contains only minor amounts of clay and silt is generally of moderate permeability. Clayey till, however, is of low permeability. Dune sand and lake-deposited sand, which are well sorted although relatively fine-grained, also are of moderate permeability. Lake-deposited silt and clay or silty, clayey sand is generally of low permeability.

The drift mantle of Delta County varies greatly in thickness, as shown in figure 6. The glacial drift is thickest in the northeastern part of the county and in an area west of Little Bay de Noc; in at least one place, it is more than 200 feet thick. In the western part of the

county and in the Stonington and Garden Peninsulas, the drift is generally thin or discontinuous.

Figure 7, which shows the generalized configuration of the bedrock surface, was constructed largely from well records and bedrock-outcrop data and calculated on the basis of preliminary topographic sheets available at the time of the field study. Figures 6 and 7 indicate preglacial valleys in the bedrock surface extending northeastward from Big Bay de Noc and Little Bay de Noc, both of which probably represent submerged extensions of these bedrock valleys. Parts of these valleys are buried under 100 to 200 feet of glacial sediments.

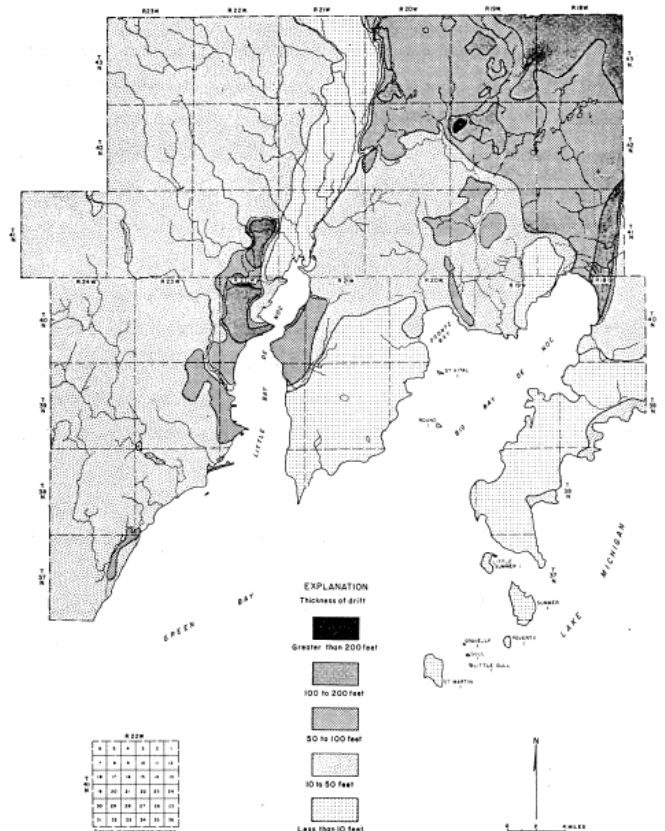


Figure 6. Generalized isopach map showing thickness of the glacial drift in Delta County.

Till

About half of Delta County is underlain by deposits of till. On figure 5, these deposits underlie areas mapped as till plains, moraines, and drumlins, which are distinguished basically by physiographic differences rather than by differences in lithology or water-bearing characteristics. Till plains (also called "ground moraines" on some maps) are areas of relatively low relief having gently rolling surfaces that are underlain by till deposited during relatively warm intervals in the glacial stages, when the ice front was wasting back toward its source. Moraines are ridges composed predominantly of till. Till plains commonly lie adjacent to and between the moraines, which were built up by deposition during temporary halts in the recession of the ice. Drumlins are elongated,

streamlined deposits of till probably deposited beneath outer parts of moving ice sheets. The moving ice probably eroded the deposits to their typical shapes and was responsible for their marked parallel orientation.

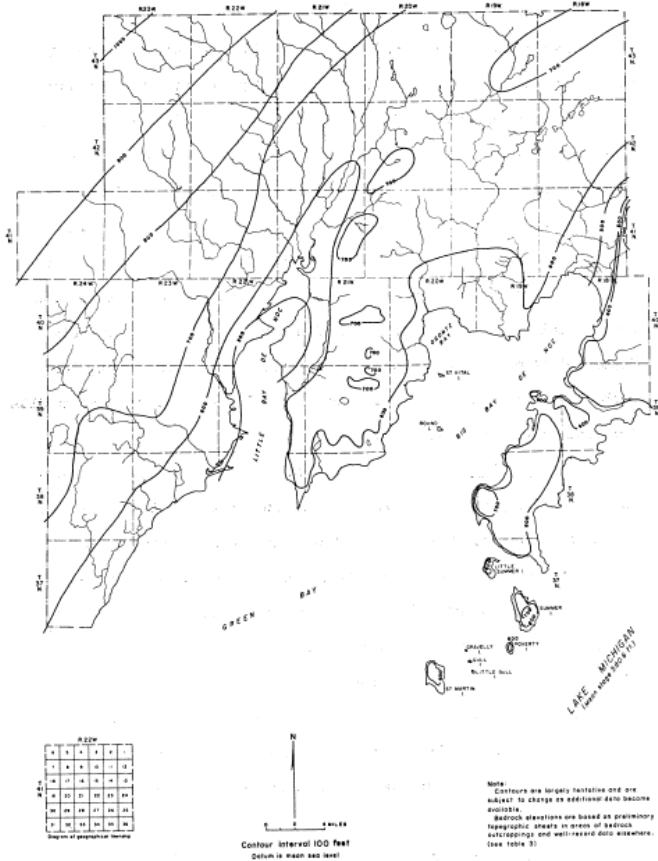


Figure 7. Map showing generalized contours on the bedrock surface of Delta County.

