HYDROGEOLOGY AND EFFECTS OF TAILINGS BASINS ON THE HYDROLOGY OF SANDS PLAIN, MARQUETTE COUNTY, MICHIGAN

By N. G. Grannemann

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4114

Prepared in cooperation with the

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

Lansing, Michigan

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND ABBREVIATIONS

The inch-pound units used in this report can be converted to the International System of Units (SI) as follows:

Multiply inch-pound unit	by	To obtain SI unit
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile $(ft^3/s)/mi^2$	0.01093	cubic meter per second per square kilometer $(m^3/s)/km^2$
gallon per minute (gal/min)	0.06308	liter per second (L/s)
	Mass	
pound, avoirdupois (lb)	453.6	gram (g)
	Temperature	
degree Fahrenheit (°F)	°C=5/9(°F-32)	degree Celsius (°C)
	Specific capacity	
gallon per minute per foot (gal/min)/ft	0.2070	liter per second per meter (L/s)/m

CONVERSION FACTORS AND ABBREVIATIONS--continued

Multiply inch-pound unit	by	To obtain SI unit
	Specific conductance	
micromho per centimeter at 25° Celsius (μmho/cm at 25°C)	1.000	microsiemen per centimeter at 25° Celsius (μS/cm at 25°C)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)

DATUM NOTE:

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 mean sea level.

HYDROGEOLOGY AND EFFECTS OF TAILINGS BASINS ON THE HYDROLOGY OF SANDS PLAIN, MARQUETTE COUNTY, MICHIGAN

By N. G. Grannemann

ABSTRACT

Sands Plain, a 225-square mile area, is near the Marquette iron-mining district in Michigan's Upper Peninsula. Gribben Basin, a settling basin for disposal of waste rock particles from iron-ore concentration, is in the western part. Because Sands Plain is near iron-ore deposits, but not underlain by them, parts of the area are being considered as sites for additional tailings basins.

Glacial deposits, as much as 500 feet thick, comprise the principal aquifer. Most ground water flows through the glacial deposits and discharges in a series of nearly parallel tributaries to the Chocolay River which flows into Lake Superior. Ninety-five percent of the discharge of these streams is ground-water runoff. The aquifer is recharged by precipitation at an average rate of 15 inches per year and by streamflow losses from the upper reaches of Goose Lake Outlet at an average rate of 2 inches per year.

Precipitation collected at two sites had mean pH values of 4.0; rates of deposition of sulfate and total dissolved nitrogen were estimated to be 17.4 and 5.8 pounds per acre per year, respectively. Dissolved-solids concentrations in water from streams ranged from 82 to 143 milligrams per liter; sulfate ranged from 4.2 to 10 milligrams per liter. Calcium and bicarbonate were the principal dissolved substances. Highest dissolved-solids concentrations in water from wells in glacial deposits were found in a major buried valley east of Goose Lake Outlet. These concentrations ranged from 14 to 246 milligrams per liter; sulfate concentrations ranged from 0.9 to 53 milligrams per liter. Because of the high ground-water component of streamflow, mean concentrations of total nitrogen and trace metals in surface water do not differ significantly from mean concentrations in ground water.

A two-dimensional digital model of ground-water flow was used to simulate water levels and ground-water runoff under steady-state and transient conditions. Predictive simulations with the steady-state model were made to determine the effects of continued operation of Gribben tailings basin and construction and operation of four hypothetical tailings basins. Operation of Gribben Basin has decreased the average rate of ground-water flow to Goose Lake Outlet by 0.9 to 1.6 cubic feet per second but has increased the average rate of ground-water flow to Warner Creek by about 0.2 cubic foot per second. Continued filling of the tailings basin to its design capacity is expected to cause a slight increase in leakage from the basin to Goose Lake Outlet.

Four hypothetical tailings basins, comprising a total of 11 square miles, were simulated by successively adding one more basin to the previous basin configuration. Net ground-water flow to streams was reduced by the simulated basins. The magnitude of these reductions depends on engineering decisions about the method of basin construction and a better understanding of the hydraulic properties of the materials used to seal the basin perimeters. The maximum total reduction in ground-water runoff due to construction and operation of 11 square miles of tailings basins is about 18 cubic feet per second compared to flow simulated by a steady-state simulation without tailings basins. If bottom sealing, rather than slurry wall construction, is used for one of the hypothetical basins, the total maximum reduction is 7.5 cubic feet per second. Under some assumed conditions, leakage from the tailings basins may slightly increase ground-water flow to Goose Lake Outlet and Warner Creek. The maximum probable leakage from all tailings basins is about 7 cubic feet per second; the minimum probable leakage is about 0.7 cubic foot per second.

