WATER RESOURCES OF THE KEWEENAW BAY INDIAN COMMUNITY, BARAGA COUNTY, MICHIGAN

U.S. Department of the Interior
U.S. Geological Survey
Water-Resources Investigations Report 98-4060

Prepared in cooperation with the
KEWEENAW BAY INDIAN COMMUNITY

Keweenaw Bay Indian Community

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by M.J. Sweat and S.J. Rheaume

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Lansing, Michigan
1998

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Denver, CO 80225-0286

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CONVERSION FACTORS, ABBREVIATED WATER QUALITY UNITS, AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
millimeter (mm)	0.03937	inch
centimeter (cm)	.3937	inch
meter (m)	3.281	foot
	Area	
square kilometer (km^2)	247.1	acre
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot
square kilometer (km^2)	.3861	square mile
hectare	.003861	square mile
	Volume	
liter (L)	.2642	gallon
cubic meter (m^3)	264.2	gallon
milliliters (ml)	.0002642	gallon
cubic meter	35.31	cubic foot
	Flow (volume per unit time)	
millimeter per year (mm)	.0394	inch per year
meter per second (m/s)	3.281	foot per second
cubic meter per second (m^3/s)	35.31	cubic foot per second
liter per second (L/s)	.03531	cubic foot per second
liter per second	15.85	gallon per minute
cubic meters per second	22.82	million gallons per day
	Transmissivity	
meter squared per day	10.76	foot squared per day
	Temperature	

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by use of the following equation:

$$°F = (1.8 \times °C) + 32$$

Abbreviated water-quality units

Chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as a weight (milligrams) of solute per unit volume (liter) of water. Likewise, micrograms per liter is a unit expressing the concentration of chemical constituents in solution as a weight (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Turbidity is a measure of opaqueness or reduced clarity of water, and is expressed in nephelometric turbidity units (NTU). Nephelometric turbidity units are a measure of the intensity of light scattered in one particular direction, predominantly at right angles to the incident light.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

Tritium concentration (or activity) in water is expressed as picoCuries per liter (pCi/L).

Vertical Datum

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Water Resources of the Keweenaw Bay Indian Community, Baraga County, Michigan

by M.J. Sweat and S.J. Rheaume

ABSTRACT

The Keweenaw Bay Indian Community (KBIC) in Baraga County uses ground water for most domestic, commercial, and industrial supplies. An industrial park within KBIC could adversely affect some ground-water supplies should contaminants be spilled at the park. Additional development of the park is being planned. Information on water supply potential and aquifer vulnerability to contamination is needed to make sound decisions about future activities at the industrial park.

Unconsolidated glacial deposits overlie bedrock within the Keweenaw Bay Indian Community. Usable amounts of ground water are withdrawn from the glacial deposits only in isolated areas. Principal aquifers are the Jacobsville Sandstone and the Michigamme Slate. Aquifer test and water level data from these principal aquifers indicate that they are confined and hydraulically connected throughout most of KBIC.

Ground water generally flows toward Keweenaw and Huron Bays and the Silver River. Between the industrial park and Keweenaw Bay, ground water flows to the southeast, toward the Bay. Along this flow path in the bedrock, glacial deposits are generally thicker than 25 meters, and contain thick lenses of clay and clay mixed with sand. The average depth to ground water along this flow path is greater than 25 meters, indicating unconfined conditions. Near the shore of Keweenaw and Huron Bays, however, and at isolated areas throughout KBIC, water levels in wells are above land surface.

Analyses of water samples collected in 1991 and 1997 indicate that the quality of ground water and surface water is suitable for most domestic, commercial, and industrial uses. However, U.S. Environmental Protection Agency secondary maximum contaminant limits for dissolved iron and manganese were exceeded in 4 and 5 wells, respectively, which may make the water from these wells unsuitable for some uses. Concentrations of lead in water from one well was above the maximum contaminant limit.

Concentrations of tritium in ground water downgradient from the industrial park indicate that at least some recharge to the Jacobsville Sandstone has taken place within the last 45 years. Where clay lenses greater than 1 meter thick overlie the glacial aquifer or the Jacobsville Sandstone, however, recharge may take longer than 45 years.

A contaminant spill at the industrial park would likely move laterally, toward Keweenaw Bay, in the glacial aquifer. Some infiltration does occur through the glacial aquifer to the bedrock aquifers. No information is available concerning the rate of movement of water within this aquifer, so it is not possible to determine the rate at which a spill would move either vertically or laterally within the glacial aquifer toward either Keweenaw Bay or the Jacobsville Sandstone.

Increased pumping from the existing well at the industrial park, or the development of additional wells, could potentially lower water levels in the Jacobsville Sandstone in the area of the park. Sufficient lowering of water levels could create unconfined conditions in the Jacobsville Sandstone, thereby increasing the susceptability of the aquifer to contamination.

INTRODUCTION

The Keweenaw Bay Indian Community (KBIC) is concerned about the possibility of deteriorating water quality in the Keweenaw Bay area in Michigan's Upper Peninsula. Changes in water quality could affect water supplies and plans for future development. The development of a 105-hectare industrial park in the western part of KBIC has the potential to affect both the quantity and quality of water supplies. Doonan and others (1970) studied ground-water resources of the Keweenaw Peninsula, and Doonan and Byerlay (1973) studied ground-water resources of Baraga County. However, detailed studies of the relation of geology, hydrology, and land use to surface and ground-water quality in the KBIC have not been made. Strategies for the protection of water resources cannot be developed until these relations are better understood. The investigation described here was conducted as a cooperative effort between KBIC and the U.S. Geological Survey (USGS) to address these information needs.

Purpose and Scope

This report describes the results of a study of the physical and chemical characteristics of ground and surface-water resources of KBIC, and relates these characteristics to geology, hydrology, and land use. The report is based on data collected in 1991 and 1997, and provides information that will be useful to water-resource planners and managers in developing strategies for water-quality protection and water-supply development. Results of chemical analyses of water samples from wells, streams, and the Assinins Wetland are included in tables at the back of the report.

Methods of Investigation

In 1991, work focused on evaluating the water quality of streams tributary to Keweenaw Bay and of the ground-water system. Water samples collected from 11 tributaries, 2 wetland ponds, and 11 wells were analyzed in the laboratory for common dissolved substances, trace metals, nutrients, bacteria, phenols, and volatile organic compounds. Temperature, pH, specific conductance, dissolved oxygen, and alkalinity were measured in the field. Streambed sediment samples were collected from selected sites for analysis of pesticides and trace metals.

In July 1997, 8 of the 11 previously sampled wells were resampled for analysis of common dissolved substances, trace metals, and nutrients. Temperature, pH, specific conductance, and alkalinity were measured in the field. Two additional wells were sampled, one in the industrial park and one near to, and similar in depth and construction, to a well sampled in 1991 that had been removed from service.

The relation of well hydraulics to the ability of the aquifer to produce water was analyzed using the results of pump tests, well capacity tests, drill logs, and maps. Local areas of ground-water discharge and recharge are tentatively identified. Where sufficient data exist, probable ground-water flow paths are identified, and their relation to water production is described. Results of field and laboratory analyses of ground-water samples were examined using graphical methods, and are presented in this report. An analysis of the surface-water and wetlands water-quality data is also presented.

Acknowledgments

Field work in 1991 was done with the assistance of Howard Reynolds, then the KBIC Environmental Coordinator, and Michael Donofrio, KBIC Fisheries Biologist. The sample and data collection in 1997 was made possible by the assistance of F. William Beaver, KBIC Geographic Information Systems (GIS) Coordinator. Stephen Aichele and F. William Beaver provided many of the GIS coverages used in illustrations for this report. Many KBIC, County, and local officials, as well as citizens, provided data, access to property and wells, and took an active interest in the project.

GENERAL DESCRIPTION OF STUDY AREA

Keweenaw Bay Indian Community is in Baraga County in the northwestern part of Michigan's Upper Peninsula, near the southern terminus of Keweenaw Bay (fig. 1). The study area comprises lands under the jurisdiction of KBIC. The land surface is generally hilly and ranges in elevation from 183 m at Keweenaw Bay to about 565 m in the southeastern part of the study area (fig. 2), with steep slopes rising from near the Keweenaw Bay shore.

The study area comprises about 290 km^2, of which about 45 km^2 is covered by Keweenaw Bay. Most of the land is forested with only a small percent of the area used for agriculture, primarily beef and dairy production. Logging, manufacturing, and tourism are the principal contributors to the economy. The 1990 population of the study area was estimated at about 6,000. The two largest communities are L'Anse and Baraga (fig. 1), with 1990 populations of about 2,500 and 1,055 respectively (U.S. Bureau of Census, 1992).

Climate at KBIC is moderated by Lake Superior and the Keweenaw Peninsula.

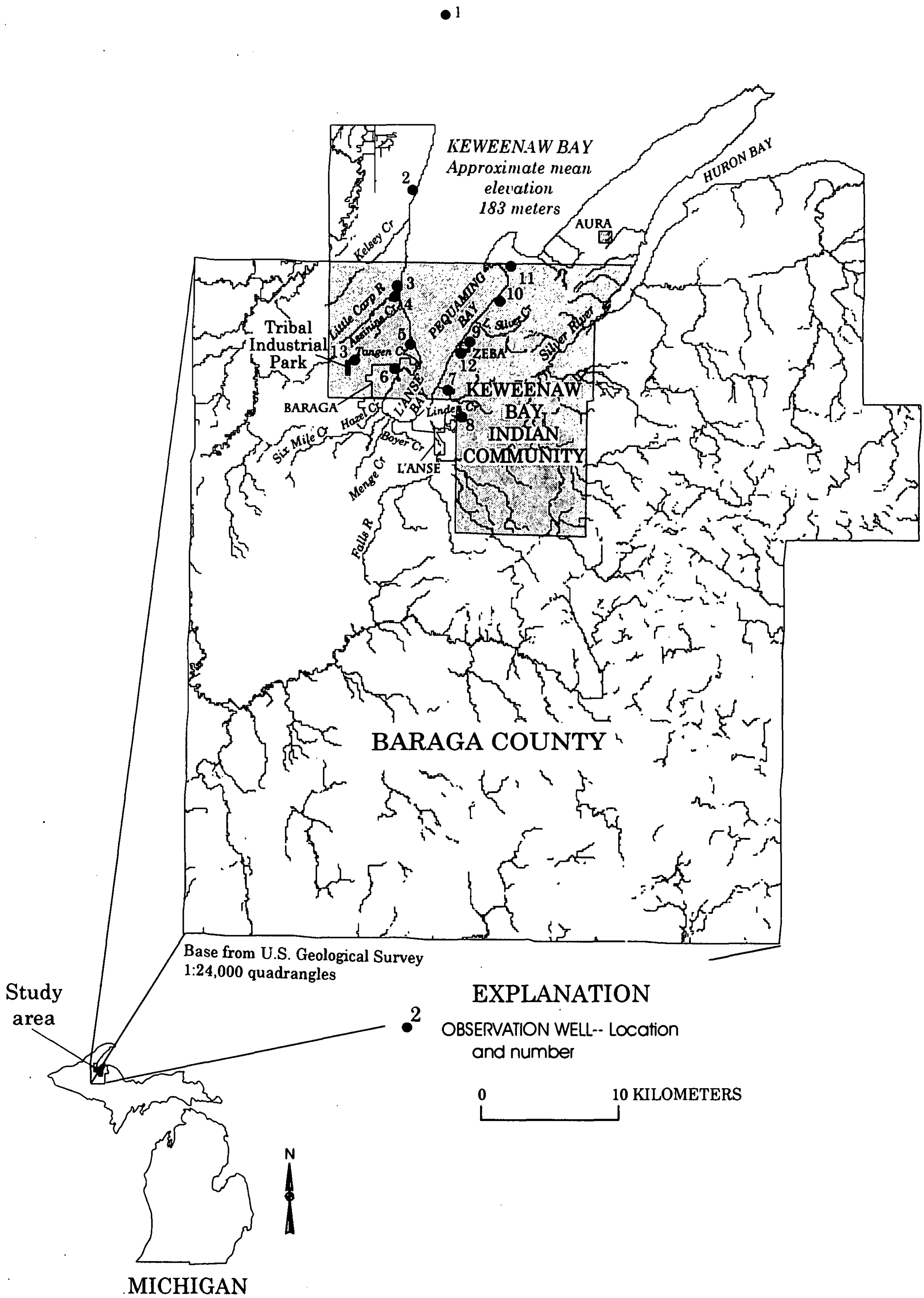

Figure 1. Location of the Keweenaw Bay Indian Community study area and location of ground-water sampling sites.

