HYDROLOGY AND LAND USE IN

GRAND TRAVERSE COUNTY, MICHIGAN

By T.R. Cummings, J.L. Gillespie, and N.G. Grannemann

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CONVERSION FACTORS

Inch-pound units used in this report can be converted to International System (SI) units as follows:

Multiply inch-pound units	By	To obtain SI units
acre	0.004047	square kilometer (km^2)
	0.4047	hectare (ha)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	28.32	liter per second (L/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	10.93	liter per second per square kilometer [$L/s)/km^2$]
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
inch (in.)	2.540	centimeter (cm)
mile (mi)	1.609	kilometer (km)
pound (lb)	0.4536	kilogram (kg)
	453.6	gram (g)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
square foot (ft^2)	0.09294	square meter (m^2)
square miles (mi^2)	2.590	square kilometer (km^2)
	259.0	hectare (ha)
ton, short	907.2	kilogram (kg)
ton per square mile (ton/mi^2)	3.503	kilogram per hectare (kg/ha)

Temperature

Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the following formula:

$$°C = (°F - 32)/1.8$$

Sea Level

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Glacial deposits are the sole source of ground-water supplies in Grand Traverse County. These deposits range in thickness from 100 to 900 feet and consist of till, outwash, and materials of lacustrine and eolian origin. In some areas, the deposits fill buried valleys that are 500 feet deep. Sedimentary rocks of Paleozoic age, which underlie the glacial deposits, are mostly shale and are not used for water supply.

Of the glacial deposits, outwash and lacustrine sand are the most productive aquifers. Most domestic wells obtain water from sand and gravel at depths ranging from 50 to 150 feet and yield at least 20 gallons per minute. Irrigation, municipal, and industrial wells capable of yielding 250 gallons per minute or more are generally greater than 150 feet deep. At places in the county where moranial deposits contain large amounts of interbedded silt and clay, wells are generally deeper and yields are much lower.

Areal variations in the chemical and physical characteristics of ground and surface water are related to land use and chemical inputs to the hydrologic system. Information on fertilizer application, septic-tank discharges, animal wastes, and precipitation indicate that 40 percent of nitrogen input is from precipitation, 6 percent from septic tanks, 14 percent from animal wastes, and 40 percent from fertilizers.

Streams and lakes generally have a calcium bicarbonate-type water. The dissolved-solids concentration of streams ranged from 116 to 380 milligrams per liter, and that of lakes, from 47 to 170 milligrams per liter. Water of streams is hard to very hard; water of lakes ranges from soft to hard. The maximum total nitrogen concentration found in streams was 4.4 milligrams per liter. Water of lakes have low nitrogen concentrations; the median nitrate concentration is less than 0.01 milligrams per liter. Pesticides (Parathion and Simazine) were detected in low concentrations at six stream sites; 2,4-D was detected in low concentrations in water of two lakes. Relationships between land use and the yield of dissolved and suspended substances could not be established for most stream basins.

Calcium and bicarbonate are the principal dissolved substances in ground water. Dissolved-solids concentrations ranged from 70 to 700 milligrams per liter; the countywide mean concentration is 230 milligrams per liter. The mean nitrate concentration is 1.3 milligrams per liter; about 1.6 percent of the county's ground water has nitrate concentrations that exceed the U.S. Environmental Protection Agency's maximum drinking water level of 10 milligrams per liter. An effect of fertilizer applications on ground-water quality is evident in some parts of the county.

INTRODUCTION

An increased demand for water by irrigators, municipalities, and industries is affecting development throughout the country. Long-term effects, however, can rarely be predicted without detailed geologic and hydrologic information. Along with climate, geologic conditions control the natural chemical characteristics of water. Concern over the changes in the natural quality of both ground and surface waters has prompted examination of how land use modifies the suitability of water for its varied uses. Such changes are usually subtle, and not easily measured in a short period of time.

This study is one of a series of three county studies that attempt to relate hydrology to land use in Michigan. Other studies have been conducted in Van Buren and Kalamazoo Counties. Grand Traverse County was selected because agricultural development, although intense at places, was not as prevalent countywide as in the areas previously studied, and because general environmental conditions are different in the northern part of Michigan's Lower Peninsula.

The study was done in cooperation with Grand Traverse County and the Geological Survey Division of the Michigan Department of Natural Resources. The compilation of land-use data, information of fertilizer use, animal populations, and septic-tank installations were the responsibility of the Grand Traverse County Extension Service. Collection and analysis of geologic, hydrologic, and water-quality data were the responsibility of the U.S. Geological Survey.

Purpose and Scope

This report describes the results of a study of the chemical and physical characteristics of ground and surface water in Grand Traverse County and to relate these characteristics to land use. The investigation required an assessment of the chemical inputs to the hydrologic system, including those of precipitation, animal wastes, septic tanks, and fertilizers. Data on geology and hydrology, which provide the necessary basis for interpretations, were also collected and evaluated. Readily available land-use data were compiled for use.

General Description of Study Area

Grand Traverse County is in the northwestern part of Michigan's Lower Peninsula (fig. 1). On the north it is bounded by the East and West Arms of Grand Traverse Bay, a part of Lake Michigan. The Boardman River, which drains the central part of the county, flows to the Bay. The land surface is flat to rolling and ranges in elevation from about 580 ft (feet) above sea level at Lake Michigan to about 1,180 ft in the southeastern part of the county (fig. 2). The county has about 240 lakes and ponds.

The county comprises about 485 mi^2 (square miles) and is composed principally of cropland, orchards, and forests. Its population is about 55,000 (U.S. Bureau of Census, 1982). The largest community is Traverse City, which has a population of about 15,000 (fig. 3).

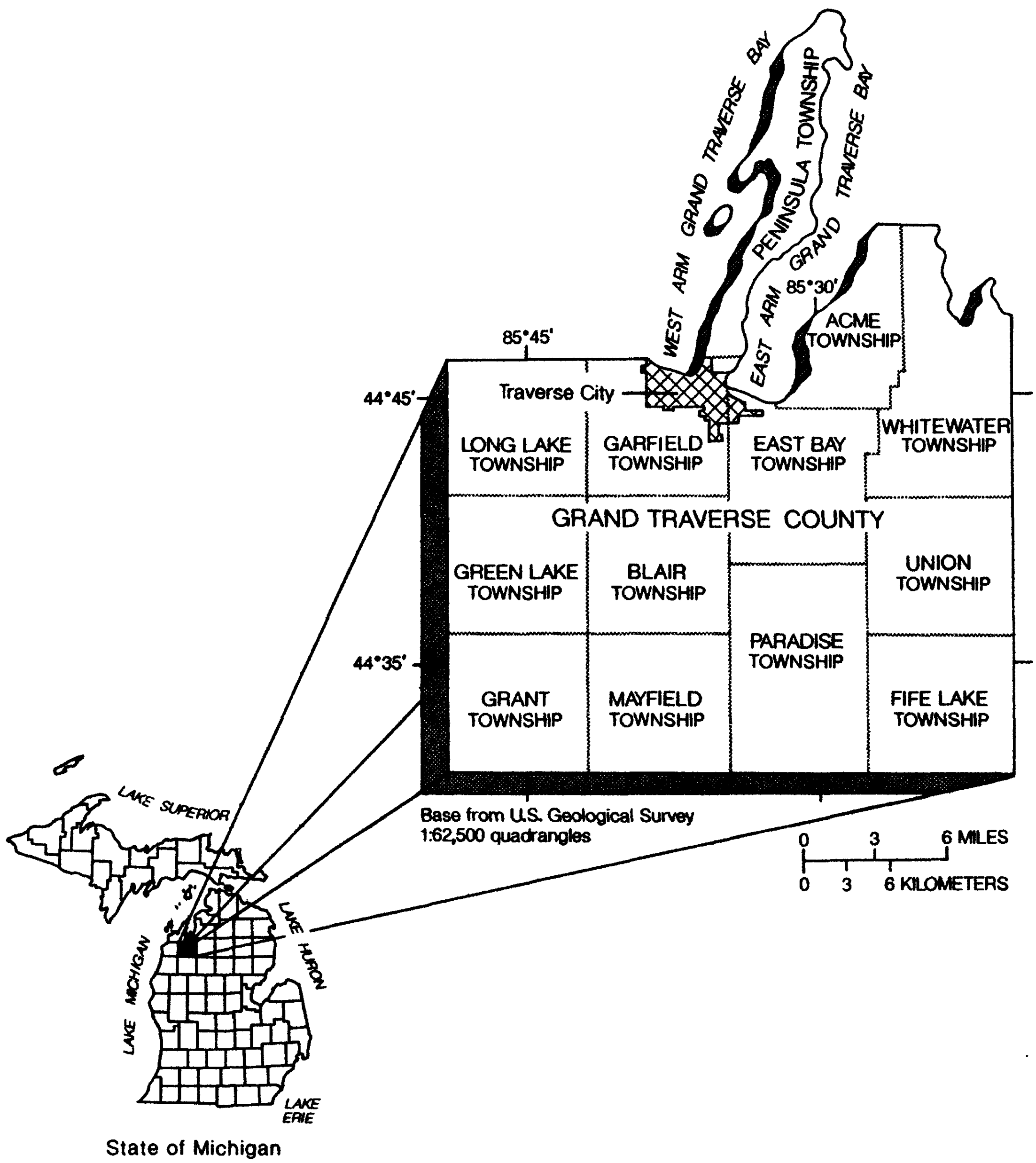


Figure 1.--Location of Grand Traverse County.

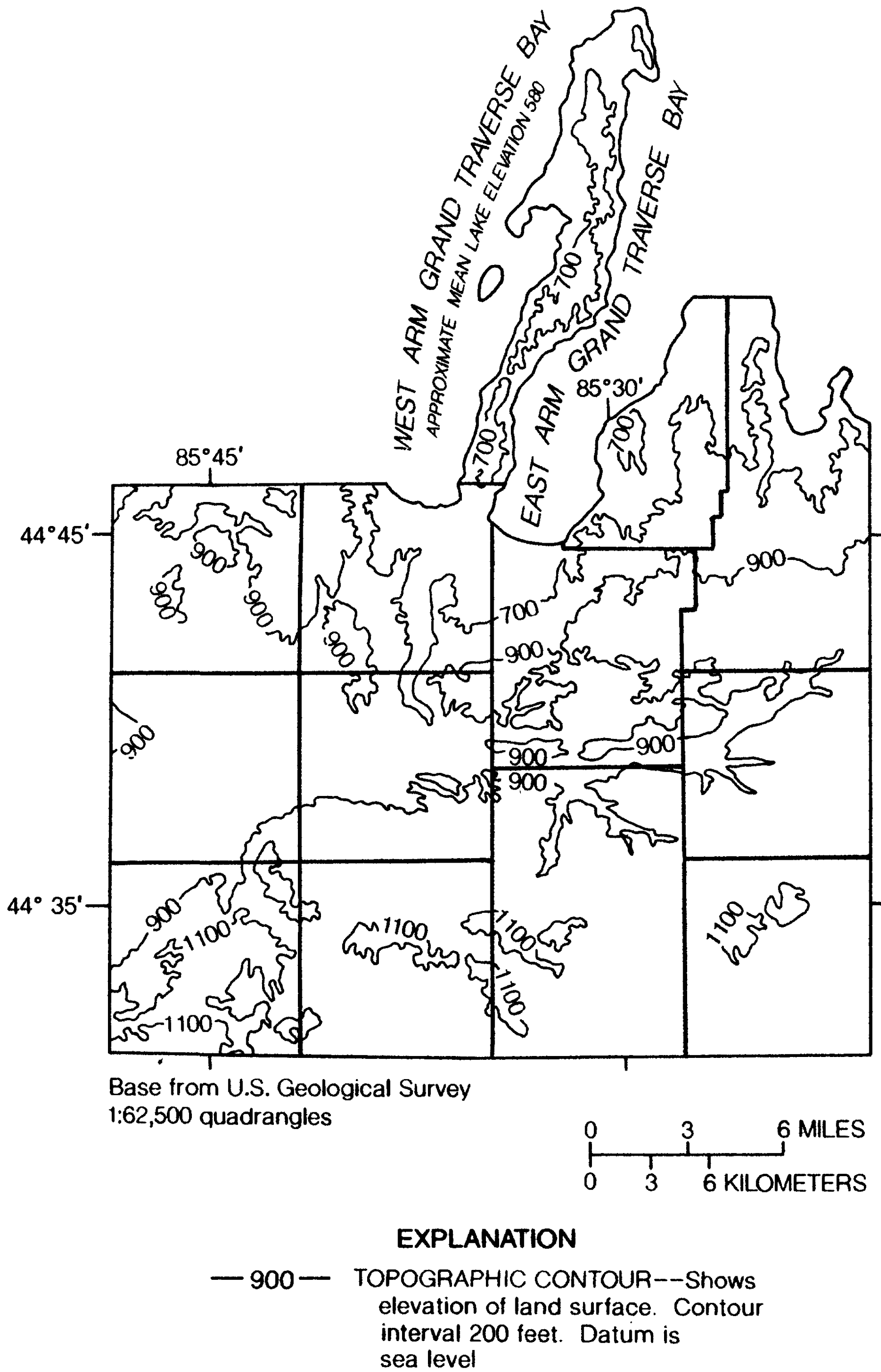


Figure 2.--Elevation of land surface.

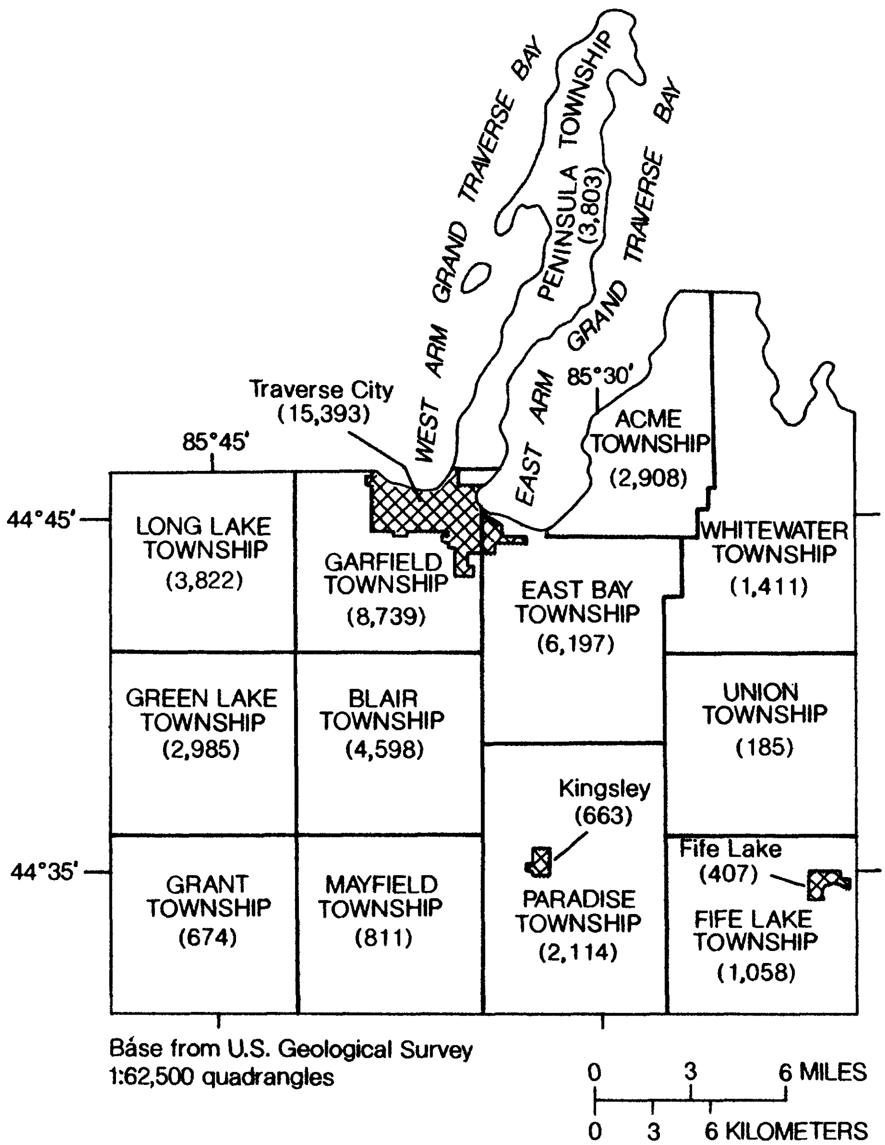


Figure 3.--Population in 1980, by township.
(U.S. Bureau of Census, 1982.)

Average annual precipitation for Grand Traverse County is about 31 in. (inches). It ranges from 30 in. at Grand Traverse Bay to 32 in. inland. Average snowfall, measured from July to June, ranges from 87 in. at Traverse City to 106 in. at the Village of Fife Lake in the southeastern part of the County (Fred Nurnberger, Michigan Weather Service, oral commun., 1990). Mean monthly temperatures range from 16 °F (Fahrenheit) to 65 °F.

Farming is an important part of the county's economy. Fruits, vegetables, and field crops can be raised satisfactorily with rainfall; however, irrigation increases yields and provides greater profits. About 2,000 acres are irrigated (R.L. Van Til, Michigan Department of Natural Resources, written commun., 1985). From 1970 to 1977, the amount of water used for irrigation increased 324 percent. Tourism is also important to the economy. In summer, the mild climate, the bay, and the many lakes make the county a popular recreational area. In winter, abundant snow and ice-covered lakes provide excellent conditions for winter sports. Oil and gas exploration and development are expanding in the southeastern part of the county.

Of the 55,000 residents of Grand Traverse County, about 40,000 depend on ground water for domestic supplies. The remaining residents obtain water from the Traverse City municipal systems, which pumps water from the East Arm of Grand Traverse Bay.

GEOLOGY

Grand Traverse County is underlain by sedimentary rocks of Paleozoic age that consist mostly of shale, limestone, and sandstone. Glacial deposits, the result of continental glaciation during the Pleistocene Epoch, consist of gravel, sand, silt, and clay. These unconsolidated deposits completely cover the bedrock surface and are as much as 900 ft thick at places.

Bedrock

Bedrock directly underlying the glacial deposits is divided into six geologic units (fig. 4). These geologic units are, in ascending order, the Antrim, Ellsworth, Sunbury, and Coldwater Shales, and the Marshall and Michigan Formations. The four shale units underlie all of the county except for the southeastern part which is underlain by the Marshall and Michigan Formations. The Marshall Formation is primarily a sandstone; the Michigan Formation is primarily a limestone.

Structurally, bedrock underlying the county is part of the Michigan basin, a bowl-shape feature with a center that roughly coincides with the geographical center of Michigan's Lower Peninsula (fig. 1). Geologic units dip toward the center of the basin where the youngest rocks subcrop. Therefore, the bedrock units in Grand Traverse County dip southeastward.

Elevation of the bedrock surface ranges from about 200 ft below sea level in the western part of the county to about 700 ft above sea level in the southeastern part of the county. Weathering and erosion throughout geologic time have created this variable relief. During periods of glaciation, erosion deepened pre-existing bedrock valleys and filled them with unconsolidated

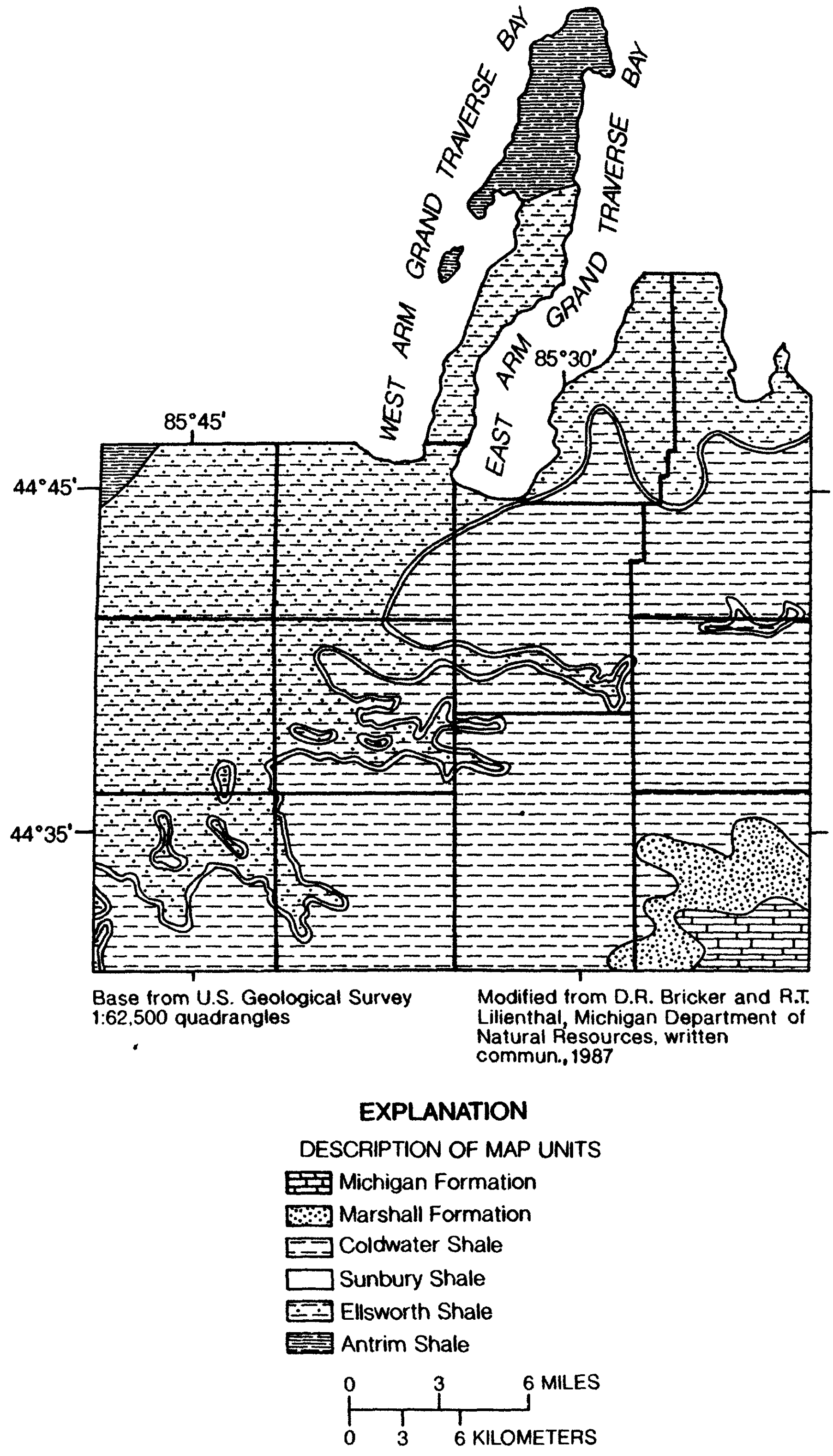


Figure 4.--Areal distribution of bedrock.

glacial deposits. One major buried valley, 500 ft below the elevation of the surrounding bedrock surface, trends north-south in the southwestern part of the county; two other major buried valleys trend east-west (fig. 5).

Scant data are available to determine the elevation of bedrock in the northwestern part of the county and on Old Mission Peninsula (pl. 1). At present, there are no wells that penetrate bedrock in these areas. Analysis of data from the few wells that do exist indicate that bedrock is at least 300 ft below land surface.

Glacial Deposits

Continental glaciation ended about 10,000 years ago in the northwestern Lower Peninsula of Michigan. As the glaciers melted, they left behind extensive deposits of gravel, sand, silt, and clay. The thickness of these deposits ranges from about 100 to about 900 ft. The lithology of the upper part of these deposits is indicated by the logs of 36 wells (table 1, at back of report) installed by the U.S. Geological Survey. At some locations the glacial deposits have been reworked, eroded by wind and streams, or eroded by wave action in the ancestral Great Lakes, whose water levels fluctuated as much as 200 ft after deglaciation (Hough, 1958).

Glacial deposits found in Grand Traverse County include till, glaciofluvial, and lacustrine deposits. Alluvial deposits of more recent origin occur near stream channels; eolian deposits occur near shorelines. The different types of glacial deposits are associated with landforms, such as till plains, outwash plains, moraines, and lake plains. The composition of these deposits, however, ranges from coarse gravel to clay.

Till is a mixture of gravel, sand, silt, and clay. In Grand Traverse County, till can be either coarse or fine grained. At some locations, boulders and cobbles also are present. Surficially, moraines in the county are composed of till that is primarily sand, gravel, and silt; moraines contain a relatively small amout of clay (Farrand, 1982). The moraines, which trend east-west, were formed when sediments were deposited as the glacier retreated. The Manistee moraine crosses the northern part of the county; the Port Huron moraine crosses the southern part (fig. 6).

Relief in areas of moraines is variable and is referred to as hummocky topography. Hummocky topography developed when differential melting of the glacier caused sediment to accumulate in low areas on the ice surface, which prevented the ice from melting rapidly. Depressions or kettle lakes on the land surface are places where ice blocks covered by sediment melted.

Till plains are present on Old Mission Peninsula and in the extreme northeastern part of the county. Topography at these locations consists of rolling plains and drumlins. Drumlins are smooth, glacially formed hills, elongated and aligned parallel to the direction of glacier movement. Drumlins are commonly found in fields; similar forms are found grouped together. The drumlins were probably caused by a readvance of glacial ice for a relatively short period of time.

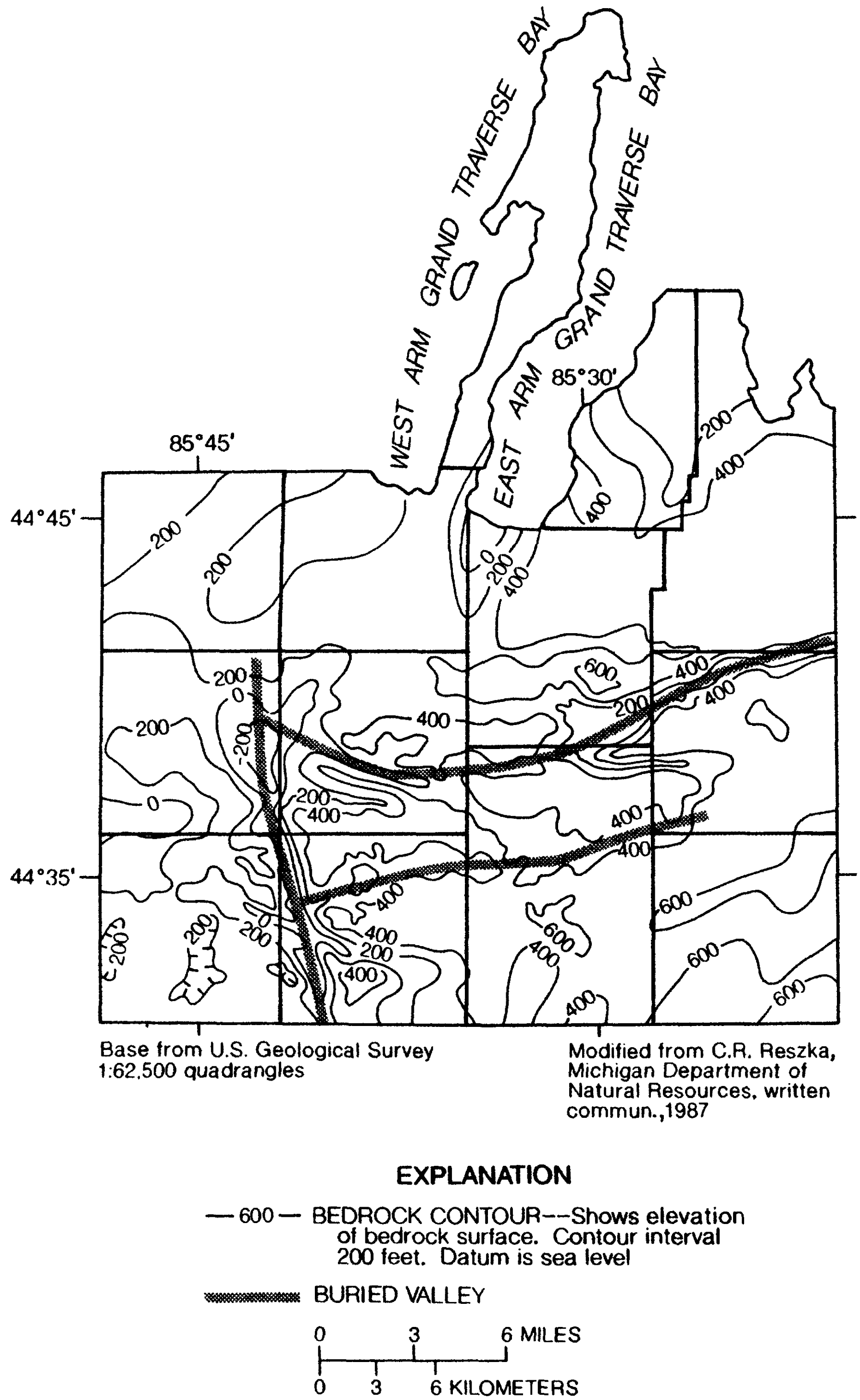


Figure 5.--Buried valleys and configuration of the bedrock surface.

