Water Resources of the Marquette Iron Range Area, Michigan

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1842

Prepared in cooperation with the State of Michigan

Water Resources of the Marquette Iron Range Area, Michigan

By S. W. WIITALA, T. G. NEWPORT, *and* E. L. SKINNER

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1842

Prepared in cooperation with the State of Michigan

A study designed to provide water facts in planning orderly development and in guiding management of water resources of the area

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 67-193

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GLOSSARY

[Adapted from Pluhowski and Kantrowitz (1964) and Langbein and Iseri (1960)]

Acre-foot: The quantity of water required to cover 1 acre to a depth of 1 foot; equal to 43,560 cubic feet or 325,851 gallons.

Aquiclude: A formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring.

Aquifer: A formation, or group of formations, or a part of a formation that is water bearing.

Artesian water: The occurrence of ground water under sufficient *hydrostatic head* to rise above the upper surface of the *aquifer*.

Base flow: Discharge entering stream channels as effluent from the *ground-water reservoir;* the fair-weather flow of streams.

Color: Color, in water analysis, is an expression of the visual appearance of water completely free of suspended material. Color is expressed in units of the platinum-cobalt scale.

Concentration: The weight of dissolved solids or sediment per unit weight of solution. Concentration is expressed in parts per million (ppm)—a unit weight of a constituent in a million unit weights of solution. For chemical concentrations the computation is based on a million unit weights of clear solution containing water-dissolved solids; for sediment concentration it is based on the mixture of water-dissolved solids and sediment.

Cubic feet per second: The discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, whose velocity is 1 foot per second; equivalent to 448.8 gallons per minute.

Climatic year: The 12-month period from April 1 to March 31.

Cone of depression: A conical depression, on a *water table* or piezometric surface, produced by pumping.

Direct runoff: The water that moves over the land surface directly to streams promptly after rainfall or snowmelt.

Discharge, ground-water: The process by which water is removed from the *zone of saturation*; also, the quantity of water removed.

Diversion: The taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Evapotranspiration: Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plant *transpiration*.

Ground-water reservoir: An *aquifer* or a group of related aquifers.

Ground-water runoff: That part of the streamflow which consists of water discharged into a stream channel by seepage from the *ground-water reservoir;* same as *base flow*.

Head (hydrostatic head): The height of a vertical column of water, the weight of which, in a unit cross section, is equal to the hydrostatic pressure at a point.

Hydraulic gradient: The rate of change of *hydrostatic head* per unit of distance of flow at a given point and in a given direction.

Hydrograph: A graph showing changes in *stage*, flow, velocity, or other aspect of water with respect to time.

Mean annual flood: The arithmetic average of an infinitely long series of annual peak flows; the flood having a *recurrence interval* of 2.33 years.

Part per million: One milligram of solute in 1 kilogram of solution.

Perched ground water: Ground water separated from an underlying body of ground water by unsaturated deposits.

Permeability: The capacity of a material to transmit a fluid.

Permeability, coefficient of: The rate of flow of water in gallons per day, through a cross section of 1 square foot under a *hydraulic gradient* of 1 foot per foot at a temperature of 60°F; also referred to as the field coefficient of permeability when the units are given in terms of the prevailing temperature of the water. It is equal to the *coefficient of transmissibility* divided by the thickness of the aquifer.

Porosity: The ratio of the aggregate volume of interstices in a rock or deposit to its total volume, expressed as a percent.

Recharge, ground-water: The process by which water is added to the *zone of saturation;* also, the quantity of water added.

Recurrence interval (return period): The average interval of time within which the given flood will be equaled or exceeded once; also, the average interval of time within which a flow equal to or lower than a given low flow will occur once.

Regulation: The artificial manipulation of the flow of a stream.

Runoff: The water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Saturation, zone of: The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Soil moisture: Water diffused in the soil or in the upper part of the zone of aeration from which water is discharged by the *transpiration* of plants or by soil evaporation.

Specific capacity: The yield of a well, in gallons per minute, divided by the drawdown in the well, in feet.

Specific conductance: The conductance of a cube of a substance 1 centimeter on a side, measured as reciprocal ohms or mhos. Commonly reported as millionths of mhos or micromhos, at 25°C.

Specific yield: The ratio of the volume of water drained from a saturated deposit by gravity to the volume of the deposit.

Stage: The height of a water surface above an established datum plane; also, gage height.

Storage, coefficient of: The volume of water, expressed as a decimal fraction of a cubic foot, released from storage in a column of the aquifer having a cross-sectional area of 1 square foot and a height equal to the full thickness of the *aquifer* when the *head* is lowered 1 foot.

Surface water: Water on the surface of the earth.

Thermocline: The stratum in a body of water in which there is a marked change in temperature per unit of depth.

Transmissibility, coefficient of: The rate of flow of water in gallons per day, at the prevailing water temperature, through each vertical strip of *aquifer* 1 foot wide having a height equal to the thickness of the aquifer and under a *hydraulic gradient* of 1 foot per foot.

Transpiration: The quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time; also, the process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere.

Underflow: The movement of water in the *ground-water reservoir;* also, the quantity of water moving in the ground-water reservoir through any vertical plane.

Water table: The upper surface of the *zone of saturation,* except where the surface is formed by an impermeable body.

Water-table aquifer: An *aquifer* containing water under *water-table conditions.*

Water-table conditions: The condition under which water occurs in an *aquifer* that is not overlain by an *aquiclude* and that has a *water table.*

Water year: A 12-month period from October 1 to September 30. Designated as the year ending September 30.

WATER RESOURCES OF THE MARQUETTE IRON RANGE AREA, MICHIGAN

By S. W. WIITALA, T. G. NEWPORT, and E. L. SKINNER

ABSTRACT

Large quantities of water are needed in the beneficiation and pelletizing processes by which the ore mined from low-grade iron-formations is upgraded into an excellent raw material for the iron and steel industry. Extensive reserves of low-grade iron-formation available for development herald an intensification of the demands upon the area's water supplies. This study was designed to provide water facts for public and private agencies in planning orderly development and in guiding the management of the water resources to meet existing and new requirements.

Inland lakes and streams are the best potential sources of water for immediate development. The natural flow available for 90 percent of the time in the Middle and East Branches of the Escanaba River, the Carp River, and the Michigamme River is about 190 cubic feet per second. Potential storage sites are identified, and their complete development could increase the available supply from the above streams to about 450 cubic feet per second.

Outwash deposits are the best potential sources of ground water. Large supplies could be developed from extensive outwash deposits in the eastern part of the area adjacent to Goose Lake Outlet and the East Branch Escanaba River. Other areas of outwash occur in the vicinity of Humboldt, West Branch Creek, and along the stream valleys. Streamflow data were used to make rough approximations of the ground-water potential in some areas. In general, however, the available data were not sufficient to permit quantitative evaluation of the potential ground-water supplies.

Chemical quality of the surface and ground waters of the area is generally acceptable for most uses. Suspended sediment in the form of mineral tailings in effluents from ore-processing plants is a potential problem. Existing plants use settling basins to effectively remove most of the suspended material. Available records indicate that suspended-sediment concentrations and loads in the receiving waters have not been significantly increased by these operations.

Present water use is about 60 cubic feet per second in the area. Thus, available water supplies are believed to be adequate for existing and foreseeable new uses. Water management, rather than water availability, is of prime consideration in this area. Time distribution of available water supplies, distribution of water to points of use, effect of surface-water development upon ground water and vice versa, and possible conflicts with competing uses are some of the management problems that are discussed. The presence of many inland lakes, favorable storage sites on streams, and several promising acquifers provide flexibility in

possible water-management operations. A discussion of the interrelationships between surface and ground water and a ground-water budget are presented to render a better understanding of the hydrologic system with which water management will be concerned.

INTRODUCTION

Not many years ago, interest in water resources of the Marquette Iron Range area was casual. Most water was clear and cool and seemed to be in ample supply and conveniently at hand to satisfy the modest requirements of the area. Largely within the past decade, however, development of new mining methods and processes for beneficiating ore from low-grade iron-formations has placed a new demand on the area's water resources. Relatively large supplies of water are now needed in processes that separate iron ore from waste rock and in transporting ground ore through the beneficiating plants. Thus, a new large water use has been thrust upon an upland area where the streams are small and where bedrock is at or near the surface in many places. Realistic planning for development of the vast reserves of low-grade iron ore in the area requires a knowledge of the total water-supply potential and an appraisal of the impact that the new water use will have upon other uses and water-related activities.

PURPOSE AND SCOPE

The principal purpose of this report is to provide water facts that will enable managers and planners, public and private, to make sound decisions in the development and management of the water resources of the area. An auxiliary purpose is the presentation of information that will show the effects of future developments upon the water resource and related elements in the area's environment.

This report is limited to the physical aspects—description, occurrence, and distribution—of the water resources and related implications of these aspects. Economic and social aspects of water-resources development, though of vital importance, are outside the scope of this report. Insofar as available data and funds permitted, the evaluation of the water resources is quantitative; however, the ground-water evaluation is largely qualitative. The water resources are considered as a single hydrologic system, the elements of which are identified and their interrelationships shown, and the use that can be imposed upon the resources is estimated. The natural chemical and physical quality and changes in quality effected by water use are described.

In short, this report should be a useful guide to planning water use and control facilities and to managing the water supplies intelligently. Nevertheless, engineering studies will be needed for design of specific projects.

PREVIOUS STUDIES

Many Federal, State, and private studies have been made of the geology of the Marquette Iron Range. Among these are U.S. Geological Survey Monographs 28 and 52 which summarize the bedrock geology, reports by Swanson (1930) and Zinn (1931) which also described the bedrock geology of parts of the iron range, and a report by Leverett (1917) on the glacial geology of a broad segment of the Lake Superior region that includes this area. Many of the individual studies were reported in technical journals such as those of the Society of Economic Geologists, the American Institute of Mining and Metallurgical Engineers, and the Lake Superior Mining Institute.

The only previous investigation dealing primarily with water was that of Stuart, Brown, and Rhodehamel (1954). They studied the ground-water hydrology of the Marquette iron-mining district with the objective of developing methods for water control in underground mining operations to improve safety and also to reduce mining costs. Included in Stuart's report are maps showing detailed surficial geology and the configuration of the water table and bedrock surface.

ACKNOWLEDGMENTS AND PERSONNEL

This investigation, which spanned the period 1961–65, was authorized by a cooperative agreement between the U.S. Geological Survey and the State of Michigan. The work was carried on under the general direction of: A. D. Ash, district engineer; M. Deutsch, district geologist, succeeded by G. E. Hendrickson; and G. W. Whetstone, district chemist, succeeded by C. R. Collier. R. L. Knutilla, hydraulic engineer, U.S. Geological Survey, made many of the analyses and computations for the surface-water phase of this study.

Invaluable assistance, in direct participation in some of the field investigations and in furnishing data from their files, was provided by the Cleveland-Cliffs Iron Co. by S. W. Sundeen, manager of ore research and development, and R. E. Magnuson, Jr., assistant to the vice president, mining. Results of the company's pumping test on Goose Lake-Sands plain were made available to the Geological Survey for this study.

Much of the data used in this study was collected over a period of years by the U.S. Geological Survey in cooperation with State agencies. Data from files of State agencies, particularly the Michigan Geological Survey, Michigan Water Resources Commission, and Michigan Department of Health, were used freely in this investigation.

Thanks are also due Mr. Douglas Hart of the Michigan State

Highway Department for furnishing the results of a seismic test made in the Goose Lake-Sands plain area, local well drillers for furnishing drilling records and other geologic information, and local waterworks officials who supplied data on water use.

DESCRIPTION OF THE AREA

LOCATION AND LIMITS

This report covers a roughly rectangular area immediately south and west of Marquette in the north-central part of Michigan's Upper Peninsula (fig. 1). From Lake Superior at the northeast corner, the area extends to the Marquette County line on the west and to Gwinn on the south. The north boundary generally coincides with the drainage divide between the Dead and Carp River basins, and the south boundary, with the divide between Middle and West Branches of the Escanaba River. The area comprises about 610 sq mi (square miles), almost exactly a third of the area of Marquette County, the largest county in Michigan.

Marquette Iron Range extends east and west across the north half of the area. Cities of Ishpeming and Negaunee, and most of the other communities in the area, are clustered along the range. Villages of Gwinn and Princeton are located on a short spur of the range in the southeast corner of the area.

TOPOGRAPHY

Except near Lake Superior and along the east edge, the area is a highland resembling a plateau with locally rough topography. Elevations range from 602 feet above mean sea level at Lake Superior to 1,870 feet at the top of Summit Mountain 3 miles south of Negaunee. Along the range are numerous pits and subsidence areas in the vicinity of abandoned mines and near some active mines. Lake Angeline, just south of Ishpeming, is one of the largest of such areas. A sandy plain 2 to 6 miles wide containing scattered knobs of bedrock extends south and east from Goose Lake to the southeast corner of the area. Immediately to the east of this plain the land descends steeply to the valley of the Chocolay River, and the result is a zone of rugged topography. Except along the iron range, the area is generally heavily wooded.

DRAINAGE

The area contains all or part of four river basins—the Carp, Chocolay, Michigamme, and Escanaba (fig. 1). The Carp and Chocolay Rivers drain into Lake Superior, while the others drain into Lake Michigan. The Carp River basin, the only one entirely

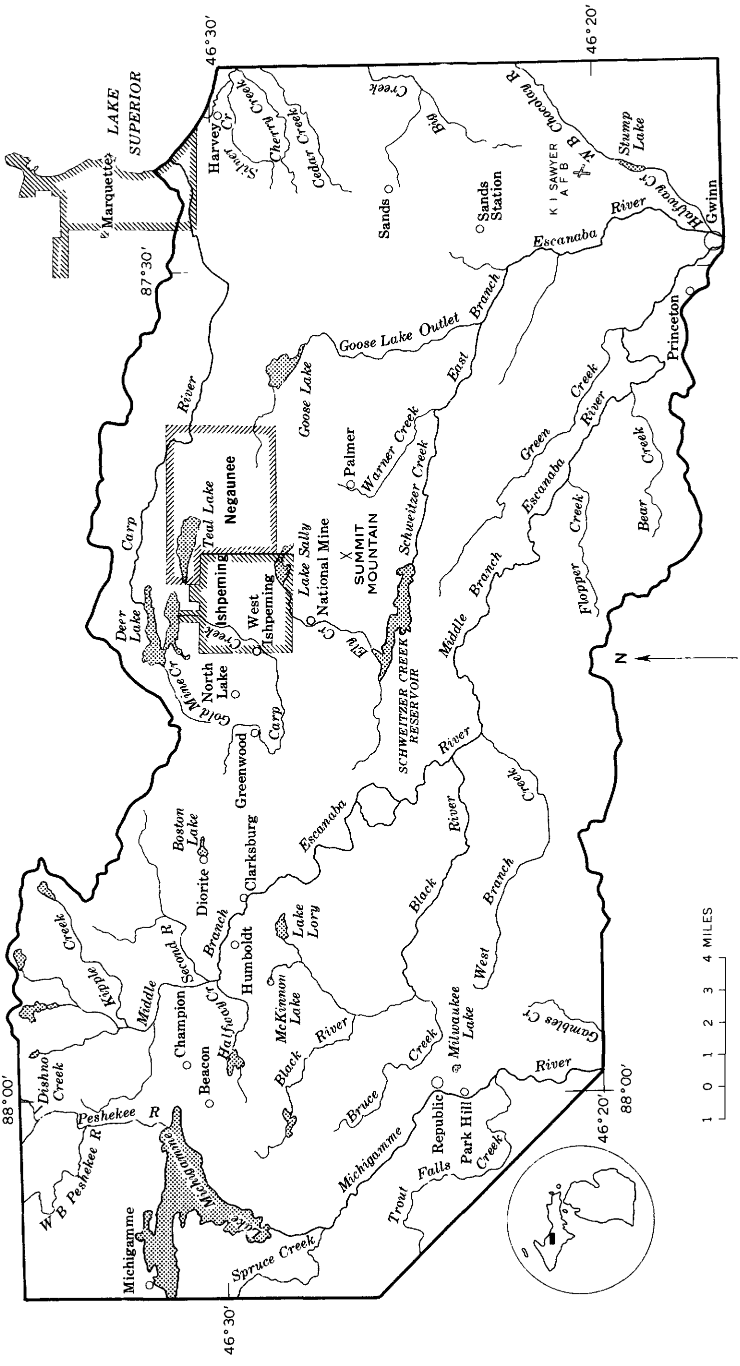


Figure 1.—Marquette Iron Range area.

within the report area, drains 74.3 square miles in the northeastern part of the area. The eastward-flowing tributaries of the Chocolay River drain the dissected zone east of Goose Lake-Sands plain. The Michigamme River and its tributaries and scenic Lake Michigamme occupy the western part of the area. The Peshekee River, the principal tributary to Lake Michigamme, drains into the lake from the north. The remainder of the area, 361 sq mi, is drained by the East and Middle Branches of the Escanaba River which join at Gwinn to form the main stream. The East Branch rises in the rough terrain south of Ishpeming, while the Middle Branch heads in the rugged wilderness northeast of Lake Michigamme. Both streams flow southeasterly across the area. A total of 243 lakes ranging in size from less than an acre to 4,212 acres are scattered over the area.

CLIMATE

Lake Superior has a general moderating effect upon the climate of this area. Mean monthly temperatures range from 15°F in January to 66°F in July at Ishpeming (fig. 2). The average annual temperature is 40.8°F. The growing season is about 4 months long with the average dates of the last spring and the first fall temperatures of 32°F or colder being May 28 and September 21, respectively.

Annual precipitation at Ishpeming averaged 31.72 inches for the period 1931–60 and 30.97 inches for the period 1899–1963. The wettest month is July, and the driest is February (fig. 3). About 65 percent of the annual precipitation occurs in the 6-month period, April to September. The most intense precipitation is associated with thunderstorms, about 29 of which occur per year. Snowfall is heavy, averaging about 100–110 inches per winter season. Recorded maximum depths of snow on the ground have ranged between 50 and 60 inches in this area (Eichmeier, 1964, fig. 9).

The period encompassed by this study was very dry. The 2-year and 3-year periods ending in 1963 were the second lowest such periods in the record for Ishpeming since 1899. Thus hydrologic data obtained during this study are of special significance because they represent rather severe drought conditions. Recorded data, especially on streamflow, obviated extensive interpolations in the extreme low-flow range.

The average annual lake evaporation for this region is estimated to be about 31 inches, about 80 percent of which occurs in the May–October period (Kohler and others, 1959, pls. 2 and 4). Variation in evaporation by months for the Weather Bureau's evaporation station at Germfask Wildlife Refuge about 80 miles east of Ishpeming is shown in figure 4. A coefficient depending upon geographic loca-

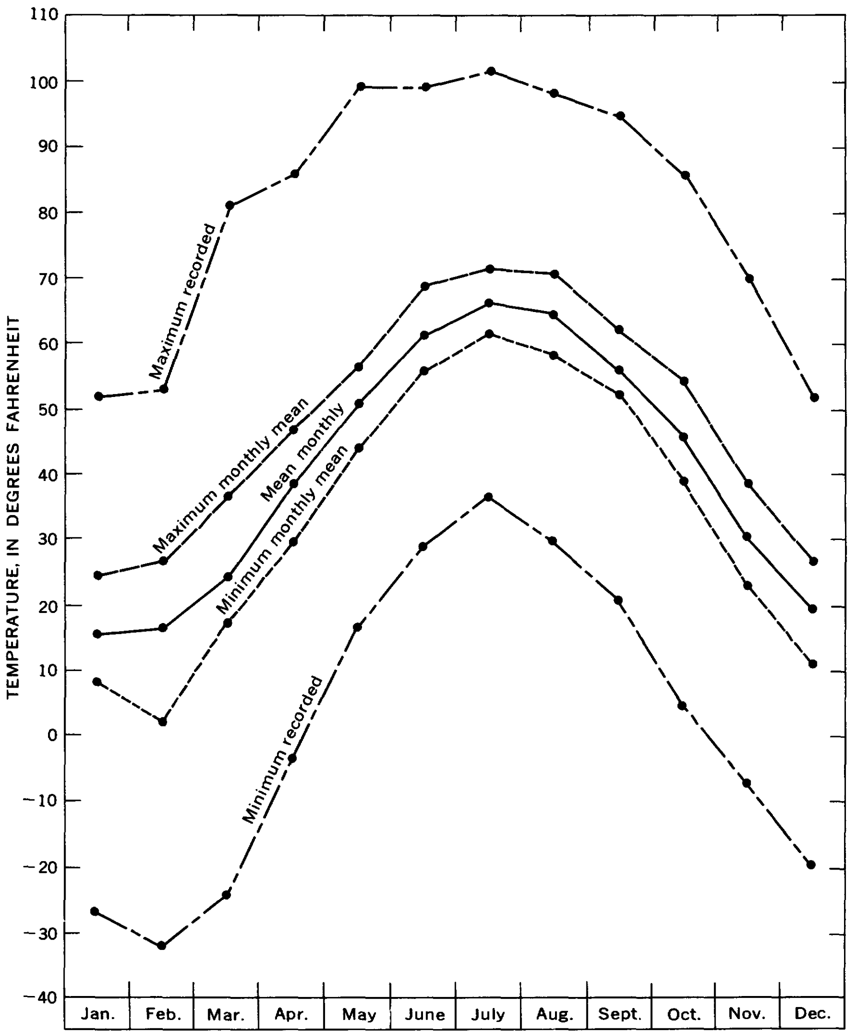


FIGURE 2.—Air temperatures at Ishpeming, 1931–60.

tion, elevation, time of year, exposure, and other factors must be applied to pan evaporation to obtain estimates of lake evaporation. The average annual class A pan coefficient for this area is about 80 percent (Kohler and others, 1959, pl. 3). It seems reasonable to assume that the Germfask data can be used for preliminary estimates of evaporation losses from lakes in the Marquette area.

243-028 O—67——2

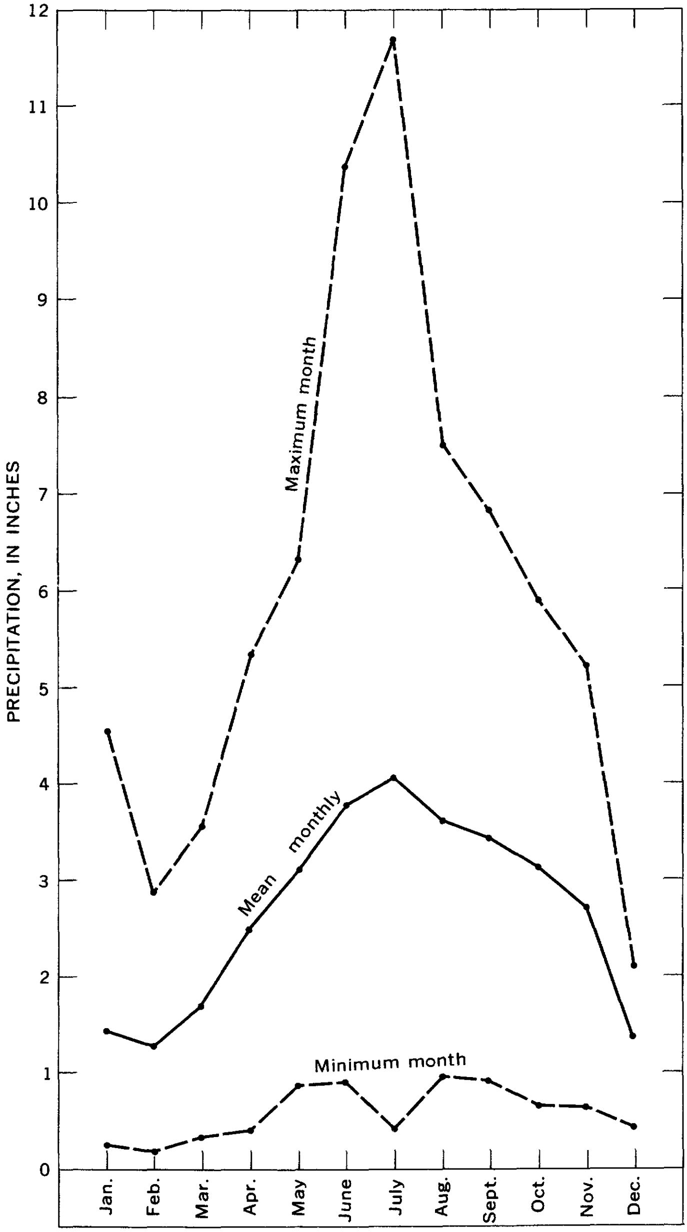


FIGURE 3.—Precipitation at Ishpeming, 1931–60.

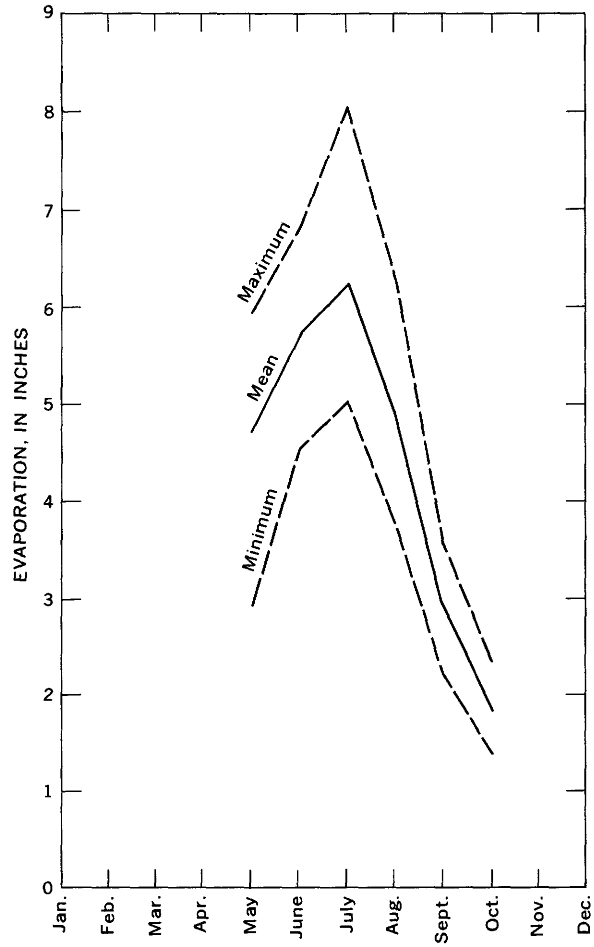


FIGURE 4.—Monthly evaporation from a class A pan, Germfask Wildlife Refuge, 1939–62 (fragmentary record for some months).

INDUSTRY, AGRICULTURE, AND POPULATION

W. A. Burt and a party of government surveyors discovered iron ore near Teal Lake at Negaunee on September 19, 1844. Mining began at Jackson mine near Negaunee in 1846. Until the discovery of iron ore in the country, the United States seemed destined to be an agricultural nation. The Lake Superior region, therefore, has exerted a profound effect upon our national economy. Ever since the opening of Jackson mine, the economy of Marquette County has been geared to the iron-ore industry. Total shipments of iron ore from the Marquette Iron Range are shown in figure 5.

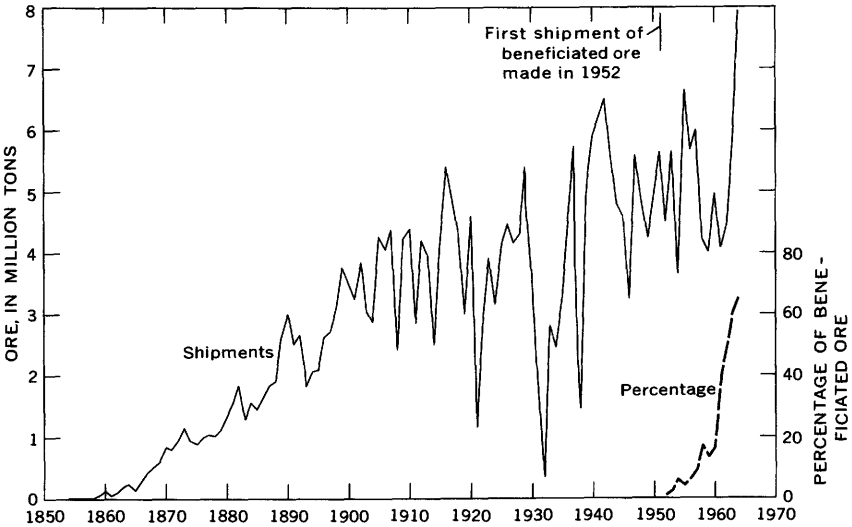


FIGURE 5.—Total shipments of iron ore from the Marquette Iron Range, 1854–1964, and percentage of total shipment made up of beneficiated ore, 1952–64. (From compilations prepared by Michigan Dept. Conserv., Geol. Survey Div.)

In the early 1950's the imminent depletion of high-grade ore deposits that could be mined economically portended a drastic decline in iron-ore production and a corresponding slump in the area's economy. But development of new mining methods and processes for producing an excellent, marketable product from vast deposits of low-grade iron-formation provided a new stimulus to the area. Beneficiated-ore shipments from the range began in 1952 and by 1964 made up 65 percent of the total iron-ore shipments (fig. 5). Ore shipments in 1964 were record high, an effective indication that mining and processing of iron ore promise to remain the dominant industry in the area for a long time to come. Demand upon the water resources of the area will undoubtedly intensify as beneficiated-ore production continues to increase and eventually replace all other production.

Production of sand and gravel, lumbering, and agriculture are other pursuits associated with the area's natural resources. In recent years about half a million tons of sand and gravel were produced in the county. One large producer is located in the northeast corner of the report area about 3 miles east of Goose Lake. Lumbering was an important activity at one time but passed from prominence after the area was cut over. Less than 50 persons were employed in forestry in Marquette County in 1950 (Michigan State University, 1960). About 5 percent of the land area of the county was in farms in 1959, producing products valued at nearly a million dollars (U.S. Bureau of the Census, 1962). Most of the farms, however, are outside of the area covered by this report.

Very few statistics are available on tourism and recreation in the area. This industry, however, provides probably the best potential for economic diversification in the area. K. I. Sawyer Air Force Base, about 5 miles northeast of Gwinn, is an important government facility. About two-thirds of Marquette County's 1960 population of 56,154 lived in the area covered by this report. Of these, about 19,000 lived in the cities and townships of Ishpeming and Negaunee. In 1965, in the county, 2,930 persons were associated with the iron-ore industry, an increase of more than 500 from 1964 and about 1,300 from the recent minimum in 1960 (S.W. Sundeen, oral commun.).

STREAMFLOW-GAGING STATION AND WELL-NUMBERING SYSTEMS

Locations where streamflow and ground-water information has been obtained are identified in tables and some illustrations of this report by numbers. For locations on streams, the numbers conform to the numbering system used for the national network of gaging stations in the U.S. Geological Survey's annual reports on surface-water supply since 1958. Numbers are assigned in ascending sequence in downstream order. Thus, numbers for locations in the headwaters of a basin are smaller than those for locations near the mouth. Numbers for locations on a tributary are intermediate between numbers for locations on the main stream above and below the tributary.

The well-numbering system is referenced to land-line location. A well number consists of three segments; the first two designate township and range, and the third designates the section and well within the section. Well 48N29W19–1, for example, is well 1 in sec. 19, T. 48 N., R. 29 W.

GEOLOGIC SETTING

The Marquette Iron Range area is underlain by igneous and metamorphic rocks of Precambrian age and sedimentary rocks of Cambrian age. Bedrock is exposed at the surface or covered only by soil in most of the north half of the area. Elsewhere the bedrock is overlain by glacial drift and alluvium of Pleistocene and Recent age.

The early geologic history of the area is very complex. The Precambrian bedrock was faulted, folded, intruded, and metamorphosed until the original character of the rocks was completely changed. Weathering and erosion reduced the Precambrian highlands before the Paleozoic seas covered a part of the area. The Pleistocene, or ice age, began at about the time that the bedrock had been eroded to approximately the present altitudes. Glaciers advanced and retreated over the area several times. Upon melting, the ice left behind a blanket of till and outwash that covers much of the area today.

BEDROCK

Bedrock formations consist of various kinds of igneous, metamorphic, and sedimentary rocks ranging in age from early Precambrian to Cambrian. The metamorphic rocks are mostly quartzites, schists, gneisses, and metavolcanics. Igneous rocks, which intrude the metamorphic rocks, are chiefly granite, diorite, and basic igneous rocks. The Precambrian bedrock crops out in many places on the ridges and knobs. Glacial action has rounded the tops of the knobs and polished the bedrock surface. Cambrian rocks, chiefly sandstones, underlie the glacial drift in the southeastern part of the county.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits can be classified into four general groups—till, lacustrine deposits, outwash and alluvium, and swamp deposits. Their extent and distribution are shown on the surface-geology map (pl. 1). Till and bedrock were mapped as one unit. The lacustrine deposits were not mapped separately but included with the outwash and the swamp deposits.

TILL

Till is unsorted, or poorly sorted, unstratified drift deposited directly from glacial ice without subsequent movement by wind or water. It is a very heterogeneous material ranging from clay to large boulders and from well-rounded to sharply angular rock fragments. In this study area, the known thickness of the till deposits range from less than a foot to 60 feet.

Two types of till predominate in this area. One type, the most common, is sandy and gravelly, brown to yellowish-brown till containing a small percentage of very fine material and varying amounts of cobbles and large boulders. Very coarse till deposits, in which boulders are the dominant constituent, are found near Republic in NW¼ sec. 5, T. 46 N., R. 29 W., near West Ishpeming in NE¼ sec. 7, T. 47 N., R. 27 W., and at the south limit of the area in SW¼ sec. 32, T. 46 N., R. 28 W. The other type of till has the characteristic red stain of iron oxide caused by presence of considerable amounts of red clay. It is found in the area south of Ishpeming near Schoolhouse Lake in sec. 24, T. 47 N., R. 27 W.

LACUSTRINE DEPOSITS

Glacial and postglacial lake deposits consist of varved clay, calcareous marl, and bedded sand and gravel; all may contain decayed vegetation in places. An exposure of these lacustrine deposits is found in the subsidence area of the Morris mine in SE¼ sec. 1, T. 47 N., R. 28 W. These deposits occupy a very minor part of the area.

OUTWASH AND ALLUVIUM

Outwash is stratified drift deposited beyond the limits of the glacier. It was spread along the valley floors and as deltas or alluvial fans by the melt-water streams of retreating glaciers. Alluvium is material deposited by streams since the final retreat of the glaciers. These deposits are very similar in lithology and are considered as one unit in this report.

Outwash and alluvium consist mostly of sand and gravel and small amounts of silt. Near the source, the materials are coarse and tend to be heterogeneous with beds of sand and gravel interlayered between cobbles and boulders. The sand and gravel beds are composed of lenses, generally lying as steeply dipping foreset beds. Crossbedding and marked differences in the sorting of the various sand and gravel beds are notable features. These characteristics indicate the rapidly changing conditions of deposition that must have existed when the outwash materials were deposited from the heavily laden melt-water streams. Logs of selected auger holes in outwash deposits are given in table 24.

The known thickness of outwash and alluvium deposits ranges from less than a foot to 260 feet. A large area of outwash on the east side of Goose Lake Outlet and East Branch Escanaba River extends from Goose Lake southward to the southeast corner of the area (pl. 1). A second large area of outwash is in the south-central part generally between the Michigamme and Middle Branch Escanaba Rivers in, and near, the basin of West Branch Creek. Smaller areas of outwash are found in the area north of Humboldt near the mouth of Second River and along Morgan Creek in the Carp River basin. Knobs of bedrock are exposed at several places in these outwash areas.

SWAMP DEPOSITS

Swamp deposits consist of decayed or decaying organic matter (peat and muck) mixed in places with silt and fine sand. These deposits accumulated in poorly drained parts of the area after the glacial ice melted. They are found along streams and around many of the lakes. Swamps also occur in rock basins, kettles, and depressions in ground moraine. Swamp deposits are relatively shallow. The maximum known thickness of peat is 12 feet in a rock basin near Schweitzer Creek in SW¼NE¼ sec. 2, T. 46 N., R. 27 W.

WATER RESOURCES OF THE AREA

Water is available to the area from Lake Superior, inland lakes and streams, and aquifers.

An almost inexhaustible supply of water of excellent quality is available from Lake Superior. Distribution of Lake Superior water to the iron range would involve relatively long pipelines and pumping lifts of more than 900 feet. Problems associated with this development are primarily economic and political rather than hydrologic. For that reason, this source is not considered further in this report.

Inland lakes and streams are the best potential sources of water for immediate development. Though the area is an upland where the streams are small, runoff is generally abundant making a considerable amount of water available for development. The quality of surface water is generally adequate for most uses. In following sections of this report data are given on streamflow characteristics and behavior of lakes; interpretations are made to estimate storage requirements and frequency of high and low flows; and information is provided on the description and significance of the chemical and physical quality of surface water.

Adequacy of underground sources of water is dependent upon the permeability, thickness, and extent of the water-bearing formations and the ease with which they yield water to wells. Two types of aquifers are identified in the Marquette Iron Range—bedrock and overlying glacial drift or alluvium. Bedrock, in general, yields only small quantities of water to wells. Consequently, the discussion of ground water is confined mostly to the glacial-drift aquifers. Locations of the principal aquifers are shown, their physical and hydraulic properties are described, elevation and fluctuations of underground water levels are delineated, and chemical quality of the ground water is described.

Fundamentally, all these sources depend upon precipitation for their supply. Because waters in streams, lakes, and aquifers have a common source and because water can and does migrate from the surface into the ground and vice versa, the characteristics and movement of these waters are interrelated. A later section of this report is devoted to describing these interrelations so that the effects of, and upon, water-resources development may be better understood. Water managers, too, can benefit by considering the interplay of the various hydrologic factors.

STREAMS AND INLAND LAKES

Some of the physical features of principal streams of the area are given in table 1.

TABLE 1.—*Physical features of principal streams*

River and tributaries	Drainage area (sq mi)	Approximate length (miles)	Approximate slope for reach indicated (feet per mile)
Middle Branch Escanaba	234	55	26, above Kipple Creek; 8, Kipple Creek to County Highway 565; 13, County Highway 565 to mouth.
Middle Branch Escanaba principal tributaries:			
Black River	50. 8		
West Branch Creek	32. 4		
Flopper Creek	9. 2		
Bear Creek	13. 2		
Green Creek	19. 0		
East Branch Escanaba (Ely Creek-Schweitzer Creek-East Branch).	127	30	28.5, Ely Creek; 16, Schweitzer Creek, 7.25, Schweitzer Creek to mouth.
East Branch Escanaba principal tributaries:			
Green Creek	8. 2		
Warner Creek	14. 4		
Goose Lake Outlet	37. 8		
Michigamme (above Gambles Creek).	283	50	11.5, Peshekee River; 4.5, Lake Michigamme to Gambles Creek.
Michigamme principal tributaries:			
Peshekee River	134		
Spurr River	27. 9		
Spruce River	31. 4		
Trout Falls Creek	23. 6		
Carp (Carp Creek-Carp River).	74.3	35	13, Carp Creek; 7.5, Deer Lake to Carp River Lake; 108, Carp River Lake to mouth.
Carp principal tributaries:			
Gold Mine Creek	4. 9		
Morgan Creek	6. 9		
Chocolay tributaries:			
West Branch Chocolay	10. 5	9	32.
Big Creek	24. 5	10. 5	52.
Cedar Creek	12. 0	6. 5	78.
Cherry Creek	5. 6	5	50.
Silver Creek	10. 8	5	72.

The Middle and East Branches of the Escanaba River drain the heart of the area. Rising in the northwest and north-central parts, they flow in a general southeasterly direction, joining at Gwinn to form the Escanaba River which eventually empties into Lake Michigan at Escanaba. Their central location in relation to the area of mining activity invites their development. Water from the Middle Branch is already being used at Humboldt mine and water from Schweitzer Creek in the East Branch basin is used at Empire mine.

The Michigamme River is the largest stream in the area. Its principal tributary, the Peshekee River, drains a rugged wilderness area that contains practically no year-round human habitation. The Michigamme basin contains many natural lakes. The total area of water surface in the basin upstream from Republic amounts to more than 5 percent of the drainage area at that point. Lake Michigamme, covering more than 4,200 acres, exerts a natural regulating effect upon the Michigamme River flow. Water from the river is being used at Republic mine.

Carp River flows in a general easterly direction across the northeastern part of the area and empties into Lake Superior at Marquette. The dominant feature of this basin is Deer Lake, a storage reservoir for Carp River hydroelectric plant at Marquette. A sufficient volume of storage is available in this lake to completely regulate flow of Carp River.

Tributaries of the Chocolay River at the eastern extremity of the area are small streams that tumble down precipitous courses draining the east face of the Marquette moraine. The copious flow in these streams is due, in part at least, to ground-water flow from the adjacent East Branch Escanaba River basin.

DATA AVAILABLE

A large mass of basic water data was collected for this study. Sites where information was obtained and the kind of information obtained are shown on plate 2. Figure 6 shows data available on surface waters of the area. Continuous records of streamflow, water temperature, and sediment yield provided the framework for analyses and evaluations. Occasional measurements and samplings, which were made somewhat systematically, when correlated with the continuous records were useful in broadening the areal coverage of hydrologic data to encompass most of the area. Gaging stations on Middle Branch Escanaba River near Ishpeming and on East Branch Escanaba River at Gwinn served as the real nucleus for the streamflow analyses. By statistical correlation with records for these stations, the continuous and intermittent short-term records could be used to make flow estimates representative of a much longer period.

Estimates obtained by correlation are less accurate than recorded events or experience. The random nature of hydrologic events im-

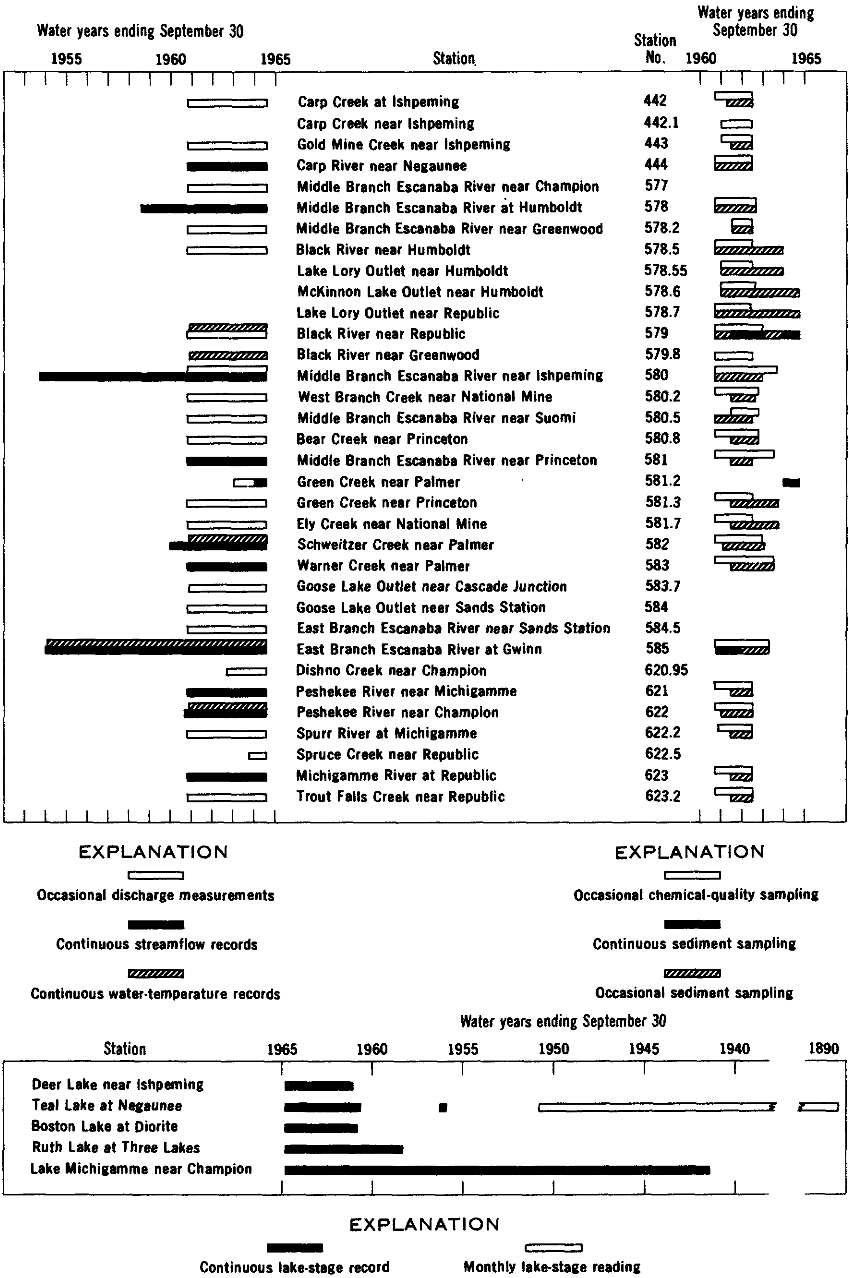


FIGURE 6.—Available surface-water data.

poses some degree of uncertainty in any conclusion or forecast intended to guide future development.

STREAMFLOW CHARACTERISTICS

In considering the surface-water supplies of a region, the following questions are likely to be asked: How does streamflow vary with season and area? How much water is available at specific locations? What are the low flows, and how often do droughts occur? How can storage improve the low flows? Are floods a problem, and how often do they occur? The next five sections will provide information on these questions.

Considerable emphasis is placed upon low-flow characteristics of streams because, without storage, the low flows fix the upper limit of developable surface-water supply. With storage, the maximum developable supply is determined by the average flow. This absolute maximum, however, is seldom realized because of physical and economic limitations.

SEASONAL AND AREAL VARIATION

The rate, volume, and distribution of runoff depend upon climate and the physical characteristics of the watershed. Seasonal variations in streamflow, which are closely related to climate, have similar patterns over relatively large areas. In the central part of Michigan's Upper Peninsula, average streamflow is generally lowest during the winter when most of the precipitation occurs as snow and streamflow is maintained by ground-water seepage (fig. 7). The annual short-period minimums, however, such as those for 1 and 7 days, usually occur during late summer or early fall. Streamflow is high during and immediately following the spring breakup. Often more than half of the annual runoff occurs in April and May. Intense thunderstorm rainfall, usually over small areas, occasionally causes high streamflows in the summer.

Although the average streamflow for the 3-year period used in preparation of figure 7 was only about 70 percent of the long-term average, the relative distribution of flow by months is demonstrated. Figure 7 also shows an areal variation in runoff. The runoff from the Peshekee River basin greatly exceeds that from the Middle and East Branch Escanaba River basins. Average annual runoff for the 3-year period was 17.5 inches for the Peshekee basin as compared with 9.7 and 7.6 inches for the Middle and East Branch basins, respectively. As discussed subsequently, the East Branch Escanaba River basin loses some of its runoff by underground flow into the Chocolay River basin.

The comparatively large runoff from the Peshekee River basin probably is caused by more precipitation over that basin than over the

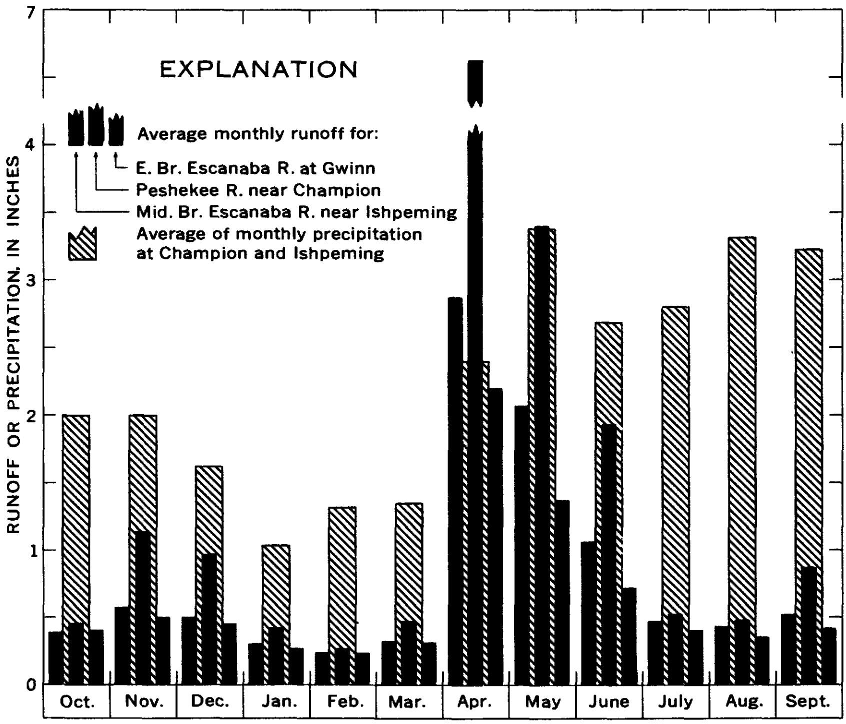


FIGURE 7.—Average monthly precipitation and runoff at selected stations for the 3-year period ending September 30, 1964.