Till plains. The northwestern part of the county is underlain by a till plain (fig. 5), which extends northward into Alger and Marquette Counties. The low relief of this plain is interrupted in many places by hills and ridges formed by the underlying Trenton and Black River formations. These rocks lie at relatively shallow depth (fig. 6) throughout nearly all the area of the till plain. Another till plain lies at the north end of the Stonington Peninsula. Till deposits are present elsewhere in Delta County, especially on the Stonington and Garden Peninsulas, but these deposits are discontinuous or form only a veneer over the bedrock surface; hence, they are not shown on figure 5. Because the deposits underlying the till plains in Delta County are generally thin and of low permeability, they will not yield supplies of water adequate for most uses.

Three samples of till-plain deposits were collected in Delta County for analysis of permeability and particle-size distribution by the Hydrologic Laboratory of the U. S. Geological Survey at Denver. The analyses (De 1, 2, and 3, fig. 8) show that the sorting of the till-plain deposits is generally poor and the permeability is low. Sample De 1 was composed of almost 80 percent of clay and silt by weight and had a permeability of 4

meinzers. Sample De 2 contained nearly 50 percent sand and gravel particles by weight and had a lower permeability (0.2 meinzers) than sample De 1, which contained less clay and was better sorted in the silt-size range. The permeability of sample De 3 was not determined in the laboratory, but probably was higher than that of samples De 1 and 2, because of its lower clay and silt content and better sorting in the fine- and medium-sand range.

Drumlins. Several drumlins composed of glacial till are present in the southwestern part of the county, in Tps. 37 and 38 N., R. 24 W. The till is very similar in composition to the till-plain deposits described above. Sample De 4 (fig. 8) was almost identical in clay and silt content to sample De 3 but had a somewhat higher content of larger sized particles. The permeability of this sample was determined as 17 meinzers. Because of the generally low permeability of the drumlin till, the drumlins are not a potentially important source of ground water.

Moraines. Moraines are ridges composed predominantly of glacial till deposited along the relatively static front of a glacier. Commonly they include, and are associated with, deposits of stratified outwash. The distribution of the moraines in Delta County is shown in figure 5. One large moraine trends southward along the western part of the county from near the city of Marquette in Marquette County to the vicinity of the village of Ford River. This moraine consists of numerous low hills and ridges composed of a characteristically red till. Samples De 6 and 7 (fig. 8) indicate that till from this moraine contains a larger percentage of coarse materials by weight and is considerably more permeable than the adjacent till-plain deposits. The relatively high permeability of sample De 7 does not indicate that the moraine in the vicinity of the sampling point is a source of large quantities of water, as morainal deposits in the western part of the county are considerably thinner than those in the eastern part. Most wells drilled in the areas mapped as moraine in the western part of the county tap the underlying Trenton and Black River formations. A few domestic supplies of water are obtained from these morainal deposits by dug wells of large diameter.

In the northeastern part of the county, several large discontinuous moraines extend from the Alger and Schoolcraft County lines along the Sturgeon and Whitefish Rivers to the shore of Ogontz Bay, west of Nahma. The portion of the moraine along the Sturgeon River is a continuation of the Newberry moraine of Schoolcraft and Alger Counties described by Bergquist (1936, p. 69-75). The portion along the Whitefish River appears to be a continuation of the Munising moraine, also described by Bergquist (p. 79-80). In the northeastern part of the county, the moraine is characterized by rugged relief and deep pot-hole lakes. The topography of the southern part of the moraine is much more subdued, as a result of wave erosion by the succession of glacial Great Lakes. The composition of this moraine is predominantly sand and gravel, although

some clay is present. Sample De 8 contained less than 5 percent of clay and silt by weight and 85 percent of gravel- and boulder-sized particles. The clay content, however, generally increases toward the south. In one area, the drift deposits underlying this moraine are 200 feet thick or more (fig. 6). The morainal deposits in this area may yield moderate quantities of water to wells, although there are local variations in composition and permeability. A few domestic wells obtain small supplies of water from these deposits, but for the most part the area is very sparsely populated and generally undeveloped. The water table is controlled by the level of the surrounding lakes and streams, and much of the morainal till lies above the regional water table.

A segment of a moraine in T. 41 N., R. 18 W., is an extension of the Cooks moraine, most of which lies in Schoolcraft County (Bergquist, 1936, p. 68-69). This moraine ranges in composition from a clayey till to a boulder till, although it is composed predominantly of a silty sand. As much as 200 feet of drift underlies the moraine along the trace of a bedrock valley extending northward from Little Bay de Noc. Moderate quantities of water, sufficient for domestic use, may be available to wells that are properly constructed to screen out the silt and fine sand.