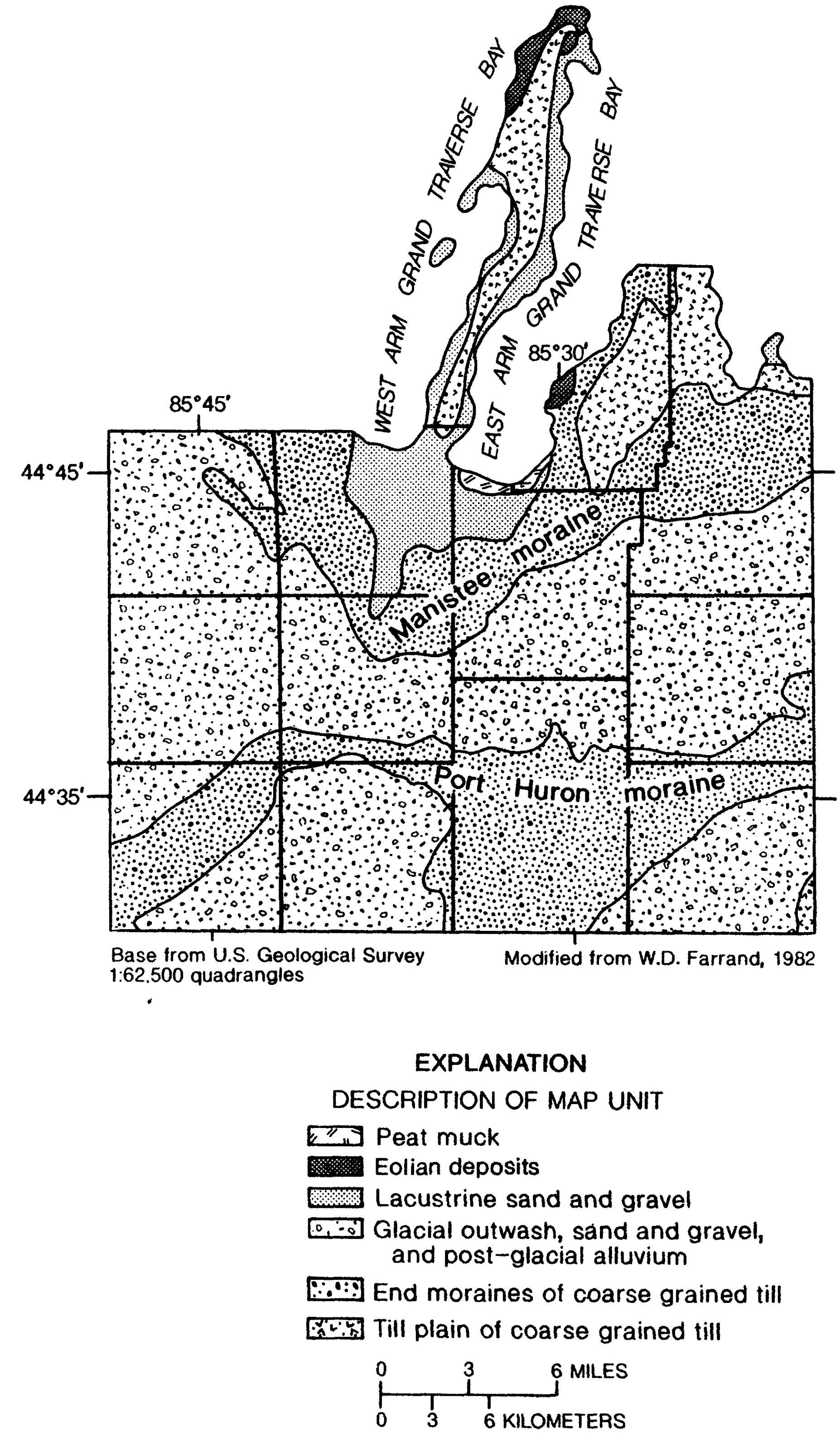


Figure 6.--Areal distribution of glacial deposits.

Outwash plains, which are stratified sand and gravel deposits, are formed by glacial meltwater as multiple braided stream systems coalesce at or near ice margins. An extensive outwash plain trends east-west across the middle of the county between the Manistee and Port Huron moraines. It was created by sediment-laden meltwater that flowed from glacial ice when the Manistee moraine was formed (fig. 6). Outwash in the southeastern and southwestern parts of the county is similarly associated with the Port Huron moraine. Drainage of the outwash plains was to the west-southwest.

Relief of the outwash plains changes from level to gently steepening in the direction of ancestral drainage. The area of greatest relief on the outwash plains occurs where the Boardman River has downcut into the plain to flow to Lake Michigan. Relief in this area is as great as 150 ft.

Lacustrine deposits range from sand to clay, depending on the depositional environment. High-energy environments, such as beaches, are composed mostly of sand; low-energy environments, such as distal parts of lakes, are predominantly clay. In Grand Traverse County, lacustrine deposits such as beach sands, deltaic sands, and lakebed clays, are found at the surface and in the subsurface. Beach sands are found along Old Mission Peninsula. From Traverse City east to Acme, the area is a sandy lake plain. Deltaic sand deposits are found where the ancestral Boardman River downcut through the Manistee moraine and flowed into ancestral Grand Traverse Bay. The relief of lacustrine deposits is usually flat except where old beach ridges are found.

Eolian deposits are found at the tip of Old Mission Peninsula and consist mostly of well-sorted sand. These deposits are topographic highs, and are dune shaped. They were formed by northeasterly winds from Lake Michigan. Other eolian deposits are found on the eastern shore of the East Arm of Grand Traverse Bay. Alluvial deposits are found mostly along the Boardman River, whose flood plain is as much as 4,000 ft wide.

HYDROLOGY

In Grand Traverse County, about 16 in. of the annual average precipitation (31 in.) are evaporated or transpired by plants. Of the remaining 15 in., about 4 in. become streamflow; about 11 in. percolate to the water table and recharge ground-water reservoirs.

Surface Water

Grand Traverse County is drained largely by the Boardman River in the northern and central part, by the Betsie River and its tributaries in the western part, and by tributaries of the Manistee River in the southern part. The county has about 240 lakes and ponds which comprise about 28 mi^2 or 6 percent of the county (Humphrys and Green, 1962).

Streams

A daily discharge record on the Boardman River near Mayfield (U.S. Geological Survey surface-water station 04127000) has been obtained since 1952. Average discharge for the period of record is 196 ft^3/s (cubic feet per second). The maximum discharge, 1,220 ft^3/s, occurred in September 1961; the minimum, 30 ft^3/s, occurred in January 1965. Figure 7 shows hydrographs for this station from October 1983 through September 1986.

During this investigation, measurements of discharge were made periodically at 24 sites at the time water-quality samples were collected. The locations of these sites are shown on plate 1; maximum and minimum discharges at each site are given in table 2. Twenty-four drainage areas, lettered A to X, have been defined based on the locations of these sites. Figure 8 shows the boundaries of these areas. Based on the data shown in table 2, runoff at high flow ranged from 0.77 $(ft^3/s)/mi^2$ (cubic feet per second per square mile) at Anderson Creek near Buckley to 5.7 $(ft^3/s)/mi^2$ at Hospital Creek at Traverse City. Runoff at low flow ranged from 0.056 $(ft^3/s)/mi^2$ at Tobeco Creek near Elk Rapids to 1.5 $(ft^3/s)/mi^2$ at Williamsburg Creek near Williamsburg.

Lakes and Ponds

The lakes in Grand Traverse County range from 0.1 to 2,860 acres in size; a depth as great as 102 ft has been measured. Long Lake is the largest in the county; Green Lake is the deepest. The location of principal lakes is shown on plate 1. About 71 percent of the lakes have neither inlet nor outlet, about 20 percent have inlets and outlets, about 8 percent have outlets only, and less than 1 percent have inlets only. With the exception of Peninsula Township, lakes and ponds are well distributed throughout the county.

Ground Water

In Grand Traverse County, most ground water is contained and flows in the glacial deposits that overlie bedrock. It generally flows toward Grand Traverse Bay or to streams that are tributary to the bay, except in the southern part of the county where it flows to the south, southeast, and southwest out of the county. The occurrence and distribution of water in bedrock has not been thoroughly investigated, and little is known of its movement.

Aquifers

The nature and size of pore spaces and other openings in rocks are the primary factors controlling the movement and storage of ground water in aquifers. The major aquifers in the county are the outwash sand and gravel and lacustrine sand deposits. These deposits, which have large interconnected pore spaces, readily transmit water and are the most common sources of water. Till, lacustrine silts and clays, and other fine-grained deposits have relatively low porosity which restricts the flow of water; they yield only small amounts of water to wells.

Within the glacial deposits, layers of till or till and clay are present in much of the county. Figure 9 is a geologic section from Bellen Lake through Long, Bass, and Silver Lakes that shows an increase in fine-grained units from west to east. These units divide the glacial deposits into many water-bearing units. In the lower units, ground water is partly confined by till and clay; in areas where outwash or lacustrine sand deposits are at land surface, however, ground water is unconfined.

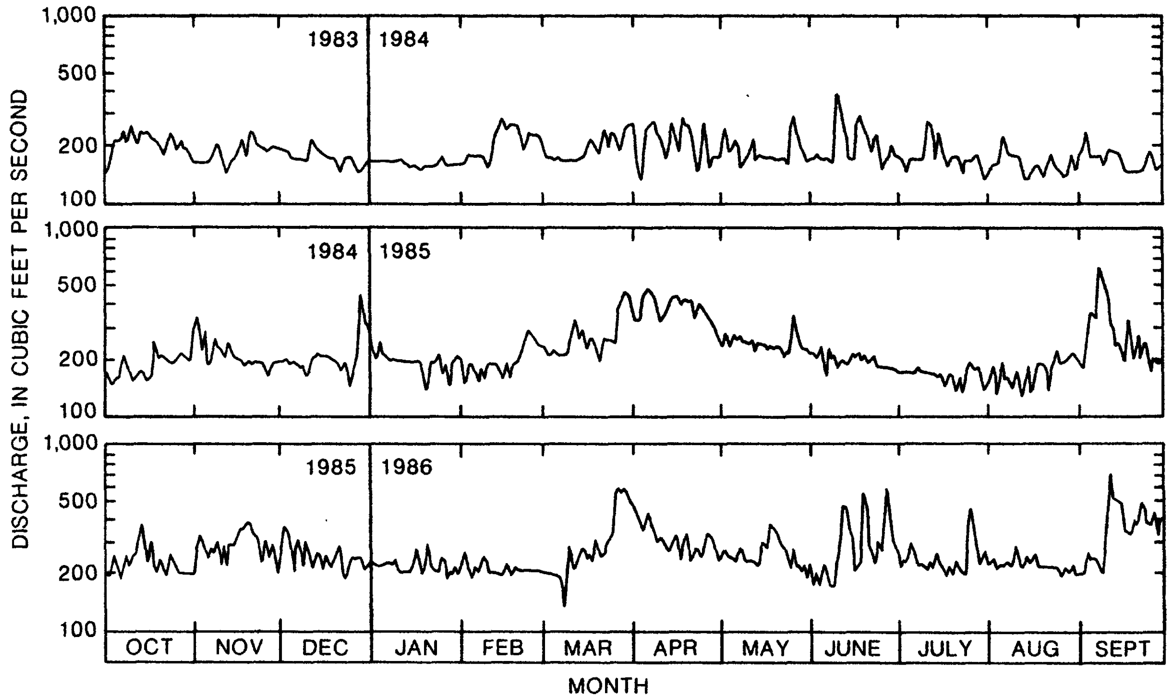
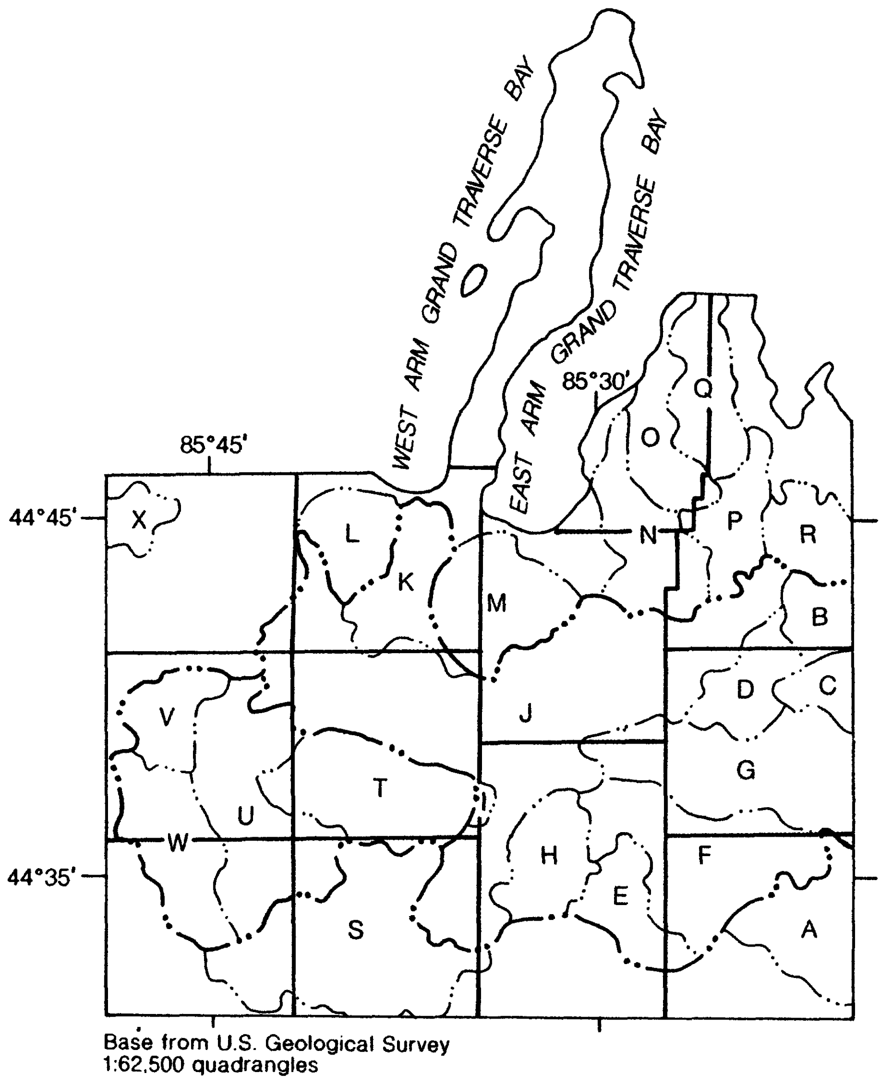


Figure 7.--Discharge of Boardman River near Mayfield, October 1983 through September 1986.

Table 2.--Maximum and minimum discharges at periodically measured sites in Grand Traverse County, 1984-86

[ft^3/s, cubic feet per second]

Site number	Station number and name	Number of measurements	Maximum discharge (ft^3/s)	Minimum discharge (ft^3/s)
1	04123706 Fife Lake Outlet near Fife Lake	7	22	9.2
2	04123910 Anderson Creek near Buckley	22	25	6.4
3	04126525 Mason Creek near Grawn	7	17	7.6
4	04126532 Duck Lake Outlet near Interlochen	7	52	22
5	04126546 Green Lake Inlet near Interlochen	20	132	16
6	04126550 Betsie River near Karlin	7	93	42
7	04126958 North Branch Boardman River near South Boardman	7	91	43
8	04126950 South Branch Boardman River near South Boardman	8	70	38
9	04126970 Boardman River at Brown Bridge Road near Mayfield	23	338	99
10	04126995 Jackson Creek near Kinglsey	6	11	4.5
11	04126997 East Creek near Mayfield	22	115	16
12	04126991 Boardman River below Brown Bridge Pond near Mayfield	21	393	106
13	04127008 Swainston Creek at Mayfield	22	19	11
14	04127019 West Branch Jaxon Creek near Mayfield	7	1.2	.11
15	04127250 Boardman River near Traverse City	22	539	217
16	04127490 Boardman River at Traverse City	22	577	192
17	04127498 Hospital Creek at Traverse City	22	44	8.5
18	04127520 Mitchell Creek at Traverse City	23	28	4.7
19	04127528 Acme Creek at Acme	22	22	13
20	04127535 Yuba Creek near Acme	22	22	5.0
21	04127550 Tobeco Creek near Elk Rapids	22	19	.61
22	04127600 Battle Creek near Williamsburg	22	19	9.4
23	04127620 Williamsburg Creek near Williamsburg	22	28	12
24	04126845 Cedar Run near Cedar	3	10	8.3



EXPLANATION

MAJOR DRAINAGE AREA BOUNDARY

DRAINAGE AREA BOUNDARY

(F) DRAINAGE AREA--Letter identifies drainage area

0 3 6 MILES

0 3 6 KILOMETERS

Figure 8.--Drainage areas.

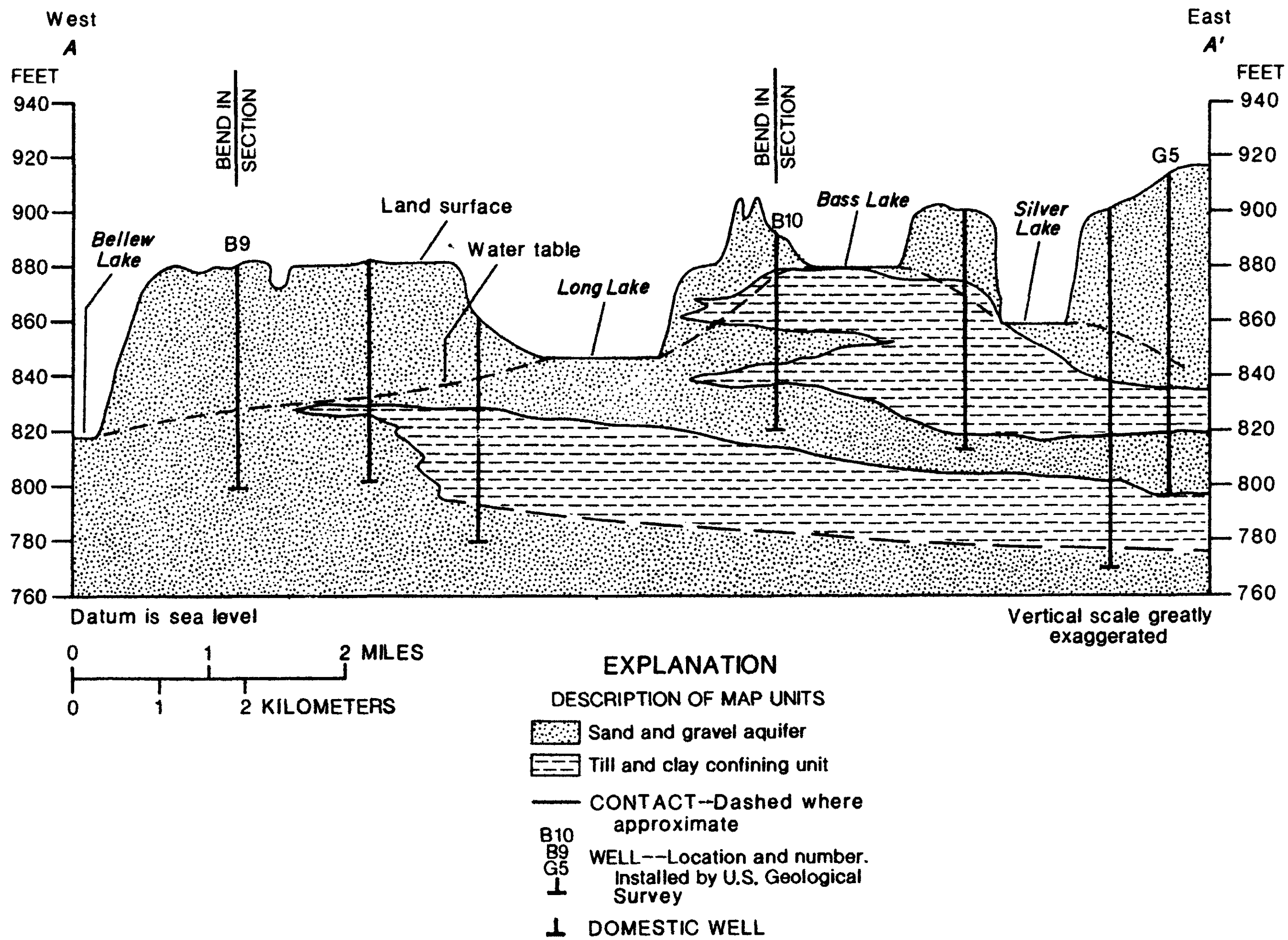


Figure 9.--Relation of till and clay confining units to sand and gravel aquifers near Long, Bass, and Silver Lakes. (Line of section shown on plate 1.)

The Marshall Formation, a sandstone, underlies about 14 mi^2 of the southeastern part of Grand Traverse County. It is a well known and productive aquifer in other parts of Michigan. Few wells have penetrated the formation in the county, however, and little is known about its hydraulic properties. Other bedrock in the county is not likely to yield significant water at most places.

Water Table and Ground-Water Flow

The elevation of the water table, directions of horizontal ground-water flow, and ground-water divides are shown on plate 2. The map was prepared by determining depth-to-water from well-drillers' records and subtracting the depth from the land-surface elevation shown on U.S. Geological Survey topographic quadrangles. These values were hand contoured to show lines of equal elevation. Where well-record coverage in the county was sparse, the elevation of streams and lakes were used to estimate the elevation of the water table.

The configuration of the water table is similar to the land-surface topography, except that the variation of the elevation of the water table is subdued. For example, the water table is about 40 ft higher on Old Mission Peninsula than it is at Grand Traverse Bay; variation in land surface elevation is as much as 200 ft between the two areas. Most ground water in the county flows toward the bay.

A major influence on the configuration of the water table and direction of ground-water flow is the Boardman River. Ground water flowing northward discharges to the river, which has cut a deep valley in the glacial deposits. Ground water on either side of the valley flows to the river, which eventually discharges to Grand Traverse Bay. Some ground water beneath confining units probably flows under the river.

In the northwestern part of the county near Bass Lake, a major ground-water divide extends north to south for about 10 mi, and then eastward to the southeastern edge of the county near Fife Lake. North and east of the divide, ground water discharges toward the Boardman River or Grand Traverse Bay. South and west of the divide, ground water flows toward adjacent counties.

The water table fluctuates throughout the year. Water levels usually rise during the winter and spring when evapotranspiration is low; they decline during summer when evapotranspiration is high. Ground-water levels in 20 observation wells were measured during 1985-86 (table 3, at back of report). Measurements of water levels in an observation well near Fife Lake from 1976-88 indicate that the water table responds to changes in rainfall and/or snowmelt (fig. 10). Seasonal and long-term responses to recharge are evident. For example, a rise of 1 to 2 ft in the water level occurs each spring. Long-term responses are less dramatic and are related to annual precipitation. Figure 10 shows precipitation for and the departure from normal precipitation at Traverse City Airport during 1976-88. During a period of reduced precipitation, such as during 1980-82, water levels were low. When precipitation was normal or above, as during 1983-86, water levels increased. Snowmelt usually occurs in late March. At about this time, ground-water levels begin to rise for 2 or 3 months, depending on the amount and time of

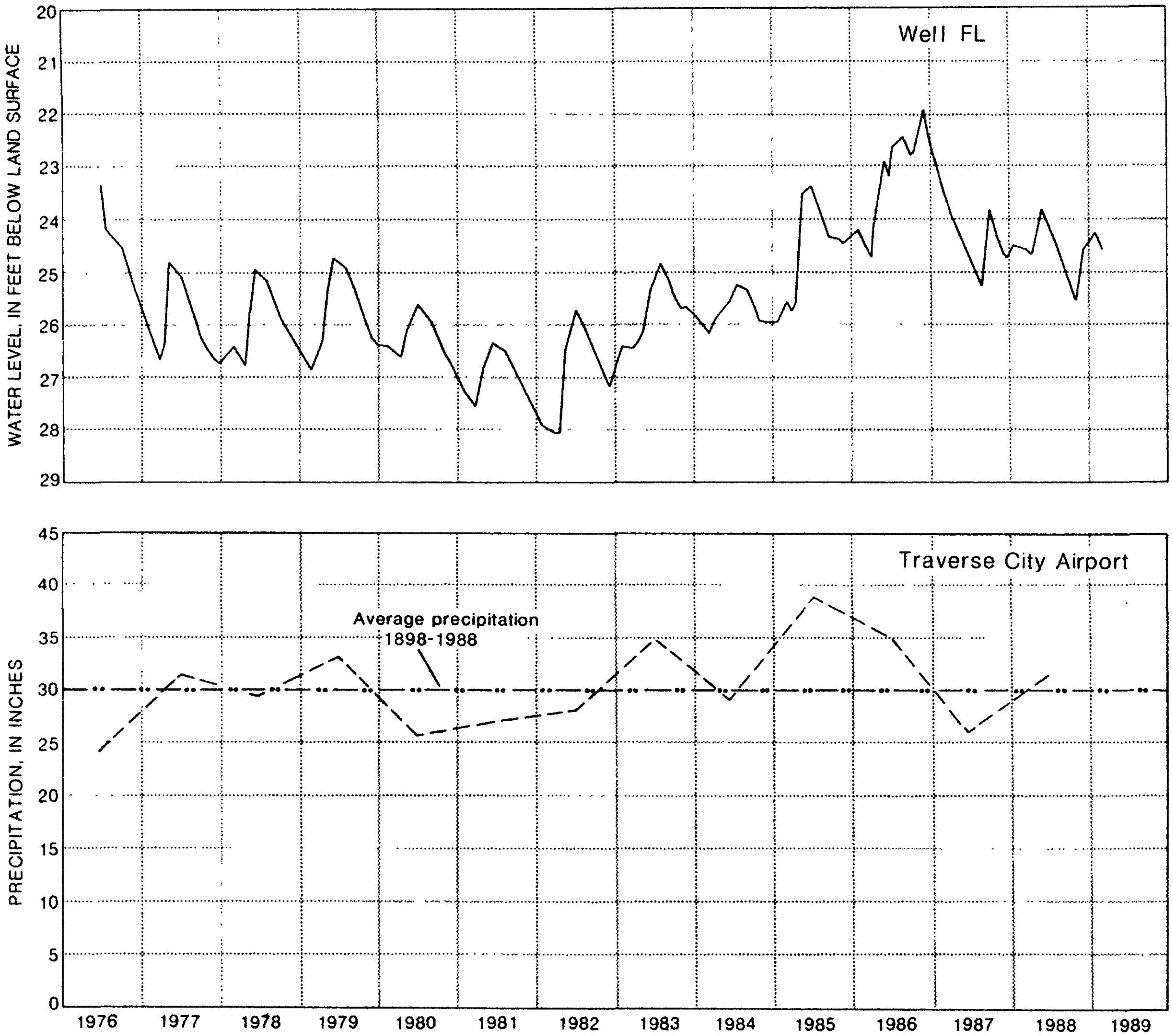


Figure 10.--Water-level fluctuations in observation well FL near Fife Lake, 1976-88, and annual precipitation at the Traverse City Airport, 1976-88.

rainfall. Seasonal water-level peaks usually occur between late May and early July. Occasionally, a second peak occurs in late autumn when rainfall increases and evapotranspiration decreases.

Depth and Yield of Water-Bearing Deposits

Plate 3 is a map showing generalized depth to water-bearing deposits in Grand Traverse County. The map indicates the depth to which a well must be drilled within the glacial deposits to obtain a domestic water supply of 10 gal/min (gallons per minute). If the hydraulic properties of the glacial deposits near the water table are unsatisfactory, depth of drilling may need to be increased to find a water-bearing zone. These zones are usually coarse-grained sand and gravel deposits.

In general, outwash and lacustrine deposits are coarse-grained. Wells installed in these deposits are usually shallow because the water table is close to the land surface. Where outwash or lacustrine deposits are present, most wells are less than 100 ft deep. Confining units are usually not present in these areas at shallow depths.

Fine-grained materials, associated with till and distal lacustrine deposits, are found in parts of the county where moraines are present. Wells in these areas range from 100 to 300 ft deep and generally have low yields. At least one confining unit usually is present, but the deepest wells will penetrate through multiple confining units to reach a productive zone.

Depth to water is related to type of glacial deposit in the county. The highest land-surface elevations and greatest topographic relief are associated with morainal deposits; the depth to water in these areas is greater than in areas of outwash deposits. Even though some of the deposits are coarse grained and could yield water to wells, they are above the water table. Outwash and lacustrine deposits are associated with low topographic relief and low land-surface elevations. Depth to water is less in these areas than in moranial areas. In a few areas where the water table is only a few feet below land surface, coarse-grained deposits sufficient to store water are not present.