INTRODUCTION

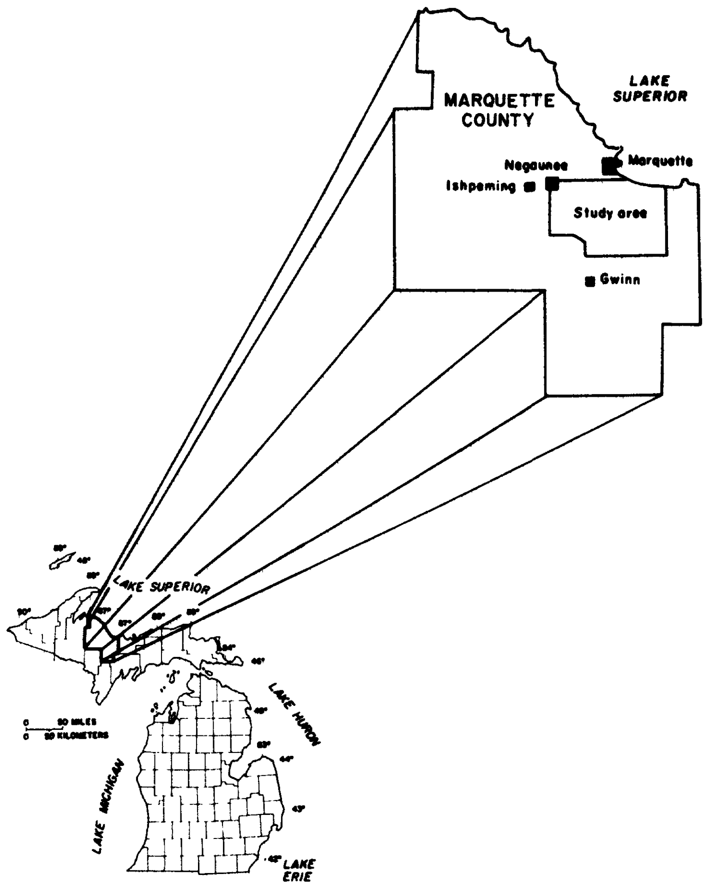


Figure 1.--Location of Sands Plain study area in Michigan's Upper Peninsula.

Sands Plain is southeast of the Marquette iron-mining district in Marquette County in the north-central part of Michigan's Upper Peninsula (fig. 1). It is an area of glacial deposits adjacent to and overlying igneous, metamorphic, and sedimentary rocks. Iron-ore, discovered in 1844 about 6 mi (miles) northwest of Sands Plain, has been the most important factor in the economic development of this part of the Upper Peninsula. At present, all iron-ore is mined from Negaunee Iron-formation, which contains about 35 percent iron--an amount too low for efficient smelting. The rock is crushed and ground to liberate iron-ore particles that are concentrated and formed into pellets containing about 65 percent iron.

Water is an important factor in the concentration process. Waste-rock particles (tailings) are moved in a slurry to settling basins; excess water from the basins is passed through a series of additional basins or, as in the Gribben Basin (pl. 1), through a clarifier prior to being discharged to a stream. Because of its nearness to the iron-mining area, Sands Plain is a possible site for new tailings basins that could cover as much as 11 mi^2 (square miles).

The study area is relatively undeveloped, except at K. I. Sawyer Air Force Base, Negaunee, and Harvey. In addition, about 100 single-family residences have been constructed at the intersection of county roads 480 and 553. Land in much of the study area has been and is being forested--primarily for pulpwood. Sand and gravel are mined in the north. Much of the area is currently used for hunting, berry-picking, skiing, snowmobiling, and other outdoor recreation.

Purpose and Scope

The purposes of this report are to:

1. Describe the hydrogeology of the Sands Plain area, emphasizing the relationship between ground water and surface water.

2. Provide background data on the quality of surface and ground water before additional tailings basins are constructed in the area. In addition, quality of precipitation is provided for background data.

3. Evaluate the possible hydrologic effects of construction and operation of hypothetical tailings basins in the Sands Plain area.

The study included evaluation of the area's geology, hydrology, and quality of water by collecting new field data as well as re-evaluating existing data. The field data collected for this report was obtained from 1979-81.

Methods of Investigation

Thickness, extent, and lithologic characteristics of glacial deposits, bedrock geology, and hydraulic properties of rocks and soils were determined by evaluating the data from 38 newly constructed observation wells (pl. 1), by evaluating drillers' logs and hydrologic records of domestic and previously constructed observation wells, and by field reconnaissance. Seismic data provided by the Cleveland-Cliffs Iron Co. helped in the geologic interpretation of the unconsolidated material and in determining the altitude of bedrock. Streamflow data were collected at 29 miscellaneous and partial-record sites, and at five gaging stations. Chemical and physical characteristics of water from 33 wells, 21 stream sites, and 4 lakes were determined (pl. 1). Water-quality samples were collected using standard U.S. Geological Survey procedures and then analyzed by U.S. Geological Survey laboratories in either Atlanta, Georgia or Denver, Colorado.

A two-dimensional, finite-difference, digital-computer model was developed to simulate observed ground-water levels and streamflow. The model was then used to estimate the effects that construction and operation of additional tailings basins would have on streamflow and ground-water levels.

Acknowledgments

Acknowledgment is made to all persons who provided assistance in the course of this study and to the private citizens who granted access to their property. Special acknowledgment is made to the Cleveland-Cliffs Iron Co. which provided historical data not otherwise accessable, to Dr. John Hughes for providing many insights for interpreting glacial geology, and to the Michigan Department of Natural Resources for providing domestic well logs and other geologic data.

Previous Studies

The water resources of Sands Plain were described in a report of the Marquette Iron Range area by Wiitala, Newport, and Skinner (1967). This report was updated by Grannemann (1979). A study by Stuart, Brown, and Rhodehamel (1954) of an area that includes about 2 mi^2 of Sands Plain relates underground mining operations to ground water in the Marquette iron-mining district. The hydrogeology of several small ground-water basins in the Marquette Iron Range has been described in reports by Supina (1974, 1979), but neither of these reports deals specifically with Sands Plain. An evaluation of the geology and hydrology of Marquette County for environmental planning was done by Twenter (1981). Doonan and Van Alstine (1982) studied the water-yielding capacity of rocks in the county.