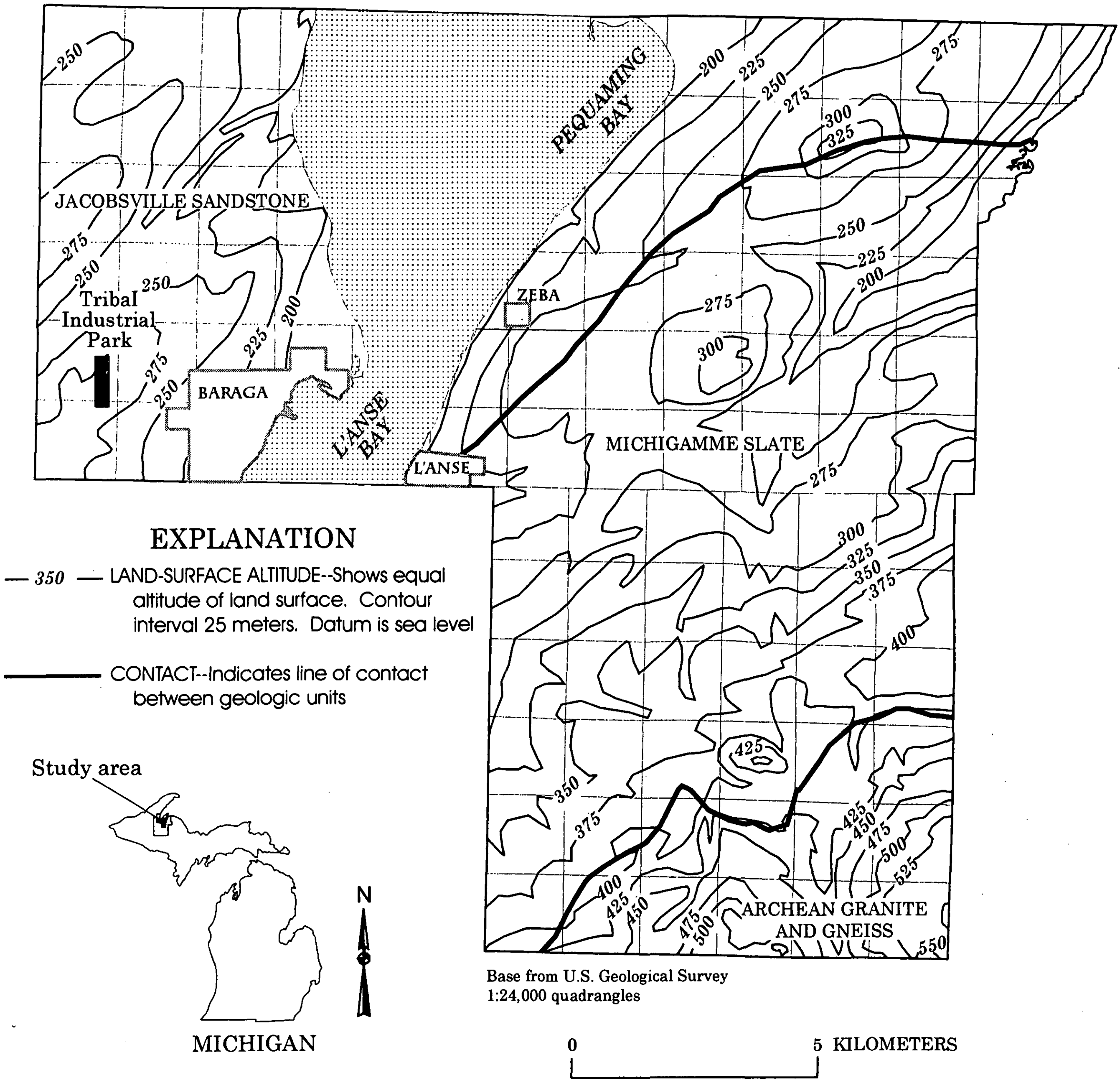

Figure 2. Elevation of land surface and approximate contact between geologic units within the study area. (Geology from Reed and Daniels, 1987.)

Precipitation is influenced by the location of Keweenaw Bay, and tends to increase predominantly in the downwind direction, (southeast and east) from the Bay. Average annual precipitation is about 100 cm per year. Average rainfall is about 57 cm; average annual snowfall is about 365 cm. Extreme temperatures range from about -40 °C to about 32°C; mean monthly temperatures range from about -11 °C to about 17 °C (National Oceanic and Atmospheric Administration, 1997, pp. 2-3, 8, 11).

GEOLOGIC SETTING

The geology of the Keweenaw Bay Indian Community consists of unconsolidated alluvial and glacial deposits of Pleistocene age and consolidated strata of Keweenawan, early Proterozoic, and Archean age. The general lithologic characteristics of these deposits are described below. Specific lithologic data were obtained from well logs on file with the Indian Health Service and with the Michigan Department of Public Health.

Alluvium

Alluvium in the study area consists of sand, gravel, and clay reworked from glacial till and lakebed deposits; peat bogs; and marl deposits. Generally, these deposits are thin and probably contain some glacial outwash material at depth. Most areas of alluvium are too small to map.

Glacial Deposits

During the Wisconsin Stage glaciation, the entire Keweenaw Peninsula was covered by up to 3000 m of ice (Sugden, 1977) and many glacial features are apparent in the study area. Depositional features include various types of moraines. Hughes (1963) estimated that 80 percent of the Keweenaw Peninsula is covered by hummocky, boulder-rich glacial sediments deposited as ground moraine. Glacier-related deposits of water-laid origin are described by Regis (1993) and include outwash, eskers, deltas, kames, and channel deposits.

In the study area, glacial deposits are primarily a yellow and brown to reddish boulder clay or till, lake clay, or sand. Some coarse-grained outwash also occurs. Most of the deposits are thin and locally are absent in areas of bedrock outcrops. The deposits range in thickness from a few millimeters to several tens of meters, however, and stratified lake sand from 60 to 90 m thick, with seams of lake clay, is reported in the Six Mile Creek and Pequaming Bay areas.

Bedrock

Intrusive and metamorphic bedrock units in the study area were deposited between 1100 and 1000 million years ago (Ma) as part of the Midcontinent rift system of North America (Bornhorst and Rose, 1994, p. 10.) These granitic and gneissic rocks underlie younger metamorphic and sedimentary deposits of slate and sandstone throughout the study area, but are too deeply buried in all but the southeast part of the study area to be used as aquifers. These rocks are the oldest, and topographically highest rocks in the study area. They consist of schistose and gneissic intrusives, and contain masses of syenite schist, hornblende-rich gneiss, and massive granite. They are the uppermost bedrock unit only in the extreme southeast part of the study area.

The Michigamme Slate is the uppermost bedrock unit throughout most of the eastern half of the study area, with the exception previously noted, and in the area northeast of Pequaming Bay, where it is not present because of erosion. It consists of dark quartz slate to graphitic slate and graywacke, mica schist and gneiss, and quartzite locally recrystallized as schist. Ferruginous beds of iron ore, conglomerate, and chert are common. The Michigamme Slate may be as much as a few hundred meters thick.

The Jacobsville Sandstone is the uppermost bedrock unit throughout the western half of the study area, and along the southeastern shore of Keweenaw Bay, south of Pequaming Bay, from about Zeba southwestward, and from Pequaming Bay northeast toward Huron Bay. It consists of a light-red to brown quartz sandstone with beds of red arkosic sandstone, red micaceous sandy shale, and conglomerate, and is in unconformable contact with the underlying Michigamme Slate. Its thickness ranges from about 300 m in the northwest part of the study area to less than 1 mm where it pinches out at the south end of Keweenaw Bay. The Jacobsville Sandstone is exposed in cliffs along most of Keweenaw Bay's shoreline.

GEOHYDROLOGY

The Little Carp, the Falls, and the Silver Rivers are the principal streams in the Keweenaw Bay Indian Community, and about 160 lakes and ponds have been mapped. About 42 percent of the 100 cm of annual precipitation runs off to the streams (Blumer and others, 1997, p. 43-44); of the remainder, most either evaporates or is transpired by plants, and some recharges the ground water. The streams in KBIC ultimately drain to the southern parts of either Keweenaw or Huron Bays. The communities of Baraga and L'Anse obtain their water supplies from Keweenaw Bay. Glacial deposits provide usable amounts of ground water locally, but the principal aquifers in the KBIC are the bedrock units.

Ground Water

Ground water is the principal source of drinking water for most households in the KBIC, and for most industrial and agricultural uses. The Jacobsville Sandstone and the Michigamme Slate are the principal aquifers in the study area, and they supply most of the domestic and commercial wells in the study area. Wells on the west side of Keweenaw Bay are typically completed in the Jacobsville Sandstone. On the east side of the Bay, wells near the shore are completed in either the Jacobsville Sandstone or unconsolidated surficial deposits. Inland from the Bay, wells are typically completed in the Michigamme Slate or, in the extreme southeastern part of the study area, in Archean granite or gneiss.

Glacial aquifers

Glacial deposits are a source of water in two small areas (fig. 3), one in the west-southwest part of the KBIC, and another just south of Pequaming Bay, in the north-central part. In most of the area, the glacial deposits form a semi-confining unit on top of the underlying bedrock, and they are locally thin or absent.

Water-supply wells completed in the glacial deposits are generally greater than 30 m deep, although they may be as shallow as 10 m. In general, water is withdrawn from lenses of sand and gravel, and wells in these deposits will yield less than 1 L/s (Twenter, 1966b). Locally, wells 15 cm or more in diameter occasionally yield several tens of liters of water per second, especially if the wells are completed in sand and gravel deposits along streams. The maximum reported depth to water in glacial deposits was 67 m (based on water levels in 24 wells, recorded with Indian Health Service and Michigan Department of Public Health between 1967 and 1995); depth to water ranged from 1.5 to 67 m between 1969 and 1997.

Jacobsville Sandstone

The Jacobsville Sandstone is the principal aquifer along Keweenaw Bay. The KBIC industrial park well is completed in the Jacobsville Sandstone, as are most wells that supply water to Tribal housing units. These wells are generally deep, ranging from about 15 to 140 m, although most wells are greater than 60 m deep. Twenter (1966a) and Rheaume (1991) report that wells completed in the Jacobsville Sandstone near the KBIC are likely to yield less than 1 L/s, although wells greater than 15 cm diameter occasionally yield several liters per second. The Jacobsville Sandstone is well cemented and thus has low primary permeability, and Vanlier (1963) reports that most water in nearby Alger County moves along fractures and separations in bedding planes. Wells completed in the Jacobsville Sandstone may produce saline water.

The potentiometric surface in the Jacobsville Sandstone within the KBIC is shown in figure 4. On the west side of Keweenaw Bay the surface rapidly increases in elevation away from the Bay, reaching a ground-water divide along the western edge of the study area. Assuming isotropy in the potentiometric head distribution, flow is generally from the west to the east, toward Keweenaw Bay, and the Little Carp River and then to Keweenaw Bay. Many wells completed in the Jacobsville Sandstone flow at the land surface, particularly near the shoreline of Keweenaw Bay. The water table is at or near land surface along the Little Carp