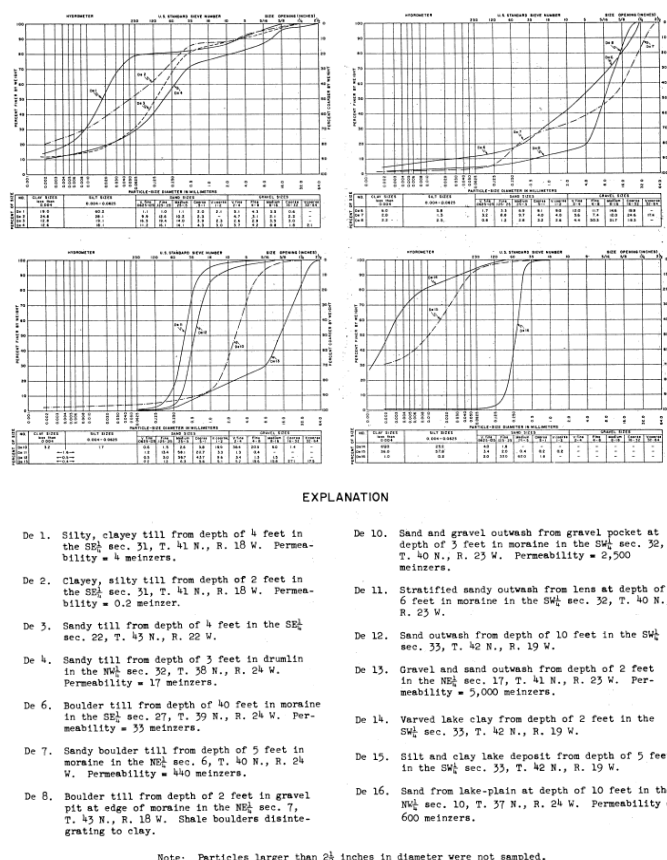


Figure 8. Particle-size-distribution curves of glacial-drift samples from Delta County.

Outwash

Large deposits of outwash sand and gravel occur in the northeastern part of the county (fig. 5). Smaller outwash deposits are present in many parts of the county, especially along the flanks of the moraines. Lenses of outwash are included within morainal deposits or are buried under swamp and lake sediments. Detailed field mapping necessary to delineate these smaller outwash deposits accurately was beyond the scope of the present reconnaissance; hence, only the large areas underlain by outwash deposits in the northeastern part of the county are shown on figure 4.

The outwash deposits are the most permeable of the glacial-drift deposits of Delta County, as they contain little or now clay and silt and are well sorted (fig. 8). Sample De 11 contained 58 percent of medium sand by weight, and sample De contained 90 percent of medium to very coarse sand. Samples De 10 and 13 had permeabilities of 2,500 and 5,000 meinzers, respectively.

Glacial-Lake Deposits

Large areas in Delta County are underlain by sand, silt, and clay deposited in the glacial Great Lakes. For the most part, the surficial lake sediments are composed of sand, and hence the lake-plain areas shown on figure 5 are mapped as "sandy lake plain". Over large areas of the county, the lake deposits are saturated with water and are covered by a thin mantle of swamp deposits.

Permeability is controlled by the size and degree of sorting of the component particles and is affected greatly by relatively small percentages of silt or clay. Samples De 14 and 15 (fig. 8), collected from the sandy lake plain north of Big Bay de Noc contained 69 and 36 percent clay, and 25 and 58 percent silt, respectively, and undoubtedly were of very low permeability. In general, however, the lake deposits are sandy and are sources of supply for domestic wells in various places throughout the county. Most of the wells tapping the lake sand are shallow, small-diameter driven wells equipped with sand points.

A sand sample collected from a swamp-covered lake plain in sec. 10, T. 37 N., R. 24 W., had a permeability of 600 meinzers (sample De 16, fig. 8). The sample was extremely well sorted, consisting of 95 percent of fine- and medium-sized sand grains. It appears that the deposit from which the sample was taken was originally a dune, but was subsequently submerged in the waters of the glacial Great Lakes.

Dune Sand

Areas of windblown sand are prevalent in the county. Although very permeable, these deposits are above the water table in most areas, and thus cannot be considered as a source of water to wells. However, because of high infiltration capacities, they are important

as avenues of ground-water recharge to areas they occupy.

Source and Recharge Areas

The initial source of all fresh ground water in the aquifers of Delta County is precipitation, and the average annual precipitation over the county is 29.2 inches. Most of the precipitation, however, does not enter the ground-water reservoirs but is dissipated by evaporation, transpiration, and direct runoff into streams.

The amount of precipitation that does enter the ground-water reservoirs is influenced by several 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 parts of the county that are underlain by permeable glacial sediments (fig. 5) and in large areas of the county where permeable limestone and dolomite at or near the surface have large infiltration capacities. Some areas of the county are underlain by clayey glacial sediments, which impede infiltration of precipitation into the ground-water reservoirs. Infiltration is retarded also in areas where shale or shaly limestone or dolomite is at or near the surface, such as in the Stonington Peninsula.