Domestic wells in most of the county obtain sufficient supplies from wells 50 to 150 ft deep. These wells usually have a 4-in.-inside diameter casing, a screened interval of 4 ft, and yield at least 20 gal/min. Irrigation, municipal, and industrial wells are usually 150 to 450 ft deep and are capable of yielding 250 gal/min or more. These wells have at least a 6-in.-inside diameter casing and have a much greater screened interval in the water-bearing zone than do domestic wells.

Hydraulic Properties of Aquifers

The only bedrock units in the county that may have potential for providing usable supplies of water are the sandstones of the Marshall Formation. Because of the depth at which the Marshall Formation lies and because the formation is not tapped for water supplies, no hydrogeologic data regarding the formation were collected during this study. Other bedrock units that underlie the glacial deposits are thought to be as poor aquifers in Grand Traverse County as they are in other parts of the State because they consist principally of shales.

The hydraulic properties of the glacial deposits depend on the type of deposit. Aquifer tests were conducted at two locations during this study to determine the horizontal hydraulic conductivity and specific yield of glaciofluvial deposits. The tests were conducted north of Fife Lake (well FL) and south of Karlin (well GP1) (plate 1). The transmissivity of deposits at well FL was 4,300 ft^2/d (feet squared per day); the specific yield was 0.30. The transmissivity of deposits at well GP1 was 2,500 ft^2/d; the specific yield was 0.25. Hydraulic conductivities were 80 and 50 ft/d (feet per day) for wells FL and GP1, respectively. Aquifer-test data from previous investigations are available at the Village of Kingsley and at the U.S. Coast Guard Air Station, Traverse City. Analysis of the aquifer test conducted at the Village of Kingsley for a public-supply well indicates transmissivity ranges from about 3,000 to 3,800 ft^2/d for the leaky confined sand and gravel aquifer. Hydraulic conductivities determined for the aquifer range from 55 to 70 ft/d. Analysis of the aquifer test made at the U.S. Coast Guard Air Station indicates that transmissivity ranges from 1,800 to 2,600 ft^2/d for the unconfined sand and gravel aquifer. Horizontal hydraulic conductivity calculated from the transmissivity ranges from 100 to 150 ft/d. No aquifer tests have been conducted in fine-grained deposits such as till or lacustrine clay.

The velocity of horizontal ground-water flow depends on the hydraulic gradient, the hydraulic conductivity, and the effective porosity of the aquifer. Near well FL, the velocity of ground water is about 1 ft/d. At the U.S. Coast Guard Air Station, velocities ranged from 3 to 6 ft/d because of comparatively steep gradients, high hydraulic conductivities, and low effective porosities.

WATER QUALITY AND LAND USE

In Grand Traverse County, as in other parts of Michigan and the country, the relation of land use to the chemical and physical characteristics of water is not always evident. To investigate possible relations in Grand Traverse County, current information on the chemical inputs to the hydrologic system, particularly the nitrogen input, was considered essential. Data on fertilizer applications, animal wastes, septic-tank discharges, and chemical composition of precipitation were compiled as the first step in evaluating water quality.

Inventory of Land Use

The Michigan Department of Natural Resources' Division of Land Resource Programs is responsible for implementing the Michigan Resource Inventory Act of 1979. One requirement of the act is that a current-use inventory of each county be maintained. Land use or land cover is classified using 46 catagories, which are designed to identify existing use of every 2.5- to 5.0-acre area of land in the State. Land use or cover exceeding 4 percent of the total area of Grand Traverse County include: northern hardwood forest land, 24.73 percent; cropland, 16.14 percent; mixed pine forest land, 14.63 percent; herbaceous openland, 10.68 percent; orchards, 5.19 percent; single-family duplex, 4.56 percent; and lowland hardwoods, 4.15 percent (Michigan Department of Natural Resources, written commun., March 27, 1985). Table 4 lists land-use data for Grand Traverse County by township. Although data tabulated in table 4 are accurate indications of land classification, the actual area in a township devoted to a given use may be substantially less than that falling within a classification. In order to relate water quality to agricultural use, and in order to provide a basis for estimating chemical inputs to the hydrologic system, the Grand Traverse County Extension Service compiled information on the amount of field and fruit crops grown in each township in 1988. These data are given in table 5.

Table 4.--Land-use data for Grand Traverse County

[mi^2, square miles; percent, percentage of total area]

Township or city	Residential, mobile home parks		Business district, shopping center, commercial, institutional		Industrial		Transportation, communications, utilities		Cropland, confined feeding operations, permanent pasture, other agricultural lands	
	mi^2	Percent	mi^2	Percent	mi^2	Percent	mi^2	Percent	mi^2	Percent
Acme	1.65	6.75	0.21	0.85	0.042	0.17	0.095	0.39	5.54	22.82
Blair	1.80	4.99	.19	.53	.11	.30	.016	.04	7.12	19.74
Grant	.61	1.69	.0094	.03	.00	.00	.00	.00	11.90	32.94
East Bay	3.54	8.30	.24	.56	.00	.00	.16	.37	3.97	9.32
Fife Lake	.53	1.46	.084	.24	.00	.00	.00	.00	3.96	11.00
Garfield	3.22	11.49	.68	2.43	1.07	3.80	.081	.29	8.28	29.51
Green Lake	1.88	5.34	.41	1.17	.036	.10	.13	.36	1.67	4.75
Long Lake	2.42	6.80	.029	.08	.00	.00	.00	.00	7.37	20.72
Mayfield	.068	.19	.014	.04	.0045	.01	.00	.00	18.17	50.10
Paradise	.73	1.39	.086	.15	.00	.00	.11	.28	10.86	20.53
Peninsula	2.69	9.33	.033	.12	.041	.14	.00	.00	.22	.76
Union	.11	.30	.00	.00	.00	.00	.00	.00	.17	.48
Whitewater	1.08	2.19	.046	.09	.012	.02	.24	.49	3.82	7.75
Traverse City	2.86	35.71	1.27	15.79	.66	8.20	1.15	14.31	.13	1.62

Table 4.--Land-use data for Grand Traverse County--Continued

Township or city	Orchards, bush fruits, vineyards, horticulture area		Herbaceous openland		Northern hardwood, aspen/birch, lowland hardwood, pine, other upland conifers, lowland conifers, managed christmas tree plantation		Streams and waterways, lakes, reservoirs		Other uses	
	mi^2	Percent	mi^2	Percent	mi^2	Percent	mi^2	Percent	mi^2	Percent
Acme	4.60	18.94	3.24	13.34	6.26	25.76	0.14	0.59	2.70	10.39
Blair	.55	1.52	6.95	19.29	17.00	47.16	.35	.97	1.97	5.46
Grant	.00	.00	3.36	9.28	18.33	50.54	.73	2.02	1.27	3.50
East Bay	1.11	2.61	4.41	10.34	23.82	55.85	2.50	5.86	2.90	6.79
Fife Lake	.00	.00	2.00	5.55	26.03	72.32	1.24	3.43	2.16	6.00
Garfield	.94	3.35	4.40	15.67	5.34	19.03	1.03	3.69	3.01	10.74
Green Lake	.030	.09	3.54	10.09	17.60	50.12	6.34	18.05	3.49	9.93
Long Lake	.19	.53	4.21	11.83	13.65	38.36	5.83	16.38	1.88	5.30
Mayfield	.00	.00	3.27	9.02	12.74	35.12	.15	.40	1.87	5.12
Paradise	.12	.22	7.17	13.56	30.84	58.31	.058	.11	2.92	5.45
Peninsula	14.28	49.54	2.27	7.88	6.97	24.17	.88	3.06	1.44	5.00
Union	.00	.00	1.55	4.29	32.25	89.32	.19	.54	1.83	5.07
Whitewater	3.33	6.74	4.89	9.91	30.91	62.62	.54	1.10	4.49	9.09
Traverse City	.0097	.12	.50	2.35	.57	7.10	.32	3.97	.55	10.83

Table 5.--Field and fruit crops, by township, 1988

[Values shown are in acres. --, crop not grown, Data from Grand Traverse County Extension Service]

Township	Alfalfa	Corn	Wheat	Oats	Barley	Rye	Green beans	Sweet corn	Cherries	Apples	Plums	Miscel-laneous fruits
Acme	644	860	27	34	--	--	--	--	2,426	253	94	50
Blair	155	339	9	26	--	12	158	--	--	--	--	--
East Bay	386	157	--	--	--	12	--	--	388	38	15	8
Fife Lake	105	171	59	--	--	7	--	--	--	--	--	--
Garfield	465	400	--	50	--	15	--	9	485	63	19	10
Grant	1,513	2,875	546	241	6	55	852	14	--	--	--	--
Green Lake	65	81	9	--	--	--	--	--	--	--	--	--
Long Lake	355	422	--	--	--	--	--	--	--	--	--	--
Mayfield	1,602	2,932	831	175	13	100	1,408	11	--	--	--	--
Paradise	3,074	1,474	168	161	--	30	666	--	--	--	--	--
Peninsula	--	--	--	--	--	--	--	--	5,335	570	208	110
Union	--	--	--	--	--	--	--	--	--	--	--	--
Whitewater	564	260	26	23	--	--	--	--	873	253	34	18

Irrigation of Agricultural Land

Irrigation of land in Grand Traverse County is not as extensive as it is in some Michigan counties. According to Bedell and Van Til (1979) there were 63 irrigators countywide in 1977. About 2,080 acres were irrigated in the county in 1985 (Van Til, Michigan Department of Natural Resources, written commun., 1985). On a daily basis, 360,000 gal (gallons) of water are withdrawn, 89 percent of which are obtained from ground-water sources. Figure 11, based on data provided by the Grand Traverse County Extension Service, shows the distribution of irrigated acreage in the county in 1987. Most irrigation is subsurface or trickle; only 8 to 10 percent of water is applied by spraying.

Collection of Water-Quality Data

In the spring of 1984, a reconnaissance of Grand Traverse County was made to select locations at which surface water-quality data would be collected. Twenty-four sites, numbered 1 to 24 (pl. 1), were selected for periodic sampling. Beginning in June 1984, samples were collected monthly at 15 of the

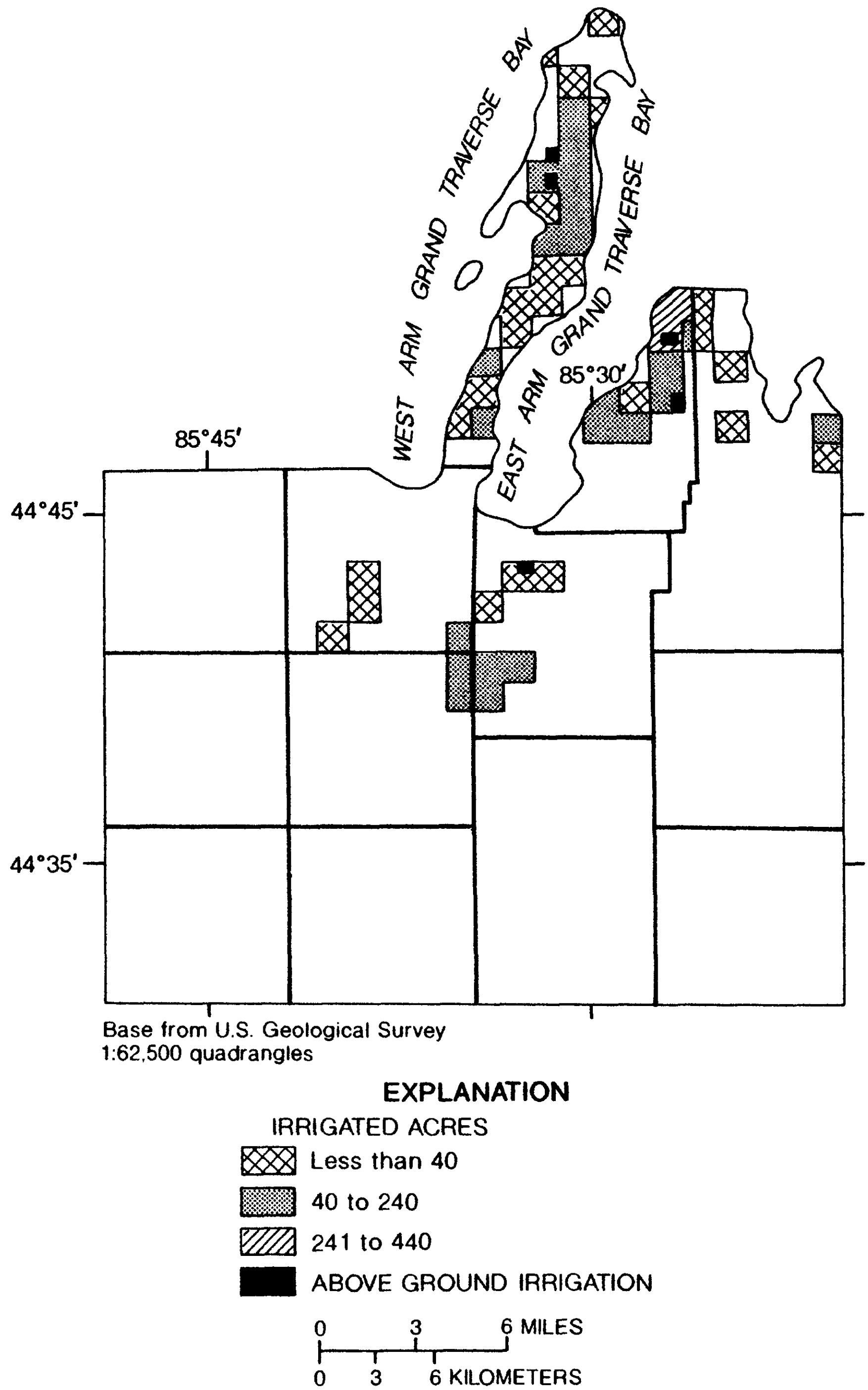


Figure 11.--Irrigated agricultural lands in 1987.

sites and analyzed for total[1] ammonia, total nitrite, total nitrate, total organic nitrogen, total phosphorous, total orthophosphorous, and suspended sediment. At times during the investigation, concentrations of dissolved and total nitrogen and phosphorous were simultaneously measured to determine the fraction transported in the dissolved and suspended phases at the 15 sites. At an additional nine sites, samples were collected three to eight times during the study for the same nitrogen and phosphorous analyses. At the time of sampling, specific conductance, temperature, pH, and dissolved-oxygen concentration were measured. A discharge measurement, necessary for load and runoff computations, was made at the time of sampling. Comprehensive chemical analyses of surface water, which included the major dissolved substances and trace metals, were made on samples collected at 15 sites during high and low flow conditions (table 6, at back of report). Pesticide concentrations were measured at 15 stream sites. Chemical and physical characteristics of water from 15 lakes, numbered L1 to L15, were also measured.

Water from 34 wells drilled for this project was analyzed for major dissolved substances, trace metals, and pesticides. At 211 locations, water was collected from domestic wells and analyzed for nitrate and chloride by the U.S. Geological Survey; specific conductance was measured at the time of sampling. The Michigan Department of Public Health provided 596 analyses of water from wells from their files. These analyses commonly include determinations of specific conductance, iron, sodium, nitrate, hardness, chloride, and fluoride.

Water quality of precipitation was measured at a site established near Kingsley (pl. 1). Sixty-four analyses of pH and specific conductance of rainfall and snow were made; 34 analyses of sulfate, nitrogen compounds, and phosphorus were made.

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[1] In this report, individual nitrogen compounds are referred to as "total" when laboratory analysis measured both the suspended and dissolved fractions of the compound in an unfiltered sample. "Dissolved" preceeding an individual compound indicates that the sample was filtered through a 0.45 µm (micrometer) filter at streamside, and thus the analytical result indicates that amount of the compound transported in solution. All nitrogen compounds, whether dissolved or total, are reported "as nitrogen" or "as N". As "nitrogen" or "as N" also apply in those discussions where neither the total or dissolved designation is appropriate. "Total nitrogen" or "dissolved nitrogen" indicates the sum of each of the individual compounds reported as N; "total" and "dissolved" are applied to phosphorus compounds in the same manner. All measured values are reported "as phosphorus" or "as P".

Results of analyses are reported in µg/L (micrograms per liter) or in mg/L (milligrams per liter), except when other reporting units are appropriate. Analyses made by the U.S. Geological Survey for this study have been published in the Survey's annual series of water-data reports (Miller and others, 1987, and Blumer and others, 1988).

Chemical Inputs to the Hydrologic System

Fertilizer Applications

According to the Grand Traverse County Extension Service about 960 tons of nitrogen, phosphorus, and potassium in commercial fertilizers are applied to agricultural land each year in the county. Table 7 lists the amounts applied to the principal field and fruit crops.

Table 7.--Fertilizer application in Grand Traverse County

[Data from Grand Traverse County Extension Service. Results are in pounds per acre per year]

Field or fruit crop	Fertilizer application		
	Nitrogen (as N)	Phosphorus (as P)	Potassium (as K)
Alfalfa	0	30	260
Apples	75	10	60
Barley	30	20	50
Cherries	120	10	60
Corn	130	20	100
Corn (sweet)	80	30	150
Miscellaneous fruits	100	10	60
Oats	30	10	80
Plums	120	10	60
Rye	30	20	50
Wheat	30	20	110

Data in table 7 have been used in conjunction with data in table 5, which shows the acreage of each field or fruit crop, to compute nitrogen application rates by township (table 8). In computing the nitrogen application rates for a township, the area of streams, waterways, lakes, and reservoirs has been subtracted from the township area prior to the computation.

Table 8.--Nitrogen application rates, by township

[(lb/acre)/yr, pounds per acre per year; (ton/mi^2)/yr, tons per square mile per year]

Township	Nitrogen application (as N)	
	(lb/acre)/yr	(ton/mi^2)/yr
Acme	28.5	9.1
Blair	2.20	.70
East Bay	2.83	.91
Fife Lake	1.09	.35
Garfield	6.99	2.24
Grant	18.7	6.0
Green Lake	.59	.19
Long Lake	2.88	.92
Mayfield	19.8	6.3
Paradise	6.58	2.1
Peninsula	40.2	12.9
Union	0	0
Whitewater	5.28	1.7

Countywide, 9.4 (lb/acre)/yr (pounds per acre per year) or 3.0 (ton/mi^2)/yr (tons per square mile per year) of nitrogen as N are applied to the land as fertilizer. Highest application rates occur in the northern townships of Peninsula and Acme (40.2 and 28.5 (lb/acre)/yr), where cherries are the principal fruit crop, and in the southwestern townships of Mayfield and Grant (19.8 and 18.7 (lb/acre)/yr), where corn is the principal crop.

Animal Wastes

Estimates of the amount of nitrogen deposited on land by animals are based on a survey of the number and type of animals by the Grand Traverse County Cooperative Extension Service, and on daily nitrogen production data of Miner and Willrich (1970). The Extension Service identified 10,500 hogs, 2,795 beef cattle, 1,925 dairy cattle, 800 buffalo, and 100 sheep in the county. The area of streams, waterways, lakes, and reservoirs has been subtracted from the township area prior to computing the nitrogen deposited. Countywide, average deposition of nitrogen as N is 3.22 (lb/acre)/yr or 1.03 (ton/mi^2)/yr. Table 9 shows, by township, estimates of the amount of nitrogen deposited each year.

Table 9.--Nitrogen deposited by animals, by township

[(lb/acre)/yr, pounds per acre per year; (ton/mi^2)/yr, tons per square mile per year]

Township	Nitrogen deposited (as N)	
	(lb/acre)/yr	(ton/mi^2)/yr
Acme	a	a
Blair	0.56	0.18
East Bay	2.66	.85
Fife Lake	.19	.06
Garfield	13.62	4.36
Grant	10.78	3.45
Green Lake	a	a
Long Lake	1.06	.34
Mayfield	6.79	2.17
Paradise	4.91	1.57
Peninsula	a	a
Union	a	a
Whitewater	1.67	.54

[a] Insignificant number of animals identified during survey.

Septic-Tank Discharges

The amount of nitrogen discharged from septic tanks has been estimated for each township. The estimates have been based on the number of septic tank installations, on demographic data provided by the Tri-County Health Department in Traverse City, and on studies of nitrogen discharge from septic tanks by Winneberger (1982). The area of streams, waterways, lakes, and reservoirs has been subtracted from the township area prior to computing the nitrogen discharge. Table 10 shows these estimates.

Table 10.--Nitrogen discharge by septic tanks, by township

[(lb/acre)/yr, pounds per acre per year; (ton/mi²)/yr, tons per square mile per year]

Township	Nitrogen discharge (as N)	
	(lb/acre)/yr	(ton/mi²)/yr
Acme	1.69	0.54
Blair	1.90	.61
East Bay	2.65	.85
Fife Lake	.67	.21
Garfield	4.66	1.49
Grant	.33	.11
Green Lake	2.14	.68
Long Lake	2.36	.75
Mayfield	.28	.09
Paradise	.50	.16
Peninsula	2.29	.73
Union	.16	.05
Whitewater	.63	.20

Countywide, an average of 1.41 (lb/acre)/yr or 0.45 (ton/mi²)/yr of nitrogen as N is discharged from septic tanks.

Precipitation

Samples of rainfall and snow were collected near Kingsley in the southcentral part of the county from October 1984 to September 1986 (pl. 1). Sixty-four measurements of specific conductance and pH were made during the period; nitrogen, phosphorus, and sulfate were measured during the first 18 months (table 11, at back of report). Table 12 shows the maximum, mean, and minimum concentrations of nitrogen, phosphorus, and sulfate in rainfall and snow based on 34 precipitation events.

Table 12.--Maximum, mean, and minimum concentrations of nitrogen, phosphorus, and sulfate in rainfall and snow, October 1984 to March 1986

[Concentrations are in milligrams per liter; <, less than]

Substance	Maximum concentration	Mean concentration	Minimum concentration
Dissolved sulfate	12	2.7	0.7
Total ammonia	3.1	.61	.13
Total organic nitrogen	1.4	.35	.00
Total nitrite	.04	.01	<.01
Total nitrate	2.0	.40	.10
Total nitrogen	6.5	1.4	.50
Total orthophosphorus	.04	.01	<.01
Total phosphorus	.08	.02	<.01

Mean concentrations in Grand Traverse County do not differ appreciably from those found at other locations in Michigan. Table 13 compares these values to those cited in other studies.

Table 13.--Comparison of mean concentrations of nitrogen, phosphorus, and sulfate in rainfall and snow in Michigan

[Concentrations are in milligrams per liter; <, less than]

	Northern Lower Peninsula[a]	Marquette County[b]	Hillsdale County[c]	Van Buren County[d]	Grand Traverse County
Dissolved sulfate	--	2.4	--	2.5	2.7
Total ammonia	0.29	.28	0.48	.39	.61
Total organic nitrogen	--	.15	.41	.12	.35
Total nitrite	.002	.00	.01	<.01	.01
Total nitrate	.44	.34	.58	.59	.40
Total nitrogen	--	.79	1.5	1.0	1.4
Total orthophosphorus	.03	.00	.02	.01	.01
Total phosphorus	.04	.01	.05	.02	.02

[a] Pecor and others, 1973.

[b] Grannemann, 1984.

[c] Cummings, 1978.

[d] Cummings and others, 1984.

Figure 12 shows frequency distributions of specific conductance and pH based on all measurements made between October 1984 and September 1986. Specific conductance ranged from 5 μS/cm (microsiemens per centimeter at 25 degrees celsius) (snow) to 63 μS/cm (snow); the median value was 19 μS/cm. The pH ranged from 3.7 (rain) to 6.3 (snow); the median value was 4.4.

Nitrogen, phosphorus, and sulfate loads in precipitation in Grand Traverse County have been estimated using precipitation data collected at Traverse City by the National Oceanic and Atmospheric Administration (1984, 1985, 1986). From October 1984 through September 1986, precipitation, normally about 29.7 in., was about 22 percent greater than the long-term average. Mean concentrations have been used to estimate deposition of nitrogen, phosphorus, and sulfate in rainfall and snow in Grand Traverse County. Table 14 shows deposition rates.

Table 14.--Nitrogen, phosphorus, and sulfate deposition by rainfall and snow

[(lb/acre)/yr, pounds per acre per year; $(ton/mi^2)/yr$, tons per square mile per year]

Substance	Nitrogen (as N), phosphorus (as P), and sulfate (as SO_4) deposition	
	(lb/acre)/yr	$(ton/mi^2)/yr$
Dissolved sulfate	18	5.8
Total ammonia	4.1	1.3
Total organic nitrogen	2.4	.77
Total nitrite	.07	.02
Total nitrate	2.7	.87
Total nitrogen	9.4	3.0
Total orthophosphorus	.07	.02
Total phosphorus	.13	.04

The above values were in general agreement with values found in Michigan by Richardson and Merva (1976) at Pellston and Houghton Lake, by Cummings (1978) in Hillsdale and Calhoun Counties, by Cummings and others (1984) in Van Buren County, by Grannemann (1984) in Marquette County, and by Pecor and others (1973) at Houghton Lake.

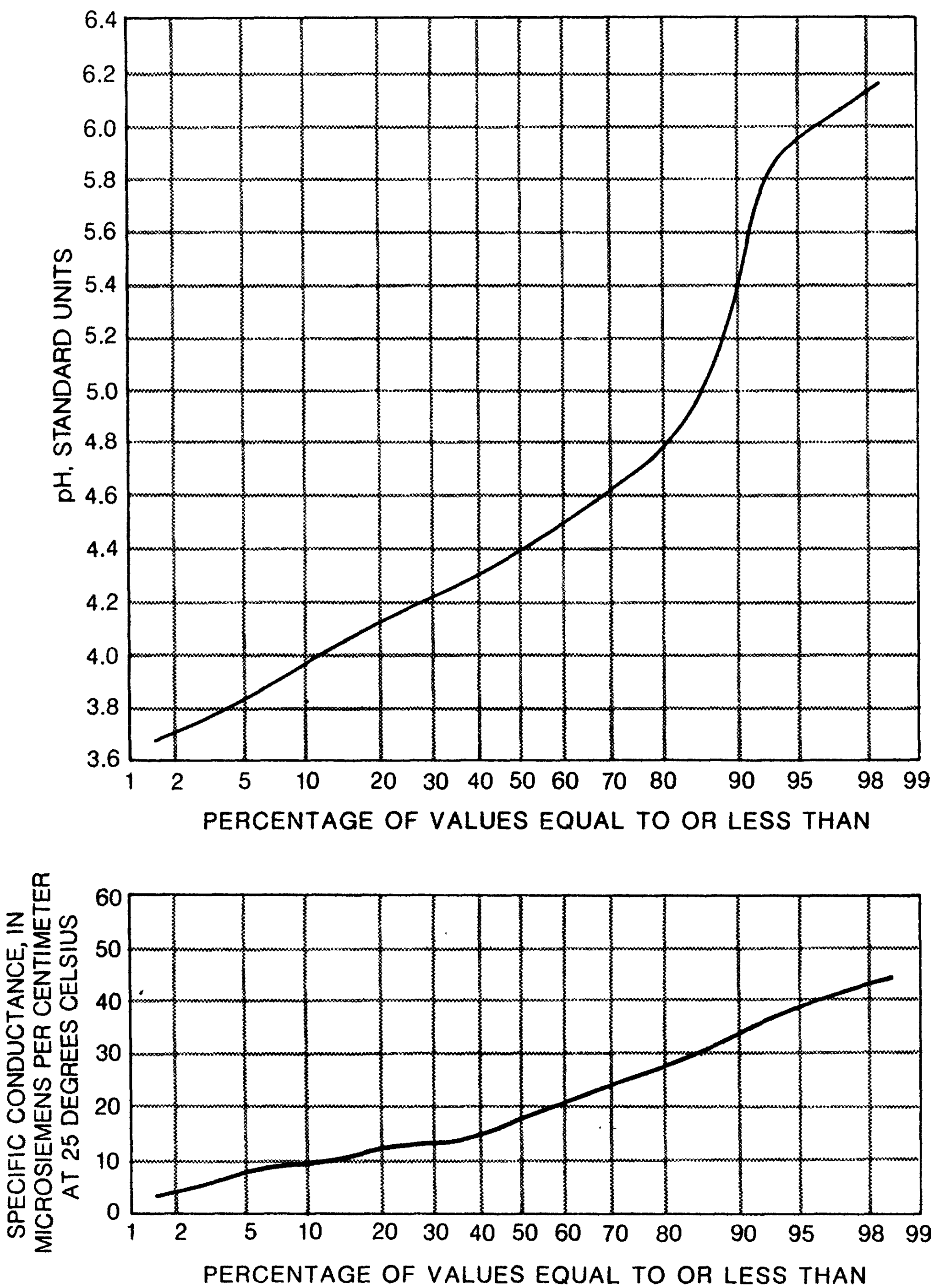

Figure 12.--Frequency distributions of specific conductance and pH of precipitation near Kingsley.