Middle and East Branch basins, especially during winter. Most of the difference in runoff occurs in April and May, the period when snowmelt runs off. Eichmeier (1946, fig. 10) shows that accumulated snow depths are usually greater in the Peshekee River basin than in the area east of that basin. Thus, precipitation shown in figure 7 probably is not representative of that over the Peshekee River basin. Storage in many lakes of the Peshekee basin helps to maintain a relatively high flow in the Peshekee River well into summer. When that storage is exhausted after prolonged dry weather, the Peshekee River flow becomes quite small. Evidently few, or small, aquifers feed the stream. In the drought year 1963, flow in the Peshekee River was generally greater than that in the Middle Branch Escanaba River until August (fig. 8). Then it remained generally lower than the flow in the Middle Branch until the drought ended in November. The hydrographs in figure 8 also represent typical distribution of daily streamflow in the area.

Another way of showing the areal variation in runoff is illustrated in figure 9. Runoff for the 1963 water year varies from less than 6

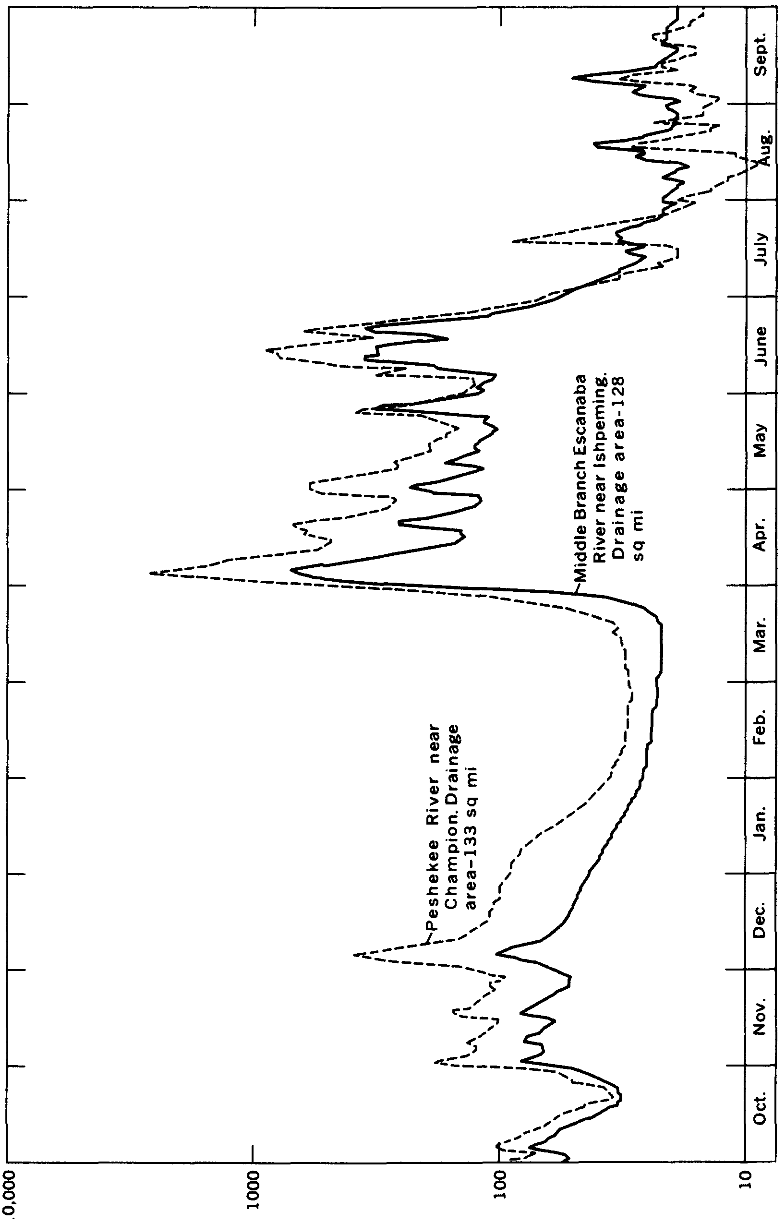


FIGURE 8.—Daily mean discharge for water year ending September 30, 1963, at gaging stations in the Peshekee and Middle Branch Escanaba River basins.

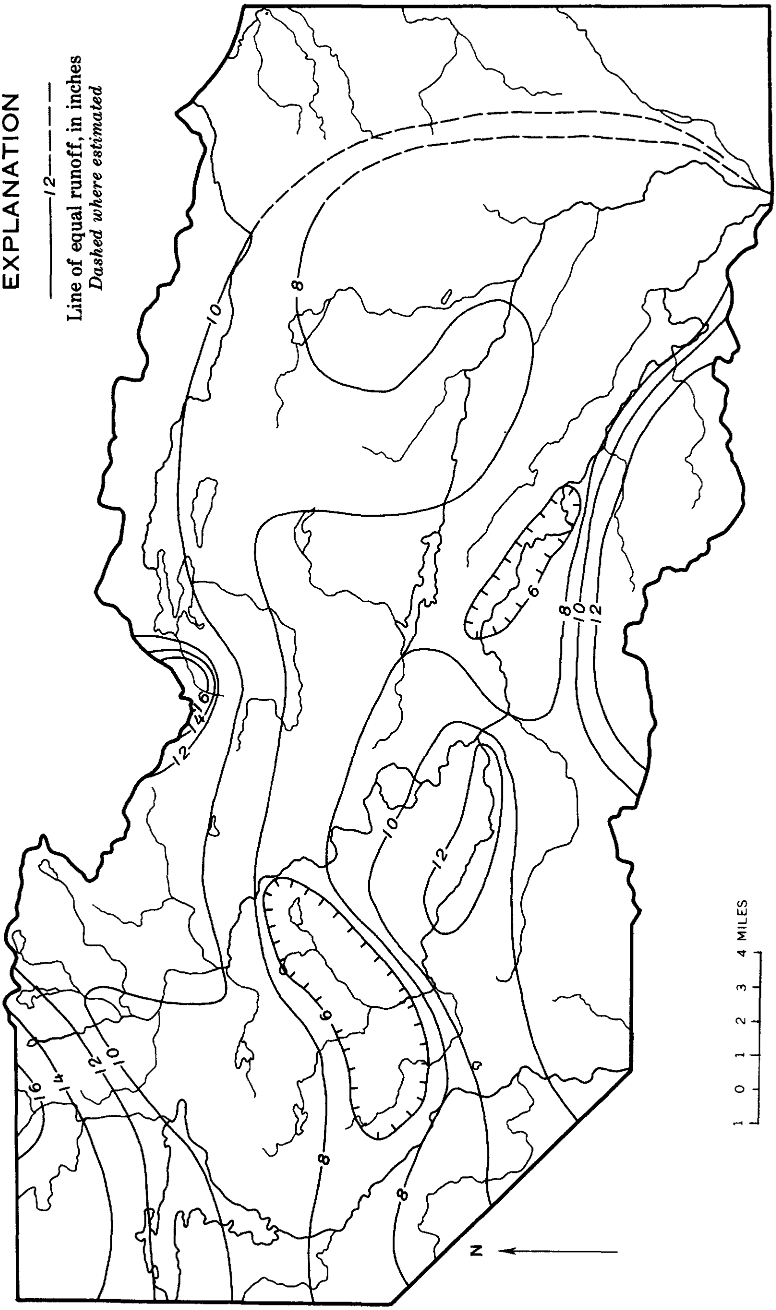


FIGURE 9.—**Areal variation in runoff for the water year ending September 30, 1963.**

to more than 16 inches. Areal differences in runoff are probably more noticeable in dry years when most of the runoff is derived from ground-water sources. Thus, figure 9 can also be used as a rough indicator of the ground-water potential. Other factors, however, can obscure this relationship. For example, ground-water discharge is not responsible for the high runoff in the Peshekee River basin, and high ground-water discharge in the Goose Lake Outlet basin is not reflected in runoff because of interbasin underflow. In wet years, frequent storm runoff and winter thaws preclude easy identification of ground-water discharge.

FLOW DURATION

Flow-duration curves afford a convenient means of characterizing the flow of streams. They show, for a particular period of time, the percentage of time that given flows were equaled or exceeded. The entire regimen of a river's flow is incorporated into a single curve. Flow-duration curves for the gaging station on Middle Branch Escanaba River, near Ishpeming are shown in figure 10. These curves show, for example, that streamflow at this station was equal to or greater than 28 cfs (cubic feet per second) 90 percent of the time during the period 1955–64, and equal to or greater than 23 cfs 90 percent of the time during the period 1962–64. Conversely, the flow was less than 28 and 23 cfs for 10 percent of the time during the two periods, respectively. The period 1955–64 is the period of actual record, and 1962–64 is the period during which most of the data for this study were obtained (fig. 6). Evidently the recent 3-year period was substantially drier than the longer period—an average of about 30 percent drier. Duration curves for the periods 1955–64 and 1944–64 for the gaging station on Sturgeon River near Sidnaw were nearly identical. The Sturgeon River basin adjoins the Michigamme River basin, and the Sidnaw station is only 25 miles west of Lake Michigamme. Therefore, it is reasonable to assume that the same relationship holds for this study area—namely, that the 1955–64 period is actually representative of the longer period 1944–64.

Using methods of correlation and analysis described by Searcy (1959), flow-duration data were computed for all locations unaffected by regulation where continuous or occasional, but systematic, discharge records were obtained (table 2). These data cover only the lower half of the duration curve, from the median discharge (flow equaled or exceeded 50 percent of the time) to the minimum. From the standpoint of water supply, this half is the significant part of the duration curve for unregulated streams. The data, of course, are less reliable for locations having short-term records. Medium and low-flow data in table 2 are also shown in terms of cubic feet per second per square mile to facilitate comparisons between streams.

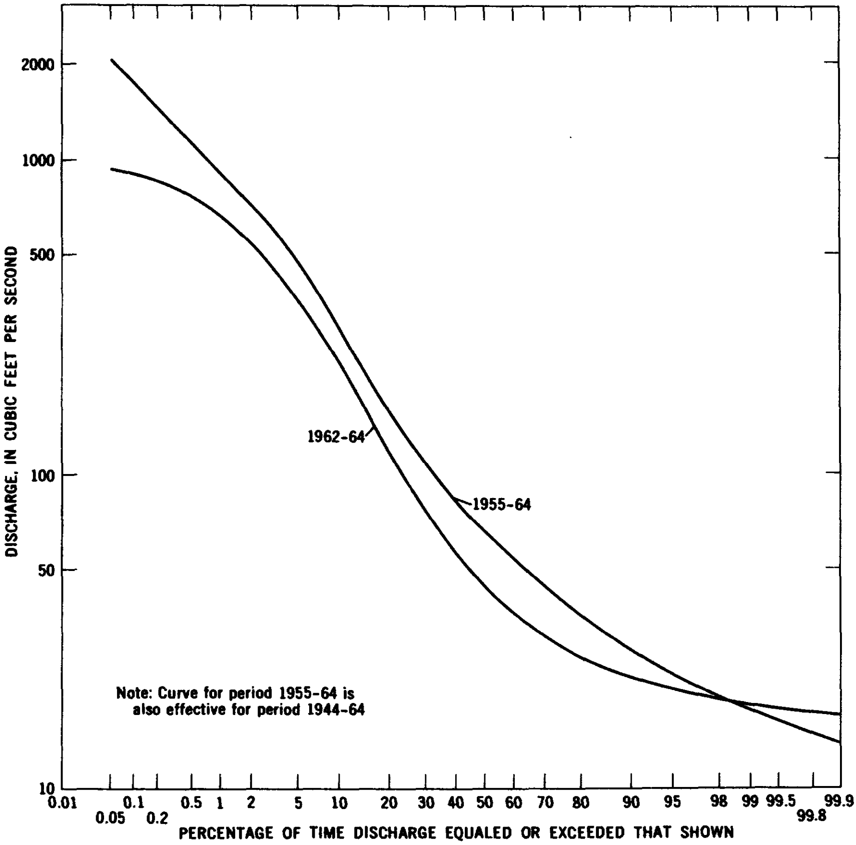


FIGURE 10.—Duration curves of daily discharge, Middle Branch Escanaba River near Ishpeming.

TABLE 2.—*Streamflow characteristics at data-collection sites*

[Data adjusted to period 1944–64. Discharge and low-flow data in cubic feet per second and in cubic feet per second per square mile (italicized)]

Station No.	Station name	Drainage area (sq mi)	Discharge equaled or exceeded for percentage of time shown				Average discharge	Average 7-day low flow for the recurrence interval shown				Average 30-day low flow for the recurrence interval shown				Mean annual flood (cfs)	10-year flood (cfs)
			50	70	90	95		2 yrs	5 yrs	10 yrs	20 yrs	2 yrs	5 yrs	10 yrs	20 yrs		
442	Carp Creek at Ishpeming	16.5	8.2 *.61*	6.5 *.39*	4.8 *.29*	4.0 *.24*	12 *.73*	5.0 *.30*	3.4 *.21*	3.0 *.18*	------	5.2 *.31*	4.0 *.24*	3.2 *.19*	------	------	------
443	Gold Mine Creek near Ishpeming.	4.89	5.0 *1.02*	4.0 *.82*	3.0 *.61*	2.8 *.57*	7.0 *1.43*	3.0 *.61*	2.5 *.51*	2.0 *.41*	------	3.5 *.72*	2.7 *.55*	2.3 *.47*	------	------	------
444	Carp River near Negaunee [1]	51.4	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
577	Middle Branch Escanaba River near Champion.	23.7	11 *.46*	6.0 *.25*	2.5 *.11*	1.6 *.067*	27 *1.14*	2.0 *.084*	.6 *.025*	.3 *.013*	------	3.5 *.15*	1.2 *.051*	.5 *.021*	------	------	------
578	Middle Branch Escanaba River at Humboldt.	46.0	23 *.50*	15 *.33*	9.0 *.20*	7.4 *.16*	45 *.98*	9.0 *.20*	5.4 *.12*	4.0 *.087*	------	11 *.24*	6.6 *.14*	4.8 *.10*	------	1,030	1,800
578.2	Middle Branch Escanaba River near Greenwood.	73.3	37 *.50*	25 *.34*	15 *.20*	12 *.16*	73 *1.00*	15 *.20*	9.5 *.13*	7.5 *.10*	------	18 *.25*	11 *.15*	8.5 *.12*	------	1,100	1,900
578.5	Black River near Humboldt.	11.3	5.0 *.44*	2.6 *.23*	.8 *.071*	.3 *.027*	13 *1.15*	.7 *.062*	.08 *.0071*	.02 *.0018*	------	1.3 *.11*	.3 *.027*	.06 *.0053*	------	------	------
579	Black River near Republic	34.4	14 *.41*	8.2 *.24*	4.0 *.12*	2.8 *.081*	31 *.90*	4.0 *.12*	1.6 *.047*	1.0 *.029*	------	5.2 *.15*	2.2 *.064*	1.2 *.035*	------	250	440
579.8	Black River near Greenwood.	50.8	25 *.49*	15 *.30*	8.0 *.16*	6.3 *.12*	52 *1.02*	8.0 *.16*	3.5 *.069*	2.5 *.049*	------	10 *.20*	5.2 *.10*	3.5 *.069*	------	580	1,000
580	Middle Branch Escanaba River near Ishpeming.	128	65 *.51*	45 *.35*	28 *.22*	23 *.18*	127 *.99*	28 *.22*	18 *.14*	14 *.11*	11 *.086*	33 *.26*	21 *.16*	16 *.13*	13 *.10*	1,230	2,100
580.2	West Branch Creek near National Mine.	19.6	10 *.51*	7.2 *.37*	4.5 *.23*	3.8 *.19*	17 *.87*	4.2 *.21*	2.7 *.14*	2.0 *.10*	------	5.0 *.26*	3.3 *.17*	2.5 *.13*	------	------	------
580.5	Middle Branch Escanaba River near Suomi.	179	95 *.53*	68 *.38*	48 *.27*	42 *.23*	175 *.98*	50 *.28*	35 *.20*	28 *.16*	------	55 *.31*	38 *.21*	31 *.17*	------	1,600	2,800
580.8	Bear Creek near Princeton	11.8	9.0 *.76*	8.0 *.68*	7.0 *.59*	6.8 *.58*	11 *.93*	7.2 *.61*	6.5 *.55*	6.1 *.52*	------	7.5 *.64*	6.8 *.58*	6.3 *.53*	------	------	------
581	Middle Branch Escanaba River near Princeton.	210	129 *.61*	96 *.46*	67 *.32*	58 *.28*	215 *1.02*	67 *.32*	48 *.23*	39 *.19*	------	76 *.36*	54 *.26*	43 *.20*	------	1,830	3,200
581.3	Green Creek near Princeton	13.8	7.0 *.51*	5.5 *.40*	4.5 *.33*	4.2 *.30*	11 *.80*	4.7 *.34*	3.8 *.28*	3.3 *.24*	------	5.0 *.36*	4.0 *.29*	3.5 *.25*	------	------	------
581.7	Ely Creek near National Mine.	9.25	2.5 *.27*	1.6 *.17*	1.0 *.11*	0.8 *.086*	5.2 *.56*	1.0 *.11*	.6 *.065*	.4 *.043*	------	1.2 *.13*	.7 *.076*	.5 *.054*	------	------	------
582	Schweitzer Creek near Palmer.[1]	23.6	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
583	Warner Creek near Palmer	14.2	6.9 *.49*	4.8 *.34*	3.3 *.23*	2.9 *.20*	15 *1.06*	3.8 *.27*	2.6 *.18*	2.0 *.14*	------	4.2 *.30*	2.8 *.20*	2.1 *.15*	------	------	------
583.7	Goose Lake Outlet near Cascade Junction.	21.8	10 *.46*	5.2 *.24*	2.8 *.13*	2.3 *.11*	23 *1.05*	3.5 *.16*	1.8 *.083*	.8 *.037*	------	4.0 *.18*	2.0 *.092*	1.0 *.046*	------	------	------

584	Goose Lake Outlet near Sands Station.	37.5	15 *.40*	10 *.27*	7.0 *.19*	6.2 *.17*	29 *.77*	8.0 *.21*	5.5 *.15*	4.2 *.11*	-------- --------	8.5 *.23*	6.0 *.16*	4.5 *.12*	-------- --------	450	790
584.5	East Branch Escanaba River near Sands Station.	96.6	40 *.41*	28 *.29*	20 *.21*	18 *.19*	70 *.72*	23 *.24*	17 *.18*	14 *.14*	-------- --------	25 *.26*	18 *.19*	15 *.16*	-------- --------	970	1,700
585	East Branch Escanaba River at Gwinn.	124	54 *.44*	38 *.31*	28 *.23*	26 *.21*	94 *.76*	32 *.26*	24 *.19*	20 *.16*	17 *.14*	34 *.27*	25 *.20*	21 *.17*	18 *.15*	1,200	2,100
620.95	Dishno Creek near Champion.	19.5	9.5 *.49*	6.1 *.31*	3.4 *.17*	2.5 *.13*	20 *1.03*	2.2 *.11*	1.2 *.062*	.8 *.041*	-------- --------	3.2 *.16*	1.8 *.092*	1.2 *.062*	-------- --------	--------	--------
621	Peshekee River near Michigamme.	66.5	46 *.69*	30 *.45*	17 *.26*	13 *.20*	98 *1.48*	12 *.18*	6.8 *.10*	4.9 *.074*	-------- --------	17 *.26*	10 *.15*	6.5 *.098*	-------- --------	1,400	2,430
622	Peshekee River near Champion.	133	88 *.66*	54 *.41*	28 *.21*	19 *.14*	200 *1.50*	18 *.14*	9.6 *.072*	6.5 *.049*	-------- --------	27 *.20*	15 *.11*	9.5 *.071*	-------- --------	2,450	4,300
622.2	Spurr River at Michigamme.	26.4	19 *.72*	13 *.49*	8.0 *.30*	6.0 *.23*	38 *1.44*	5.5 *.21*	3.0 *.11*	2.0 *.076*	-------- --------	7.8 *.30*	4.5 *.17*	3.0 *.11*	-------- --------	--------	--------
622.5	Spruce Creek near Republic.	31.2	13 *.42*	10 *.32*	6.5 *.21*	5.5 *.18*	23 *.74*	5.7 *.18*	4.0 *.13*	3.2 *.10*	-------- --------	7.0 *.22*	5.0 *.16*	4.0 *.13*	-------- --------	390	680
623	Michigamme River at Republic.	240	165 *.69*	110 *.46*	70 *.29*	50 *.21*	300 *1.25*	47 *.20*	30 *.13*	22 *.092*	-------- --------	65 *.27*	40 *.17*	29 *.12*	-------- --------	1,200	2,100
623.2	Trout Falls Creek near Republic.	23.1	9.2 *.40*	6.8 *.29*	4.5 *.20*	3.6 *.16*	15 *.65*	3.5 *.15*	2.5 *.11*	2.0 *.087*	-------- --------	4.5 *.20*	3.1 *.13*	2.4 *.10*	-------- --------	--------	--------

[1] Discharge regulated.

For the locations listed in table 2, the lower part of the flow-duration curve can be drawn using data in columns headed,"Discharge equaled or exceeded for percentage of time shown." The slope of the lower part of the duration curve is a good index of basin storage, including ground-water storage. A flat slope indicates a generous amount of storage, whereas a steep slope indicates lesser storage. The flow-duration curves are flattest for Bear and Green Creeks near Princeton and Gold Mine Creek near Ishpeming. The steepest are for locations in the headwater areas of the Middle Branch Escanaba and Black Rivers.

The extremes of the flow-duration curve are subject to frequent revision because of the erratic variation in minimum and maximum values of streamflow. The 90-percent point on the duration curve has been used by various investigators as an index of low flow because the point is sufficiently far from the minimum to be fairly stable and yet low enough to be significant. The term "low flow", where used subsequently in this report, means the discharge equaled or exceeded 90 percent of the time. The flow of unregulated streams is shown in plate 4. Average and median flows are also shown, thereby providing a fairly complete definition of the streamflow characteristics of this area.

The average streamflow (discharge) given in table 2 represents the maximum supply that can be developed. An examination of duration curves available for Upper Peninsula streams indicates that the average flow corresponds to the discharge at, or near, the 26-percent point on the flow-duration curve.

FREQUENCY OF LOW FLOWS

The flow-duration curve is useful for preliminary studies and for comparisons between streams; however, because it does not present the flows in their natural sequence, whether the lowest flows occurred consecutively or were scattered throughout the record cannot be determined. This deficiency is overcome by low-flow frequency curves which show the average frequency with which specific discharges may be expected to recur as the lowest average flow for periods of prestated length.

Figure 11 contains a family of curves for each of two stations showing the frequency of low flows. In low-flow frequency studies, the data are analyzed by climatic years (year beginning April) so that the complete low-water season is contained in the annual period. The curves for the Ishpeming station, for example, show that on an average of about once in 10 years the average flow for 7-day and 120-day periods may be as low, or lower than, 14 and 25 cfs, respectively. Frequency, expressed as recurrence interval, must be interpreted as the average time between occurrences. Thus, a 7-day average flow of 14 cfs or lower may occur in 2 successive years, but chances are that only 10 such events will occur in a 100-year period. Expressed in terms of probability, the 10-year low flow has a 10-percent chance (reciprocal of recurrence interval) of occurring in any 1 year. Data on the magnitude and frequency of the average 7-day and 30-day low flows are given in table 2.

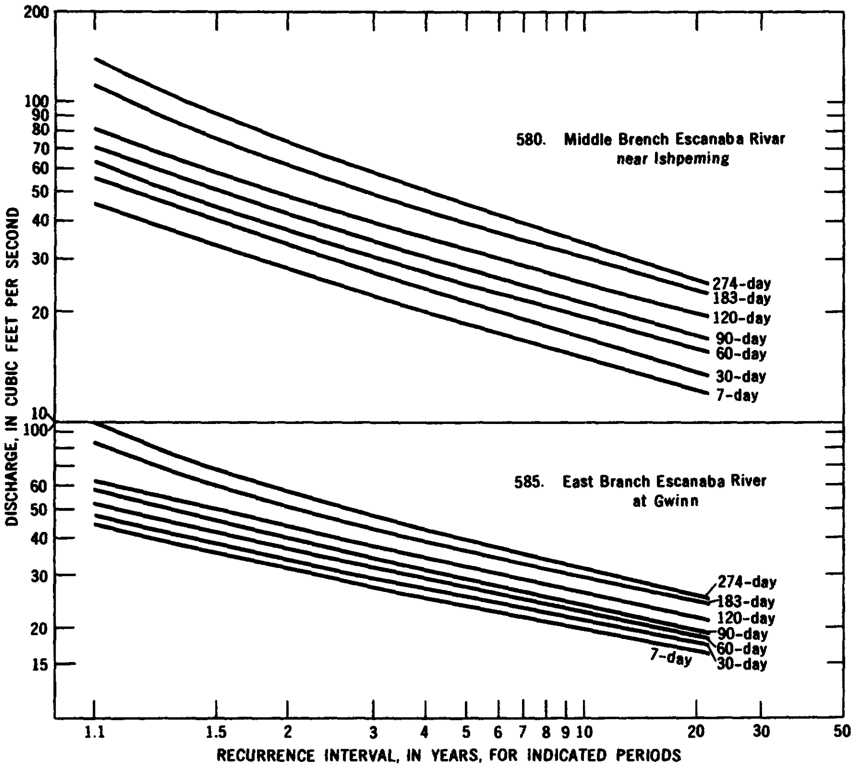


FIGURE 11.—Low-flow frequency curves for two gaging stations in the Escanaba River basin, adjusted to period 1943–63.

STORAGE ANALYSIS

If the low flow of a stream cannot supply the water demanded, then storage or supplemental sources must be considered. Storage requirements may be investigated by analyzing the low-flow records of streams in relation to anticipated demands. Frequency is incorporated into the investigations by basing the storage analyses upon low-flow frequency curves like those shown in figure 11. Inclusion of frequency in the analyses permits evaluation of the economics of storage projects.

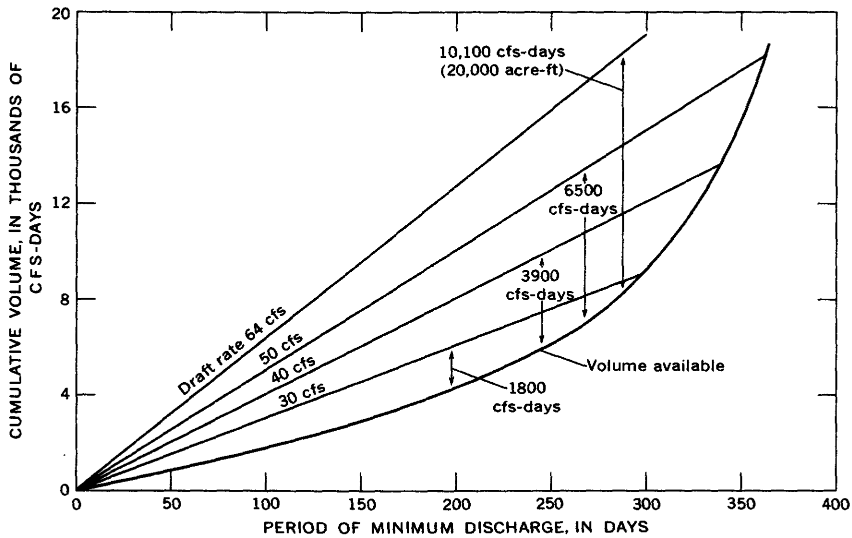


FIGURE 12.—Frequency-mass curve and draft-storage lines for 20-year recurrence interval, Middle Branch Escanaba River near Ishpeming.

Figure 12 is an example of a draft-storage-frequency relationship and was prepared from flows at the 20-year recurrence interval contained in the upper family of curves in figure 11. Figure 12 shows for example, that a storage volume of 10,100 cfs-days or 20,000 acre-ft, would fail to support a draft rate of 64 cfs on an average of once in 20 years.

Draft-storage-frequency curves for 5- and 20-year recurrence intervals for Middle Branch Escanaba River near Ishpeming and East Branch Escanaba River at Gwinn are given in figure 13. These curves show, for example, that 10,000 acre-ft of storage would support a draft rate of 45 cfs at both stations with a 5-percent chance of inadequacy in any year. The same volume of storage can support draft rates of 64 and 58 cfs if a 20-percent chance of inadequacy can be tolerated. Draft rates shown in this report do not take into account water lost by evaporation and seepage. To allow for such losses, users of these figures should increase the storage needed or decrease the draft rate.

The storage required to provide selected flows for the 20-year recurrence interval is shown for three stations on plate 4. Reliability of the values given for Peshekee River near Champion is less than that for the other two stations because the Peshekee records are so short.

Draft-storage-frequency analyses for 11 stations in central and western Upper Peninsula were used to develop regional relationships (fig. 14). These curves permit estimation of storage requirements for any

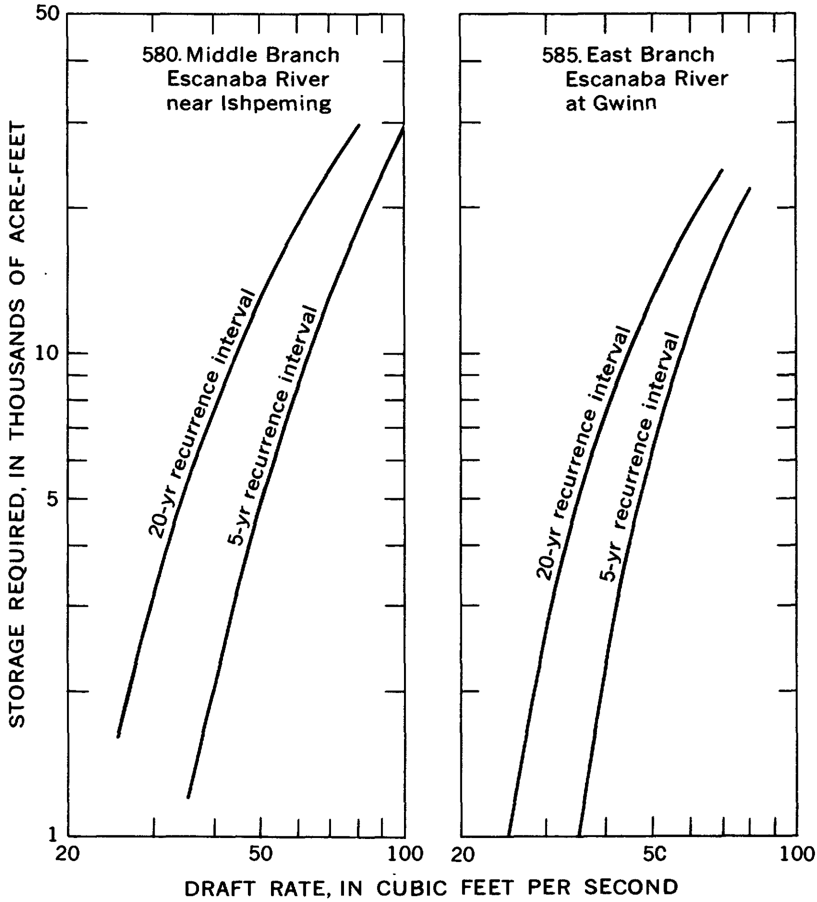


FIGURE 13.—Draft-storage-frequency relations for 5- and 20-year recurrence intervals.

site where the low-flow index is known or can be estimated. The index, the flow in cubic feet per second per square mile equaled or exceeded 90 percent of the time, is given in table 2 or on plate 4. Thus, for Black River near Greenwood the low-flow index is 0.16 cfs per sq mi (8÷50.8). Use of this index in figure 14 indicates that a storage of 9,400 acre-ft (185 acre-ft per sq mi) is needed to maintain a flow of 25 cfs (0.5 cfs per sq mi) at this location. Regional relationships as shown are useful for preliminary studies of storage requirements.

Improvement in water supply attributable to storage is illustrated in figures 15 to 17. The lower profile in these illustrations represents flow equaled or exceeded 90 percent of the time—the flow presently (1965) available without storage. Except as noted in the next paragraph, the bars represent the storage capacity available at sites listed

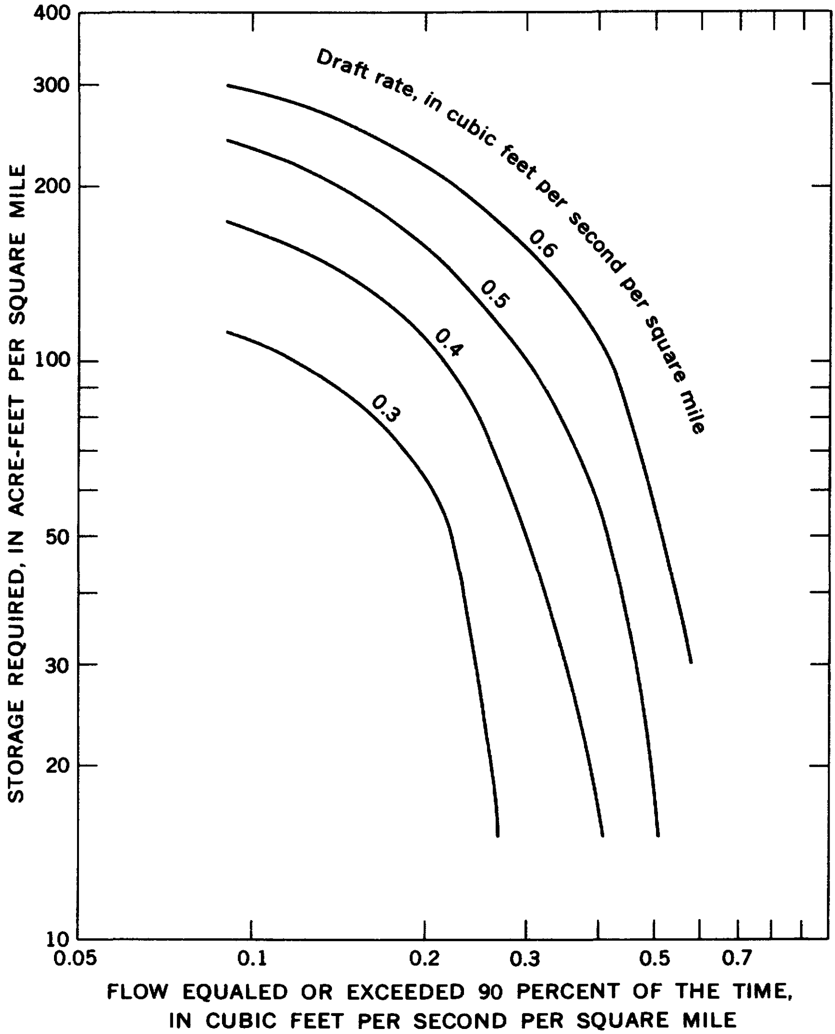


FIGURE 14.—Regional draft-storage curves for the 20-year recurrence interval for central and western Upper Peninsula.

in table 4 in the section on lakes and reservoirs. The upper profile represents the flow available if storage is provided as indicated by the bars. Figure 15 shows, for example, that at mile 20 on the Middle Branch Escanaba River about 43 cfs is presently available. By providing storage as indicated at miles 20, 25, 26.6, 34.5, and 50 (a total of about 33,200 acre-ft) the available supply can be raised to about 100 cfs. The present (1965) diversion for Humboldt mine, which is

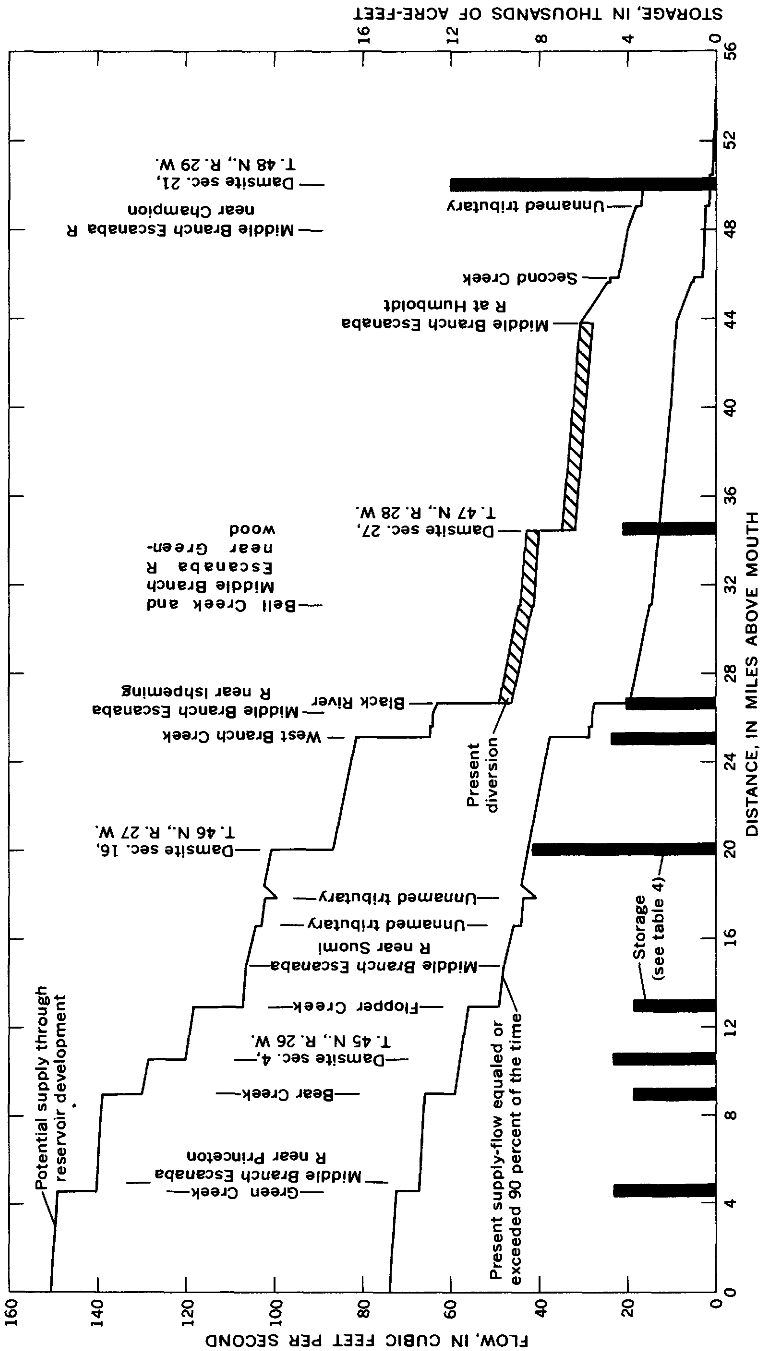


FIGURE 15.—Low flow and potential water supply for the Middle Branch Escanaba River.

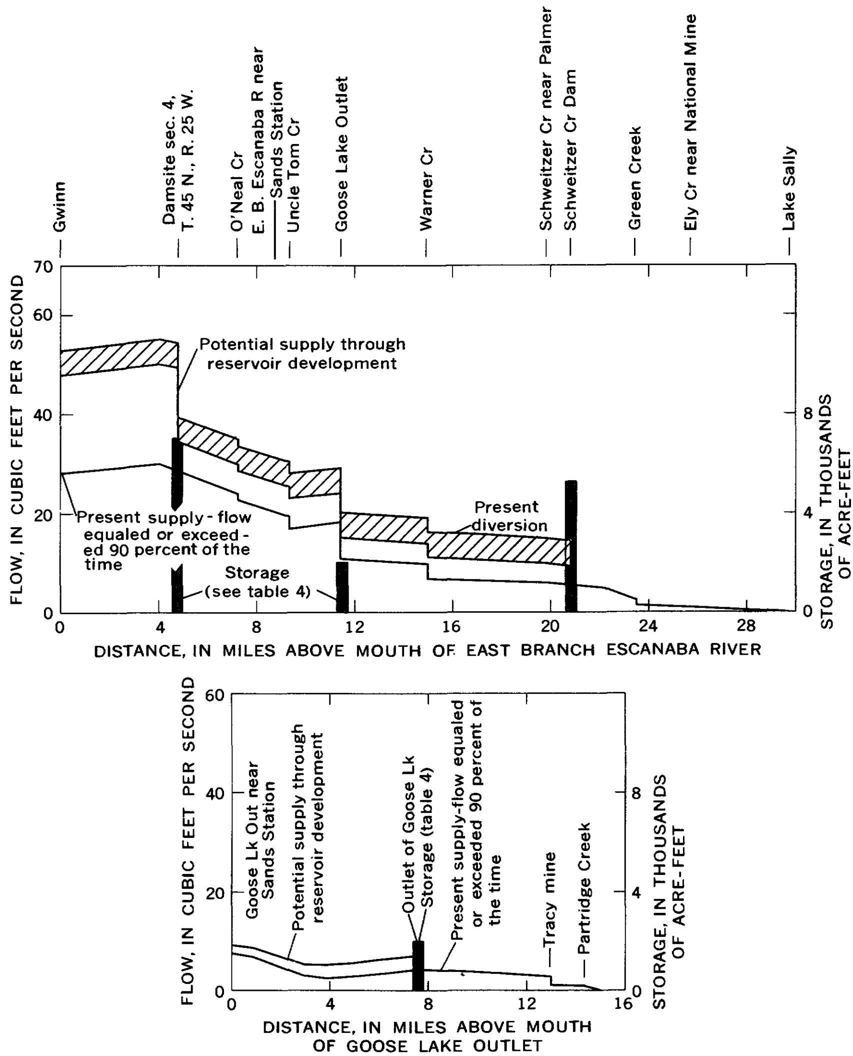


FIGURE 16.—Low flow and potential water supply for the East Branch Escanaba River and Goose Lake Outlet.

withdrawn from the river at mile 43.8 and returned via the Black River at mile 26.6, is also shown.

Some assumptions and estimates were made in preparing the profiles of potential supply. The many streamflow measurements that were available, however, permitted definition of the profiles with a fair degree of confidence. In some instances, the storage shown (bars) does not agree with that shown in table 4 for the same site. At sites

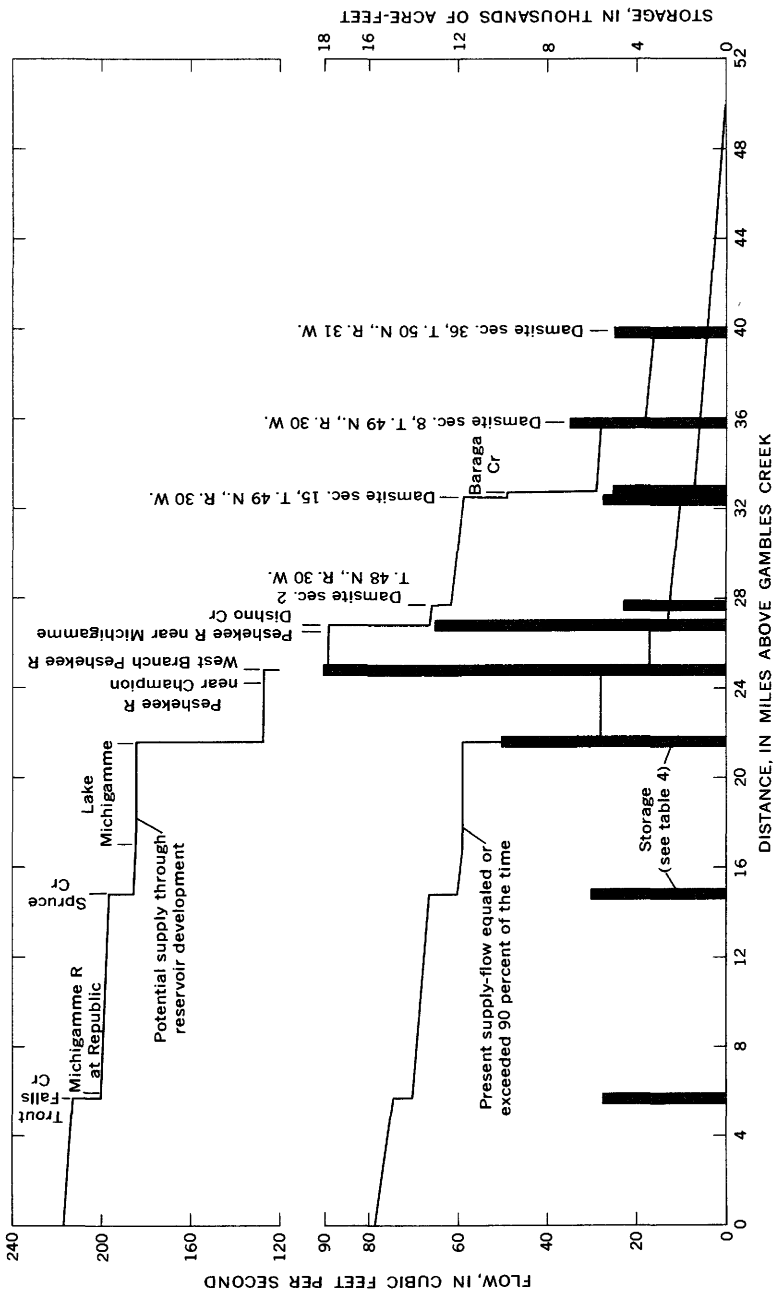


FIGURE 17.—Low flow and potential water supply for the Michigamme River.

having a large storage capacity, such as that at mile 50 on the Middle Branch Escanaba River (fig. 15), only the storage needed to support draft rates equal to the average discharge are shown in figures 15 to 17. The fact that additional storage space is available does not increase the long-term yield from the area; therefore, only the storage needed to support the supply that may be developed is shown. In other instances, upstream storage sites were assumed to have preempted the flow-regulation potential so that only a part of the storage at downstream points could be used.

Figures 15 to 17 clearly demonstrate that the best potential for developing surface-water supplies is in the Middle Branch Escanaba and Michigamme River basins. The East Branch Escanaba River basin, as subsequently explained, offers the best potential for ground-water development.

FLOODS

Floods were not of primary interest in this study. Yet no hydrologic analysis is complete without consideration of this phase of streamflow. Streams must be bridged, flood plains must be crossed, adequate spillways must be provided at impoundments, pumphouses and water intakes must be properly located, and depleted storage in reservoirs must be replenished periodically. These, and perhaps other, considerations require a knowledge of floodflows.

Most floods in this area occur during spring as the result of snowmelt or a combination of snowmelt and rain. The record floods of April and May 1960 were of the latter type. Records for the adjacent Sturgeon River basin indicate that the 1960 flood was the greatest in at least 30 years, and perhaps longer. Damage from this flood was light, however, because of the lack of damage potential on most of the flood plains. Occasional summer floods are caused by heavy thunderstorm rainfall. On July 29, 1949, for example, more than 5 inches of rain fell in Ishpeming in about 2 hours (U.S. Weather Bureau climatological data). Estimated damage amounted to several hundred thousand dollars, mostly to roadways and open fields.

Information on the magnitude and frequency of floods in the St. Lawrence River basin is contained in a recent report (Wiitala, 1965). Regional curves for recurrence intervals of 2.33 (mean annual flood), 5, 10, and 25 years showing the relation between magnitude of flood peaks and size of drainage area (fig. 18) have been computed from the relationships contained in the St. Lawrence River basin report. The curves are applicable to unregulated streams draining more than 30 sq mi. For example, a flood peak equal to or greater than 1,750 cfs can be expected to occur on an average of about once in 10 years at a site in area B (see fig. 19), where the drainage area is 100 sq mi.