Movement of Ground Water

The movement of water underground is similar to movement in surface streams, by gravity from high to low levels. Percolation of water through and around 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 differ greatly, 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 -- appear as seeps or springs, join the flow of streams, enter lakes, or escape -- to the atmosphere by evaporation and transpiration. Where undisturbed by manmade diversions, the water table conforms generally to the configuration of the overlying land surface and exactly to the piezometric 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 may migrate from an aquifer of high head, to one of lower head.

Discharge of Ground Water

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 and associated bays.

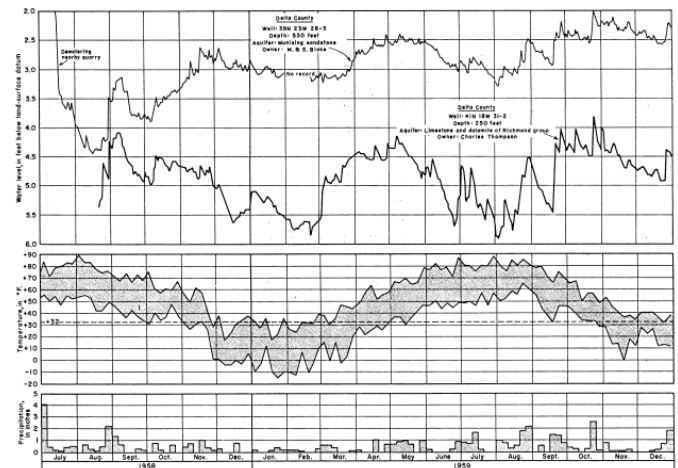


Figure 9. Hydrographs of wells 41N 18W 31-2 and 39N 23W 28-3, 5-day temperature ranges, and 5-day precipitation totals at Escanaba, 1958-59.

Water-Level Fluctuations

Effects of Climate

Although long-term records of changes in water levels in wells in Delta County are not available, the relation between levels and the influences of climate for the short period of record is shown in figures 9 and 10. According to available data, ground-water levels in Delta County fluctuate with seasonal changes in the rate of recharge to and discharge from the aquifers. During the spring, water from snow-melt and rainfall infiltrates into the ground, and water levels in wells rise. This infiltration to the aquifers is reduced by greatly increased evapotranspiration during the warm weather and the growing season. Water levels, therefore, usually decline throughout the summer and early fall. The end of the growing season in the fall combined with precipitation greater than is needed to satisfy soil-moisture requirements may result in some recharge to the aquifers. Below-freezing temperatures in late fall and in the winter preclude any further appreciable recharge, as the ground is frozen and precipitation is in the form of snow.

Figure 9 shows the fluctuations of water levels in two wells along with records of precipitation and temperature at Escanaba. The fluctuations of water levels in well 39N 23W 28-3, finished in the sandstone, are not as large as those in well 41N 18W 31-2, finished in the limestone and dolomite, owing to the greater storage capacity of the sandstone. The limestone is dense, and storage is confined largely to cracks, crevices, and fissures, whereas water in the sandstone is stored in both primary and secondary openings. Heavy rains in late August and early September of 1958 caused water

levels to rise sharply in both wells. During the fall, water levels in the Thompson well declined, but those in the Blake well rose because of recovery after dewatering of a nearby quarry. (See "Effects of Discharging Wells.") Water stages in both wells declined until early March 1959, when above-freezing daytime temperatures resulted in recharge to the aquifers from the melting of about 5 inches of the snow cover. The rising trend continued, as the remainder of the snow cover melted during March. The seasonal decline that began in May was frequently interrupted by heavy rainfall and was reversed in August after the first of about 15 inches of precipitation that was received in the period August through October. Seasonal declines resumed in November, but these were temporarily halted by recharge from more than half an inch of rainfall during a brief thaw late in December.

Infrequent measurements of water level in two shallow wells in the limestone and dolomite of the Richmond group (fig. 10) show markedly sharper fluctuations in water level, but in general the levels in these wells react to the same climatic factors. (See well 41N 18W 31-2, fig. 9.)

The fluctuations of water level in well 42N 18W 17-2 (fig. 10), finished in the glacial drift, are typical of fluctuations in other wells finished in drift aquifers in the Northern Peninsula, which respond primarily to climatic conditions. Heavy precipitation in the late summer and fall of 1959 resulted in unseasonal rises of water level in the well.

In well 43N 19W 24-3, finished in the Trenton and Black River formations, the fluctuations of water level are similar to but smaller than those in the drift aquifer. The water-level record for this well was derived from a continuous recording gage until October, 1959, when monthly measurements were begun.

Effects of Pumping

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. However, 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 pumped well. Continued discharge expands the cone until the resultant decline 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 an aquifer exceeds the recharge, the water level will continue to decline.