Chemical and Physical Characteristics of Water

Streams

Specific conductance, dissolved-oxygen concentration, pH, and temperature.--Specific conductance is a measure of the ability of water to conduct an electrical current, and thus it is indicative of the amount of dissolved substances. Laboratory measurements of dissolved solids (residue on evaporation) and measurements of specific conductance suggests the following approximate relation for streams in Grand Traverse County:

Dissolved-solids concentration (mg/L) = -6 + 0.59 x Specific conductance (µS/cm)

Specific conductance of water at the 24 periodic sampling sites ranged from 206 µS/cm at Boardman River near Mayfield (Site 12) to 655 µS/cm at Hospital Creek at Traverse City (Site 17) (table 15, at back of report). Based on the above relation, the dissolved-solids concentration of streams in Grand Traverse County ranged from about 116 to about 380 mg/L. In general, highest dissolved-solids concentrations, based on specific conductance, were found in Garfield, East Bay, Mayfield, southern Blair, Acme, and northwestern Whitewater Townships. Mean dissolved-solids concentration in these areas is about 270 mg/L. In southern Whitewater, Union, Fife Lake, southern East Bay, Paradise, Long Lake, Green Lake, and Grant Townships, mean dissolved-solids concentration is about 190 mg/L. In general, streams having the highest dissolved-solids concentrations drain areas having the greatest urban development and most extensive agricultural activity.

The specific conductance of most streams in Grand Traverse County increases as stream discharge decreases. During this study, samples for the analysis of a wide range of chemical and physical characteristics were collected in April and June 1986 (table 6). Specific conductance and stream discharge were measured at the time samples were collected. Figure 13 shows how specific conductance increased as streamflow decreased during the months of April and June. (Sites immediately downgradient from a lake were not used in preparing the figure.) A line of regression suggests that a decrease in flow of about 30 percent will result in an increase in specific conductance (and dissolved-solids concentration) of about 10 percent. A decrease in flow of about 80 percent suggests an increase in specific conductance of about 40 percent. The general accuracy of the relation in figure 13 was verified by making similar calculations using the periodic measurements of streamflow and specific conductance published by Miller and others (1987) and by Blumer and others (1988), which are summarized in table 15 (at back of report).

Dissolved-oxygen concentrations of streams in Grand Traverse County are typical of those at other locations in Michigan. Mean percent saturation of dissolved oxygen ranged from 71 percent at West Branch Jaxson Creek near Mayfield (Site 14) to 104 percent at Duck Lake Outlet near Interlochen (Site 4) (table 15). Lowest concentrations occurred at Anderson Creek near Buckley (5.9 mg/L) (Site 2), at Yuba Creek near Acme (5.9 mg/L) (Site 20), and at Tobeco Creek near Elk Rapids (4.7 mg/L) (Site 21).

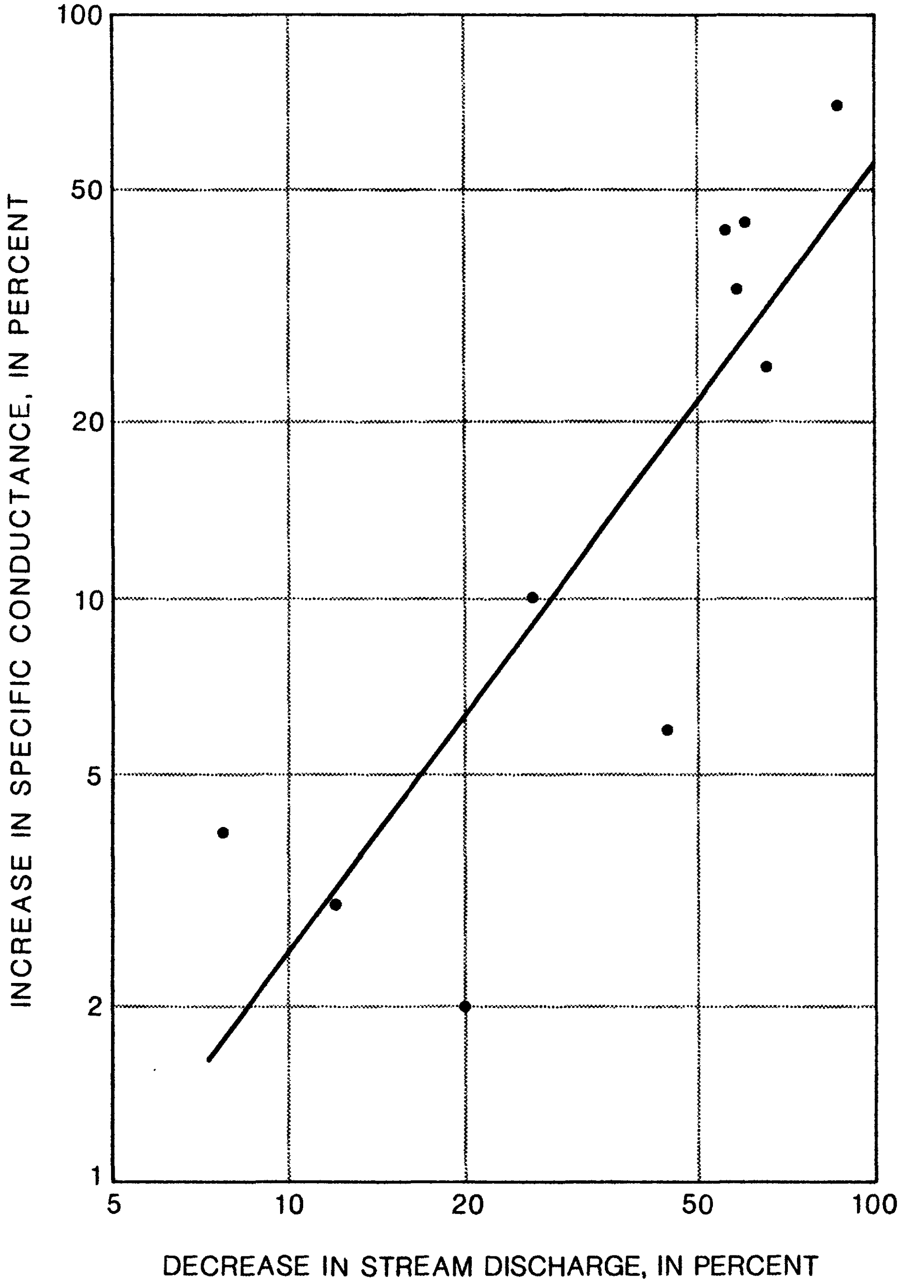

Figure 13.--Relation of specific conductance to stream discharge.

Values of pH ranged from 7.2 at Mason Creek near Grawn (Site 3) and at Tobeco Creek near Elk Rapids (Site 21) to 8.6 at Duck Lake Outlet near Interlochen (Site 4) and at Betsie River near Karlin (Site 6). Mean pH values at all sites ranged from 7.7 at Fife Lake Outlet near Fife Lake (Site 1) to 8.4 at Betsie River near Karlin (Site 6).

Common dissolved substances and physical properties.--Surface water in Grand Traverse County is of a calcium bicarbonate type--that is, calcium constitutes more than 50 percent of the cations and bicarbonate constitutes more than 50 percent of the anions. Although the principal ions in water of Hospital Creek near Traverse City (Site 17) and Anderson Creek near Buckley (Site 2) are calcium and bicarbonate, sulfate and chloride concentrations are proportionally higher at these sites than at other locations. No significant areal variations in concentrations of common dissolved substances or physical properties seem to occur in the county. Based on the U.S. Geological Survey's water-hardness classification scale[2], water of all streams is hard to very hard at low to mean flow.

The following table (table 16), based on analyses of water shown in table 6, lists countywide mean concentrations of some of the dissolved substances and physical properties measured.

Table 16.--Mean concentrations of selected dissolved substances and physical properties of streams

[Concentrations are in milligrams per liter]

Substance or property	Mean concentration	Substance or property	Mean concentration
Silica (SiO_2)	7.0	Chloride (Cl)	8.4
Calcium (Ca)	50	Fluoride (F)	.1
Magnesium (Mg)	11	Hardness (as $CaCO_3$)	170
Sodium (Na)	4.6	Dissolved solids	
Potassium (K)	1.0	Sum	192
Alkalinity (as $CaCO_3$)	161	Residue	198
Sulfate (SO_4)	12		

[2] The U.S. Geological Survey (Durfor and Becker, 1964) has classified the hardness of water as follows: 0 to 60 mg/L, soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; and 181 mg/L or greater, very hard.

Nitrogen and phosphorus.--One of the objectives of this study was to determine the amount of nitrogen and phosphorus transported by streams, and to relate if possible, the amount transported to land use. Countywide, 389 analyses of each of the following were made: Total ammonia, total nitrate, total nitrite, total organic nitrogen, total nitrogen, total orthophosphorus, and total phosphorus. Table 17 (at back of report) gives the maximum, mean, and minimum concentrations of each substance at each site. The maximum total nitrogen concentration was 4.4 mg/L at Yuba Creek near Acme (Site 20); the minimum total nitrogen concentration was 0.19 mg/L at Acme Creek at Acme. The highest mean concentration (2.0 mg/L) also was found at this site. Nitrogen and phosphorus concentrations, based on all stream sites in the county, are given in the following table (table 18).

Table 18.--Maximum, mean, and minimum concentrations of total nitrogen and phosphorus of streams

[Concentrations are in milligrams per liter; <, less than]

Substance	Maximum concentration	Mean concentration	Minimum concentration
Total ammonia	0.42	0.46	<0.01
Total nitrite	.300	.006	<.001
Total nitrate	3.98	.39	.005
Total organic nitrogen	1.9	.46	.05
Total nitrogen	4.4	.90	.19
Total orthophosphorus	.08	<.01	<.01
Total phosphorus	.10	.01	<.01

The mean concentrations tabulated in table 18 are slightly lower than the mean concentrations computed for 19 National Stream Quality Accounting Network stations operated by the U.S. Geological Survey at locations distributed throughout the State. Based on the data of Cummings (1984, p.46-55), the statewide mean concentration of nitrate at these stations was 0.85 mg/L. No pattern of areal differences in nitrogen or phosphorus occurred within Grand Traverse County.

Phosphorus concentrations were low throughout the county. The maximum concentration was found at Site 1 near Fife Lake, where total phosphorus concentration was 0.10 mg/L; total orthophosphorus was 0.08 mg/L. The mean total phosphorus concentration, based on all sites in the county, was 0.01 mg/L; The mean total orthophosphorus concentration was <0.01 mg/L.

A significant amount of nitrogen and phosphorus in streams may be associated with the suspended sediments. Burwell and others (1975), in a study in west-central Minnesota, found that 96 percent of the nitrogen, and 66 to 84 percent of the phosphorus, were transported in the dissolved phase. In

Van Buren County, Michigan, Cummings and others (1984) found that 79 to 98 percent of the nitrogen, and 50 to 81 percent of the phosphorus, were transported in the dissolved phase.

From 1984 to 1986, the fraction of nitrogen and phosphorus transported by streams in the dissolved and suspended phases in Grand Traverse County was measured. Samples were prepared for analysis by using a sample splitter at streamside immediately after sample collection. The half of the sample for dissolved analysis was filtered through a 0.45-μm filter; the unfiltered half was analyzed for the total amounts of each substance in water. The following table (table 19), based on 54 to 68 analyses, shows the maximum, mean, and minimum concentrations of dissolved nitrogen and dissolved phosphorus countywide.

Table 19.--Maximum, mean, and minimum concentrations of dissolved nitrogen and phosphorus of streams

[Concentrations are in milligrams per liter; <, less than]

Substance	Maximum concentration	Mean concentration	Minimum concentration
Dissolved ammonia	0.10	0.02	<0.01
Dissolved nitrite	.03	<.01	<.01
Dissolved nitrate	.90	.29	.00
Dissolved organic nitrogen	.68	.31	.16
Dissolved orthophosphorus	.03	.01	<.01
Dissolved phosphorus	.04	.01	<.01

Comparison of these results with the results of corresponding analyses of total nitrogen and total phosphorus of split samples indicates that most nitrogen and phosphorus is transported in the dissolved phase. Table 20 shows the average percent dissolved and percent suspended.

Table 20.--Average percentages of dissolved and suspended nitrogen and phosphorus of streams

Substance	Percent	
	Dissolved	Suspended
Ammonia	73.0	27.0
Nitrite	a	a
Nitrate	94.8	5.2
Organic nitrogen	79.0	21.0
Orthophosphorus	a	a
Phosphorus	69.3	30.7

[a] Values reported as "less than" preclude computation.

Trace metals.--Concentrations of trace metals are generally low in water of streams in Grand Traverse County. A comparison of concentrations of trace metals with U.S. Environmental Protection Agency (USEPA) drinking-water regulations (table 21) indicates that none of the concentrations exceeded the USEPA maximum contaminant levels.

Table 21--Drinking-water regulations of the U.S. Environmental Protection Agency

[μg/L, micrograms per liter; mg/L, milligrams per liter; --, no level set. Data from U.S. Environmental Protection Agency, 1986a and 1986b]

Contaminant	Maximum contaminant levels for inorganic chemicals	Secondary maximum contaminant levels
Arsenic (As)	50 μg/L	--
Barium (Ba)	1 mg/L	--
Cadmium (Cd)	10 μg/L	--
Chloride (Cl)	--	250 mg/L
Chromium (Cr)	50 μg/L	--
Color (units)	--	15 units
Copper (Co)	--	1 mg/L
Fluoride (F)	4 mg/L	2 mg/L
Iron (Fe)	--	300 μg/L
Lead (Pb)	50 μg/L	--
Manganese (Mn)	--	50 μg/L
Mercury (Hg)	2 μg/L	--
Nitrate (NO_3 as N)	10 mg/L	--
pH (standard units)	-- --	6.5 to 8.5 units
Selenium (Se)	10 μg/L	--
Silver (Ag)	50 μg/L	--
Sulfate (SO_4)	--	250 mg/L
Zinc (Zn)	--	5 mg/L
Total dissolved solids	--	500 mg/L

Pesticides, polychlorinated biphenyls, and polychlorinated napthalenes.--Samples were collected at 15 stream sites in June, August, and September 1986, and analyzed for the following polychlorinated biphenyls (PCB), polychlorinated napthalenes (PCN), and pesticides:

Aldrin, total
Ametryne, total
Atrazine, total
Chlordane, total
Cyanazine, total
Cyprazine, total
DDD, total
DDE, total
DDT, total
Diazinon, total
Dieldrin, total
Disyston, total
Endrin, total
Endosulfan, total
Ethion, total
Guthion, total
Heptachlor, total
Heptachlorepoxide, total

Lindane, total	Prometryne, total
Malathion, total	Propazine, total
Methomyl, total	Propham, total
Methoxychlor, total	Sevin, total
Methylparathion, total	Silvex, total
Methltrithion, total	Simazine, total
Mirex, total	Simetryne, total
Parathion, total	Toxaphene, total
Perthane, total	Trithion, total
PCB, total	2,4-D, total
PCN, total	2,4,5-T, total
Prometone, total	2,4-DP, total

Only two of the above compounds--Parathion and Simazine--were detected in water (table 22).

Table 22. Pesticide concentrations in streams, 1986

[Analyses by U.S. Geological Survey. µg/L, micrograms per liter; <, less than]

Site number	Station number and name	Date	Parathion, total (µg/L)	Simazine, total (µg/L)
13	04127008 Swainston Creek at Mayfield	June 4, 1986	<0.01	0.3
15	04127250 Boardman River near Traverse City	June 4, 1986	<.01	.1
16	04127490 Boardman River at Traverse City	June 4, 1986	<.01	.2
17	04127498 Hospital Creek at Traverse City	June 5, 1986	<.01	.4
20	04127535 Yuba Creek near Acme	June 3, 1986	.01	<.1
21	04127550 Tobeco Creek	June 3, 1986	.01	.1

Suspended sediment.--Suspended-sediment concentrations of streams in Grand Traverse County are lower than those in many parts of the county, and lower than in many other parts of the State. For example, the mean suspended-sediment concentration of streams in Van Buren County was 16.3 mg/L (Cummings, 1984); in Grand Traverse County the mean concentration is 8.5 mg/L.

The maxium concentration, 84 mg/L, was found at Site 17 (Hospital Creek at Traverse City). (See table 15.) The highest mean concentration (36 mg/L) also was found at this site. The maximum suspended-sediment concentration exceeded 30 mg/L at only 10 of the 24 sites.

A relation of suspended-sediment concentration to streamflow is not evident from the data. Figure 14 is a plot of concentration versus streamflow at three sites. The results shown are typical of those found elsewhere in the county.

Table 23 lists the estimated suspended-sediment discharge, in tons per day, at each sampling site.

Table 23.--Estimated maximum, mean, and minimum suspended-sediment discharges at periodic sampling sites, 1984-86

[Results are in tons per day]

Site	Maximum	Mean	Minimum	Site	Maximum	Mean	Minimum
1	0.15	0.06	0.00	13	2.4	0.59	0.12
2	.71	.15	.02	14	.02	.01	.00
3	.89	.27	.03	15	17	5.5	.59
4	.56	.24	.00	16	33	4.6	.83
5	1.5	.52	.10	17	8.7	1.6	.05
6	1.3	.46	.10	18	2.2	.52	.05
7	5.2	1.6	.35	19	.89	.41	.10
8	5.9	1.4	.15	20	1.7	.30	.02
9	18	4.9	.80	21	.75	.18	.01
10	.30	.09	.01	22	1.8	.52	.10
11	1.5	.47	.09	23	.88	.25	.04
12	4.2	1.1	.39	24	.29	.13	.04

Relation of Land Use to Suspended Sediment and Nitrate Yields

Nitrogen, phosphorus, and suspended-sediment data collected during this study were examined to determine if any relations existed between yield of these substances and land use in a drainage area (fig. 8). Because both total phosphorus and orthophosphorus concentrations were commonly less than the detection limit, no computations of yield from a drainage area were possible. Analysis of the nitrogen concentration data--ammonia, nitrite, nitrate, and organic nitrogen--suggested that, if a relation between yield and drainage area existed, the relation could be established only for nitrate. Table 24 shows the estimated yield in $(ton/mi^2)/yr$ of suspended sediment and nitrate for each area.

Negative yields shown in table 24 indicated that there was a net loss of either nitrate or suspended sediment. In most instances the net loss can be attributed to the trapping of suspended sediment in the lake, or to

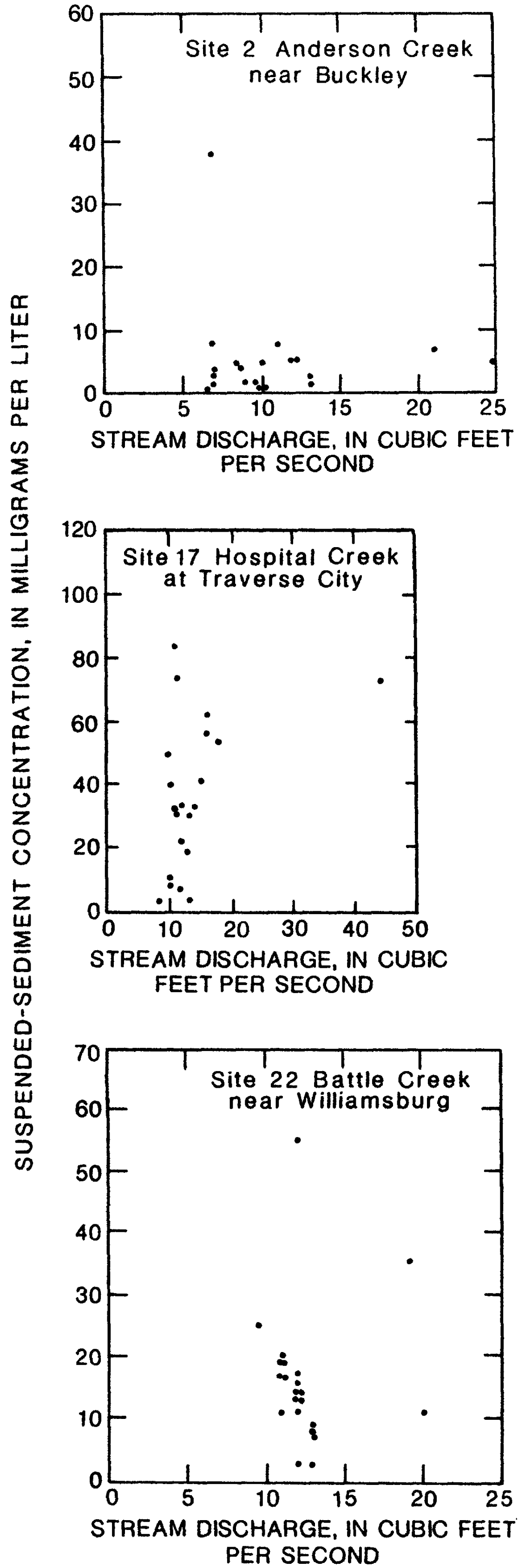

Figure 14.--Relation of suspended-sediment concentration
to stream discharge.

chemical and biological processes that decrease the nitrogen concentration. Figure 15 shows the areal distribution of nitrate and sediment yields by drainage area.

A comparison of land-use data given in table 4 to yields of both nitrate and suspended sediment showed no relation, probably because of the unusually low suspended-sediment concentrations of streams in Grand Traverse County. Similarly, nitrate concentrations also are low if compared to those of other streams in the State (Cummings, 1984).

Table 24.--Estimated annual yields of nitrate and suspended sediment in Grand Traverse County

[Drainage areas are identified on figure 8. Negative values indicate input is greater than output from area. mi^2, square miles; $(ton/mi^2)/yr$, tons per square mile per year]

Drainage area	Size of area (mi^2)	Yield: Nitrogen, nitrate, total (as N) ($(ton/mi^2)/yr$)	Yield: Suspended sediment ($(ton/mi^2)/yr$)
A	23.6	0.034	0.99
B	69.2	.33	8.2
C	46.1	.42	11
D	8.7	-.097	81
E	9.1	.26	3.7
F	22.4	.63	6.1
G	26.0	-.084	-53
H	10.0	.42	22
I	.79	.046	3.1
J	73.7	.29	16
K	9.0	4.1	-36
L	7.7	.79	73
M	14.6	.40	13
N	12.9	.18	12
O	8.4	1.4	13
P	8.0	.87	11
Q	10.8	.031	6.0
R	8.7	.44	22
S	32.3	.28	1.7
T	16.9	.45	5.8
U	22.7	-.22	-.45
V	7.4	.57	14
W	12.6	-.50	-1.8
X	10.5	.50	4.4

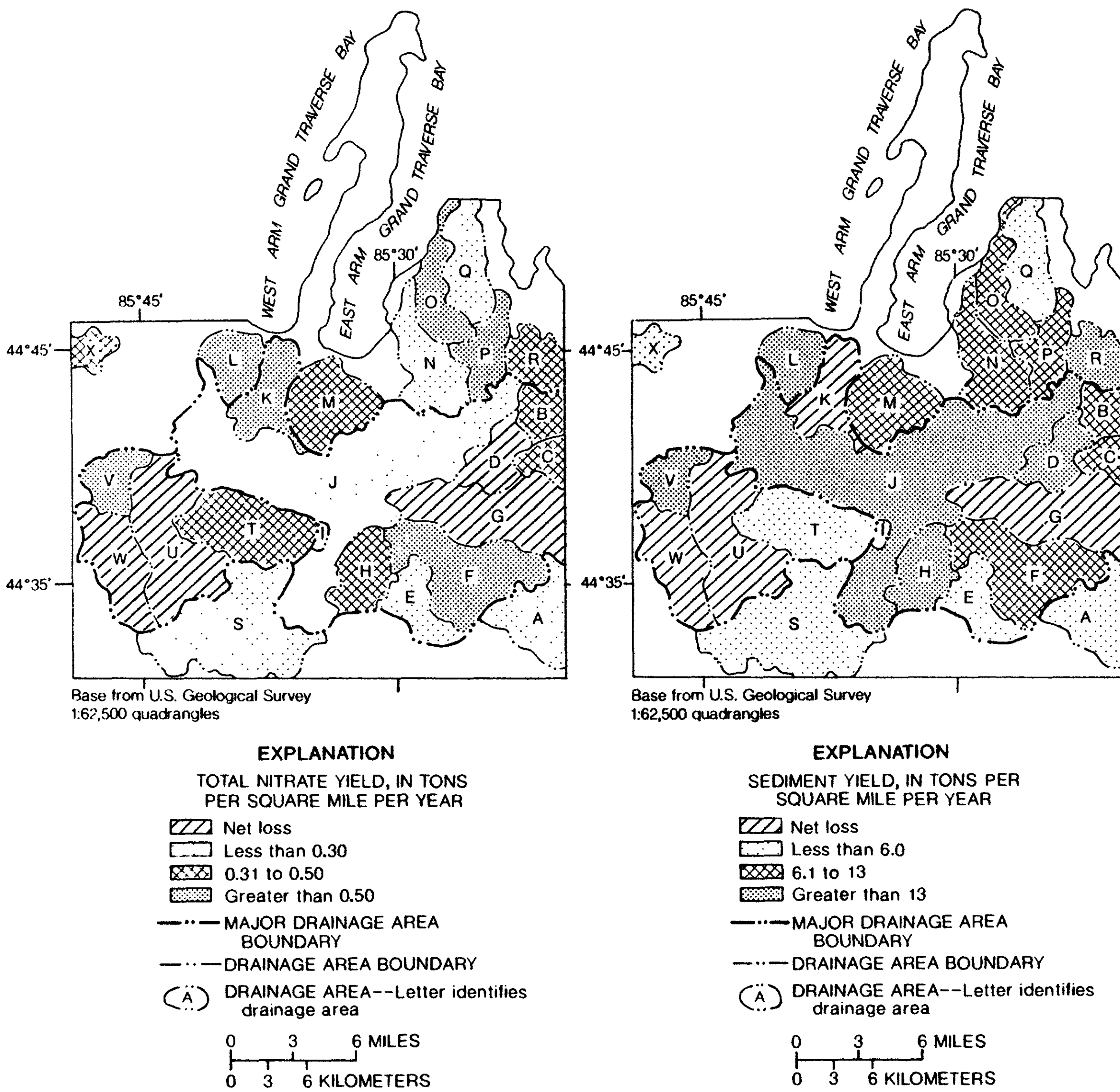

Figure 15.--Nitrate and sediment yields by drainage area.

Lakes

Chemical and physical characteristics of water from 15 lakes were measured during this study (table 25, at back of report). The locations of these lakes are identified on plate 1. Water-quality data, collected at three surface water sites immediately downstream from Boardman Lake (Site 16), Keystone Pond (Site 15), and Brown Bridge Pond (Site 12), are probably indicative of the water quality of the upstream lakes. Water in each of the 15 lakes is of a calcium bicarbonate type. Hardness ranges from soft to hard. Magnesium concentrations exceed sodium concentrations; sulfate concentrations generally exceed chloride concentrations. Dissolved-solids (sum of constituents) concentrations ranged from 47 mg/L at Bass Lake near Grawn (Site L15) to 170 mg/L at Duck Lake near Interlochen and Brewster Lake near Kingsley (Sites L5 and L8). The mean dissolved-solids concentration of all lakes was 123 mg/L.

Concentrations of nitrogen and phosphorus in water of lakes were generally low. Median concentrations computed from data given in table 25 were: Ammonia, 0.02 mg/L; nitrite, <0.01 mg/L; nitrate, <0.01 mg/L; and organic nitrogen, 0.49 mg/L. The only significant deviation from these values was the concentration of ammonia (0.42 mg/L) in water of Prescott Lake near Old Mission (Site L2). The median concentration of total phosphorus, based on all analyses, was 0.01 mg/L. Major alterations of water quality due to cultural activities are not obvious.

Water for the analysis of pesticides was collected from Fife Lake, Prescott Lake, Elk Lake, Long Lake, Duck Lake, Spider Lake, Sand Lake No. 1, and Brewster Lake. Analyses were made for the following 25 pesticides:

Ametryne, total
Atrazine, total
Cyanazine, total
Diazinon, total
Disyston, total
Ethion, total
Guthion, total
Malathion, total
Methomyl, total
Methylparathion, total
Methyltrithion, total
Parathion, total
Phorate, total
Prometone, total
Prometryne, total
Propazine, total
Propham, total
Sevin, total
Silvex, total
Simazine, total
Simetryne, total
Trithion, total
2,4-D, total
2,4,5-T, total
2,4-DP, total

Concentrations of pesticides exceeding the detection limit were found only in Long Lake near Interlochen and Duck Lake at Interlochen. On September 2 and 3, 1986, water from both lakes had a 2,4-D concentration of 0.02 µg/L.