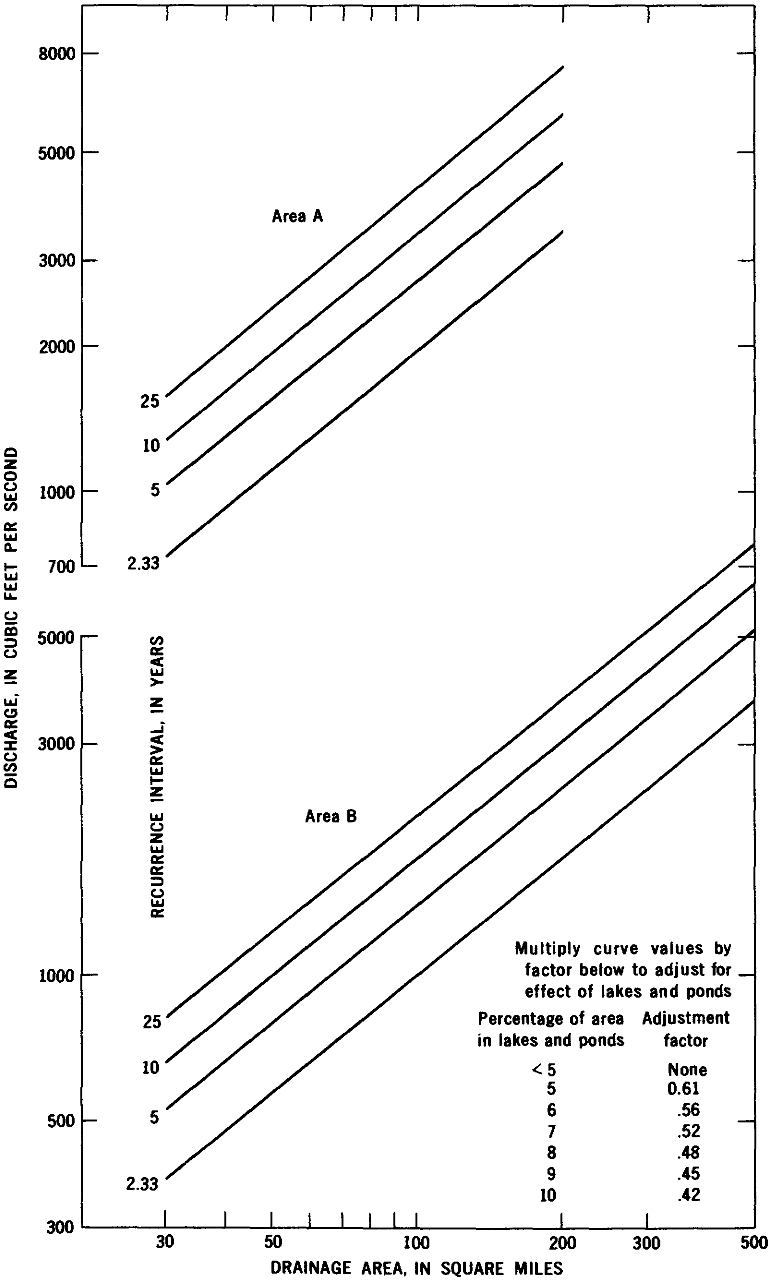


FIGURE 18.—Magnitude and frequency of annual floods.

Lakes and ponds were found to have an attenuating effect upon floodflows, this effect necessitating application of an adjustment factor when lakes and ponds constitute 5 percent or more of the basin area. If, in the previous example, 5 percent of the area was in lakes and ponds, the 10-year flood would be 1,750 × 0.61, or 1,070 cfs.

Flood data for gaging stations on unregulated streams draining 30 sq. mi. or more are given in figure 19. The depths given are only approximate because of the inherent nonuniformity of natural stream channels. In general, the depth of flow is referred to the control section which is usually a short distance downstream from the gage. Elevations given for the water surface are also approximate because at several gages the high-water stage-discharge relation is not completely defined and at others the gages have not been precisely tied in with sea-level datum. Though approximate, data in figure 19 give the user a general idea of the characteristics of floodflows at several locations.

LAKES AND RESERVOIRS

Water can be stored on the surface in lakes, ponds, swamps, and stream channels. The storage vehicle may be natural—such as a lake, swamp, or other depression—or it may be artificial—such as a reservoir created by a dam.

The most readily perceived sources of surface storage in this area are the 243 natural lakes, which range in size from less than an acre to more than 4,200 acres (table 3). Some are large enough and favorably located to warrant consideration as sources of water supply. For the most part, however, their present use is related to recreational and esthetic values.

Levels of inland lakes respond to variations in precipitation somewhat like streamflow although the amplitude and rate of change of water level are dampened by the available storage and physical characteristics of the basin. Fluctuations in water levels of five lakes in, or near, the report area during the water year ending September 30, 1963, are graphed in figure 20. Lake Michigamme and Ruth Lake (a few miles west of Lake Michigamme) are natural lakes having inlets and outlets; Boston Lake has no inlet and, in the year shown, had no outflow during the last 2½ months; Teal Lake has neither a defined inlet nor outlet. Deer Lake is a storage reservoir for the hydroelectric plant at Marquette. As indicated in figure 20, the range in fluctuations in water levels of natural lakes tends to be directly related to the size of the area that contributes runoff to them. The effect of man's control is obvious in the graph for Deer Lake. Possibly greater ranges in lake levels would occur in years when precipitation was more nearly normal.

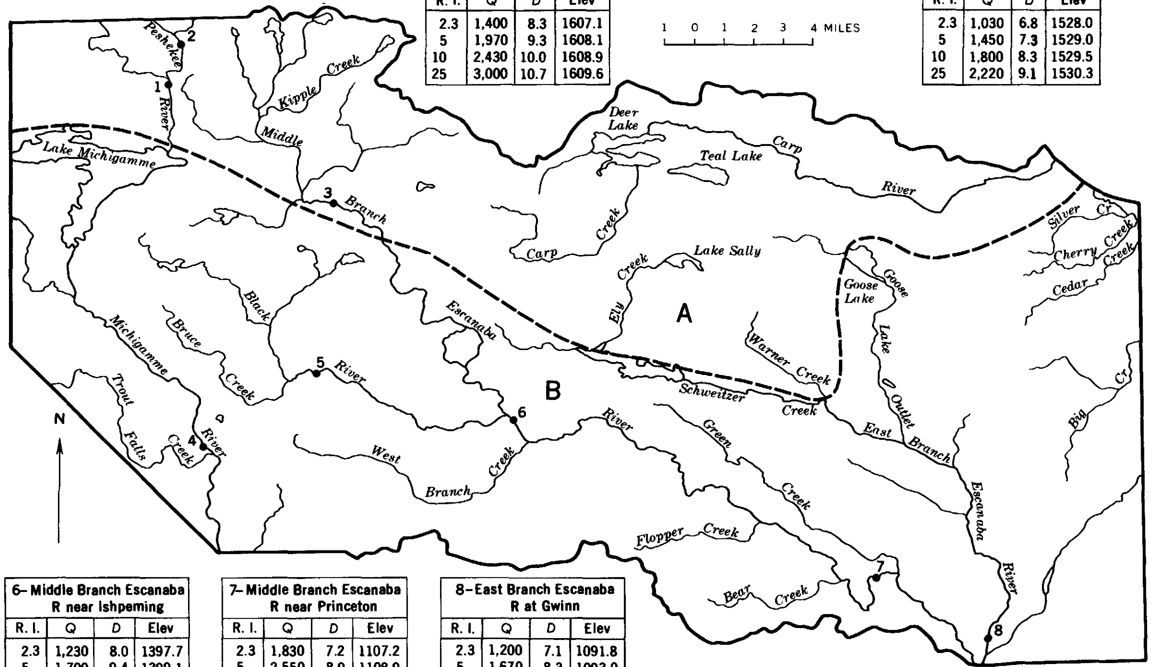
EXPLANATION

R. I. = Average recurrence interval, in years
Q = Flood discharge, in cubic feet per second
D = Approximate depth of flow, in feet
Elev = Water surface, in feet above mean sea level
A and B = Hydrologic areas

1- Peshekee R near Champion			
R. I.	Q	D	Elev
2.3	2,450	5.6	1564.0
5	3,400	6.8	1565.2
10	4,300	7.8	1566.2
25	5,300	8.8	1567.2

2- Peshekee R near Michigamme			
R. I.	Q	D	Elev
2.3	1,400	8.3	1607.1
5	1,970	9.3	1608.1
10	2,430	10.0	1608.9
25	3,000	10.7	1609.6

3- Middle Branch Escanaba R at Humboldt			
R. I.	Q	D	Elev
2.3	1,030	6.8	1528.0
5	1,450	7.3	1529.0
10	1,800	8.3	1529.5
25	2,220	9.1	1530.3



4- Michigamme R at Republic			
R. I.	Q	D	Elev
2.3	1,200	4.1	1469.1
5	1,700	4.9	1469.9
10	2,100	5.5	1470.5
25	2,500	6.1	1471.6

5- Black R near Republic			
R. I.	Q	D	Elev
2.3	250	3.2	1468.2
5	350	3.8	1468.8
10	440	4.2	1469.2
25	550	4.8	1469.8

6- Middle Branch Escanaba R near Ishpeming			
R. I.	Q	D	Elev
2.3	1,230	8.0	1397.7
5	1,700	9.4	1399.1
10	2,100	10.4	1400.1
25	2,600	11.7	1401.3

7- Middle Branch Escanaba R near Princeton			
R. I.	Q	D	Elev
2.3	1,830	7.2	1107.2
5	2,550	8.9	1108.9
10	3,200	10.4	1110.4
25	3,900	11.9	1111.9

8- East Branch Escanaba R at Gwinn			
R. I.	Q	D	Elev
2.3	1,200	7.1	1091.8
5	1,670	8.3	1093.0
10	2,100	9.3	1094.0
25	2,550	10.3	1095.0

FIGURE 19.—Frequency, discharge, depth, and elevation of floods at selected gaging stations.

TABLE 3.—*Summary of lakes*

[After Humphrys and Green (1962)]

Lake name	Surface area (acres)	Location		
		Section	Township N.	Range W.
Echo	68.0	5	45	24
		31, 32	46	24
Walton	16.0	5	45	24
Cameron	11.0	8	45	24
Farmer	32.0	16, 17	45	24
Beauyan	7.5	20	45	24
Morbit	38.0	20, 21, 29	45	24
Little	454.0	19, 20, 29, 30	45	24
Provost	34.0	7, 18	45	24
Martin	16.0	6, 7	45	24
Little Trout	10.0	1	45	25
Noren	18.0	13, 24	45	25
Irene	11.0	24	45	25
Mehl	78.0	24, 25	45	25
Airport	6.7	23	45	25
Slough	36.0	14, 23	45	25
Swanzy	7.0	11, 14	45	25
Stump	34.0	2, 11	45	25
Mud	87.0	14, 15	45	26
Perch	31.0	9, 10, 15, 16	45	26
Boot	25.0	13, 14	45	27
Francoeur	8.3	2	45	28
Little Perch	25.0	3	45	28
Engman	53.0	32, 33	46	24
Silver	6.2	32	46	24
Wilson	26.7	32	46	24
Powell	27.0	8, 9	46	25
Voelker	13.7	22	46	27
Long	25.0	4, 5	46	27
		32, 33	47	27
Perch	40.0	33, 34	46	28
Ross	7.5	15	46	28
Island	28.0	15	46	28
Tanglefoot	9.3	20	46	28
Skinnies	28.0	31	46	28
		25, 36	46	29
Long	50.0	34, 35	46	29
		2, 3	45	29
Sunson	12.0	35	46	29
Twin	5.8	35	46	29
Birch	37.0	11	46	29
Third	18.0	21, 22	46	29
Horseshoe	22.0	21	46	29
Beaver	12.0	21	46	29
Bengston	7.0	29	46	29
Milwaukee	50.0	8, 17	46	29
Perch	47.0	8	46	29
Hot Jack	30.0	24	46	30
Wahlstrom	14.0	24	46	30
Buschell	6.0	2	47	25
Strawberry	11.0	33	47	25
Pelesier	94.0	9, 10, 16	47	25
Little Pelesier	12.0	4, 9	47	25
Carp River	30.0	5, 6, 8	47	25
Harvey	6.5	30, 31	47	25

TABLE 3.—*Summary of lakes*—Continued

[After Humphrys and Green (1962)]

Lake name	Surface area (acres)	Location		
		Section	Township N.	Range W.
Grace	5. 0	13	47	26
Mud	7. 0	12	47	26
Goose	395. 0	13, 14, 15, 23, 24	47	26
Gribben	46. 0	34	47	26
Palmer	19. 0	25	47	27
Schoolhouse	13. 0	24	47	27
Ogden	57. 0	13, 14	47	27
Miller	25. 0	13	47	27
Foster	12. 0	23	47	27
Tilden	53. 0	23	47	27
Sally	136. 0	14, 15	47	27
Minnie	16. 0	11	47	27
Gunpowder	6. 0	11, 12	47	27
Grass	0. 0	15	47	27
Angeline	70. 0	10, 11, 15	47	27
Bancroft	22. 0	3, 4	47	27
Bacon	14. 0	3	47	27
Blue	23. 0	33	47	27
Rock	26. 0	5, 8	47	27
Cooper	34. 0	5	47	27
		32	48	27
North	12. 0	1, 2	47	28
Lowmoor	36. 0	8	47	28
Lory	140. 0	13	47	29
Autio	12. 0	15	47	29
McKinnon	11. 0	10	47	29
Mud	10. 0	16	47	29
Tower	8. 5	32	47	29
Granite	40. 0	Many	47	29
Fish	156. 0	5, 6, 8	47	29
Kirk	4. 2	30	47	29
Perch	33. 0	7	47	29
Egg	1. 6	7	47	29
Mud	8. 5	6	47	29
Juncob	29. 0	35, 36	47	30
Buto	20. 0	30	47	29
		25	--------	30
Twin	47. 0	13, 24	47	30
Goose	107. 0	13, 14	47	30
Horseshoe	37. 0	12	47	30
Nirish	13. 0	23, 26	47	30
Perch	1. 7	22	47	30
Dashwa	8. 6	15, 16	47	30
Gibson	61. 0	5, 6	47	30
		31, 32	48	30
Morgan Pond	7. 0	35	48	26
Horseshoe	6. 2	27	48	26
Baldwin Kiln	10. 0	21	48	26
Picket	3. 0	30	48	26
Teal	466. 0	31	48	26
		35, 36	--------	27
Deer	897. 0	Many	48	27
Goldmine	23. 0	26, 35	48	28
Boston	50. 0	32, 33	48	28
Brocky	90. 0	6, 7	48	28

243-028 O—67——4

TABLE 3.—*Summary of lakes*—Continued

[After Humphrys and Green (1962)]

Lake name	Surface area (acres)	Location		
		Section	Township N.	Range W.
Trembath	28.0	24	48	29
Wolf	109.0	2	48	29
		35	49	29
Log	174.0	3, 4, 10	48	29
Round	40.0	16, 17	48	29
Glass	37.0	17, 20	48	29
Bush	34.0	6, 7	48	29
Gravel	9.0	26	48	30
Arvid	22.0	14, 15	48	30
Hilltop	6.0	12	48	30
Arsenault	1.6	2	48	30
Northwestern	5.0	22	48	30
Mud	5.0	22	48	30
Michigamme	4,212.0	Many	Many	Many
Sixteen	10.0	16, 17, 21	48	30
Indian	102.0	5	48	30
		32	49	30
Little Michigamme	28.0	31	48	30
		36	48	31
Thomas	141.0	7	48	30
		12	48	31

NOTE.—In addition, about 123 unnamed small lakes, ranging in size up to about 5 acres, are distributed throughout the area.

Long-term records for Teal Lake and Lake Michigamme show no definable trends (fig. 21). Precipitation records for Ishpeming show an accumulated deficiency from normal of about 24½ inches for the 3-year period ending in 1925 and about 6 inches for the 2-year period ending in 1946. These deficiencies undoubtedly account for all, or at least part, of the declines in Teal Lake levels shown for those periods. Such pronounced response in lake levels, however, is not evident in the 4 years ending in 1910 when the accumulated precipitation deficiency was 23½ inches nor in the 3 years ending in 1963 when the deficiency was 20½ inches. Diversion of about 2 cfs of water pumped from mines into Teal Lake has been going on for some years and probably moderated the 1961–63 decline in the lake's level. At Lake Michigamme, the maximum recorded level of 1,557.1 feet above mean sea level occurred in the spring of 1960, and the minimum of 1,549.2 feet occurred in the fall of 1948. The average annual range between maximum and minimum levels of Lake Michigamme is 4.5 feet.

The great variation in water levels, the size, and the proximity to existing and potential mining developments direct special attention to Lake Michigamme. Flashy spring runoff from the Peshekee River basin undoubtedly accounts for the characteristic steep rise in water level of this lake during the spring freshet season (fig. 20). A large discharge capacity at the outlet permits quick removal of the runoff temporarily stored in the lake. These conditions are not conducive to the best utilization of the storage potential of the lake. Construction of a dam at the outlet would greatly improve the water-management possibilities of the lake. Control of outflow from the lake would permit a gradual winter drawdown to provide storage space for the copious spring runoff. The drawdown would augment the normally low winter flows and, by lowering the winter lake level, reduce ice damage to beaches, docks, piers, and other riparian property. In an engineering study of Lake Michigamme levels, the Michigan Department of Conservation concluded that the most desirable spring and summer lake levels were 1,553.5 and 1,551.5 feet above mean sea level, respectively. Drawdown from the spring to summer level would thus provide about 8,000 acre-ft of stored water for potential use. A second reservoir downstream from Lake Michigamme would be desirable to hold this water for release in late summer when outflow from Lake Michigamme would have to be reduced to maintain the desired summer level. Lake Michigamme thus affords considerable opportunity for imaginative water management to benefit withdrawal uses of water and lake-level control.

The total water-surface area of the lakes listed in table 3 is somewhat more than 10,000 acres, about 2½ percent of the area covered by this study. An average fluctuation of 2 feet in lake level over this area is equivalent to a volume of 20,000 acre-ft, or a runoff of 0.6 inch from the 610 sq mi of the area—probably a conservative estimate of the usable natural storage in these lakes.

Artificial storage can be used to modulate the variability of streamflow by storing water in periods of surplus for release during periods of low flow. Topography of this area is favorable for reservoir development. From a map study, 25 locations were selected as possible damsites (fig. 22), data for which are contained in table 4. The sites inventoried, however, do not necessarily exhaust the possibilities for storage development in and near the area. Data in table 4 are approximate and useful only for preliminary planning. Detailed field investigations and economic analyses would be needed for final project planning and design.

Refill potential indicated in table 4 was rated on the basis of the probability of replacing the entire storage volume annually. Somewhat arbitrarily, the refill potential was rated as excellent if the storage capacity was less than 3 inches, good if between 3 and 4½ inches, fair if between 4½ and 6 inches, and poor if greater than 6 inches. For

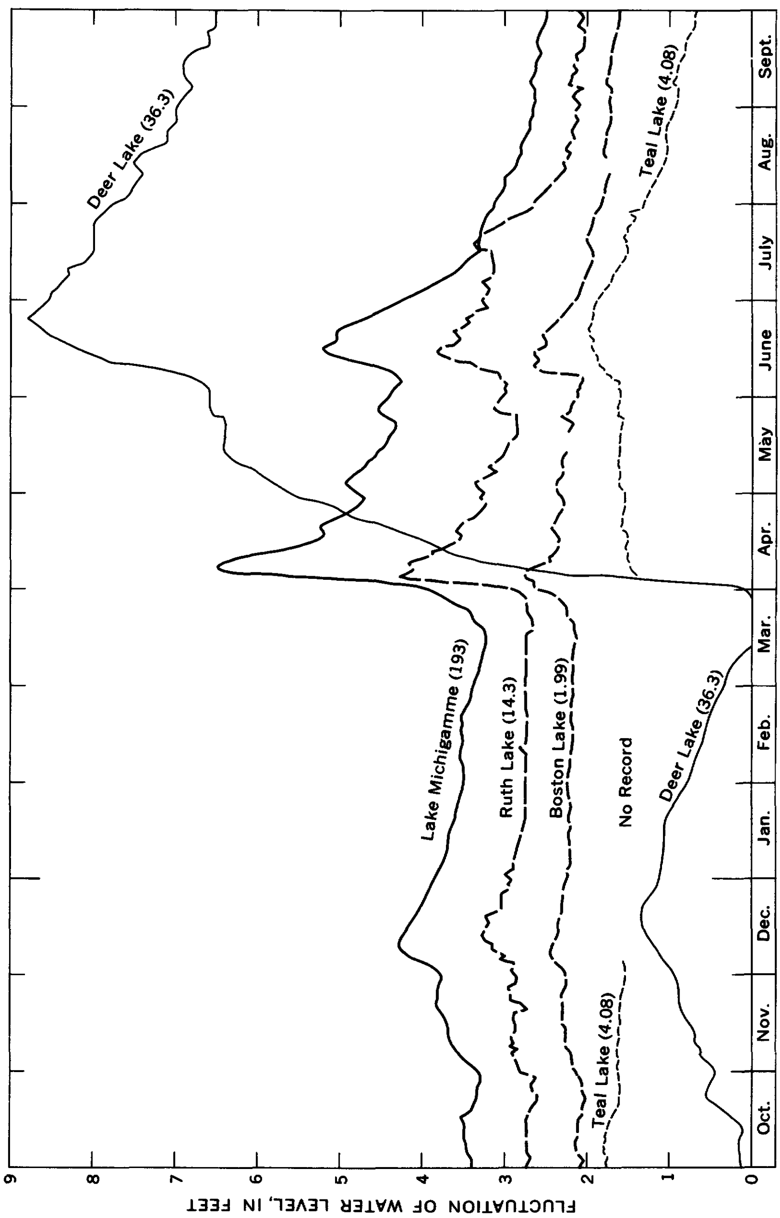


FIGURE 20.—Water levels in five lakes for water year ending September 30, 1963. Number in parentheses is area, in square miles, tributary to lake.

TABLE 4.—*Inventory of possible damsites*

[Map numbers on fig. 22. Refill potential: P, poor; F, fair; E, excellent]

Map No.	Stream or lake	Location: Section	Location: Township N.	Location: Range W.	Drainage area (sq mi)	Approximate height of dam (feet)	Elevation of crest (feet above mean sea level)	Pond area (acres)	Storage capacity: Acre-ft	Storage capacity: Equivalent runoff from basin (inches)	Refill potential	Remarks
1	Carp Creek	13	47	28	10.5	40	1,490	490	5,400	9.5	P	
2	Big Creek	5	46	24	14.5	90	820	470	17,000	22	P	
3	Middle Branch Escanaba	21	48	29	16.5	55	1,640	1,100	26,000	30	P	
4	do	27	47	28	67	30	1,500	460	4,200	1.25	E	
5	Black River	35	47	29	34	30	1,500	390	4,000	2.25	E	
6	West Branch Creek	23	46	28	31	25	1,420	440	4,700	2.75	E	
7	Middle Branch Escanaba	16	46	27	170	60	1,390	580	8,300	1	E	
8	Flopper Creek	36	46	27	8.0	50	1,280	200	3,700	8.5	P	
9	Middle Branch Escanaba	4	45	26	192	40	1,220	330	4,600	.5	E	
10	Bear Creek	7	45	26	5	30	1,460	370	3,700	14	P	
11	Green Creek	24	46	27	8	60	1,300	530	11,000	26	P	
12	Middle Branch Escanaba	7	45	25	230	65	1,160	550	16,000	1.25	E	
13	Goose Lake	24	47	26	14.6	6	1,222	520	2,000	2.5	E	
14	East Branch Escanaba	4	45	25	112	35	1,140	600	7,000	1.25	E	
15	Peshekee River	36	50	31	19	20	1,800	580	5,000	5	F	Outside limits of map (fig. 22).
16	do	8	49	30	23	30	1,740	640	9,000	7.25	P	Do.
17	Baraga Creek	10	49	30	8.5	20	1,730	500	7,000	15.5	P	Do.
18	Peshekee River	15	49	30	38	30	1,700	450	5,500	2.75	E	Do.
19	do	2	48	30	46	65	1,680	1,200	23,000	9.5	P	Do.
20	Dishno Creek	6	48	29	19.5	80	1,700	1,400	35,000	34	P	
21	West Branch Peshekee	3	48	30	55.5	30	1,680	1,300	18,000	6	F	
22	Beaufort Lake	21	48	31	20	6	1,616	820	1,600	1.5	E	Outside limits of map (fig. 22).
23	Lake Michigamme	9	47	30	193	7	1,554	4,200	8,400	.75	E	
24	Spruce Creek	18	47	30	22	50	1,620	320	6,000	5	F	
25	Trout Falls Creek	14	46	30	12.5	30	1,540	440	5,000	7.5	P	

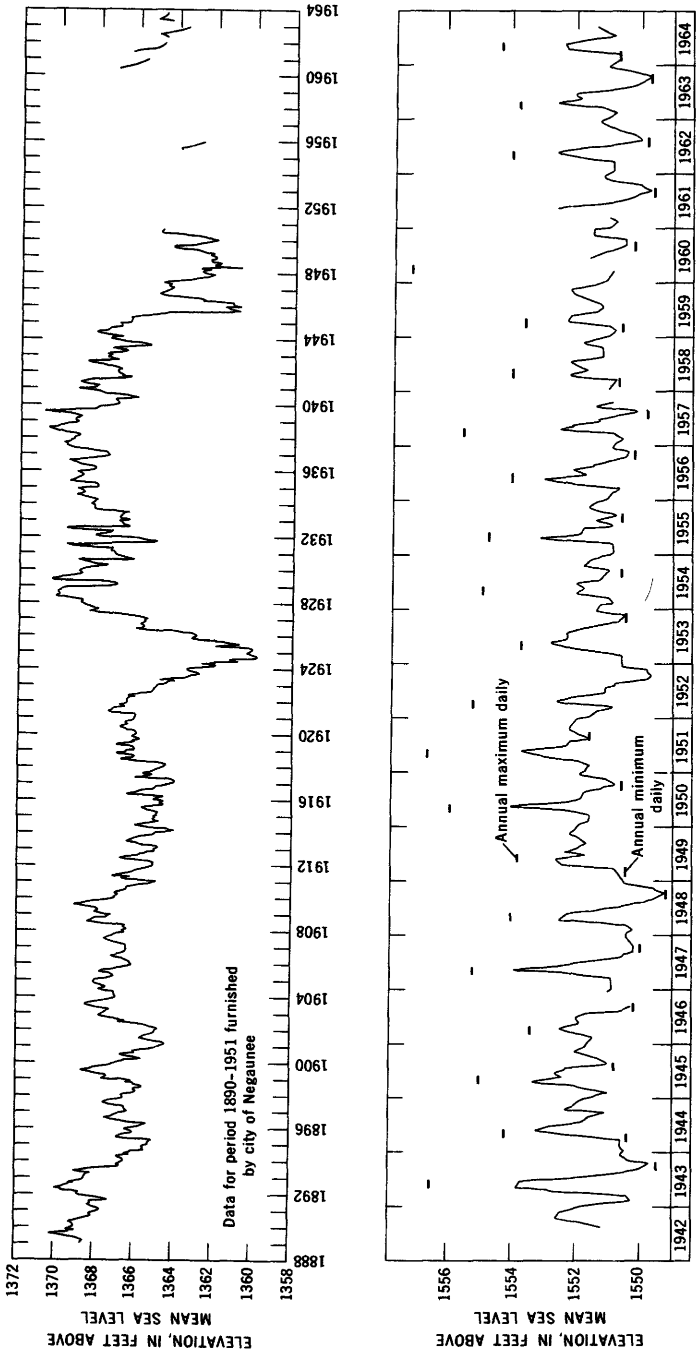


FIGURE 21.—Monthly mean water levels, Teal Lake, 1890–1951, 1956, 1961–64, and Lake Michigamme, 1942–64.

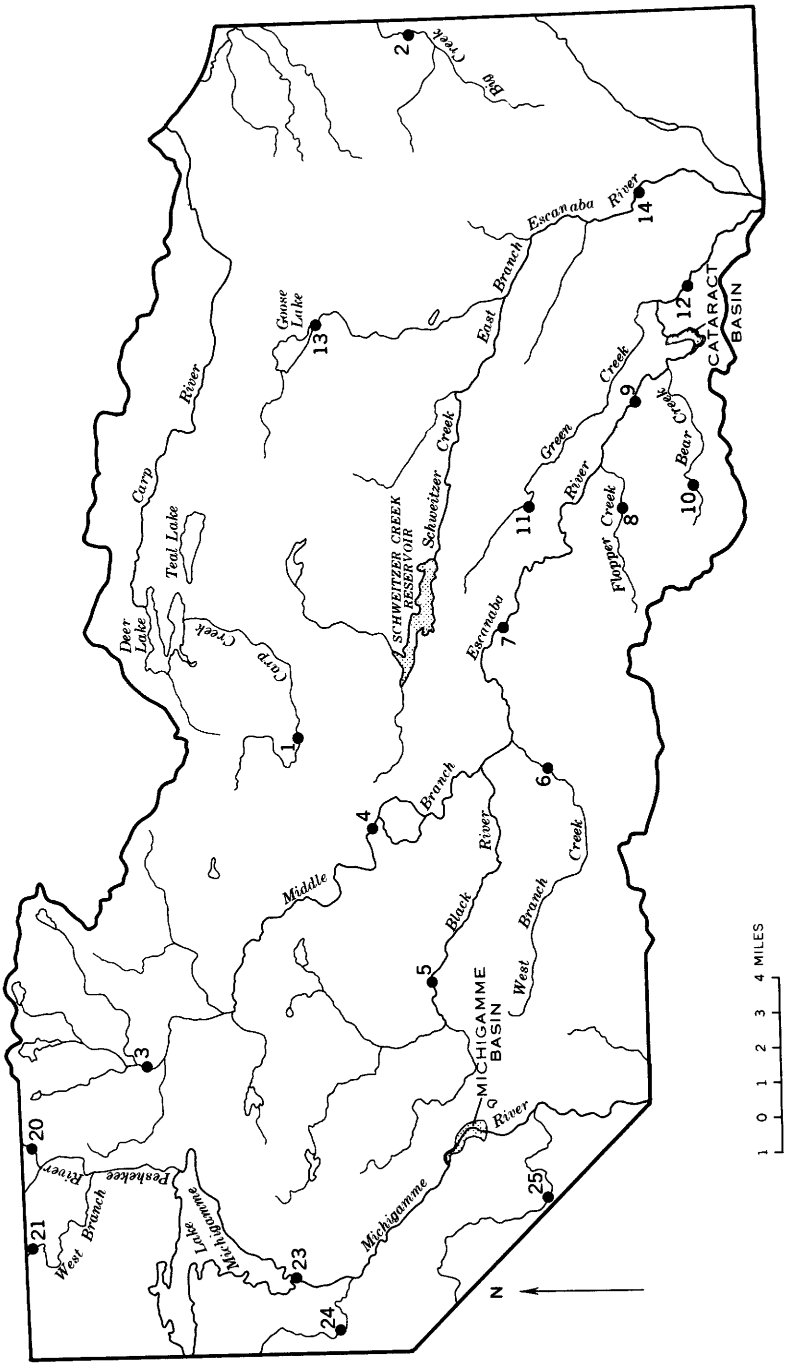


Figure 22.—Possible damsites (see table 4).

example, the refill potential is excellent for a storage equivalent to 2 inches of runoff because available streamflow records indicate that at least this volume of runoff can be expected every spring.

Several factors make sites 3 and 20 (table 4) attractive for possible utilization. The storage capacity at each is large, more than enough to satisfy all the present (1965) industrial water needs in the Middle and East Branch Escanaba River basins; the impoundment area of each is in virginal brush and woodland where little or no conflict with existing land and water uses would be expected; and the damsite at each is in a gorge where construction costs per unit of storage would be relatively low. Installation of diversion facilities at Dishno Creek, site 20, would allow release of Dishno Creek water into the headwaters of the Middle Branch Escanaba River for transport to points of need. Some subsidiary benefits applicable to lake-level control on Lake Michigamme might be derived from a reservoir on Dishno Creek. The Dishno Creek drainage area, however, is not large enough to provide substantial benefit to Lake Michigamme and to assure refilling of the reservoir each spring.

Construction of dams at outlets of some natural lakes could provide a modest amount of storage at relatively low cost. Goose Lake, in particular, seems worthy of such development because of its size, proximity to industrial activity, and freedom from riparian occupance. Storage estimates given for the lakes listed in table 4 (sites 13, 22, and 23) are conservative. They do not include storage that could be realized by drawing the lakes down to below-normal levels in winter to capture more of the spring runoff.

Existing artificial storage developments include Deer Lake, Schweitzer Creek Reservoir, and small impoundments at hydroelectric stations on Middle Branch Escanaba River near Princeton and on Michigamme River at Republic.

Deer Lake is the largest reservoir in the area. At full pond level, 1,390 feet above mean sea level, it contains 22,500 acre-ft of storage (fig. 23), equivalent to about 11½ inches of runoff from its watershed of 36.3 sq mi. The water is used for power generation at Carp River powerplant in Marquette. A small intake reservoir for this powerplant is located about 5 miles upstream from the mouth at Lake Superior. The powerplant, which operates under a head of about 608 feet, is one of the highest head hydroelectric plants in the United States east of the Mississippi River. Storage in Deer Lake is usually replenished during the spring runoff season and is released during the remainder of the year. The graph showing the 1963 water levels (fig. 20) is probably typical of the operating pattern. The flow of the Carp River is completely regulated by this reservoir. The storage capacity is so large that the lake is seldom filled to full pond level.

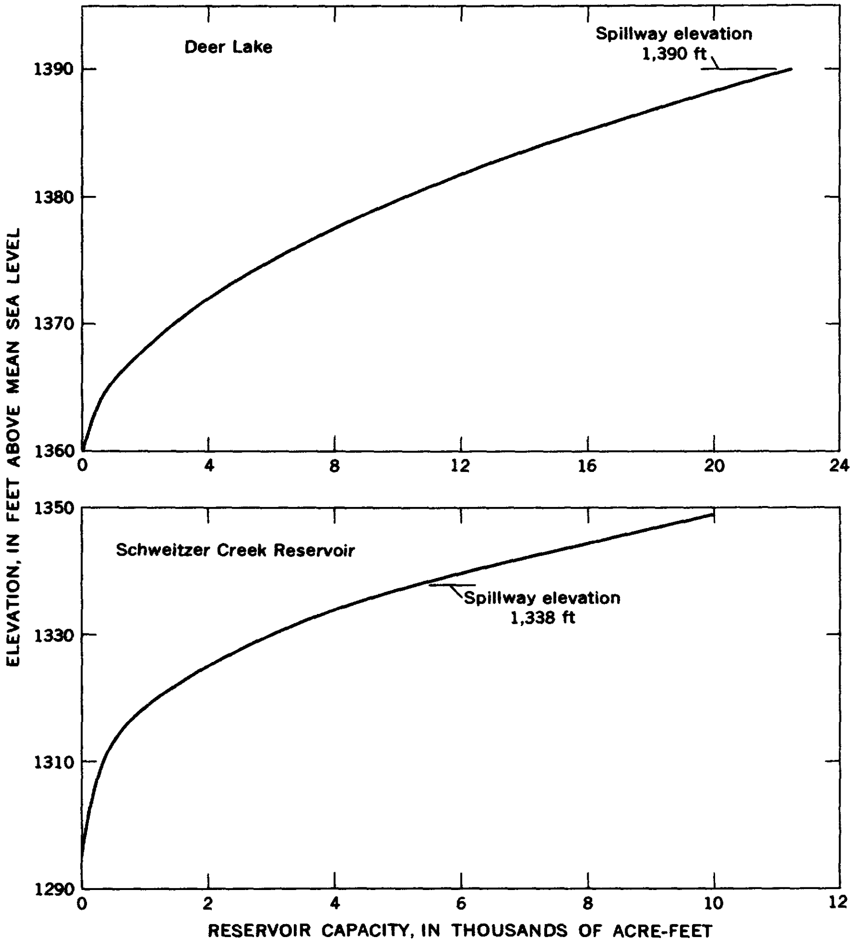


Figure 23.—Storage-capacity curves for Deer Lake and Schweitzer Creek Reservoir.

Schweitzer Creek Reservoir, completed in 1962, has a capacity of 5,300 acre-ft at the full pond level of 1,338 feet above mean sea level (fig. 23). This amount of storage is equivalent to 4.3 inches of runoff from the watershed of 23.1 sq mi. Water is withdrawn from the reservoir for use at Empire mine near Palmer. Sufficient water is released from the reservoir to maintain a flow of at least 3.5 cfs in Schweitzer Creek at the gaging station about 1½ miles downstream from the dam. Because the iron-ore industry's water demands are not seasonal, a relatively steady draft is imposed upon the reservoir. Storage is replenished during the spring high-water season. Waste waters from the Empire mine operations are discharged into settling basins south of the reservoir from which they eventually pass into Green Creek, a tributary of the Middle Branch Escanaba River. This use thus constitutes a diversion from the East Branch Escanaba River basin.

Impoundments for hydroelectric stations on Middle Branch Escanaba River near Princeton and on Michigamme River at Republic are shown in figure 22 as Cataract Basin and Michigamme Basin, respectively. Because of the small variation in water levels at these plants, these ponds represent a very small storage volume. The powerplant at Republic was abandoned in the summer of 1963. Perhaps a greater fluctuation in the pond level can be tolerated henceforth, thus providing a modest amount of storage.

QUALITY OF SURFACE WATERS

Preceding sections on surface water have dealt principally with the question, "How much water is available?" But water must also withstand certain tests of quality for the various uses it is intended to satisfy. Also, some uses effect changes in water quality that must be considered by succeeding users. Consequently, the following several sections will deal with the questions, "What kind of water is available?" and "How do uses affect the water quality?" The ensuing discussion of water quality is divided into considerations of the dissolved mineral matter and gases that make up chemical quality; of the suspended sediment characteristics which are of special significance in the potential water-use pattern of this area; and of the temperature of surface waters.

CHEMICAL QUALITY

Water in streams of the Marquette Iron Range area is generally of suitable quality for most uses. With few exceptions, the water is potable, and concentrations of dissolved minerals are generally well below suggested maximum limits set forth in the 1962 drinking water standards of the U.S. Public Health Service.

Quality criteria for industrial water supplies vary widely and depend upon the purposes for which the water is used. Therefore, no single set of water-quality standards could adequately cover all requirements. Although "industries are generally willing to accept for most processes water that meets drinking water standards" (McKee and Wolf, 1963, p. 92), some industries do require water of better quality. A comprehensive discussion of water-quality criteria for individual industries is contained in the McKee and Wolf report. The source and significance of chemical constituents and physical properties commonly found in waters of the Marquette Iron Range area are shown in table 5.

TABLE 5.—*Source and significance of chemical constituents and properties commonly found in natural surface and ground water in the Marquette Iron Range area*

[USPHS, U.S. Public Health Service]

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from nearly all rocks and soils.	Contributes to formation of boiler scale Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from the common iron-bearing minerals present in most formations.	Oxidizes to a reddish-brown sediment. Stains utensils, enamelware, clothing, and other articles. Unsatisfactory for food processing, dyeing, laundering, bleaching, beverages, textiles, processing of ice. USPHS (1962) drinking water standard suggest that iron should not exceed 0.3 ppm.
Manganese (Mn)	Dissolved from manganese-bearing minerals. Present in most acid waters.	Same objectionable features as iron. Causes brown-black stain. USPHS (1962) drinking water standards suggest that manganese should not exceed 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved principally from gypsum, limestone, and dolomite formations. Also found in some quantity in almost all formations. Large quantities are found in brines.	Impart hardness and scale-forming properties to water; are soap consuming (see hardness). Unsuitable for laundries, steam plants, textile processing, and dyeing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in sea water, brines, feldspars, and sewage.	Cause boiler foaming when present in large amounts. Combine with chloride to give a salty taste. Large quantities may limit use for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate minerals such as limestone and dolomite.	Raise the alkalinity and usually pH of water. In combination with calcium and magnesium, cause carbonate hardness and scale. Release corrosive carbon dioxide gas on heating.
Sulfate (SO_4)	Dissolved from shales and gypsum. Oxidation of sulfides. Commonly associated with coal-mining operations. Contributed by some industrial wastes.	With calcium, forms hard scale in steam boilers. Imparts cloudiness to ice. Causes bitter taste when combined in large amount with other ions. Calcium sulfate considered beneficial in brewing processes. USPHS (1962) drinking water standards recommend that sulfate content not exceed 250 ppm.
Chloride (Cl)	Dissolved in varying amounts in all soils and rocks. Also found in brines, sea water, and sewage.	Calcium and magnesium chloride may hydrolyze and increase the corrosive activity of water. In large amounts gives salty taste. USPHS (1962) drinking water standards recommend that chloride content should not exceed 250 ppm.
Fluoride (F)	Small amount available from most rocks and soils. Most fluoride concentrations over 1 ppm usually found in sodium waters. Primary source of high concentrations is industrial pollution. Added to many municipal supplies by fluoridation.	May cause mottling of enamel on teeth of children if present in amounts in excess of about 1.5 ppm. About 1 ppm reduces incidence of tooth decay in children (Maier, 1950). USPHS recommends control limits based upon annual average of maximum daily air temperatures. (See USPHS, 1962, p. 8.)
Nitrate (NO_3)	Decaying organic matter. Nitrate fertilizers. Sewage.	Investigations by Comly (1945) indicate that high concentrations (more than 44 ppm expressed as NO_3) may cause methemoglobinemia (infant cyanosis). USPHS (1962) drinking water standards suggest a limit of 45 ppm. Encourages growth of algae and other organisms which produce undesirable tastes and odors. Higher than local average may suggest pollution.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Often includes some water of crystallization.	USPHS (1962) drinking water standards recommend that the dissolved solids should not exceed 500 ppm. However, 1,000 ppm is permitted under certain circumstances. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.

TABLE 5.—*Source and significance of chemical constituents and properties commonly found in natural surface and ground water in the Marquette Iron Range area*—Continued

Constituent or property	Source or cause	Significance
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; more than 181 ppm, very hard (U.S. Geol. Survey).
Specific conductance (micromhos at 25° C).	Dissolved mineral content of the water.	Indicates degree of mineralization. Is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
pH (hydrogen-ion concentration or activity).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates generally raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Color	Yellow-to-brown color of some waters is usually caused by organic matter extracted from leaves, roots, and other organic substances. Color in water also results from industrial wastes and sewage.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Turbidity	Turbidity is the optical property of a suspension with reference to the extent to which the penetration of light is inhibited by the presence of insoluble material. Turbidity is a function of both the concentration and particle size of the suspended material (not to be confused with suspended sediment).	The USPHS recommends that turbidity not exceed 5 ppm in drinking and culinary water. Generally turbidity adversely affects fish production by excluding light and thereby interfering with the growth of plants important in fish-food cycle (McKee and Wolf, 1963, p. 290).
Temperature	Climatic conditions, use of water as a cooling agent, industrial pollution.	Affects usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground waters from moderate depths usually are nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells, the water temperature generally increases on the average about 1°F with each 60-foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the volume of water.

Variations in specific conductance, which is a measure of the degree of mineralization, of surface waters are shown in figure 24. The effect of dilution in water-quality improvement is also illustrated. For example, water in McKinnon Lake Outlet has a specific conductance of 334 micromhos, which indicates considerable mineralization. Dilution with less mineralized water from Lake Lory Outlet and with water from the Black River and Bruce Creek reduces the conductance to 98 micromhos by the time the water reaches the gaging station on Black River near Republic. The two streams having conductance of

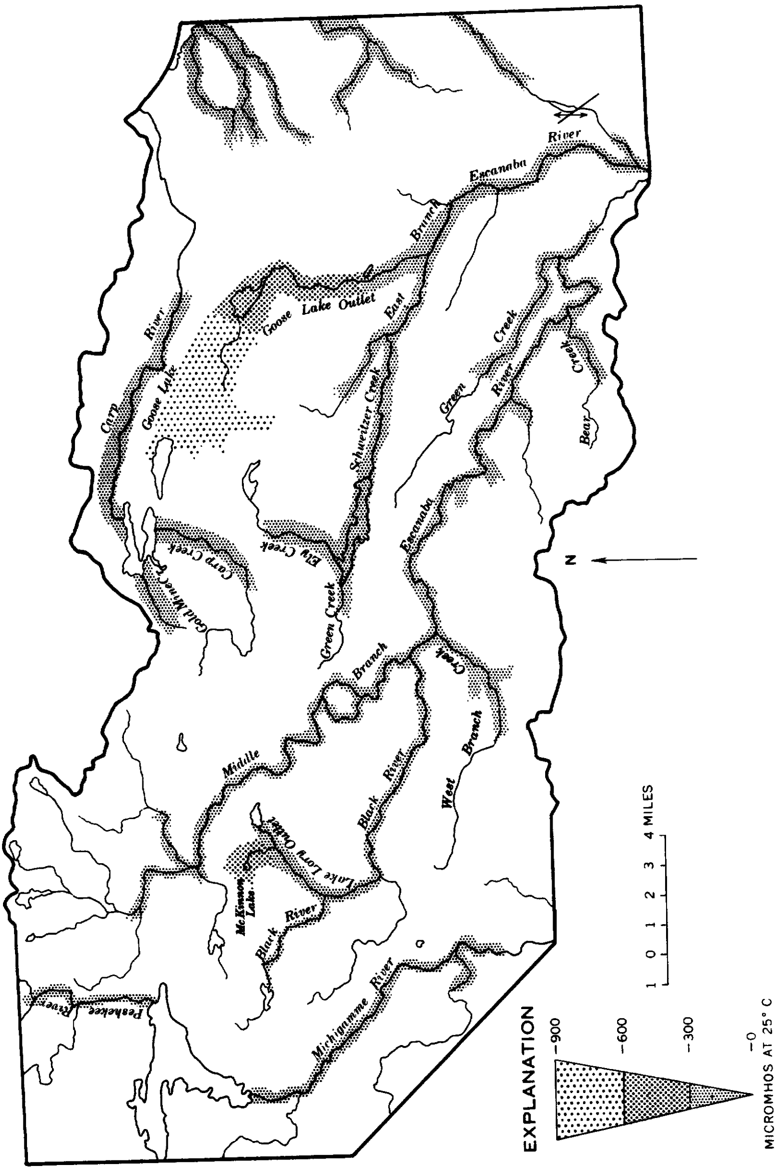


FIGURE 24.—Specific conductance of low flows in streams. (Low flow is the flow equaled or exceeded 90 percent of the time.)

300 micromhos or more receive water pumped from mines or waste water from iron-ore processing operations. The higher mineralizations are generally due to marked increases in calcium, magnesium, and sulfate.

The relation of total hardness to specific conductance of surface water is shown in figure 25. This relationship has not been significantly affected by the mining industry.

MIDDLE BRANCH ESCANABA RIVER BASIN

Water in the Middle Branch Escanaba River basin is of the calcium bicarbonate type and is generally soft except in the outlet streams from Lake Lory and McKinnon Lake. (See table 6.) Dissolved solids range from about 50 to slightly more than 200 ppm (parts per million). Dissolved oxygen is generally abundant.

Water quality in the main stream conforms to the basinwide description and varies only slightly in chemical and physical characteristics throughout its course. Downstream from Black River, there is a slight increase in color, turbidity, and dissolved solids. The pH of the water increases progressively downstream from Black River and reaches a value higher than 8.0 at times at the gaging station near Princeton. Dissolved oxygen is abundant and also increases as the water moves downstream. A supersaturated condition has been noted at times near Princeton. This condition probably results from aeration of the water as it passes through the hydroelectric powerplant located about 100 yards upstream from the Princeton gaging station.