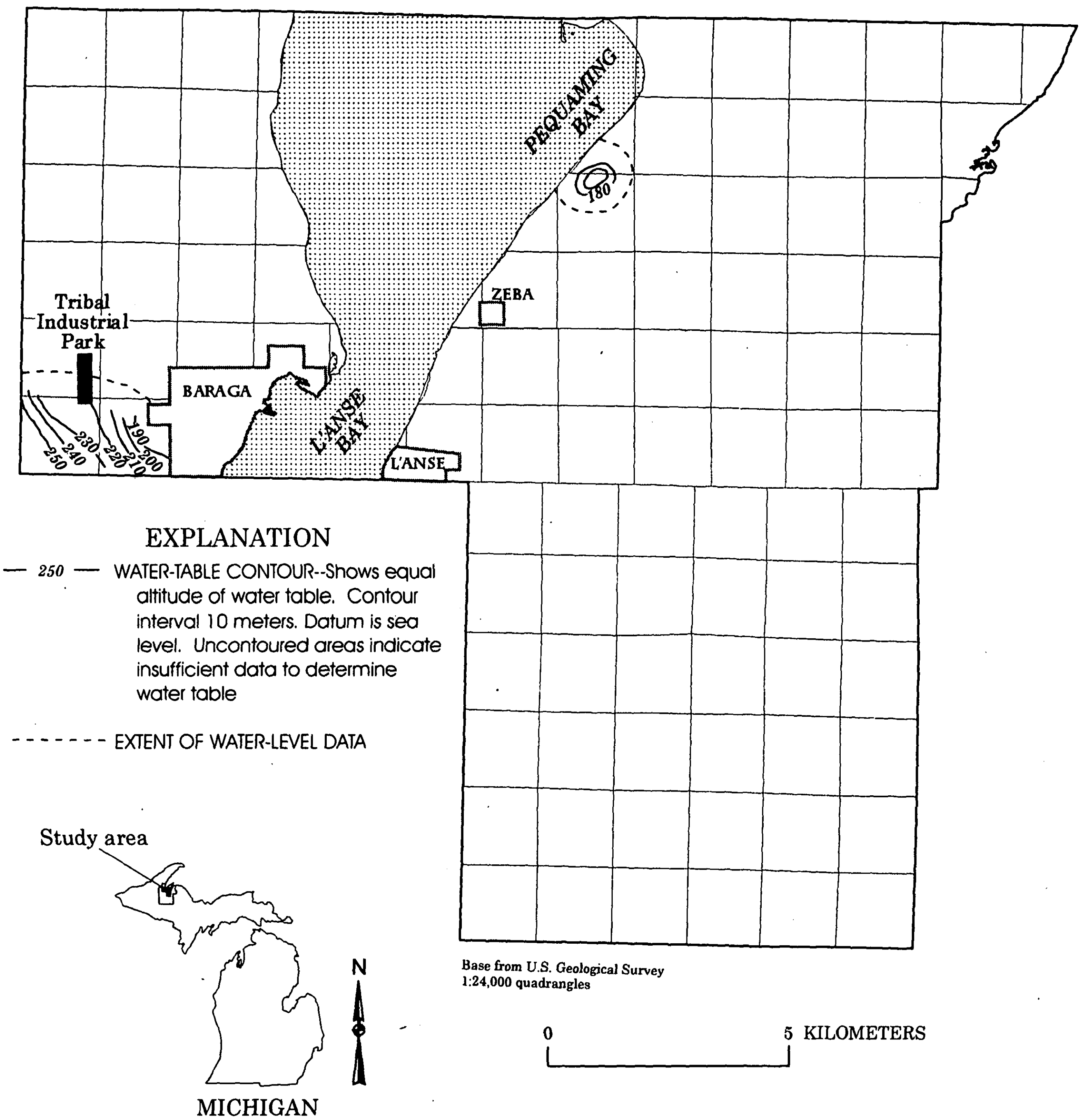

Figure 3. Extent of surficial deposits used as an aquifer, and water-table map (1969-97) in the surficial deposits.

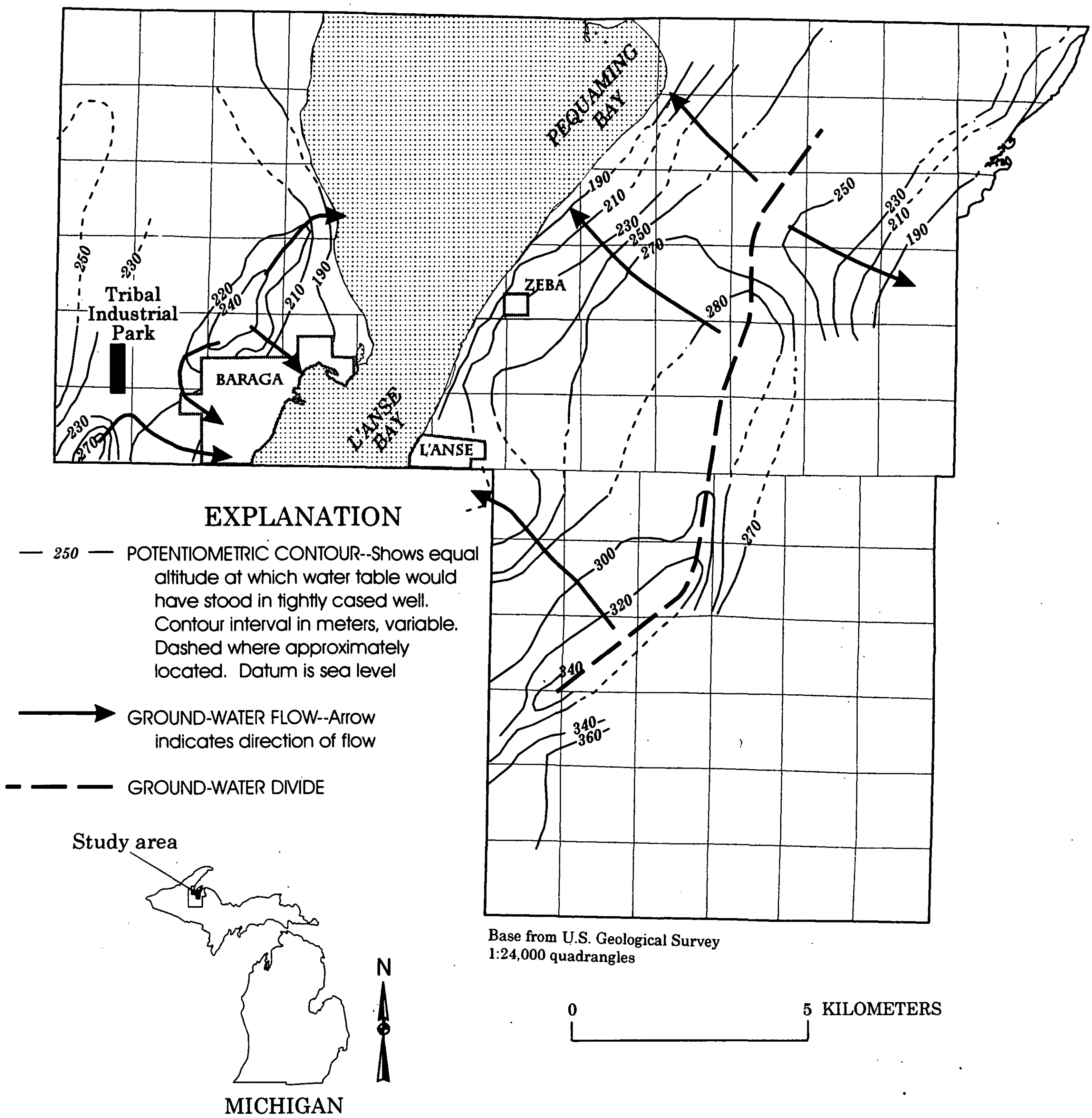

Figure 4. Potentiometric surface in the bedrock formations underlying the Keweenaw Bay Indian Community, and direction of ground-water flow.

River, the Assinins Wetlands, and many areas along the shore of Keweenaw Bay. This indicates that ground-water flow potential has an upward component in this part of the aquifer. The chance of contamination of water in the Jacobsville Sandstone from directly overlying surficial sources is lessened in areas where the potentiometric surface is at or above land surface.

On the east side of Keweenaw Bay, the potentiometric surface increases to the east, reaching a ground-water divide between Keweenaw and Huron Bays. Because wells in this area commonly are completed in both aquifers, and the producing zone of wells is open to both aquifers, the potentiometric surface on the east side of Keweenaw Bay is a combination of the potentiometric surface in both aquifers. Flow is to both sides of the ground-water divide, toward Keweenaw Bay on the west side of the divide and toward the Silver River and Huron Bay on the east side of the divide.

Michigamme Slate

East of Keweenaw Bay and south of Huron Bay, the Michigamme Slate is the principal aquifer where the Jacobsville Sandstone is not present. Wells completed in the Michigamme Slate range in depth from about 15 to 92 m; most wells are between about 45 and 60 m deep. As with wells completed in the overlying Jacobsville Sandstone, reported yields from the Michigamme Slate are generally less than 1 L/s, although some wells greater than 15 cm diameter occasionally yield several liters per second.

Water levels in the Michigamme Slate are similar to those in the Jacobsville Sandstone in certain areas southeast of Pequaming Bay. Figure 4 shows the potentiometric surface of water in the Michigamme Slate where it is used as an aquifer in the study area. The potentiometric surface is near or above land surface along the shore of Keweenaw and Pequaming Bays, and increases rapidly in elevation as distance from the shore increases. Ground-water flow is generally to the northwest toward Keweenaw Bay, except for a small area in the northeastern part of the study area, where flow is to the southeast toward the Silver River and Huron Bay. The direction of ground-water flow could not be determined for the southeastern part of the study area because of a lack of data for this area.

Archean granite and gneiss

Archean granite and gneiss is used as a water-supply aquifer in the southeastern part of the study area; however, only 6 logs were located for wells completed in these rocks. No wells completed in these rocks were sampled for water quality, and no attempt is made to draw inferences about water availability and directions of ground-water flow from the few data available. Wells generally are not drilled to the granite and gneiss where these rocks are overlain by the Michigamme Slate or the Jacobsville Sandstone.

Water table and ground-water flow

Logs for 265 wells completed in the bedrock in the study area were obtained from Indian Health Service and the Michigan Department of Public Health and analyzed to assess head distribution and flow direction within the study area (well locations not shown). Reported water levels for 64 percent (170) of these wells were above the top of the bedrock surface, indicating confined conditions. For the remaining 36 percent (95) of the wells, water levels were below the top of the bedrock, by an average of about 8 m, possibly indicating unconfined conditions. Data from pump tests or drawdown/recovery tests were available for 21 of the wells. The drawdown data were analyzed to determine the storage and hydraulic conductivity of the bedrock. Storage coefficients were generally in the range of 10^{-5}, at the lower end of values reported by Freeze and Cherry (1979, p 60) for confined aquifers; hydraulic conductivities ranged from 10^{-4} to 10^{1} m/d, generally within the range given by Freeze and Cherry (1979, p. 29, table 2.2) for typical sandstone and fractured metamorphic rocks. In general, the aquifers are confined, except north of Baraga, where unconfined conditions exist in 2 areas where bedrock is steeply rising away from Keweenaw Bay.

Directions of ground-water flow in the KBIC can be inferred from a potentiometric map. The map in figure 4 is drawn on the basis of water levels measured between 1969 and 1997, and is a composite of water levels in both the Jacobsville Sandstone and the Michigamme Slate. Ground water flows from high potential elevations to low potential elevations. Assuming that water flows with equal ease in any direction (isotropic conditions), flow is perpendicular to potentiometric contours. The contour information is not sufficiently detailed, however, to determine flow direction at specific locations.

The hydraulic gradient in the study area mimics the contours of the land surface; it is steep near the shore of Keweenaw Bay, under the steep slopes and cliffs leading to the Bay, and shallow away from the shore, under areas of upland highs and broad, flat expanses of land. There are hydraulic divides between Keweenaw Bay and Huron Bay and between Keweenaw Bay and streams draining to the Silver River. In the western part of the study area, there may be a hydraulic divide between Keweenaw Bay and drainage basins west of the study area.

Ground-Water Recharge Rates

Concentrations of tritium, a radioactive hydrogen isotope with atomic mass of 3, increased in rainwater following atomic testing in the atmosphere in 1952-1964 (Michel, 1989). Although tritium does not present a health concern, concentrations of tritium in ground water are used as an indicator of post 1953 recharge. Because tritium has a relatively short radiometric half-life (12.3 years), the concentration of this isotope makes it a useful indicator of ground-water recharge in the last 45 years. If detectable concentrations of tritium (5.7±3.2 pCi/L) are present in water, then some part of that water must have entered the aquifer after 1953. A lack of detectable concentrations of tritium in water, however, is not necessarily indicative of pre-1953 recharge. No significant amounts of tritium have been artificially introduced to the atmosphere since 1964, and the tritium concentrations are declining naturally with the radioactive decay of the isotope.

Tritium concentrations in water sampled in the KBIC in 1997 ranged from <5.7±3.2 to 29.1±3.8 pCi/L. These data are useful for estimating a time period during which recharge occurred. The maximum concentration in water from the Jacobsville Sandstone was 29.1±3.8 pCi/L, at well 6. Using decay-corrected concentrations of tritium in rainwater based on tritium-deposition estimates of Michel (1989), as calculated by Nicholas and others (1994, p 56) for southeast Michigan, it is possible to determine a time period during which this water entered the Jacobsville Sandstone. On the basis of the tritium curve of Nicholas and others (1994), and accounting for different units, water with tritium concentrations between 4.9 and 30.0 pCi/L recharged the aquifers sometime between 1954 and the early 1980's. The reporting limit for tritium analysis is greater than the minimum concentration for which an age determination is possible. Although tritium concentrations in ground water below the detection limit are of indeterminate age, they are more likely to correspond to areas recharged prior to 1954, or after the mid-1980's, than water with higher tritium concentrations.