Ground Water

Chemical and physical characteristics of water from 34 observation wells drilled for this study were measured. Locations of these wells are shown on plate 1; analyses of the major dissolved substances and properties and of trace metals are given in table 26 (at back of the report). Water for the analysis of pesticides, polychlorinated biphenyls (PCB), and polychlorinated napthalenes (PCN) was collected from 19 wells (B1-B4, B6, B7, B9, B10, B12-14, B16-19, B21, G1, G2, and G15). None were detected. (Analyses were made for the same compounds as those selected for surface water analyses.) Calcium and bicarbonate were the principal dissolved substances in all waters. Dissolved-solids (sum of constituents) concentrations in water ranged from 70 to 700 mg/L; the mean concentration was 230 mg/L. The approximate relation between specific and dissolved-solids concentration of ground water in Grand Traverse County is:

Dissolved-solids concentration (mg/L) = -0.92 + 0.57 x Specific conductance (µS/cm)

Median values of chemical and physical characteristics, based on data in table 26, and on data summarized in table 27, were compared to median values found by Cummings (1989) in a survey of natural ground-water quality. Table 28 shows the comparision for 31 selected substances or properties. In general, the quality of ground water in Grand Traverse County does not differ appreciably from that considered natural on a statewide basis. Although instances of ground-water contamination have been documented (Twenter and others, 1983, and Michigan Department of Natural Resources, 1989), significant modification of water quality countywide is not evident. Compared to USEPA drinking-water regulations (table 21), all waters represented by analyses in table 26 are suitable for human consumption, with the exception of water from well B18, which contained 11 mg/L of nitrate. Based on data collected by the Michigan Department of Public Health, however, nitrate concentrations at scattered locations do exceed USEPA drinking-water regulations.

Nitrate.-- Studies of nitrate in ground water in Grand Traverse County have been restricted largely to Peninsula Township. Iversen (1975) reviewed available nitrate data and speculated on reasons why water from many wells contained more than 10 mg/L. Rajagopal (1978) studied nitrate in ground water in eight townships in the vicinity of Traverse City, including Peninsula Township, and found a relation between ground-water quality and land use. Ellis (1982) investigated the concentration of nitrate in soils as it is affected by reshaping the land surface, and determined the concentration of nitrate leaching from septic-tank drain fields. He concluded that land reshaping was not likely to be a major cause of ground-water contamination, but that the potential for contamination of ground water by septic systems was serious.

A total of 807 analyses made by the U.S. Geological Survey, the Michigan Department of Public Health, and the Tri-County Health Department in Traverse City have been used in calculating mean concentrations of nitrate in ground water for each township (table 29). The mean concentration, based on all data collected, is 1.3 mg/L.

Table 27.--Maximum, mean, and minimum values of specific conductance, nitrate concentration, and chloride concentration in ground water

[Analyses by U.S. Geological Survey. mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Township	Number of analyses	Range: Specific conductance (µS/cm) Maximum	Mean	Minimum	Nitrate (NO_3) as N (mg/L) Maximum	Mean	Minimum	Chloride (Cl) (mg/L) Maximum	Mean	Minimum
Acme	17	581	436	329	8.7	1.6	0.1	18	4.8	0.7
Blair	7	770	501	227	1.5	.76	.1	78	23	.6
East Bay	20	1,940	436	253	3.9	.74	.1	26	8.4	.7
Fife Lake	11	626	354	250	10	1.6	.1	31	8.8	.4
Garfield	17	856	456	224	5.7	1.1	.1	91	13	.8
Grant	7	662	434	341	4.7	2.2	.1	29	9.3	.9
Green Lake	12	509	330	177	2.1	.26	.1	8.5	4.6	.6
Long Lake	15	491	372	274	8.7	2.0	.1	8.7	3.2	.6
Mayfield	19	932	516	251	8.8	2.4	.1	96	15	.6
Paradise	29	529	382	247	6.7	1.2	.1	19	6.5	.4
Peninsula	35	1,200	645	351	10	2.5	.1	150	12	.1
Union	5	312	266	241	1.1	.59	.1	6.3	2.6	.5
Whitewater	17	581	436	329	8.7	1.6	.1	18	4.8	.7

Table 28.--Comparison of ground-water quality in Grand Traverse County with statewide ground-water quality

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; °C, degrees Celsius]

Constituent or property	Median concentration	
	[a]Statewide	[b]Grand Traverse County
Alkalinity (mg/L as $CaCO_3$)	155	180
Arsenic, total (µg/L as As)	1	<1
Calcium, dissolved (mg/L as Ca)	50	58
Chloride, dissolved (mg/L as Cl)	4.4	5.5
Chromium, total recoverable (µg/L as Cr)	<20	<10
Fluoride, dissolved (mg/L as F)	.1	<.1
Hardness, total (mg/L as $CaCO_3$)	200	200
Hardness, noncarbonate (mg/L as $CaCO_3$)	12	18
Iron, total recoverable (µg/L as Fe)	560	175
Manganese, total recoverable (µg/L as Hg)	22	20
Magnesium, dissolved (mg/L as Mg)	17	13
Mercury, total recoverable (µg/L as Hg)	<.50	<.1
Nitrogen, ammonia, total (mg/L as N)	.05	.03
Nitrogen, nitrate, total (mg/L as N)	.01	.09
Nitrogen, nitrite, total (mg/L as N)	<.01	<.01
Nitrogen, organic, total (mg/L as N)	.13	.17
pH (standard units)	7.7	7.7
Phosphorus, total (mg/L as P)	<.01	.01
Phosphorus, ortho, total (mg/L as P)	<.01	.01
Potassium, dissolved (mg/L as K)	1.4	.7
Selenium, total (µg/L as Se)	<1	<1
Silica, dissolved (mg/L as SiO_2)	11	7.6
Silver, total recoverable (µg/L as Ag)	<1	<1
Sodium, dissolved (mg/L as Na)	6.8	2.0
Solids, residue at 180°C, dissolved (mg/L)	244	200
Solids, sum of constituents, dissolved (mg/L)	240	205
Specific conductance (µS/cm))	426	413
Strontium, total recoverable (µg/L as Sr)	150	40
Sulfate, dissolved (mg/L as SO_4)	13	13
Temperature (°C)	9.5	9.0
Zinc, total recoverable (µg/L as Zn)	60	235

[a] Cummings, 1989.
[b] This investigation.

Table 29.--Mean concentrations of nitrate in ground water, by township

[Concentrations are in mg/L (milligrams per liter)]

Township	Mean nitrate concentration (mg/L as N)
Acme	1.3
Blair	.62
East Bay	.84
Fife Lake	.67
Garfield	.83
Grant	1.9
Green Lake	.33
Long Lake	1.9
Mayfield	2.1
Paradise	1.4
Peninsula	2.9
Union	.36
Whitewater	1.3

A frequency distribution of all county nitrate concentrations (fig. 16) indicates that 90 percent are equal to or greater than 0.02 mg/L, 75 percent are equal to or greater than 0.05 mg/L, 25 percent are equal to or greater than 0.95 mg/L, and 10 percent are equal to or greater than 3.5 mg/L. These concentrations are slightly higher than those common in natural ground waters. Cummings (1989) found the nitrate concentrations of 50 percent of Michigan's natural ground waters were equal to or less than 0.01 mg/L, and 90 percent were equal to or less than 0.59 mg/L. About 1.6 percent of the county's ground waters equal or exceed the maximum contaminant level of 10 mg/L for drinking water (U.S. Environmental Protection Agency 1986a). Similar studies of Van Buren County (Cummings and others, 1984) and Kalamazoo County (Rheaume, 1990) indicate that in Van Buren County about 15 percent of nitrate concentrations in ground water equaled or exceeded the USEPA drinking-water regulation, and in Kalamazoo County, about 8 percent did so.

Some differences in the nitrate concentration of ground water seem to be related to how land is used. Figure 17 shows frequency distributions of nitrate in ground water from nonagricultural land, agricultural land, irrigated agricultural land, and irrigated agricultural land in Peninsula Township, where the amount of fertilizer nitrogen applied [40.2 (lb/acre)/yr] is about four times the countywide average. The effect of higher fertilizer application rates on nitrate concentrations of ground water seems evident. For example, figure 17 shows that, at the 25-percent frequency, the nitrate concentration of ground water in Peninsula Township is about seven times as great as the nitrate concentration of ground water in nonagricultural land in the county.

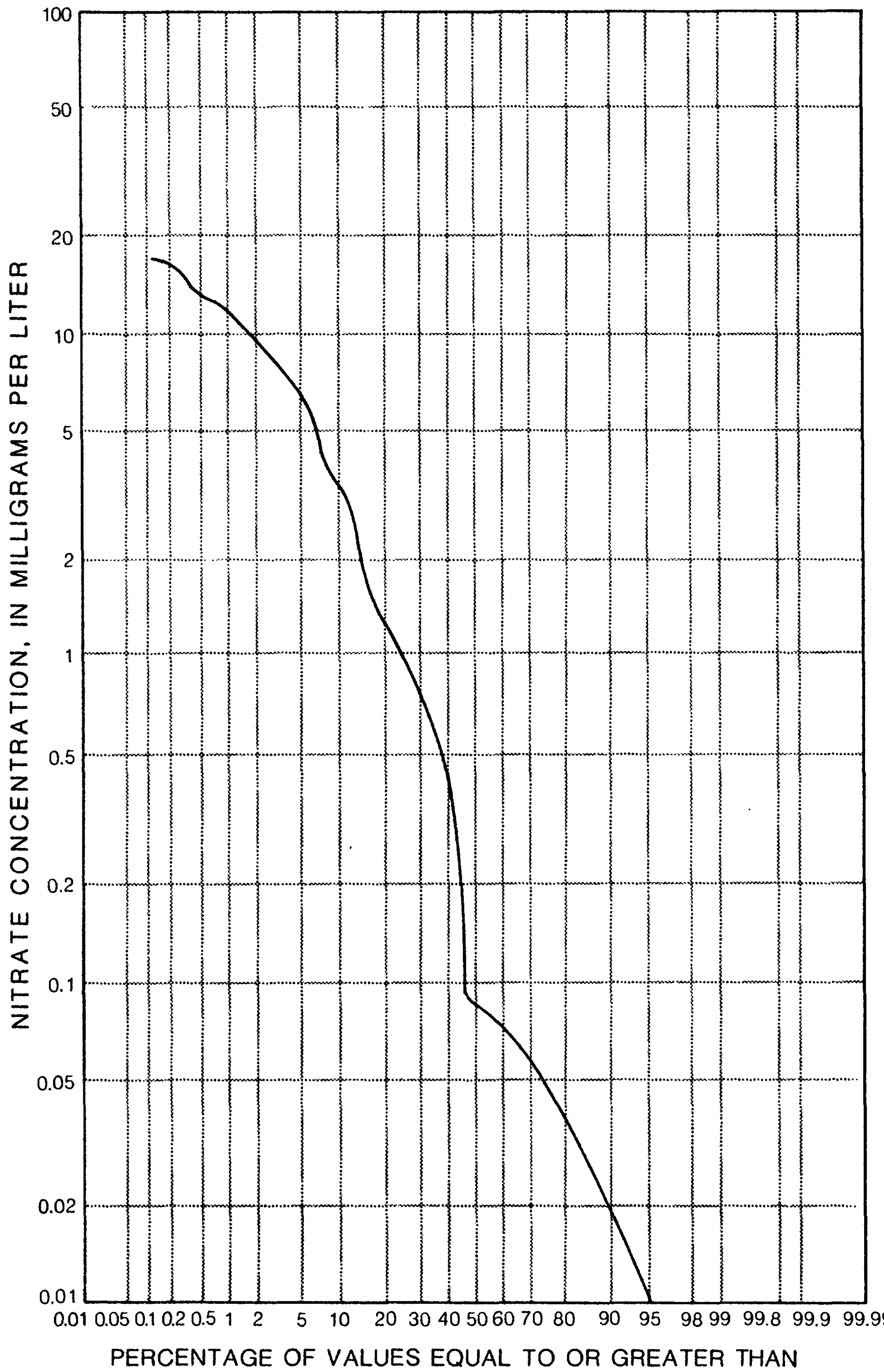

Figure 16.--Frequency distribution of nitrate concentrations in ground water.

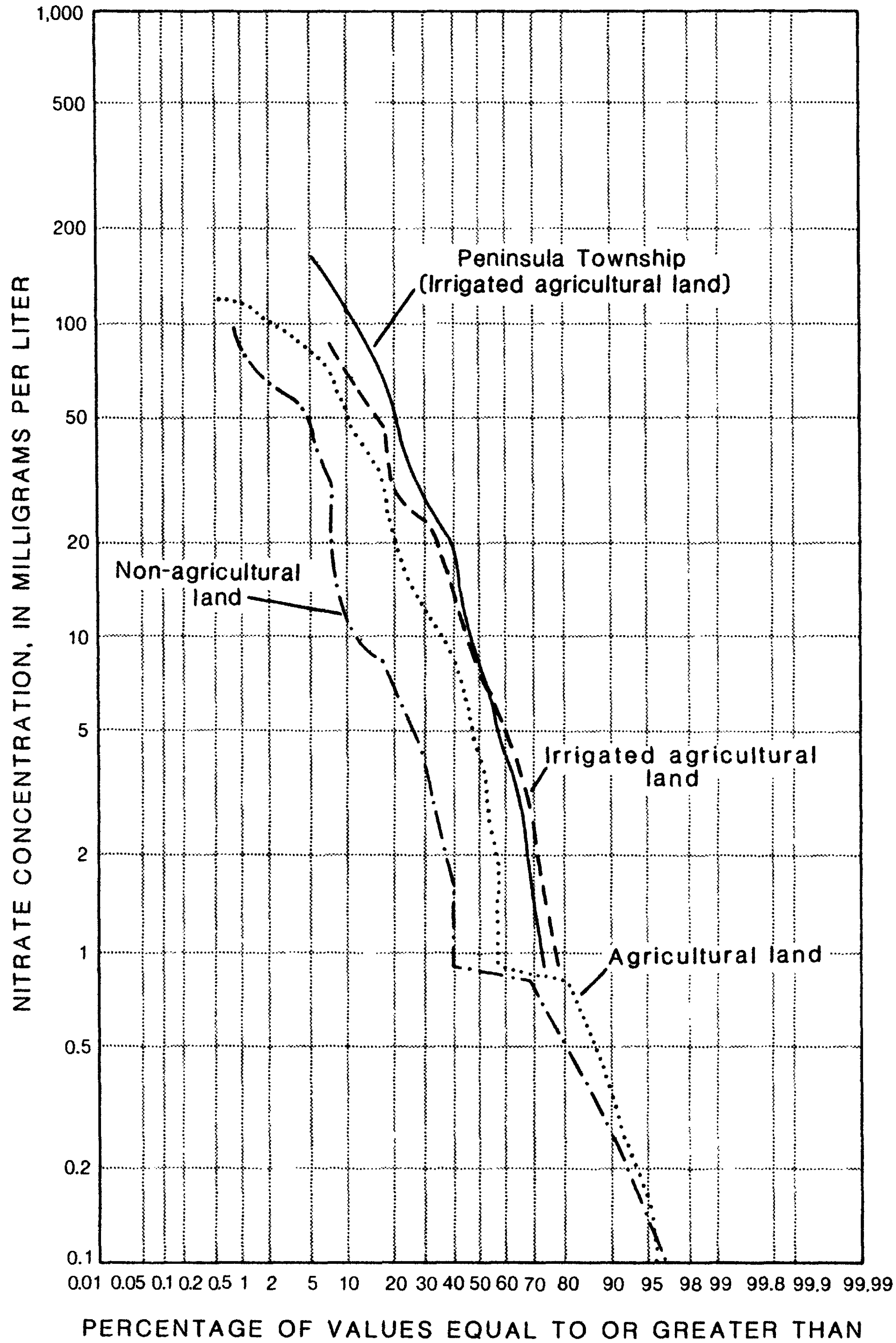

Figure 17.--Frequency distributions of nitrate concentrations in ground water from non-agricultural land, agricultural land, irrigated agricultural land, and irrigated agricultural land in Peninsula Township.

In some agricultural areas in Michigan, use of fertilizers has caused ground waters near the land surface to have a higher concentration of nitrate than do deeper waters. A least-square regression of well depth versus nitrate concentration indicated no significant relation exists in Grand Traverse County; in some townships, such as Peninsula, a relation is more evident, however.

Comparison of total nitrogen input to nitrate concentration in ground water.--Surface or near-surface inputs of nitrogen in Grand Traverse County are largely from precipitation, fertilizers, septic tanks, and animal wastes. Based on mean values previously cited, total nitrogen input from these sources is about 7.5 (ton/mi^2)/yr in the county. The following table shows the percentage composition of nitrogen input.

Table 30.--Percentage composition of nitrogen input

[(ton/mi^2)/yr, tons per square mile per year]

Source	Nitrogen input	
	(ton/mi^2)/yr	Percent
Precipitation	3.0	40
Septic tanks	0.45	6
Animal wastes	1.0	14
Fertilizers	3.0	40

Nitrogen application rates of fertilizers (table 8), nitrogen deposited by animals (table 9), and septic-tank discharges (table 10) have been compared to the mean nitrate concentration of ground water in each township. Figure 18 shows the relation and a regression line whose correlation coefficient is 0.76. A second, dashed line is the regression relation of nitrogen application rates of fertilizer and nitrate concentrations of ground water. Regressions of mean nitrate concentrations of ground water and animal nitrogen deposition and septic-tank discharges had correlation coefficients of 0.25 and 0.092, respectively. This indicates that the effect of animal wastes and septic-tanks on ground water cannot be demonstrated on a countywide basis with the available data, although locally each could be significant.

Chloride.--In many areas of the country, oil- and gas-drilling activities affect the chemical characteristics of surface and ground waters. Brines are commonly encountered during drilling, and some of the brines may migrate to or be discharged at land surface. In Grand Traverse County, records of the Geological Survey Division, Michigan Department of Natural Resources, indicate that 750 oil and gas wells have been drilled; about 65 percent of the wells were dry holes. About 84 percent of all wells have been drilled in Blair, Grant, Mayfield, and Paradise Townships. To investigate the effect of drilling on ground water in the county, 845 analyses of chloride from county,

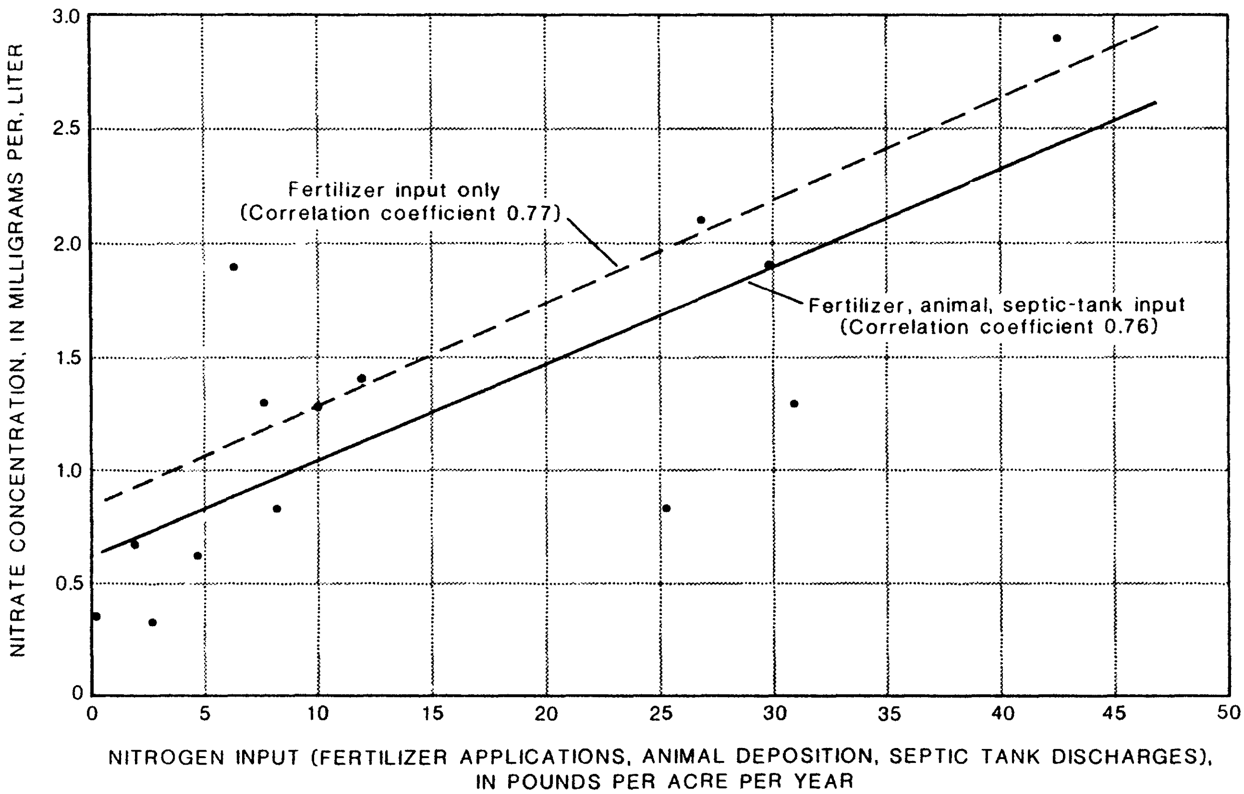

Figure 18.--Relation of nitrate concentrations of ground water to nitrogen input.

State, and U.S. Geological Survey files were analyzed. Separate frequency distributions of chloride concentrations in ground water for Blair, Grant, Mayfield, and Paradise Townships and for the remaining nine townships were prepared. Figure 19, which shows these frequency distributions, suggests a possible effect. At a frequency of 50 percent, ground water in Blair, Grant, Mayfield, and Paradise Townships has a chloride concentration about 2 mg/L higher than in other areas; at a frequency of 10 percent, a difference of 9 mg/L is indicated. Chloride concentrations of water at only four locations exceeded the USEPA drinking-water regulation of 250 mg/L.

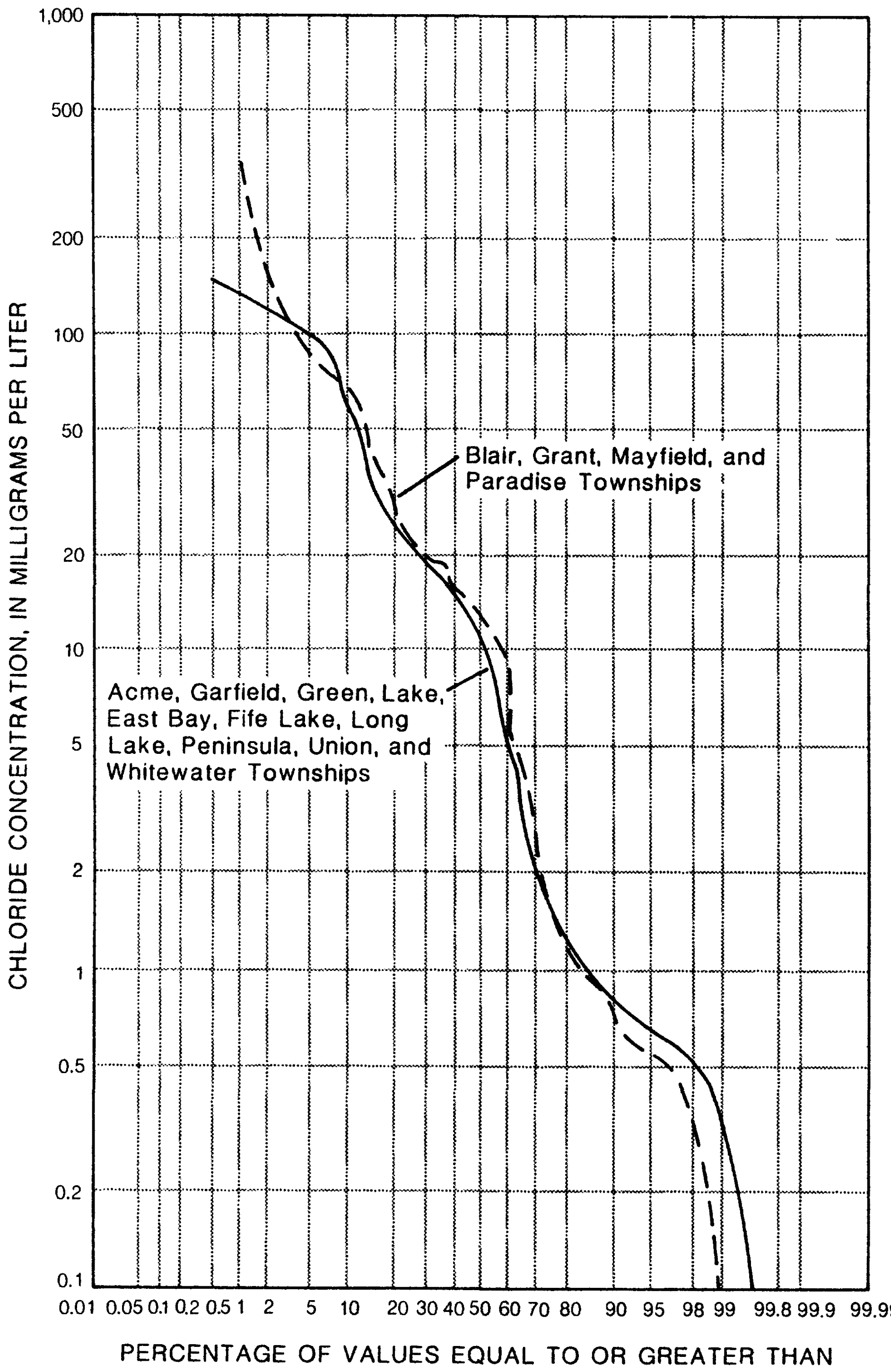

Figure 19.--Frequency distribution of chloride concentrations in ground water.

SUMMARY

Nearly 55,000 people live in Grand Traverse County. Of these, about 40,000 use ground water for domestic-water supplies. The remaining residents are supplied by the Traverse City municipal system which pumps water from the East Arm of Grand Traverse Bay. About 2,000 acres of land in the county are irrigated in the county; ninety percent of the irrigators use ground water.

The principal surficial geologic units in the county are glacial deposits; these are underlain by sedimentary bedrock of Paleozoic age that consists mostly of shale, which is a poor source of ground water. The Marshall Sandstone in the southeastern part of the county, however, may have potential for development. Glacial deposits, 100 to 900 ft thick, are the present (1990) source of ground-water supplies. Of the glacial deposits, outwash and lacustrine sand are the most productive aquifers. Most domestic wells obtained adequate supplies of water from sand and gravel at depths of 50 to 150 ft. Most irrigation wells capable of yielding more than 250 gal/min are generally more than 150 ft deep.

Areal differences in the chemical and physical characteristics of ground and surface water were determined and related to land use. Information on fertilizer applications, animal wastes, septic-tank discharges, and precipitation were compiled and analyzed. Data indicate that the application of nitrogen in fertilizer in the 13 townships ranged from 0 to 12.9 $(ton/mi^2)/yr$. The highest rate was found in Peninsula Township; rates of 6.0 $(ton/mi^2)/yr$ or greater also occured in Acme, Grant, and Mayfield Townships. Nitrogen deposited in animal waste in each township ranged from insignificant amounts in four townships to 4.36 $(ton/mi^2)/yr$ in Garfield Township. Countywide, mean nitrogen deposition by animals was 1.03 $(ton/mi^2)/yr$. Nitrogen discharged to the subsurface by septic tanks in each township ranged from 0.05 to 1.49 $(ton/mi^2)yr$; the mean value for the county was 0.45 $(ton/mi^2)/yr$. Precipitation contributed 3.0 $(ton/mi^2)/yr$ of nitrogen. On the basis of mean values, the percentage of total nitrogen input from these four major sources was 40 percent from precipitation, 6 percent from septic tanks, 14 percent from animal wastes, and 40 percent from fertilizers.

On the basis of specific conductance measurements, the dissolved-solids concentration of water of streams ranged from 116 to 380 mg/L. Mean percent saturation of dissolved oxygen at each site ranged from 71 at West Branch Jaxson Creek near Mayfield to 104 at Duck Lake Outlet near Interlochen. The lowest concentration of dissolved oxygen, 4.7 mg/L, was found at Tobeco Creek near Elk Rapids. Values of pH ranged from 7.2 at Mason Creek near Grawn to 8.6 at Duck Lake Outlet near Interlochen and at Betsie River near Karlin. Water at most sites is of a calcium bicarbonate type. Water at all sites may be classed as hard to very hard at low to mean flow. Total nitrogen concentrations ranged from 0.19 to 4.4 mg/L.