Water in the Black River is very soft. There are many swamps in the headwaters, and the water has a color ranging from 100 to 180 at the most upstream points sampled. Color is reduced in the downstream reaches by diluting effect of ground-water seepage. During low flow, hardness of water flowing out of Lake Lory and McKinnon Lake is about 85 and 130 ppm, respectively. These lakes are used as tailings basins for Humboldt mine. Downstream from Lake Lory Outlet, dissolved solids, iron and manganese, turbidity, and sometimes bicarbonate, sulfate, chloride, nitrate, and total hardness increase noticeably. Despite the effects of Lake Lory and McKinnon Lake Outlets, water quality of Black River is not significantly degraded. At Black River Falls, about a mile above the mouth of Black River, effects of Lake Lory and McKinnon Lake Outlets are not noticeable. Consequently, ore-processing operations at Humboldt mine have not had an appreciable effect on the chemical quality of Black River.

Water in West Branch and Green Creeks is similar in quality to that in the main stream. Consequently, these streams affect the quality of the main stream very slightly. Since November 1963, however, head-

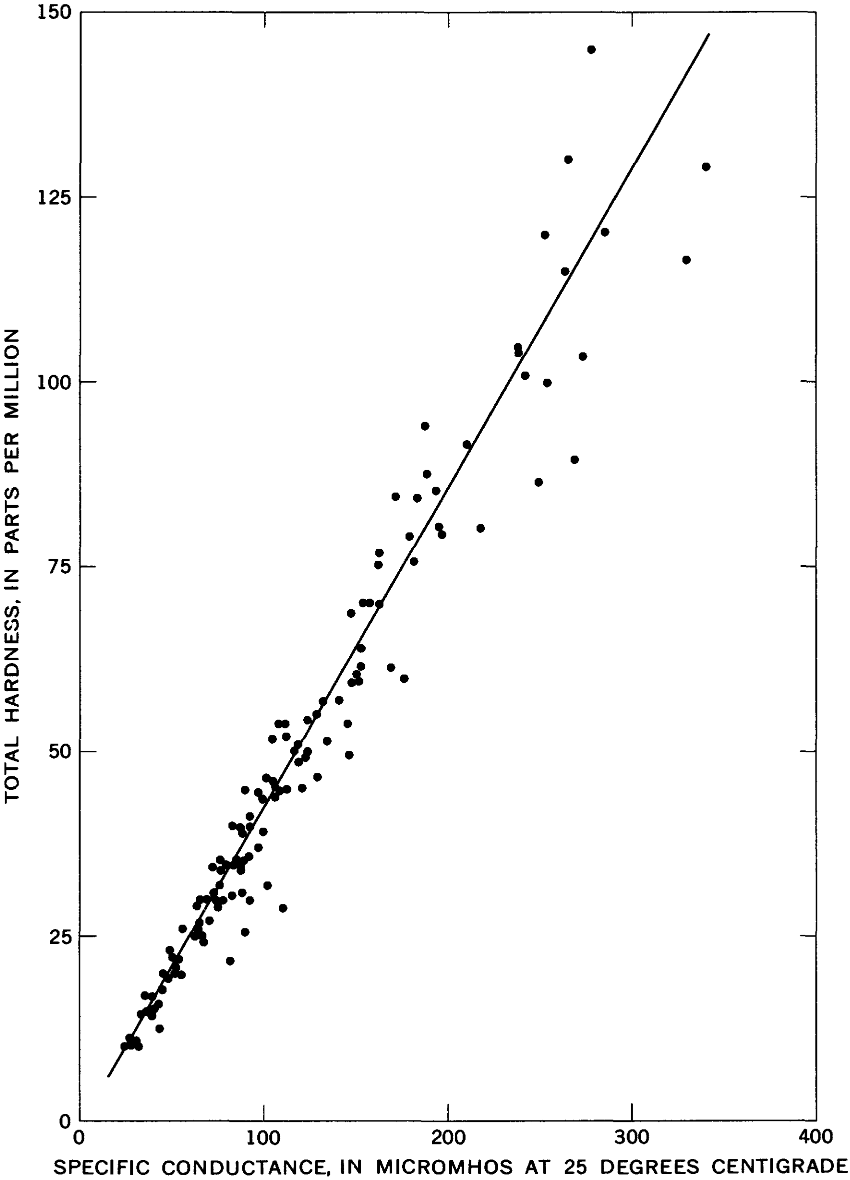


FIGURE 25.—Relation of total hardness to specific conductance of surface water.

waters of Green Creek basin have been used as a tailings basin for Empire mine. This development will probably have some effect upon the chemical quality of water in Green Creek although no data are available at this time (1965) to confirm the assumption.

TABLE 6.—*Chemical quality of surface water*

[Results in parts per million except as indicated

Station	Source	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
578	Middle Branch Escanaba River at Humboldt.	7-20-61	9.7	12	1.9	0.22	13	2.9	1.4	1.0	50
		10- 2-61	28	9.3	.83	.28	------	------	------	------	30
		4-26-62	326	5.1	.31	.03	4.8	.6	.8	.5	8
		11-14-62	24	20	.95	.00	------	------	------	------	38
		1-14-63	10	------	------	------	------	------	------	------	34
		4- 4-63	452	5.4	------	------	------	------	------	------	------
		4- 5-63	378	5.8	------	------	------	------	------	------	------
		4- 9-63	158	15	.55	.13	------	------	------	------	20
		7-26-63	10	------	------	------	------	------	------	------	56
578.2	Middle Branch Escanaba River near Greenwood.	4-25-62	[1] 450	5.7	.29	.03	------	------	------	------	8
		11-14-62	[1] 35	12	.87	.00	------	------	------	------	38
		4- 9-63	[1] 240	6.2	.50	.15	------	------	------	------	18
578.5	Black River near Humboldt.	7-20-61	[1] 1.5	3.8	[2] .91	[2] .11	------	------	------	------	8
		8-24-61	[1] .1	6.4	.57	[2] .00	------	------	------	------	12
		4-26-62	[1] 55	4.8	.55	.04	------	------	------	------	2
		11-15-62	[1] 7	13	1.0	.05	------	------	------	------	14
		4- 9-63	[1] 30	6.1	.59	.13	------	------	------	------	6
578.55	Lake Lory Outlet (Upper station, tributary to Black River) near Humboldt.	10- 2-61	[1] 1	10	.34	.11	------	------	------	------	54
		4-26-62	[1] 5	8.0	2.0	.36	------	------	------	------	25
		11-15-62	[1] 1	35	.47	.05	------	------	------	------	72
		1-14-63	[1] 1	------	------	------	------	------	------	------	78
		4- 5-63	[1] 5	------	------	------	------	------	------	------	------
578.6	McKinnon Lake Outlet near Humboldt.	10- 2-61	[1] 3	9.6	2.7	3.6	------	------	------	------	32
		4-26-62	[1] 10	10	3.1	.88	------	------	------	------	46
		11-15-62	[1] 1.5	39	.28	.05	------	------	------	------	88
		1-14-63	[1] 4	------	------	------	------	------	------	------	90
		4- 5-63	[1] 6	11	------	------	------	------	------	------	------
		4- 9-63	[1] 3	11	7.1	.10	------	------	------	------	24
		4-24-63	[1] 1	11	------	------	------	------	------	------	90
578.7	Lake Lory Outlet (Lower station, tributary to Black River) near Republic.	7-20-61	[1] 2.5	13	1.9	1.3	------	------	------	------	56
		8-24-61	[1] 1	10	.26	[2] .00	------	------	------	------	66
		10- 2-61	[1] 6	9.4	.85	.57	------	------	------	------	27
		4-26-62	[1] 30	8.3	2.2	.86	------	------	------	------	27
		11-15-62	[1] 5	14	.35	.02	------	------	------	------	52
		1-14-63	[1] 5	------	------	------	------	------	------	------	74
		4- 5-63	[1] 20	7.8	------	------	------	------	------	------	------
		4- 9-63	[1] 10	7.0	.61	.00	------	------	------	------	26
579	Black River near Republic.	7-20-61	4.9	11	[2] .66	[2] .23	7.7	3.4	3.1	2.7	42
		8-24-61	1.9	7.6	.79	.09	8.2	3.5	2.4	2.0	43
		10- 2-61	27	8.7	1.0	.28	------	------	------	------	22
		4-26-62	157	5.8	.92	.38	4.3	.9	1.6	1.1	9
		11-15-62	14	13	.84	.05	9.5	3.5	4.2	1.4	26
		1-15-63	9.2	------	------	------	------	------	------	------	36
		4- 5-63	105	------	------	------	------	------	------	------	------
		4- 9-63	54	31	.64	.15	------	------	------	------	32
		9-24-63	3.4	5.7	------	------	------	------	11	4.9	60
579.8	Black River near Greenwood.	7-19-61	[1] 9	9.0	1.5	.17	------	------	------	------	38
		8-24-61	[1] 5	7.6	1.1	.15	8.6	2.9	2.0	1.5	41
		4-25-62	[1] 250	6.0	.66	.17	4.6	.6	1.1	.9	7
		11-14-62	[1] 22	11	.92	.00	------	------	------	------	22
		4- 9-62	[1] 125	14	.62	.18	------	------	------	------	20
580	Middle Branch Escanaba River near Ishpeming.	7-19-61	37	8.8	.87	.09	9.4	2.7	2.2	.7	40
		8-24-61	23	9.5	.29	[2] .01	------	------	------	------	54
		4-25-62	680	5.9	.40	.06	------	------	------	------	8
		11-14-62	59	9.8	.82	.00	------	------	------	------	34
		1-15-63	33	------	------	------	------	------	------	------	40
		4- 5-63	724	------	------	------	------	------	------	------	------
		4- 9-63	346	18	.57	.16	------	------	------	------	26
		7-11-63	27	------	------	------	------	------	------	------	48
		7-22-64	[1] 19	------	------	------	14	3.9	3.6	.9	60
580.2	West Branch Creek near National Mine.	7-19-61	[1] 5.5	8.2	.65	.02	6.5	1.3	2.0	.2	25
		4-25-62	[1] 60	5.5	1.6	.06	------	------	------	------	11
		11-14-62	[1] 10	11	1.2	.00	------	------	------	------	38
		4- 9-63	[1] 30	6.7	.93	.13	------	------	------	------	24
		7-11-63	3.0	------	------	------	------	------	------	------	63

See footnotes at end of table.

of the Middle Branch Escanaba River basin

Color referred to platinum-cobalt scale]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Loss on ignition	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen: Ppm	Dissolved oxygen: Percent saturation
7.0	0.5	0.1	0.4	68	------	44	4	98	7.4	50	2	8.4	84
11	1.0	------	.6	73	39	33	8	76	6.8	60	4	------	------
8.8	1.0	.0	.8	46	26	14	8	33	5.9	75	.3	8.2	68
13	.5	------	.9	89	27	36	5	86	7.1	85	2	------	------
8.0	1.5	.4	.4	64	24	36	8	76	6.7	35	2	------	------
------	------	------	------	------	------	------	------	40	------	65	1	------	------
------	------	------	------	------	------	14	------	40	------	65	1	------	------
9.2	1.0	------	------	------	------	20	4	55	6.6	65	.2	------	------
------	------	------	------	------	------	46	0	105	7.0	65	3	------	------
8.8	1.0	------	.8	56	32	16	10	38	6.0	70	.3	------	------
14	.5	------	1.1	70	21	38	7	88	6.8	90	2	------	------
8.8	2.0	------	------	------	------	19	4	56	6.3	20	1	------	------
3.8	1.5	------	2.7	------	------	------	------	36	5.6	180	------	------	------
6.8	1.0	------	.4	68	------	14	4	36	6.3	170	2	------	------
8.0	1.0	------	1.1	71	50	10	8	27	5.2	100	.6	------	------
8.6	.5	------	1.7	61	30	16	4	44	6.4	180	1	------	------
6.4	2.0	------	------	------	------	10	5	31	5.8	100	.4	------	------
10	1.0	------	.4	96	58	50	6	117	7.0	55	4	------	------
16	1.0	------	.9	69	34	27	6	90	6.3	46	110	------	------
14	3.0	------	1.0	129	35	61	2	150	7.1	100	3	------	------
9.8	4.5	------	.2	108	24	70	6	153	7.1	25	2	------	------
------	------	------	------	------	------	25	------	66	------	65	1	------	------
17	2.0	------	.6	94	------	32	6	102	6.7	35	190	8.9	75
17	5.0	------	6.1	103	42	49	12	148	6.5	30	210	------	------
44	8.0	------	38	244	95	128	56	338	7.8	60	4	------	------
49	8.0	------	27	195	52	117	43	330	7.5	25	2	------	------
------	------	------	21	------	------	62	------	168	------	40	10	------	------
37	9.0	------	45	182	------	89	70	267	6.0	30	8	------	------
25	7.0	------	------	------	------	100	26	253	7.0	45	15	------	------
6.2	2.0	------	1.4	------	------	------	------	112	6.9	180	------	------	------
8.0	2.5	------	.5	97	------	50	0	123	7.3	45	5	8.6	92
19	3.0	------	1.2	104	44	37	15	97	6.6	100	30	9.8	82
14	2.0	------	1.9	77	37	30	8	91	6.3	90	120	------	------
31	5.5	------	25	150	47	81	38	217	7.2	75	2	------	------
40	6.5	------	22	178	55	103	42	273	7.5	30	3	------	------
------	------	------	5.0	------	------	28	------	75	------	70	2	------	------
19	5.0	------	18	106	40	47	26	129	6.4	80	1	------	------
5.6	.5	.2	1.2	71	26	33	0	88	6.8	80	20	------	------
8.8	1.2	.0	.3	72	21	35	0	88	7.0	42	5	8.8	98
15	1.0	------	1.2	86	47	29	11	77	6.5	70	10	10.2	86
8.4	1.0	.1	1.4	58	30	14	6	40	5.9	140	17	6.6	57
19	3.0	.2	8.9	93	49	38	16	101	6.7	120	2	11.4	84
20	4.0	------	8.1	112	42	52	22	134	6.9	80	8	------	------
------	------	------	------	------	------	15	------	44	------	90	1	------	------
10	3.0	------	------	------	------	22	0	81	6.8	90	1	------	------
24	8.0	------	34	------	------	87	38	249	7.0	35	1	10.0	92
7.2	1.0	------	.8	------	------	------	------	77	6.8	65	------	------	------
8.0	1.0	.0	.3	66	22	34	0	79	6.9	46	3	8.0	86
8.8	1.0	.1	1.2	52	30	14	8	35	6.1	50	10	10.4	94
16	1.5	------	4.5	82	34	30	12	74	6.5	130	1	------	------
9.2	3.0	------	------	------	------	21	4	62	6.3	80	1	------	------
6.4	1.0	.1	.4	56	------	34	2	81	7.3	35	2	8.8	95
9.2	.5	------	.1	72	------	47	3	101	7.3	25	1	------	------
12	1.0	------	1.0	51	30	15	8	38	5.9	90	3	------	------
12	.5	------	2.1	78	33	35	7	82	6.9	140	2	------	------
9.2	1.5	------	.8	71	23	39	6	87	7.1	35	3	------	------
------	------	------	------	------	------	30	------	72	------	90	1	------	------
10	2.0	------	------	------	------	24	2	66	6.8	80	1	------	------
------	------	------	------	------	------	42	2	93	7.0	60	1	------	------
7.0	.0	------	------	79	------	51	2	118	7.6	32	------	------	------
4.6	.0	.0	.6	36	------	22	1	50	6.6	50	.7	------	------
9.2	1.0	------	1.0	50	37	17	8	36	6.0	90	.8	------	------
9.2	.5	------	1.4	71	30	36	5	74	7.3	100	4	------	------
8.0	3.0	------	------	------	------	25	6	60	6.4	60	1	------	------
6.8	1.0	------	------	------	------	53	2	111	6.7	35	2	------	------

243-028 O—67——5

TABLE 6.—*Chemical quality of surface water of the*

Station	Source	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
580.5	Middle Branch Escanaba River near Suomi.	4-25-62	[1] 800	5.8	0.42	0.04	------	------	------	------	8
		11-14-62	[1] 95	17	.68	.05	------	------	------	------	48
		4- 9-63	[1] 450	6.2	.42	2.0	------	------	------	------	12
		7-11-63	39	------	------	------	------	------	------	------	52
580.8	Bear Creek near Princeton.	7-19-61	[1] 8	10	[2] .13	[2] .05	------	------	------	------	92
		4-25-62	[1] 40	6.0	.22	.05	------	------	------	------	40
		11-13-62	[1] 13	26	.21	.13	------	------	------	------	[3] 94
		4- 9-63	[1] 25	20	.45	.14	------	------	------	------	82
		7-11-63	3.7	------	------	------	------	------	------	------	114
581	Middle Branch Escanaba River near Princeton.	7-19-61	[1] 340	8.3	[2] .24	[2] .05	------	------	------	------	54
		8-23-61	80	7.8	.55	.12	14	4.0	1.2	0.6	58
		4-25-62	830	5.9	.41	.09	5.2	1.0	.9	0.9	10
		11-14-62	365	17	.66	.02	------	------	------	------	48
		4- 9-63	472	60	.32	.15	------	------	------	------	[3] 52
		4-21-64	776	5.8	------	------	4.9	1.4	.9	.9	10
581.2	Green Creek near Palmer.	4-21-64	[1] 25	6.9	------	------	8.2	2.8	.9	.6	20
581.3	Green Creek near Princeton.	7-19-61	[1] 5.5	9.9	1.0	.05	------	------	------	------	59
		4-24-62	[1] 45	5.7	.28	.03	------	------	------	------	10
		11-13-62	[1] 9	11	.65	.10	------	------	------	------	46
		4-10-63	[1] 10	11	.50	.00	------	------	------	------	26

[1] About.
[2] In solution when analyzed.
[3] Includes 4 ppm CO_3.

Unlike other small streams in the basin which have soft, bicarbonate-type waters, water in Flopper and Bear Creeks is moderately hard. Although these waters are of good quality, they are more mineralized, have a higher pH, and contain more alkalinity (bicarbonate) than other streams in the basin. These conditions are characteristic of small streams draining glacial outwash.

EAST BRANCH ESCANABA RIVER BASIN

Water in the East Branch Escanaba River basin is predominately of the calcium bicarbonate type. During low flow, water in the headwater streams and in the lower main stem near Sands Station ranges from soft to moderately hard, and concentrations of dissolved solids are generally less than 150 ppm. Dissolved oxygen is generally abundant, and sometimes East Branch Escanaba River at Gwinn becomes supersaturated. Results of analyses of water in this basin are contained in table 7.

Middle Branch Escanaba River basin—Continued

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Loss on ignition	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen	
						Calcium, magnesium	Noncarbonate					Ppm	Percent saturation
8.0	0.0	------	1.0	57	32	15	8	38	6.1	85	4	------	--------
10	1.0	------	1.2	84	31	40	1	93	7.7	80	2	------	--------
8.2	2.0	------	------	----------	------	20	10	45	6.5	60	1	------	--------
------	------	------	------	----------	------	44	2	99	7.2	50	2	------	--------
8.4	.5	------	.4	----------	------	--------	------	160	7.3	32	--------	------	--------
7.6	1.0	------	.6	73	33	42	9	83	6.7	70	.8	------	--------
9.2	1.0	------	.3	122	------	79	0	179	8.5	20	2	------	--------
9.4	1.0	------	------	----------	------	68	1	148	7.1	25	2	------	--------
7.2	2.0	------	------	----------	------	94	1	188	7.5	10	1	------	--------
7.6	.8	------	.4	----------	------	--------	------	98	7.0	31	--------	7.8	89
8.8	.5	0.0	.2	76	------	52	4	104	7.0	18	5	10	105
7.6	2.0	.0	1.0	48	28	17	9	39	6.2	60	1	5.4	46
11	1.5	------	1.2	97	32	43	4	99	7.5	100	2	------	--------
8.8	2.0	------	------	----------	------	27	0	110	8.6	90	2	------	--------
9.2	1.0	.2	1.7	47	18	18	10	48	5.8	50	8	------	--------
18	1.0	.2	1.3	66	14	32	16	76	6.3	50	2	------	--------
5.8	.5	------	.4	----------	------	--------	------	104	7.3	32	--------	------	--------
6.8	1.0	------	.7	53	30	15	7	36	6.2	65	.6	------	--------
9.2	.0	------	.6	70	18	40	2	90	7.1	55	2	------	--------
9.2	1.0	------	------	----------	------	25	4	62	6.6	45	1	------	--------

Hydrogen sulfide gas is detectable at Schweitzer Creek Reservoir and at the ore-processing plant at Empire mine. Hydrogen sulfide occurs in deep areas of the reservoir below thermocline barriers and is believed to be generated in the reservoir by sulfur bacteria acting upon sulfurous material under anaerobic conditions (conditions in which no free oxygen is present). Hydrogen sulfide is toxic to fish and in large concentrations is toxic to animals and humans.

Water for release to Schweitzer Creek and for delivery to Empire mine is withdrawn from the deeper part of the reservoir. Change in pressure as the water emerges from the outlet pipe causes the release of malodorous hydrogen sulfide gas to the atmosphere at the downstream face of the dam. The gas usually dissipates before air currents carry it beyond the immediate area of the dam. That part retained in water released to Schweitzer Creek also dissipates readily after aeration and is not detectable at the gaging station 1½ miles downstream.

TABLE 7.—*Chemical quality of surface water*

[Results in parts per million except as indicated.

Station	Source	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
581.7	Ely Creek near National Mine.	7-19-61	[1] 1.5	7.2	0.74	0.70	------	------	------	------	94
		4-25-62	[1] 30	5.5	.16	.02	------	------	------	------	21
		11-14-62	[1] 3	9.5	.23	.05	------	------	------	------	64
		4- 9-63	[1] 12	7.9	.37	.00	------	------	------	------	44
582	Schweitzer Creek near Palmer.	7-19-61	11	8.8	.29	.06	------	------	------	------	82
		4-25-62	98	5.7	.13	.07	------	------	------	------	22
		11-14-62	11	22	.21	.13	------	------	------	------	76
		4- 4-63	1.3	8.8	------	------	------	------	------	------	------
		4- 8-63	1.1	15	------	------	------	------	------	------	83
		4- 9-63	1.0	17	.54	.15	------	------	------	------	90
		7-17-63	2.8	------	1.5	.75	------	------	------	------	90
		9-25-63	3.5	8.4	------	------	------	------	------	------	102
583	Warner Creek near Palmer.	7-19-61	4.6	13	.36	.07	------	------	------	------	88
		4-24-62	116	5.2	.23	.06	------	------	------	------	14
		11-13-62	7.5	15	.33	.13	------	------	------	------	54
		4- 5-63	83	------	------	------	------	------	------	------	------
		4- 8-63	39	------	------	------	------	------	------	------	------
		4-10-63	28	18	.32	.05	------	------	------	------	38
		10-17-63	6.3	7.2	------	------	------	------	------	------	78
		4-21-64	49	------	------	------	9.1	5.1	2.4	1.2	38
583.36	Unnamed tributary to Goose Lake Inlet near Negaunee.	5- 7-63	[1] 1	3.7	------	------	102	19	------	------	134
583.37	Goose Lake Inlet near Palmer.	4-10-63	[1] 8	20	.32	.12	33	7.8	6.2	1.6	66
		5- 7-63	4	7.0	------	------	37	6.6	------	------	64
583.40	Partridge Creek at Negaunee.	5- 7-63	[1] 2	7.1	------	------	102	17	------	------	84
583.41	Partridge Creek near Negaunee.	5- 7-63	[1] 2	6.0	------	------	93	8.8	------	------	80
583.42	Tracy mine outflow at Negaunee.	5- 7-63	[1] .5	8.6	------	------	192	16	------	------	142
583.5	Goose Lake Inlet near Negaunee.	11- 7-61	[1] 5	------	[2] .09	------	94	14	15	5.9	107
		5- 7-63	[1] 10	5.8	------	------	75	8.3	------	------	82
584	Goose Lake Outlet near Sands Station.	11- 6-61	[1] 25	------	[2] .36	------	31	6.4	4.3	1.7	65
		7-26-63	8.9	------	------	------	------	------	------	------	78
585	East Branch Escanaba River at Gwinn.	7-19-61	42	8.2	[2] .15	[2] .00	18	4.2	3.0	1.2	66
		8-23-61	34	6.4	.26	.07	18	4.0	2.2	.7	66
		4-24-62	538	5.5	.21	.06	8.9	1.1	1.4	.8	15
		11-13-62	64	57	.49	.05	21	2.0	14	1.1	[3] 64
		4- 4-63	505	6.0	------	------	------	------	------	------	------
		4- 5-63	318	6.9	------	------	------	------	------	------	------
		4- 8-63	196	9.3	------	------	------	------	------	------	------
		4- 9-63	170	34	.56	.18	------	------	------	------	52
		9-25-63	22	7.4	------	------	------	------	------	------	72
		4-21-64	318	15	------	------	12	3.2	2.8	1.1	33

[1] About.
[2] In solution when analyzed.
[3] Includes 14 ppm CO_3.

of the East Branch Escanaba River basin

Color referred to platinum-cobalt scale]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Loss on ignition	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen	
						Calcium, magnesium	Noncarbonate					Ppm	Percent saturation
31	9.0	------	21	------	------	------	------	284	7.0	12	------	------	------
11	1.5	------	.9	57	------	30	13	69	6.6	36	1.0	------	------
24	8.0	------	8.2	130	------	78	26	196	7.4	25	3	------	------
18	5.0	------	3.3	83	------	45	9	121	7.0	30	2	------	------
11	2.0	------	2.3	------	------	------	------	158	7.3	10	------	8.4	91
8.4	1.0	------	.6	66	18	28	10	63	6.6	55	.8	------	------
14	3.0	------	2.4	120	------	69	7	161	7.6	25	2	------	------
------	------	------	------	------	------	52	------	112	------	35	20	------	------
12	3.0	------	1.3	------	------	67	------	151	7.6	15	3	------	------
7.8	3.0	------	------	------	------	77	3	162	7.1	15	2	------	------
------	------	------	------	------	------	76	2	161	7.2	30	4	------	------
6.0	2.0	------	------	------	------	84	1	183	6.8	80	5	5.8	50
10	4.0	------	2.3	------	------	------	------	173	7.5	13	------	------	------
7.6	1.0	------	.7	59	23	21	10	52	6.3	70	.8	------	------
12	3.0	------	1.7	100	29	55	11	129	7.2	70	1	------	------
------	------	------	------	------	------	25	------	62	------	65	2	------	------
------	------	------	------	------	------	------	------	69	------	45	1	------	------
9.8	3.0	------	------	------	------	36	5	92	6.9	55	1	------	------
7.8	6.5	------	.9	------	------	70	6	156	6.9	90	70	------	------
13	5.0	------	------	58	------	44	12	107	7.1	------	5	------	------
226	5.0	------	------	450	------	333	223	640	7.5	10	3	------	------
68	4.0	0.0	.8	185	16	115	60	263	7.6	20	3	------	------
69	6.0	------	------	177	------	120	67	261	7.3	25	2	------	------
282	78	------	------	629	------	325	256	910	7.2	4	10	------	------
220	61	------	------	511	------	268	203	762	7.2	4	120	------	------
418	33	------	------	834	------	546	429	1,040	7.4	1	200	------	------
204	21	------	3.0	427	------	292	205	632	7.3	------	------	------	------
155	21	------	------	348	------	221	154	512	7.3	15	120	------	------
50	5.5	------	.5	148	------	104	51	237	7.3	------	------	------	------
34	5.0	------	------	------	------	92	28	211	6.8	8	2	------	------
12	.5	.1	.9	84	------	62	8	140	7.2	15	.4	8.8	94
11	.5	.0	.3	81	------	62	8	132	7.1	15	2	10.1	106
14	1.0	.1	.8	58	27	26	14	64	6.4	5	2	11.2	94
22	2.0	.1	1.0	175	27	60	0	176	9.0	100	3	12.4	95
------	------	------	------	------	------	31	------	81	------	55	10	------	------
------	------	------	------	------	------	------	------	100	------	55	2	------	------
------	------	------	------	------	------	48	------	119	------	45	2	------	------
24	4.0	------	------	------	------	53	10	146	7.0	50	2	------	------
13	4.0	------	------	------	------	68	9	152	7.2	20	1	9.4	87
19	2.0	.2	1.8	87	21	43	16	106	6.3	50	2	------	------

Hydrogen sulfide liberated at the dam, though detectable at times, is not a serious problem at present (1965). Hydrogen sulfide in water delivered to Empire mine, however, is not liberated until it reaches the mine. There the gas is released by aeration before the water enters the plant.

Iron precipitates, which impede the flow of water in pipes, have been troublesome at Empire mine. Precipitation of iron is probably caused by action of bacteria in the water supply. This bacterial action is borne out at Empire mine by the fact that addition of chlorine, which would be expected to reduce bacterial action, has greatly inhibited the precipitation of iron in the pipes. McKee and Wolf (1963) thoroughly discuss the interrelationships of bacteria, sulfur, and iron.

Water in Goose Lake Inlet, unlike other streams in the East Branch Escanaba River basin, is of the calcium sulfate type and is moderately mineralized. Partridge Creek, a tributary of the inlet, receives pumpage from underground mines where dispersed gypsum is known to exist. This pumpage has increased the mineralization of Partridge Creek and changed the water of the inlet from a calcium bicarbonate type to a calcium sulfate type. Downstream from Partridge Creek, Goose Lake Inlet contains water that is very hard (221–292 ppm) and has concentrations of dissolved solids ranging from 348 to 427 ppm. Water quality in Goose Lake Outlet is much better than that in the inlet. This improvement is due to dilution with less mineralized water in Goose Lake and downstream in the outlet. The outlet water is moderately hard and generally contains less than 200 ppm of dissolved solids; however, concentrations up to 245 ppm were measured during periods of low flow. The dissolved solids content decreases progressively downstream as the water becomes diluted with less mineralized ground-water discharge. There is no evidence that water pumped from mines into Partridge Creek has any effect upon water quality in the main stem of the East Branch Escanaba River.

MICHIGAMME RIVER BASIN

Water in the Michigamme River basin is a calcium bicarbonate type, very soft, and has a dissolved-solids concentration of less than 100 ppm (table 8). Dissolved oxygen generally is equal to or greater than 7.5 ppm and 83 percent saturation. These conditions generally exist in streams throughout the year. Color (25–140) is the only objectionable quality characteristic of water in the streams.

Milwaukee Lake is used as a settling basin for tailings from Republic mine. Its water is of the calcium bicarbonate type, moderately hard, and contains concentrations of dissolved solids ranging from 100 to 125 ppm. Concentration of iron is generally about 5 ppm and manganese, about 3 ppm. Color is moderate, but turbidity is very high (220 ppm). No noticeable amounts of the tailings sediments are reaching Michigamme River.

CARP RIVER BASIN

Water in the Carp River basin is of the calcium bicarbonate type, generally soft to moderately hard, and contains dissolved solids in concentrations ranging from 50 to nearly 200 ppm (table 9).

Upstream from Ishpeming, Carp Creek has a soft, calcium bicarbonate type water with generally less than 0.5 ppm of iron. From Ishpeming to Deer Lake, Carp Creek remains a calcium bicarbonate type of water, but municipal wastes received at Ishpeming cause the water to become more mineralized, moderately hard, and higher in iron content (nearly 1.0 ppm).

Water quality of Gold Mine Creek, which drains into Deer Lake, is very similar to that of Carp Creek below Ishpeming. A gradual improvement in quality due probably to the modest pickup of less mineralized ground-water discharge is noted as the water moves downstream from Deer Lake. For the most part, the water quality of Carp River is similar to that of Carp Creek above Ishpeming.

CHOCOLAY RIVER BASIN

Only a few samples were collected for chemical analysis from the Chocolay River and its small tributaries in the eastern part of the report area. All were obtained during periods of base flow when mineralization should be at or near maximum. Because most of the flow of these streams is derived from the large ground-water body underlying the outwash plain extending southward from Goose Lake, their water quality should represent the quality characteristics of ground water. Water in the streams sampled is of the calcium bicarbonate type, is soft to moderately hard, is low in color (generally less than 5), and has little turbidity (about 4 ppm or less).

Results of chemical analyses of water at sites in the Chocolay River basin and at other miscellaneous sites in the report area are contained in table 10.

SUSPENDED SEDIMENT

By R. F. Flint

Suspended sediment in a stream is fine fragmental rock material which is transported or held in suspension by the upward components of turbulent currents or by colloidal suspension. Most suspended sediment originates from weathering and erosion; however, there are many activities of man which tend to increase the rate of natural

TABLE 8.—*Chemical quality of surface*

[Results in parts per million except as indicated.

Station	Source	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
621	Peshekee River near Michigamme.	7-20-61	11	6.0	0.46	0.07	------	------	------	------	36
		4-25-62	1,040	4.0	.26	.04	------	------	------	------	5
		11-14-62	55	7.2	.59	.00	------	------	------	------	20
		4- 5-63	1,270	------	------	------	------	------	------	------	------
		4- 8-63	718	------	------	------	------	------	------	------	------
		4-10-63	430	4.6	.34	.00	------	------	------	------	10
622	Peshekee River near Champion.	7-20-61	19	5.4	.55	.00	8.2	1.6	0.7	0.2	32
		4-25-62	1,620	4.2	.25	.06	3.0	.7	.5	.5	2
		11-14-62	100	22	.59	.00	------	------	------	------	34
		4- 4-63	2,860	4.4	------	------	------	------	------	------	------
		4- 5-63	2,290	4.5	------	------	------	------	------	------	------
		4- 8-63	1,280	4.7	------	------	------	------	------	------	------
		4-10-63	872	4.9	.36	.00	------	------	------	------	10
622.2	Spurr River at Michigamme.	8-24-61	[1] 7	5.9	.47	.11	------	------	------	------	33
		4-25-62	[1] 120	5.5	.27	.08	6.3	2.8	.9	.8	10
		11-14-62	[1] 20	18	.21	.00	------	------	------	------	34
		4-10-63	[1] 100	6.5	.62	.40	------	------	------	------	16
623	Michigamme River at Republic.	7-20-61	[1] 300	5.3	[2] .06	[2] .00	5.2	1.5	1.6	.4	18
		4-26-62	1,620	5.4	.50	.00	------	------	------	------	12
		11-15-62	283	6.0	.28	.00	------	------	------	------	20
		4- 9-63	1,560	39	.31	.14	------	------	------	------	[3] 40
623.2	Trout Falls Creek near Republic.	7-20-61	[1] 4	9.2	[2] .24	[2] .05	------	------	------	------	70
		4-26-62	[1] 100	5.5	.30	.04	------	------	------	------	15
		11-15-62	[1] 15	17	.60	.02	------	------	------	------	50
		4- 9-63	[1] 70	8.0	.59	.15	------	------	------	------	24

[1] About.
[2] In solution when analyzed.
[3] Includes 4 ppm CO_3.

TABLE 9.—*Chemical quality of*

[Results in parts per million except as indicated.

Station	Source	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
442	Carp Creek at Ishpeming.	7-20-61	[1] 6	11	0.48	0.08	------	------	------	------	91
		4-25-62	[1] 30	5.8	.34	.09	------	------	------	------	27
		11-14-62	[1] 8	19	.38	.16	------	------	------	------	92
		4-10-63	[1] 18	35	.48	.12	------	------	------	------	65
442.1	Carp Creek near Ishpeming.	10- 5-61	[1] 10	9.6	.86	.30	------	------	------	------	98
		4-24-62	[1] 35	6.0	.48	.06	16	3.3	3.2	1.5	41
		11-14-62	[1] 10	11	.72	.06	28	7.9	6.3	2.0	94
		4-10-63	[1] 20	8.3	1.0	.35	------	------	------	------	64
443	Gold Mine Creek near Ishpeming.	8-24-61	[1] 3	13	.22	.12	------	------	------	------	158
		4-24-62	[1] 15	7.8	.24	.06	------	------	------	------	46
		11-13-62	[1] 5	21	.26	.13	------	------	------	------	142
		4- 9-63	[1] 12	13	.46	.12	------	------	------	------	80
444	Carp River near Negaunee.	7-20-61	70	5.2	2.0	.13	22	5.0	4.0	2.0	75
		8-24-61	51	7.2	.39	.14	25	5.8	3.9	1.6	98
		4-25-62	85	4.8	.27	.17	8.1	1.4	.8	.5	21
		11-14-62	30	15	.26	.10	------	------	------	------	102
		4-10-63	25	18	.79	.59	------	------	------	------	52

[1] About.

water of the Michigamme River basin

Color referred to platinum-cobalt scale]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Loss on ignition	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen	
						Calcium, magnesium	Noncarbonate					Ppm	Percent saturation
5.6	0.5	------	0.4	------	------	------	------	70	6.9	35	------	------	------
7.2	2.0	------	1.0	42	33	11	7	26	5.7	90	0.5	------	------
8.8	1.0	------	1.4	62	30	20	4	52	6.6	140	4	------	------
------	------	------	------	------	------	12	------	30	------	75	1	------	------
------	------	------	------	------	------	------	------	28	------	65	1	------	------
5.2	1.0	------	------	------	------	11	3	30	6.0	65	2	------	------
4.8	.0	0.2	.5	45	18	27	1	63	7.1	50	.7	8.5	94
6.4	2.0	.0	1.2	41	24	10	9	25	5.6	75	.2	11.6	97
7.2	1.0	------	1.2	89	37	27	0	70	7.0	140	2	------	------
------	------	------	------	------	------	------	------	29	------	85	1	------	------
------	------	------	------	------	------	11	------	29	------	75	1	------	------
------	------	------	------	------	------	------	------	27	------	75	1	------	------
5.2	1.0	------	------	------	------	11	3	28	6.0	75	1	------	------
9.2	.5	------	.4	61	------	31	4	72	6.8	24	1	------	------
19	1.0	.1	.9	63	26	27	19	66	6.3	75	.4	9.6	83
7.8	.5	------	.6	93	20	48	20	121	7.1	100	1	------	------
26	3.0	------	------	------	------	35	22	87	7.0	55	1	------	------
6.2	.5	.2	.7	41	20	19	4	49	6.6	35	10	7.4	85
9.0	2.0	------	.9	42	33	17	7	40	6.2	50	.5	------	------
9.0	.5	------	.8	40	23	22	6	53	7.0	100	2	------	------
8.4	3.0	------	------	------	------	31	0	87	8.3	65	.2	------	------
8.0	.5	------	.8	------	------	------	------	125	7.5	44	------	------	------
10	1.0	------	.9	54	28	23	11	49	6.2	80	.4	------	------
12	1.5	------	.9	97	31	47	6	104	7.4	120	2	------	------
11	1.0	------	------	------	------	29	10	65	6.4	65	1	------	------

surface water of the Carp River basin

Color referred to platinum-cobalt scale]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Loss on ignition	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Turbidity	Dissolved oxygen	
						Calcium, magnesium	Noncarbonate					Ppm	Percent saturation
12	3.5	------	0.9	------	------	------	------	179	7.0	25	------	------	------
10	2.0	------	.7	76	31	34	12	76	6.6	50	2	------	------
16	4.0	------	1.2	138	22	86	10	193	7.5	45	2	------	------
14	7.0	------	------	------	------	58	5	152	7.1	50	2	------	------
28	13	------	------	192	------	122	42	287	6.8	30	10	6.0	56
18	1.0	0.1	3.6	90	30	54	20	124	6.5	50	3	7.2	64
27	8.0	.1	6.2	147	28	103	26	238	6.9	50	4	8.3	61
23	8.0	10	------	------	------	81	28	196	6.6	30	4	------	------
20	.5	------	.2	174	------	145	16	277	7.5	11	4	------	------
14	1.0	------	1.2	88	12	53	16	108	6.8	55	1.0	------	------
22	2.0	------	.4	176	------	130	14	265	7.8	10	1	------	------
18	2.0	------	------	------	------	84	18	172	7.0	30	2	------	------
15	4.0	.2	1.9	112	22	76	14	171	6.9	30	2	6.2	67
12	4.5	.0	.2	124	23	86	6	188	7.1	21	1	7.8	83
10	1.0	.0	.8	50	22	26	9	57	6.4	50	3	10.7	82
26	8.0	------	1.1	160	------	101	18	242	7.4	13	2	------	------
9.6	2.0	------	------	------	------	45	2	112	7.0	30	2	------	------

TABLE 10.—*Chemical quality of surface water at miscellaneous sites*

[Results in parts per million except as indicated. Color referred to platinum-cobalt scale]

Station	Stream	Location	Date	Instantaneous discharge (cfs)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color	Turbidity
								Carp River basin										
443.40	Carp River	NW¼ sec. 27, T. 48 N., R. 27 W.	7-12-63	29.1	------	------	------	------	95	19	8.5	------	96	18	221	7.0	20	3
443.60	Carp River	N½ sec. 30, T. 48 N., R. 26 W.	7-12-63	27.3	------	------	------	------	102	14	8.5	------	96	12	217	6.9	30	2
443.80	Unnamed tributary to Carp River.	NW¼ sec. 29, T. 48 N., R. 26 W.	7-12-63	.21	------	------	------	------	63	6.0	1.5	------	55	4	121	6.8	22	2
444.02	Carp River	NW¼ sec. 2, T. 47 N., R. 26 W.	7-12-63	32.2	------	------	------	------	114	37	12	------	124	30	286	7.1	25	2
444.05	Carp River	SE¼ sec. 6, T. 47 N., R. 25 W.	7-12-63	33.5	------	------	------	------	110	36	10	------	119	29	277	7.0	25	2
								Chocolay River basin										
445.32	Silver Lead Creek	NW¼ sec. 1, T. 45 N., R. 25 W.	7-26-63	7.31	------	------	------	------	58	5.8	3.0	------	51	4	120	7.0	2	3
			7-21-64	8.57	------	------	------	------	46	9.2	7.0	------	53	16	143	6.7	7	------
445.36	West Branch Chocolay River.	SW¼ sec. 21, T. 46 N., R. 24 W.	7-26-63	15.7	------	------	------	------	58	6.2	5.5	------	52	4	137	7.1	5	3
			7-21-64	13.4	------	------	------	------	54	9.6	5.0	------	52	8	137	7.6	7	------
445.52	Big Creek	NW¼ sec. 18, T. 46 N., R. 24 W.	7-21-64	3.98	------	------	------	------	77	8.4	1.0	------	72	9	147	7.8	5	------
445.57	Peterson Creek	SW¼ sec. 36, T. 47 N., R. 25 W.	7-17-63	.15	------	------	------	------	98	6.6	2.0	------	83	2	168	6.9	5	2
			7-21-64	.08	------	------	------	------	97	7.8	1.0	------	85	6	167	7.8	2	------
445.59	Peterson Creek	SW¼ sec. 5, T. 46 N., R. 24 W.	7-26-63	2.23	------	------	------	------	99	8.0	2.5	------	86	5	174	7.1	1	4
			7-21-64	1.92	------	------	------	------	94	8.8	1.0	------	83	6	165	7.9	6	------
445.60	Big Creek	SE¼ sec. 5, T. 46 N., R. 24 W.	7-26-63	13.8	------	------	------	------	96	7.2	2.0	------	82	4	169	7.2	3	1
			7-21-64	12.6	------	------	------	------	90	8.0	.5	------	79	5	160	7.8	5	------
445.63	Big Creek	SW¼ sec. 28, T. 47 N., R. 24 W.	7-21-64	24.8	------	------	------	------	98	6.8	1.0	------	85	4	170	7.9	5	------
445.70	Cedar Creek	SW¼ sec. 26, T. 47 N., R. 25 W.	7-17-63	.10	------	------	------	------	70	7.6	6.5	------	53	0	143	7.2	6	.5
			7-21-64	.30	------	------	------	------	67	5.2	4.0	------	59	4	123	7.7	2	------
445.74	Cedar Creek	NW¼ sec. 19, T. 47 N., R. 24 W.	7-26-63	10.6	------	------	------	------	92	5.4	1.5	------	74	0	154	7.1	2	1
			7-21-64	10.2	------	------	------	------	82	5.2	1.5	------	69	2	142	7.8	3	------
445.80	Cherry Creek	NW¼ sec. 23, T. 47 N., R. 25 W.	7-26-63	.20	------	------	------	------	99	5.2	3.5	------	82	1	166	7.0	1	.5
			7-21-63	.05	------	------	------	------	90	6.4	3.0	------	78	4	155	7.5	5	------
445.82	Cherry Creek	SW¼ sec. 13, T. 47 N., R. 25 W.	7-26-63	9.24	------	------	------	------	118	8.8	3.0	------	102	6	205	7.2	1	.4

445.83	Cherry Creek	SE¼ sec. 13	7-21-64	18.6					106	7.6	2.0		90	3	183	7.5	2	
445.88	Chocolay River	NE¼ sec. 8, T. 47 N., R. 24 W.	7-26-63	104					104	6.4	2.0		86	1	179	7.2	5	2
			7-21-64	105					95	7.6	2.0		83	5	170	8.0	6	
445.90	Silver Creek	NE¼ sec. 15, T. 47 N., R. 25 W.	7-25-63	.18					141	7.0	2.5		115	0	234	7.3	2	.5
			7-21-64	.10					126	6.8	1.0		106	3	207	7.8	2	
445.94	Silver Creek	SW¼ sec. 12, T. 47 N., R. 25 W.	7-26-63	5.66					116	5.2	1.0		97	2	192	7.2	3	2
			7-21-64	5.27					111	6.8	1.0		94	3	194	7.6	3	
445.95	Silver Creek	NE¼ sec. 12, T. 47 N., R. 25 W.	7-26-63	7.54					132	5.8	2.0		110	2	217	7.1	1	.5
			7-21-64	7.05					126	7.2	2.0		108	5	212	8.1	5	
	Middle Branch Escanaba River basin																	
580.26	West Branch Creek	SW¼ sec. 13, T. 46 N., R. 28 W.	7-22-64	7.07	14	4.6	2.4	1.0	63	4.4	1.0	81	54	2	120	7.9	40	
580.31	Middle Branch Escanaba River.	NW¼ sec. 18, T. 46 N., R. 27 W.	7-22-64	26.8	14	4.2	3.0	1.8	64	7.2	0	89	52	0	129	6.3		
580.38	Middle Branch Escanaba River.	NW¼ sec. 23, T. 46 N., R. 27 W.	7-11-63	43.4					53	6.0	1.5		44	1	99	6.6	45	2
			7-22-64	35.6	12	4.0	1.8	.8	55	4.8	1.0	69	46	2	104	7.5	28	
580.40	Middle Branch Escanaba River.	Sec. 23, T. 46 N., R. 27 W.	7-22-64	33.6	12	4.0	1.8	.8	54	4.4	.0	75	46	2	102	7.5	25	
580.43	Voelker Lake Outlet	SW¼ sec. 23, T. 46 N., R. 27 W.	7-11-63	2.61					62	5.2	1.5		51	0	109	6.8	7	1
			7-22-64	2.59					59	6.4	1.0		51	2	106	7.4	17	
580.44	Middle Branch Escanaba River.	NE¼ sec. 26, T. 46 N., R. 27 W.	7-22-64	36.1	13	3.5	1.8	.7	55	4.6	1.0	69	47	2	102	7.5	23	
580.47	Unnamed tributary to Middle Branch Escanaba River.	Center of sec. 26, T. 46 N., R. 27 W.	7-11-63	1.94					82	6.4	2.0		66	0	139	7.0	7	1
			7-22-64	1.70	17	4.9	1.4	.4	70	5.2	.0	76	62	5	127	7.6	10	
580.60	Flopper Creek	SW¼ sec. 31, T. 46 N., R. 26 W.	7-11-63	4.28					90	8.4	1.0		76	2	158	7.4	5	1
	East Branch Escanaba River basin																	
583.60	Goose Lake Outlet	NE¼ sec. 24, T. 47 N., R. 26 W.	7-26-63	5.51					86	100	13		163	92	383	7.0	6	2
			7-21-64	7.23	41	7.7	8.7	3.5	56	84	12	208	134	88	325	7.0	8	
583.70	Goose Lake Outlet	NW¼ sec. 36, T. 47 N., R. 26 W.	7- 7-63	[1] 20	49	7.8			68	101	14	245	154	98	365	7.2	8	1
			7-26-63	3.31					78	87	12		146	82	344	6.8	5	2
			7-21-64	3.50	39	7.2	8.1	3.2	68	74	10	202	127	72	311	7.1	15	
583.72	Goose Lake Outlet	SW¼ sec. 36, T. 47 N., R. 26 W.	7-26-63	4.53					88	69	11		136	64	317	6.9	9	5
583.80	Goose Lake Outlet	SW¼ sec. 1, T. 46 N., R. 26 W.	7-21-64	4.74	36	6.9	6.6	2.9	74	59	8.0	180	119	58	280	7.1	28	
583.90	Goose Lake Outlet	NW¼ sec. 12, T. 46 N., R. 26 W.	7-21-64	5.81	27	5.0	4.1	1.7	70	32	4.0	142	88	30	205	7.4	20	
584.00	Goose Lake Outlet	SE¼ sec. 12, T. 46 N., R. 26 W.	7-26-63	8.93					78	34	5.0		92	28	211	6.8	8	2
585.05	Halfway Creek	SE¼ sec. 21, T. 45 N., R. 25 W.	7-26-63	8.62					66	4.4	2.5		54	0	119	7.0	5	2
			7-21-64	8.08	16	2.8	1.5	.5	59	3.8	1.0	73	52	3	113	7.5	20	

[1] About.

erosive processes. Common among these activities are agriculture, construction, and mining. The quantity of natural sediments transported or available for transportation by streams is affected by the form and intensity of precipitation and other climatic conditions, character of the soil mantle, plant cover, topography, and land use. The size of individual sediment particles transported or available for transport influences the mode of transportation. Colby (1963, p. 10) states that fine sediment particles are mainly or entirely carried in suspension and may be moved great distances downstream at about the velocity of the flow. Coarser particles may be moved in suspension, rolled or skipped along the stream bed, or transported alternately by both these modes. Large sediment particles are moved intermittently for short distances and deposited on the streambed either permanently or semipermanently, depending on sizes of the particles.