Results of analyses of 3 of 5 samples from the Jacobsville Sandstone indicate some portion of the water was recharged to the aquifer between 1954 and the early 1980's. For the glacial aquifers, tritium concentrations in 1 of 5 samples indicates some portion of the water was recharged to the aquifer between 1954 and the early 1980's. Generally, glacial aquifers of sand or sand and gravel are more readily recharged than are bedrock aquifers. However, confined or semi-confined layers of sands and gravels in these deposits may not recharge as readily. For example, well 7 is deep (28 m), completed in a gravel and sand aquifer, and is overlain by more than 15 m of clay and mixed clay and sand, which could effectively prevent rapid recharge to the aquifer. Well 8 is shallow (15 m) and completed in sand and slate. The producing zone of this well is overlain by about 4 m of clay. It is also possible that this well is actually completed in the Michigamme Slate, which would not be expected to receive recharge as readily as would an unconsolidated sand aquifer.

Recharge to aquifers in the past 45 years is indicated by ground water with detectable tritium. These aquifers generally are unconfined sand, sand and gravel, and bedrock exposed at the surface or covered by a thin mantle of unconsolidated sediments. Such is the case in well 5, which is a shallow (15 m) well completed in sand, and which has less than one half meter of clay mixed with sand overlying the water-bearing sand. Wells 2, 4, and 6, which are all completed in the Jacobsville Sandstone, and have <4, <1, and <4 m of sand and mixed sand and clay over the bedrock, respectively, also had detectable concentrations of tritium, indicating at least partial recharge in the past 45 years.

Susceptibility to Contamination

The susceptibility of aquifers to contamination is of concern to residents of the KBIC. Contamination can occur from infiltration of materials spilled on the land surface, and by migration of contaminants once they enter ground water. Lusch and others (1992) found that most of the northern part of the study area is overlain by moderately or slowly permeable soils, which would slow the migration of surface contaminants into ground water. Soils in the southern part of the study area are more permeable, however, and thus the ground water here could be more susceptible to contamination. The direction of ground-water flow also influences the susceptibility of the aquifers to contamination. Throughout the study area, flow is lateral, towards Keweenaw and Huron Bays, which would lessen the susceptibility of deep aquifers to contamination. There is also an upward flow potential in the ground-water system in many places, which also lessens the susceptibility of the aquifer to contamination.

Soils over the Jacobsville Sandstone and the Michigamme Slate are only moderately to slowly permeable, and recharge is limited by the capacity of the soils to transmit water. Thus, in areas where the aquifer is deeply buried, the aquifer is less prone to contamination from surface sources than it is in areas where the aquifer is only thinly covered (areas of bedrock highs). Once any contaminants reached the water within the Jacobsville Sandstone, however, they would move laterally toward Keweenaw Bay.

Surficial spills of contaminants in the area of the industrial park would likely be confined to the upper layers of the glacial deposits. Steep slopes between the industrial park and Keweenaw Bay would tend to channel runoff over and through the shallow surficial deposits, and toward Keweenaw Bay. A more detailed study of the industrial park area, including sampling additional wells and conducting aquifer tests, would be required to make a more definitive statement about the susceptibility to contamination of the aquifer, below the industrial park and downgradient of the industrial park.

Surface Water

The Keweenaw Bay Indian Community is drained by several small creeks and drainage ditches, most of which flow to Keweenaw Bay. There are numerous small wetlands, ponds, and lakes in the Community.

Ponds and Wetlands

Within the KBIC, about 160 lakes and ponds have been identified and named (Humphrys and Green, 1962, pp. 7A-7F). Wetlands, such as the Assinins Wetlands, are significant hydrologic features of the study area. Many more unnamed, often unmapped or undelineated wetlands exist. Wetland is a general term used to define a group of wet habitats, and includes areas that are permanently wet or are intermittently water covered (Bates and Jackson, 1987, p 737). These waterbodies range in size from less than 0.1 ha to about 16 ha. None is used for public water supply.

Streams

Three streams drain most of the study area. To the west of Keweenaw Bay, the Little Carp River drains most of the area west and north of Baraga. To the south of Keweenaw Bay, tributaries of the Falls River drain the southcentral part of the study area. Silver River and its tributaries drain much of the eastern third of the study area. Small areas along the eastern shore of Keweenaw and Pequaming bays are drained by small, unnamed streams. None is used for public drinking water supply (Bedell, 1982, pp. 20-21).

Keweenaw Bay

Keweenaw Bay, the principal surface-water body within the study area, covers 45 km^2, or about one-sixth of the KBIC. The Bay reaches a depth of more than 80 m in the study area, but in most areas is about 10 to 60 m deep (Coastal Dynamics, INC., 1985, p. 6). It is the source of water for municipal supplies in Baraga and L'Anse (Bedell, 1982, pp. 20-21).

WATER QUALITY

Water samples were collected in 1991 from 11 ground-water sites and 13 surface-water sites. In 1997, eight of the ground-water sites were resampled, and 2 additional ground-water sites were sampled (figure 1). A well at the KBIC industrial park was sampled in 1997 as part of planning for possible future development. Physical characteristics of the water were measured when the samples were collected, and the samples were analyzed at the U.S. Geological Survey's National Water Quality Laboratory (NWQL) in Arvada, Colorado.

Ground Water

Ground water in the study area is generally acceptable for human consumption, with few exceptions. Results of chemical analyses are shown in table 1. The concentrations of chemical constituents in the water samples analyzed are generally less than the recommended U.S. Environmental Protection Agency (USEPA) primary maximum contaminant level (MCL) and secondary maximum contaminant levels (SMCL) for drinking water (table 2), and less than the recommended USEPA primary maximum contaminant level goal (MCLG) (United States Environmental Protection Agency, 1996). SMCLs are unenforceable federal guidelines regarding taste, odor, color, and certain other non-aesthetic effects of drinking water. USEPA recommends SMCLs to States as reasonable goals, but Federal law does not require water systems to comply with them. States may, however, adopt their own enforceable regulations governing these concerns. Exceptions are described below.

Wells 1, 3, and 9 (table 1) were sampled in 1991 but not in 1997. Well 1 is outside the current study area, in an area thought to not contribute to ground water used by the KBIC, based on ground-water flow directions shown in figure 4. Concentrations of manganese (560 μg/L) in water from well 1 exceeded the SMCL of 0.05 mg/L (50 μg/L). Manganese, under aerobic conditions or in combination with other minerals or bacteria, can cause objectionable stains, appearance, taste, and odors.

Well 3 was installed by the USGS in 1991 and removed after the field portion of the 1991 study was completed. Well 3 was a shallow (less than 3.3 m deep) well completed in lakebed sands in the Assinins Wetland. The pH of water from this well was more acidic (pH=5.8) than the USEPA SMCL (pH=6.5). An iron concentration of 1,900 μg/L, which exceeds the SMCL of 0.3 mg/L (300 μg/L), was measured in water from this well. Iron, under aerobic conditions, or in combination with other minerals or bacteria, can cause objectionable stains, appearance, taste, and odors. The zinc concentration of 2,200 μg/L of water from this well is less than the SMCL of 5 mg/L (5,000 μg/L). This zinc concentration may be due to the well construction materials and methods of installation, which consisted of driving a galvanized pipe into the ground. The acidity (low pH) of the water also could cause a reaction with the well pipe, causing zinc from the galvanizing process to enter into solution. Hardness in water from well 3 was 14 mg/L, less than the Michigan Department of Public Health minimum objectionable level for hardness of 25 mg/L. Overly soft water such as this can be corrosive to pipes, and could also cause zinc from the galvanizing process to enter into solution.

Well 9, at Zeba Michigan, is no longer used because of bacterial contamination. The well has been removed, and the borehole has been plugged. At the time well 9 was sampled in 1991, the water was within the established USEPA MCLs and SMCLs for drinking water.

Of the remaining wells, objectionable (greater than 300 μg/l) levels of iron were detected in samples from wells 5 (35,000 μg/L) and 8 (310 μg/L); objectionable (greater than 50 μg/l) levels of manganese were detected in samples from wells 5 (220 μg/L), 6 (130 μg/L), 7 (60 μg/L), and 8 (68 μg/L). Hardness was below the lower State recommended level for hardness of 25 mg/L in samples from well 5 (21 mg/L).

Of particular note is the lead level (2 μg/L) of water from well 4. USEPA MCLs do not allow for

Table 1. Chemical and physical characteristics of ground water in the Keweenaw Bay Indian Community

[Analyses by U.S. Geological Survey. --, no analysis made; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; 420JCBV, Jacobsville Sandstone; 112LKBDS, Lakebed sands; 112SAND, Sand; 112SDGV, Sand and gravel]

Well number	Well location and owners name (Township, range, section)	Date sample collected	Time	Depth of well, total (meters)	Aquifer	Specific conduct-ance, field (µS/cm)	Water temper-ature (°C)
1	T53N R33W S24 Larry Julien	10-8-91	0930	35	420JCBV	839	8.1
2	T52N R33W S15 Garfield Hood	10-8-91	1115	46	420JCBV	338	9.0
		7-9-97	1100			279	9.0
3	T51N R33W S15 U.S. Geological Survey	8-21-91	0845	3	112LKBDS	48	13.1
4	T51N R33W S15 Assinins Catholic Church	10-8-91	1305	72	420JCBV	463	11.9
		7-8-97	1445			222	10.0
5	T51N R33W S22 The Pines	10-10-91	0840	15	112SAND	157	8.5
		7-8-97	1145			401	11.5
6	T51N R33W S27 Michael Whitty	10-9-91	1330	56	420JCBV	775	10.4
		7-8-97	1400			735	9.8
7	T50N R33W S4 Martha Koskela	10-9-91	1015	28	112SDGV	261	9.7
		7-8-97	1545			219	10.5
8	T50N R33W S3 Brewery Road Facility	10-10-91	0935	15	112SAND	407	10.7
		7-8-97	1000			329	11.0
9	T51N R32W S19 Zeba Methodist Church	10-10-91	1025	35	420JCBV	299	10.5
10	T51N R32W S8 John Seppenen	10-8-91	1540	46	112SDGV	295	9.1
		7-9-97	1300			297	8.5
11	T51N R32W S4 Robert Ramsey	10-9-91	0840	11	112SDGV	125	7.4
		7-9-97	1230			93	7.0
12	T51N R32W S19 Stan and Pauline Struce	7-10-97	1000	43	420JCBV	252	8.8
13	T51N R33W S29 Tribal Industrial Park	7-9-97	0915	131	420JCBV	180	12.0

Table 1. Chemical and physical characteristics of ground water in the Keweenaw Bay Indian Community--Continued

Well number	Turbidity (NTU)	Oxygen, dissolved (mg/L)	pH (standard units)	Silica, dissolved (mg/L as SiO2	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 SO4	Chloride, dissolved (mg/L as Cl)
1	1.0	3.4	8.1	6.7	64	15	64	5.7	8.3	230
2	.40	0	8.0	8.9	20	2.9	47	3.5	17	36
	.27	--	7.6	8.5	19	2.7	47	3.3	15	34
3	2.4	.6	5.8	7.8	3.7	1.2	.80	1.0	.50	.20
4	.90	1.8	7.5	6.9	11	1.3	89	2.2	20	72
	.26	--	7.1	6.2	11	1.9	50	2.5	11	14
5	23	.2	6.5	20	5.5	1.7	2.0	.70	1.4	2.4
	3.7	--	7.8	11	34	6.7	55	3.5	.40	41
6	.30	0	7.2	10	64	14	87	5.4	5.8	110
	3.7	--	7.2	8.5	73	15	86	5.4	9.3	146
7	.50	.7	8.2	13	38	9.0	4.1	1.3	1.3	5.2
	1.2	--	7.8	13	38	8.6	3.8	1.3	1.5	3.5
8	1.0	.1	8.0	18	49	15	16	2.4	<.1	28
	4.7	--	7.8	17	48	15	15	2.4	<.1	26
9	85	.5	7.1	11	39	5.2	18	2.3	5.3	13
10	.40	1.3	7.9	21	37	16	3.9	4.4	3.2	1.8
	.2	--	7.9	19	35	15	3.6	4.3	2.5	.28
11	1.4	4.4	7.1	12	16	4.1	1.6	1.2	9.6	2.1
	2.2	--	6.5	12	14	3.5	1.4	1.2	5.9	1.0
12	.14	--	7.8	9.7	18	2.2	52	1.2	4.1	4.0
13	.26	--	7.6	10	27	7.4	5.9	1.5	6.5	1.2