Detailed mapping of the bedrock has been prevented by a thick mantle of glacial deposits overlying most of Sands Plain. However, bedrock in some parts of the study area has been mapped by Gair and Thaden (1968) and by Gair (1975). Case and Gair (1965) interpreted aeromagnetic data collected in Marquette and surrounding counties; Oray (1971) investigated regional gravity variations in the eastern portion of the Upper Peninsula of Michigan. Hamblin (1958) described the sandstones of northern Michigan, and Cannon and Simmons (1973) described the geology of the Southern Complex of the Marquette Iron Range, which included Sands Plain. Boyum (1975) prepared a general bedrock map of the Marquette Iron Range.

Glacial deposits were studied and mapped by Leverett (1929). Leverett's map was subsequently updated by Martin (1957). Some general mapping of glacial deposits in the Upper Peninsula was done by Black (1969). Hughes (1978) described a forest buried in glacial deposits that was uncovered during the construction of the Gribben Basin.

Description of Study Area

The Sands Plain study area comprises 225 mi^2 (pl. 1). It is drained by the East Branch Escanaba River, which flows to Lake Michigan, and by the Chocolay River, which flows to Lake Superior. The Marquette Iron Range lies in the northern and western parts of the study area and extends westward beyond the Marquette County border.

Population of the area is about 26,000 (U.S. Department of Commerce, 1980) and is concentrated at Negaunee, Harvey, and K. I. Sawyer Air Force Base. Negaunee has a population of 5,248 people, only some of whom live in the study area. Harvey, and the township in which it is included, has a total population of 5,685. About 5,600 people live or work at the Air Force Base.

Topography

The west-central part of the study area is a relatively flat-lying sandy plain comprising about 40 mi^2. This plain, the altitude of which ranges from 1,200 to 1,260 ft (feet), gave rise to the name Sands Plain. Smaller sandy plains, with altitudes ranging from 1,100 to 1,160 ft, lie east of the higher plain and cover about 7 mi^2. Steep-faced north- and northwest-trending terraces (moraines) are east and northeast of the plains. Nearly parallel, narrow, steep-sided stream valleys dissect the terraces. Near Lake Superior, the land surface is mostly flat or slightly undulating and is dissected by only a few streams.

West-trending bedrock ridges and hills of the Marquette Iron Range form topographic highs in the northwestern part of the study area. There, the altitude rises to more than 1,500 ft in places (fig. 2).

Climate

Meteorological data have been collected in the study area by the U.S. Air Force at K. I. Sawyer Air Force Base and by the U.S. Geological Survey at Sporley Lake and Cherry Creek (pl. 1). Data are available from the National Oceanic and Atmospheric Administration weather stations just outside the study area at Ishpeming (2 mi west of Negaunee), Marquette (2 mi north of Harvey), and Marquette County Airport (4 mi northeast of Negaunee). Average monthly and yearly precipitation amounts are shown in tables 1 and 2. Precipitation is greatest during spring and summer; the highest usually occurs in June and

Table 1.--Average monthly precipitation at meteorological stations near Sands Plain (includes water equivalent of snow)

Station	Period of record	Precipitation (in.)											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Ishpeming	1940-69	1.22	1.16	1.65	2.50	3.22	3.87	3.63	3.57	3.37	2.64	2.59	1.53
Marquette (city)	1940-69	1.57	1.53	1.88	2.65	2.91	3.54	2.96	3.04	3.37	2.42	3.03	1.97
Marquette (airport)	1961-80	1.54	1.52	1.88	2.60	2.93	3.44	3.07	3.01	3.45	2.44	2.99	1.97
K. I. Sawyer Air Force Base	1967-81	2.20	1.78	2.28	2.71	3.22	4.08	3.85	3.16	3.73	3.27	2.32	2.53
Cherry Creek	1979-81	--	--	--	3.56	2.01	3.10	2.69	2.62	2.85	3.96	1.75	--
Sporley Lake	1979-81	--	--	--	3.43	1.79	3.21	2.45	3.16	2.70	3.53	1.44	--

Table 2.--Total annual precipitation at meteorological stations near Sands Plain (includes water equivalent of snow)

Year	Precipitation (in.)			
	K. I. Sawyer Air Force Base	Ishpeming	Marquette (city)	Marquette (airport)
1970	35.18	31.14	30.63	35.03
1971	34.79	38.38	33.63	39.53
1972	32.09	33.85	33.70	36.81
1973	43.28	37.45	31.66	42.66
1974	28.88	30.53	29.09	35.72
1975	37.22	34.63	30.79	37.26
1976	25.40	21.26	24.28	28.83
1977	44.27	36.80	36.02	47.55
1978	38.26	37.09	31.72	38.07
1979	40.22	37.16	40.92	--
1980	27.08	30.49	33.92	31.25
Average	35.15	33.53	32.40	37.27