The quantity of suspended sediment moved by streams may be determined from sediment concentration and discharge of streams. Streams draining the Marquette Iron Range transport very small quantities of suspended sediment. Even during times when high streamflow was produced by rainfall and snowmelt and the capacity of the streams to carry sediment was great, very low concentrations of sediment were measured. The geology and the prevailing land use and vegetative cover in the area prevent large quantities of sediment from reaching the streams.

Sediments from ore-processing plants introduce new problems in the area. Operations of plants engaged in beneficiation, pelletizing, and ore improvement make use of settling ponds and recirculating basins to prevent waste material from entering the streams. In these basins practically all the sand (0.062–2.00 mm diam), silt (0.004–0.062 mm), and most of the clay (less than 0.004 mm) particles are removed by retaining the waste slurry for a sufficient time to allow the sediment to settle in the pond. Flocculants, such as alum, have been used to help settle the suspended matter in the tailings basins. Clays which do not settle out are carried over the outlet channels to streams. When sufficient concentrations of these clay particles are present, the water has a reddish, turbid appearance. This condition has been observed occasionally in outlets from the tailings basins. Owing to the small size of these particles, they may travel many miles through the stream system by colloidal suspension. As the concentration becomes reduced by dilution from greater streamflow, the red appearance is reduced until finally it is unnoticeable.

To date, the mining industry in the Marquette Iron Range has introduced only small amounts of very fine sediments into streams. No evaluation has been made of the effects of sediment upon aquatic life in these streams. Stallings (1957, p. 44), however, suggests that investigators in the field of aquatic life agree that sediment tends to blanket the bottom of streams, thus eliminating organisms upon which fish feed as well as destroying the nesting and spawning areas of a great many kinds of fish. Sediment-laden streams do not transmit light as readily as does clear water. Thus, suspended sediment tends to make an unfavorable environment for the more desirable fish.

Sediments in effluents from ore-processing plants have been analyzed for particle-size distribution, concentration, and specific gravity. These effluents present few problems now, as most of the sediments are retained in settling basins and are not allowed to enter streams. Analyses of the sediments, however, are important because their results provide a knowledge of the suspension characteristics of these sediments and suggest the need for adequate areas for settling basins to retain these sediments.

The principal purpose of the sediment studies reported here is to define the natural suspended-sediment characteristics of streams in the area and to evaluate the effect of wastes discharged from ore-processing and pelletizing operations upon these characteristics. These operations are carried on at Humboldt mine, Empire mine, Republic mine, and at Eagle Mills. Their locations are shown in figure 1, but for convenience of reference and to show more detail they are also shown in figure 26. Included in this figure are locations of sampling sites at tailings basins that are referred to in the subsequent discussion.

MIDDLE BRANCH ESCANABA RIVER BASIN

A good definition of suspended-sediment characteristics was obtained at 14 locations in the basin. Data collected provide a background or index against which the effect of changes in land and water use may be compared. Maximum and minimum sediment concentrations and loads observed in streams of this basin are shown in table 11, which contains a summary of observed extremes for all sampling locations in the area.

Concentration and discharge of sediment in streams of the Black River basin are low. Concentrations are generally less than 100 ppm. The greatest variations in concentration were observed in the outlet streams from McKinnon Lake and Lake Lory, both of which serve as settling basins for tailings from Humboldt mine.

As noted previously, the natural yield of sediment in the entire area is low. Because concentrations of natural sediments are generally low, determination of particle-size distribution was not practical for most streams. Particle-size analyses could be made, however, for some

TABLE 11.—*Summary of suspended-sediment extremes*

[T, less than 0.05 ton; several, greater than 5, less than 20; many, greater than 19; D, daily during several months]

Station No.	Station name	Period of record	Number of samples	Observed concentrations: Minimum Ppm	Observed concentrations: Minimum Date	Observed concentrations: Maximum Ppm	Observed concentrations: Maximum Date	Computed sediment discharges: Minimum Tons per day	Computed sediment discharges: Minimum Date	Computed sediment discharges: Maximum Tons per day	Computed sediment discharges: Maximum Date
	Carp River basin										
442	Carp Creek at Ishpeming	4-62 to 4-63	3	2	11-14-62	24	4-10-63	T	11-14-62	1.2	4-10-63.
443	Gold Mine Creek near Ishpeming.	4-62 to 4-63	3	1	11-13-62	5	4-24-62, 4-10-63	T	11-13-62	.2	4-24-62, 4-10-63.
444	Carp River near Negaunee	8-61 to 4-63	4	2	11-14-62	12	4-25-62	0.2	11-14-62	2.8	4-25-62.
	Middle Branch Escanaba River basin										
578	Middle Branch Escanaba River at Humboldt.	7-61 to 9-63	26	1	Several	16	11-14-62	T	Several	4.8	4-23-62.
578.2	Middle Branch Escanaba River near Greenwood.	4-62 to 4-63	3	2	11-14-62, 4-9-63	3	4-25-62	0.2	11-14-62	3.6	4-25-62.
578.5	Black River near Humboldt	8-61 to 9-64	14	2	4-15-64	18	2-28-64	T	Several	1.2	4-26-62.
578.55	Lake Lory Outlet near Humboldt.	10-61 to 9-64	31	1	3-13-63, 4-5-63, 4-22-64.	25	2-28-64	T	Many	.4	4-23-62.
578.6	McKinnon Lake Outlet near Humboldt.	10-61 to 9-64	39	1	3-31-64, 7-6-64	92	4-26-62	T	do	3.1	4-15-64.
578.7	Lake Lory Outlet near Republic.	7-61 to 9-64	41	1	3-13-63, 4-5-63, 9-11-63.	55	12-12-61	T	Several	3.0	3-13-62.
579	Black River near Republic	7-61 to 9-64	D	1	Many	31	2-13-62	T	Many	5.9	4-15-64.
580	Middle Branch Escanaba River near Ishpeming.	7-61 to 9-63	27	1	11-14-62, 3-13-63, 4-9-63, 9-12-63.	11	3-14-62	.1	9-8-62, 3-13-63, 8-6-63, 9-12-63.	14	4-23-62.
580.2	West Branch Creek near National Mine.	4-62 to 4-63	3	1	11-14-62	2	4-25-62, 4-9-63	T	11-14-62	.3	4-25-62.
580.5	Middle Branch Escanaba River near Suomi.	8-61 to 9-63	4	1	4-9-63	15	11-14-62	.6	8-23-61	22	4-25-62.
580.8	Bear Creek near Princeton	4-62 to 9-63	4	1	4-25-62, 7-11-63	4	4-9-63	T	7-11-63	.3	4-9-63.
581	Middle Branch Escanaba River near Princeton.	4-62 to 9-63	3	1	11-13-62, 4-9-63	2	4-25-62	1.0	11-13-62	4.5	4-25-62.
581.2	Green Creek near Palmer	10-63 to 9-64	12	1	12-3-63, 12-31-63, 4-28-64, 5-18-64, 8-12-64.	19	1-27-64	T	Several	.1	11-7-63, 1-27-64.
581.3	Green Creek near Princeton	4-62 to 9-64	14	1	Several	5	10-9-63	T	do	.6	4-18-64.

					East Branch Escanaba River basin						
581.7	Ely Creek near National Mine	4-62 to 9-64	13	1	Several	33	4-13-64	T	Several	3.6	4-13-64.
582	Schweitzer Creek near Palmer	11-61 to 11-63	29	1	5-8-62, 6-12-62, 1-15-63.	96	11-5-62	T	do	9.5	11-5-62.
583	Warner Creek near Palmer	4-62 to 9-64	9	1	4-23-62	25	10-17-63	T	11-13-62, 12-3-63	1.8	4-5-63.
585	East Branch Escanaba River at Gwinn.	7-61 to 4-64	*D	1	Many	58	4-13-64	T	Many	67	4-13-64.
					Michigamme River basin						
621	Peshekee River near Michigamme.	4-62 to 4-63	3	1	11-14-62	2	4-25-62, 4-10-63	0.1	11-14-62	5.6	4-25-62.
622	Peshekee River near Champion.	11-61 to 11-63	25	1	2-13-62, 11-14-62, 12-27-62, 9-11-63.	10	4-4-63	.1	2-13-62, 8-17-62, 8-6-63, 9-11-63, 11-5-63.	77	4-4-63.
622.2	Spurr River at Michigamme	4-62 to 4-63	3	1	4-10-63	6	11-14-62	.3	11-14-62, 4-10-63	.6	4-25-62.
623	Michigamme River at Republic.	4-62 to 4-63	3	1	4-9-63	2	4-26-62, 11-15-62	1.5	11-15-62	8.7	4-26-62.
623.2	Trout Falls Creek near Republic.	4-62 to 4-63	3	1	11-15-62	4	4-26-62, 4-9-63	T	11-15-62	1.1	4-26-62.

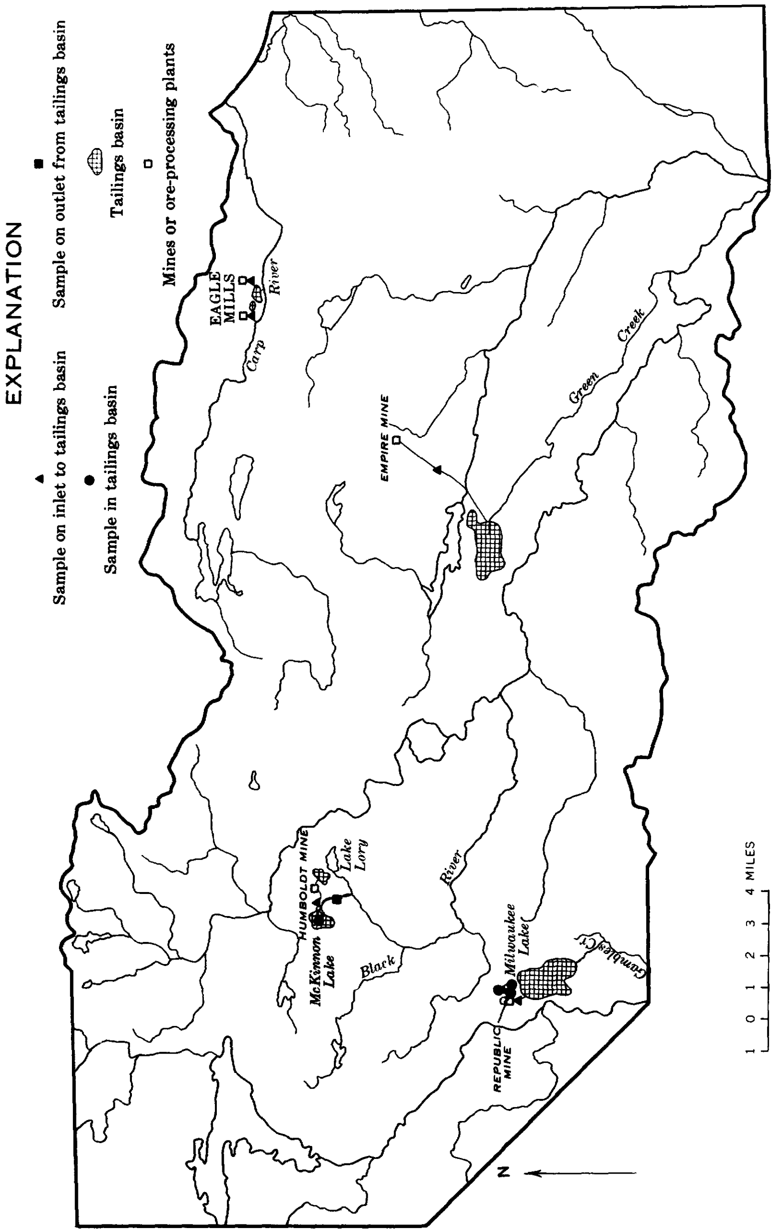


FIGURE 26.—Tailings basins and sediment-sampling sites.

samples withdrawn from McKinnon Lake Outlet which occasionally transports significant concentrations of tailings.

A sediment concentration of 45,400 ppm was measured in the effluent entering McKinnon Lake from Humboldt mine and was composed of 7 percent clay, 60 percent silt, and 33 percent sand (table 12). In the lake, near the center levee, was found a concentration of 262 ppm having a size distribution of 99 percent clay and 1 percent silt. This material did not flocculate when analyzed in a medium of native (lake) water, a fact indicating that it would probably be carried in suspension when discharged from the lake. Sediment concentration of McKinnon Lake Outlet was less than 50 ppm in the sample analyzed and was composed of 90 percent clay, 2 percent silt, and 8 percent sand. The silt and sand probably originated from a pasture between the lake and the sampling site. Thus, McKinnon Lake serves as a very efficient settling basin, trapping the silt and sand particles and leaving only some clay in suspension.

In table 12 the second analysis for each location shows the particle-size distribution when flocculation is permitted and the reaction that takes place in the tailings ponds is thus simulated. The smaller particles have flocculated and settled out in groups rather than singly.

Daily observations of suspended sediment were obtained at the gaging station on Black River near Republic from April 26, 1962, to September 30, 1963. These records are contained in table 13, and they are summarized in table 14, which is included in the next section dealing with suspended sediment in the East Branch Escanaba River basin. The significance of data collected at this station is also discussed in the next section.

EAST BRANCH ESCANABA RIVER BASIN

Locations in the basin where suspended-sediment data were obtained and maximum and minimum concentrations and loads were observed are listed in table 11. The variation in concentration was about the same as that in the Middle Branch Escanaba River basin. The maximum concentration, 96 ppm at Schweitzer Creek near Palmer, was observed during the period when Schweitzer Creek Dam, 1½ miles upstream, was under construction. Sediment concentration and loads will be reduced to very low values at this point after the area around the dam has been stabilized and a good vegetative cover has been established.

Daily observations of suspended sediment were made at the Gwinn gaging station on the main stem from August 24, 1961, to June 30, 1963 (table 15). These data are summarized, by water year, in table 14 along with similar data for Black River near Republic, and a comparison can be made between the data for the two stations for the

243-028 O—67——6

TABLE 12.—*Analyses of suspended sediment in plant effluents and in the receiving waters*

[First 8 analyses are of water-sediment mixtures taken within settling basin or from an outlet sampling point; last 10 analyses are of water-sediment mixtures as these mixtures came from plant or mine. Second analysis for each location shows particle-size distribution when flocculation is permitted. Kind of plant discharge at location: Be, beneficiation; P, pelletizing; O, ore improvement. Methods of analysis: B, bottom-withdrawal; C, chemically dispersed; M, mechanically dispersed; N, in native water; S, sieve; W, in distilled water]

Location	Date of collection	Specific gravity	Suspended sediment											Methods of analysis
			Concentration of sample (ppm)	Concentration of suspension analyzed (ppm)	Percentage of sample finer than indicated size, in mm									
					Clay [1]		Silt			Sand				
					0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	
McKinnon Lake Outlet near Humbolt	10-2-61		47	381	87	90	92	92	92	92	100			BWCM
McKinnon Lake near Humbolt (center levee)	7-16-63		262	546	97	99	99	99	100					SBWCM
			262	591	84	95	98	98	99	100				SBN
Milwaukee Lake near Republic (at dike, southeast end of lake)	7-16-63		91	400	91	97	98	98	99	100				SBWCM
Milwaukee Lake near Republic (at channel flume)	7-16-63		60	538	99	99	100							SBWCM
			60	511	81	86	98	99	100					SBN
Milwaukee Lake near Republic (at south flume)	7-16-63		59	448	98	99	100							SBWCM
			59	579	82	90	98	98	100					SBN
Eagle Mills (P)	8-20-64	4.64	3,220	2,360	6	7	10	26	51	88	99	100		SBWCM
			3,220	1,770			1	13	26	65	95	100		SBN
Eagle Mills (O)	8-20-64	4.38	45,400	5,960	31	44	57	68	84	94	98	100		SBWCM
			45,400	5,900				6	85	92	99	100		SBN
Empire mine (Be and P)	8-20-64	2.98	382,000	7,930	6	12	23	50	74	92	96	100		SBWCM
			382,000	7,700					53	92	96	100		SBN
Humboldt mine (Be and P)	8-20-64	3.07	45,400	3,870	5	7	13	26	47	67	95	100		SBWCM
			45,400	3,480	2	5	9	10	41	58	91	100		SBN
Republic mine (Be and P)	8-20-64	3.02	77,900	5,350	3	5	9	20	41	54	82	98	100	SBWCM
			77,900	5,100	2	4	7	14	40	57	80	96	100	SBN

[1] Lane (1947, p. 937).

period of concurrent record. Daily records at the Gwinn station were obtained to get detailed information on the natural sediment yield in the area for a representative period. Streamflow was lower than normal, however, during the period covered. An annual sediment yield of 2.33 tons per sq mi was recorded for the 1962 water year when streamflow was about 85 percent of the long-term average at the Gwinn station. Thus, an average annual sediment yield of about 2½ to 3 tons per sq mi for the area is indicated. This yield is extremely low in comparison with yields observed in many other parts of the country. For example, at a rate of 3 tons per sq mi per year, more than a thousand centuries would be needed to fill Schweitzer Creek Reservoir (5,300 acre-ft) with sediment if a trap efficiency of about 80 percent and weight of the sediment of 70 pounds per cubic foot are assumed.

TABLE 13.—*Records of suspended sediment, Black River near Republic*

[t, less than 0.05 ton; m, computed from estimated-concentration graph, less than 0.05 ton]

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	April 1962			May 1962			June 1962		
1				154	13	5.4	39	6	0.6
2				138	10	3.7	33	7	.6
3				115	9	2.8	29	3	.2
4				98	10	2.6	26	6	.4
5				90	9	2.2	27	4	.3
6				98	10	2.6	26	4	.3
7				85	9	2.1	23	3	.2
8				75	8	1.6	21	3	.2
9				73	7	1.4	18	4	.2
10				68	6	1.1	22	5	.3
11				61	7	1.2	36	5	.5
12				55	7	1.0	28	5	.4
13				64	10	1.7	21	5	.3
14				83	9	2.0	17	6	.3
15				74	8	1.6	15	7	.3
16				63	8	1.4	13	6	.2
17				53	8	1.1	11	5	.1
18				47	8	1.0	13	5	.2
19				57	8	1.2	18	13	.6
20				57	8	1.2	16	7	.3
21				48	8	1.0	14	5	.2
22				47	8	1.0	11	6	.2
23				69	7	1.3	9.6	9	.2
24				69	5	.9	16	10	.4
25				65	4	.7	15	10	.4
26	154	10	4.2	53	4	.6	11	10	.3
27	149	8	3.2	43	3	.3	9.2	10	.2
28	170	9	4.1	36	5	.5	7.6	10	.2
29	173	8	3.7	37	4	.4	6.6	9	.2
30	160	9	3.9	45	5	.6	6.9	8	.1
31				44	5	.6			
Total	806		19.1	2,164		46.8	558.9		8.9

TABLE 13.—*Records of suspended sediment, Black River near Republic*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	July 1962			August 1962			September 1962		
1	5.9	9	0.1	3.4	5	t	8.8	1	t
2	4.9	10	.1	2.9	5	t	7.6	3	0.1
3	4.6	10	.1	2.7	6	t	5.5	2	t
4	4.3	8	.1	2.9	5	t	4.9	2	t
5	4.3	9	.1	2.4	11	0.1	4.6	1	t
6	4.0	10	.1	2.4	6	t	4.0	1	t
7	4.0	11	.1	2.4	5	t	3.4	2	t
8	4.0	10	.1	2.0	5	t	2.9	3	t
9	3.2	8	.1	2.0	5	t	4.3	3	t
10	2.9	9	.1	1.8	5	t	8.8	3	.1
11	4.0	8	.1	1.8	4	t	18	3	.1
12	3.7	6	.1	8.0	3	.1	16	4	.2
13	3.2	4	t	8.8	2	t	13	4	.1
14	2.9	5	t	7.3	2	t	12	5	.2
15	2.9	5	t	5.5	2	t	9.2	4	.1
16	2.4	4	t	4.6	3	t	9.2	2	t
17	2.2	4	t	4.0	2	t	12	2	.1
18	2.0	6	t	3.2	2	t	11	3	.1
19	2.0	5	t	2.9	3	m	9.2	2	t
20	3.2	3	t	2.9	3	t	8.8	1	t
21	3.4	1	t	2.7	2	t	8.4	1	t
22	3.4	2	t	2.2	1	t	8.8	2	t
23	3.4	4	t	4.0	1	t	9.2	2	t
24	4.0	3	t	8.0	1	t	14	3	.1
25	10	4	.1	10	2	.1	23	4	.2
26	6.9	3	.1	7.6	1	t	25	5	.3
27	5.2	3	t	5.5	2	t	25	5	.3
28	4.6	3	t	4.3	1	t	23	4	.2
29	4.3	3	t	3.2	2	t	20	6	.3
30	4.3	3	t	5.2	1	t	16	5	.2
31	3.7	4	t	6.6	1	t			
Total	123.8		1.9	133.2		1.0	345.6		3.1

Maximum daily load (May 1)	tons	5.4
Minimum daily load (many days, July–Sept.)	do	<.05
Maximum daily mean concentration (May 1, June 19)	ppm	13
Minimum daily mean concentration (several days, July–Sept.)	ppm	1
Sediment discharge per square mile	tons	2.35
Sediment discharge per acre-foot runoff	do	0.0098
Total discharge for period	cfs-days	4,131.5
Total load for period	tons	80.8
Drainage area	sq mi	34.4

TABLE 13.—*Records of suspended sediment, Black River near Republic*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	October 1962			November 1962			December 1962		
1	13	5	0.2	15	1	t	14	3	0.1
2	12	2	.1	15	1	t	14	3	.1
3	12	1	t	13	2	0.1	14	3	.1
4	15	2	.1	12	2	.1	15	3	.1
5	16	2	.1	13	2	.1	18	3	.1
6	14	2	.1	13	2	.1	18	7	.3
7	13	1	t	16	2	.1	16	7	.3
8	12	2	.1	17	2	.1	15	7	.3
9	13	2	.1	16	1	t	14	6	.2
10	13	2	.1	15	1	t	12	5	.2
11	13	1	t	14	1	t	11	4	.1
12	12	2	.1	14	1	t	11	3	.1
13	9.8	2	.1	13	2	.1	11	3	.1
14	8.9	2	.1	12	2	.1	10	3	.1
15	8.9	1	t	14	2	.1	10	3	.1
16	8.5	2	t	16	2	.1	10	3	.1
17	7.7	2	t	15	2	.1	10	3	.1
18	6.9	2	t	15	2	.1	10	3	.1
19	6.9	2	t	14	2	.1	9.5	3	.1
20	6.6	3	.1	14	2	.1	9.5	3	.1
21	6.6	4	.1	13	3	.1	9.5	3	.1
22	6.6	4	.1	12	3	.1	9.5	3	.1
23	6.9	3	.1	12	3	.1	9	3	.1
24	6.9	3	.1	11	3	.1	9	2	t
25	8.1	2	t	11	3	.1	9	4	.1
26	8.5	1	t	10	3	.1	9	4	.1
27	8.9	2	.1	10	3	.1	8.5	4	.1
28	10	2	.1	11	3	.1	8.5	4	.1
29	10	2	.1	12	3	.1	8	4	.1
30	12	2	.1	13	3	.1	8	3	.1
31	14	1	t	----------	----------	----------	8	3	.1
Total	320.7	----------	2.5	401	----------	2.6	348.0	----------	3.8
	January 1963			February 1963			March 1963		
1	7.5	3	0.1	5	4	t	4.6	1	t
2	7.5	2	t	5	4	0.1	4.6	1	t
3	7.3	2	t	5	4	.1	4.6	1	t
4	7.3	2	t	5	3	.1	4.6	1	t
5	7.3	1	t	5.5	2	t	4.6	1	t
6	7.3	1	t	5.5	2	t	4.6	1	t
7	7.5	4	.1	5.5	2	t	4.6	1	t
8	7.5	5	.1	5.5	2	t	4.5	1	t
9	8	5	.1	5.5	3	t	4.5	1	t
10	8	5	.1	5.5	3	t	4.5	1	t
11	8.5	5	.1	5.5	3	t	4.5	1	t
12	8.9	5	.1	5.5	3	t	4.5	1	t
13	9	5	.1	6.2	1	t	4.5	1	t
14	9	5	.1	5.5	1	t	4.4	1	t
15	9	5	.1	5.2	1	t	4.4	1	t
16	9	4	.1	4.9	1	t	4.4	1	t
17	8.5	3	.1	4.9	1	t	4.5	1	t
18	8	3	.1	4.9	1	t	4.5	1	t
19	7.5	3	.1	4.9	2	t	5	1	t
20	7	3	.1	4.9	2	t	5	1	t

TABLE 13.—*Records of suspended sediment, Black River near Republic*—Continued

Day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day
	January 1962			February 1962			March 1962		
21	6.5	3	0.1	4.9	2	t	5	1	t
22	6	3	.1	4.9	2	t	5	1	t
23	6	3	.1	4.9	2	t	5.5	1	t
24	5.5	2	t	4.9	2	t	6.6	1	t
25	5.5	2	t	4.9	2	t	8.5	7	0.2
26	5	2	t	4.6	2	t	11	10	.3
27	5	2	t	4.6	1	t	14	4	.2
28	5	2	t	4.6	1	t	18	4	.2
29	4.9	2	t				25	8	.5
30	5	2	t				35	12	1.1
31	5	3	t				55	20	3.0
Total	219.0		2.2	143.7		1.0	280.0		5.8
	April 1962			May 1963			June 1963		
1	90	18	4.4	50	8	1.1	29	3	0.2
2	131	11	3.9	45	9	1.1	26	5	.4
3	144	7	2.7	38	9	.9	28	5	.4
4	127	4	1.4	34	8	.7	30	5	.4
5	104	2	.6	30	8	.6	26	5	.4
6	86	3	.7	28	7	.5	27	5	.4
7	72	2	.4	26	6	.4	30	5	.4
8	62	2	.3	38	5	.5	32	5	.4
9	54	2	.3	45	5	.6	35	7	.7
10	48	3	.4	40	5	.5	79	10	2.1
11	43	4	.5	35	5	.5	103	6	1.7
12	37	5	.5	30	5	.4	86	5	1.2
13	32	6	.5	31	5	.4	74	6	1.2
14	30	6	.5	34	5	.4	86	6	1.4
15	28	4	.3	32	5	.4	69	5	.9
16	27	5	.4	30	5	.4	61	5	.8
17	28	5	.4	27	6	.4	50	5	.7
18	26	5	.4	26	6	.4	41	4	.4
19	48	6	.8	25	4	.3	57	5	.8
20	60	5	.8	26	2	.1	84	5	1.1
21	50	5	.7	29	1	.1	63	5	.8
22	44	4	.5	28	1	.1	48	4	.5
23	42	2	.2	27	2	.1	36	4	.4
24	32	3	.2	26	4	.3	29	4	.3
25	32	4	.3	84	10	2.3	24	4	.2
26	28	4	.3	93	7	1.8	22	5	.3
27	26	3	.2	71	2	.4	20	4	.2
28	24	4	.2	59	1	.2	17	8	.4
29	29	4	.3	50	3	.4	15	5	.2
30	53	8	1.1	40	4	.4	13	2	.1
31				32	3	.2			
Total	1,637		24.2	1,209		16.9	1,340		19.4

TABLE 13.—*Records of suspended sediment, Black River near Republic*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	July 1963			August 1963			September 1963		
1	12	2	0.1	1.6	5	t	3.1	3	t
2	9.8	2	.1	1.6	5	t	4.0	2	t
3	8.9	2	t	1.6	4	t	5.2	5	0.1
4	7.7	2	t	1.3	5	t	4.9	5	.1
5	6.9	5	.1	1.0	3	t	4.0	7	.1
6	6.2	5	.1	1.0	4	t	4.0	5	.1
7	6.2	5	.1	2.7	6	t	13	3	.1
8	7.7	3	.1	2.7	4	t	8.1	5	.1
9	5.9	2	t	2.3	3	t	5.2	5	.1
10	4.9	2	t	1.7	3	t	4.2	5	.1
11	4.6	3	t	1.4	6	t	3.6	4	t
12	4.2	2	t	2.0	5	t	4.0	3	t
13	3.8	1	t	3.6	5	t	4.0	2	t
14	4.0	1	t	4.2	7	0.1	3.6	2	t
15	3.6	1	t	3.4	4	t	3.1	2	t
16	3.4	1	t	4.2	2	t	2.9	5	t
17	4.0	1	t	9.3	4	.1	3.1	2	t
18	4.6	2	t	5.5	4	.1	3.1	2	t
19	4.2	2	t	4.0	2	t	3.6	1	t
20	4.2	2	t	3.4	1	t	4.0	2	t
21	3.8	2	t	2.9	2	t	3.8	2	t
22	3.1	4	t	2.7	4	t	4.0	1	t
23	2.4	6	t	2.9	5	t	3.4	1	t
24	2.3	5	t	2.7	2	t	3.4	2	t
25	2.0	6	t	2.9	2	t	3.2	2	t
26	1.8	3	t	2.9	5	t	2.7	5	t
27	1.6	2	t	2.7	2	t	2.4	3	t
28	1.4	3	t	2.9	2	t	2.4	7	t
29	1.3	3	t	2.9	1	t	2.7	5	t
30	1.2	2	t	2.7	1	t	2.7	4	t
31	1.7	3	t	2.9	2	t	----------	----------	--------
Total	139.4	----------	1.1	89.6	----------	0.9	121.4	----------	1.3

Maximum daily load (Apr. 1)	tons	4.4
Minimum daily load (many days, Oct.-Mar., July-Sept.)	do	<.05
Maximum daily mean concentration (Mar. 31)	ppm	20
Minimum daily mean concentration (Oct.-Nov., Jan.-Mar., May, July-Sept.)	ppm	1
Sediment discharge per square mile	tons	2.38
Sediment discharge per acre-foot runoff	do	0.0066
Total discharge for water year	cfs-days	6,248.8
Total load for water year	tons	81.7
Drainage area	sq mi	34.4

TABLE 14.—*Summary of suspended-sediment data for two stations at which daily records were obtained*

[5-1-62 to 6-30-63, period of record common to both sites; drainage area in parentheses after station name]

Period	Water discharge (cfs-days)	Sediment discharge (tons)	Sediment yield		Daily concentration (ppm)		Daily load (tons)	
			Tons per acre-ft of runoff	Tons per sq mi	Max	Min	Max	Min
East Branch Escanaba River at Gwinn (124 sq mi)								
8-24-61 to 9-30-61	1,564	8.1	0.0026	0.065	7	1	1.6	0.1
10-1-61 to 9-30-62	29,526	289.2	.0049	2.33	13	1	22	.1
5-1-62 to 6-30-63	30,144	317.9	.0053	2.56	18	1	23	.1
10-1-62 to 6-30-63	18,383	211.4	.0058	1.70	18	1	23	.1
Black River near Republic (34.4 sq mi)								
4-26-62 to 9-30-62	4,131.5	80.8	0.0098	2.35	13	1	5.4	0.01
5-1-62 to 6-30-63	9,223.9	140.1	.0076	4.07	18	1	5.4	.01
10-1-62 to 9-30-63	6,248.8	81.7	.0066	2.38	18	1	4.4	.01

Data for the concurrent period in table 14 indicate that the Black River basin yields slightly more sediment than the East Branch Escanaba River basin. The difference is insignificant, however, and could be caused by several factors.

The Sands plains area of the East Branch basin would likely contribute less sediment to the stream because the soil is coarse and more resistant to transport by surface flow than the finer textured soils prevalent throughout the iron range. Other physical differences of the basins, including geology, topography, drainage density, and land use, all tend to influence to some degree the sediment yield. Part of the difference may be attributed to Humboldt mine operation which contributes some fine material to the Black River.

The range in concentration for the two basins was the same. The mean concentrations for the common period when weighted with discharges for the basins differ by less than 2 ppm, the greater being that for the Black River. For the brief period of 14 months any significance which this comparison might have is not proved.

MICHIGAMME RIVER BASIN

Very little sediment is carried in the streams of this basin. Data (table 11) indicate that natural sediment yield from the basin is the lowest in the report area.

Milwaukee Lake and an area immediately south of the lake (fig. 26) are used as tailings basins for Republic mine. Determinations of sediment concentration and particle sizes of sediments in waters entering, and in, these basins are listed in table 12. Sediment concentration in Milwaukee Lake was only about 25 percent of that measured in McKinnon Lake, the tailings basin for Humboldt mine. Effluent discharged into Milwaukee Lake is somewhat coarser than that discharged into McKinnon Lake (table 12), a fact probably accounting to some extent for the relatively low concentration in Milwaukee Lake. Outflow from the Republic mine tailings basins is discharged into Gambles Creek about 2½ miles above the mouth. A suspended-sediment concentration of 103 ppm was measured in this outflow in April 1964 at a point about 100 yards upstream from Gambles Creek. No sediment problems have resulted from Republic mine operations.

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*

[Asterisk indicates tons per day computed from estimated-concentration graph]

Day	August 1961: Mean discharge (cfs)	August 1961: Suspended sediment — Mean concentration (ppm)	August 1961: Suspended sediment — Tons per day	September 1961: Mean discharge (cfs)	September 1961: Suspended sediment — Mean concentration (ppm)	September 1961: Suspended sediment — Tons per day
1				30	1	0.1
2				41	1	.1
3				46	1	.1
4				38	1	.1
5				35	1	.1
6				35	1	*.1
7				34	1	.1
8				33	1	.1
9				32	1	.1
10				31	2	.2
11				46	2	.2
12				66	2	.4
13				67	3	.5
14				84	7	1.6
15				82	2	.4
16				66	2	*.4
17				54	2	*.3
18				47	2	*.2
19				43	2	.2
20				40	2	*.2
21				37	2	*.2
22				36	2	.2
23				36	2	*.2
24	32	5	0.4	36	1	.1
25	32	3	.2	37	1	.1
26	32	2	.2	36	1	
27	32	1	.1	35	1	.1
28	32	1	.1	34	1	.1
29	32	1	.1	34	1	.1
30	31	1	.1	40	1	.1
31	30	1	.1			
Total	253		1.3	1,311		6.8

Maximum daily load (Sept. 14)	tons	1.6
Minimum daily load (many days, Aug.-Sept.)	do	.1
Maximum daily mean concentration (Sept. 14)	ppm	7
Minimum daily mean concentration (many days, Aug.-Sept.)	ppm	1
Sediment discharge per squaremile	tons	.065
Sediment discharger per acre-foot runoff	do	0.0026
Total discharge for period	cfs-days	1,564
Total load for period	tons	8.1
Drainage area	sq mi	124

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	October 1961			November 1961			December 1961		
1	82	1	0.2	60	2	0.3	52	2	0.3
2	91	1	.2	68	2	.4	52	2	.3
3	72	2	.4	110	3	.9	53	1	.1
4	58	2	.3	105	3	.8	87	2	.5
5	52	2	.3	91	3	.7	142	5	1.9
6	48	1	.1	84	2	.4	120	4	1.3
7	44	3	.4	74	5	1.0	110	2	.6
8	41	3	.3	68	2	.4	97	3	.8
9	38	3	.3	61	2	.3	90	3	.7
10	38	1	.1	60	2	.3	80	4	*.9
11	37	1	.1	56	2	.3	74	3	.6
12	37	1	.1	56	1	.2	70	2	.4
13	47	1	.1	57	2	.3	65	2	.4
14	72	1	.2	56	2	.3	62	3	.5
15	78	2	.4	54	2	.3	59	4	.6
16	66	2	.4	55	2	.3	57	4	.6
17	58	2	.3	58	2	.3	56	3	.4
18	52	1	.1	58	4	.6	54	2	.3
19	50	2	.3	55	5	.7	53	3	.4
20	50	2	.3	52	2	.3	52	3	.4
21	49	2	.3	50	3	.4	50	3	.4
22	47	2	*.2	50	2	*.3	48	3	.4
23	46	1	*.1	52	2	.3	47	3	.4
24	50	2	*.3	55	1	.1	46	3	.4
25	51	2	.3	56	1	.2	45	2	.2
26	50	2	.3	58	1	.2	43	2	.2
27	47	2	.3	57	1	.2	42	2	.2
28	47	2	.2	55	2	*.3	41	3	.3
29	52	2	.3	54	2	*.3	41	2	.2
30	68	3	.6	53	2	*.3	40	2	.2
31	70	2	.4	---------	---------	--------	40	2	.2
Total	1,688	---------	8.2	1,878	---------	11.7	1,968	---------	15.1
	January 1962			February 1962			March 1962		
1	39	2	0.2	32	4	0.3	35	4	0.4
2	39	2	.2	32	3	.2	35	3	.3
3	39	2	.2	32	2	.2	35	5	.5
4	38	2	.2	31	2	.2	35	3	.3
5	38	2	.2	31	2	.2	34	3	.3
6	38	1	.1	31	2	.2	34	2	.2
7	38	1	*.1	31	2	.2	34	2	.2
8	37	1	.1	31	3	.2	34	2	.2
9	37	1	*.1	31	2	.2	34	2	.2
10	37	2	*.2	31	2	.2	34	2	.2
11	37	2	.2	31	2	.2	34	1	.1
12	37	2	.2	31	2	.2	34	1	.1
13	36	2	.2	31	2	.2	35	2	.2
14	36	1	.1	31	1	.1	35	2	.2
15	36	1	.1	31	2	.2	36	5	.5
16	35	1	.1	31	2	.2	37	2	.2
17	35	2	.2	32	2	.2	37	2	.2
18	35	2	.2	32	2	.2	38	2	.2
19	34	3	.3	33	2	.2	39	2	.2
20	34	2	.2	33	4	.4	39	2	.2

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*—Continued

Day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day	Mean discharge (cfs)	Suspended sediment: Mean concentration (ppm)	Suspended sediment: Tons per day
	January 1962			February 1962			March 1962		
21	34	2	0.2	34	3	0.3	39	3	0.3
22	34	2	.2	34	2	.2	40	3	.3
23	34	3	.3	35	3	.3	41	3	.3
24	33	2	*.2	35	3	.3	43	4	.5
25	33	2	*.2	35	3	.3	46	3	.4
26	33	1	.1	35	3	.3	50	3	.4
27	32	3	.2	35	2	.2	58	6	*.9
28	32	2	.2	35	2	.2	76	10	*2
29	32	1	.1	---	---	---	120	13	4.2
30	32	2	.2	---	---	---	132	12	4.3
31	32	2	.2	---	---	---	140	10	*4
Total	1,096	---	5.5	907	---	6.3	1,493	---	22.5
	April 1962			May 1962			June 1962		
1	150	8	*3	310	2	1.7	115	4	1.2
2	150	7	2.8	284	2	1.5	106	5	1.4
3	145	4	1.6	244	2	1.3	96	2	.5
4	146	4	1.6	208	2	1.1	93	2	.5
5	156	2	.8	192	2	1.0	102	2	.6
6	180	4	1.9	214	2	1.2	102	3	.8
7	251	8	5.4	203	2	1.1	92	4	1.0
8	249	5	3.4	184	2	1.0	83	4	.9
9	264	4	2.8	184	2	1.0	77	3	.6
10	222	2	1.2	172	2	.9	81	3	.6
11	228	2	1.2	156	1	.4	164	8	3.5
12	221	2	1.2	146	1	.4	197	7	3.7
13	214	2	1.2	152	2	.8	147	4	1.6
14	222	1	.6	202	2	1.1	108	3	1.9
15	210	2	1.1	198	2	1.1	89	7	1.7
16	200	2	1.1	166	2	.9	77	9	1.9
17	217	2	1.2	142	2	.8	69	9	1.7
18	275	3	2.2	125	2	.7	68	10	1.8
19	328	3	2.6	129	2	.7	79	10	2.1
20	318	3	2.6	160	2	.9	79	9	1.9
21	314	3	2.5	143	1	.4	70	9	1.7
22	438	9	11	138	2	.7	66	10	1.8
23	613	13	22	221	3	1.8	63	11	1.9
24	573	8	12	239	3	1.9	68	13	2.4
25	487	6	7.9	200	3	1.6	64	10	1.7
26	442	5	6.0	160	3	1.3	59	8	1.3
27	396	4	4.3	136	4	1.5	53	9	1.3
28	402	3	3.2	117	4	1.3	50	8	1.1
29	388	3	3.1	115	2	.6	47	7	.9
30	336	2	1.8	136	3	1.1	44	7	.8
31	---	---	---	129	4	1.4	---	---	---
Total	8,735	---	113.3	5,505	---	33.2	2,608	---	44.8

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	July 1962			August 1962			September 1962		
1	42	7	0.8	28	3	0.2	49	2	0.3
2	41	7	.8	28	7	.5	44	1	.1
3	41	8	.9	26	6	.4	38	1	.1
4	39	4	.4	31	3	.2	34	2	.2
5	38	4	.4	30	3	.2	36	2	.2
6	37	2	.2	29	4	.3	33	2	.2
7	37	2	.2	30	4	.3	28	2	.2
8	36	3	.3	30	4	.3	26	2	.1
9	36	5	.5	29	5	.4	28	2	.2
10	36	3	.3	28	4	.3	34	2	.2
11	38	3	.3	26	3	.2	68	3	.6
12	36	4	.4	30	3	.2	54	2	.3
13	34	2	.2	43	3	.3	48	3	.4
14	33	2	.2	42	3	.3	56	2	.3
15	32	4	.3	36	3	.3	46	2	.2
16	31	2	.2	32	4	.3	46	2	.2
17	31	2	.2	30	5	.4	57	3	.5
18	31	2	.2	29	2	.2	52	3	.4
19	31	3	.2	28	2	.2	52	2	.3
20	32	3	.2	28	2	.2	65	2	.4
21	34	2	.2	26	2	.1	60	2	.3
22	34	2	.2	25	2	.1	59	3	.5
23	33	3	.3	26	3	.2	58	4	.6
24	34	4	.4	41	3	.3	60	5	.8
25	38	2	.2	52	3	.4	86	3	.7
26	41	2	.2	46	3	.4	77	2	.4
27	35	3	.3	36	2	.2	75	1	.2
28	32	4	.3	32	2	.2	70	2	.4
29	31	7	.6	28	1	.1	62	2	.3
30	30	6	.5	39	2	.2	56	2	.3
31	30	3	.2	43	2	.2	---	---	---
Total	1,084	---	10.6	1,007	---	8.1	1,557	---	9.9

Maximum daily load (Apr. 23)	tons	22
Minimum daily load (many days, Oct.–Mar., Aug., Sept.)	do	.1
Maximum daily mean concentration (Mar. 29, Apr. 23, June 24)	ppm	13
Minimum daily mean concentration (many days, Oct.–Mar., Sept.)	ppm	1
Sediment discharge per square mile	tons	2.33
Sediment discharge per acre-foot runoff	do	0.0049
Total discharge for water year	cfs-days	29,526
Total load for water year	tons	289.2
Drainage area	sq mi	124

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*—Continued

Day	October 1962 Mean discharge (cfs)	October 1962 Suspended sediment: Mean concentration (ppm)	October 1962 Suspended sediment: Tons per day	November 1962 Mean discharge (cfs)	November 1962 Suspended sediment: Mean concentration (ppm)	November 1962 Suspended sediment: Tons per day	December 1962 Mean discharge (cfs)	December 1962 Suspended sediment: Mean concentration (ppm)	December 1962 Suspended sediment: Tons per day
1	53	3	0.4	77	2	0.4	57	2	0.3
2	50	4	.5	78	1	.2	58	2	.3
3	49	2	.3	75	2	.4	58	2	.3
4	77	2	.4	72	2	.4	60	3	.5
5	77	2	.4	71	1	.2	76	8	1.6
6	70	1	.2	82	2	.4	77	6	1.2
7	63	2	.3	89	11	2.6	65	2	.4
8	60	2	.3	89	4	1.0	60	2	.3
9	59	2	.3	80	1	.2	56	2	.3
10	55	2	.3	72	1	.2	54	2	.3
11	52	2	.3	69	2	.4	52	7	1.0
12	52	1	.1	67	1	.2	50	5	.7
13	46	2	.2	64	2	.3	49	3	.4
14	46	1	.1	62	1	.2	48	3	.4
15	45	1	.1	60	1	.2	47	3	.4
16	45	1	.1	69	4	.7	47	3	.4
17	43	1	.1	80	9	1.9	47	3	.4
18	40	1	.1	74	4	.8	47	3	.4
19	39	1	.1	70	2	.4	46	2	.2
20	38	1	.1	67	2	.4	45	2	.2
21	38	1	.1	67	2	.4	44	2	.2
22	38	1	.1	66	2	.4	42	1	.1
23	40	1	.1	60	2	.3	41	1	.1
24	42	2	.2	57	2	.3	40	1	.1
25	42	2	.2	56	2	.3	39	1	.1
26	41	1	.1	55	2	.3	38	1	.1
27	41	2	.2	55	2	.3	37	1	.1
28	43	1	.1	54	2	.3	36	2	.2
29	44	2	.2	54	2	.3	35	2	.2
30	46	2	.2	55	2	.3	35	1	.1
31	60	3	.5	---	---	---	34	2	.1
Total	1,534	---	6.7	2,046	---	14.7	1,520	---	11.4

Day	January 1963 Mean discharge (cfs)	January 1963 Suspended sediment: Mean concentration (ppm)	January 1963 Suspended sediment: Tons per day	February 1963 Mean discharge (cfs)	February 1963 Suspended sediment: Mean concentration (ppm)	February 1963 Suspended sediment: Tons per day	March 1963 Mean discharge (cfs)	March 1963 Suspended sediment: Mean concentration (ppm)	March 1963 Suspended sediment: Tons per day
1	33	3	0.3	26	2	0.1	26	6	0.4
2	33	3	.3	26	2	.1	26	6	.4
3	32	2	.2	26	2	.1	26	6	.4
4	32	2	.2	26	2	.1	26	6	.4
5	31	2	.2	26	2	.1	25	6	.4
6	31	2	.2	27	2	.1	25	6	.4
7	30	1	.1	27	2	.1	25	6	.4
8	30	1	.1	27	2	.1	25	6	.4
9	30	1	.1	27	2	.1	24	6	.4
10	29	1	.1	27	2	.1	24	6	.4
11	29	1	.1	27	3	.2	24	7	.4
12	29	2	.2	26	5	.4	24	7	.4
13	28	2	.2	26	6	.4	24	6	.4
14	28	2	.2	27	6	.4	24	6	.4
15	28	2	.2	27	5	.4	24	6	.4
16	27	2	.1	27	5	.4	24	6	.4
17	27	2	.1	27	5	.4	24	6	.4
18	27	2	.1	27	6	.4	24	6	.4
19	27	2	.1	27	6	.4	25	6	.4
20	27	2	.1	27	6	.4	25	6	.4

TABLE 15.—*Records of suspended sediment, East Branch Escanaba River at Gwinn*—Continued

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	January 1963			February 1963			March 1963		
21	27	2	0.1	27	6	0.4	25	5	0.3
22	27	2	.1	27	6	.4	26	5	.4
23	27	2	.1	27	6	.4	27	5	.4
24	27	2	.1	27	6	.4	28	5	.4
25	27	2	.1	27	6	.4	29	5	.4
26	26	2	.1	27	6	.4	31	5	.4
27	26	2	.1	27	6	.4	34	5	.4
28	26	2	.1	27	6	.4	38	5	.5
29	26	2	.1	----	----	----	45	5	.6
30	26	2	.1	----	----	----	60	5	.8
31	26	2	.1	----	----	----	90	5	1.2
Total	879	----	4.3	749	----	8.0	927	----	13.8

Day	Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment		Mean discharge (cfs)	Suspended sediment	
		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day		Mean concentration (ppm)	Tons per day
	April 1963			May 1963			June 1963		
1	196	7	3.7	138	3	1.1	60	3	0.5
2	362	13	13	126	2	.7	60	2	.3
3	481	18	23	115	2	.6	61	2	.3
4	479	18	23	105	1	.3	65	2	.4
5	358	11	11	94	2	.5	60	1	.2
6	279	7	5.3	87	2	.5	60	1	.2
7	226	7	4.3	81	1	.2	63	1	.2
8	194	6	3.1	109	2	.6	60	1	.2
9	170	3	1.4	142	3	1.2	60	1	.2
10	143	4	1.5	120	2	.6	84	2	.4
11	134	3	1.1	106	1	.3	132	4	1.4
12	121	3	1.0	93	1	.2	119	3	1.0
13	113	2	.6	91	1	.2	117	3	.9
14	105	2	.6	98	3	.8	152	8	3.3
15	100	2	.5	92	3	.7	146	9	3.5
16	96	4	1.0	85	2	.4	122	6	2.0
17	95	3	.8	79	3	.6	107	3	.9
18	90	2	.5	80	3	.6	94	3	.8
19	124	4	1.3	76	3	.6	116	4	1.2
20	154	3	1.2	71	3	.6	219	11	6.5
21	136	3	1.1	73	2	.4	194	8	4.2
22	116	2	.6	76	2	.4	145	3	1.2
23	106	1	.3	71	3	.6	115	2	.6
24	97	1	.3	67	2	.4	95	3	.8
25	89	1	.2	79	3	.6	82	2	.4
26	85	1	.2	100	4	1.1	71	1	.2
27	83	1	.2	84	3	.7	62	3	.5
28	81	1	.2	74	3	.6	60	2	.3
29	83	1	.2	69	2	.4	59	1	.2
30	126	3	1.0	65	2	.4	60	2	.3
31	----	----	----	60	2	.3	----	----	----
Total	5,022	----	102.1	2,806	----	17.2	2,900	----	33.1

Maximum daily load (Apr. 3, 4)	tons	23
Minimum daily load (many days, Oct., Dec.-Feb.)	do	.1
Maximum daily mean concentration (Apr. 3, 4)	ppm	18
Minimum daily mean concentration (many days, Oct.-Jan., Apr.-June)	ppm	1
Sediment discharge per square mile	tons	1.70
Sediment discharge per acre-foot runoff	do	0.0058
Total discharge for period	cfs-days	18,383
Total load for period	tons	211.4
Drainage area	sq mi	124

CARP RIVER BASIN

Only three or four analyses are available at each of the three sampling sites in the Carp basin (table 11). The samples were obtained, however, during periods of low and moderately high streamflow and provided an indication of the range of concentration and load to be expected in these streams. Deer Lake probably traps most of the sediment transported to it. Thus, sediment contained in the Carp River, the outlet stream from Deer Lake, is contributed by the area below the lake or by the pelletizing and ore-processing plants at Eagle Mills (fig. 26).