Well number	Fluoride, dissolved (mg/L as F)	Nitrogen, ammonia, total (mg/L as N	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, total (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (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, organic + ammonia, total (mg/L as N)
1	0.30	0.010	<0.010	<0.05	<0.05	<0.01	--	--	<0.20
2	.30	<.010	<.010	<.05	<.05	<.01	--	--	<.20
	.37	--	<.015	--	<.05	<.01	--	--	<.20
3	<.10	.190	.160	<.05	<.05	<.01	--	0.31	.500
4	.60	<.010	<.010	<.05	<.05	<.01	--	--	<.20
	.27	--	<.015	--	.084	<.01	--	--	<.20
5	.20	.310	.340	<.05	<.05	.01	--	.39	.700
	.30	--	.340	--	<.05	<.01	--	--	.495
6	.20	.021	.010	<.05	<.05	<.01	--	--	<.20
	.21	--	<.015	--	<.05	<.01	--	--	<.20
7	.10	2.80	2.80	.190	.210	.05	0.14	.30	3.10
	<.1	--	<.015	--	<.05	<.01	--	--	<.20
8	.20	.090	.080	<.05	<.05	<.01	--	--	<.20
	.23	--	.029	--	<.05	<.01	--	--	<.20
9	<.1	.050	.021	.360	.350	.03	.33	--	<.20
10	.20	.021	<.010	.100	.120	<.01	--	--	<.20
	.22	--	<.015	--	.086	<.01	--	--	<.20
11	.10	<.010	<.010	.171	.171	<.01	--	--	<.20
	<.1	--	<.015	--	.069	<.01	--	--	<.20
12	.10	--	<.015	--	.066	<.01	--	--	<.20
13	<.1	--	<.015	--	<.05	<.01	--	--	<.20

Table 1. Chemical and physical characteristics of ground water in the Keweenaw Bay Indian Community--Continued

Well number	Phos-phorus, ortho, total (mg/L as P)	Phos-phorus, total (mg/L as P)	Phos-phorus, dis-solved (mg/L as P)	Phenols, total (µg/L)	Alka-linity, field (mg/L as $CaCO_3$)	Hard-ness (mg/L as $CaCO_3$)	Hard-ness, noncar-bonate (mg/L as $CaCO_3$)	Bicar-bonate, dis-solved (mg/L as HCO_3)	Solids, sum of consti-tuents, dis-solved (mg/L)	Solids, residue at 180 °C, dis-solved (mg/L)
1	<0.010	0.021	<0.010	<1	60	220	160	73	433	467
2	<.010	.021	<.010	<1	106	62	--	129	201	197
	<.010	<.010	<.010	--	115	60	--	--	194	205
3	<.010	.080	.010	2	20	14	--	24	31	43
4	<.010	.030	.010	1	106	33	--	129	271	271
	.030	.026	.010	--	125	37	--	--	170	171
5	.290	.310	.310	1	66	21	--	81	83	138
	<.010	<.010	<.010	--	235	120	--	--	271	292
6	<.010	.021	.010	1	136	220	--	166	453	436
	<.010	<.010	<.010	--	315	250	--	--	498	526
7	<.010	<.010	<.010	1	132	130	--	161	161	147
	<.010	<.010	<.010	4	170	130	--	--	153	156
8	<.010	.010	.041	1	184	180	--	224	--	232
	<.010	<.010	<.010	--	235	180	--	--	--	245
9	.050	.060	<.010	1	122	120	--	131	178	172
10	<.010	.010	<.010	1	160	160	--	195	189	168
	.010	<.010	<.010	--	185	150	--	--	180	181
11	<.010	<.010	<.010	1	58	57	71	71	77	80
	<.010	<.010	<.010	--	60	50	--	--	70	79
12	<.010	<.010	<.010	3	190	56	--	--	194	207
13	.012	<.010	.013		135	100	--	--	126	129

Well number	Alum-inum, dis-solved (µg/L as Al)	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Beryl-lium, dis-solved (µg/L as Be)	Cad-mium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Cobalt, dis-solved (µg/L as Co)	Copper, dis-solved (µg/L as Cu)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Lithium, dis-solved (µg/L as Li)
1	20	<1	980	<0.5	<1.0	<1	<3	<1	83	<1	26
2	20	3	100	1	<1.0	<1	<3	2	10	<1	20
	8.0	--	94	--	--	--	<3	--	9.9	--	18
3	110	<1	15	<.5	2.0	<1	5	<1	1,900	<1	<4.0
4	20	<1	77	<.5	<1.0	3	<3	75	22	2	48
	12	--	76	--	--	--	<3	--	13	--	29
5	100	<1	60	<.5	<3.0	<5	<3	7	35,000	<1	<4.0
	<5.0	--	2,205	--	--	--	4.8	--	453	--	40
6	<10	<1	650	<.5	<1.0	<1	<3	2	25	<1	75
	<5.0	--	759	--	--	--	<3	--	152	--	67
7	10	<1	130	<.5	<1.0	<1	<3	5	100	<1	6.0
	<5.0	--	138	--	--	--	<3	--	86	--	4.9
8	10	2	210	<.5	<1.0	<1	<3	<1	310	<1	9.0
	<5.0	--	222	--	--	--	<3	--	107	--	7.0
9	20	<1	530	<.5	<1.0	1	<3	2	100	<1	23
10	20	2	100	<.5	<1.0	<1	<3	1	48	<1	15
	<5.0	--	103	--	--	--	<3	--	22	--	11
11	20	<1	60	<.5	<1.0	<1	<3	5	95	<1	<4.0
	11	--	60	--	--	--	9.9	--	675	--	<4.0
12	<5.0	--	449	--	--	--	<3	--	4.7	--	36
13	11	--	77	--	--	--	<3	--	10	--	5.0

Table 1. Chemical and physical characteristics of ground water in the Keweenaw Bay Indian Community--Continued

Well number	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Tritium,[1] total (pCi/L)
1	560	<0.1	<10	<1	<1	<1.0	400	<6	18	--
2	7.0	<.1	<10	1	<1	<1.0	430	270	10	--
	5.7	--	<10	<1	<1	<1.0	435	200	--	10.6±3.2
3	45	<.1	<10	1	<1	<1.0	17	<6	2200	--
4	5.0	<.1	20	1	<1	<1.0	240	9	180	--
	4.2	--	<10	<1	<1	<1.0	221	36	--	23.4±3.8
5	220	<.1	<10	2	<1	<1.0	30	40	54	--
	104	--	<10	1.5	<1	<1.0	699	<6	--	21.8±3.2
6	130	<.1	<10	<1	<1	<1.0	1200	<6	30	--
	132	--	<10	<1	<1	<1.0	1316	<6	--	29.1±3.8
7	60	<.1	<10	<1	<1	<1.0	94	<6	23	--
	61	--	<10	<1	<1	<1.0	94	<6	--	<5.7±3.2
8	68	<.1	<10	<1	<1	<1.0	270	<6	9.0	--
	61	--	<10	<1	<1	<1.0	273	<6	--	<5.7±3.2
9	24	<.1	<10	<1	<1	<1.0	640	<6	560	--
10	2.0	<.1	<10	<1	<1	<1.0	190	9	210	--
	<1.0	--	<10	<1	<1	<1.0	199	8	--	<5.7±3.2
11	6.0	.8	<10	1	<1	<1.0	30	<6	20	--
	38	--	<10	<1	<1	<1.0	28	<6	--	49.6±4.5
12	3.2	--	<10	<1	<1	<1.0	315	<6	--	19.2±3.8
13	2.0	--	<10	<1	<1	<1.0	107	<6	--	67.2±5.8

1. For concentrations above the method reporting limit (5.7 pCi/L), the number given is the tritium concentration and the 2-sigma uncertainty reported by the lab.

Table 2. Drinking-water regulations of the U.S. Environmental Protection Agency

[TT, treatment technique; unless otherwise specified, units of measurement are in milligrams per liter (mg/L); MFL, million fibers per liter; pCi/L, picocuries per liter; --, no level set or proposed. Data retrieved on 11/19/96 from the World Wide Web at http://www.epa.gov/OST/Tools/dwstds.html, U.S. Environmental Protection Agency, 1996]

Contaminant	Maximum contaminant level goal	Maximum contaminant level	Secondary maximum contaminant level
National primary drinking water standards			
Acrylamide	zero	TT[1]	--
Alachlor (Lasso)	zero	0.002	--
Aldicarb[2]	0.001	.003	--
Aldicarb Sulfone[2]	.001	.002	--
Aldicarb Sulfoxide[2]	.001	.004	--
Antimony	.006	.006	--
Asbestos	7 MFL	7 MFL	--
Atrazine (Atranex, Crisazina)	.003	.003	--
Arsenic	none[3]	.05	--
Barium	2	2	--
Benzene	zero	.005	--
Benzo[a]Pyrene (PAH)	zero	.0002	--
Beryllium	.004	.004	--
Beta Particle & Photon Emitters	zero	4 mrem/yr	--
Cadmium	.005	.005	--
Carbofuran (Furadan 4F)	.04	.04	--
Carbon Tetrachloride	zero	.005	--
Chlordane	zero	.002	--
Chromium	.1	.1	--
Copper	1.3	TT[4]	1.0
Cyanide	.2	.2	--
2,4-D (Formula 40, Weeder 64)	.07	.07	--
Dalapon	.2	.2	--
Di(2-ethylhexyl)adipate	.4	.4	--
Di(2-ethylhexyl)phthalate	zero	.006	--
Dibromochloropropane (DBCP)	zero	.0002	--
o-Dichlorobenzene	.6	.6	--
p-Dichlorobenzene	.075	.075	--
1,2-Dichloroethane	zero	.005	--
1,1-Dichloroethylene	.007	.007	--
cis-1,2-Dichloroethylene	.07	.07	--
trans-1,2-Dichloroethylene	.1	.1	--
Dichloromethane	zero	.005	--
1,2-Dichloropropane	zero	.005	--
Dinoseb	.007	.007	--
Diquat	.02	.02	--
Endothall	.1	.1	--
Endrin	.002	.002	--
Epichlorohydrin	zero	TT[1]	--
Ethylbenzene	.7	.7	--

Table 2. Drinking-water regulations of the U.S. Environmental Protection Agency --Continued

Contaminant	Maximum contaminant level goal	Maximum contaminant level	Secondary maximum contaminant level
Ethylene dibromide	zero	.00005	--
Flouride[5]	4.0	4.0	2.0
Giardia Lamblia	zero	TT[6]	--
Glyphosate	.7	.7	--
Gross Alpha Particle Activity	zero	15 pCi/L	--
Heptachlor (H-34, Heptox)	zero	zero	--
Heptachlor Epoxide	zero	.0002	--
Heterotrophic Plate Count	zero	TT[5]	--
Hexachlorobenzene	zero	.001	--
Hexachlorocyclopentadiene	.05	.05	--
Lead	zero	TT[4]	--
Legionella	zero	TT[5]	--
Lindane	.0002	.0002	--
Methoxychlor (DMDT, Marlate)	.04	.04	--
Monochlorobenzene	.1	.1	--
Mercury	.002	.002	--
Nickel	.1[7]	.1[6]	--
Nitrate (as nitrogen)	10	10	--
Nitrite (as nitrogen)	1	1	--
Total Nitrate/Nitrite	10	10	--
Oxamyl (Vydate)	.2	.2	--
Pentachlorophenol	zero	.001	--
Picloram	.5	.5	--
Polychlorinated Bipenyls (PCBs)	zero	.0005	--
Radium 226 & Radium 228 Comb.	zero	5 pCi/L	--
Selenium	.05	.05	--
Simazine	.004	.004	--
Styrene	.1	.1	--
Sulfate	deferred[8]	deferred[8]	250
2,3,7,8-TCDD (Dioxin)	zero	.00000003	--
Tetrachloroethylene	zero	.005	--
Thallium	.0005	.002	--
Toluene	1	1	--
Total Coliforms	zero	none	--
Total Trihalomethanes	----	.1	--
Toxaphene	zero	.003	--
2,4,5-TP (Silvex)	.05	.05	--
1,2,4-Trichlorobenzene	.07	.07	--
1,1,1-Trichloroethane	.2	.2	--
1,1,2-Trichloroethane	.003	.005	--
Trichloroethylene	zero	.005	--
Turbidity	zero	TT[5]	--
Vinyl Chloride	zero	.002	--
Viruses	zero	TT[5]	--
Xylenes	10	10	--