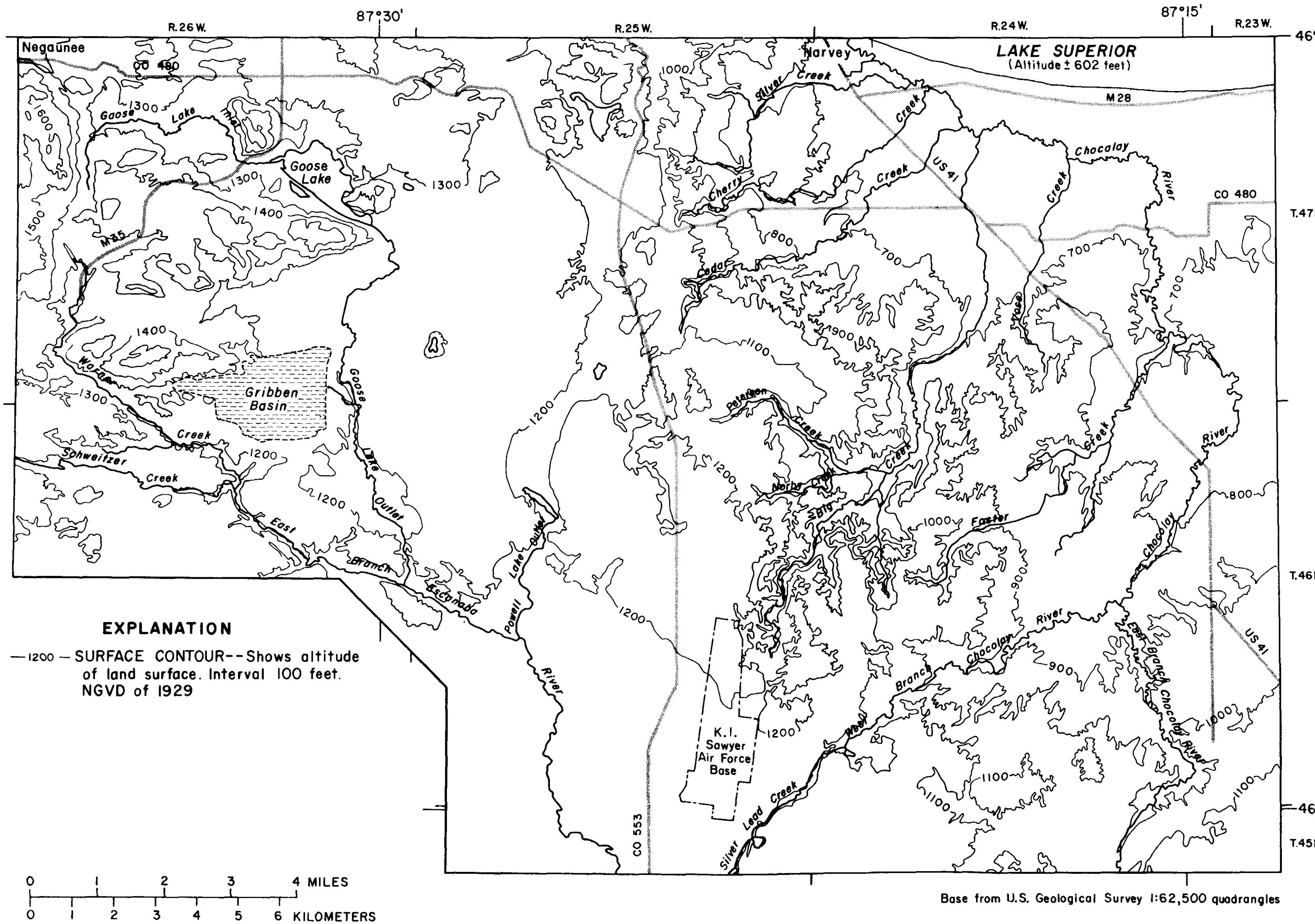


Figure 2.--Altitude of land surface.

lowest in February. From April to September, most precipitation occurs as rain; from November to early March it is usually snow. Annual precipitation averages about 34 in. and ranges from 21 to 47 in. Annual snowfall is 104, 105, and 108 in. for Ishpeming, Marquette, and K. I. Sawyer Air Force Base, respectively. Lake Superior locally modifies the climate by increasing cloudiness and moderating temperatures. Mean monthly temperatures at Ishpeming range from 14.7°F in January to 65.7°F in July (Michigan Department of Agriculture, 1971). The lowest recorded air temperature at Ishpeming is -30°F; the highest is 99°F, with an annual average of 41.0°F. At Marquette, average air temperature is 42.6°F.

GEOLOGY

The major geological features at Sands Plain are due to the distribution of different types of bedrock and to deposition of rock and soil debris from glacial ice. Bedrock consists of igneous, metamorphic, and sedimentary rocks (table 3). Glacial deposits, a result of glaciation that ended about 10,000

Table 3.--Description of rocks

Age				Geologic unit	Lithology
Phanerozoic	Cenozoic	Quaternary	Pleistocene	Glacial deposits; till, outwash and drainage channel deposits, and lacustrine deposits	Till is a poorly sorted, nonstratified mixture of sand, silt, clay, gravel, and boulders. Outwash and drainage channel deposits are composed of well-sorted, stratified sand and gravel with some silt. Lacustrine deposits are stratified mixtures of sand, silt, and clay with some gravel. Maximum known thickness of glacial deposits in the study area is 459 feet.
Phanerozoic	Paleozoic	Cambrian	Late	Trempealeau Formation	Dolomitic limestone. Maximum thickness is about 300 feet.
Phanerozoic	Paleozoic	Cambrian	Late	Munising Sandstone	Unit consists of a basal conglomerate overlain by a well-sorted, medium-grained competent sandstone and an upper poorly sorted, friable sandstone. Maximum thickness is about 100 feet.
Proterozoic	Middle			Jacobsville Sandstone	A mottled red or reddish-brown feldspathic sandstone containing lenses of red or gray conglomerate and some red shale. Four lithologic units are recognized: a basal conglomerate, a lenticular sandstone, a massive sandstone, and an upper red siltstone. Thickness varies from 1 to 100 feet.
Proterozoic	Middle			Intrusive rock	Mostly diabase dikes. Massive, dark gray, medium- to fine-grained; in places extensively argillized.
Proterozoic	Early			Metamorphosed dikes and sills	Mostly metadiabase dikes. Ranges from thin, fine-grained intrusions that may be greatly altered to thick, coarse-grained instrusions that are relatively resistant to alteration; variable in appearance and composition.
Proterozoic	Early			Negaunee Iron-formation	Iron-rich metasedimentary rock, in places extensively oxidized. Near Palmer, thickness ranges from 450 to 1,300 feet.
Proterozoic	Early			Metasedimentary rocks, undifferentiated	Includes Goodrich Quartzite, Siamo Slate, Ajibik Quartzite, Wewe Slate, Kona Dolomite, Mesnard Quartzite, and Enchantment Lake Formation.
Archean				Compeau Creek Gneiss	Mostly gneiss composed of light-colored, quartz-feldspar with some pegmatite, and, locally, some layered rock.
Archean				Older Archean rocks	Mostly medium-grained chlorite-quartz-muscovite schist, quartz-plagioclase-chlorite schist, and actinolitic schist cut by thin dikes.