Sediment contained in effluent from the ore-improvement plant at Eagle Mills is much finer than that produced by the other plants (table 12). Sediments from both plants at Eagle Mills contain much less sand-sized material than sediments discharged at Humboldt and Republic mines. Carp River receives the seepage from the tailings basins of Eagle Mills plant. No measurement of suspended-sediment concentration in Carp River below Eagle Mills is available.

TEMPERATURE

Temperature is an important and often a critical factor in determining the suitability of water for many uses. It has varied effects on the chemical, physical, and biological processes that occur in water. It affects the palatability of water, water-treatment processes, industrial value of water, and suitability of water for supporting aquatic life (table 5).

Most streams in this area are trout streams and as such are a valuable resource. Trout thrive best in an environment in which maximum water temperatures seldom exceed about 68°F. Developments that would raise the water temperatures above this level for prolonged periods should be avoided. In general, developments made thus far have had no deleterious effects upon water temperatures. For example, Schweitzer Creek Reservoir, where the release for streamflow is withdrawn from near the bottom of the pool, has actually reduced water temperatures in the stream during the summer months.

Water temperatures are largely determined by the average air temperature. Consequently, seasonal fluctuations in water temperature are quite similar to the pattern established by air temperatures. The volume of ground-water inflow to streams, however, has a marked influence upon water temperature. Streams with a high base flow will tend to have lower water temperatures during the summer. Conversely, such streams would tend to have higher water temperatures during late fall, winter, and early spring. Discharge of industrial and municipal wastes into streams may also affect water temperatures.

Water temperatures in this area, however, are not significantly affected from these sources.

Continuous records of water temperature were obtained at five gaging stations. These records are summarized in the duration table (table 16) which shows, for a particular period of record, the percentage of days during which water temperatures were at or below a specific value. For example, at all five stations the water temperature was at the freezing point on an average of about 30 percent of the days. For Schweitzer Creek near Palmer, the water temperature was 66°F. or less during 90 percent of the days. The lower temperature of Schweitzer Creek at high duration percentages corroborates the statement made above regarding the effect of the reservoir on water temperature.

TABLE 16.—*Duration of water temperatures for streams*

Station	Period of record (water years)	Water was at or below indicated temperature, °F, for following percentage of days							Max temp (°F)
		30	40	50	60	70	80	90	
Black River near Republic	1962–64	32	36	46	55	60	66	71	81
Middle Branch Escanaba River near Ishpeming	1962–64	32	37	46	55	60	65	70	78
Schweitzer Creek near Palmer	1962–64	32	38	47	53	58	62	66	76
East Branch Escanaba River at Gwinn	1956–64	32	37	45	54	60	66	70	77
Peshekee River near Champion	1962, 1964	32	34	47	56	62	68	73	81

Maximum, mean, and minimum monthly water temperatures and maximum and minimum instantaneous values for each month at the Gwinn gaging station are shown in figure 27. Similarity in the seasonal pattern with that of air temperature (fig. 2) is obvious. The average annual water temperature for the period was 46°F.

GROUND WATER

At the present time (1965), ground water in the Marquette Iron Range area is used only for rural and small public water supplies. In a few places, possibilities exist for developing relatively large ground-water supplies for industrial needs, and in several other places, modest ground-water supplies could be developed that might be especially valuable as supplementary sources of supply. Ground water is a significant element in the total hydrologic system and must be considered in any evaluation of the water resources of the area.

Although ground water is discussed separately from surface water, the two are not independent. The major part of streamflow in most places in this area is derived from ground water. In a few other places, streams provide recharge to ground water. The two sources of

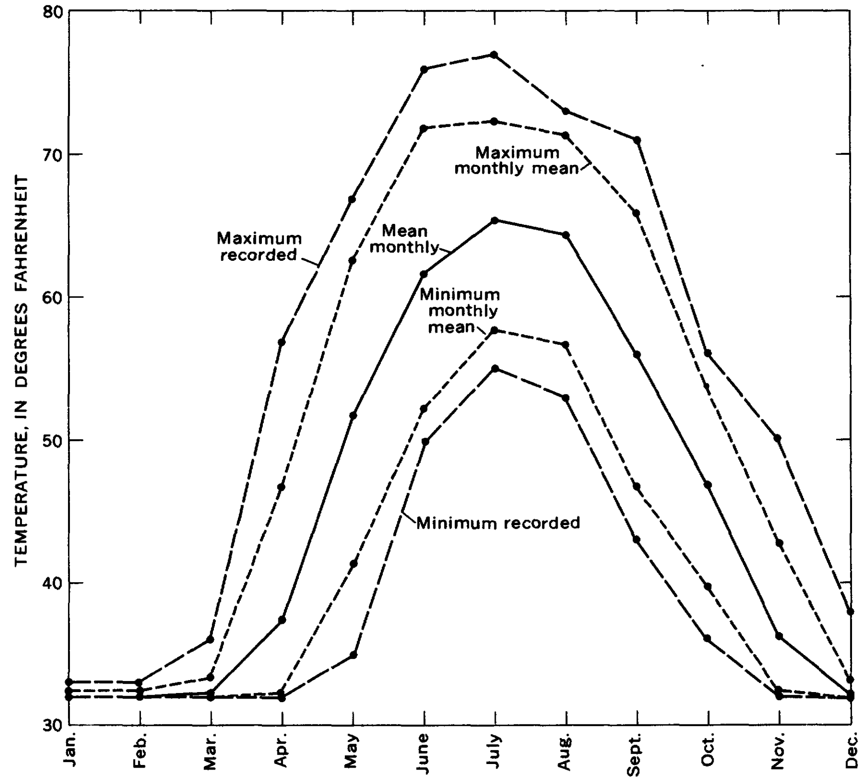


FIGURE 27.—Water temperatures, East Branch Escanaba River at Gwinn, October 1956 to September 1964.

supply are closely related, and the development of one source affects the availability of water from the other.

In the following subsections of this discussion of ground water, the general aspects of ground-water occurrence, recharge, discharge, and storage are briefly considered; characteristics of specific ground-water areas are described insofar as data permit; and quality of ground waters is defined. Geologic conditions are of special significance in determining the occurrence and availability of ground water. Therefore, geologic factors are an integral part of this discussion.

OCCURRENCE OF GROUND WATER

Ground water in the Marquette Iron Range area occurs in intergranular openings in glacial drift and in fracture openings in underlying igneous and metamorphic rocks. Much more water is stored in the glacial drift than in the Precambrian bedrock. Figure 28 shows the general thickness of glacial drift in the area. Because of the very irregular surface of the bedrock under the drift and scarcity of sub-

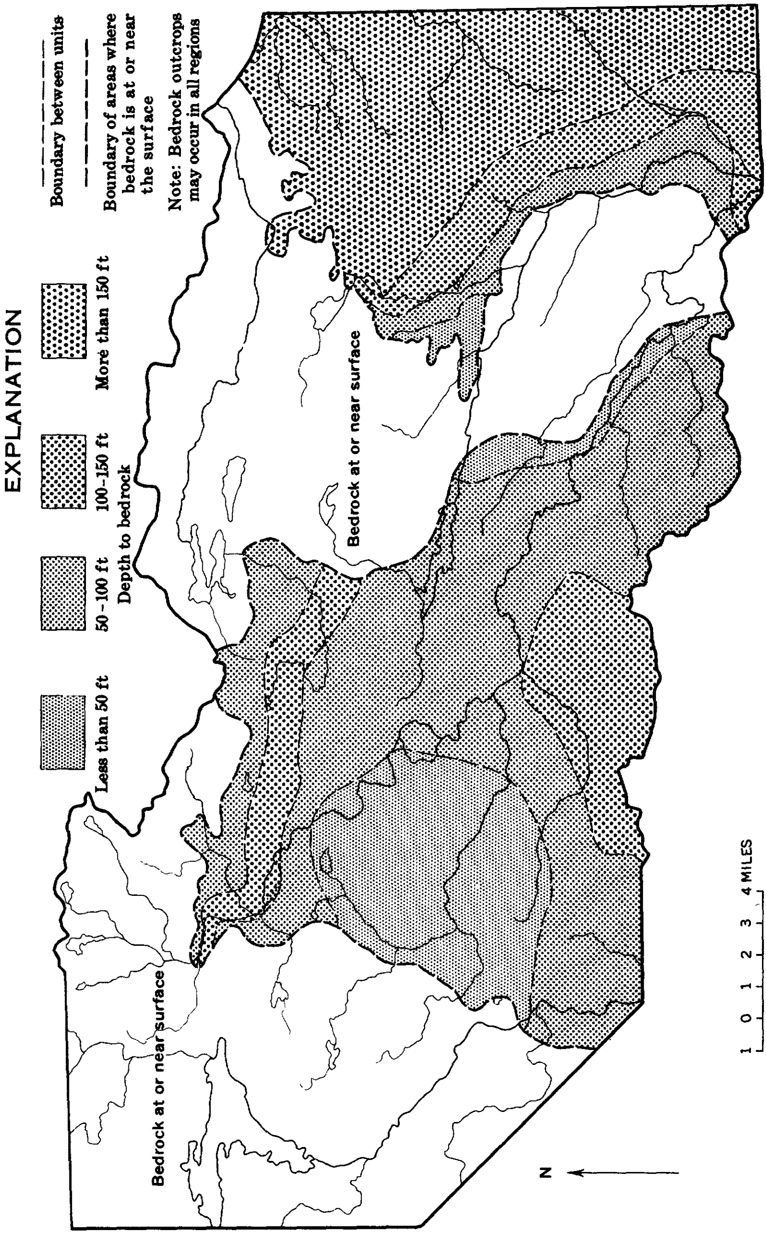


FIGURE 28.—Thickness of glacial drift.

surface information, a detailed map could not be drawn. Small outcrops of bedrock occur in all areas shown on the map. Conversely, small pockets of drift, as much as 200 feet thick, occur in areas where bedrock is shown to be at or near the surface. Water-supply potential of the drift aquifiers (water-bearing formations) is related to their thickness. In the eastern part of the area, ground water also occurs in both intergranular and fracture openings in Paleozoic sandstones. The amount of water stored in the sandstones is unknown.

Below the water table all openings in earth materials are filled with water. The top of the zone of saturation generally is at the land surface in the vicinity of lakes and swamps but may be more than 100 feet below the surface in upland areas. Water in this zone is unconfined where saturated sediments are overlain by permeable materials. Water is confined where the saturated aquifer is overlain by relatively impermeable materials and the hydraulic head is higher than the top of the permeable saturated zone. Confined water frequently is referred to as artesian water, and wells tapping water-bearing formations containing confined water are called artesian wells.

SOURCE OF GROUND WATER

All ground water in the area is derived, directly or indirectly, from local precipitation. The amount of water which may percolate to the ground-water body depends chiefly on the amount and timing of precipitation, character of the soil and underlying earth materials, and slope and vegetal cover of the surface. On the plains underlain by sandy soil and permeable outwash, 18 inches of water, or more, per year may percolate to the water table; it may be considerably less in drought years. On steep hills, however, where nearly impermeable Precambrian bedrock is at or near the surface, the total percolation may be less than 1 inch per year. Growing vegetation reduces soil moisture, which must be replenished before substantial percolation to the water table can occur. Thus, dense vegetation generally reduces recharge more than a sparse one.

Wherever the water surface in a stream is above the water table in an adjoining aquifer, seepage from the stream contributes to ground water. This condition exists along Goose Lake Outlet for several miles below Goose Lake, along Middle Branch Escanaba River above the tributary draining the area south of Voelker Lake, along Flopper and Bear Creeks for short reaches, and possibly elsewhere. Streams in flood often provide temporary recharge by seepage into the banks of the stream channel. The bank storage is returned to the stream when the stream stage recedes to normal level. Recharge from lakes is also possible when the hydraulic gradient is from the lake to the acquifer.

Indirect recharge from one aquifer to another undoubtedly occurs in the southeastern part of the area where glacial drift overlies permeable sandstone and limestone bedrock. A very small amount of indirect recharge probably results from flow through fractures in Precambrian bedrock into adjacent glacial deposits in many parts of the area. A larger amount of indirect recharge occurs as ground water flows from aquifers in the morainal uplands into the outwash deposits in stream valleys.

MOVEMENT OF GROUND WATER

The amount of water that moves through a unit cross-sectional area of an aquifer depends upon the permeability of the aquifer and the hydraulic gradient. The general formula $Q=PIA$ illustrates this relationship, where Q is the rate of flow; P, permeability of the aquifer; I, hydraulic gradient; and A, cross-sectional area. In most ground-water problems, movement of water through an aquifer can be expressed as $Q=TIL$, where Q is the rate of flow in gallons per day; T, transmissibility in gallons per day per foot; I, hydraulic gradient in feet per mile; and L, width in miles of the cross section through which the flow occurs. The transmissibility of glacial materials in this area ranges from about 3,000 to 150,000 gpd per ft (gallons per day per foot). Transmissibility of bedrock is probably much smaller.

The direction of movement of ground water, approximately at right angles to the contours, is indicated by the water-level contours on plate 3. The general direction of movement in the central part of of the area is to the southeast, although there are many local variations. In the eastern part of the area, ground water generally moves toward the east and northeast. If the cross-sectional area, transmissibility, and amount of water moving through the aquifer are everywhere the same, the gradient of the water table will also remain the same. A steepening of the gradient is caused by the following changes: (1) the cross-sectional area of the aquifer is decreasing, (2) the aquifer is becoming less permeable, or (3) more water is moving through the aquifer. Steepening of the gradient of the water table near a stream is a normal condition.

CHANGES IN GROUND-WATER STORAGE

The water table and the volume of ground water in storage fluctuate continually in response to changes in recharge and discharge. A declining water table indicates that water is being discharged faster than it is being replenished (a net loss of ground water from storage). A rising water table indicates that water is being replenished faster than it is being discharged (a net gain in storage). Fluctuations in ground-water levels exhibit a definite seasonal pattern of rising in the spring in response to recharge from snowmelt and rainfall and of falling for the rest of the year. Sometimes, however, a second rise occurs in the fall as a result of rain. Water levels nearly always decline during the summer and winter. In summer, the potential recharge is captured by growing vegetation, and in winter it is temporarily stored as snow and ice. The lowest water levels usually occur in late winter or early spring, just before the spring breakup.

Fluctuations of water levels in two unlike aquifers are illustrated in figure 29. Well 47N28W3-1 is in a permeable outwash formation

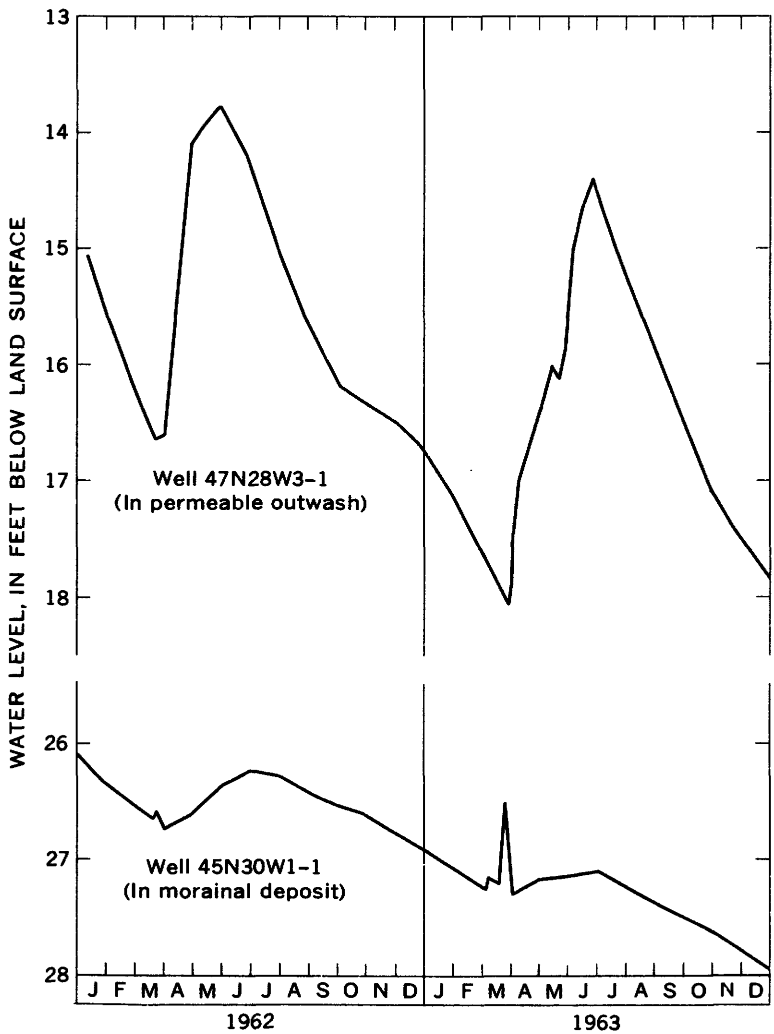


FIGURE 29.—Water levels in two wells penetrating different aquifers.

in the Humboldt area. Well 45N30W1–1 is in a morainal deposit containing a considerable amount of clay. The pip in the hydrograph of this well in the spring of 1963 was probably caused by surface-water flow into and subsequent drainage from this dug well. Areas containing the two wells probably received about the same amount and kind of precipitation during the 2-year period. Yet the change of water levels in the two aquifers is markedly different. The formation containing the well whose water levels are shown in the upper graph apparently receives and transmits more water than the formation containing the other well.

The range and rate of water-level fluctuations in this area are influenced chiefly by the amount, rate, and timing of precipitation; proximity of discharge (recharge) base-level controls; topographic situation; and permeability and storage capacity of the soil and underlying materials. A rise of 1 foot in the water table might indicate an increase of 3 inches of ground-water storage in some areas and less than 1 inch in others.

GROUND-WATER AREAS

Previous discussion has pointed out that the best sources of ground water are the deposits of outwash and alluvium. The quantity of water present is dependent upon porosity, saturated thickness, and areal extent of the deposits. The amount of water that may be developed is dependent upon the amount of recharge to the deposits and the capacity of the deposits to yield water to wells. The open texture of outwash materials makes them receptive to direct recharge from precipitation falling upon the area. When such deposits are hydraulically connected to streams, additional recharge is possible by drawing the ground-water levels down sufficiently to reverse the gradient so that water from the stream can percolate to the ground-water body.

In the next three subsections of this report, areas of extensive outwash deposits are discussed in detail. These areas are shown in figure 30, which is a generalization of the more detailed delineation on the surficial geology map (pl. 1).

GOOSE LAKE-SANDS PLAIN AREA

The most important of the areas having potential for ground-water development is the outwash plain, 2½ to 6 miles wide, that extends southward from near Goose Lake for about 13 miles to the southeast corner of the report area. The plain is a plateaulike area adjoining the area of rugged topography in the western part of the Chocolay River basin. Thickness of the unconsolidated materials

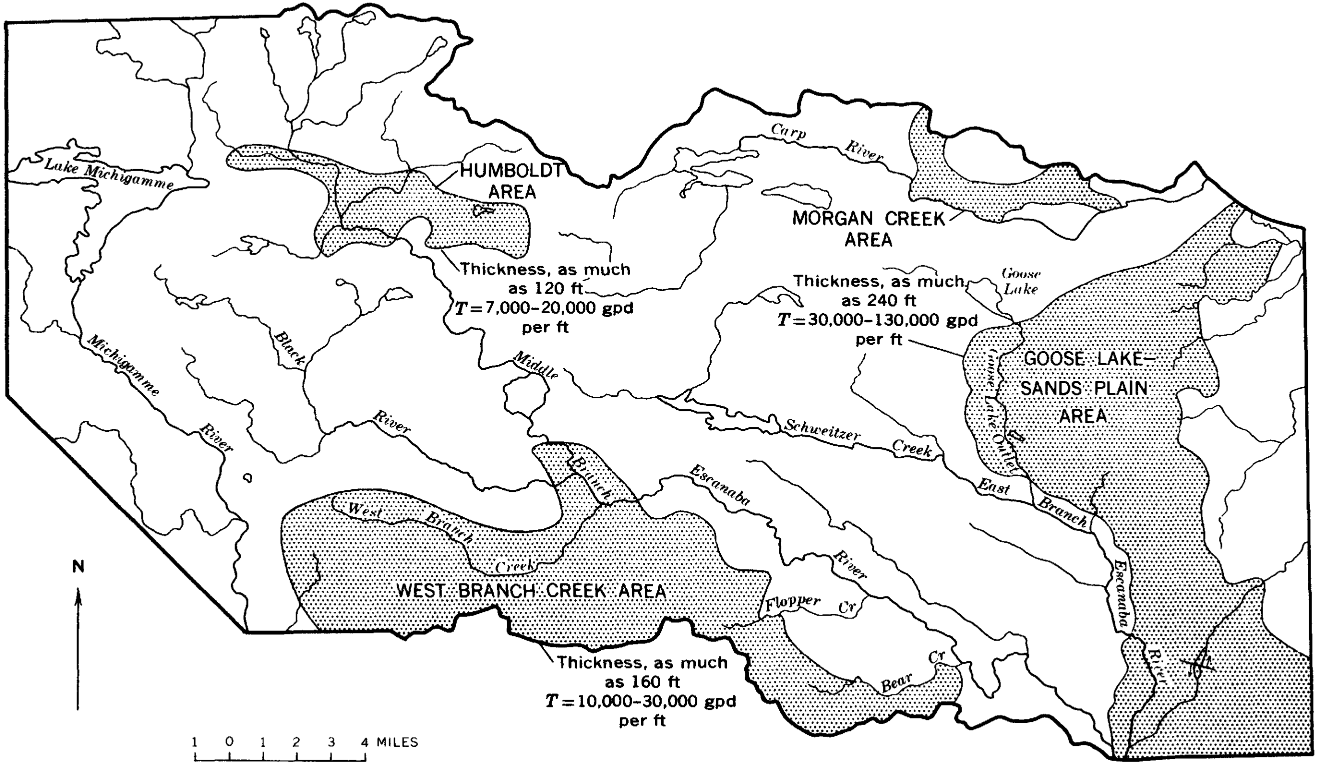


FIGURE 30.—Areas of outwash from which ground-water supplies might be developed. ***T*, coefficient of transmissibility.**

making up this formation ranges from zero along the west edge to more than 240 feet. A number of holes were augered into this formation to obtain geologic and water data for this report. Records of some of these wells are contained in table 23. Only two wells augered into this outwash material reached bedrock. The best information on the depth to bedrock at any point is that obtained from a refraction seismic test sounding made by Michigan State Highway Department near Cascade, about 1½ miles southeast of Goose Lake. In a 1,000-foot traverse, depth to bedrock was found to range from about 165 to 240 feet. Knobs of exposed bedrock scattered about the outwash plain indicate that the bedrock surface underlying the outwash is very irregular.

The material constituting these outwash deposits is mostly sand (table 24). At two wells in NW¼ sec. 36, T. 47 N., R. 26 W., about 2 miles directly south of Goose Lake and adjacent to Goose Lake Outlet, about 60 feet of good, clean gravel was found in the upper part of the formation.

Depths to the water table range from less than 5 to at least 150 feet. The general movement of ground water is toward the east and northeast (pl. 3). The profile, figure 31, shows that flow from the Goose Lake Outlet basin is pirated by ground-water underflow to the Chocolay River basin.

Water-bearing and water-transmitting characteristics of aquifers are defined by the coefficients of storage and transmissibility. (See "Glossary.") These two coefficients permit evaluation of the water-producing capability of aquifers and determination of the effects of ground-water withdrawal upon water levels in the area. They may be determined by aquifer tests wherein the effect of pumping a well at a constant rate is measured in the pumped well and in observation wells penetrating the aquifer. One such test was made by Cleveland-Cliffs Iron Co. in May 1964 on a well in NW¼ sec. 36, T. 47 N., R. 26 W., where 60 feet of gravel was recorded. An 8-inch test well was pumped at a constant rate of 310 gpm (gallons per minute) for 15 hours, and water levels were measured in nine observation wells during the period of pumping and the period of recovery following cessation of pumping. The average coefficient of transmissibility computed from the test data was 130,000 gpd per ft, and the average coefficient of storage was 0.16.

Computation of hydraulic characteristics from aquifer test data involves the following assumptions: (1) that the aquifer is of infinite areal extent and of uniform thickness, (2) that the well receives water throughout the full thickness of the aquifer, (3) that the aquifer is homogeneous and transmits water equally in all directions, (4) that

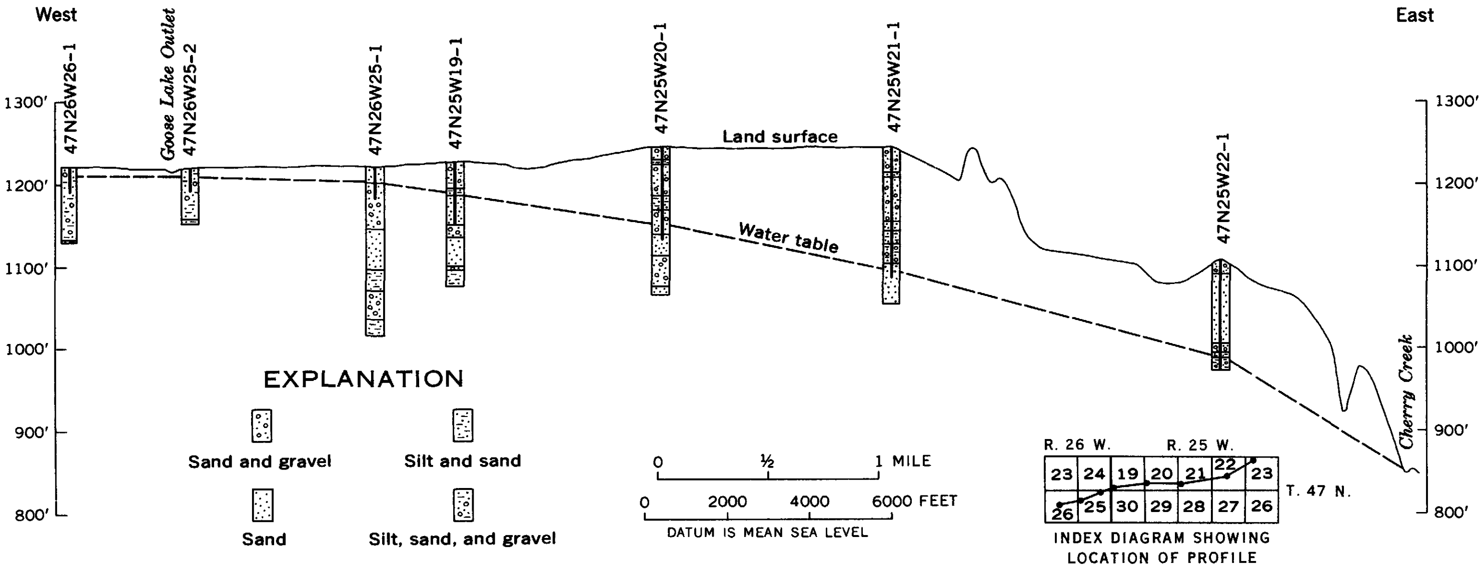


FIGURE 31.—Profile of water table between Goose Lake Outlet and Cherry Creek.

water in the aquifer is released from storage instantaneously, and (5) that the aquifer receives no recharge during the pumping period. These assumptions are seldom fulfilled, but results can be useful if the limitations are recognized.

Contour maps of the water table and streamflow measurements that define the accretion rate of ground-water flow to streams can also be used to obtain estimates of the hydraulic properties of ground-water bodies. In this method, a reach of stream is selected where the streamflow is known at the upstream and downstream ends of the reach. Flow lines are drawn encompassing the reach and the area contributing ground-water flow to the reach. Flow lines, or paths followed by water particles as they move toward points of discharge, are drawn perpendicular to the water-table contours. With this information and adaptation of procedures described by Harder and Drescher (1954), a flow-net analysis can be made from which recharge to, and transmissibility of, the aquifer can be computed.

This method was used at Goose Lake Outlet where three series of streamflow measurements defining flow at seven points along the stream were available (fig. 32). The streamflow measurements were made during periods of base flow when there was no surface runoff. Goose Lake Outlet loses flow to ground water in the first 3 miles below Goose Lake and picks up flow from ground water in the next 4 miles. Only the gaining reaches were used in the flow-net analysis. Water-table contours (fig. 33) were drawn upon the basis of measurements to water level in wells made on July 21, 1964. They do not, therefore, coincide exactly with those shown on plate 3, which were based on water-level measurements made at another time.

The coefficient of transmissibility, T, was computed at seven places in the flow net using (1) only streamflows measured July 21, 1964, and (2) the average of three streamflow measurements at each point. The computed T ranged from 9,500 to 46,000 gpd per ft and averaged 32,000.

The mean of several determinations of recharge was about 18 inches. If the measured pickup of streamflow, which was remarkably constant between miles 4.95 and 0.80, represented average conditions, then the average annual recharge to ground water can be expected to approximate 18 inches. This recharge is relatively high, but it is within the range of possibility for the kind of material making up the deposit. An average annual recharge of 18 inches would permit development of about 10 mgd (million gallons per day) in the Goose Lake Outlet area between the railroad on the east and the ledge along the west side. Recharge diverted from the stream would increase the possible yield. Also, pumping from the aquifer would increase the yield by expand-

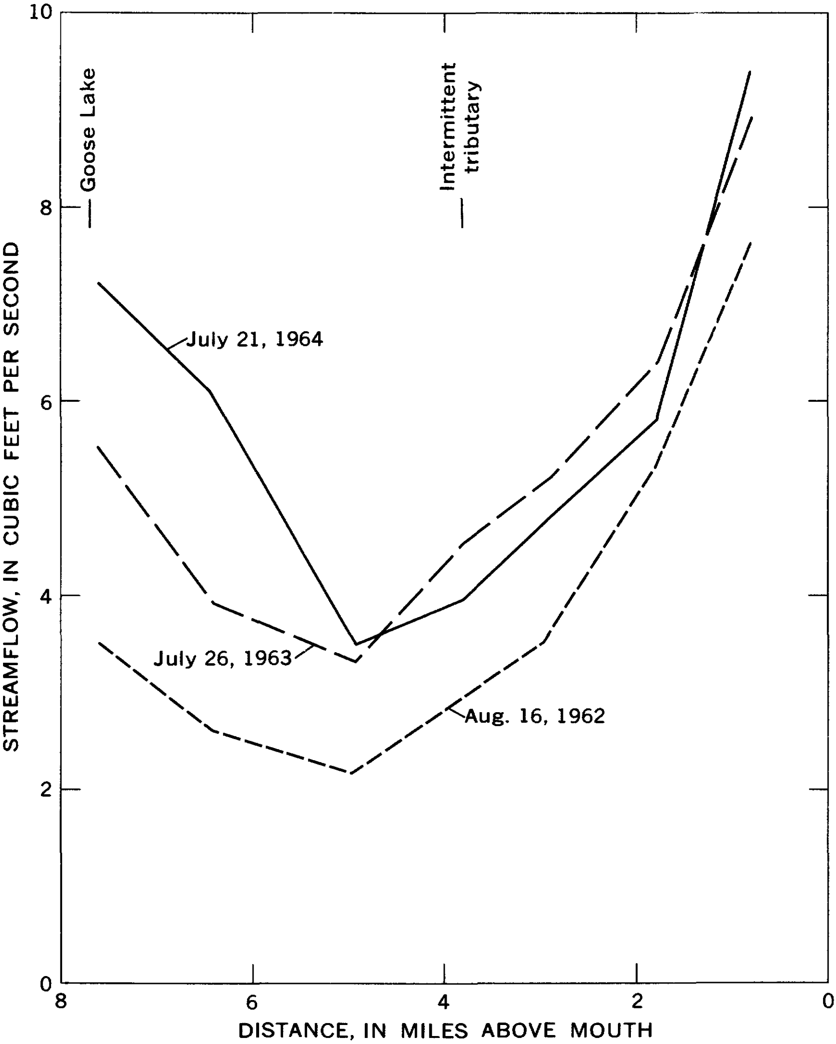


FIGURE 32.—Variation of streamflow along Goose Lake Outlet.

ing the opportunity for percolation to the water table and by reducing natural evapotranspiration.

The aquifer test and flow-net analysis give considerably different values of T. The aquifer-test results, however, represent conditions at a point where the best water-bearing materials in the area were found. Also, the effects of observation wells that did not fully penetrate the aquifer and of the nearby stream would tend to give falsely high values of T. On the other hand, results of the flow-net analysis represent areal averages in which the variations in the formation are integrated

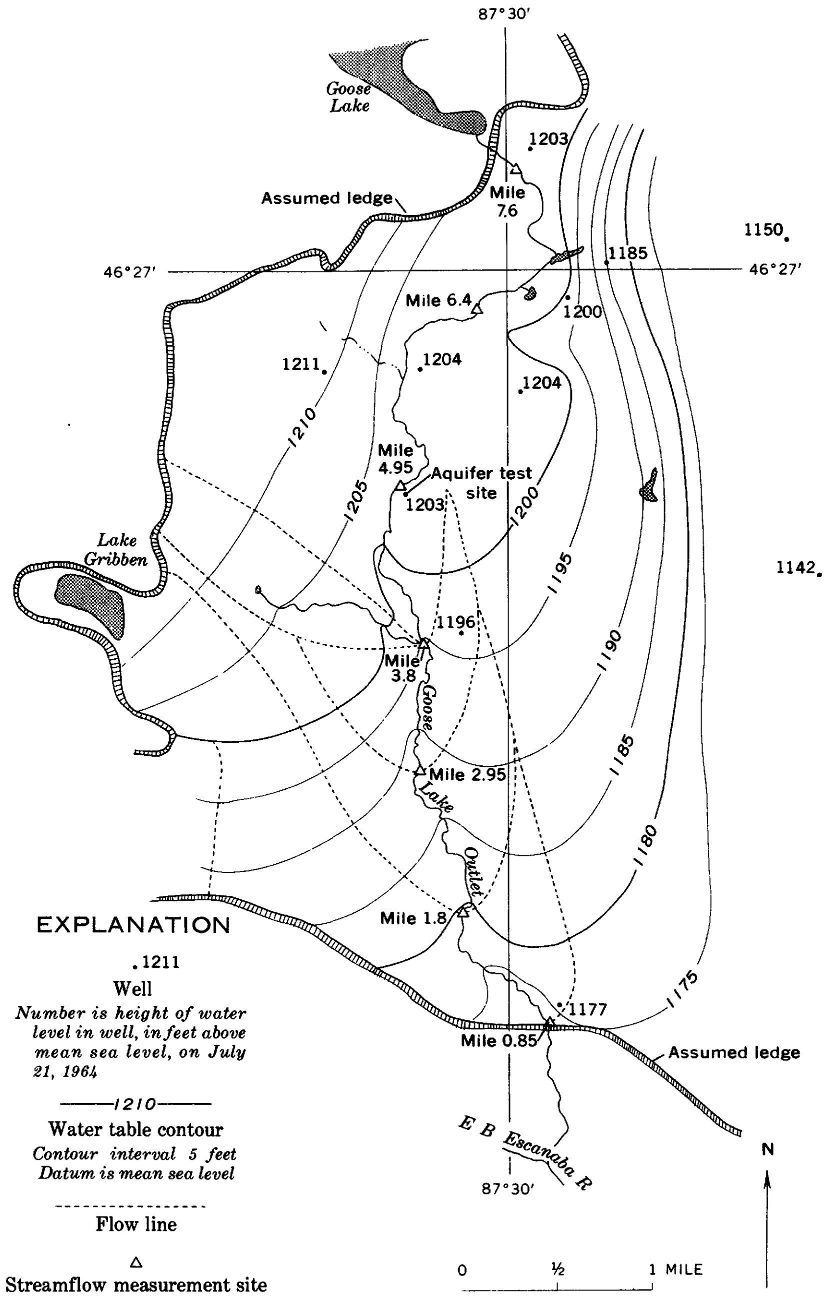


FIGURE 33.—Data used in making flow-net analysis of Goose Lake Outlet area.

The flow-net analysis is, at best, a reconnaissance method incapable of yielding precise results.

Time-distance-drawdown relations for the Goose Lake Outlet aquifer are shown in figure 34. The storage coefficient computed

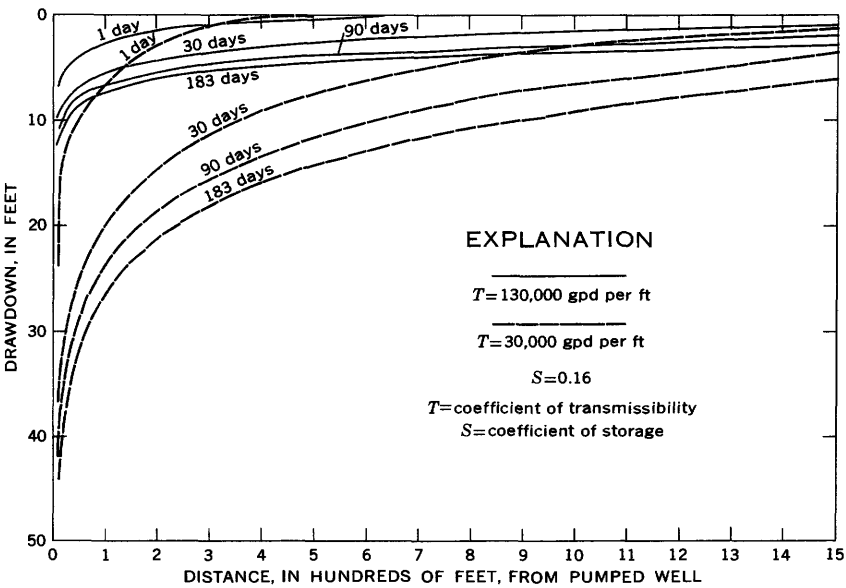


FIGURE 34.—Time-distance-drawdown relations for two values of transmissibility and a pumping rate of 1,000 gpm for the outwash plain along Goose Lake Outlet with no recharge.

from the aquifer test and two values of transmissibility encompassing the range of values likely to pertain in this area were used in preparing the figure. These curves show, for example, that at a distance of 500 feet from the pumped well drawdown after 30 days of pumping would be about 3 feet if T is 130,000 gpd per ft and about 7½ feet if T is 30,000 gpd per ft. For a T of 130,000, drawdown does not change greatly with respect to distance beyond a distance of about 500 feet. Therefore, well spacing of about 1,000 feet would be reasonable to avoid excessive interference between wells. For a T of 30,000 and the same pumping rate, however, well spacing would have to be increased to about 2,000 feet to avoid undue interference between wells. Drawdown is directly proportional to the pumping rate; if the pumping rate were reduced to 500 gpm, the indicated drawdowns would be halved.

Continued withdrawal and consumptive use or diversion of water from wells near Goose Lake Outlet would inevitably reduce the flow

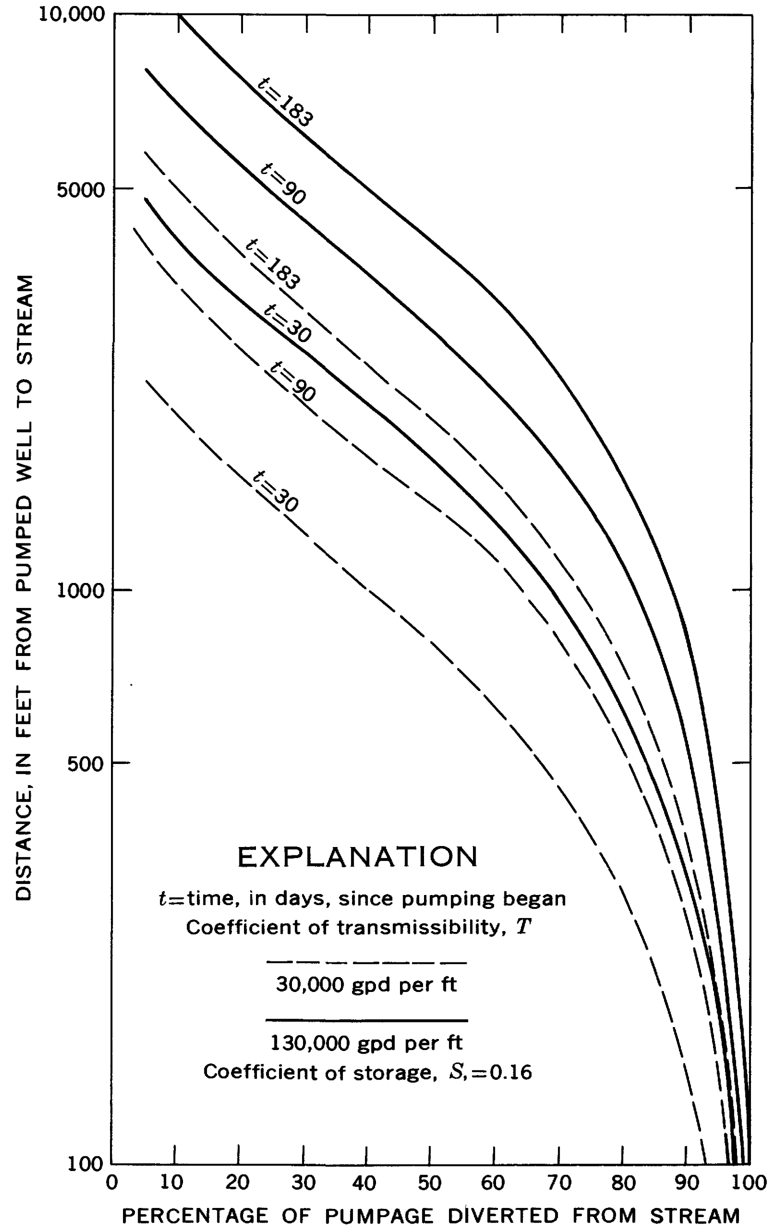


FIGURE 35.—Theoretical relation between percentage of pumped water diverted from a stream and the distance of the pumped well from the stream.

in the stream. The proportion of pumped water that would theoretically be diverted from the stream varies with the distance of the well from the stream (fig. 35). The curves shown were computed from charts by Theis and Conover (1963). As an example, for a T of 130,000 gpd per ft and a pumping rate of 1,000 gpm from a well 500 feet from the stream, about 84 percent, or 840 gpm, of the pumpage theoretically would be derived from the stream after 30 days of pumping, provided that there was no recharge to the aquifer. Charts developed by Theis and Conover are based on the assumption that the stream fully penetrates the aquifer. Actual diversion of water from the stream, therefore, would be considerably less than the theoretical figure. On the other hand, the occurrence of severe drought conditions after a relatively long period of continuous pumping would tend to increase the actual diversion from the stream.

Estimated low flow of Goose Lake Outlet at the aquifer test site is 2.8 cfs, or 1,260 gpm (table 2). Therefore, for a T of 130,000 gpd per ft the well pumping 1,000 gpm at a distance of 500 feet from the stream theoretically would reduce the low flow to about 420 gpm, or 0.9 cfs. As pointed out in the preceding paragraph, however, the actual effect upon streamflow probably would be considerably less. Thus, figure 35 would be a conservative guide for planning ground-water development inasmuch as it overestimates the effects upon streamflow. Careful and conservative planning is necessary when it is noted that a flow of less than 0.5 cfs was measured at the test site in February 1964.

To minimize the effect upon streamflow, a well field could be designed so that summer pumping would be from wells some distance east of the stream. These wells would thus intercept water that, for the most part, passes as ground-water flow into the Chocolay River basin. Flow in streams receiving this underflow would be diminished, but ground-water withdrawal would have to be large before serious depletion would occur. Two or more lines of wells paralleling the stream could accomplish the same purpose. In this scheme, the wells nearest the stream would be pumped when streamflow was high, and those farther away, when streamflow was low.

Because of the permeable surface materials in this area, water spreading could probably be used successfully to increase recharge to ground water. Diversion of a part of the high-water flow into ditches or furrows crossing the area would afford a greater opportunity for water to infiltrate into the ground. Construction of control works at the outlet of Goose Lake would enable regulation of streamflow to increase the effectiveness of these operations. Careful planning of the spreading layout would be needed to prevent loss of water to the Chocolay River basin before interception by the producing wells.

Only the northern part of this outwash area, especially that part adjacent to Goose Lake Outlet, has been considered in this discussion.

Good ground-water supplies can probably be developed farther south in the area. These supplies are of less immediate interest because of the longer distance from potential mining developments. Copious flow in Halfway and Silver Lead Creeks (plate 4, table 10) indicates large ground-water inflow to these streams and probable interbasin underflow from East Branch Escanaba River.