Trace metal concentrations are generally low in water of streams; pesticides were detected at some sites. The maximum pesticide concentration was 0.4 mg/L Simazine at Hospital Creek at Traverse City. The mean suspended-sediment concentration of streams in Grand Traverse County was 8.5 mg/L. The maximum suspended-sediment concentration, 84 mg/L, was found at Hospital Creek at Traverse City.

Relations between land use and the yield of dissolved and suspended substances from individual drainage areas could not be established, probably because concentrations of nitrogen, phosphorus, and suspended sediment are lower than concentrations found at many other locations in Michigan.

Water of lakes in Grand Traverse County is of a calcium bicarbonate type. Magnesium concentrations generally exceed sodium concentrations, and sulfate concentrations generally exceed chloride concentrations. Dissolved-solids (sum) concentrations ranged from 47 mg/L (Bass Lake near Grawn) to 170 mg/L (Duck Lake near Interlochen and Brewster Lake near Kingsley). The mean dissolved-solids concentration of all lakes in the county was 123 mg/L. Concentrations of nitrogen and phosphorus in water of lakes were generally low; the median concentration of nitrate of all lakes was less than 0.01 mg/L. Pesticides were detected only in Long Lake and Duck Lake; a concentration of 0.02 µg/L of 2,4-D was found in the water of each.

Calcium and bicarbonate are the principal dissolved substances in ground water. Dissolved-solids concentrations ranged from 70 to 700 mg/L; the mean concentration was 230 mg/L. The mean nitrate concentration of ground waters in the county was 1.3 mg/L; 90 percent have a nitrate concentration equal to or greater than 0.02 mg/L and 10 percent have a concentration equal to or greater than 3.5 mg/L. About 1.6 percent of the county's ground waters have concentrations of nitrate that equal or exceed the USEPA maximum contaminant level of 10 mg/L for drinking water. The effect of fertilizer applications on the nitrate concentration of ground water is evident in some parts of the county.

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DEFINITION OF TERMS

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. It is also called a ground-water reservoir.

Bedrock. Designates consolidated rocks underlying glacial deposits.

Braided stream. A stream consisting of interwoven channels constantly shifting through islands of alluvium and sandbanks.

Concentration. The weight of dissolved solids or sediment per unit volume of water expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Contour. An imaginary line connecting points of equal elevation, whether the points are on the land surface, on the clay surface, or on a potentiometric or water-table surface.

Discharge. The rate of flow of a stream; reported in cubic feet per second (ft^3/s).

Divide. A line of separation between drainage systems. A topographic divide delineates the land from which a stream gathers its water; a ground-water divide is a line on a potentiometric or water-table surface on each side of which the potentiometric surface slopes downward away from the line.

Elevation. Vertical distance of a point or line above or below the National Geodetic Vertical Datum of 1929. The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929". In this report, all elevations are above NGVD of 1929.

Equipotential line. A line in an aquifer on which every point has the same potentiometric head. As used in this report, equipotential lines define the water table. The value identifying a given line is the elevation of all points on that line.

Ground water. Water that is in the saturated zone from which wells, springs, and ground-water runoff are supplied.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In general terms, hydraulic conductivity is the ability of a porous medium to transmit water.

Hydrograph. A graph showing the variations of stage, flow velocity, discharge, or other aspects of water with respect to time.

NGVD of 1929. See Elevation.

Permeability. A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium alone, and is independent of the nature of the fluid and of the force field.

Potentiometric surface. In aquifers, the level to which water will rise in tightly cased wells. More than one potentiometric surface is required to describe the distribution of head. The water table is a particular potentiometric surface.

Recharge. The process by which water is infiltrated and is added to the zone of saturation. It is also the quantity of water added to the zone of saturation.

Runoff. That part of precipitation that appears in streams; 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.

Specific capacity. The rate of discharge of water from a well divided by the drawdown of water level within the well.

Specific conductance. A measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Because the specific conductance is related to amount and type of dissolved material, it is used for approximating the dissolved-solids concentration of water. For most natural waters the ratio of dissolved-solids concentration (in milligrams per liter) to specific conductance (in microsiemens per centimeter) is in the range 0.5 to 0.8.

Specific yield. The ratio of the volume of water that the rock, after being saturated, will yield by gravity, to the volume of rock. It is commonly used for unconfined or water-table aquifers as being virtually equal to storage coefficient. Specific yield of most unconfined aquifers ranges from 0.1 to 0.3 and averages about 0.2.

Storage coefficient. The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Defines conditions in both confined and unconfined aquifers. The storage coefficient of most confined aquifers ranges from 0.00005 to 0.002. For unconfined aquifers, storage coefficient virtually equal specific yield.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is tranmsitted through a unit width of the aquifer under a unit hydraulic gradient.

Water table. That surface in an unconfined water body at which the pressure is atmospheric. It is defined by levels at which water stands in wells.

TABLES OF DATA

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey

Well number	Location[1]	Lithology	Depth (feet below land surface)
B1	29N 10W 9DBAB	Glacial deposits:	
		Sand, clay, and gravel	0 - 18
		Sand, gravel (fine to medium), and clay	18 - 27
		Clay, sand, and gravel	27 - 42
		Sand (fine to coarse) and gravel (fine to coarse) with clay	42 - 56
		Sand (fine to very coarse) with gravel and trace of clay	56 - 72
B2	28N 9W 5BCAD	Glacial deposits:	
		Sand (medium to coarse) and gravel (fine to medium)	0 - 17
		Sand (medium to coarse) and gravel with clay and trace of silt	17 - 25
		Sand (medium to very coarse) and gravel (fine to coarse)	25 - 35
		Clay with gravel (medium)	35 - 50
		Sand (fine to coarse)	50 - 54
		Clay and gravel	54 - 58
		Sand (medium to coarse) with trace of gravel (fine)	58 - 64
B3	28N 9W 31AABA	Glacial deposits:	
		Sand (fine) with clay	0 - 25
		Sand (fine), gravel, and clay	25 - 51
		Sand (medium to coarse) with gravel	51 - 58
		Sand (fine to medium)	58 - 64
B4	27N 9W 8DDCD	Glacial deposits:	
		Sand (very fine to medium)	0 - 58
		Clay with sand (very fine) and trace of gravel	58 - 68
		Gravel and sand (fine to medium)	68 - 73
		Sand (medium to very coarse)	73 - 78
		Sand (fine to coarse) with trace of gravel (medium)	78 - 113
B5	27N 9W 27AAAD	Glacial deposits:	
		Sand (fine to medium)	0 - 16
		Sand (medium to coarse)	16 - 37
		Sand (very fine to medium)	37 - 47
		Sand (fine to very coarse)	47 - 105
		Clay	105 - 107

[1] The well-location system for Michigan indicates the location of wells within a rectangular subdivision of land with reference to the Michigan meridian and base line. The first two segments of the well-location designation indicate township and range, either north (N), south (S), east (E), or west (W). The number in the third segment designates the section, and the letters A through D designate successively smaller subdivisions of the section. Thus, a well designated as 29N 10W 9DBAB is located to the nearest 2.5 acres and is within section 9.

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
B6	27N 10W 29CBBC	Glacial deposits:	
		Sand (medium to very coarse) and gravel (fine to coarse)	0 - 13
		Sand, gravel (fine to coarse), and clay	13 - 23
		Clay, with sand and gravel	23 - 37
		Sand, gravel (fine to medium), and clay	37 - 40
		Clay, with sand and gravel (fine)	40 - 53
		Clay and sand	53 - 57
		Sand (medium to very coarse) trace of gravel	57 - 70
B7	27N 11W 5ACDA	Glacial deposits:	
		Sand and gravel (fine to coarse)	0 - 6
		Clay, sand, and gravel	6 - 35
		Sand (very fine to medium)	35 - 45
		Sand (fine to very coarse)	45 - 70
		Sand (very fine to medium)	70 - 78
		Sand (fine to very coarse)	78 - 101
B8	27N 12W 6DDCA	Glacial deposits:	
		Sand (fine to coarse) and trace of gravel (fine to medium)	0 - 16
		Sand (medium to very coarse)	16 - 68
		Sand (very fine to fine)	68 - 74
		Sand (very fine) with clay	74 - 81
		Sand (fine to medium)	81 - 87
		Sand (very fine to fine) with clay	87 - 107
		Sand (medium to coarse) and trace of clay	107 - 115
		Clay with sand (fine)	115 - 152
		Sand (fine to medium) and trace of clay	152 - 157
		Clay with sand (fine)	157 - 167
		Gravel with clay	167 - 173
		Sand (very fine to fine) and clay	173 - 188
		Clay	188 - 209
		Sand (medium to very coarse) and gravel (fine to medium)	209 - 217
B9	27N 12W 29BCBC	Glacial deposits:	
		Sand (fine to medium) and trace of gravel (fine to medium)	0 - 12
		Sand (fine to coarse) and gravel (fine)	12 - 22
		Sand (very fine to medium)	22 - 28
		Sand (very fine to coarse) and gravel (fine)	28 - 54
		Sand (very fine to fine)	54 - 57
		Sand (fine to medium), trace of gravel	57 - 62
		Sand (fine to coarse) and gravel (fine to medium)	62 - 81

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
B10	27N 12W 35DCAA	Glacial deposits:	
		Sand (fine to coarse)	0 - 11
		Clay	11 - 33
		Sand (fine to very coarse)	33 - 46
		Clay and sand (medium to coarse)	46 - 50
		Sand (fine to medium)	50 - 57
		Sand (medium to very coarse)	57 - 68
B11	26N 10W 12CCAD	Glacial deposits:	
		Sand (medium to coarse)	0 - 8
		Sand (fine to very coarse) with gravel (fine to medium)	8 - 13
		Sand (very fine to medium)	13 - 37
		Sand (fine to very coarse), gravel (medium), and clay	37 - 53
		Sand (very fine to medium)	53 - 78
		Sand (medium to coarse)	78 - 82
		Clay, sand, and gravel	82 - 84
		Sand (fine to medium) and trace of gravel	84 - 93
		Clay, sand (fine to very coarse), and gravel (fine)	93 - 98
		Sand (very fine to medium)	98 - 110
B12	26N 10W 33CCAA	Glacial deposits:	
		Sand (medium) and trace of gravel (medium)	0 - 13
		Clay, with sand (very fine to medium)	13 - 29
		Sand (fine to medium)	29 - 44
		Sand (fine to medium) and clay	44 - 57
		Clay	57 - 83
		Sand (very fine to fine)	83 - 93
B13	26N 11W 22BABB	Glacial depostis:	
		Sand (fine to coarse)	0 - 18
		Sand (medium to very coarse) and gravel (fine)	18 - 22
		Sand (fine to medium) with trace of gravel	22 - 53
		Sand (coarse to very coarse) with gravel	53 - 55
		Sand (medium to coarse)	55 - 59
B14	26N 12W 19BCBC	Glacial deposits:	
		Sand (medium to coarse)	0 - 6
		Sand (medium to very coarse) and gravel (fine)	6 - 18
		Sand (fine to medium) with trace of gravel	18 - 36
		Sand (medium to coarse)	36 - 40
B15	25N 9W 10CBBB	Glacial deposits:	
		Sand (fine to medium)	0 - 35
		Sand (medium to coarse) with trace of gravel	35 - 55
		Sand (fine to medium)	55 - 58
		Sand (medium to coarse) with trace of gravel	58 - 90
		Sand (coarse) with clay	90 - 95
		Clay with sand (fine)	95 - 109
		Sand (fine to coarse)	109 - 117

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
B16	25N 9W 34CABB	Glacial deposits:	
		Sand (very fine to medium)	0 - 38
		Sand (fine to very coarse), gravel (fine to medium), and clay	38 - 41
		Clay	41 - 52
		Sand (fine to coarse) and trace of gravel	52 - 74
		Sand (fine to very coarse) with gravel (fine)	74 - 98
B17	25N 10W 26CBCC	Glacial deposits:	
		Sand (very fine to medium) and trace of gravel (fine)	0 - 39
		Sand (fine to very coarse), gravel, with trace of clay	39 - 50
		Sand (very fine to medium)	50 - 58
		Sand (fine to very coarse), gravel, with trace of clay	58 - 73
		Sand (very fine to medium)	73 - 83
		Sand (fine to very coarse), gravel, and trace of clay	83 - 106
		Sand (very fine to very coarse) and trace of gravel	106 - 111
B18	25N 11W 10BABA	Glacial deposits:	
		Sand with gravel	0 - 8
		Clay with sand	8 - 20
		Clay, sand, and gravel	20 - 28
		Sand (very fine to fine)	28 - 30
		Sand (fine to very coarse) with trace of gravel (fine)	30 - 51
B19	25N 11W 33CCCC	Glacial deposits:	
		Sand (fine to coarse)	0 - 9
		Sand (very fine to fine)	9 - 13
		Sand (fine to medium)	13 - 19
		Sand (medium to very coarse) and trace of gravel (fine to medium)	19 - 38
		Sand (very fine to medium)	38 - 42
		Sand (medium to very coarse)	42 - 58
		Sand (fine to medium)	58 - 62
		Clay	62 - 65
B20	25N 12W 16AAAA	Glacial deposits:	
		Sand (very fine to medium)	0 - 13
		Sand (medium to very coarse) with gravel	13 - 24
		Sand (very fine to coarse)	24 - 53
		Sand (very fine to fine)	53 - 67
		Sand (very fine to medium)	67 - 93
		Sand (fine to coarse) with gravel (fine)	93 - 107
		Sand (fine to coarse) with clay	107 - 118
		Sand (medium to very coarse) and gravel (fine)	118 - 124
		Sand (fine to medium) and gravel (fine)	124 - 147

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
B21	27N 9W 4BBDB	Glacial deposits:	
		Clay	0 - 8
		Clay, sand (very fine to fine), and gravel	8 - 18
		Sand (fine to medium) with gravel and clay	18 - 34
		Sand (very fine to medium)	34 - 43
		Clay with sand (fine to medium)	43 - 44
G1	28N 10W 4CAAC	Glacial deposits:	
		Sand (medium to coarse) with trace of gravel	0 - 6
		Clay and sand (very fine to medium)	6 - 8
		Sand (fine to coarse) with silt, clay, and gravel (fine to very coarse)	8 - 34
		Sand (fine to coarse) with trace of gravel	34 - 48
		Sand (very fine to medium)	48 - 70
		Sand (very fine to very coarse) with silt, clay, and some gravel	70 - 97
		Sand (fine to very coarse) with gravel (fine to medium)	97 - 121
		Clay	121 - 141
		Sand (fine to coarse) with silt and clay	141 - 147
		Sand (fine to coarse)	147 - 186
		Sand (fine to very coarse) with trace of gravel	186 - 190
G2	28N 9W 10DCCB	Glacial deposits:	
		Sand (medium to coarse)	0 - 23
		Sand with clay and silt	23 - 29
		Clay	29 - 38
		Clay with sand	38 - 62
		Sand, silt, and clay with trace of gravel	62 - 112
		Sand with trace of gravel	112 - 127
		Sand (medium to very coarse)	127 - 130
		Clay	130 - 131
G3	27N 9W 12ABDD	Glacial deposits:	
		Sand (fine to coarse) with trace of gravel (fine to medium)	0 - 8
		Sand (fine to very coarse), gravel (fine to coarse), with trace of silt	8 - 23
		Sand (fine to coarse), with clay and silt	23 - 70
		Sand (fine to very coarse)	70 - 82
G4	27N 9W 31ABCC	Glacial deposits:	
		Sand (fine to very coarse) with trace of gravel	0 - 43
		Sand (medium to very coarse) with gravel	43 - 53
		Sand (fine to coarse) with trace of silt	53 - 63
		Sand (fine to coarse) with trace of gravel	63 - 108

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
G5	27N 11W 32BDAA	Glacial deposits:	
		Sand (fine to very coarse) with gravel, silt, and clay	0 - 17
		Sand (fine to very coarse)	17 - 22
		Sand (fine to very coarse) with gravel, silt, and clay	22 - 33
		Sand (fine to very coarse) with trace of gravel	33 - 41
		Sand (medium to very coarse), silt and clay, with gravel	41 - 56
		Sand (fine to coarse) with trace of gravel	56 - 61
		Gravel (fine to coarse) with silt, clay, and sand (fine to very coarse)	61 - 74
		Sand (very fine to very coarse) with silt and clay, and gravel	74 - 83
		Clay and silt with sand (fine to coarse) and gravel	83 - 97
		Sand (medium to coarse) with clay, silt, and gravel	97 - 104
		Sand (fine to coarse)	104 - 107
		Sand (fine to very coarse) with clay and silt, and gravel	107 - 111
		Sand (fine to coarse) with trace of gravel	111 - 120
G6	26N 9W 30CCCC	Glacial deposits:	
		Sand (fine to medium)	0 - 12
		Sand (very fine to very coarse) with gravel	12 - 64
G7	26N 9W 26DDDC	Glacial deposits:	
		Sand (very fine to medium) with silt	0 - 9
		Sand (very fine to coarse)	9 - 17
		Clay and silt, with gravel and sand (coarse)	17 - 18
		Sand (very fine to coarse)	18 - 23
		Sand (very fine to coarse) with gravel	23 - 35
G8	26N 10W 8ABCC	Glacial deposits:	
		Sand (fine to coarse) and gravel (medium to coarse)	0 - 19
		Sand (fine to coarse) with gravel and silt	19 - 27
		Gravel (fine to coarse) with silt, clay, and sand (medium to very coarse)	27 - 37
		Sand (fine to coarse) with trace of gravel	37 - 64
		Clay, silt, sand, and gravel	64 - 92
		Sand (fine to coarse) with trace of gravel	92 - 102
		Sand (fine to very coarse) with gravel	102 - 124
		Sand (fine to coarse), gravel, silt, and clay	124 - 128
		Sand (fine to very coarse) with gravel	128 - 149
		Sand (fine to very coarse), gravel, silt, and clay	149 - 223
		Sand with gravel	223 - 226

Table 1.--Lithologic logs for wells installed by the U.S. Geological Survey--Continued

Well number	Location	Lithology	Depth (feet below land surface)
G9	25N 9W 18BCBC	Glacial deposits:	
		Sand (very fine to fine)	0 - 22
		Sand (medium to coarse) with trace of gravel	22 - 38
		Sand (very fine to coarse)	38 - 40
G10	26N 11W 31BCBB	Glacial deposits:	
		Sand (fine to very coarse), gravel (fine to coarse), silt, and clay	0 - 22
		Sand (fine to very coarse) with trace of gravel	22 - 42
		Sand (fine to very coarse)	42 - 62
		Sand (fine to very coarse) with gravel	62 - 68
		Sand (fine to very coarse)	68 - 74
G11	25N 11W 24BCCA	Glacial deposits:	
		Sand (fine to very coarse) and gravel (fine to coarse)	0 - 81
		Sand (very fine to very coarse), silt and clay, and gravel	81 - 96
		Sand (very fine to very coarse) and gravel	96 - 102
G12	25N 12W 18DABD	Glacial deposits:	
		Sand (fine to coarse) with gravel and silt	0 - 26
		Sand (fine to coarse) with trace of gravel	26 - 63
		Sand (fine to very coarse) with gravel	63 - 83
		Sand (fine to very coarse) with trace of gravel and silt	83 - 90
G13	26N 9W 14ABAA1	Glacial deposits:	
		Sand (very fine to very coarse) and gravel	0 - 13
		Sand (very fine to coarse) with gravel	13 - 53
		Sand (very fine to very coarse) and gravel	53 - 77
G14	26N 9W 14ABAA2	Glacial deposits:	
		Sand (very fine to very coarse) and gravel	0 - 13
		Sand (very fine to coarse) with gravel	13 - 53
		Sand (very fine to very coarse) and gravel	53 - 77
G15	25N 12W 28CCCC	Glacial deposits:	
		Sand (fine to coarse) and gravel (fine to coarse)	0 - 8
		Sand (very fine to very coarse), gravel (fine to coarse), silt, and trace of clay	8 - 12
		Sand (very fine to very coarse), gravel, and silt	12 - 33
		Sand (very fine to very coarse) with gravel, silt, and clay	33 - 46
		Sand (very fine to medium) and clay with silt	46 - 52
		Sand (very fine to medium) and clay with gravel	52 - 60
		Sand (fine to coarse)	60 - 65

Table 3.--Elevation of water table in wells installed by the U.S. Geological Survey

[Elevation is in feet above National Geodetic Vertical Datum of 1929]

Well number	Location	Date	Elevation of water table (feet)	Well number	Location	Date	Elevation of water table (feet)
B1	29N 10W 9DBAB	Sept. 24, 1985	601	B6	27N 10W 29CBBC	Sept. 25, 1985	754
		Oct. 29, 1985	601			Oct. 30, 1985	754
		Dec. 10, 1985	601			Dec. 11, 1985	754
		Jan. 13, 1986	601			Jan. 16, 1986	754
		Feb. 19, 1986	601			Feb. 19, 1986	754
		Apr. 10, 1986	602			Apr. 10, 1986	755
		May 6, 1986	603			May 7, 1986	755
		June 3, 1986	602			June 3, 1986	755
		Oct. 2, 1986	602			Oct. 2, 1986	756
B2	28N 9W 5BCAD	Oct. 4, 1985	603	B7	27N 11W 5ACDA	Sept. 25, 1985	688
		Oct. 30, 1985	603			Oct. 31, 1985	688
		Dec. 10, 1985	604			Dec. 11, 1985	688
		Jan. 15, 1986	604			Jan. 13, 1986	688
		Feb. 19, 1986	600			Feb. 21, 1986	688
		Apr. 10, 1986	606			Apr. 10, 1986	689
		May 6, 1986	605			May 8, 1986	689
		June 3, 1986	605			June 3, 1986	687
		Oct. 2, 1986	606			Oct. 2, 1986	689
B3	28N 9W 31AABA	Sept. 26, 1985	685	B8	27N 12W 6DDCA	Oct. 3, 1985	770
		Oct. 29, 1985	682			Oct. 31, 1985	770
		Dec. 10, 1985	683			Dec. 11, 1985	770
		Jan. 15, 1986	682			Jan. 13, 1986	770
		Feb. 20, 1986	682			Feb. 21, 1986	770
		Apr. 10, 1986	683			Apr. 10, 1986	770
		May 6, 1986	684			May 8, 1986	771
		June 3, 1986	684			June 3, 1986	771
		Oct. 2, 1986	684			Oct. 2, 1986	771
B4	27N 9W 8DDCD	Sept. 26, 1985	816	B9	27N 12W 29BCBC	Sept. 24, 1985	834
		Oct. 29, 1985	816			Oct. 29, 1985	834
		Dec. 10, 1985	816			Dec. 10, 1985	833
		Jan. 13, 1986	816			Jan. 13, 1986	833
		Feb. 20, 1986	816			Feb. 20, 1986	833
		Apr. 10, 1986	816			Apr. 10, 1986	833
		May 7, 1986	816			May 8, 1986	834
		June 3, 1986	817			June 3, 1986	835
		Oct. 2, 1986	818			Oct. 2, 1986	834
B5	27N 9W 27AAAD	Sept. 24, 1985	891	B10	27N 12W 35DCAA	Sept. 24, 1985	844
		Oct. 29, 1985	891			Oct. 29, 1985	844
		Dec. 10, 1985	891			Dec. 10, 1985	844
		Jan. 13, 1986	891			Jan. 13, 1986	844
		Feb. 20, 1986	891			Feb. 20, 1986	844
		Apr. 10, 1986	891			Apr. 10, 1986	845
		May 7, 1986	891			May 6, 1986	846
		June 3, 1986	892			June 4, 1986	844
		Oct. 2, 1986	893			Oct. 2, 1986	845

Table 3.--Elevation of water table in wells installed by the U.S. Geological Survey--Continued

Well number	Location	Date	Elevation of water table (feet)
B11	26N 10W 12CCAD	Sept. 25, 1985	846
		Oct. 31, 1985	846
		Dec. 11, 1985	848
		Jan. 16, 1986	846
		Feb. 20, 1986	846
		Apr. 10, 1986	846
		May 7, 1986	847
		June 3, 1986	847
		Oct. 2, 1986	847
B12	26N 10W 33CCAA	Oct. 3, 1985	907
		Oct. 30, 1985	907
		Dec. 11, 1985	907
		Jan. 15, 1986	907
		Feb. 19, 1986	907
		Apr. 10, 1986	908
		May 6, 1986	908
		June 3, 1986	908
		Oct. 2, 1986	908
B13	26N 11W 22BABB	Sept. 25, 1985	860
		Oct. 30, 1985	860
		Dec. 11, 1985	861
		Jan. 16, 1986	861
		Feb. 21, 1986	861
		Apr. 10, 1986	862
		May 6, 1986	863
		June 4, 1986	863
		Oct. 2, 1986	862
B14	26N 12W 19BCBC	Sept. 24, 1985	840
		Oct. 29, 1985	840
		Dec. 10, 1985	841
		Jan. 13, 1986	840
		Feb. 20, 1986	840
		Apr. 10, 1986	842
		May 6, 1986	842
		June 4, 1986	841
		Oct. 2, 1986	842
B15	25N 9W 10CBBB	Sept. 24, 1985	1,017
		Oct. 29, 1985	1,018
		Dec. 10, 1985	1,018
		Jan. 13, 1986	1,018
		Feb. 19, 1986	1,018
		Apr. 10, 1986	1,018
		May 6, 1986	1,019
		June 6, 1986	1,019
		Oct. 2, 1986	1,020
B16	25N 9W 34CABB	Sept. 24, 1985	961
		Oct. 29, 1985	961
		Dec. 10, 1985	961
		Jan. 13, 1986	961
		Feb. 19, 1986	961
		Apr. 10, 1986	961
		May 6, 1986	961
		June 6, 1986	962
		Oct. 2, 1986	962
B17	25N 10W 26CBCC	Sept. 24, 1985	960
		Oct. 29, 1985	961
		Dec. 10, 1985	961
		Jan. 13, 1986	961
		Feb. 19, 1986	961
		Apr. 10, 1986	961
		May 6, 1986	962
		June 6, 1986	962
		Oct. 2, 1986	963
B18	25N 11W 10BABA	Sept. 25, 1985	1,039
		Oct. 30, 1985	1,039
		Dec. 11, 1985	1,040
		Feb. 19, 1986	1,039
		Apr. 10, 1986	1,041
		May 6, 1986	1,041
		June 6, 1986	1,041
		Oct. 2, 1986	1,040
B19	25N 11W 33CCCC	Sept. 24, 1985	1,019
		Oct. 29, 1985	1,019
		Dec. 10, 1985	1,018
		Jan. 15, 1986	1,018
		Feb. 19, 1986	1,018
		Apr. 10, 1986	1,018
		May 6, 1986	1,019
		June 5, 1986	1,020
		Oct. 2, 1986	1,019
B20	25N 12W 16AAAA	Sept. 24, 1985	912
		Oct. 29, 1985	912
		Dec. 10, 1985	912
		Jan. 13, 1986	912
		Feb. 20, 1986	912
		Apr. 10, 1986	912
		May 6, 1986	913
		June 4, 1986	913
		Oct. 2, 1986	913

Table 6.--Chemical and physical characteristics of water at stream sites

[Analyses by U.S. Geological Survey. --, no analysis made; <, less than; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units]

Site number	Station number and name	Date	Time	Stream-flow, instan-taneous (ft^3/s)	Specific conduct-ance lab (µS/cm)	Temper-ature (°C)	Turbid-ity (NTU)
2	04123910 Anderson Creek	April 2, 1986	1045	25	321	8.5	0.5
	near Buckley	June 5, 1986	1000	10	462	15.0	1.5
5	04126546 Green Lake Inlet	April 3, 1986	1100	132	287	7.5	1.4
	near Interlochen	June 3, 1986	1645	41	315	20.5	1.2
9	04126970 Boardman River	April 3, 1986	0800	338	240	7.0	1.8
	at Brown Bridge Road	June 4, 1986	0930	143	322	12.0	1.2
	near Mayfield						
11	04126997 East Creek	April 2, 1986	1500	55	239	8.0	1.4
	near Mayfield	June 4, 1986	1400	24	341	13.0	1.4
12	04126991 Boardman River	April 2, 1986	1645	393	215	12.0	1.5
	below Brown Bridge Pond	June 4, 1986	1100	158	316	15.5	1.5
	near Mayfield						
13	04127008 Swainston Creek	April 2, 1986	1330	19	351	9.0	1.9
	at Mayfield	June 4, 1986	1300	14	386	13.5	2.1
15	04127250 Boardman River	April 3, 1986	1230	539	254	10.0	2.0
	near Traverse City	June 4, 1986	1530	257	347	18.5	3.0
16	04127490 Boardman River	April 3, 1986	1000	577	283	8.0	1.0
	at Traverse City	June 4, 1986	0930	320	360	17.0	1.2
17	04127498 Hospital Creek	April 3, 1986	1315	16	539	8.0	2.6
	at Traverse City	June 5, 1986	0845	10	533	11.5	3.0
18	04127520 Mitchell Creek	April 3, 1986	1430	12	396	9.0	.9
	at Traverse City	June 5, 1986	1045	6.7	421	11.5	2.5
19	04127528 Acme Creek	April 4, 1986	1115	20	322	7.0	1.2
	at Acme	June 5, 1986	1330	16	329	11.5	1.2
20	04127535 Yuba Creek	April 4, 1986	0930	15	353	6.5	1.2
	near Acme	June 3, 1986	1600	5.3	441	17.0	1.2
21	04127550 Tobeco Creek	April 2, 1986	1600	19	262	14.0	.4
	near Elk Rapids	June 3, 1986	1500	2.7	445	18.0	2.0
22	04127600 Battle Creek	April 2, 1986	1100	13	318	7.5	1.7
	near Williamsburg	June 3, 1986	1030	12	331	9.5	1.2
23	04127620 Williamsburg	April 2, 1986	1400	16	325	10.5	.8
	Creek near Williamsburg	June 3, 1986	1300	14	336	14.5	1.5