Table 2. Drinking-water regulations of the U.S. Environmental Protection Agency- -Continued

Contaminant	Maximum contaminant level goal	Maximum contaminant level	Secondary maximum contaminant level
National secondary drinking water standards[9]			
Aluminum	--	--	.05 to .20
Chloride	--	--	250
Color	--	--	15 color units
Corrosivity	--	--	noncorrosive
Foaming agents	--	--	.5
Iron	--	--	.3
Manganese	--	--	.05
Odor	--	--	3 threshold odor numbers
pH	--	--	6.5-8.5
Silver	--	--	.1
Total Dissolved Solids(TDS)	--	--	500
Zinc	--	--	5
Conductivity[10]	--	--	--
Hardness[11]	--	--	--
Sodium[12]	--	--	--

1. Each Public Water System must certify annually in writing to the State (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used in drinking water systems, the combination (or product) of dose and monomer level does not exceed the levels specified as follows: (1) Acrylamide = 0.05% dosed at 1 ppm (or equivalent) and (2) epichlorohydrin = 0.01% dosed at 20 ppm (or equivalent).
2. These levels are not in effect. EPA plans to repropose levels in the future.
3. The Maximum Contaminant Level Goal (MCLG) for this contaminant was withdrawn and is currently under review.
4. The lead and copper rule is a treatment technique that requires water systems to take tap water samples from homes with lead pipes or copper pipes with lead solder and/or with lead service lines. If more than 10 percent of these samples exceed an action level of 1.3 mg/L for copper or 0.015 mg/L for lead, the system is triggered into additional treatment.
5. Under review.
6. These contaminants are regulated under the Surface Water Treatment Rule (40 CFR 141.70-141.75).
7. The Maximum Contaminant Level Goal (MCLG) and Maximum Contaminant Level (MCL) for nickel have been withdrawn.
8. The proposed Maximum Contaminant Level Goal (MCLG) and Maximum Contaminant Level (MCL) for Sulfate is 500 mg/L.
9. Secondary Drinking Water Standards are unenforceable federal guidelines regarding taste, odor, color, and certain other non-aesthetic effects of drinking water. EPA recommends them to States as reasonable goals, but federal law does not require water systems to comply with them. States may, however, adopt their own enforceable regulations governing these concerns.
10. Michigan Department of Public Health has set the objectionable level at 850 μS/cm or greater.
11. Michigan Department of Public Health has set the objectionable level at less than 25 or greater than 250 mg/L.
12. Michigan Department of Public Health has set the objectionable level at 250 mg/L or greater.

the presence of lead, and recommend treatment of water containing even small amounts of lead. Because no blank samples (water of known quality that help identify possible sources of contamination) were prepared at the time this sample was taken, it is not possible to say with certainty that the lead originated in the aquifer. It is possible that the measured lead concentration is an artifact of the sampling equipment, or that it resulted from leaching of lead at solder joints in plumbing in the household from which the sample was taken.

Turbidity was above the MCL and MCLG (both of which require treatment to 0.0 NTU) in all samples (0.30-85 NTU); however, this is a level set for public water supplies on the assumption that all suppliers of public water have the ability to filter and treat the water in such as a way as to decrease turbidity to zero. This is a standard set for aesthetic reasons, and the turbidity levels reported for water from all wells is below any noticeable or objectionable level.

Ground-Water Types

Ground-water samples collected in this study can be recognized on the basis of their major-ion composition, as illustrated in figure 5. Water from the glacial aquifers is typically a calcium-magnesium-bicarbonate type, whereas water from the Jacobsville Sandstone aquifer is more variable in composition. This variability is likely a consequence of areal and vertical differences in the hydraulic characteristics and lithologic composition of the Jacobsville Sandstone. Most of the wells sampled are open to long intervals of rock; therefore, water samples from a single well likely represent mixtures of water from several depths within the aquifer.

In general, sodium and calcium are the principal cations in ground water in the western part of the study area, with decreasing sodium and increasing calcium and magnesium concentrations toward the east. Chloride is the principal anion in ground water in the western part of the study area, with decreasing chloride and increasing bicarbonate concentrations toward the east.

Surface Water

In 1991, the Assinins Wetland was evaluated as a potential site for fish farming. Measurements of streamflow at the wetland's inlets and outlet (fig. 6) were made during high and low-flow conditions. A gage was installed to measure seasonal fluctuations in water stage and water temperature in the wetland. Three 5.1-cm diameter wells were installed in the glacial deposits to determine aquifer lithology and water quality. A continuous recorder was installed on the center well (KEW2R) to measure water-table fluctuations. Streamflow and water quality were measured at 11 streams.

Water samples were collected at two locations in the wetland, at one down-gradient well, and at the wetland's outlet (fig. 6), to determine the quality of water discharging to and from the wetland. The samples were analyzed for common dissolved substances, trace metals, nutrients, bacteria, phenols, pesticides, and volatile organics. Temperature, pH, specific conductance, dissolved oxygen, and alkalinity of water samples were measured in the field. Results of analyses of water samples from the Assinins Wetland are in table 3; results of analyses of water samples from streams are in table 4.

Sediment samples were collected at two locations in the wetland (fig. 6) and at three stream sites (fig. 6). The samples were analyzed for trace metals. Results of the analyses of sediment samples from the Assinins Wetland are in table 3; results of the analyses of sediment samples from the streams are in table 4. These data were collected in 1991 to provide a basis for assessing the potential use of the Assinins Wetland as fish rearing ponds, and the general quality of Keweenaw Bay with respect to fisheries management issues. The data collection for this work was not completed; hence, no assessment is made of the quality of water in Keweenaw Bay, nor is the quality of the water sampled related to water quality standards for fishery management.

The chemical characteristics of water from all 3 sources at Assinins Wetland (well, wetland, stream) sampled are similar, likely reflecting similar sources. Streams were sampled near their mouths, either upstream of their confluence with other streams, or upstream of where they enter Keweenaw Bay. The wetland was sampled at 2 locations, one near the point where water is believed to exit the wetland, and one near the center of a chain of apparently

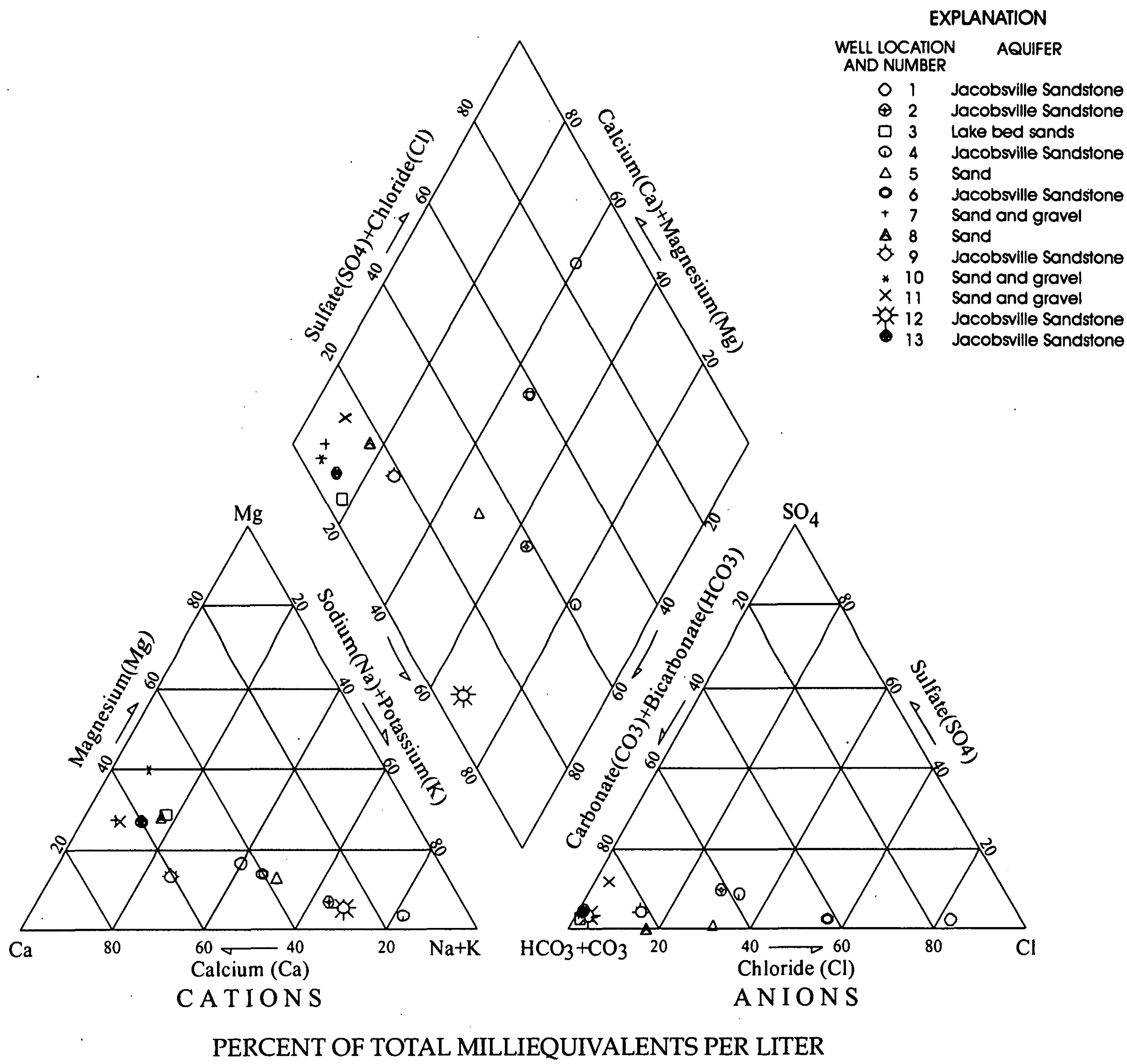

Figure 5. Trilinear diagram of ground-water chemistry, Keweenaw Bay Indian Community (1991 and 1997 data).

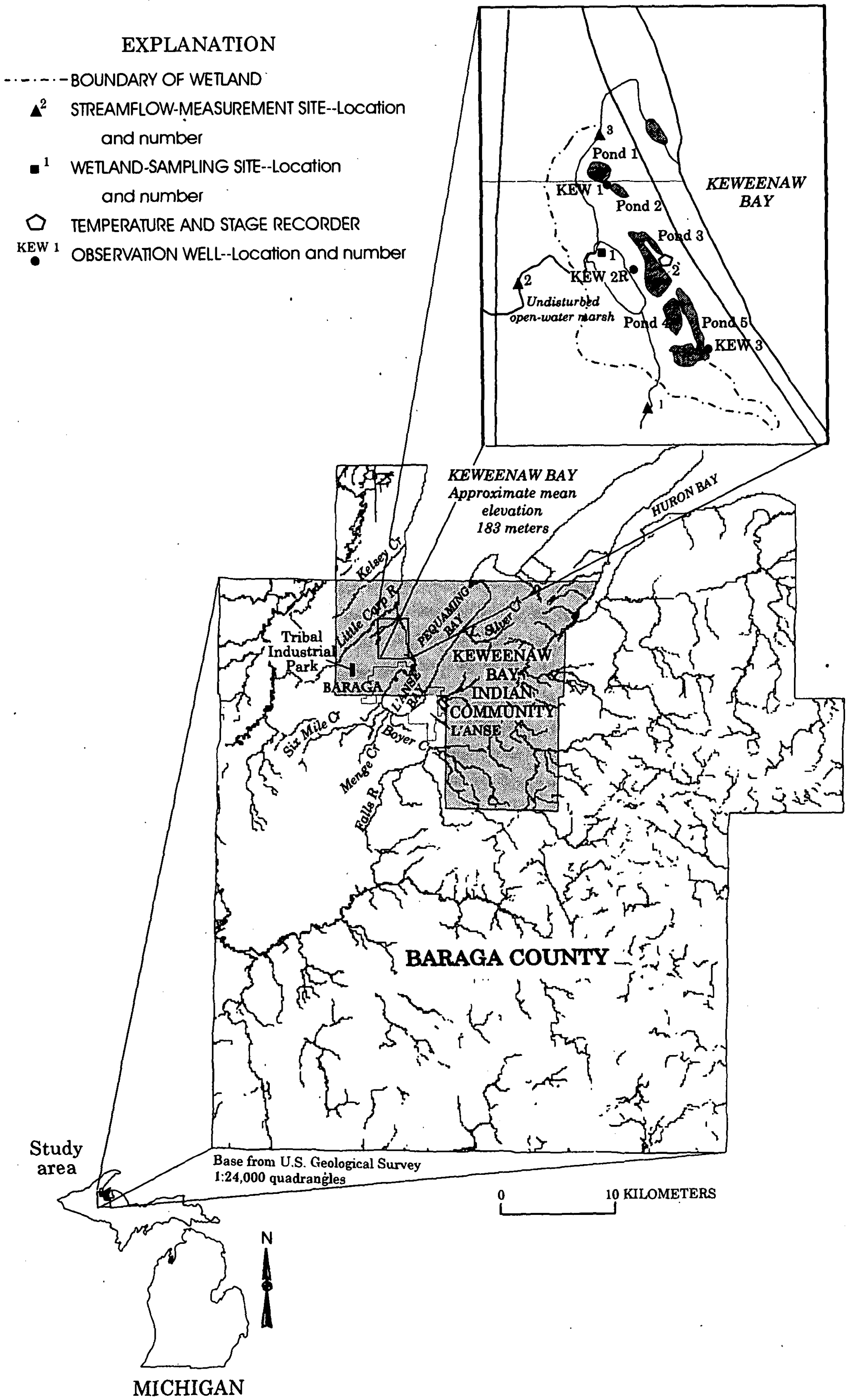

Figure 6. Location of wetlands and surface-water sites, 1991.