HUMBOLDT AREA

Outwash deposits in this area are discontinuous. Those deposits covering the largest area are in the Second Creek-Middle Branch Escanaba River area north of Humboldt and in the vicinity of Boston Lake. More than 100 feet of saturated thickness is indicated in some places. Very little information on the nature of the outwash materials is available.

Base-flow data for Gold Mine Creek near Ishpeming and Carp Creek at Ishpeming suggest that the outwash area at and east of Boston Lake may be contributing to the flow of these streams. Water-level contours (pl. 3) also suggest that interbasin flow occurs between the Middle Branch Escanaba and Carp River basins.

Pumping tests of several wells in the area north of Humboldt indicated coefficients of transmissibility ranging from 7,000 to 20,000 and averaging about 12,000 gpd per ft (Stuart, Brown, and Rhodehamel, 1954, p. 64). These are relatively low transmissibility values for outwash materials and are probably due to the poor sorting of the outwash. Areal distribution of streamflow measurements made in the area did not permit estimation of the hydraulic properties by flow-net analysis.

Streamflow measurements did show, however, a fairly large and steady yield from an 8½-sq mi area just upstream from the gaging station on Middle Branch Escanaba River at Humboldt. This area includes the lower half mile of Halfway Creek, downstream 2 miles of Second Creek, Middle Branch to the Chicago and Northwestern Railway bridge, and the area containing the test wells mentioned in the preceding paragraph. Streamflow measurements made during five different periods of base flow indicated an average yield of 4.7 cfs from this area. This yield is equivalent to an annual recharge of about 7½ inches which is probably less than the average annual recharge because nearby streams were at low flow during these determinations. Possibly 3 to 5 cfs (2–3 mgd) could be withdrawn from this area, but more testing would be needed to support this estimate.

Wells placed near streams in this area would be likely to diminish flow in the Middle Branch from which water for Humboldt mine is being diverted. Withdrawal of water for Humboldt mine must already be curtailed at times because of low flow in the stream. Therefore, any ground-water development in the area should be planned so that depletion of streamflow is minimized. Ground water, however, could be used as a supplemental source of supply for short periods, for periods when streamflows is ample, or for integrated operation with surface storage reservoirs in the basin above Humboldt.

WEST BRANCH CREEK AREA

Outwash deposits occur near and along the boundary of the report area south of West Branch Creek to the headwaters of Flopper and Bear Creeks. These deposits blend into relatively extensive marsh areas, along West Branch Creek, which also may be fairly good aquifers. Therefore, definition of the areal extent of this ground-water area is somewhat nebulous. The area east of West Branch Creek and extending into Flopper and Bear Creek basins is probably the best potential source of ground water in this area. Flopper and Bear Creeks have high, well-sustained base flows. A relatively large base-flow contribution is indicated for the area draining into the 2½-mile reach of West Branch Creek from County Highway 581 to the mouth.

About a dozen wells were augered in and near this general area for this study. The few available logs indicate sandy materials with considerable silt and sometimes with boulders at depth. Only one well, 46N28W27–1, reached bedrock, 71 feet below the surface. Depth to water ranged from less than 10 to almost 60 feet, depending upon topographic location.

Flow-net analysis for the reach of West Branch Creek from County Highway 581 to the mouth indicated a coefficient of transmissibility of about 30,000 gpd per ft. Similar analyses for Flopper and Bear Creeks indicated transmissibilities of about 10,000 and 17,000 gpd per ft, respectively. These values of T are very approximate because lack of water-level data necessitated definition of water-table contours mainly upon the basis of topographic interpretation. Estimates of recharge from these analyses ranged from about 7 to more than 20 inches.

With this information it is almost impossible to estimate a potential ground-water yield for the area. The presence of a ground-water body, or bodies, is inferred from streamflow measurements which indicate relatively large base-flow contributions from some areas.

In the three ground-water areas that have been discussed, definition of aquifer yield has been hampered by lack of producing wells. Because these areas are as yet untapped, there is no information available on the response of water levels to withdrawal. As pointed out by Conkling (1946, p. 286), determination of the safe yield for virgin ground-water basins is extremely difficult, if not impossible. The only

243-028 O—67——8

recourse is to consider the few pumping tests that have been made and to use flow measurements of streams draining the areas containing the aquifers. Characteristics of the three areas discussed are summarized in table 17.

TABLE 17.—*Summary of characteristics of ground-water areas*

Area	Thickness (feet)	Lithology	Coefficient of transmissibility (gpd per ft)	Potential development	Feasibility of diverting pumped water to points of use	Water quality
Goose Lake-Sands plain area.	Up to about 240.	Coarse to fine gravel, coarse to fine sand, silt, and clay. The upper part of the formation contains more of the coarser materials; more silt and clay below 70-ft depth.	Possibly ranges between about 30,000 and 130,000.	Pumping test and flow-net analysis indicate that possibly 7 to 10 mgd could be developed in an area adjacent to Goose Lake Outlet. Possibilities elsewhere were not investigated but seem to be good where water table is fairly close to surface.	Convenient to mining area in Palmer vicinity.	Water is hard and has dissolved solids >200 ppm near Goose Lake Outlet. Farther from outlet water is moderately hard and less mineralized. Iron content generally greater than drinking water std.
Humboldt area.	Up to about 120.	Medium to fine gravel, coarse to fine sand, silt, and clay. Many fine sand and silt lenses.	About 7,000 to 20,000.	Possibly 2 to 3 mgd in area between Second Creek and Middle Branch Escanaba River north of Humboldt. Needs more testing and exploration to define potential.	Relatively close to active and potential mining areas.	In Second Creek area water is very soft with low mineralization. In Boston Lake area water moderately hard and more mineralized.
West Branch Creek area.	Up to about 160.	Medium to fine gravel, coarse to fine sand, silt, and clay.	About 10,000 to 17,000.	Potential yield not estimated. Streamflow measurements indicate fairly high base flows in some places.	Relatively remote from mining areas and areas of demand for domestic water use.	Water very soft to moderately hard. Dissolved solids generally less than 100 ppm. Iron content generally greater than 0.3 ppm.

OTHER GROUND-WATER AREAS

Several large-diameter wells that were formerly used for dewatering the glacial overburden are located in the vicinity of Morris mine, in sec. 1, T. 47 N., R. 28 W., near Ishpeming. These wells could possibly supply several thousand gallons per minute of water.

A small area of outwash in SW¼ sec. 25 and SE¼ sec. 26, T. 47 N., R. 27 W., about 2 miles directly west of Palmer, might be a source of ground water. Proximity of this area to Empire mine makes it attractive if only as a supplementary source of supply. More detailed investigation by test drilling would be needed to estimate the potential of this area.

A fairly large area of outwash is contained in the basin of Morgan Creek, a tributary of the Carp River (fig. 30). No information is available from which the potential of the area can be estimated.

Valleys of many streams contain deposits of outwash and alluvium. Moderate supplies of ground water may be available from these sources.

QUALITY OF GROUND WATER

Ground water is fairly constant in chemical composition and temperature. It is usually more mineralized than surface water because it is in contact with earth materials for a longer time; however, it is generally clearer and has fewer tastes and odors than surface supplies. Chemical quality and temperature of ground-water supplies in the Marquette Iron Range area are considered in the next two subsections of this report.

CHEMICAL QUALITY

The chemical character of ground water is indicated by the analyses of water samples from 62 wells and 3 mine-pumpage systems (table 18). One sample was taken from a well in bedrock, one sample from a well in glacial till, and the remaining 60 samples were from wells in outwash or alluvium. The general suitability of the water may be assessed by comparison of the analyses in table 18 with criteria for drinking water standards given in table 5.

Water containing less than 500 ppm of dissolved solids is generally suitable for domestic and most industrial uses if it is not hard and does not contain an excessive amount of iron. Mine pumpage showed the highest mineralization, ranging from 370 to 964 ppm of dissolved solids. Dissolved-solids content of water from wells in outwash or alluvium ranged from 26 to 258 ppm. Of these, the highest contents (greater than 200 ppm) were observed in water from wells adjacent to Goose Lake Outlet. Evidently infiltration of water from the stream accounts for this condition. Dissolved-solids content was markedly less in water from wells half a mile or more away from the stream. The lowest mineralization was observed in water from wells near Second Creek north of Humboldt, near Black River, and at K. I. Sawyer Air Force Base near Silver Lead Creek.

TABLE 18.—*Chemical analyses of ground water*

[Aquifer sampled: Qd, Quaternary glacial till; Qo, Quaternary glacial outwash or alluvium; p€, Precambrian rocks, undifferentiated. Asterisk indicates mine discharge. Chemical constituents in parts per million]

Well	Aquifer	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos)	pH	Temperature (°F)
48N29W19-1	Qo	7- 8-63			23	3.5	2.3	1.1	86	5.2	1.8			100	72	148	8.1	46
26-1	Qo	8-28-63		0.62	2.8	1.1	1.2	.5	26	5.2	1.0		0.01	26	12	48	6.9	49
48N28W30-1	Qo	8-28-63		.29	7.0	2.9	1.5	1.0	40	1.8	0		.03		36	30	6.5	46
48N26W34-1	Qo	7- 8-64			25	4.7	.9	2.0	92	5.2	4.5			102	82	169	7.8	47
47N29W 2-1	Qo	9- 6-63		.14	5.7	2.0	1.8	.8	28	10	0		.02	34	22	68	6.6	47
3-1	Qo	9- 6-63		.23	24	9.9	22	1.9	26	15	80		.02	207	101	348	6.3	53
34-1	Qo	8-28-63		.66	13	5.8	2.2	1.2	85	1.6	2.0		.02	94	56	151	6.6	48
36-1	Qo	8-28-63		.86	15	6.4	2.6	1.2	68	13	3.0		.02	83	64	145	6.7	50
47N28W3-1	Qo	10-17-62	16	5.6	25	6.8	2.0	.6	107	3.6	1.0	0.1		127	90	181	6.8	45
8-1	Qo	7- 8-64			41		9.4	3.4	103	49	13			194	125	306	7.5	47
15-1	Qd	7- 8-64			10		3.7	2.3	18	7.6				64	36	110	9.7	47
28-1	Qo	8-28-63		.38	16		7.4	5.3	82	18	4.0		.02	103	67	187	6.6	48
35-1	Qo	8- 8-64			19		3.6	2.3	65	25	1.8			106	68	168	7.4	47
47N27W9-1	*p€	1-13-60	8.3	9.2	63	25	32	7.2	195	64	69	.2	6.5	370	261	661	7.9	44
47N26W5-1	*p€	8-17-59	9.7	.55	233	16.0	17.0	14.0	200	465	40.0	.4	1.0	964	648	1200	7.3	50
8-1	*p€	2-29-60	8.9	1.2	99	7.7	18	10	196	172	2.0	.6	.2	446	280	743	7.1	
19-1	p€	9-28-61	7.7	1.4	25	16	9.0	.3	172	8.8	1.0	.2	0	154	129	272	7.2	46
24-1	Qo	7-25-63		2.4	45	9.2	9.6	3.3	86	88	32		.15	228	150	440	6.9	48
25-1	Qo	7-24-63		1.6	43	13	7.7	3.3	92	84	12		3.2	217	161	363	6.5	47
25-2	Qo	7- 9-64			12	4.9	3.3	4.0	42	24	3.0			88	50	133	8.0	47
25-3	Qo	7- 9-64			40	11	8.8	3.0	94	83	8.0			238	145	347	7.1	47
26-1	Qo	7- 9-64			8.2	4.3	1.2	.2	39	3.2	1.0			87	38	77	6.9	
36-1	Qo	7- 9-64			30	2.5	4.8	2.2	27	71	7.0			157	86	224	7.2	47
36-9	Qo	5-28-64							130	5.6	1.5				109	204	7.5	44
47N25W12-1	Qo	7- 8-64			18	4.5	3.8	2.5	44	34	4.0			96	62	162	7.5	46
15-1	Qo	9- 6-63		.08	34	8.7	2.2	.6	140	10	1		.01	134	121	238	7.3	49

19-1	Qo	7-9-64	----	----	48	14	5.6	3.0	80	108	10	----	----	258	178	387	7.3	47
20-1	Qo	7-25-63	----	8.1	22	5.2	3.1	1.6	74	27	5.5	----	----	108	76	188	6.4	45
21-1	Qo	7-16-64	----	----	----	----	----	----	73	25	4.5	----	----	----	75	186	7.1	45
22-1	Qo	8-28-63	----	----	41	11	2.9	1.7	134	46	1.0	----	.04	186	147	304	6.7	45
24-1	Qo	7-8-64	----	----	14	3.1	2.3	1.8	53	11	2.0	----	----	63	48	114	7.5	45
32-1	Qo	7-24-64	----	.25	18	3.5	2.7	1.9	63	17	4	----	4.5	86	60	151	6.7	48
47N24W28-1	Qo	7-8-64	----	----	18	7.4	2.6	2.3	73	24	2.0	----	----	105	76	178	7.2	46
46N29W18-1	Qo	8-28-63	----	.45	23	5.8	2.9	2.6	93	20	10	----	.06	115	82	209	6.6	50
22-1	Qo	8-28-63	----	----	8.6	2.7	1.8	1.0	24	16	3.0	----	.03	45	32	85	6.8	47
30-1	Qo	9-6-63	----	.10	30	14	3.1	1.0	102	13	29	----	0	160	133	290	7.2	51
36-1	Qo	8-28-63	----	----	16	5.4	4.4	2.6	70	17	3.0	----	.03	88	62	154	6.6	50
46N28W1-1	Qo	8-28-63	----	.23	15	6.3	1.6	1.2	47	4.8	8.5	----	.30	69	64	136	8.5	47
8-1	Qo	8-28-63	----	.50	4.0	1.9	1.2	.5	16	7.4	9.5	----	.06	33	18	62	6.2	50
12-3	Qo	8-28-63	----	.25	14	3	.8	.7	57	.8	2.0	----	.2	56	48	99	6.7	49
15-1	Qo	7-8-64	----	----	11	3.5	.9	1.2	48	4.4	1.0	----	----	51	42	90	7.7	48
27	Qo	7-8-64	----	----	16	3.1	2.3	1.2	51	15	2.8	----	----	75	53	128	7.5	49
32	Qo	8-28-63	----	----	16	4.9	1.6	.7	51	26	5.0	----	.06	84	60	144	6.6	49
46N27W17-1	Qo	8-28-63	----	1.6	21	6.2	3.1	1.2	79	20	2.0	----	.1	102	78	175	6.7	----
19-1	Qo	7-8-64	----	----	9.0	2.0	2.0	.8	23	5.6	1.0	----	----	51	30	80	9.3	48
31-1	Qo	8-28-63	----	1.5	14	6.4	2.0	1.0	66	7.6	2.0	----	----	68	62	127	6.8	49
46N26W12-1	Qo	7-9-64	----	----	7.1	1.8	1.6	.6	24	11	2.0	----	----	50	25	69	7.6	48
31-1	Qo	9-10-64	----	----	28	7.0	3.1	1.4	90	30	0	----	0	126	99	212	6.6	47
46N25W9-1	Qo	7-24-63	----	3.0	13	6.9	1.9	1.2	75	6.8	3.0	----	.06	83	60	137	6.6	48
11-1	Qo	7-26-63	----	----	12	1.4	1.5	.7	44	2.2	1.5	----	----	48	36	77	7.4	52
16-1	Qo	7-24-63	----	.47	20	4.4	4.6	4.4	79	18	9.5	----	.06	96	68	190	6.9	47
36-1	Qo	3-16-60	6.6	.01	11	1.8	.6	.1	40	3.2	.5	.1	----	44	35	74	8.2	46
36-2	Qo	6-19-63	7.2	.10	16	3.2	1.3	.4	57	6.2	3.0	.1	----	70	53	114	8.1	47
36-3	Qo	6-19-63	6.4	1.3	10	2.2	.9	.3	41	4.4	1.0	.1	----	47	34	74	7.7	47
36-4	Qo	6-21-63	7.5	.17	11	2.0	.9	.4	42	4.4	2.0	0	----	50	36	76	7.8	46
36-5	Qo	6-19-63	10	.04	19	3.6	1.7	.9	80	4.4	1.5	.1	----	81	62	128	7.7	47
36-6	Qo	6-19-63	8.3	.04	17	3.4	.9	.7	60	8.6	2.5	.1	----	72	56	118	8.0	47
36-8	Qo	6-20-63	6.0	2.4	9.2	1.6	.9	.3	32	3.6	1.0	.1	----	44	30	65	8.6	47
46N24W5-1	Qo	7-8-64	----	----	17	6.8	2.3	2.5	77	15	3.8	----	----	47	70	167	7.3	48
45N28W3-1	Qo	8-28-63	----	.44	12	6.6	1.2	.5	61	9.6	3.0	----	.08	65	57	123	6.7	47
45N26W15-1	Qo	9-10-63	----	.30	17	14	2.5	1.8	118	10	1.0	----	.01	102	100	199	7.2	46
	Qo	7-7-64	----	----	34	15	1.2	1.1	171	8.0	2.8	----	----	161	147	278	8.0	45
45N25W11-1	Qo	9-6-63	----	1.6	30	5.2	11	7.9	78	26	28	----	.02	151	96	274	7.0	47
23-1	Qo	9-10-63	----	.20	22	6.2	3.4	2.1	88	13	4.0	----	.02	106	80	178	6.9	47
45N24W5-1	Qo	7-7-64	----	----	17	1.8	2.3	.9	52	14	2.2	----	----	74	50	125	7.4	46

Water in this area, as indicated by the pH value, ranges from slightly acid to slightly alkaline. The lowest pH, 6.2, was observed in water from a well in outwash near the Black River and the highest pH, 9.7, was observed in water from the well in glacial till in the Carp Creek basin near Greenwood.

Hardness of water is of particular interest because it affects some processes, such as flotation processes, used by the iron-ore industry. It is not, however, a serious problem in ground waters of this area, most of which are soft or moderately hard. Only mine pumpage was very hard, ranging from 261 to 648 ppm equivalent calcium carbonate. Water was hard, between 121 and 180 ppm, in wells along Goose Lake Outlet where dissolved-solids content was also relatively high. Water in nearly half of the wells in outwash or alluvium was soft, 60 ppm or less.

Concentration of iron is relatively high, making it the most objectionable constituent in ground waters of the area. Drinking-water standards suggest an upper limit of 0.3 ppm for iron concentration. When the iron concentration exceeds about 1 ppm, precipitates may form which clog pipes, pumps, and fixtures. High concentrations of iron and manganese prompted the abandonment of Ely Township well 47N28W3–1. Of the 37 samples having an iron analysis, more than half showed a concentration exceeding 0.3 ppm and about one-third showed a concentration exceeding 1 ppm. One of the mine-pumpage samples had an iron concentration of 9.2 ppm, and one of the wells on the Goose Lake-Sands plain had water with an iron concentration of 8.1 ppm.

TEMPERATURE

Ground-water temperatures in the area were generally in the middle to high forties (° F). However, observations were made mostly during the summer so that temperatures shown in table 18 are somewhat higher than the average temperature of ground water. Though the annual fluctuation of ground-water temperature is much less than that of surface-water, there is still some seasonal variation which, in addition to air temperature, depends upon depth below land surface; kind, quantity, and distribution of recharge; and pattern of ground-water movement. The average ground-water temperature is usually near the mean annual air temperature for the locality.

INTERRELATIONSHIPS BETWEEN SURFACE AND GROUND WATER

Up to this point, the various subjects that have been considered have been discussed somewhat independently of each other. In this section, however, an attempt is made to define the interrelationships that exist in the different phases of the water cycle and to show that a natural balance exists wherein a change in one element may produce changes in one or more others.

THE HYDROLOGIC CYCLE

Water is a dynamic resource, forever on the move. It rises by evaporation from the oceans into the atmosphere; is transported by winds, often over long distances; precipitates as dew, rain, sleet, hail, or snow; and finds its way to streams to begin the journey back to the ocean. Some water may be delayed at the surface to be all or partly evaporated; some may go underground and reappear as springs or seeps; and some may percolate into the soil to be evaporated from there or taken up by plants for discharge to the atmosphere by the process of transpiration. The water that is precipitated as snow may be locked for months in the snow mantle; but eventually it finds its way back to the sea in the never-ending movement of the hydrologic cycle.

The total movement of water in the local hydrologic cycle is governed principally by the amount and distribution of precipitation. U.S. Weather Bureau records for the long-term period 1899–1963 at Ishpeming and for the 10-year period 1955–64 at Ishpeming and Champion indicate an average annual precipitation of 31 inches. Records for the gaging station on Middle Branch Escanaba River near Ishpeming indicate that streamflow for the 1955–64 period averaged about 14 inches per year. The difference, 17 inches, is the average annual water loss to evaporation and transpiration. Thus, of the total available supply, about 55 percent is lost to evapotranspiration, and 45 percent runs off. Nationwide, losses average about 72 percent, and runoff averages about 28 percent of the available supply.

The 14 inches of runoff is the manageable water supply of this area. Estimated present (1965) water use, excluding that water used for hydroelectric-power generation, is equivalent to about 1½ inches of runoff from the area. Of this runoff, roughly half an inch is estimated to be lost by evaporation or incorporated into plant, animal, or mineral matter, and the rest is returned to the streams. Therefore, about 13½ inches of water leaves the area for disposition elsewhere. These relationships, amounting to a generalized hydrologic budget for the area, are shown schematically in figure 36. This illustration conveys a very auspicious picture of water availability in the area. Figures shown, however, are averages which represent the top limit of possible development. Because of the variability of supply with time, the practical limit of availability is much lower.

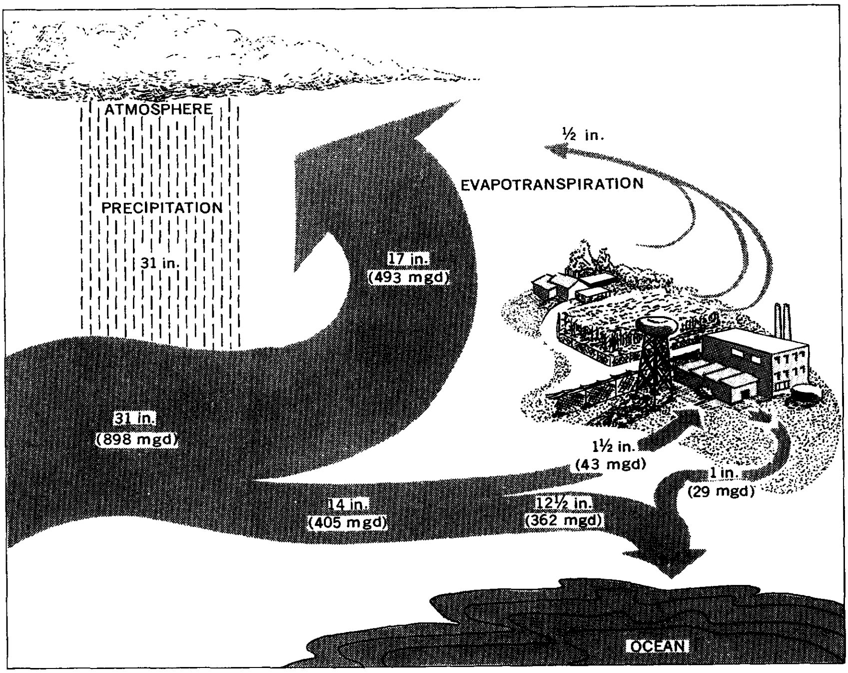


FIGURE 36.—Hydrologic budget. (Adapted from committee print 3, Select Committee on National Water Resources, 86th Congress, 2d Session, 1960.)

The relative contribution of direct and ground-water runoff to streams varies considerably. From records for the Middle Branch Escanaba River, on an average, about 8½ inches of the 14 inches of runoff are estimated to be derived from ground-water outflow, and 5½ inches, from direct surface-water runoff. In dry years, the ground-water component of streamflow is greater percentagewise than it is in wet years. Geology seems to play the dominant role in determining the apportionment. Porous outwash deposits readily absorb precipitation and snowmelt for infiltration to the underlying ground-water body where water may be detained for long periods and drain away slowly and uniformly to become the principal component of streamflow. Streams draining such areas have a high sustained flow and often exhibit remarkable uniformity in discharge. West Branch, Flopper, and Bear Creeks and the Chocolay River tributaries in the eastern part of the area have these characteristics. Some streams traversing permeable outwash deposits, such as Goose Lake Outlet, provide almost continuous recharge to the ground. On the other hand, impermeable till and bedrock at the surface cannot easily absorb precipitation and snowmelt which are in these places discharged as direct runoff. Streams draining these areas are flashy, have low flows in rainless periods, and respond quickly to rainstorms and snowmelt. The Peshekee River and Ely and Warner Creeks exhibit these tendencies.

Evapotranspiration includes water evaporated from exposed water surfaces and moist soil and water transpired by vegetation. Plants extract water held as soil moisture or water from ground-water storage or the capillary fringe above the water table if their roots penetrate these zones. Transpiration is probably quite small during the non-growing season.

GROUND-WATER DISCHARGE

Water from the ground water underlying a drainage basin can be discharged in four ways: (1) By seepage to springs, lakes, and streams, (2) by evapotranspiration, (3) by pumping from wells, and (4) by underflow to adjacent basins. Pumping from wells constitutes a minor withdrawal at the present time (1965), equivalent to about 0.18 inch of runoff from the area, and is not considered further in this discussion. The first mode of discharge, effluent seepage, is the dominant one of the remaining three.

EFFLUENT SEEPAGE

Except when and where the ground-water table is lower than the stream, discharge to streams by ground-water seepage is almost continuous. Effluent seepage may be interrupted during relatively short periods of rising streamflow when the river stage is higher than the adjacent ground-water stage. When the river stage begins to fall, however, effluent seepage from bank storage is restored. Even before the river stage begins to fall, some of the flow passing a point may be ground water from upstream basins where streamflow is already receding. During rainless periods, and after all the channel storage has drained away, streamflow is derived entirely from ground-water seepage. In winter when precipitation occurs mostly as snow, streamflow is maintained by ground-water discharge for long periods.

Analysis of streamflow records for periods when flow is principally ground-water discharge makes possible the definition of base-flow recession curves. These curves show how the ground-water discharge would vary with time if no surface-water runoff or ground-water recharge occurred during the period of drainage. Many basins require at least two curves to define base-flow recession—one for the non-growing season when evapotranspiration from ground water is small and another for the growing season when evapotranspiration demands are high. Two curves have been defined for the gaging station on

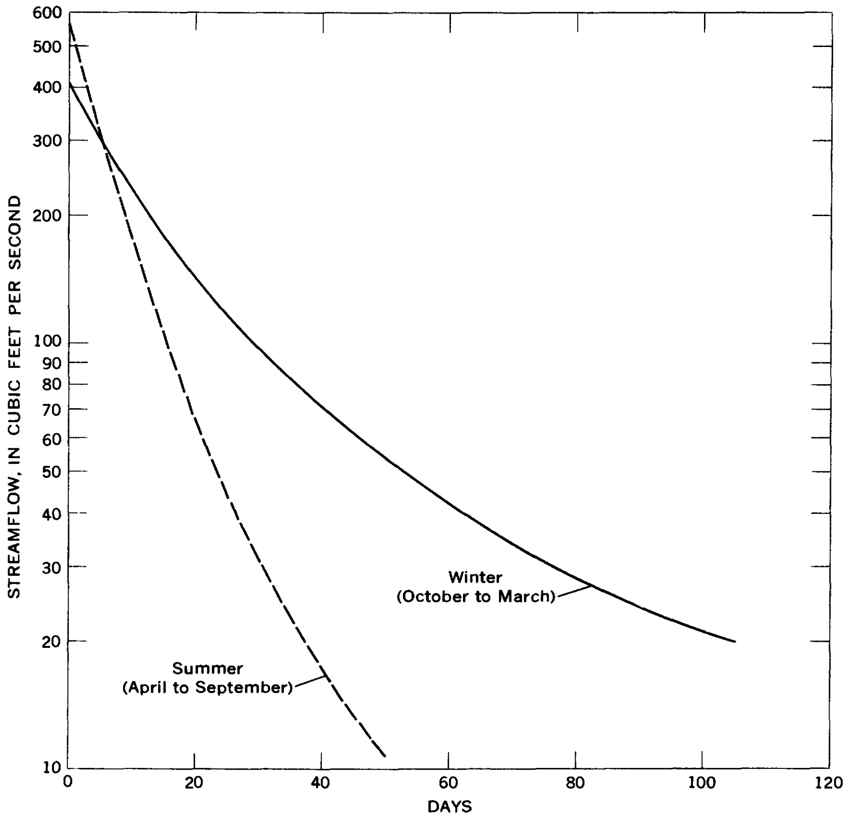


FIGURE 37.—Base-flow recession curves, Middle Branch Escanaba River near Ishpeming.

Middle Branch Escanaba River near Ishpeming (fig. 37). These curves indicate that evapotranspiration strongly influences ground-water discharge in this basin.

By superimposing the applicable base-flow recession curve upon recession segments of the 1963 streamflow hydrograph for the Ishpeming gaging station, the total flow could be separated into surface- and ground-water runoff (fig. 38). The separation is subjective and depends a great deal upon the judgment of the individual making the analysis. The surface- and ground-water runoff is listed by months in table 19. About 68 percent of the total streamflow in 1963 was derived from ground water.

The relationship between the elevation of the water table and base (ground-water) flow for the Middle Branch basin above the Ishpeming gage is shown in figure 39. The upper graph shows the average distance to water below land surface in eight wells in the basin. The lower graph shows the base flow as determined from figure 38. A

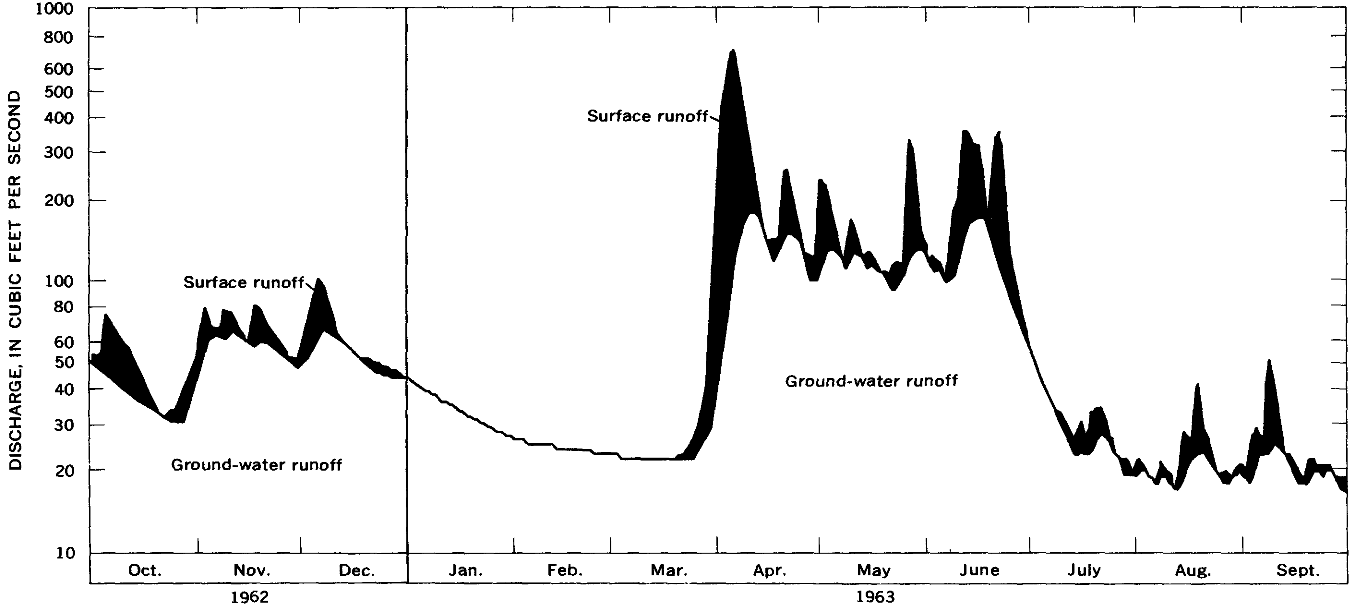


FIGURE 38.—Surface- and ground-water runoff for water year ending September 30, 1963, Middle Branch Escanaba River near Ishpeming.

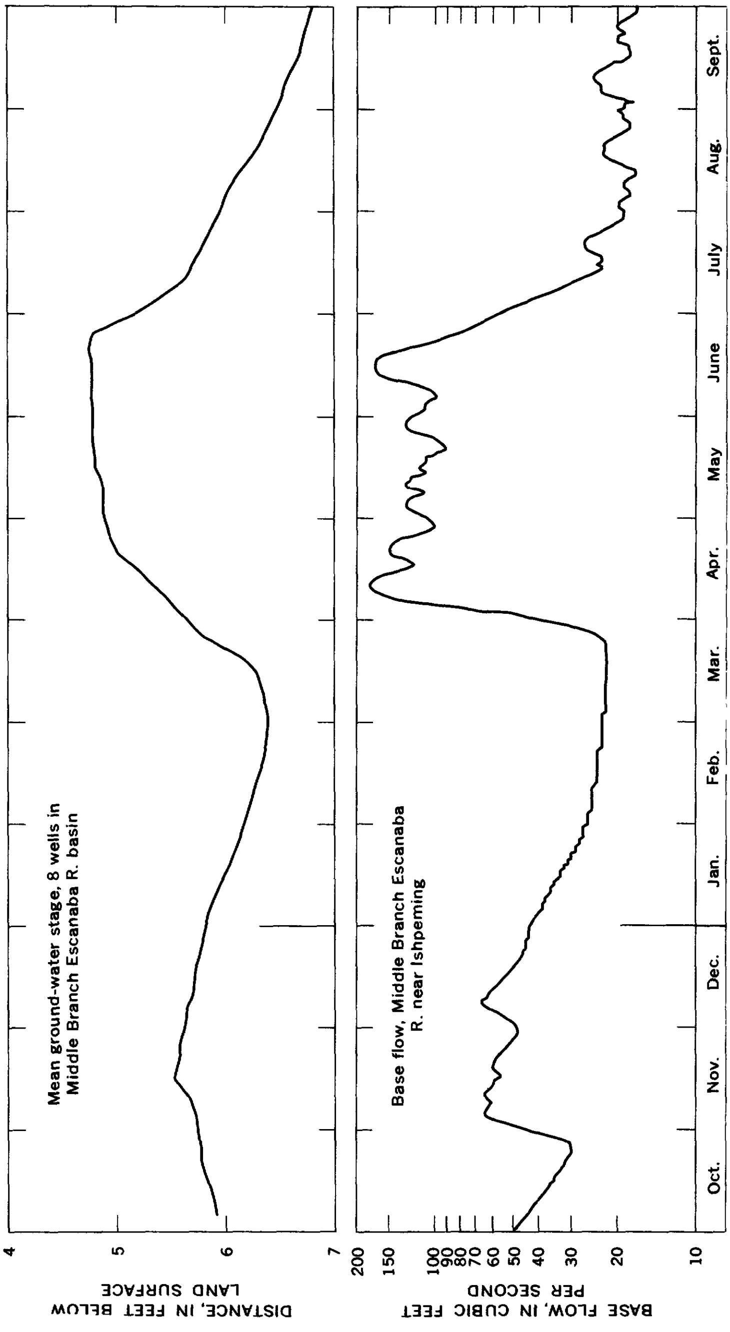


FIGURE 39.—Base flow and ground-water stage for water year ending September 30, 1963, Middle Branch Escanaba River basin.

fairly good correlation between the graphs is evident. The poor correlation indicated for early April may be caused by inclusion in the base flow of a considerable amount of interflow, the flow derived from shallow depth which drains away quickly. Figure 39 illustrates the close connection between streamflow and ground-water levels. Sufficient information was not available to define similar relationships for other basins in the area.

EVAPOTRANSPIRATION

Evapotranspiration from the ground-water reservoir is dependent upon climatic factors, the depth to the water table, and the nature of the vegetation and plant root system. It varies areally and seasonally. In basins of high relief it may occur chiefly in valleys and low-lying areas. That it can affect effluent seepage to streams is demonstrated by the two base-flow recession curves shown in figure 37.

Another way of showing the effect of evapotranspiration upon the base flow of a stream is illustrated in figure 40. These curves were derived by plotting streamflow when it was known to consist entirely of ground-water flow versus the concurrent average ground-water stage in eight wells. Because the curves were not well defined by the data, they should be considered as approximations. They are useful, however, in the ground-water budget calculations that are described subsequently. The difference in base flow shown by the curves for a specific stage is ascribed to evapotranspiration draft from the ground-water reservoir at that stage. Below some stage, undefined by the data. there would apparently be no evapotranspiration loss from ground water.

INTERBASIN UNDERFLOW

For the Middle Branch Escanaba River basin and for most other basins in the area, interbasin underflow is probably negligible. Drainage divides, for the most part, follow ridges where bedrock is at or near the surface. Such conditions offer little opportunity for interbasin diversion.

The East Branch Escanaba River basin, however, occupies a topographic position favoring underflow to the adjacent Chocolay River basin. The eastern part of the East Branch basin is on a plateau about 500 feet higher than the Chocolay River. This part of the basin is an extensive outwash plain overlying an equally extensive aquifer. Bedrock is at considerable depth along the topographic divide between the basins. The water table slopes steeply to the east (fig. 31). All these conditions are conducive to subsurface underflow from the East Branch basin to the Chocolay basin.

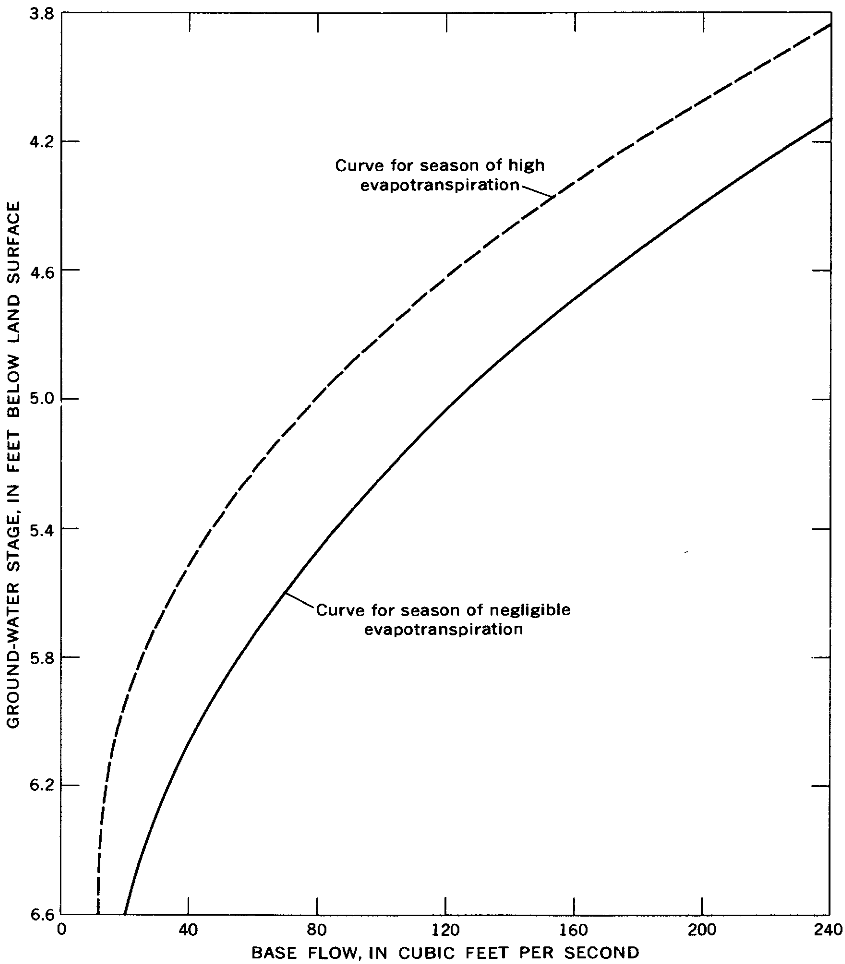


FIGURE 40.—Rating curves of mean ground-water stage versus base flow at Middle Branch Escanaba River near Ishpeming.

Discharge measurements made of Chocolay River tributaries draining the east slope of the Marquette Moraine during the summers of 1962 through 1964 confirm the existence of substantial underflow from the East Branch basin. The measurements, all made during baseflow conditions, indicate exceedingly high yields from these small streams—generally many times greater than concurrent yields indicated for other streams in the report area. When measurements were made, the crystal clear and cold water in these streams indicated a nearby ground-water source. The average annual loss from the East Branch basin by interbasin underflow is estimated to be on the order of 30 to 40 cfs.

GROUND-WATER RECHARGE

Recharge, the process by which water is added to ground water underlying a drainage basin, can occur in four ways: (1) By percolation of precipitation falling on the land surface, (2) by percolation from bodies of surface water, (3) by interbasin underflow, and (4) by artificial means such as water spreading and recharge wells. Ordinarily, most recharge in a basin is derived from precipitation infiltrating to the water table. It is usually greatest in spring and early summer and least in winter, although it can be very small during dry summers.

NATURAL RECHARGE

Water that reaches the ground-water reservoir underlying a basin can be estimated by a ground-water budget analysis. The analysis used here is similar in most respects to the procedure developed by Schicht and Walton (1961). It is based on the following equation:

$$Pg = Rg + ETg \pm U \pm Sg$$

where

Pg = ground-water recharge,
Rg = ground-water runoff,
ETg = ground-water evapotranspiration,
U = interbasin underflow, and
Sg = change in ground-water storage.

A ground-water budget was prepared for the Middle Branch Escanaba River basin above the gaging station near Ishpeming for the 1963 water year. All the terms in the budget were expressed in units of inches of water over the basin. The ground-water runoff, or base flow, was determined from hydrographic separation of streamflow into its surface- and ground-water components (fig. 38). Evapotranspiration was estimated from the curves in figure 42 by using monthly mean ground-water stages. Underflow into or out of the basin was considered negligible. Change in ground-water storage was determined as the product of the monthly change in a ground-water stage and a storage coefficient.

The storage coefficient was computed in two ways: (1) By dividing the runoff for January and February 1963, all base flow, by the inches change in ground-water stage during the 2 months, and (2) by computing the ground-water storage depletion obtained by integrating the winter base-flow recession curve (fig. 37) between the base-flow discharges indicated for June 20 and September 30, 1963, and dividing this value (inches) by the inches change in ground-water stage between the two dates. Coefficients of 0.068 and 0.06 were obtained from these computations and 0.06 was used. This storage coefficient represents a basin-wide average and may not be indicative of the coefficents that apply for individual aquifers in the basin.

The ground-water budget and supporting hydrologic data are contained in table 19. Monthly precipitation is shown so that components of runoff and of the ground-water budget can be compared with the basin supply. The annual recharge of 7 inches and the annual evapotranspiration from ground water of 1.82 inches, 30 and 8 percent of basin supply, respectively, seem to be reasonable. Some of the monthly values of the budget could be substantially in error, however.

TABLE 19.—*Precipitation, runoff, and ground-water budget for Middle Branch Escanaba River basin above Ishpeming gage for water year ending September 30, 1963*

[Precipitation: Average of U.S. Weather Bureau stations at Champion and Ishpeming. Ground-water stage: In feet below land surface; data from fig. 39. Symbols: *Rs*, surface runoff; *Rg*, ground-water runoff; *Rt*, total runoff; *ETg*, evapotranspiration from ground water; Δ*Sg*, change in ground-water storage; and *Pg*, recharge to ground water. Asterisk indicates estimated]

Month	Hydrologic data						Ground-water budget (inches)			
	Precipitation (inches)	Runoff (inches)			Ground-water stage (feet)					
		Rs	*Rg*	*Rt*	Mean	Change during month	*Rg*	*ETg*	Δ*Sg*	*Pg*
October	2.08	0.09	0.34	0.43	5.80	+0.21	0.34	*0.10	+0.15	0.59
November	1.01	.08	.50	.58	5.61	+.12	.50	*.05	+.09	.64
December	1.60	.07	.48	.55	5.71	−.20	.48		−.14	.34
January	.89	0	.30	.30	5.98	−.37	.30		−.27	.03
February	.76	0	.20	.20	6.30	−.24	.20		−.17	.03
March	1.47	.08	.21	.29	6.10	+.76	.21		+.55	.76
April	1.99	1.32	1.11	2.43	5.21	+.76	1.11	.38	+.55	2.04
May	2.66	.40	1.02	1.42	4.81	+.10	1.02	.39	+.07	1.48
June	4.26	.68	1.00	1.68	4.81	−.40	1.00	.38	−.29	1.09
July	1.92	.02	.26	.28	5.67	−.78	.26	.29	−.56	
August	2.54	.03	.18	.21	6.22	−.52	.18	.16	−.37	
September	1.87	.03	.18	.21	6.65	−.34	.18	.07	−.25	
Total	23.05	2.80	5.78	8.58			5.78	1.82	−.64	7.00

Recharge in 1963 was probably less than average because precipitation was about 8 inches less than normal. Ground-water budget calculations (not shown) were also made for the 1962 water year when basin precipitation was 27.7 inches, or somewhat more than 3 inches below normal. Recharge of 8.74 inches and an evapotranspiration loss of 2.04 inches from ground water were obtained for 1962. These values are 32 and 7.4 percent, respectively, of basin supply for that year. Ground-water runoff was 25 percent of the basin precipitation, the same proportion as in 1963. These results indicate that for the Middle Branch basin annual ground-water recharge is about a third, and annual ground-water runoff is about a fourth, of the annual precipitation. The difference, 10 percent or less, is the annual evapotranspiration loss from ground water. It is believed that these results should also be representative of the entire report area wherever physical conditions are generally similar to those in the Middle Branch basin.

The computed recharge, like the computed storage coefficient, is an average for the basin. The Middle Branch basin contains rather extensive areas of till and areas where bedrock is at, or near, the surface. In some of these areas the saturated thickness of the unconsolidated material above bedrock may be very small. Recharge would consequently be small, much less than the basin average. On the other hand, recharge in areas containing permeable outwash, alluvium, or marsh deposits would be much greater than the average. Recharge two times or more greater than the basin average does not seem unreasonable for such areas. Approximations obtained by flow-net analysis along selected reaches of streams traversing glacial outwash deposits indicate recharges as much as 18 inches or more per year. Natural recharge by percolation from surface-water bodies and by interbasin underflow occurs under special conditions and at selected places that have been mentioned previously.

ARTIFICIAL RECHARGE

The relatively small withdrawal of ground water in the area (about 5 mgd in 1964) has not stimulated development of artificial recharge. At Palmer, which obtains its water supply from a well adjacent to Warner Creek, incidental recharge has probably been induced from Warner Creek whenever the pumping level in the well was below creek level. No ground-water installations, however, utilize induced recharge on a sustained basis. Artificial recharge could become a useful water-management operation if ground-water supplies for industrial use are developed. The feasibility of water spreading to recharge the aquifer south of Goose Lake has been mentioned. Further possibilities exist wherever permeable deposits are contiguous with bodies of surface water. The surficial geology map (pl. 1) can be used for preliminary identification of such areas. At these places, wells near the streams or lakes could be pumped to lower the ground-water level to induce recharge from surface water.

Inducing recharge from surface water necessarily depletes that supply in the reach from which surface water is drawn. Some depletion can be tolerated in most streams. The time of year, prevailing streamflow and amount of streamflow needed to sustain aquatic life, and other demands upon the same source would establish the water-management pattern best suited for a specific development. If the water used is returned to the stream with quality unimpaired, there

243-028 O—67——9

should be no adverse effects upon downstream water users. In fact, an induced recharge system will increase flows downstream from the point where the flow is returned because of the storage effect.

STREAMFLOW

Streamflow represents an integration of all factors operating in the hydrologic system in an area. A water particle at a point in a stream entered the system as precipitation and flowed overland into a channel or infiltrated into the ground where it slowly moved to a point of discharge into the stream, or it may have followed a combination of these paths. Enroute it picked up various minerals or materials by solution or suspension. The quantity and quality of streamflow at a point are therefore a unique expression of the environmental influences in the basin upstream from that point.