Table 6.--Chemical and physical characteristics of water at stream sites--Continued

Site number	Color (platinum-cobalt units)	Oxygen dissolved (mg/L)	pH (standard units)	Silica, dissolved (mg/L AS SiO_2)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
2	40	8.0	7.80	3.7	45	9.6	4.3	1.0	11	12
	20	8.2	7.80	4.4	68	14	6.1	1.2	18	21
5	25	10.6	7.90	7.2	41	9.9	3.0	.8	10	5.4
	5	9.4	8.40	6.6	45	11	4.0	.8	11	6.5
9	35	10.6	8.00	6.0	34	7.5	3.2	.8	12	7.1
	10	10.1	8.20	7.3	46	10	3.8	.6	8.8	8.6
11	32	11.0	8.00	7.0	33	7.8	2.9	.9	10	6.1
	10	10.3	8.30	8.0	48	12	4.3	.9	11	8.2
12	40	9.8	7.90	5.9	30	6.5	2.9	.8	12	6.4
	15	10.0	8.40	7.0	45	10	3.9	.7	8.5	8.1
13	10	11.2	8.20	7.8	50	11	5.8	1.2	11	9.4
	5	10.5	8.40	8.5	58	12	5.5	.9	16	11
15	30	10.2	8.00	6.4	36	7.8	3.4	.9	15	7.6
	10	9.7	8.30	7.6	52	12	4.8	.9	10	8.8
16	35	10.8	8.10	6.6	39	8.5	5.2	1.0	13	9.8
	20	9.2	8.30	7.4	52	11	6.7	1.0	11	12
17	27	12.4	8.10	9.6	76	17	14	1.5	18	23
	8	9.9	8.20	9.9	74	17	12	1.2	23	18
18	10	11.9	8.40	7.2	59	13	5.2	1.2	12	8.7
	5	10.5	8.40	8.4	62	14	4.7	.9	14	7.0
19	12	12.2	8.30	8.2	47	11	3.2	.9	12	4.6
	3	10.9	8.30	8.2	47	11	2.8	.7	12	3.4
20	20	10.3	7.90	3.0	53	12	2.7	1.2	14	5.6
	35	7.8	8.00	5.4	66	16	3.2	1.2	16	5.3
21	23	9.4	8.00	3.8	38	7.9	1.9	1.8	12	4.7
	50	7.9	7.90	4.9	68	15	3.3	1.2	12	6.1
22	5	11.8	8.30	8.5	46	11	3.3	.7	9.4	4.0
	2	11.1	8.20	8.7	47	11	3.2	.6	8.6	3.8
23	12	10.8	8.30	8.0	46	11	3.5	.8	10	5.2
	5	10.2	8.20	7.8	46	12	3.3	.7	10	4.2

Table 6.--Chemical and physical characteristics of water at stream sites--Continued

Site number	Fluoride, dissolved (mg/L as F)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, Nitrite dissolved (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, organic dissolved (mg/L as N)	Phosphorus, ortho, total (mg/L as P)
2	<0.1	0.04	--	<0.01	<0.01	0.497	0.504	0.36	0.38	<0.01
	<.1	.05	0.04	<.01	<.01	.692	.684	.35	.26	<.01
5	.2	.03	.03	<.01	<.01	.168	.169	.87	.37	<.01
	.2	.06	--	<.01	<.01	.081	.083	.44	.23	<.01
9	<.1	--	.02	--	<.01	--	.196	.39	.38	<.01
	<.1	<.01	<.01	<.01	<.01	.281	.283	--	--	<.01
11	<.1	--	.01	<.01	<.01	--	.415	--	.29	<.01
	.1	.01	<.01	<.01	<.01	.769	.759	.29	--	<.01
12	<.1	.02	.02	<.01	<.01	--	.166	.38	.38	<.01
	<.1	.03	<.01	<.01	<.01	.178	.18	.37	--	<.01
13	.1	.03	.02	<.01	<.01	.292	.301	.37	.28	<.01
	.1	.01	<.01	<.01	<.01	.26	.269	.29	--	<.01
15	<.1	--	.03	--	<.01	--	.215	.38	.37	<.01
	.1	.02	.01	<.01	<.01	.23	.252	.48	.19	<.01
16	.1	.04	.04	<.01	<.01	.337	.342	--	.46	<.01
	.1	.06	.02	<.01	<.01	.289	.288	.34	.18	<.01
17	.4	.06	.05	--	<.01	--	.517	.34	.25	.01
	.4	.04	.04	<.01	<.01	--	.463	.36	.26	<.01
18	.2	.04	.03	<.01	<.01	--	.484	.36	.27	<.01
	.2	.03	.03	<.01	<.01	--	.781	.37	.17	<.01
19	<.1	--	.02	<.01	<.01	.155	--	--	.28	<.01
	.1	.02	.01	<.01	<.01	.136	.133	.18	.19	.01
20	.1	.06	.04	<.01	<.01	.853	.834	.54	.46	.01
	.1	--	.05	<.01	.01	1.40	.172	.56	.45	.03
21	<.1	.03	.02	<.01	<.01	.042	.042	.47	.38	<.01
	.2	.04	.04	<.01	<.01	.005	--	.66	--	<.01
22	<.1	.02	.02	<.01	<.01	.193	.193	.28	.28	<.01
	.2	.01	.01	<.01	<.01	.185	.189	--	--	<.01
23	.1	.03	.03	<.01	<.01	.196	.199	.27	.27	<.01
	.1	--	.03	<.01	<.01	.123	.117	.18	.17	<.01

Table 6.--Chemical and physical characteristics of water at stream sites--Continued

Site number	Phosphorus, total (mg/L as P)	Carbon, organic dissolved (mg/L as C)	Cyanide total (mg/L as CN)	Phenols total (µg/L)	Alkalinity Lab (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Hardness noncarbonate (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 °C dissolved (mg/L)	Aluminum, total recoverable (µg/L as Al)
2	0.01	7.4	<0.01	3	135	150	150	170	185	20
	.01	7.1	<.01	<1	204	230	230	260	271	<10
5	.02	5.9	<.01	2	135	140	140	160	165	<10
	.01	8.6	<.01	1	147	160	160	170	181	<10
9	.01	7.2	<.01	2	107	120	120	140	137	60
	.01	4.0	<.01	5	149	160	160	180	180	10
11	.02	6.3	<.01	1	107	110	110	130	139	70
	.01	7.4	<.01	<1	156	170	170	190	195	10
12	.01	6.9	<.01	1	94	100	100	120	128	170
	.01	4.6	<.01	2	146	150	150	170	174	10
13	.01	3.8	<.01	1	156	170	170	190	197	70
	.01	14	<.01	4	177	190	190	220	220	170
15	.01	6.9	<.01	2	113	120	120	150	149	30
	.02	4.3	<.01	<1	161	180	180	190	199	90
16	.02	3.4	<.01	<1	123	130	130	160	160	40
	.02	5.3	<.01	1	161	180	180	200	206	<10
17	.03	4.4	<.01	<1	233	260	260	300	308	70
	.03	3.4	<.01	<1	237	250	250	300	297	100
18	.01	4.6	<.01	2	189	200	200	220	227	20
	.03	3.3	<.01	<1	205	210	210	240	255	80
19	.02	3.8	<.01	3	155	160	160	180	179	30
	.01	5.0	<.01	10	161	160	160	180	179	30
20	.03	3.7	<.01	<1	167	180	180	200	200	20
	.06	10	<.01	<1	213	230	230	240	262	20
21	.01	5.9	<.01	2	124	130	130	140	148	<10
	.02	19	<.01	<1	228	230	230	250	276	<10
22	.02	2.8	<.01	<1	159	160	160	180	176	40
	.01	2.7	<.01	<1	165	160	160	180	184	<10
23	.02	3.8	<.01	<1	158	160	160	180	184	30
	.01	3.8	<.01	<1	163	160	160	180	186	<10

Table 6.--Chemical and physical characteristics of water at stream sites--Continued

Site number	Arsenic total (µg/L as As)	Barium, total recov-erable (µg/L as Ba)	Boron, total recov-erable (µg/L as B)	Cadmium total recov-erable (µg/L as Cd)	Chro-mium, total recov-erable (µg/L as Cr)	Cobalt total recov-erable (µg/L as Co)	Copper, total recov-erable (µg/L as Cu)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Lead, total recov-erable (µg/L as Pb)
2	<1	<100	<10	<1	<10	<1	2	110	72	<5
	<1	<100	<10	<1	<10	<1	2	70	47	<5
5	<1	<100	<10	<1	<10	<1	3	100	38	<5
	<1	<100	<10	<1	<10	<1	7	90	22	<5
9	<1	<100	<10	<1	<10	<1	6	200	55	6
	1	<100	<10	<1	<10	<1	6	180	38	<5
11	<1	<100	<10	<1	<10	<1	4	190	57	<5
	<1	100	<10	<1	<10	<1	4	60	18	<5
12	<1	<100	<10	<1	<10	<1	3	160	71	<5
	1	<100	<10	<1	<10	<1	5	100	18	<5
13	<1	<100	<10	<1	<10	<1	1	310	36	<5
	<1	<100	<10	<1	<10	<1	6	540	32	<5
15	<1	<100	<10	<1	<10	<1	5	280	68	<5
	<1	<100	<10	<1	10	<1	2	350	12	<5
16	<1	<100	<10	<1	<10	<1	3	190	65	<5
	<1	<100	100	<1	<10	<1	4	110	9	<5
17	<1	<100	<10	<1	<10	<1	5	710	79	<5
	<1	<100	<10	<1	<10	<1	4	960	42	<5
18	<1	<100	<10	<1	<10	<1	5	110	36	<5
	<1	<100	<10	<10	<10	<1	3	280	17	<5
19	<1	<100	<10	<1	<10	<1	2	110	23	<5
	<1	<100	<10	<1	<10	<1	4	150	13	<5
20	<1	<100	<10	<1	<10	1	3	80	36	<5
	1	100	<10	<1	<10	<1	5	150	45	<5
21	<1	<100	<10	<1	<10	<1	2	20	19	<5
	<1	<100	<10	<1	<10	<1	2	60	41	<5
22	1	<100	<10	<1	<10	<1	4	330	19	<5
	<1	<100	<10	<1	<10	<1	3	170	15	<5
23	<1	<100	--	<1	<10	<1	3	130	38	<5
	<1	<100	<10	<1	<10	<1	4	110	29	<5

Table 6.--Chemical and physical characteristics of water at stream sites--Continued

Site number	Lithium dis-solved (µg/L as Li)	Manga-nese, Total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)	Mercury total recov-erable (µg/L as Hg)	Nickel, total recov-erable (µg/L as Ni)	Sele-nium, total (µg/L as Se)	Stron-tium, total recov-erable (µg/L as Sr)	Stron-tium, dis-solved (µg/L as Sr)	Zinc, total recov-erable (µg/L as Zn)
2	<4	20	13	<0.1	<1	<1	50	41	30
	8	--	18	<.1	26	<1	--	65	10
5	5	10	4	<.1	<1	<1	60	58	<10
	5	10	9	<.1	2	<1	--	69	20
9	<4	30	11	<.1	<1	<1	50	45	<10
	4	40	10	<.1	2	<1	--	66	<10
11	<4	20	5	<.1	<1	<1	60	47	<10
	4	10	6	<.1	2	<1	80	70	<10
12	<4	30	16	<.1	<1	<1	40	40	<10
	4	40	4	<.1	3	<1	80	66	<10
13	5	40	11	<.1	2	<1	70	55	20
	5	70	9	<.1	3	<1	110	65	<10
15	5	30	15	<.1	<1	<1	--	51	<10
	6	110	4	<.1	5	<1	80	77	<10
16	<4	30	22	<.1	<1	<1	70	60	10
	6	20	6	<.1	2	<1	--	79	<10
17	7	40	29	<.1	<1	<1	110	110	<10
	8	40	14	<.1	1	<1	--	110	40
18	5	20	19	<.1	<1	<1	70	70	10
	6	40	13	<.1	<1	<1	80	72	<10
19	5	20	6	.5	1	<1	60	51	20
	5	10	<4	<.1	1	<1	60	50	20
20	6	30	11	<.1	4	<1	70	55	20
	6	50	23	<.1	3	<1	80	70	20
21	<4	<10	5	<.1	<1	<1	50	44	<10
	7	<10	7	<.1	1	<1	--	85	<10
22	<4	30	4	<.1	<1	<1	80	68	<10
	5	20	5	<.1	1	<1	--	69	<10
23	<4	40	23	<.1	<1	<1	60	58	<10
	5	40	23	<.1	2	<1	60	60	<10

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan

[Analyses by U.S. Geological Survey. --, no data or no analysis made; mg/L, milligrams per liter; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Period of collection	Rainfall, (inches)	Snow, water content (inches)	Specific conductance (µS/cm)	pH (standard units)	Sulfate dissolved (mg/L as SO_4)	Nitrogen, total (mg/L as N)
October 30, - November 2, 1984	1.6	--	18	4.4	1.9	1.3
November 9, - November 11, 1984	.77	--	20	4.5	2.0	1.3
November 21, - November 28, 1984	.30	--	18	4.4	--	.90
November 30, - December 4, 1984	.50	--	13	4.8	--	--
December 11, - December 13, 1984	--	0.40	31	4.4	1.8	1.2
December 14, - December 17, 1984	--	.30	32	4.8	--	--
December 21, - December 24, 1984	--	.80	18	4.7	1.2	.80
December 27, - December 28, 1984	1.1	--	12	4.9	2.6	1.0
December 31, 1984 - January 2, 1985	--	.71	5	5.2	--	--
January 16. - January 23, 1985	--	.95	14	4.6	1.2	1.1
February 10, - February 14, 1985	--	1.10	63	4.9	.7	6.5
February 14, - February 19, 1985	--	.21	12	4.7	--	1.6
February 21, - February 26, 1985	--	1.14	22	4.4	1.6	.60
March 9, - March 26, 1985	--	.84	14	4.6	--	--
March 26, - April 2, 1985	--	.50	28	4.3	4.2	1.7
April 4, - April 9, 1985	--	1.90	18	4.8	3.2	1.5
April 19, - April 20, 1985	--	.45	19	6.3	--	--
April 24, - April 25, 1985	.75	--	24	4.4	2.8	.90
May 10, 1985	.20	--	28	6.2	4.2	2.3
May 12, - May 13, 1985	.20	--	32	4.2	3.5	1.7
May 15, 1985	.35	--	28	4.2	2.0	1.0
May 20, 1985	.16	--	34	6.2	--	--
May 25, - May 27, 1985	1.9	--	27	4.3	3.7	1.6
June 8, - June 9, 1985	.35	--	15	5.9	2.3	1.4

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan--Continued

Period of collection	Rainfall, (inches)	Snow, water content (inches)	Specific conductance (µS/cm)	pH (standard units)	Sulfate dissolved (mg/L as SO_4)	Nitrogen, total (mg/L as N)
June 15, - June 17, 1985	.51	--	11	4.4	1.6	.90
June 22, - June 23, 1985	0.23	--	10	6.0	3.2	2.2
July 7, - July 8, 1985	.15	--	11	5.0	--	--
July 25, 1985	1.8	--	51	3.8	5.3	--
July 28, - July 29, 1985	.38	--	15	4.8	1.9	1.1
August 5, - August 6, 1985	1.1	--	17	4.5	--	.70
August 12, - August 18, 1985	.76	--	37	4.0	4.4	.90
August 23, - August 27, 1985	2.3	--	27	4.1	--	--
August 28, - August 30, 1985	.85	--	27	4.1	--	--
September 3, - September 4, 1985	.90	--	17	4.8	3.1	--
September 5, - September 6, 1985	2.3	--	14	4.6	1.5	.70
September 7, - September 9, 1985	2.5	--	13	4.6	1.7	.70
September 18, 1985	1.7	--	31	4.3	3.4	1.6
September 21, - September 25, 1985	9.0	--	18	4.6	--	--
October 4, - October 7, 1985	.38	--	25	4.2	--	--
October 9, - October 10, 1985	.60	--	15	4.3	--	--
October 12, - October 13, 1985	1.25	--	14	4.4	1.4	.60
October 23, - October 24, 1985	.20	--	--	--	--	--
November 2, - November 5, 1985	1.40	--	16	4.5	1.1	.50
November 6, - November 7, 1985	--	0.33	--	--	--	--
November 13, 1985	--	.54	23	5.3	--	--
November 16, - November 19, 1985	1.50	--	14	4.3	--	1.5
November 19, - November 20, 1985	.40	--	10	4.6	--	--
December 1, - December 11, 1985	--	--	20	4.3	--	--
December 22, - December 24, 1986	--	--	38	5.4	1.4	1.0
January 2, - January 7, 1986	--	--	19	4.6	1.8	1.6

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan--Continued

Period of collection	Rainfall, (inches)	Snow, water content (inches)	Specific conductance (µS/cm)	pH (standard units)	Sulfate dissolved (mg/L as SO_4)	Nitrogen, total (mg/L as N)
March 25, - March 26, 1986	0.50	--	25	5.8	12	1.7
April 1, 1986	.32	--	--	--	--	--
April 3, - April 4, 1986	.25	--	--	--	--	--
April 4, - April 7, 1986	.52	--	39	4.2	30	3.2
April 8, - April 9, 1986	.06	--	--	--	--	--
April 14, - April 15, 1986	.25	--	--	--	--	--
April 15, - April 16, 1986	.18	--	--	--	--	--
April 26, 1986	.20	--	58	4.0	--	--
May 15, - May 16, 1986	.95	--	23	4.1	--	--
May 16, - May 19, 1986	.75	--	--	--	--	--
June 4, - June 5, 1986	--	--	29	4.0	--	--
June 11, - June 12, 1986	.45	--	--	--	--	--
June 12, - June 13, 1986	.55	--	--	--	--	--
June 19, 1986	.23	--	24	4.1	--	--
June 24, 1986	.75	--	7	5.1	--	--
June 26, 1986	1.18	--	16	4.3	--	--
June 26, - June 27, 1986	1.10	--	--	--	--	--
July 12, - July 13, 1986	.23	--	15	4.2	--	--
July 15, - July 18, 1986	.25	--	24	4.0	--	--
July 24, - July 25, 1986	2.83	--	--	--	--	--
August 9, 1986	.84	--	24	4.1	--	--
August 14, - August 15, 1986	--	--	14	4.3	--	--
September 3, - September 4, 1986	1.10	--	56	3.7	--	--
September 9, - September 12, 1986	3.45	--	9	4.8	--	--
September 14, - September 22, 1986	3.05	--	20	4.4	--	--
September 25, - September 26, 1986	1.55	--	--	--	--	--
September 28, - September 29, 1986	3.30	--	16	4.5	--	--

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan--Continued

Period of collection	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, nitrate, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)
October 30, - November 2, 1984	0.84	0.26	0.02	0.18	--	0.02
November 9, - November 11, 1984	.54	.46	<.01	.30	--	.01
November 21, - November 28, 1984	.23	.27	.01	.39	<0.01	<.01
November 30, - December 4, 1984	--	--	--	--	--	--
December 11, - December 13, 1984	.06	.64	<.01	.50	--	.03
December 14, - December 17, 1984	--	--	--	--	--	--
December 21, - December 24, 1984	.29	.31	<.01	.20	--	.04
December 27, - December 28, 1984	.04	.76	<.01	.20	<.01	<.01
December 31, 1984 - January 2, 1985	--	--	--	--	--	--
January 16, - January 23, 1985	.40	.40	<.01	.30	--	.01
February 10, - February 14, 1985	1.4	3.1	<.01	2.0	<.01	<.01
February 14, - February 19, 1985	.87	.33	.02	.38	--	--
February 21, - February 26, 1985	.06	.36	.04	.26	.02	.01
March 9, - March 26, 1985	--	--	--	--	--	--
March 26, - April 2, 1985	.36	.84	<.01	.50	.08	.01
April 4, - April 9, 1985	.19	.91	<.01	.40	--	.03
April 19, - April 20, 1985	--	--	--	--	--	--
April 24, - April 25, 1985	.13	.47	<.01	.30	<.01	<.01
May 10, 1985	.30	1.3	.02	.68	.07	<.01
May 12, - May 13, 1985	.46	.74	.02	.48	.03	.01
May 15, 1985	.12	.48	<.01	.40	<.01	<.01
May 20, 1985	--	--	--	--	--	--
May 25, - May 27, 1985	.00	1.0	<.01	.60	<.01	<.01
June 8, - June 9, 1985	.11	.79	.01	.49	.01	<.01
June 15, - June 17, 1985	.32	.48	<.01	.10	.03	<.01

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan--Continued

Period of collection	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, nitrate, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)
June 22, - June 23, 1985	1.2	0.68	<0.01	0.32	0.03	0.02
July 7, - July 8, 1985	--	--	--	--	--	
July 25, 1985	.08	.52	<.01	--	<.01	<.01
July 28, - July 29, 1985	.13	.67	.02	.28	<.01	<.01
August 5, - August 6, 1985	.02	.38	<.01	.30	<.01	<.01
August 12, - August 18, 1985	.00	.50	<.01	.40	.02	.02
August 23, - August 27, 1985	--	--	--	--	--	--
August 28, - August 30, 1985	--	--	--	--	--	--
September 3, - September 4, 1985	--	.51	<.01	--	.02	.02
September 5, - September 6, 1985	.24	.16	<.01	.30	.03	.01
September 7, - September 9, 1985	.03	.37	<.01	.30	--	.02
September 18, 1985	.69	.51	<.01	.40	.02	<.01
September 21, - September 25, 1985	--	--	--	--	--	--
October 4, - October 7, 1985	--	--	--	--	--	--
October 9, - October 10, 1985	--	--	--	--	--	--
October 12, - October 13, 1985	.14	.26	<.01	.20	.02	.04
October 23, - October 24, 1985	--	--	--	--	--	--
November 2, - November 5, 1985	.07	.13	.01	.29	.02	.01
November 6, - November 7, 1985	--	--	--	--	--	--
November 13, 1985	--	--	--	--	--	--
November 16, - November 19, 1985	1.1	.19	<.01	.21	.01	.01
November 19, - November 20, 1985	--	--	--	--	--	--
December 1, - December 11, 1985	--	--	--	--	--	--
December 22, - December 24, 1985	.57	.33	<.01	.10	.02	<.01
January 2, - January 7, 1986	.05	.85	<.01	.70	.01	.01

Table 11.--Chemical and physical characteristics of precipitation near Kingsley, Michigan--Continued

Period of collection	Nitrogen, organic, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, nitrate, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)
March 25, - March 26, 1986	0.44	0.86	0.02	0.38	0.04	0.03
April 1, 1986	--	--	--	--	--	--
April 3, - April 4, 1986	--	--	--	--	--	--
April 4, - April 7, 1986	2.3	.26	<.01	--	.56	.32
April 8, - April 9, 1986	--	--	--	--	--	--
April 14, - April 15, 1986	--	--	--	--	--	--
April 15, - April 16, 1986	--	--	--	--	--	--
April 26, 1986	--	--	--	--	--	--
May 15, - May 16, 1986	--	--	--	--	--	--
May 15, - May 19, 1986	--	--	--	--	--	--
June 4, - June 5, 1986	--	--	--	--	--	--
June 11, - June 12, 1986	--	--	--	--	--	--
June 12, - June 13, 1986	--	--	--	--	--	--
June 19, 1986	--	--	--	--	--	--
June 24, 1986	--	--	--	--	--	--
June 26, 1986	--	--	--	--	--	--
June 26, - June 27, 1986	--	--	--	--	--	--
July 12, - July 13, 1986	--	--	--	--	--	--
July 15, - July 18, 1986	--	--	--	--	--	--
July 24, - July 25, 1986	--	--	--	--	--	--
August 9, 1986	--	--	--	--	--	--
August 14, - August 15, 1986	--	--	--	--	--	--
September 3, - September 4, 1986	--	--	--	--	--	--
September 9, - September 12, 1986	--	--	--	--	--	--
September 14, - September 22, 1986	--	--	--	--	--	--
September 25, - September 26, 1986	--	--	--	--	--	--
September 28, - September 29, 1986	--	--	--	--	--	--

Table 15.--Measurements of specific conductance, pH, and concentrations of dissolved oxygen, and suspended sediment at stream sites, 1984-86

[Analyses by U.S. Geological Survey. µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

Site number	Number of analyses		Specific conductance (µS/cm)	pH (standard units)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturated)	Sediment, suspended (mg/L)
1	7	Maximum	283	7.9	10.2	94	4
		Mean	249	7.7	8.2	77	2
		Minimum	229	7.3	6.3	61	0
2	22	Maximum	484	8.4	11.6	102	38
		Mean	421	7.8	8.6	77	5
		Minimum	307	7.5	5.9	63	1
3	7	Maximum	469	8.3	13.4	101	41
		Mean	439	8.0	10.6	98	10
		Minimum	405	7.2	8.6	96	1
4	7	Maximum	316	8.6	14.4	117	4
		Mean	302	8.3	10.7	104	2
		Minimum	288	8.0	8.3	88	0
5	22	Maximum	326	8.4	12.5	107	11
		Mean	299	8.0	9.4	86	3
		Minimum	254	7.8	6.0	62	<1
6	7	Maximum	326	8.6	13.3	118	6
		Mean	297	8.4	10.6	100	2
		Minimum	243	8.1	9.0	85	1
7	7	Maximum	336	8.3	12.6	98	21
		Mean	315	8.1	10.7	95	8
		Minimum	273	7.6	8.8	90	2
8	8	Maximum	326	8.4	12.8	93	31
		Mean	301	8.2	10.3	90	9
		Minimum	274	7.6	8.0	86	1
9	23	Maximum	349	8.4	12.6	96	27
		Mean	305	8.2	10.6	93	10
		Minimum	232	7.7	8.7	90	3
10	6	Maximum	313	8.4	12.1	109	10
		Mean	305	8.2	10.1	92	5
		Minimum	294	8.0	8.7	68	1
11	22	Maximum	354	8.3	13.2	100	11
		Mean	295	8.2	11.0	96	5
		Minimum	229	7.7	9.3	92	2
12	21	Maximum	352	8.5	12.8	128	4
		Mean	303	8.2	11.1	101	2
		Minimum	206	7.9	9.9	89	1

Table 15.--Measurements of specific conductance, pH, and concentrations of dissolved oxygen, and suspended sediment at stream sites, 1984-86--Continued

Site number	Number of analyses		Specific conductance (µS/cm)	pH (standard units)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturated)	Sediment, suspended (mg/L)
13	22	Maximum	411	8.4	12.8	128	60
		Mean	373	8.2	11.1	101	15
		Minimum	345	7.6	9.9	89	3
14	7	Maximum	340	8.0	10.5	80	12
		Mean	304	7.8	8.1	71	4
		Minimum	271	7.4	6.8	67	1
15	22	Maximum	382	8.4	13.1	112	23
		Mean	338	8.1	10.4	96	6
		Minimum	246	7.7	8.5	89	1
16	22	Maximum	408	8.5	14.1	109	41
		Mean	353	8.2	10.6	96	5
		Minimum	292	8.0	8.0	86	1
17	22	Maximum	655	8.3	13.5	98	84
		Mean	556	8.2	10.8	92	36
		Minimum	412	8.0	7.3	74	2
18	22	Maximum	486	8.5	13.7	106	77
		Mean	428	8.3	10.8	94	19
		Minimum	315	8.0	7.9	81	3
19	22	Maximum	380	8.4	13.1	105	20
		Mean	328	8.3	11.3	100	9
		Minimum	259	8.0	10.1	96	2
20	22	Maximum	491	8.2	12.6	100	35
		Mean	422	8.0	9.7	85	10
		Minimum	310	7.5	5.9	64	1
21	22	Maximum	521	8.2	12.2	91	42
		Mean	434	7.8	7.8	73	9
		Minimum	277	7.2	4.7	34	0
22	22	Maximum	360	8.4	12.5	102	55
		Mean	329	8.2	10.9	97	16
		Minimum	272	7.7	8.6	92	3
23	22	Maximum	369	8.3	13.0	101	25
		Mean	339	8.1	10.5	93	6
		Minimum	288	7.7	8.2	86	1
24	3	Maximum	329	8.2	12.5	110	11
		Mean	316	8.2	11.7	100	5
		Minimum	306	8.1	11.1	89	2