years ago, consist of till, outwash, and drainage channel deposits, and lacustrine deposits. Geologic characteristics of the study area are based on outcrops and on information from nearly 300 wells (fig. 3).

Description of Bedrock

Schist and gneiss of Archean age, the oldest bedrock, outcrop and subcrop in the central and southwestern parts of the study area (fig. 4). Metasedimentary rocks of Early Proterozoic age outcrop in the northern part of the area. Several metasedimentary rock units contain iron formation, of which the Negaunee Iron-formation has been the most extensively mined. Sedimentary rocks of Middle Proterozoic to Late Cambrian age subcrop in the eastern half. The oldest sedimentary rock, the Jacobsville Sandstone of Middle Proterozoic age, rests on an eroded surface of igneous and metamorphic rocks. In some locations, the Jacobsville Sandstone is overlain by the Munising Sandstone and Trempealeau Formation both of Cambrian age.

Bedrock Structure

Erosional and structural features of bedrock are often reflected by the altitude of the bedrock surface (fig. 5). Where rock was structurally weak (such as along fractures and faults), valleys formed; where it was resistant to erosion, prominences formed. Glacial deposits obscure much of the bedrock topography; however, data from wells and seismic studies reveal two major and several minor buried valleys. These valleys were eroded by ancient streams and glacial ice and were later filled with glacial deposits. One major valley extends from the area north of Gribben Basin to Lake Superior following the northeast-trending Palmer fault (fig. 5). Another major valley extends from K. I. Sawyer Air Force Base to Lake Superior, generally following the course of Big Creek. The altitude of bedrock and its variable resistance to erosion affected the movement of glacial ice. The predominant pathway taken by ice during the last glacial advance was up the now-buried valleys from Lake Superior.

The Palmer fault, the major fault in the area, is upthrown on the south side near Goose Lake and near the west edge of the study area (fig. 4), but is upthrown about 3,500 ft on the north side in the Palmer basin (Gair, 1975). The fault probably extends further east than shown but is unmapped there because its trace is concealed by glacial deposits. North of the Palmer fault, foliation trends east-northeastward; south of the fault, much of the foliation trends southeastward (Gair and Thaden, 1968). Fractures are common in most rocks; folds occur in the metasedimentary rocks near Goose Lake.