A decline of the piezometric surface always results from the discharge of water from a well. Where several wells are pumped or allowed to flow, a composite cone of depression is formed, which may extend over a large

area. Water levels in other wells within this cone of depression are thus lowered. This is illustrated by the hydrograph of observation well 39N 23W 28-3 (fig. 9), which was affected by dewatering operations in a nearby quarry in July and August 1958. The dewatering was the same in effect, as pumping a well of very large diameter. The water level in the observation well recovered during October and November of that year, although this was a period of normal decline of water levels, as illustrated in the hydrograph of well 41N 18W 31-2. Whereas a decline of the piezometric surface always results from the development of an aquifer, an unnecessary decline of the piezometric surface is caused by the waste of water, as from unrestricted flowing wells or by underground leakage from poorly constructed wells or deteriorated well casings. Such waste may cause wells to cease flowing, decrease yields, and increase the cost of pumping water.

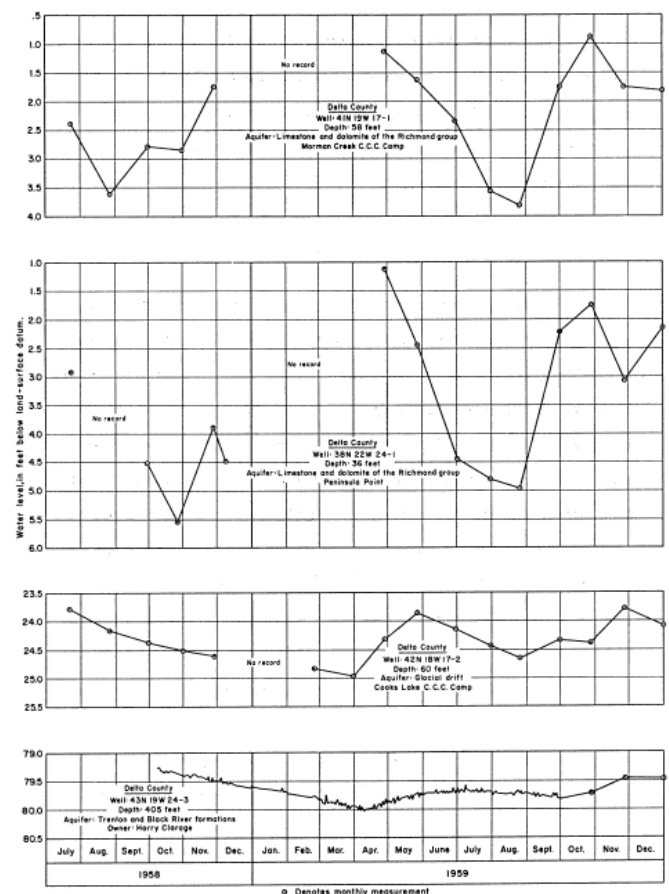


Figure 10. Hydrographs of observation wells in Delta County, 1958-59.

Use of Ground Water

The cities of Escanaba and Gladstone obtain their municipal water supplies from Little Bay de Noc. The village of Nahma obtains its supply from Big Bay de Noc. Ground water is used for the municipal supply in the villages of Ford River and Gardena. The rest of the county is supplied by privately owned wells or springs.

Stock and domestic use, including the use by the tourist industry, accounts for most of the ground water used in the county. Only a small amount of the water is used by industry. Although large untapped supplies of ground water are available in many areas of Delta County, the most populated and developed areas are located where large ground-water supplies for municipal and industrial use are not readily available.

QUALITY OF WATER

Ground Water

The minerals 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 such factors 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 ppm (parts per million) of dissolved mineral matter is herein considered saline regardless of its composition.

The hardness of waters sampled in the county is listed in table 5. 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 ground water.

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

<u>Class</u>	<u>Hardness</u> <u>(parts per million)</u>
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.

The remainder of the chemical analyses of ground-water samples collected in Delta County also are given in table 5. Geo-chemical interpretation of these analyses is aided by the diagrams on figure 11. These are drawn by plotting the concentrations of six key ions, in equivalents per million (epm), and connecting the points plotted according to a technique devised by Stiff (1951). The diagrams are plotted on a diminishing scale in order to confine those of the highly mineralized samples to a reasonable size. Differences in water of various chemical types are apparent by comparison of the shape of the diagrams. The size of the diagram indicates the

concentration of the chief minerals in the sample, although differences between samples are not as readily apparent as they would be if the diagrams would be plotted to an arithmetic scale such as is used in figure 12. Diagrams of this type are useful in determining the source of; the sampled water, the general chemical character of the aquifer, and variations in chemical composition of water within a given aquifer. They may be used also to detect interformational leakage or movement of water from one aquifer to another through uncased wells.

The Munising sandstone may contain water of good quality throughout the county, although much additional geochemical information is needed to determine whether the downdip portions of the formation contain saline water. Well 40N 22W 21-3 is cased through overlying formations and probably draws water only from the Munising sandstone. The diagram of a water sample collected from this well (fig. 11) shows that water from the Munising sandstone is of the calcium magnesium bicarbonate type. Analyses of samples of water from uncased wells that also tap the Munising sandstone (table 5) show higher mineral content, probably due to admixtures of water from overlying aquifers.