Table 17.--Maximum, mean, and minimum concentrations of total nitrogen and total phosphorus at stream sites, 1984-86

[Results in milligrams per liter. Analyses by U.S. Geological Survey. <, less than]

Site number	Number of analyses		Nitrogen, ammonia total (as N)	Nitrogen, nitrate total (as N)	Nitrogen, nitrite total (as N)	Nitrogen organic total (as N)	Nitrogen, total (as N)	Phosphorus, ortho total (as P)	Phosphorus, total (as P)
1	7	Maximum	0.16	0.080	0.012	0.84	0.98	0.08	0.10
		Mean	.08	.047	.001	.51	.68	.02	.03
		Minimum	.04	.027	<.001	.16	.37	<.01	<.01
2	22	Maximum	.16	2.17	.018	1.1	3.5	.01	.02
		Mean	.06	.910	.009	.46	1.6	<.01	.01
		Minimum	<.01	.377	<.001	.24	.9	<.01	<.01
3	7	Maximum	.06	.987	.013	1.3	1.8	.01	.04
		Mean	.03	.765	.011	.59	1.4	<.01	.01
		Minimum	<.01	.357	.002	.24	1.0	<.01	<.01
4	7	Maximum	.13	.141	.010	1.1	1.2	<.01	.01
		Mean	.05	.071	.004	.56	.66	<.01	<.01
		Minimum	<.01	.034	<.001	.26	.45	<.01	<.01
5	22	Maximum	.14	.196	.011	1.1	1.1	<.01	.03
		Mean	.06	.113	.004	.50	.63	<.01	.01
		Minimum	<.01	.041	<.001	.21	.35	<.01	<.01
6	7	Maximum	.04	.124	.007	.67	.60	<.01	.04
		Mean	.02	.068	.003	.43	.50	<.01	.01
		Minimum	<.01	.037	<.001	.26	.43	<.01	<.01
7	7	Maximum	.04	.467	.012	.99	1.4	<.01	.01
		Mean	.02	.337	.005	.46	.90	<.01	<.01
		Minimum	<.01	.298	<.001	.16	.61	<.01	<.01
8	8	Maximum	.04	.469	.010	1.2	1.5	<.01	.01
		Mean	.02	.410	.004	.49	.93	<.01	<.01
		Minimum	<.01	.316	>.001	.16	.64	<.01	<.01
9	23	Maximum	.24	.500	.029	1.3	1.5	.02	.02
		Mean	.04	.316	.006	.44	.86	<.01	.01
		Minimum	<.01	.210	>.001	.06	.55	<.01	<.01
10	6	Maximum	.06	.401	.006	.88	1.4	<.01	.09
		Mean	.04	.352	.003	.40	.84	<.01	.02
		Minimum	.02	.283	.001	.24	.65	<.01	<.01
11	22	Maximum	.20	.984	.010	1.3	1.9	.01	.04
		Mean	<.01	.664	.004	.38	1.1	<.01	.01
		Minimum	<.01	.091	<.001	.16	.30	<.01	<.01
12	21	Maximum	.08	.315	.034	.87	1.1	<.01	.02
		Mean	.03	.223	.005	.40	.66	<.01	.01
		Minimum	<.01	.091	<.001	.05	.37	<.01	<.01

Table 17.--Maximum, mean, and minimum concentrations of total nitrogen and total phosphorus at stream sites, 1984-86--Continued

Site number	Number of analyses		Nitrogen, ammonia total (as N)	Nitrogen, nitrate total (as N)	Nitrogen, nitrite total (as N)	Nitrogen organic total (as N)	Nitrogen, total (as N)	Phosphorus, ortho total (as P)	Phosphorus, total (as P)
13	22	Maximum	0.10	0.386	0.016	1.1	1.4	0.01	0.03
		Mean	.03	.296	.003	.40	.76	<.01	.01
		Minimum	<.01	.246	<.001	.17	.49	<.01	<.01
14	7	Maximum	.07	.200	.014	1.6	1.8	<.01	.02
		Mean	.05	.076	.007	.66	.86	<.01	.01
		Minimum	.02	.007	<.001	.23	.37	<.01	<.01
15	22	Maximum	.07	.370	.022	.77	1.2	.01	.03
		Mean	.02	.258	.005	.34	.65	<.01	.01
		Minimum	<.01	.163	<.001	.15	.42	<.01	<.01
16	22	Maximum	.42	.520	.052	.93	1.5	.03	.09
		Mean	.15	.347	.010	.49	.99	.01	.02
		Minimum	<.01	.161	<.001	.18	.68	<.01	<.01
17	22	Maximum	.12	.648	.023	1.0	1.5	.02	.05
		Mean	.06	.499	.008	.47	1.1	.01	.02
		Minimum	<.01	.406	<.001	.23	.74	<.01	<.01
18	22	Maximum	.12	.855	.023	1.9	2.6	.02	.04
		Mean	.06	.633	.008	.51	1.2	.01	.02
		Minimum	<.01	.300	<.001	.25	.65	<.01	<.01
19	22	Maximum	.08	.210	.015	.60	1.0	.03	.03
		Mean	.02	.143	.006	.28	.49	<.01	.01
		Minimum	<.01	.045	<.001	.08	.19	<.01	<.01
20	22	Maximum	.07	3.98	.127	1.5	4.4	.03	.06
		Mean	.04	1.28	.012	.58	2.0	.01	.02
		Minimum	<.01	.298	<.001	.28	.76	<.01	<.01
21	22	Maximum	.12	.238	.028	1.7	1.7	.01	.02
		Mean	.04	.058	.006	.81	.91	<.01	.01
		Minimum	<.01	.005	<.001	.36	.52	<.01	<.01
22	22	Maximum	.14	.828	.077	1.2	1.3	.01	.02
		Mean	.03	.222	.007	.40	.64	<.01	.01
		Minimum	<.01	.116	<.001	.17	.32	<.01	<.01
23	22	Maximum	.26	.472	.300	1.2	1.4	.01	.02
		Mean	.06	.214	.008	.37	.65	<.01	.01
		Minimum	<.01	.050	<.001	.05	.33	<.01	<.01
24	3	Maximum	.06	1.28	.016	.28	1.5	<.01	.01
		Mean	.04	.535	.007	.23	.81	<.01	<.01
		Minimum	.02	.152	.002	.14	.46	<.01	<.01

Table 25.--Chemical and physical characteristics of water of lakes

[Analyses by U.S. Geological Survey. --, no analysis made; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Site number	Station name	Date	Time	Specific conductance lab (µS/cm)	Temperature (°C)	Turbidity (NTU)
L1	Fife Lake at Fife Lake	August 28, 1986	1500	248	19.5	1.1
L2	Prescott Lake near Old Mission	August 29, 1986	1345	176	17.0	1.6
L3	Elk Lake in northeast Grand Traverse County	September 2, 1986	1200	274	19.5	1.5
L4	Long Lake near Interlochen	September 2, 1986	1500	154	20.5	.5
L5	Duck Lake near Interlochen	September 3, 1986	1230	300	19.5	--
L6	Spider Lake near Mayfield	September 3, 1986	1500	198	20.5	.5
L7	Sand Lake No. 1 near Williamsburg	September 4, 1986	1100	220	20.0	2.0
L8	Brewster Lake near Kingsley	September 4, 1986	1530	341	17.5	.6
L9	Green Lake near Interlochen	September 3, 1986	1400	279	20.0	--
L10	Silver Lake near Grawn	September 3, 1986	1030	229	20.5	--
L11	Arbutus Lake near Mayfield	September 3, 1986	1830	251	20.0	--
L12	Rennie Lake near Mayfield	September 3, 1986	1130	202	19.0	--
L13	Fish Lake near Buckley	September 3, 1986	1500	155	20.0	--
L14	Grass Lake near Mayfield	September 4, 1986	1330	228	21.0	--
L15	Bass Lake near Grawn	September 3, 1986	0900	85	20.0	--

Table 25.--Chemical and physical characteristics of water of lakes--Continued

Site number	Color (platinum-cobalt units)	Oxygen dissolved (mg/L)	pH (standard units)	Silica, dissolved (mg/L as SiO_2)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
L1	5	8.2	8.2	8.2	40	7.7	3.3	1.1	9.8	5.8
L2	10	5.7	8.0	1.7	29	5.4	1.8	.7	8.5	3.7
L3	3	8.5	8.4	6.6	37	11	3.9	.9	11	5.9
L4	5	10.4	8.2	.2	23	4.2	1.2	.7	9.7	2.0
L5	--	9.4	8.6	6.6	41	12	3.0	.8	14	5.2
L6	5	10.0	8.5	.5	29	6.1	3.6	.8	6.8	7.3
L7	5	10.0	8.7	.9	39	3.8	<.2	.5	8.6	.7
L8	15	8.3	8.4	2.8	45	11	2.4	.9	18	8.7
L9	--	9.2	8.5	5.2	38	11	4.1	.8	10	6.5
L10	--	8.5	8.4	6.6	29	7.4	5.7	1.2	7.5	10
L11	--	9.2	8.4	6.7	38	10	4.8	.8	6.3	10
L12	--	9.0	8.6	.9	29	6.5	--	.8	7.1	13
L13	--	8.4	7.4	.7	24	4.9	1.1	.8	7.5	4.7
L14	--	--	7.7	1.2	38	5.8	.2	.8	11	5.3
L15	--	8.0	8.2	.2	13	2.4	.7	.6	6.9	1.9

Table 25.--Chemical and physical characteristics of water of lakes--Continued

Site number	Fluoride, dissolved (mg/L as F)	Nitrogen, ammonia total (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, organic dissolved (mg/L as N)	Nitrogen, total (mg/L as N)	Phosphorus, ortho, total (mg/L as P)
L1	<0.1	--	0.08	<0.01	<0.01	--	--	--	0.42	<0.01
L2	.2	0.42	.41	<.01	<.01	<0.01	0.78	0.19	1.2	<.01
L3	.1	.02	--	<.01	<.01	.18	.28	--	.48	<.01
L4	.2	.01	--	<.01	<.01	--	.29	--	--	<.01
L5	.2	.01	.03	<.01	<.01	--	.49	.57	--	<.01
L6	<.1	.02	.02	<.01	<.01	<.01	.58	.38	.61	<.01
L7	<.1	.02	--	<.01	<.01	--	.78	--	--	<.01
L8	.1	.02	--	<.01	<.01	<.01	.48	--	.51	<.01
L9	.2	.01	.01	<.01	<.01	--	.49	.49	--	<.01
L10	.1	.02	.02	<.01	<.01	--	.38	.28	--	<.01
L11	<.1	.01	--	<.01	<.01	--	.49	--	--	<.01
L12	<.1	.02	.01	<.01	<.01	--	.48	.39	--	<.01
L13	<.1	.02	.02	<.01	<.01	--	.58	.48	--	<.01
L14	<.1	.02	.01	<.01	<.01	--	.88	--	--	<.01
L15	<.1	.03	.02	<.01	<.01	--	.57	.48	--	<.01

Table 25.--Chemical and physical characteristics of water of lakes--Continued

Site number	Phos-phorus, total (mg/L as P)	Carbon, organic dis-solved (mg/L as C)	Cyanide total (mg/L as CN)	Phenols total (μg/L)	Alka-linity Lab (mg/L as $CaCO_3$)	Hard-ness (mg/L as $CaCO_3$)	Hard-ness noncar-bonate (mg/L as $CaCO_3$)	Solids, sum of consti-tuents, dis-solved (mg/L)	Solids, residue at 180 °C dis-solved (mg/L)	Alum-inum, total recov-erable (μg/L as Al)
L1	0.02	5.6	<0.01	2	117	130	15	150	144	150
L2	.02	9.4	<.01	5	80	95	15	100	99	<10
L3	<.01	2.7	<.01	2	128	140	10	150	180	<10
L4	.01	4.1	<.01	3	69	75	6	83	99	<10
L5	<.01	7.6	.03	<1	140	150	12	170	184	--
L6	<.01	--	<.01	--	91	98	7	110	117	--
L7	.01	6.6	<.01	2	107	110	6	--	128	20
L8	.03	6.2	--	3	141	160	17	170	178	<10
L9	.01	--	--	--	131	140	9	150	172	--
L10	.01	--	--	--	94	100	9	120	129	--
L11	.01	--	--	--	126	140	10	150	164	--
L12	<.01	--	--	--	82	99	17	110	134	--
L13	.01	--	--	--	69	80	11	85	97	--
L14	--	--	--	2	--	120	13	--	138	--
L15	.02	--	--	--	35	42	7	47	72	--

Table 25.--Chemical and physical characteristics of water of lakes--Continued

Site number	Arsenic total (µg/L as As)	Barium, total recov-erable (µg/L as Ba)	Boron, total recov-erable (µg/L as B)	Cadmium total recov-erable (µg/L as Cd)	Chro-mium, total recov-erable (µg/L as Cr)	Cobalt total recov-erable (µg/L as Co)	Copper, total recov-erable (µg/L as Cu)	Iron, total recov-erable (µg/L as Fe)	Iron, dis-solved (µg/L as Fe)	Lead, total recov-erable (µg/L as Pb)
L1	<1	<100	50	<1	<10	<1	4	50	7	<5
L2	3	<100	<10	<1	<10	<1	1	10	7	<5
L3	<1	<100	<10	<1	10	<1	2	20	3	<5
L4	<1	<100	<10	<1	<10	3	1	<10	<3	<5
L5	--	200	<10	--	--	--	--	--	30	--
L6	<1	--	<10	<1	<10	2	2	80	5	<5
L7	1	<100	<10	<1	<10	<1	<1	70	7	<5
L8	<1	<100	<10	<1	<10	<1	<1	<10	5	<5
L9	--	--	--	--	--	--	--	--	--	--
L10	--	--	--	--	--	--	--	--	--	--
L11	--	--	--	--	--	--	--	--	--	--
L12	--	--	--	--	--	--	--	--	--	--
L13	--	--	--	--	--	--	--	--	--	--
L14	--	--	--	--	--	--	--	--	--	--
L15	--	--	--	--	--	--	--	--	--	--

Table 25.--Chemical and physical characteristics of water of lakes--Continued

Site number	Lithium dis-solved (µg/L as Li)	Manga-nese, Total recov-erable (µg/L as Mn)	Manga-nese, dis-solved (µg/L as Mn)	Mercury total recov-erable (µg/L as Hg)	Nickel, total recov-erable (µg/L as Ni)	Sele-nium, total (µg/L as Se)	Stron-tium, total recov-erable (µg/L as Sr)	Stron-tium, dis-solved (µg/L as Sr)	Zinc, total recov-erable (µg/L as Zn)
L1	4	40	<1	--	3	<1	50	49	40
L2	<4	30	<1	0.1	3	<1	40	27	20
L3	<4	10	<1	.4	2	<1	60	58	10
L4	4	10	2	.4	4	<1	--	21	<10
L5	<10	--	<10	--	--	--	--	110	--
L6	4	20	1	.3	5	<1	20	32	30
L7	11	<10	<1	.4	2	<1	50	23	10
L8	13	20	<1	1.1	1	<1	80	57	<10
L9	7	--	--	--	--	--	--	84	--
L10	7	--	--	--	--	--	--	32	--
L11	6	--	--	--	--	--	--	63	--
L12	5	--	--	--	--	--	--	61	--
L13	5	--	--	--	--	--	--	24	--
L14	13	--	--	--	--	--	--	46	--
L15	4	--	--	--	--	--	--	18	--

Table 26.--Chemical and physical characteristics of ground water

[Analyses by U.S. Geological Survey. --, no analysis made; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius: µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelemetric turbidity units]

Well number	Date	Time	Depth of well, total (feet)	Specific conductance, lab (µS/cm)	Temperature (°C)	Turbidity (NTU)	pH (standard units)
B1	November 14, 1985	1000	69	494	10.5	0.7	7.60
B2	November 15, 1985	0930	60	450	9.0	5.5	7.60
B3	November 14, 1985	1200	66	437	10.5	.4	7.60
B4	November 15, 1985	1100	112	355	8.5	.4	7.80
B5	November 20, 1985	1500	102	280	8.0	37	7.90
B6	November 21, 1985	0930	67	440	9.0	.5	7.60
B7	November 14, 1985	0930	97	465	8.0	5.5	7.60
B8	November 14, 1985	1130	214	340	9.0	300	7.80
B9	November 14, 1985	1430	79	334	7.5	.3	7.80
B10	November 15, 1985	0935	68	287	8.5	.6	7.80
B11	November 20, 1985	1630	108	253	9.0	.5	7.80
B12	November 14, 1985	1530	92	413	9.0	70	7.70
B13	November 21, 1985	1030	58	485	7.0	2.0	7.60
B14	November 14, 1985	1600	40	132	9.5	.3	8.50
B15	November 14, 1985	1000	117	350	8.0	.5	7.80
B16	November 14, 1985	1130	94	286	8.0	4.7	8.40
B17	November 14, 1985	1245	111	365	8.5	1.0	7.80
B18	November 14, 1985	1435	51	639	8.5	.6	7.40
B19	November 21, 1985	1200	60	416	8.5	2.2	7.90
B20	November 14, 1985	1730	147	420	8.5	40	7.70
B21	November 15, 1985	1150	41	457	9.5	20	7.70
G1	August 26, 1986	1500	193	1,200	10.0	.5	7.20
G2	August 26, 1986	--	130	--	--	2.8	--
G3	August 20, 1986	1500	82	390	9.0	9.4	7.70
G4	August 22, 1986	1300	108	334	9.0	.5	7.70
G5	August 22, 1986	1130	120	224	9.5	1.3	7.90
G6	August 22, 1986	1500	63	227	9.0	7.1	8.00
G7	August 26, 1986	1030	35	285	8.0	.7	8.00
G8	August 26, 1986	1200	226	1,940	9.5	3.4	7.90
G9	August 22, 1986	1000	38	626	9.0	.2	7.40
G10	August 21, 1986	1400	74	770	9.0	.3	7.10
G11	August 21, 1986	1030	102	537	9.0	1.8	7.50
G15	August 21, 1986	1130	65	662	9.5	1.9	7.60
GP-1	August 21, 1986	1300	80	323	9.0	8.6	7.60

Table 26.--Chemical and physical characteristics of ground water--Continued

Well number	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)
B1	8.1	80	17	1.6	0.6	36	15	<0.1
B2	17	63	17	6.6	.9	0.4	.7	.4
B3	8.0	65	18	1.7	.7	13	.9	<.1
B4	7.0	53	13	1.0	.4	9.7	1.8	<.1
B5	7.2	43	9.1	1.2	.5	6.2	.8	<.1
B6	10	65	16	1.7	.5	20	1.9	.2
B7	12	70	18	2.6	.6	27	.9	.7
B8	8.7	52	11	2.4	.5	12	.7	.3
B9	5.0	56	9.6	.6	.5	9.5	.6	<.1
B10	7.7	60	11	1.3	.4	7.3	.7	<.1
B11	7.1	39	8.0	3.0	.3	2.0	2.8	<.1
B12	9.0	63	15	1.9	.7	20	.7	.2
B13	7.3	72	15	3.0	1.0	14	24	.1
B14	3.7	20	4.6	.5	.6	6.9	.6	<.1
B15	7.3	55	13	1.1	.5	11	.7	<.1
B16	5.5	31	6.6	14	1.0	13	27	<.1
B17	9.4	57	12	2.0	.5	12	2.3	<.1
B18	6.8	100	21	1.5	1.5	19	12	<.1
B19	6.3	53	12	10	1.0	18	28	<.1
B20	9.7	61	17	3.3	.7	14	2.2	.3
B21	8.4	68	18	5.6	.8	16	9.1	<.1
G1	12	180	47	7.2	1.3	72	47	.2
G2	12	61	20	5.6	1.0	26	7.1	.1
G3	7.0	57	13	1.7	.9	14	3.0	<.1
G4	6.3	53	9.9	.9	.5	9.0	.8	<.1
G5	9.4	40	7.5	2.0	.8	1.3	2.5	.2
G6	7.1	32	7.7	1.3	.0	7.3	.6	.0
G7	3.9	38	5.0	11	.0	11	5.9	.0
G8	13	35	12	24	.0	.5	19	.0
G9	8.8	93	24	2.6	1.7	18	1.9	<.1
G10	7.2	100	23	9.2	7.5	18	31	<.1
G11	8.9	81	19	2.0	.9	16	1.6	<.1
G15	6.5	89	20	2.6	2.7	20	29	<.1
GP-1	7.5	46	13	1.4	.7	11	1.2	<.1

Table 26.--Chemical and physical characteristics of ground water--Continued

Well number	Nitrogen, ammonia total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, organic total (mg/L as N)	Nitrogen, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Alkalinity, lab (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)
B1	0.08	0.02	6.08	0.42	6.6	0.01	0.01	194	270
B2	.83	<.01	<.1	.17	1.0	.01	.04	239	230
B3	.03	.01	8.69	.77	9.5	<.01	<.01	196	240
B4	.01	<.01	.80	<.2	--	.01	<.01	171	190
B5	.05	.01	.09	.15	.3	.03	.03	137	140
B6	.04	.01	.69	<.2	--	<.01	<.01	207	230
B7	.03	.01	<.1	.37	--	<.01	.01	221	250
B8	.04	.01	.19	.26	.5	.01	.25	170	180
B9	.03	.01	.09	<.2	--	<.01	<.01	169	180
B10	.12	<.01	<.1	.08	--	<.01	.01	181	200
B11	.10	<.01	<.1	.2	--	<.01	.01	129	130
B12	.04	<.01	<.1	<.2	--	.01	.06	201	220
B13	.06	<.01	<.1	<.2	--	<.01	.01	195	240
B14	.02	.02	2.08	<.2	--	.01	<.01	55	69
B15	.01	.01	<.1	.19	--	.01	<.01	178	190
B16	.02	<.01	.29	.18	.5	.01	.02	85	100
B17	.03	<.01	1.1	.27	1.4	.01	<.01	175	190
B18	.06	.03	11.0	.64	12	<.01	<.01	265	340
B19	.04	<.01	2.1	<.2	--	<.01	.01	138	180
B20	.02	.01	<.1	.28	--	<.01	.03	207	220
B21	.02	.01	.99	<.2	--	.01	<.01	220	240
G1	.11	.04	9.96	.69	11	.01	<.01	554	640
G2	.03	.01	2.59	<.2	--	.02	.06	202	230
G3	.08	.02	2.08	.82	3.0	<.01	.07	175	200
G4	.02	<.01	<.1	<.2	--	<.01	.01	166	170
G5	1.10	<.01	<.1	.3	--	.02	.01	131	130
G6	.02	<.01	--	--	--	<.01	<.01	106	110
G7	.01	<.10	.5	<.2	--	.01	.02	116	120
G8	.24	<.01	<.1	.06	--	.02	.02	158	140
G9	.03	<.01	4.4	.37	4.8	<.01	.01	308	330
G10	.04	<.01	5.4	.46	5.9	.01	<.01	307	340
G11	.02	<.01	1.0	<.2	--	<.01	.01	257	280
G15	.03	<.01	9.1	.27	9.4	<.01	.02	230	300
GP-1	.02	<.01	<.1	<.2	--	.02	.01	157	170

Table 26.--Chemical and physical characteristics of ground water--Continued

Well number	Hard-ness, noncar-bonate (mg/L as $CaCO_3$)	Solids, sum of consti-tuents, dis-solved (mg/L)	Solids, Solids, residue at 180 °C dis-solved (mg/L)	Arsenic, total (µg/L as As)	Cadmium, total recov-erable (µg/L as Cd)	Chro-mium, total recov-erable (µg/L as Cr)	Cobalt, total recov-erable (µg/L as Co)	Copper, total recov-erable (µg/L as Cu)	Iron, total recov-erable (µg/L as Fe)
B1	270	270	298	<1	<10	<10	60	<10	490
B2	230	250	231	<1	20	<10	<50	10	2,300
B3	240	220	247	<1	10	<10	<50	<10	70
B4	190	190	188	<1	<10	<10	<50	<10	110
B5	140	150	138	<1	<10	<10	<100	<10	1,200
B6	230	240	210	<1	<10	<10	<100	<10	110
B7	250	260	266	<1	10	<10	60	<10	1,000
B8	180	190	193	1	<10	10	70	40	8,300
B9	180	180	184	<1	10	<10	60	<10	130
B10	200	200	201	2	10	<10	50	<10	1,200
B11	130	140	126	<1	<10	<10	<100	<10	180
B12	220	230	235	1	<10	10	<50	10	3,000
B13	240	250	244	1	<10	<10	<100	<10	560
B14	69	70	77	<1	<10	10	<50	10	110
B15	190	200	195	<1	10	<10	<50	10	100
B16	100	150	152	<1	<10	<10	60	<10	190
B17	190	200	191	<1	10	<10	<50	<10	100
B18	340	320	351	<1	20	10	<50	10	170
B19	180	210	206	<1	<10	<10	<100	<10	210
B20	220	230	235	<1	20	<10	<50	10	1,000
B21	240	260	260	<1	10	<10	50	<10	80
G1	640	700	765	<1	<10	<10	<50	<10	80
G2	230	250	261	<1	<10	<10	<50	<10	110
G3	200	200	200	<1	<10	<10	<50	10	380
G4	170	180	140	<1	<10	20	<50	<10	70
G5	130	140	142	<1	<10	<10	<50	<10	490
G6	110	120	124	<1	<10	<10	<50	<10	240
G7	120	140	145	<1	<10	<10	<50	<10	40
G8	140	200	195	<1	<10	10	<50	<10	740
G9	330	330	284	<1	<10	<10	<50	<10	<10
G10	340	380	297	<1	10	<10	<50	<10	60
G11	280	280	196	<1	<10	<10	<50	10	140
G15	300	310	320	<1	<10	10	<50	<10	120
GP-1	170	170	175	<1	10	10	<50	<10	740

Table 26.--Chemical and physical characteristics of ground water--Continued

Well number	Lead, total recov-erable (µg/L as Pb)	Manga-nese, total recov-erable (µg/L as Mn)	Mercury, total recov-erable (µg/L as Hg)	Nickel, total recov-erable (µg/L as Ni)	Sele-nium, total (µg/L as Se)	Silver, total recov-erable (µg/L as Ag)	Stron-tium, total recov-erable (µg/L as Sr)	Zinc, total recov-erable (µg/L as Zn)
B1	<100	20	<0.1	<100	<1	<1	40	600
B2	<100	40	<.1	100	<1	<1	130	110
B3	<100	30	<.1	100	<1	<1	30	490
B4	<100	10	<.1	<100	<1	<1	20	130
B5	<100	90	<.1	<100	<1	<1	40	300
B6	<100	20	<.1	<100	1	<1	80	160
B7	<100	30	<.1	<100	<1	<1	80	130
B8	<100	200	<.1	<100	<1	<1	120	3,300
B9	<100	10	.1	<100	<1	<1	30	170
B10	<100	40	.2	<100	<1	<1	30	50
B11	<100	60	<.1	<100	<1	<1	40	200
B12	<100	90	.1	100	<1	<1	60	720
B13	<100	220	<.1	<100	<1	<1	70	580
B14	<100	10	<.1	100	<1	<1	10	50
B15	<100	20	<.1	<100	<1	<1	30	220
B16	100	20	<.1	<100	<1	<1	30	330
B17	<100	30	<.1	<100	<1	<1	30	160
B18	100	20	<.1	<100	<1	<1	50	330
B19	<100	20	<.1	<100	<1	<1	70	220
B20	<100	50	.5	100	<1	<1	100	570
B21	<100	50	.1	<100	<1	<1	40	120
G1	100	40	<.1	100	<1	<1	240	3,500
G2	100	20	.2	<100	<1	<1	80	300
G3	<100	20	<.1	<100	<1	<1	40	240
G4	<100	10	<.1	<100	<1	<1	40	250
G5	<100	40	<.1	<100	<1	<1	40	150
G6	<100	10	<.1	<100	<1	<1	10	280
G7	<100	<10	<.1	<100	<1	<1	20	120
G8	<100	20	<.1	<100	<1	<1	210	1,100
G9	100	<10	<.1	<100	<1	<1	20	140
G10	100	10	<.1	<100	<1	<1	40	280
G11	<100	20	<.1	<100	<1	<1	80	230
G15	<100	10	<.1	<100	<1	<1	70	120
GP-1	100	40	<.1	<100	<1	<1	20	480