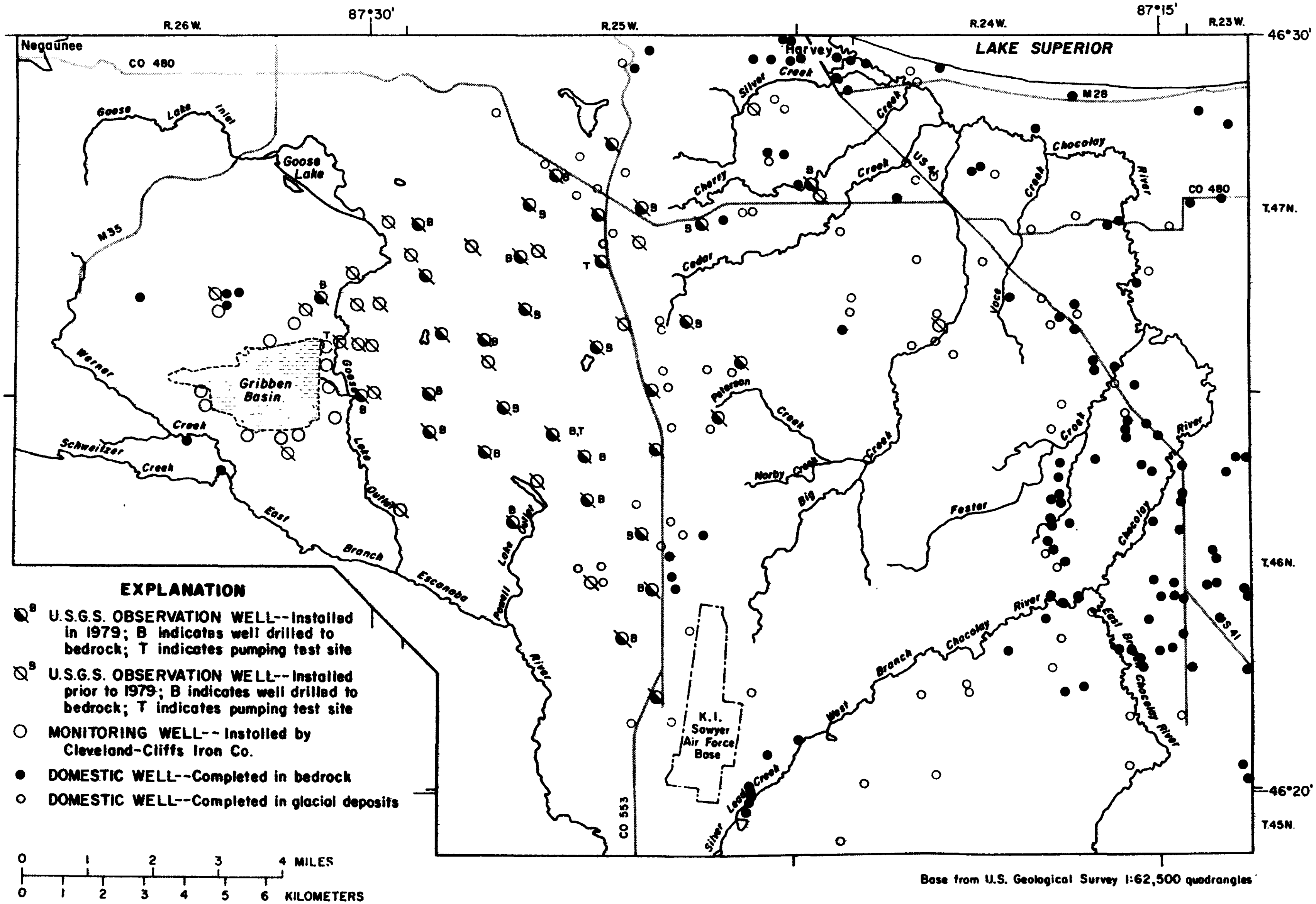


Figure 3.--Location of observation and domestic wells.

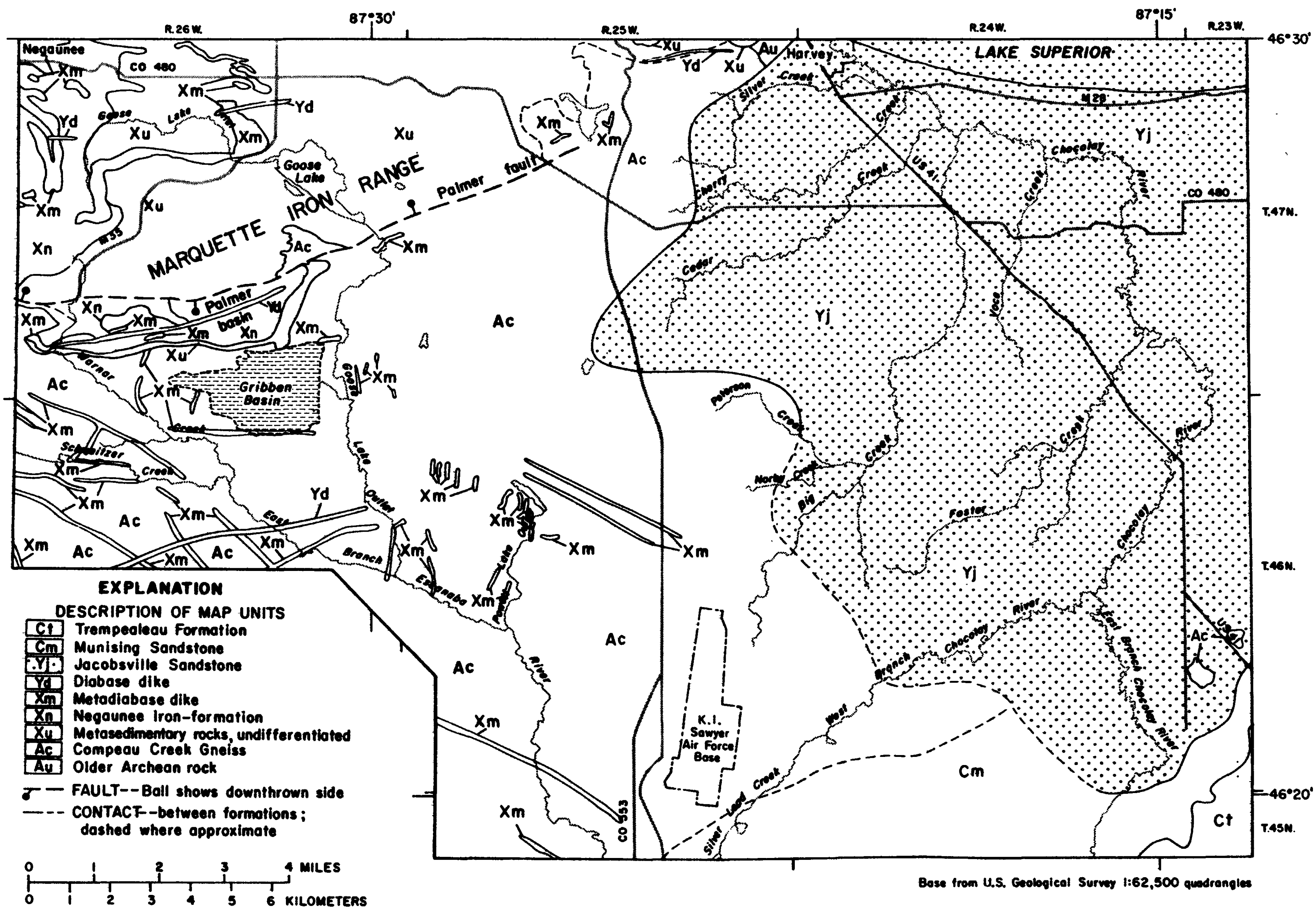


Figure 4.--Areal distribution of bedrock (see table 3 for more complete description).