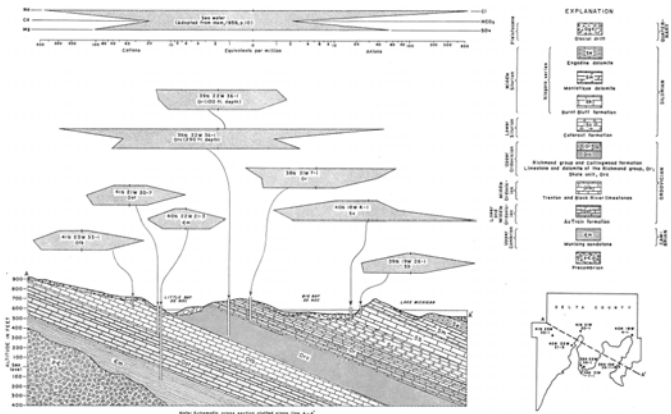


Figure 11. Diagrams showing typical chemical composition of water from the major bedrock aquifers of Delta County.

The Au Train formation yields water similar in composition to that from the Munising, although water taken from the more dolomitic parts of the Au Train tend to be somewhat harder and are higher in calcium, magnesium and bicarbonate content.

Most of the water from the Black River and Trenton limestones is of the calcium magnesium bicarbonate type and generally is suitable for most uses. Locally, however, these formations contain water high in chloride content (well 41N 21W 6-1, table 5). Data adequate to delineate the vertical and lateral distribution and to determine the origin of chloride water within the Black River and Trenton limestones are not available. The differences in chemical composition of water within these formations is illustrated by the analyses of water from wells 40N 23W 32-1 and 32-2. These wells are within 200 feet of each other, but well 32-1 is 13 feet deeper (table 3) and yields water containing almost 25 times as much chloride as the water from well 32-2 (table 5).

A sample of water obtained from well 42N 23W 3-1 at Rock on October 21, 1958, had a calcium and chloride content of 224 and 190 ppm, as compared to concentrations of 1,440 and 2,500 ppm of the same ions in a sample taken on December 12, 1958. An investigation of the site was made by the Escanaba office of the Michigan Geological Survey. It was found that the Delta County Road Commission maintained a stockpile of sand treated with calcium chloride for spreading on roads during the winter. Occasionally, a part of this sand is used to fill in low spots or puddles in the parking and driving area around the garage in the spring or summer. It was concluded that calcium chloride was leached from the sand and carried into the aquifer by rainfall. Complaints by homeowners in the vicinity suggest that contamination has migrated for a considerable distance through the aquifer.

Shale of the Collingwood formation and Richmond group may yield water that is partly connate in origin, as is indicated by a comparison of present-day sea water (from a depth of 100 feet) and the sample from a depth of 290 feet in well 39N 22W 36-1 (fig. 11). Saline water from the shale may contaminate water drawn from uncased wells tapping deeper fresh-water aquifers. The shale may have been the source of most of the sodium and chloride in water samples from wells 39N 21W 29-1 and 30-1 (table 5), which tap the Au Train and Munising formations, respectively.

Water from the limestone and dolomite of the Richmond group varies greatly in chemical composition. Some wells yield potable water of the calcium magnesium bicarbonate type; others yield water high in sodium and chloride, possibly partly connate in origin. A few wells yield water high in calcium and sulfate, probably leached from gypsum in the formation. A single well may yield water that is a mixture of all the above types, as illustrated by the diagram of the sample collected at a depth of 100 feet in well 39N 22W 36-1 (fig. 11). Sufficient data are not available to delineate sources of sodium chloride or calcium sulfate waters within the limestone and dolomite of the Richmond group. In areas where water of a quality suitable for most purposes can be obtained from these rocks, precautions should be taken to avoid tapping the underlying shale, which contains saline water. This is illustrated by the analyses of 6 samples collected from well 39N 22W 36-1 at depths ranging from 50 to 290 feet (table 5). The samples from depths of 50, 100, and 150 feet within the limestone and dolomite may be classed as potable, but samples from depths of 200, 250, and 290 feet where the well penetrated the underlying shale (fig. 11), were saline.

The Cataract formation includes beds of gypsum, which are readily dissolved by percolating ground water. The Cataract, therefore, yields water of poor quality high in calcium and sulfate content (fig. 11).

Water from the Burnt Bluff formation generally is hard or very hard but otherwise is suitable for most uses. The water is commonly of the calcium magnesium

bicarbonate type, although some wells tapping the Burnt Bluff yield water high in calcium and sulfate content, which probably results from admixtures of calcium sulfate water from the underlying Cataract formation. Well 39N 18W 17-1 (table 5), owned by the village of Garden, taps the basal part of the Burnt Bluff and yields water high in sulfate content. Pumping or unrestricted artesian flow from the basal members of the Burnt Bluff formation induces a flow of water to wells from the Cataract formation, which is hydraulically connected to the Burnt Bluff. If a well completely penetrates the Burnt Bluff formation and enters the Cataract formation, water high in calcium sulfate enters the well directly. The water from wells tapping the upper members of the Burnt Bluff contains relatively little sulfate.

Only one chemical analysis of water from the Manistique dolomite in Delta County is available. A sample of water from well 39N 18W 12-1 apparently was soft and very low in mineral content. This sample, however, may not be representative of water from these rocks, as the formation in neighboring Schoolcraft County yields harder water having a higher degree of mineralization (Sinclair, 1959).