Table 3. Chemical and physical characteristics of water of the Assinins Wetland in the Keweenaw Bay Indian Community

[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 number and name	Date sample collected	Time	Total depth of water column (meters)	Specific conductance, field (µS/cm)	Water temperature (°C)	Turbidity (NTU)	Color (platinum-cobalt units)	Oxygen, dissolved (mg/L)
1	464916088290101 — Assinins Wetland (marsh)	8-21-91	1040	3	108	15.5	4.0	70	6.0
2	464912088285401 — Assinins Wetland (pond 3)	8-21-91	1330	1	81	22.7	4.1	50	7.6

Site number	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)	Fluoride, dissolved (mg/L as F)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)
1	7.4	9.4	17	4.1	1.6	1.0	1.1	0.30	<0.10	0.18	.018
2	7.6	4.6	11	3.0	1.3	0.60	0.60	.30	<.10	.36	.371

Site number	Nitrogen, $NO_2 + NO_3$, total (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (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, organic + ammonia, total (mg/L as N)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Hydrogen sulfide, total (mg/L as H2S)
1	<0.05	<0.05	0.01	--	0.92	1.1	<0.01	0.041	11	<0.5
2	<.05	<.05	<.01	--	.64	1.0	<.01	.041	14	<.5

Site number	Phenols, total (µg/L)	Alkalinity, field (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 °C, dissolved (mg/L)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved, (µg/L as As)	Barium, dissolved, (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)
1	2	58	59	71	71	96	20	<1	34	<0.5	2.0
2	1	37	40	46	46	79	20	<1	35	.8	<1.0

Site number	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, Dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)
1	<1	<3	4	2,700	<1	<4	310	<0.1	<10	<1	<1
2	<1	<3	2	400	<1	<4	8	.4	<10	<1	<1

Table 3. Chemical and physical characteristics of water of the Assinins Wetland in the Keweenaw Bay Indian Community--Continued

Site number	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Coliform, fecal, 0.7 mM-MF (cols/100 ml)	Streptococci, fecal, KF Agar (cols/100 ml)	Arsenic, bottom material (µg/g as As)	Beryllium, bottom material (µg/g as Be)	Cadmium, bottom material (µg/g as Cd)	Chromium, bottom material (µg/g as Cr	Copper, bottom material (µg/g as Cu)
1	<1.0	34	<6	26	--	--	--	--	--	--	--
2	<1.0	27	<6	6	20	33	4	<1	<2	20	50

Site number	Lead, bottom material (µg/g as Pb)	Nickel, bottom material (µg/g as Ni)	Zinc, bottom material (µg/g as Zn)	Selenium, bottom material (µg/g as Se)	Mercury, bottom material (µg/g as Hg)
1	--	--	--	--	--
2	60	20	120	<1	0.06

Table 4. Chemical and physical characteristics of water in streams in the Keweenaw Bay Indian Community

[Analyses by U.S. Geological Survey. --, no analysis made; <, less than; m^3/s, cubic meters per second; 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 number and name	Date sample collected	Time	Streamflow, instantaneous (m^3/s)	Specific conductance, field (µS/cm)	Water temperature (°C)	Turbidity (NTU)
1	04043060 — Kelsey Creek near Keweenaw Bay	10-31-91	1300	1.23	79	4.0	2.5
2	04043065 — Little Carp River near Keweenaw Bay	10-31-91	1430	1.90	111	5.0	2.0
3	04043068 — Assinins Wetland Outlet at Assinins	8-21-91	1130	.05	199	19.0	2.6
		10-31-91	0945	1.87	132	5.0	1.5
4	04043069 — Tangen Creek at Baraga	10-30-91	1645	.09	157	5.5	4.6
5	04043070 — Hazel Creek near Baraga	10-30-91	1500	2.28	284	6.0	2.0
6	04043080 — Six Mile Creek near Baraga	10-29-91	1220	18.1	177	7.0	1.6
7	04043085 — Menge Creek near Baraga	10-29-91	1415	9.42	215	7.5	1.7
8	04043090 — Boyers Creek near Baraga	10-29-91	1520	.89	223	8.0	4.7
9	04043100 — Falls River at L'Anse	10-30-91	1220	44.4	145	5.0	1.3
10	04043105 — Linden Creek at L'Anse	10-30-91	1000	4.20	267	7.0	4.4
11	04043120 — Little Silver Creek near L'Anse	10-30-91	0820	.471	219	3.0	1.0

Site number	Color (platinum-cobalt units)	Oxygen, dissolved (mg/L)	pH (standard units)	Silica, dissolved (mg/L as SiO2)	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 SO4)	Chloride, dissolved (mg/L as Cl)
1	51	12.5	7.4	5.0	7.9	1.6	2.4	1.7	2.6	2.3
2	54	12.0	7.6	6.9	13	3.8	2.9	1.5	3.2	4.3
3	47	3.5	7.5	7.2	29	6.8	2.2	0.70	1.3	0.4
	42	9.6	7.4	6.3	17	4.9	1.9	.80	2.0	1.1

Table 4. Chemical and physical characteristics of water in streams in the Keweenaw Bay Indian Community--Continued

Site number	Color (platinum-cobalt units)	Oxygen, dissolved (mg/L)	pH (standard units)	Silica, dissolved (mg/L as SiO2)	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 SO4)	Chloride, dissolved (mg/L as Cl)
4	130	10.6	7.4	7.0	17	4.4	6.2	2.3	9.9	13
5	21	8.2	7.8	12	36	8.8	9.5	2.0	3.7	12
6	11	11.1	8.1	10	25	6.1	2.4	.90	4.9	1.5
7	12	10.6	8.0	11	32	7.4	2.0	1.1	7.0	1.7
8	51	11.2	8.0	9.1	31	8.4	2.9	2.4	15	2.8
9	52	12.8	7.8	7.9	20	4.3	2.6	.90	6.0	4.4
10	25	11.1	7.6	10	31	6.9	11	2.5	14	18
11	21	12.0	7.8	12	33	6.8	4.0	1.3	7.1	4.5

Site number	Fluoride, dissolved (mg/L as F)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, $NO_2 + NO_3$, total (mg/L as N)	Nitrogen, $NO_2 + NO_3$, dissolved (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, organic + ammonia, total (mg/L as N)
1	<0.10	0.021	0.021	<0.05	<0.05	<0.01	--	0.38	0.40
2	.20	.041	.030	<.05	<.05	<.01	--	.46	.50
3	<.10	.021	.01	<.05	<.05	<.01	--	1.4	1.4
	.20	.041	.03	<.05	<.05	<.01	--	.46	.50
4	.20	.07	.07	<.05	<.05	<.01	--	.63	.70
5	.10	.24	.25	.371	.43	.021	0.35	.16	.40
6	.20	.03	.03	<.05	.059	<.01	--	--	<.20
7	.20	.03	<.01	<.05	.064	<.01	--	--	<.20
8	.20	.03	.01	<.05	<.05	<.01	--	.47	.50
9	.20	.021	.01	<.05	<.05	<.01	--	.28	.30
10	.20	.51	.50	1.70	1.70	.11	1.59	.49	1.0
11	.20	.03	<.01	.50	.50	<.01	--	--	<.20

Table 4. Chemical and physical characteristics of water in streams in the Keweenaw Bay Indian Community--Continued

Site number	Phosphorus, ortho, total (mg/L as P)	Phosphorus, total (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Sediment, suspended (mg/L)	Sediment, suspended, % finer than .062 mm sieve	Phenols, total (μg/L)	Alkalinity, field (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Bicarbonate, dissolved (mg/L as HCO_3)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 °C, dissolved (mg/L)
1	0.021	0.021	14	4	75	<1	14	26	17	39	49
2	.021	.021	0.021	7	--	<1	42	48	51	64	72
3	<.01	.03	8.9	--	--	1	102	100	124	109	128
	<.01	<.01	11	4	84	1	59	63	72	79	82
4	<.01	<.01	22	3	78	<1	40	61	49	90	115
5	.01	.041	12	4	75	<1	122	130	149	161	163
6	<.01	<.01	4.9	6	48	1	90	88	110	105	104
7	<.01	.021	8.4	11	55	2	91	110	111	127	123
8	.01	.021	14	6	82	1	104	110	127	136	145
9	<.01	<.01	8.6	2	90	<1	64	68	78	86	95
10	.03	.06	9.3	4	94	1	90	110	110	151	163
11	<.01	<.01	6.3	2	40	3	100	110	122	133	135

Site number	Aluminum, dissolved (μg/L as Al)	Arsenic, dissolved (μg/L as Al)	Barium, dissolved (μg/L as Ba)	Beryllium, dissolved (μg/L as Be)	Cadmium, dissolved (μg/L as Cd)	Chromium, dissolved (μg/L as Cr)	Cobalt, dissolved (μg/L as Co)	Copper, dissolved (μg/L as Cu)	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Lithium, dissolved (μg/L as Li)	Manganese, dissolved (μg/L as Mn)
1	40	--	43	--	--	--	<3	--	330	--	<4	52
2	40	<1	46	<0.5	<1.0	1	<3	2	500	2	<4	19
3	60	<1	56	.8	<1.0	<1	<3	1	1,300	<1	<4	210
	30	<1	36	<.5	<1.0	<1	<3	<1	210	<1	<4	16
4	160	<1	59	<.5	<1.0	<1	<3	8	930	<1	<4	54
5	20	1	100	<.5	<1.0	<1	<3	9	130	<1	<4	90
6	30	2	60	<.5	<1.0	1	<3	<1	72	<1	<4	9
7	30	1	48	<.5	<1.0	<1	<3	<1	53	<1	<4	6
8	40	<1	47	<.5	<1.0	<1	<3	1	160	<1	<4	12
9	50	<1	27	<.5	<1.0	<1	<3	1	140	<1	<4	8
10	30	<1	61	<.5	<1.0	<1	<3	2	170	<1	<4	38
11	10	<1	130	<.5	<1.0	<1	<3	22	34	<1	<4	25

Table 4. Chemical and physical characteristics of water in streams in the Keweenaw Bay Indian Community--Continued

Site number	Mercury, dis- solved (µg/L as Hg)	Molyb- denum, dis- solved (µg/L as Mo)	Nickel, dis- solved (µg/L as Ni)	Sele- nium, dis- solved (µg/L as Se)	Silver, dis- solved (µg/L as Ag)	Stron- tium, dis- solved (µg/L as Sr)	Vana- dium, dis- solved (µg/L as V)	Zinc, dis- solved (µg/L as Zn)	Coliform, fecal, 0.7 µM-MF (cols/100 ml)	Strep- tococci, fecal, KF Agar (cols/100 ml)
1	--	<10	<1	<1	<1.0	40	<6	--	56	7
2	<0.1	<10	<1	<1	<1.0	51	<6	16	1	7
3	<.1	<10	<1	<1	<1.0	53	<6	15	180	42
	<.1	<10	<1	<1	<1.0	33	<6	88	4	31
4	<.1	<10	<1	<1	<1.0	70	<6	9	43	52
5	<.1	<10	<1	<1	<1.0	63	<6	3	32	29
6	<.1	<10	<1	<1	<1.0	45	<6	<3	10	36
7	<.1	<10	2	<1	<1.0	40	<6	6	7	72
8	<.1	<10	<1	<1	<1.0	59	<6	<3	4	43
9	<.1	<10	<1	<1	<1.0	31	<6	10	10	80
10	<.1	<10	<1	<1	<1.0	56	<6	21	7	37
11	<.1	<10	1	<1	<1.0	90	<6	<3	3	11

Site number	Arsenic, bottom material (µg/g as As)	Beryl- lium, bottom material (µg/g as Be)	Cadmium, bottom material (µg/g as Cd)	Chro- mium, bottom material (µg/g as Cr)	Copper, bottom material (µg/g as Cu)	Lead, bottom material (µg/g as Pb)	Mercury, bottom material (µg/g as Hg)	Nickel, bottom material (µg/g as Ni)	Sele- nium, bottom material (µg/g as Se)	Zinc, bottom material (µg/g as Zn)
5	7	<1	<1	2	10	<10	<10	<10	<1	0.01
9	3	<1	<1	2	3	<10	<10	<10	<1	.01
10	<1	<1	<1	2	3	<10	<10	<10	<1	<.01

unconnected, undrained ponds. One well, near what is believed to be the down-gradient end of the wetland, also was sampled.