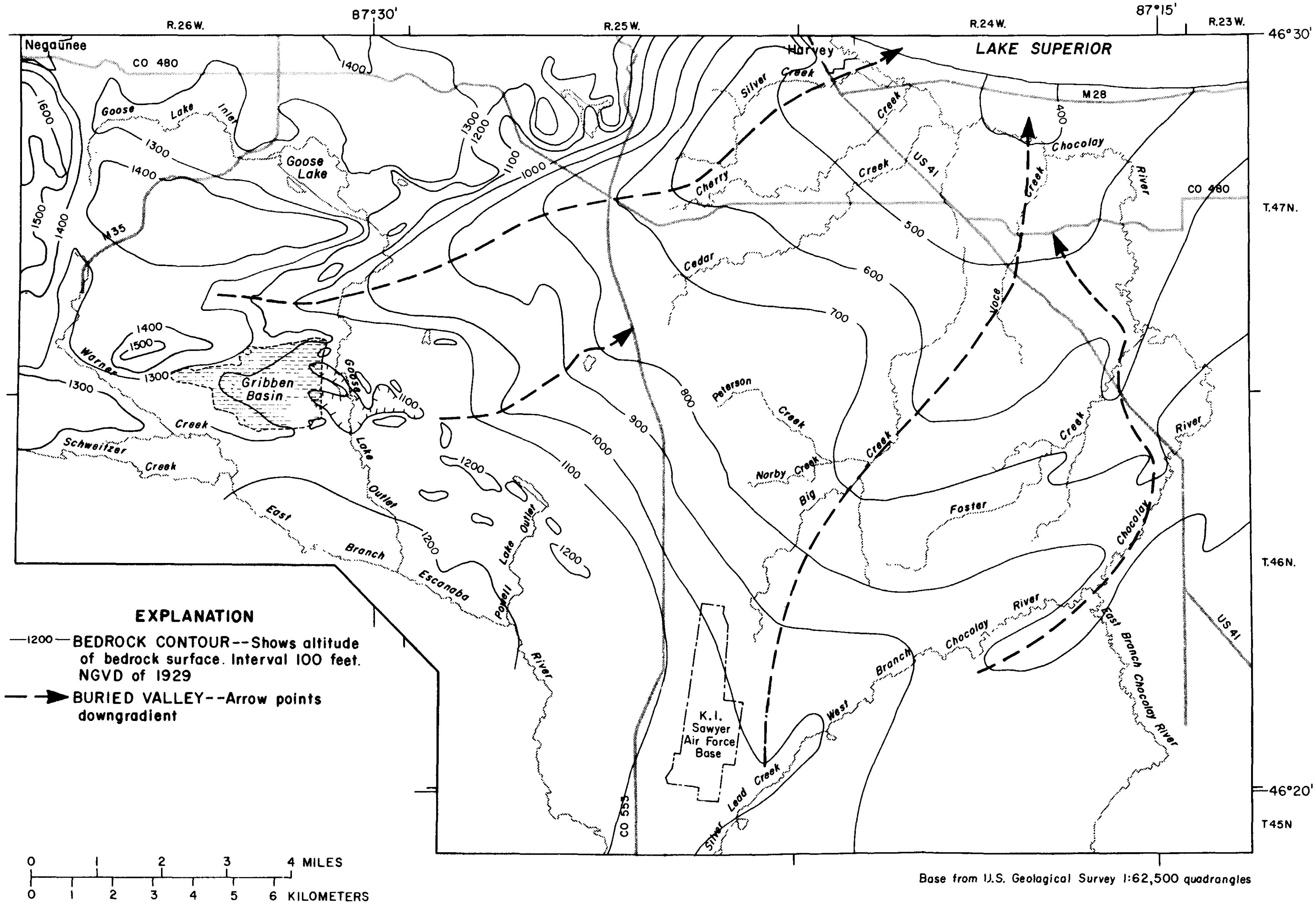


Figure 5.--Altitude of bedrock surface.

Description of Glacial Deposits

Glacial ice covered Sands Plain during four major periods. Existing glacial deposits and features are the result of ice movement during the last glaciation--the Wisconsinian Stage. A sheet of ice spread over the entire study area and far to the south near the end of this glaciation. After receding north of Sands Plain, the glacier readvanced on the area from the northeast covering most of the study area. It extended beyond the area's southern boundary (Hughes, 1978). The base of the ice advanced to an altitude of about 1,000 ft where it was halted by resistant bedrock inclined at a steeper angle. At this altitude, a ridge of till, called the Outer Marquette Moraine by Hughes (1978), was deposited (fig. 6). A thin ice sheet may have moved farther west along the Palmer fault valley. Because it was thin and of short duration, it probably did not excavate previously deposited glacial materials during this final readvance, but overrode them and deposited new till and outwash over older outwash. Sediment carried by streams flowing from the glacial ice was deposited south and west of the moraine. This sediment, comprised mostly of sand and gravel, forms the outwash in that area. The outwash is dissected by drainage channels along Goose Lake Outlet, Silver Lead Creek, and East Branch Escanaba River as well as near Powell Lake. Some of the channels are presently occupied by underfit streams; others no longer have active streams flowing in their channels. Meltwater, flowing from part of the ice sheet that was north of Sands Plain, deposited coarse-grained deposits between Goose and Pelissier Lakes as the water entered the plain. The resulting sand and gravel deposits are now being mined. Similar, but smaller, gravel deposits occur near Powell Lake.