The quality of water from the glacial-drift aquifers of the county varies considerably. The quality is determined by the composition of the drift and by the water in aquifers hydraulically connected. The drift aquifers, however, generally yield water having a lower dissolved-mineral content than that yielded by the bedrock aquifers of the county. One notable exception is the high concentration of calcium and sulfate in the sample taken from well 41N 18W 13-1 (table 5). The analysis of this sample indicates that the water has migrated from the gypsiferous Cataract formation or has been mixed with water from that aquifer.

The iron content in two samples of water from the glacial-drift was very high -- 14 and 17 ppm, and greater than the iron contained in water taken from any other aquifer. As a total iron and manganese content of 0.3 ppm in drinking water is considered objectionable (Hem, 1959, p. 238), and will cause staining on plumbing fixtures and various fabrics, treatment of water high in iron is generally desirable.

The temperature of water from most wells in Delta County ranges from 45° to 48°F (table 5). The range in temperature of water from several deep wells tapping the Munising sandstone was from 46° to 52°F.

Surface Water

Chemical analyses of water from lakes, streams, and springs in Delta County are listed in table 6 and diagrammed in figure 12. Figure 12 shows the relative uniformity in chemical content of surface water from various sources throughout Delta County; the water is predominantly of the calcium magnesium bicarbonate type. Variations in composition 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 is generally higher in mineral content than water from the various streams into which they empty, which reflects the influence of ground-water discharge on stream quality. In addition, the composition of the spring water may indicate the chemical quality of ground water in the source aquifer. This is illustrated by the sample from Moss Lake, which is fed largely by springs issuing from the Cataract formation.

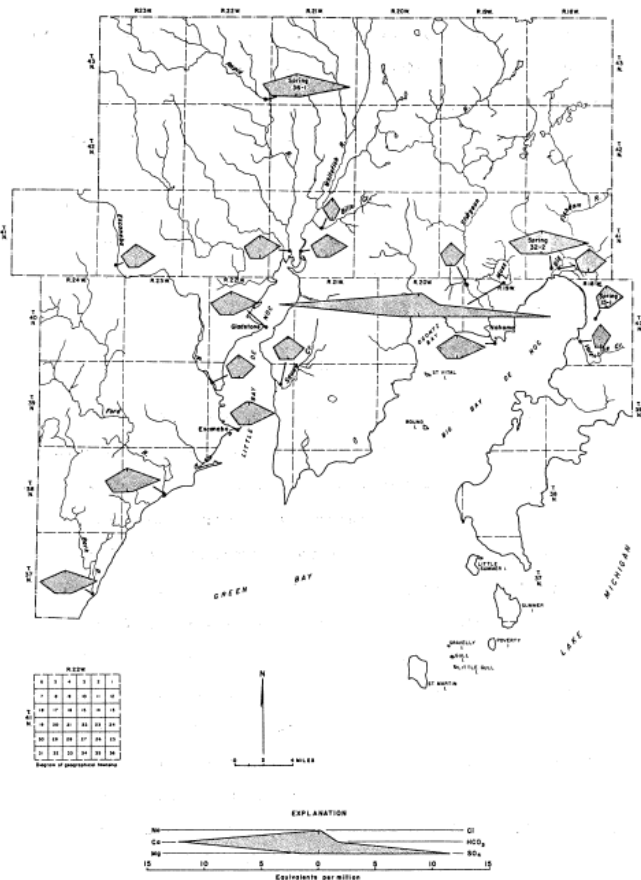


Figure 12. Diagrams showing chemical composition of surface water in Delta County.

CONCLUSIONS

The development of the ground-water resources of Delta County will involve more quality-of-water problems than problems of locating adequate quantities of water. In most areas of the county, it is possible to obtain adequate quantities of ground water suitable for most purposes. Although the Munising and Au Train formations yield fresh water in the northern and western parts of the county, the southeastward extent of the fresh water in these formations is not known. Wells drilled to these aquifers should be cased through overlying saline-water-bearing formations. The Black River and Trenton formations also are sources of fresh water in the northern and western parts of the county, but they yield saline water where they are overlain by younger bedrock formations. Limestone and dolomite of the Richmond group yield both fresh and saline water in

the area where these rocks form the bedrock surface, and the distribution of fresh water cannot be determined from presently available data. In area where wells obtain fresh water from these rocks, penetration to the underlying shale probably will permit the entrance of saline water into the well. The Cataract formation yields water high in calcium and sulfate content, and hence is not a source of suitable ground-water supplies. It has not been determined if any of the aquifers underlying the Cataract formation in the southeastern part of the county contain fresh water. Fresh water can be obtained from the Burnt Bluff and Manistique formations if precautions are taken to prevent encroachment of high-sulfate water from the underlying Cataract formation.

Moderate to large yields of ground water can be obtained from the glacial-drift aquifers in many parts of the county, but in areas where the drift is absent, thin, of low permeability, or above the regional water table, ground water must be obtained from the various bedrock aquifers described above. Drift deposits having the greatest potential for future development are in the presently undeveloped northeastern part of the county.