Water samples are grouped on the basis of their major-ion composition, as shown in figure 7. Water from the wetland well is a calcium-magnesium-bicarbonate type, and surface water in the wetland is a calcium-bicarbonate type. Stream water quality is slightly more variable, but the dominant anion remains bicarbonate. Calcium is the dominant cation of stream water; however, significant concentrations of magnesium and sodium are also present in some samples.

Comparison of the wetland-area samples to the ground-water samples collected in 1991 and 1997 (table 1) indicates that they are chemically similar to the samples from the alluvial and glacial sand and sand-and-gravel aquifers. It is likely that baseflow to these streams is dominantly ground-water discharge from the glacial aquifers, and that its composition changes only slightly or not at all during flow through the wetland. Although interactions between surface water and ground water may be important in determining some aspects of the status of ground-water supplies for the KBIC, no additional samples were collected nor measurements made in 1997.

SUMMARY AND CONCLUSIONS

The Keweenaw Bay Indian Community, in Michigan's western Upper Peninsula, is dependent upon its aquifers for drinking water and water for other uses. Throughout the community, ground water is readily available, although sometimes at depths greater than 60 m. The community of Baraga lies wholly in the study area; the north part of the village of L'Anse is in the study area. Both communities draw water from Keweenaw Bay for their municipal supplies.

The development of an industrial park on the west side of the KBIC has caused concerns for the safety of the aquifers, as the park is sited near a ground-water divide. Should contaminants be released in the park, there is a potential for contamination of down-gradient water supplies.

Most of the study area is moderately to steeply sloping, with thin alluvial and glacial deposits of unconsolidated materials overlying bedrock. The thickness of unconsolidated deposits ranges from being locally absent to having a thickness of more than 30 m. Glacial deposits are used for water supplies in 2 parts of the study area.

The principal aquifer in the study area is the Jacobsville Sandstone. Water is produced primarily from fractures and bedding planes. Analyses of pump tests in 21 wells completed in the aquifer indicated hydraulic conductivities of 10^{-4} to 10^{1} m/d and storage coefficients of 10^{-5}. Storage coefficients of this magnitude are indicative of confined conditions.

Water levels in the Jacobsville Sandstone generally indicate confined conditions, except for an area in 2 sections immediately north of Baraga, and east and down gradient from the industrial park. Locally, the aquifer is unconfined in areas of bedrock highs in the west and east parts of the study area, and in areas of outcrop along the Keweenaw Bay shoreline and valleys of small streams that drain the area. Along the Keweenaw Bay shoreline, where overlain by alluvium and glacial deposits, the aquifer is generally confined.

Water samples were collected in 1991 and 1997 to assess the current water quality in the study area, and provide information on natural and anthropogenic processes that affect water quality. Samples were collected from 11 wells in 1991 and 10 wells in 1997. Eight of the wells were sampled in both years. Three of the wells used in 1991 were either outside of the current study area or were no longer in use in 1997. The industrial park well was sampled only in 1997. Also in 1997, a well that had been removed after 1991 was replaced by a well of similar construction, and near to the discontinued well.

In general, ground-water quality is suitable for domestic, commercial, and industrial uses. Concentrations of some constituents fail to meet USEPA MCL, SMCL, or MCLG's and Michigan standards for domestic use in only a few wells. The most common ground-water quality problem in the study area is large concentrations of dissolved iron (310 - 35,000 µg/L), followed by large concentrations of dissolved manganese (60 - 560 µg/L). Water from one well had detectable levels of lead in 1991.

Water from the surficial aquifers is predominantly a calcium-magnesium-bicarbonate type.

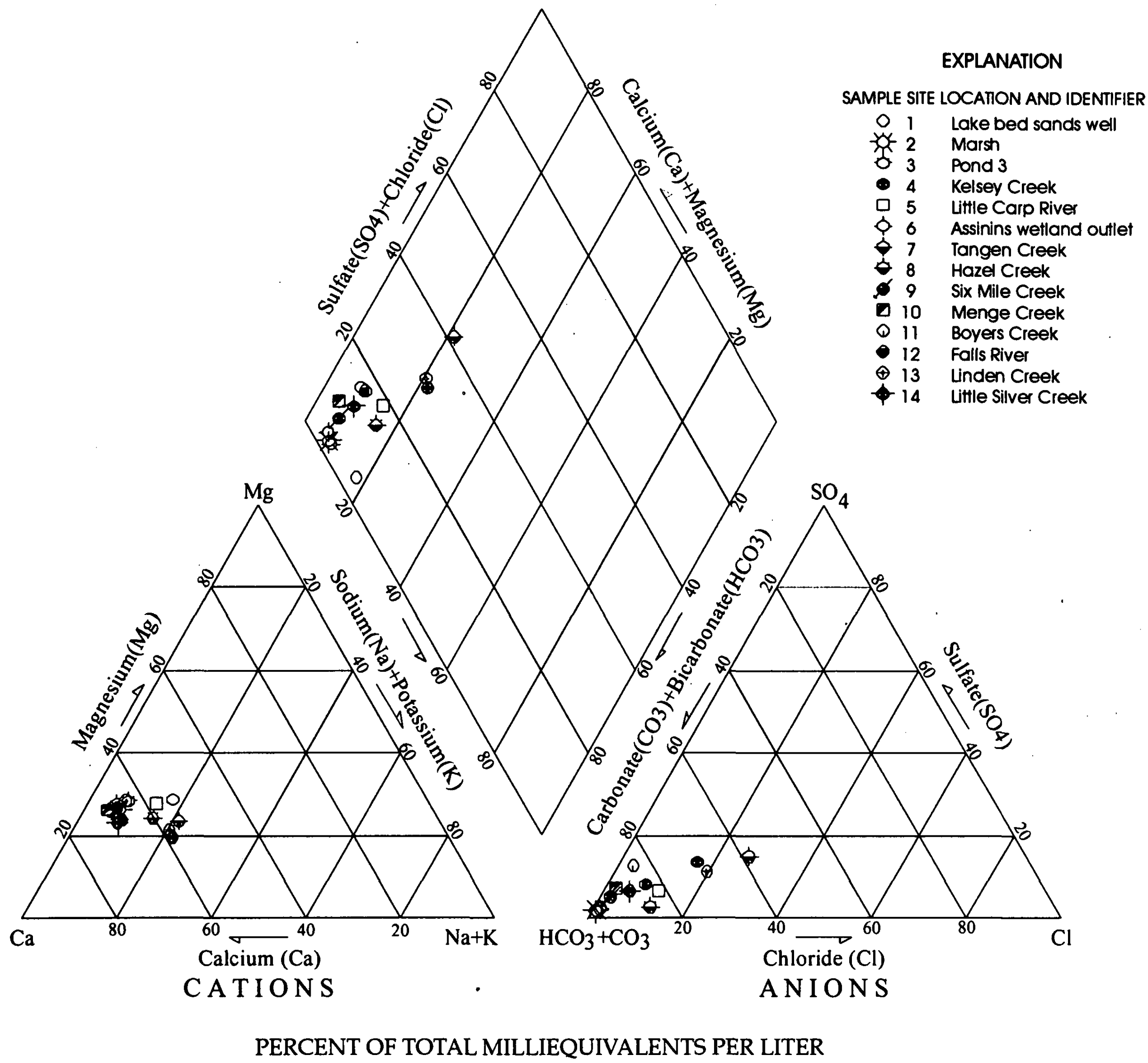

Figure 7. Trilinear diagram of surface-water, wetland open-water, and wetland well-water chemistry, Keweenaw Bay Indian Community (1991 data).

The geochemistry of water from the Jacobsville Sandstone and Michigamme Slate is more variable, and changes with location from west to east through the study area. In the western part of the study area, waters are typically of a sodium-chloride or calcium-chloride type, changing to a calcium-magnesium-bicarbonate type in the eastern part of the study area.

Ground-water flow in the study area is generally toward Keweenaw Bay, with local exceptions in the eastern part of the study area. Ground-water divides generally coincide with surface-water divides with only minor differences. In the eastern part of the study area, some ground-water flow is toward Huron Bay or Silver River. In general, ground-water flow is lateral, with an upward potential, as evidenced by flowing wells and water levels above land surface, particularly in low-lying areas near Keweenaw Bay, and along the lower slopes leading to the Bay.

The ages of ground water in KBIC, determined on the basis of concentrations of the radioactive isotope tritium, indicate that recharge to the Jacobsville Sandstone and Michigamme Slate has occurred in the last 45 years, particularly in areas where the aquifers are exposed at land surface or covered by a thin mantle (less than 5 m) of unconsolidated alluvium and glacial material. Recharge to the glacial aquifers likely occurs at the water table on an annual basis. Recharge is limited locally by the composition of the deposits, as indicated by tritium data in 2 wells indicating that recharge at the point of measurement in the glacial deposits takes more than 45 years.

Of principal concern to the Keweenaw Bay Indian Community is the susceptibility to contamination of aquifers down gradient (southeast) of the industrial park. Between 26 and 56 m of surficial material, most of which is clay or clay mixed with sand, overlies the bedrock in this area. Depth to water is between 26 and 63 m. Tritium concentrations in 2 wells down gradient from the industrial park indicate at least partial recharge to the Jacobsville Sandstone in the last 45 years. Surficial spills of contaminants in the area of the industrial park could possibly be confined to the upper layers of the surficial deposits. Steep slopes between the industrial park and Keweenaw Bay would tend to channel runoff over and through the shallow surficial deposits, toward Keweenaw Bay. However, at the industrial park, and downgradient of the industrial park, the Jacobsville Sandstone is unconfined. The industrial park is situated in an area where recharge is likely to occur to the Jacobsville Sandstone. Additional data are needed to develop a well-head protection plan for the industrial park and KBIC. Without additional data, it is not possible to make definitive statements about the safety of the water resource in the Jacobsville Sandstone, nor about it's potential for contamination from spills of contaminants on the land surface.

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GLOSSARY

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.

Base flow. The discharge entering stream channels as inflow from ground water or other delayed sources; sustained or fair-weather flow of streams.

Bedrock. Consolidated rock that underlies soil or other unconsolidated material.

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

Cubic meters per second. A unit expressing rate of discharge. One cubic meter per second is equal to the discharge of a stream 1 meter wide and 1 meter deep flowing at an average velocity of 1 meter per second.

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

Dissolved solids. Substances present in water that are in true chemical solution.

Divide. A line of separation between drainage systems. A topographic divide delineates the land from which a stream gathers it 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 (NGVD of 1929). The NGVD of 1929 is a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929." In this report, all elevations are above NGVD of 1929.

Evapotranspiration. Water withdrawn from a land area by direct evaporation from water surfaces and moist soil, and by plant transpiration. No attempt is made to distinguish between the two.

Ground water. Water that is in the saturated zone from which wells, springs, and inflow to streams are supplied.

Ground-water runoff. Ground water that has discharged into stream channels by seepage from saturated earth materials.

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.

Isotropy. The condition of having properties that are uniform in all directions.

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. An imaginary surface representing the total head of ground water and defined by the level to which water will rise in a well.

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 the precipitation that appears in the streams; the water draining from an area.

Storage coefficient. The volume of water released from storage in a vertical column of 1.0 square meter when the water table or other piezometric surface declines 1.0 meter.

Specific conductance. A measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter (mS/cm) at 25 degrees Celsius. Because the specific conductance is related to the 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) is in the range 0.5 to 0.8.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted 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. No water table exists where the upper surface of the water body is confined by low-permeability materials.