The environmental effects are manifested in the pattern of streamflow distribution. Streams draining areas having a large amount of storage, on the surface or underground, have relatively low floodflows and high dry-weather flows. In these basins most of the water takes the underground route. On the other hand, streams draining areas having little storage are flashy, with relatively high floodflows and low dry-weather flows. Here, much of the water takes the overland route to streams. These influences are reflected in the streamflow characteristics which in this report are expressed in terms of flow-duration and drought- and flood-frequency data (table 2). A study of these characteristics can be very helpful in formulating water-management practices best suited to local conditions.

WATER USE

The principal demands for water in the Marquette Iron Range area are for public supply, industrial supply, and recreation. At present, the quantity and quality of water available are adequate for existing needs. The following paragraphs contain a brief discussion of the existing uses so that their relative place in the total water-resources picture may be assessed.

PUBLIC SUPPLIES

Sufficient water of acceptable quality is needed for human survival. Thus, public supplies normally rate top priority in evaluation of water demands even though they may constitute but a small proportion of the total demand. In 1964, somewhat more than 5 mgd of water were furnished a population of 36,555 from public supplies (table 20). Per capita water use ranged from less than 20 to almost 200 gpd and averaged 142 gpd. Heaviest per capita use, as indicated for Ishpeming and Negaunee, undoubtedly reflects the influence of modest use by small commercial and industrial establishments. Almost 60 percent of the water furnished by public supplies was obtained from surface sources, and the rest was obtained from wells. Although ground water can generally be used without treatment, most of the public supplies in this area are chlorinated to reduce bacterial concentrations.

INDUSTRIAL SUPPLIES

Nearly all industrial supplies are private. The two major industrial uses of water are (1) for the mining and processing of iron ore and (2) for power generation.

WATER USE BY THE IRON-ORE INDUSTRY

In 1964 beneficiated ore made up 65 percent of the total iron-ore shipments from the Marquette Iron Range. This ore is originally derived from the low-grade iron-formation, is concentrated to a greater percentage of iron (60–65 percent), and is pelletized. Within the report area, three beneficiation plants—Empire mine at Palmer, Humboldt mine at Humboldt, and Republic mine at Republic—and one ore-improvement plant at Eagle Mills are presently in operation.

The actual mining of the iron ore places no appreciable demand upon water resources. Beneficiation and pelletizing processes, however, utilize large quantities of water. The principal uses of water in these processes are in grinding the ore, in concentrating operations, and as a medium for transporting the ore throughout the plants. Subsidiary uses of water include dust collection, cooling of bearings and compressors, heating, fire protection, and sanitary needs.

In most cases the water is clarified and recirculated in the plants with the clarifier effluent being ponded in tailings basins. These basins permit suspended solids to settle out and the water is eventually returned to streams. Although usage is high, consumption is relatively low.

The bulk of the process water used by the iron industry has its source in the Michigamme, Carp, and Middle Branch Escanaba Rivers and Schweitzer Creek. Present (1965) use by this industry exceeds 31.5 mgd, or roughly 1,400 gallons per ton of finished product. An increase in the number of processing plants and the total output of beneficiated ore seems likely. Thus the importance of water to the area's major industry can hardly be overestimated.

Water used in the beneficiation processes is degraded somewhat in quality. Hardness, total dissolved solids, sulfate, nitrate, silica, turbidity, and sediment concentrations are increased to some extent. No posttreatment is provided. Nevertheless, the discharge water is still

TABLE 20.—*Public water supplies, 1964*

Cities, towns, or communities served	Population	Supplier	Source	Capacities (1000 gpd)	Storage (1000 gal)		Treatment	Water used (avg gpd)	Sewage treatment and facilities
					Raw	Finished			
Beacon	300	North Range Mining Co.	Well (1)	14	None	3,000	Chlorination	4,500	Individual septic tanks.
Diorite	200	Ely Township	Well (1) Well (1)	10.4 13.8	None	5 (underground storage tank).	do	2,300	Do.
Forsythe Township.	3,445	Forsythe Township.	Well (1) and Kidder mine shaft.	Unknown	50 (elevated tank).	None	None	Unknown	Do.
Greenwood	400	Ely Township	Well (1)	21.6	3 (underground storage tank).	do	do	Unknown	Do.
Ishpeming	8,857	City of Ishpeming.	Inland Lakes: Sally, Ogden, Miller, Furnace Schoolhouse, Tilden.	2,650	69,260 (lake storage).	500 (elevated tank).	Chlorination	1,734,500	Postchlorination and settling.
Ishpeming Township.	2,238	Ishpeming Township.	City of Ishpeming, also well (1) scheduled for operation 1965.	Metered as needed by City of Ishpeming.	None	200 (elevated tank).	do	103,900	Postchlorination and settling—due for operation in fall 1964.
K. I. Sawyer AFB.	11,800	K. I. Sawyer AFB.	Wells (8): Nos. 1, 2, 3, and 8. Nos. 4 and 7 No. 5 No. 6	 216 each 1,080 each 1,440 108	None	2,200 (2 elevated tanks), 500 (ground level storage).	Chlorination (fluoridation to be in operation in near future).	1,550,000	Primary and secondary, trickling filter through sand bed, and postchlorination.

Negaunee	6,126	City of Negaunee.	Teal Lake	1,937	Lake storage.	300 (elevated tank).	Chlorination and fluoridation.	1,118,000	Primary, trickling filter, and final settling.
Palmer	850	Richmond Township.	Well (1)	130	135 (elevated tank).	None	None	130,000	City septic tank (9,600-cu ft capacity) for separating sludge from water.
Republic	1,417	Republic Township.	Well[1] (1) Well[1] (1) Well[1] (1)	172.8 151.2 129.6	None	300 (ground level storage).	Chlorination	137,500	Individual septic tanks. Also 90 homes in South Republic receive septic and postchlorination treatment.
National Mine	922	Tilden Township.	City of Ishpeming.	Metered as needed by City of Ishpeming.	None	None	do	44,272	Individual septic tanks.

[1] Perch Lake available for standby.

of good quality chemically and does not adversely affect the chemical quality of the receiving streams. Although large volumes of water are used by the iron-ore industry and the plant effluents are returned to streams, the chemical and physical quality of the major streams are not adversely affected and the water remains suitable for most uses.

WATER USE FOR POWER GENERATION

Water used for power generation constitutes the other major industrial water use in the area. There are four powerplants, two of which are hydroelectric plants (table 21). This use of water generally does not adversely affect the suitability or availability of water for other uses.

TABLE 21.—*Summary of data on powerplants*

Plant	Location	Owner	Rated capacity (kilowatts)	Water	
				Use	Source
Carp hydroelectric	Sec. 35, T. 48 N., R. 25 W.	Cleveland-Cliffs Iron Co.	5,600	Power	Carp River.
Escanaba hydroelectric.	Sec. 12, T. 45 N., R. 26 W.	do	2,500	do	Middle Branch Escanaba River.
Ishpeming steam	Sec. 10, T. 47 N., R. 27 W.	City of Ishpeming.	7,500	Cooling	Lake Angeline.
Ishpeming diesel	do	do	10,000	do	Do.

RECREATION

Outdoor recreation is closely related to water. The critical factors are availability and quality. Use of water for recreation does not affect the quantity and normally does not affect the quality of available water in relation to other uses.

Marquette County has many advantages for development of recreational facilities. With rugged topography, forests, pleasant streams and lakes, and spectacular scenery this area has much to offer for recreation. Hunting, fishing, swimming, boating, camping, hiking, and skiing provide enjoyment to many local and visiting outdoor enthusiasts. Annual ski meets at Ishpeming attract participants from all over the United States and Europe and spectators from many parts of the Midwest. Van Riper State Park is located at the east end of Lake Michigamme in the report area. Several county parks and nine public fishing sites maintained by the Michigan Conservation Department are located in the area.

The streams, though small, provide excellent fishing, as do many of the inland lakes. Many of the lakes are still untouched by lake-front development.

Although recreation does not impose a consumptive demand upon water or normally affect water quality, quality affects the use of water for recreation. Water must be of a quality which will sustain fish and wildlife and make possible the esthetic appreciation of nature. Industrial polution is the greatest threat to water quality in the area but thus far has not been a problem. Continued surveillance and care will be needed as industrial use of water increases.

MANAGEMENT ASPECTS OF WATER-RESOURCE DEVELOPMENT

HYDROLOGIC CONSIDERATIONS

Unlike other mineral resources, water is a renewable resource whose availability varies with time. Though manifest in different phases—as atmospheric, surface, and ground water—the water resources of an area represent a single integrated system. Each time the water-use pattern of an area changes, natural balances are upset, flow paths are altered, and vegetation, fish, and wildlife may be affected. Such changes inevitably bring conflict. Resolution of these conflicts to effect optimum benefit from water-resources development is the purview of water management.

Plants and equipment should be designed according to environmental conditions. Wise planning in the Marquette Iron Range area is possible because industrial management is aware of possible water problems.

The issue in water-resources development for this area is not primarily one of availability. An average of 14 inches of water has been estimated to run off from this area (fig. 36) while present (1965) use is only about 1½ inches. The natural flow available for 90 percent of the time in the Middle and East Branches of the Escanaba River, the Carp River, and the Michigamme River above Gambles Creek is about 190 cfs. This flow is more than three times the present (1965) water use of about 60 cfs in the area (about 8 cfs is from public supplies and the rest is supplied and used by the iron ore industry). With storage, these four streams could yield up to about 450 cfs. The issue, then, is essentially one of water management—adjusting the seasonal distribution to fit the demand, getting the water to points of use, safeguarding the physical and chemical quality to minimize deleterious effects upon fish and plant life and upon the recreation industry.

Probably the most obvious means of managing the water supply of the area is by constructing dams on streams to provide storage to moderate fluctuations in supply. Among the many possible storage sites in the area, the best are in the headwaters of the Middle Branch

Escanaba and Michigamme Rivers. Reservoirs on the Middle Branch Escanaba River and on Dishno Creek at sites 3 and 20, figure 22, could each impound more than the average flow from the area tributary to the reservoir. If built to utilize their full capacity, these reservoirs would take from 2 to 3 years to fill. If loss of this water could be tolerated during the period needed to fill the reservoirs, multiple use of storage provided could be easily achieved. Water-supply withdrawals could be limited to less than anticipated annual average runoff, thereby reducing the range in water-level fluctuation of the reservoirs, and still ample storage would be retained to provide year-round conservation ponds. The wilderness setting of these reservoirs would be especially attractive for recreational use.

The effect that proposed installations may have upon downstream interests should be recognized and gauged in planning for storage facilities. Hydroelectric plants on lower reaches of the Escanaba and Michigamme Rivers would feel the impact of developments in the area covered by this report. Industrial use of water from a reservoir on Dishno Creek would probably require exportation of water from the Michigamme basin unless the water was used in plants discharging their effluents to the Michigamme. Diversion from Dishno Creek would also tend to adversely affect low-water levels on Lake Michigamme; however, the effect would probably be small because the drainage area of Dishno Creek is only about 10 percent of the area tributary to Lake Michigamme.

Water in inland lakes offers several advantages: (1) It is of relatively constant chemical quality and relatively free of suspended matter, (2) it is generally softer than ground water, (3) seasonal turbidity and water-level changes are fairly predictable, and (4) pumping and intake installations are comparatively simple to construct. A principal disadvantage is that withdrawal of water from lakes conflicts with recreational use during the summer low-water season. Lakes could therefore best be used as standby or supplemental supplies. Storage of 8,000 acre-ft on Lake Michigamme could support a withdrawal of more than 25 cfs for the 5-month period November to March when the lake level could be lowered to make room for spring runoff. Likewise, 2,000 acre-ft of storage on Goose Lake could supply more than 10 cfs for any 3-month period. Because of absence of riparian occupance on Goose Lake, no lake-level conflict would be expected. Water stored in Goose Lake could also be used to recharge the aquifer underlying the outwash plain south of the lake.

Hydrologically, the presence of inland lakes, favorable storage sites on streams, and several promising aquifers in the area provide an enviable degree of flexibility in possible water-management schemes. Economic analyses would be needed to determine actual feasibility. Water from streams could be used when streamflow and water in storage were abundant; ground water could be used when streamflow was low and available storage depleted.

Industry does not use ground water at the present time (1965) but may do so as the area's water needs and uses increase. Well water is usually fairly constant in quality and temperature but is often harder than surface water. The cost of developing wells pumping from moderate depths would probably be less than the cost of surface reservoirs.

Storage characteristics of underground aquifers should not be overlooked. By deliberately drawing the water table down farther than it would normally fall, storage capacity would be created that would subsequently be filled by water that would otherwise run off unused during periods of high streamflow and recharge. A lower water table in summer would also mean less evapotranspiration loss from ground water. Figure 40 indicates that the evapotranspiration draft from ground water in the Middle Branch Escanaba basin would be nearly halved (from 44–24 cfs) by lowering the water table a foot, from 5 to 6 feet below land surface. Lowering the water table to 7 feet below land surface would almost eliminate evapotranspiration loss from ground water. A net gain would thus be realized from storage and consumptive use would be reduced. In this way, the ground-water reservoir is operated like a surface reservoir. This type of operation has been used successfully in some parts of Western United States (Banks, 1952); however, continued operations of this kind could cause changes in the type of vegetation covering the land surface overlying the aquifer.

Development of the aquifer south of Goose Lake would probably decrease the flow in the small tributaries of the Chocolay River that receive underflow from the East Branch Escanaba River basin. These tributaries, however, would be unlikely to go dry at any time because of the steep ground-water gradient toward these streams.

Existence of the high-head hydroelectric plant near the mouth of Carp River presents the possibility of supplemental economic benefits derived from water added to that stream. If effluents of industrial plants which obtain water from the ground or adjacent basins are discharged into the Carp River, power production at the hydroelectric station would be increased. At 1 cent per kilowatthour, each cubic foot per second of water added to the annual flow is worth about $3,500 per year in power revenue. The feasibility of this operation would depend upon acceptance of interbasin diversion by regulatory agencies and by other water users and riparians affected.

Numerous abandoned mines are scattered about the iron range. These eventually fill with water and could be developed as sources of water supply. For example, the water level in Morris mine at North Lake has risen more than 50 feet since operations were discontinued at the mine in 1961. Obviously, a great deal of water is stored in this mine. Where public water supplies are endangered or rendered unusable by mining operations, consideration might be given to development of new supplies from abandoned mines. Several communities in the mining areas of the Upper Peninsula have public supplies tapping abandoned mine shafts.

Development and use unavoidably affect water quality. Whether impoundment raises or lowers surface-water temperatures in the summer depends upon location of the outlet works at the dam. Ground-water withdrawal and consequent depletion of streamflow tend to increase water temperatures in streams during summer. Decomposition of vegetal matter in new impoundments may pose problems such as those found at Schweitzer Creek Reservoir. Gaseous hydrogen sulfide generated by this decomposition can be removed by aeration. Aeration may also be used to convert iron and manganese compounds to oxides, which are easier to remove from water. Physical quality of water may be impaired by addition of mine tailings and other insoluble particles from industrial operations. As the particles settle, they blanket the streambed and possibly smother purifying organisms and aquatic life useful as fish food. Settling ponds, as used currently at existing beneficiation plants, appear effective in minimizing this type of physical pollution.

Other hydrologic aspects of water management no doubt will evolve when actual projects go into operation. The overriding precept is that water, regardless of its environment—whether in the air, on the surface, or underground—is a single resource. Prudent management will seek to adjust operations to cope with a resource whose occurrence and distribution are greatly governed by geologic environment; whose amount varies daily, seasonally, and yearly; and whose quality depends upon its natural environment and upon the uses to which it is put.

In water-resources development and management, to obtain optimum benefits from available resources requires teamwork among all those whose interests are affected. Attention might be directed toward implementation of regional committees composed of representatives of industries operating in the area and of state and local regulatory agencies to assure mutual consideration of water needs, uses, and the disposal of wastes.

LEGAL CONSIDERATIONS

In general, the legal right to use surface water in Michigan is governed by the riparian doctrine. Each riparian or abutting landowner is entitled to have water undiminished in quantity and unimpaired in quality as the streamflow passes his property. The "reasonable use" concept applies to water needed for most purposes.

Recognizing the dependence of the iron-ore beneficiation industry upon a continuous supply of water to protect large capital investments, the State legislature in 1959 passed Act 143, Public Acts of 1959. This legislation authorizes the Michigan Water Resources Commission to grant permits for "drainage, diversion, control, or use of water" for the operation of low-grade iron-ore mining property if other feasible and economical methods of obtaining a continuing supply of water are not available and if the proposed use will not unreasonably impair public or riparian use nor endanger public health or safety.

Permits granted to date have, in general, set maximum limits upon allowable diversion and have placed appropriate restrictions so that diversions would not deplete streamflows below certain specified levels. Permits have also included provisions to obtain and maintain adequate records of the amount of water diverted and of the streamflow below the point of diversion. The legal implications of Act 143 cannot yet be defined or assessed. This law, however, is a milestone in the modification of the prevailing common law doctrine in Michigan. More experience with this law may point out needs for future legislative additions or modifications to improve its operation.

Under Act 245, Public Acts of 1929, as amended by Act 117, Public Acts of 1949, the Michigan Water Resources Commission has the responsibility to prevent unlawful pollution of waters of the State. The commission requires that, for new or added uses of waters of the State for waste-disposal purposes, a written statement shall be filed with the commission. This statement must give pertinent facts on the source and quantity of water used, the point of discharge, and the physical and chemical characteristics of the wastes to be discharged.

With respect to waters used by the iron-ore industry, the commission has generally ruled that the permittee shall make analyses and reports as specified and that plant effluents discharged to streams (1) shall not increase the suspended-solids content nor change the pH value of the receiving waters more than specified amounts, (2) shall not contain substances in sufficient quantity to injuriously affect commercial, industrial, or recreational water uses, (3) shall not contain substances in sufficient quantity to be toxic to animals, fish, or aquatic life, and (4) shall not contain untreated human sewage.

Act 184, Public Acts of 1963, requires approval of the Michigan Department of Conservation for construction of dams in streams and rivers. In addition, placement of dams or other obstructions in streams not controlled by the Department of the Army must be approved by the county board of supervisors.

Act 146, Public Acts of 1961, as amended by Acts 25 and 203, Public Acts of 1962, authorizes the Michigan Department of Conservation and county boards of supervisors to determine and maintain the normal levels of inland lakes, authorizes the building and maintenance of dams to accomplish these purposes, and prescribes ways and means of financing and administering the facilities needed to accomplish these purposes.

In regard to ground water, the common law gives a property owner the right to reasonable use of water capable of being captured on his land. A report of Michigan Agriculture Experiment Station (1950) states:

> The rule (of reasonable use), however, can be interpreted to prevent wasteful, malicious, or other unreasonable water uses, particularly when these have an adverse or injurious effect on others. The courts have indicated that under some circumstances particular water users may be liable to their neighbors for damages if it can be established that their pumping activities have so lowered local water levels as to require the abandonment or deepening of wells previously existent in the vicinity.

SUMMARY

Present availability of water, future potential, and other elements relating to the water resources are summarized in table 22, which represents, in condensed form, the present status of water knowledge in the Marquette Iron Range area. The effect of development upon the resource has been discussed in this report where such discussion was most relevant to the subject at hand.

Data on surface water that have been collected systematically since 1961 are generally adequate for evaluation of the water-supply potential for planning purposes. Streamflow quantities shown in table 22 represent yields for the drainage areas indicated. In most of the area, potential demand for industrial water supplies is probably greatest in the headwaters of the streams. For example, present withdrawal use of water from Middle Branch Escanaba River is more than half of the low flow at Humboldt (drainage area, 46 sq mi), but it is less than 7 percent of the low flow at the mouth at Princeton. Thus, utilization of all the potential supply indicated in the table would require construction of distribution facilities to transport the water to where it is needed. Figures 15 to 17, however, permit estimation of the water supply and potential at any point along the streams plotted. The greatest surface-water potential is in the Middle Branch Escanaba and the Michigamme River basins.

The quality of the surface waters is acceptable for most uses. For the kinds of use anticipated in the area, a minimum of treatment would be required. The most serious problem that could result from development is degradation of the physical quality caused by suspension of mine tailings in streamflow. Present developments, however, using settling basins to trap most of the suspended matter have not significantly increased the sediment loads in waters receiving plant wastes.

Available ground-water data and data on base flow of streams indicate that outwash deposits are potentially good sources of water. Approximate flow-net analyses in several areas suggest that annual recharge to outwash deposits could be of the order of 15 to 20 inches. Information on the extent and thickness of outwash deposits is needed to estimate the available supply. Quantitative ground-water data, which is very limited now because of lack of ground-water development, is also needed for appraisal of the available supply.

A productive aquifer underlying the outwash plain south of Goose Lake and east of the East Branch Escanaba River was identified. A potential of at least 15 cfs, or 10 mgd, is indicated for the northern part of the area containing the aquifer. Additional water could be obtained from the southern part. Another extensive ground-water body is probably located in the outwash area south and east of West Branch Creek. Headwaters of Flopper and Bear Creeks probably tap this aquifer. More information is needed to evaluate this possible source of supply.

The quality of the ground water sampled is generally suitable for most uses. Although a few samples indicated hard water, most were soft or moderately hard and contained less than 300 ppm of dissolved solids. More than half of the samples analyzed, however, indicated an iron content execeeding the recommended standard for drinking water.

TABLE 22.—*Summary of water-resources availability and developmental factors*

Source of water	Availability	Present development	Potential development	Principal problems of supply and development	Quality of water	Adequacy of data	Further studies needed
Surface water							
Carp River above Carp River Lake (drainage area, 63 sq mi).	Average flow, 60 cfs; low flow, 16 cfs.	Flow completely regulated by Deer Lake for hydroelectric power production.	Limited by present development.	Conflict with present use.	Acceptable for most uses. Iron and manganese exceed suggested standards for drinking water.	No long-term records. Correlation used to estimate supply.	Morgan Creek, which has high sustained flow, may merit further investigation.
Middle Branch Escanaba River (drainage area, 234 sq mi).	Average flow, 230 cfs; low flow, 74 cfs.	About 5 cfs withdrawn from Middle Branch and Lake Lory for Humboldt mine. Effluent returned to Black River.	With storage, up to about 150 cfs may be realized.	Storage required. Transmission to points of use. Possible sediment problems.	do	Adequate for preliminary planning.	Detailed reservoir surveys.
East Branch Escanaba River (drainage area, 124 sq mi).	Average flow, 94 cfs; low flow, 28 cfs.	About 5 cfs withdrawn from Schweitzer Creek Reservoir for Empire mine. Effluent returned to Middle Branch Escanaba River.	With storage, up to about 55 cfs may be realized.	do	Generally acceptable, but degraded by mine pumpage in inlet to Goose Lake.	do	Do.
Michigamme River above Gambles Creek (drainage area, 283 sq mi).	Average flow, 330 cfs; low flow, 79 cfs.	About 25–30 cfs withdrawn for Republic mine. Effluent returned to river via Gambles Creek.	With storage, up to about 220 cfs may be realized.	Possible conflict with lake-level control on Lake Michigamme.	Excellent	No long-term records. Correlation used to estimate supply.	Do.
Inland lakes: Lake Michigamme.	About 4,200 acres of water surface. Average annual range in water level is 4½ ft.	Heavy seasonal use for recreation.	8,000 acre-ft could be realized by lake-level control.	Conflict with recreation use.	do	Adequate. More than 20 yr of lake-stage record.	Continue record for water-management needs.
Goose Lake	About 400 acres of water surface.	None	About 2,000 acre-ft storage obtainable by constructing control at outlet.	Railroad along west shore limits maximum lake stage.	Water moderately hard.	Inadequate	Need records on lake-stage fluctuations.

Other	About 240 other lakes ranging in size from less than an acre to several hundred.	Perch, Sally, and Teal Lakes furnish municipal supply for Republic, Ishpeming, and Negaunee, respectively.	Mostly for recreation use. Modest amount available for standby supplies.	Excessive lake-stage fluctuations.	Acceptable for most uses.	Only small sampling available.	Lake-stage records on lakes most likely to be used for supply.
Ground water							
Outwash:							
Goose Lake-Sands plain.	High well yields possible. Covers relatively large area.	Eight wells near Silver Lead Creek for supply to K. I. Sawyer AFB.	About 15 cfs could be developed in northern part. (See table 10.)	Depletion of streamflow. Transmission to points of use.	Generally acceptable. Iron content often higher than standard for drinking water.	Sparse but useful for rough estimates.	Definition of extent and depth of aquifer.
West Branch Creek.	Probably high well yields possible. Relatively remote from areas of use.	None	Not enough information to evaluate. (See table 10.)	do	do	Inadequate	Definition of extent and depth of aquifer and well yields.
Other	Areas near Second Creek, Boston Lake and Morgan Creek possible for development.	Some small public and domestic supplies.	Probably could supply modest demands. (See table 10.)	do	do	do	Do.
Abandoned mines	Many scattered about iron range.	Kidder mine shaft supplies Forsythe T.	Unknown but could be substantial.	Possible quality problems.	Unknown	do	Inventory of possibilities.
Till and bedrock	Limited	None	Unknown but probably small.	High pumping costs. Possible quality problems.	Data inadequate to define.	do	

TABLE 23.—*Records of selected wells and test holes*

[Owner: Where U.S. Geological Survey is listed, the well was drilled and materials were supplied by the Survey only. Use: D, domestic; I, industrial; O, observation; P, public supply; T, test. Principal aquifer: Qd, Quaternary glacial drift; Qo, Quaternary glacial outwash; p€, Precambrian rocks, undifferentiated. Remarks: Measurements in degrees represent water temperatures in degrees Fahrenheit; measurements in gpm represent pumping rate in gallons per minute]

Well	Location in section	Owner	Driller	Use	Depth of well (feet)	Diameter of well (inches)	Exploration depth (feet)	Elevation of water level (feet above mean sea level)	Date of measurement	Principal aquifer	Remarks
48N29W19-1	SE¼SW¼	Chicago and North-western Railway Co.	U.S. Geol. Survey	O	31	1¼	127	1551.61	7-21-64	Qo	
26-1	SE¼SW¼	do	do	O	32	1¼	32	1544.47	7-21-64	Qo	49°
31-1	SE¼NW¼	North Range Mining Co.	Ford	P	89	6	89	1593	5-16-62	p€	
28W30-1	NW¼NW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	20	1¼	32	1559.39	7-21-64	Qo	46°
32-1	NE¼SE¼	Diorite	Diorite	P	38	96	38	1550	6-4-62	Qo	
32-2	NE¼SE¼	do	Hakala	P	50	6	50	1550	6-4-62	Qo	
26W28-1	NW¼NE¼	Marquette Co.	do	P	55	6	55	1396.30	7-21-64	Qo	
34-1	NE¼SE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	31	1¼	97	1273.49	7-21-64	Qo	47°
47N29W2-1	NE¼SE¼	do	do	O	19	1¼	88	1521.64	7-21-64	Qo	47°
3-1	NE¼SW¼	William Koski	Hakala	D	28	6	28	1537.50	7-21-64	Qo	53°
34-1	NW¼SW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	23	1¼	23	1489.13	7-22-64	Qo	48°
36-1	NW¼SW¼	do	do	O	19	1¼	19	1491.06	7-22-64	Qo	50°
28W1-1	NW¼SE¼	Inland Steel Co.	Layne Northwest	I	206	48		1499.81	7-16-63	Qo	
3-1	SW¼SW¼	Ely T.	Tassone	O	68	8		1559.72	7-21-64	Qo	Recorder.
4-1	NE¼NE¼	Inland Steel Co.		O	95	8		1567.64	7-21-64	p€	
8-1	NW¼NW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	18	1¼	99	1535.55	7-21-64	Qo	47°
10-3	NE¼NW¼	Greenwood Cabins	Hakala	D	65	6		1572.01	5-16-62	Qo	
11-1	NW¼SE¼	Greenwood T.		P	30	8		1515	8-28-63	Qo	
15-1	SW¼NE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	38	1¼	72	1502.38	7-21-64	Qo	47°
28-1	NW¼SW¼	do	do	O	17	1¼	32	1477.25	7-22-64	Qo	48°
35-1	NW¼SW¼	do	do	O	52	1¼	75	1440.21	7-22-64	Qo	47°
27W8-1	SE¼NW¼	Ishpeming T.	Hakala	T	162	6	162			Qo	
26W24-1	SW¼NE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	32	1¼	32	1203.16	7-22-64	Qo	48°
25-1	NE¼NE¼	do	do	O	35	1¼	202	1199.86	7-21-64	Qo	
25-2	NW¼SW¼	do	do	O	26	1¼	59	1203.68	7-21-64	Qo	47°
25-3	NW¼SE¼	do	do	O	26	1¼	122	1203.99	7-21-64	Qo	47°
26-1	NW¼SE¼	do	do	O	35	1¼	92	1210.79	7-21-64	Qo	47°
29-2	SW¼NW¼	Palmer	Hakala	P	34	8	34	1274.0	4-15-57	Qo	200 gpm.
30-3	SW¼NE¼	Cleveland-Cliffs Iron Co.	do	I	50	12	50	1292.0	9-25-62	Qo	200 gpm.
35-1	NW¼NW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	15	1¼	15	1201.87	8-19-64	Qo	45° (not shown on map).
36-1	NW¼NW¼	do	do	O	28	1¼	71	1203.22	7-21-64	Qo	
36-9	NW¼NW¼	Cleveland-Cliffs Iron Co.	Hakala	T	65	8	70	1203.08	7-21-64	Qo	44°, 310 gpm.
25W12-1	NE¼SW¼	U.S. Geol Survey	U.S. Geol. Survey	Q	36	1¼	102	676	7-21-64	Qo	46°
15-1	SW¼SW¼	Frank Bellero	Hakala	D	235	6	245	1016.56	7-21-64	Qo	49°
19-1	SW¼SW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	86	1¼	147	1184.92	7-21-64	Qo	47°

20-1	SW¼SW¼	do	do	O	103	1¼	177	1150.39	7-21-64	Qo	45°
21-1	SW¼SW¼	do	do	O	161	1¼	187	1093.00	7-21-64	Qo	
22-1	SE¼NW¼	do	do	O	135	1¼	142	986.29	7-21-64	Qo	45°
27-1	SE¼SW¼	do	do	O	82	1¼	86	1016.74	7-21-64	Qo	45°
32-1	NE¼SW¼	do	do	O	122	1¼	125	1141.51	7-21-64	Qo	48°
24W18-1	SE¼SW¼	Charles Shirtz	Owner	O	75	2	135	672.70	7-21-64	Qo	
28-1	SW¼SW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	91	1¼	112	679.53	7-21-64	Qo	46°
46N30W13-1	NW¼NE¼	Arola Bottling Co	Hakala	I	47	6	48	1490.53	5-16-62	Qo	49°, 20 gpm.
29W18-1	NW¼SE¼	Republic	Kleiman	O	33	1¼	50	1475.87	3-12-64	Qo	50°
22-1	NW¼NE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	31	1¼	32	1492.32	7-21-64	Qo	47°
30-1	NE¼NE¼	Kountry Kitchen	Kleiman	D	42	6	42	1537.10	8-28-63	Qo	
36-1	SW¼NE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	32	1¼	112	1469.79	7-21-63	Qo	50°
28W1-1	SE¼NW¼	Clarence Carlson	Tassone	D	96	6	96	1432.36	7-21-63	Qo	47°
8-1	SW¼NE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	23	1¼	99	1452.15	7-21-64	Qo	50°
12-1	NW¼SW¼	do	do	O	49	1¼	55	1403.00	11-14-62	Qo	
12-5	NW¼SW¼	do	do	O	15	1¼	32	1409.85	7-22-64	Qo	
15-1	NE¼SE¼	do	do	O	35	1¼	40	1427.29	7-22-64	Qo	48°
27-1	NE¼SE¼	do	do	O	71	1¼	71	1413.78	7-22-64	Qo	49°
32-1	SE¼SW¼	do	do	O	28	1¼	32	1435.80	7-22-64	Qo	49°
27W2-1	SW¼NE¼	Cleveland-Cliffs Iron Co	Cleveland-Cliffs Iron Co.	O	100	1¼	180			Qo	
17-1	SE¼SE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	31	1¼	57	1396.56	7-21-64	Qo	49°
19-1	SW¼SE¼	do	do	O	62	1¼	111	1423.82	7-21-64	Qo	48°
31-1	SW¼SW¼	do	do	O	71	1¼	102	1413.14	7-21-64	Qo	49°
26W2-1	SW¼SW¼	do	do	O	47	1¼	47			Qo	Destroyed.
12-1	SE¼SE¼	do	do	O	24	1¼	60	1177.41	7-21-64	Qo	48°
31-1	SW¼SW¼	do	do	O	32	1¼	32	1238.76	7-24-64	Qo	47°
25W2-1	NE¼SE¼	Francis Rochen		D	12	48	12	1171.88	1-22-64	Qo	
9-1	SW¼NW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	85	1¼	88	1144.74	7-21-64	Qo	48°
11-1	NW¼SW¼	Pine Ridge Trailer Court	Hakala	P	193	6	193	1062.00	2-25-63	Qo	52°, 70 gpm.
16-1	SE¼SE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	48	1¼	65	1159.13	7-21-64	Qo	47°
36-5	NW¼SW¼	U.S. Air Force	Layne Northwest	P	144	12	144	1090.66	7-22-64	Qo	750 gpm.
36-6	NW¼SW¼	do	do	P	144	12	144	1089.84	7-22-64	Qo	1,000 gpm.
25W5-1	SW¼SW¼	U.S. Geol. Survey	U.S. Geol. Survey	O	34	1¼	87	767.37	7-22-64	Qo	48°
45N30W1-1	SW¼NW¼	Arnold Janofski	Wisconsin-Michigan Power Co.	O	28	36	30	1516.57	3-24-63	Qd	
28W3-1	NE¼SE¼	U.S. Geol. Survey	U.S. Geol. Survey	O	32	1¼	160	1424.32	7-22-64	Qo	47°
26W8-1	NE¼NE¼	do	do	O	15	1¼	63	1209.75	7-22-64	Qo	
15-1	SW¼NE¼	do	do	O	20	1¼	58	1184.25	7-22-64	Qo	46°
25W11-1	SW¼NW¼	do	do	O	62	1¼	90	1105.88	7-21-64	Qo	47°
23	NW¼SE¼	do	do	O	65	1¼	95	1104.80		Qo	47°
28-1	NE¼NW¼	Gwinn		P, O	98	240	98	1090.97	5-31-63	Qo	
24W5-1	SW¼SW¼	U.S. Geol. Survey	U.S. Geol. Suvery	O	60	1¼	62	1114.42	7-21-64	Qo	46°

TABLE 24.—*Selected logs of auger holes in outwash deposits*

Location			Elevation (feet above mean sea level)	Material	Thickness (feet)	Depth (feet)
Section	Township N.	Range W.				
19	48	29	1,560	Sand, medium to coarse; some gravel	12	12
				Gravel, fine to coarse; some sand and silt	40	52
				Sand, fine to coarse; some gravel	35	87
				Sand, fine to coarse; some silt	5	92
				Sand, fine to coarse; some gravel	30	122
				Silt and clay, tan; some fine sand	5	127
34	48	26	1,283	Sand, medium to coarse, tan; some gravel	17	17
				Gravel, fine to coarse; some fine sand	15	32
				Sand, medium to coarse; some gravel and silt.	25	57
				Sand, medium to coarse; some silt and gravel.	35	92
				Clay, tan, silty; some very fine sand	5	97
2	47	29	1,531	Sand, fine to coarse; some gravel and silt	22	22
				Sand, fine to coarse; fine to coarse gravel	30	52
				Sand, very fine to medium, silty	15	67
				Sand, very fine to fine, very silty	15	82
				Sand, very fine to medium; silt and clay	6	88
				Bedrock(?)	----	88
35	47	28	1,482	Sand, fine to coarse; some gravel	2	2
				Sand, fine to coarse, with fine gravel, silty	5	7
				Sand, very fine to coarse; some silt and gravel.	25	32
				Gravel, well-sorted, fine to medium	5	37
				Sand, fine to coarse; some gravel	5	42
				Sand, fine to medium, silty	25	67
				Sand, very fine to fine, silty	5	72
				No sample possible; weathered bedrock	3	75
15	47	28	1,524	Gravel, medium to coarse; very fine to medium sand.	7	7
				Sand, very fine to medium; some gravel and clay.	15	22
				Sand, very fine to medium; some silt	25	47
				Sand, very fine to medium, silty	20	67
				Clay, silty, light brown	5	72
8	47	28	1,542	Sand, fine to coarse, with silt and gravel	2	2
				Sand, very fine to coarse, with silt and gravel.	10	12
				Sand, very fine to coarse, tan	15	27
				Sand, fine to medium, subrounded, clean	10	37
				Sand, fine to coarse, with fine to medium gravel.	40	77
				Sand, medium to coarse, with gravel and silt.	5	82
				Sand, very fine to medium; silt and gravel	5	87
				Clay, gray	12	99

TABLE 24.—*Selected logs of auger holes in outwash deposits*—Continued

Location			Elevation (feet above mean sea level)	Material	Thickness (feet)	Depth (feet)
Section	Township N.	Range W.				
[1] 36	47	26	1, 213	Sand, fine to medium, clean, tan	17	17
				Sand, very fine to medium; some gravel	10	27
				Sand, medium to coarse; some gravel and silt.	15	42
				Sand, medium, clean, tan	10	52
				Sand, fine to medium, silty	20	72
				Sand, fine to medium; silt and clay	10	82
				Sand, fine to medium, silty	20	102
				Sand, fine to coarse; some gravel	15	117
				Sand, fine to medium; clay	5	122
				Clay, gray	3	125
[2] 36	47	26	1, 214	Sand, fine to medium, tan	2	2
				Gravel, fine to coarse; fine to coarse sand	60	62
				Sand, very fine to coarse, silty	5	67
				Silt, tan; some clay and fine sand	4	71
26	47	26	1, 220±	Sand, fine to medium, brown	2	2
				Sand, medium to coarse; fine gravel	15	17
				Gravel, fine to coarse; fine to medium sand	5	22
				Gravel, fine to coarse; fine to coarse sand	25	47
				Gravel, fine to coarse; very fine to coarse, silty sand.	35	82
				Sand, fine to coarse; silty gravel	5	87
				Clay, gray; some silt	5	92
22	47	25	1, 105	Sand, medium to coarse; some gravel	12	12
				Sand, medium to coarse, tan	20	32
				Sand, fine to coarse, tan	70	102
				Sand, fine to coarse; fine gravel	10	112
				Sand, very fine, to medium, silty	20	132
				Sand, very fine to fine, silty; some clay	10	142
21	47	25	1, 243	Sand, very fine to coarse; coarse, silty gravel.	7	7
				Sand, medium to coarse; fine gravel	25	32
				Sand, medium to coarse, tan	5	37
				Sand, medium to coarse; some fine gravel	55	92
				Sand, medium to coarse, tan	10	102
				Sand, medium to coarse; gravel	15	117
				Sand, medium to coarse; silt and clay	25	142
				Sand, medium to coarse, silty	45	187
19	47	25	1, 226	Sand, very fine to medium; some silty gravel.	27	27
				Sand, very fine, to coarse, silty	10	37
				Sand, very fine to coarse, clean	35	72
				Gravel, fine, sand, fine to coarse	15	87
				Sand, very fine to medium, clean	35	122
				Sand, very fine to medium; clean gravel	5	127
				Sand, very fine to fine, silty	10	137
				Sand, very fine to medium, silty	10	147

[1] Location 5.
[2] Location 1.

TABLE 24.—*Selected logs of auger holes in outwash deposits*—Continued

Location			Elevation (feet above mean sea level)	Material	Thickness (feet)	Depth (feet)
Section	Township N.	Range W.				
12	47	25	695±	Sand, very fine to medium, silty	2	2
				Sand, fine to coarse; some silty gravel	5	7
				Sand, very fine to medium, silty	20	27
				Sand, fine to medium, clean	5	32
				Sand, very fine to coarse, silty	15	47
				Sand, very fine, to medium; gravel and silt.	15	62
				Sand, very fine to coarse; silt and clay	35	97
				Silt, clay; very fine sand	5	102
36	46	29	1, 484	Sand, very fine to fine, silty, tan	7	7
				Sand, very fine to medium; some gravel	10	17
				Sand, very fine to medium	5	22
				Sand, very fine to medium; some gravel	5	27
				Sand, very fine to coarse, tan	5	32
				Sand, very fine to coarse, silty with gravel	15	47
				Silt, tan	10	57
				Sand, fine to coarse; some gravel	25	82
				Sand, fine to medium	30	112
27	46	28	1, 447	Sand, medium to coarse, silty	2	2
				Sand, medium to coarse; gravel	30	32
				Sand, very fine, silty; some clay	20	52
				Sand, very fine, silty	15	67
				Sand, very fine to coarse, silty; some gravel.	4	71
				Bedrock	---	71
12	46	28	1, 409	Gravel, fine to coarse; coarse sand	7	7
				Sand, very fine to coarse; gravel with silt	5	12
				Sand, fine to coarse; gravel	10	22
				Gravel, coarse	5	27
				Silt, tan; some clay	15	42
				Gravel, coarse	5	47
				Boulders	8	55
21	46	27	1, 468	Sand, medium to coarse; silty gravel	7	7
				Gravel, coarse	5	12
				Sand, medium to coarse; fine to coarse gravel.	20	32
				Sand, medium to coarse; some gravel	35	67
				Gravel(?); no sample	5	72
				Sand, fine to coarse, clean	15	87
				Sand, very fine to coarse; clean gravel	10	97
				Sand, very fine to medium, clean	5	102
17	46	27	1, 415	Sand, fine to coarse; some clay	7	7
				Sand, very fine to coarse; gravel	10	17
				Sand, fine to medium, clean	10	27
				Sand, very fine to coarse; fine gravel	5	32
				Sand, very fine to coarse; silty gravel	10	42
				Sand, very fine to fine; silty decayed wood	10	52
				Clay, sand, gravel	5	57
12	46	26	1, 194	Sand, medium; clay	2	2
				Sand, medium, clean	10	12
				Sand, coarse; fine gravel	5	17
				Sand, coarse; fine to coarse gravel	40	57
				Clay; decayed wood	3	60

TABLE 24.—*Selected logs of auger holes in outwash deposits*—Continued

Location			Elevation (feet above mean sea level)	Material	Thickness (feet)	Depth (feet)
Section	Township N.	Range W.				
16	46	25	1, 198	Sand, medium, silty	17	17
				Sand, fine to coarse, clean	20	37
				Sand, medium to coarse; gravel	25	62
				Silt; sand, very fine	3	65
				Bedrock	----	65
3	45	28	1, 452	Sand, medium to coarse; fine, silty gravel	22	22
				Sand, medium to coarse; fine to coarse gravel.	25	47
				Sand, very fine to coarse, silty	25	72
				Sand, very fine to fine, silty	5	77
				No sample	5	82
				Sand, very fine to coarse, silty	20	102
3	45	28	--------	Sand, very fine to fine, silty	40	142
				Sand, silty	10	152
				Sand, very fine, very silty, boulders	8	160
8	45	26	1, 220	Sand, fine to coarse; fine to coarse gravel	2	2
				Sand, fine to coarse; silty gravel	5	7
				Sand, fine to coarse; clean gravel	10	17
				Sand, very fine, silty	5	22
				Sand, very fine, clean	35	57
				Sand, very fine; gravel, silt	5	62
				Clay, silt, sand, gravel, boulders	1	63
23	45	25	1, 128	Sand, medium to coarse; medium gravel	12	12
				Sand, fine to medium, tan	35	47
				Sand, fine to medium; occasional gravel	20	67
				Sand, fine to medium	20	87
				Sand, fine to coarse; fine gravel	5	92
				Sand, fine, silty	3	95
				Bedrock	----	95

REFERENCES

Banks, H. O., 1952, Utilization of underground storage reservoirs: Am. Soc. Civil Engineers Proc., Separate no. 114, v. 78, 15 p.

Colby, B. R., 1963, Fluvial sediments—a summary of source, transportation, deposition, and measurement of sediment discharge: U.S. Geol. Survey Bull. 1181–A, 47 p.

Comly, H. J., 1945, Cyanosis in infants caused by nitrates in well water: Am. Med. Assoc. Jour., v. 129, p. 112–116.

Conkling, Harold, 1946, Utilization of ground water storage in stream development: Am. Soc. Civil Engineers Trans., v. 111, p. 275–305.

Eichmeier, A. H., 1964, Snow depths in Michigan: East Lansing, Michigan Weather Service, 14 p., 10 figs., 1 table.

Harder, A. H., and Drescher, W. J., 1954, Ground-water conditions in southwestern Langlade County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1294, 39 p.

Humphrys, C. R., and Green, R. F., 1962, Michigan lake inventory: Michigan State Univ., Dept. Resource Devel. Bull. 52, p. 52A–52G.

Kohler, M. A., Nordenson, T. J., and Baker, D. R., 1959, Evaporation maps for the United States: U.S. Weather Bur. Tech. Paper 37, 13 p., 5 pl.

Lane, E. W., chm., 1947, Report of the subcommittee on sediment terminology: Am. Geophys. Union Trans., v. 28, no. 6, p. 936–938.

Langbein, W. B., and Iseri, K. T., 1960, General introduction and hydrologic definitions, *in* Part 1 *of* Manual of hydrology: U.S. Geol. Survey Water-Supply Paper 1541–A, 29 p.

Leverett, Frank, 1917, Surface geology and agricultural conditions of Michigan, Part 1, The northern peninsula: Michigan Geol. Survey Pub. 25, Geol. Ser. 21, 223 p., 22 pl., 25 figs.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria: California State Water Quality Control Board Pub. 3–A, 548 p.

Maier, F. J., 1950, Fluoridation of public water supplies: Am. Water Works Assoc. Jour., v. 42, pt. 1, p. 1120–1132.

Michigan Agriculture Experiment Station, 1950, Land economics: Michigan Agriculture Expt. Sta. [East Lansing] Quart. Jour., v. 26, no. 3, 410 p.

Michigan State University, 1960, Michigan statistical abstract [3d ed.]: East Lansing, Michigan State Univ., Bur. Business and Econ. Research, 273 p.

Olmstead, F. H., and Hely, A. G., 1962, Relation between ground water and surface water in Brandywine Creek basin, Pennsylvania: U.S. Geol. Survey Prof. Paper 417–A, 21p.

Pluhowski, E. J., and Kantrowitz, I. H., 1964, Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1768, 119 p.

Schicht, R. J., and Walton, W. C., 1961, Hydrologic budgets for three small watersheds in Illinois: Illinois State Water Survey Rept. Inv. 40, 40 p., 37 figs.

Searcy, J. K., 1959, Flow-duration curves *in* Part 2 *of* Manual of hydrology: U.S. Geol. Survey Water-Supply Paper 1542–A, p. 1–21.

Stallings, J. H., 1957, Soil conservation: Englewood Cliffs, N. J., Prentice-Hall, Inc., 575 p.

Stuart, W. T., Brown, E. A., and Rhodehamel, E. C., 1954, Ground-water investigations of the Marquette iron-mining district: Michigan Dept. Conserv., Geol. Survey Div. Tech. Rept. 3, 91 p., 8 figs.

Swanson, C. O., 1930, Report on the portion of the Marquette range covered by the Michigan Geological Survey in 1929: Michigan Dept. Conserv., Geol. Survey Div., 15 p.

Theis, C. V., and Conover, C. S., 1963, Chart for determination of the percentage of pumped water being diverted from a stream or drain, *in* Shortcuts and special problems in aquifer tests: U.S. Geol. Survey Water-Supply Paper 1545–C, p. C106–C109 [1964].

U.S. Bureau of Census, 1962, County and city data book: Washington, D.C., Govt. Printing Office, 593 p.

U.S. Public Health Service, 1962, Drinking water standards: Washington, D.C., U.S. Govt. Printing Office, U.S. Public Health Service Pub. 956, 61 p.

Wiitala, S. W., 1965, Magnitude and frequency of floods in the United States, Part 4, St. Lawrence River basin: U.S. Geol. Survey Water-Supply Paper 1677, 357 p.

Zinn, Justin, 1931, Report on the portion of the Marquette range between Humboldt and Lake Michigamme covered by the Michigan Geological Survey in 1930: Michigan Dept. Conserv., Geol. Survey Div., 18 p.

INDEX

[Italic page numbers indicate major references]