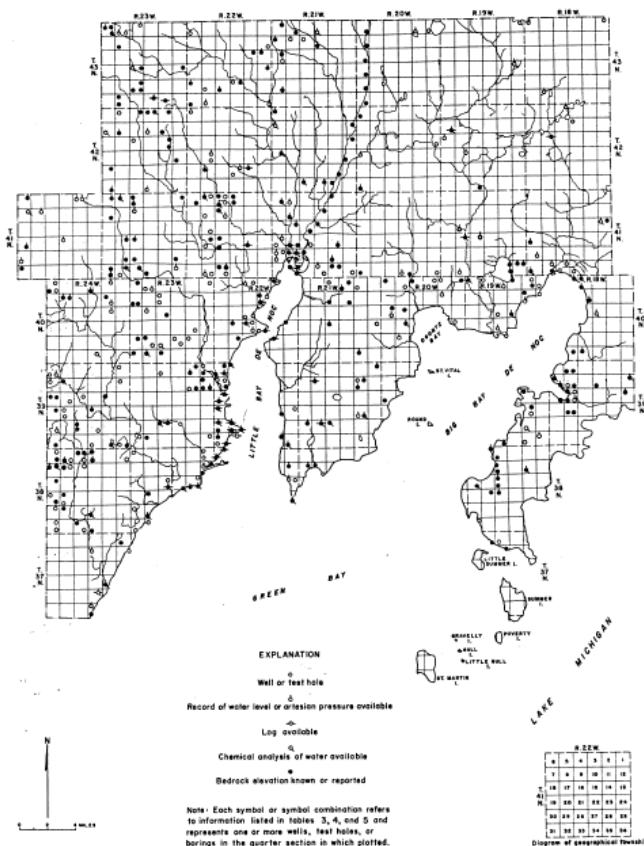


Figure 13. Map of Delta County showing availability of hydrologic, geologic, and quality-of-water data.

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AGE			NAMES AND SYMBOLS USED IN THIS REPORT LITHOLOGY	THICKNESS (feet)	HYDROLOGY
Cenozoic	Quaternary	Pleistocene	Glacial drift Undifferentiated (Qgd) Sand (Qs); Gravel (Qg) Sand and gravel (Gsg) Varied deposits of poorly sorted till ranging in composition from clayey to bouldery; sand and gravel outwash, sandy lake deposits, and dune sand, all of which are relatively well sorted.	0 to 200±	In most of the southern and western parts of the country, the drift is thin and discontinuous, and hence is a source of very small supplies of fresh ground water. The thickest and most permeable drift deposits, which have considerable potential for future development, are in the northeastern part of the county.
Paleozoic	Silurian	Middle (Niagaran)	Engadine dolomite (Sm) Massive hard bluish-white dolomite.	10±	Not an important source of water because of its small extent and thickness.
			Manistique dolomite (Sm) Thinly bedded to massive light-buff to brown and gray cherty dolomite.	150	Potentially important as a source of water in the sparsely inhabited eastern half of the Garden Peninsula.
			Burnt Bluff formation (Sb) Thinly bedded to massive light-gray to buff calcitic dolomite.	250±	Important aquifer in the Garden Peninsula. Yields moderate to large supplies of water of good quality, although generally hard. Basal strata connected hydraulically with the underlying Cataract formation.
		Early	Cataract formation (Sc) Buff to gray dense cherty, shaly dolomite and gray shale interbedded with thin layers of gypsum.	250±	Yields moderate supplies of water of poor quality – very hard, and high in calcium and sulfate content.
	Ordovician	Late	Limestone and dolomite of Richmond Group (Or) Thinly bedded shaly limestone and dolomite interbedded with shale and a few massive beds of limestone.	300±	Yields small amount of hard, but generally not objectionable, water to large-diameter shallow wells. Locally yields water high in sodium and chloride content.
			Shale unit of the Richmond group and Collingwood formation (Orc) Gray to dark-brown shale interbedded with limestone.	135 to 300	Permeability low. Contains highly saline water.
		Middle	Trenton and Black River limestones (Otb) Thin, irregular beds of gray to buff limestone and dolomite interbedded with thin shale layers or lenses.	300±	Yields moderate amounts of hard, but not objectionable, water throughout the western part of the county. Locally contains saline water.
		Early and Middle	Au Train formation (Oat) Thin- to medium-bedded sandy dolomite and dolomitic sandstone with many thin lenses of quartzose sandstone.	300±	These rocks are connected hydraulically and form a single aquifer which will yield moderate to large supplies of water of good quality in much of the county. Salinity may increase basinward. The water is under considerable pressure and will flow from wells in low areas along the Great Lakes shoreline.
	Cambrian	Late	Munising sandstone (€m) Fine- to medium-grained white to gray sandstone with lenses of silt and shale.	50 to 200±	
Precambrian or Cambrian			Jacobsville sandstone (Cj) Red and white quartzose sandstone.	?	Of small areal extent in county, if present at all. Not a potential source of water.
Precambrian			Metamorphic and igneous rocks.	?	Not a source of water.

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