During its retreat northeastward, the ice front halted again, probably because of the steep bedrock surface at the contact of the Jacobsville Sandstone and the underlying Compeau Creek Gneiss. While halted at this location, another ridge of till, the Inner Marquette Moraine, was deposited along the ice front. Streams flowing from the glacier deposited sediments in a narrow outwash plain just west and southwest of the Inner Marquette Moraine.

Advances and retreats of glacial ice were not uniform, but were punctuated by seasonal or short-term fluctuations. These fluctuations often resulted in outwash being deposited on till and till on outwash. This commonly occurred in the Strawberry Lake area. Some sediment was deposited in water ponded between the ice front and surrounding bedrock, and forests were buried in some of the sediment (Hughes, 1978). This lacustrine outwash consists primarily of silt and fine sand; but, below the outwash, as much as 17 percent are clay-sized particles. Glacial meltwater may also have been ponded between the Inner and Outer Marquette Moraines and possibly near the present-day Lake Superior shore. After the glacial ice melted, ancestral lakes in the Superior basin covered part of the area and deposited lake sediments over some glacial deposits. These glacial lakes are named Lake Houghton and Lake Nipissing; their surface altitudes were 360 and 605 ft, respectively. The present level of Lake Superior is about 602 ft. Much of the erosion of the steep-sided valleys of the Chocolay River tributaries may have occurred because of a lowered base level during the Lake Houghton interval. Deposition of beach sand and gravel near the shoreline occurred during the Lake Nipissing interval.

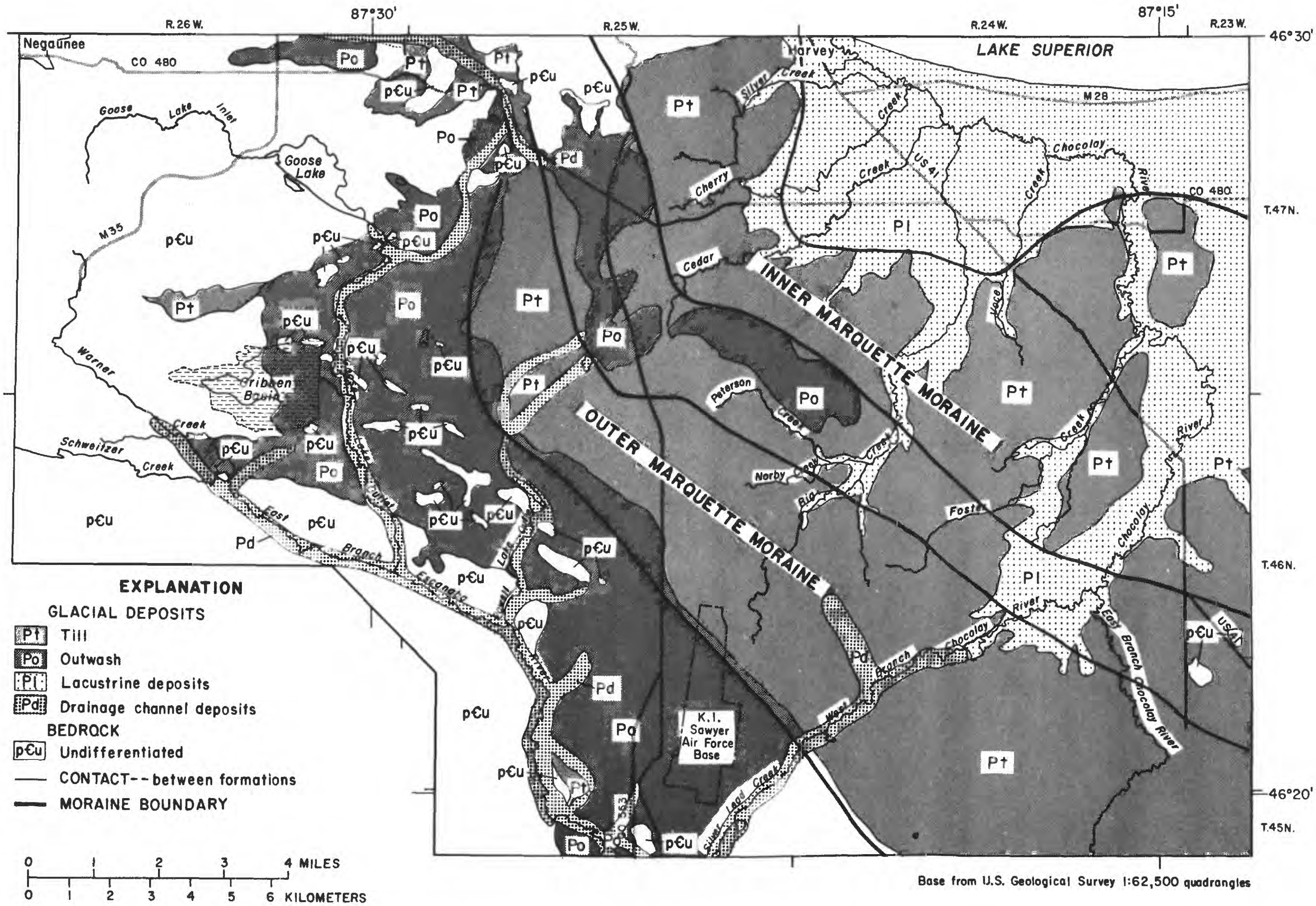


Figure 6.--Areal distribution of glacial deposits.

Glacial deposits are 0 to about 500 ft thick (fig. 7). The thickest deposits are associated with the buried valleys. Between Cedar and Big Creeks, the deposits are about 450 ft thick due to buildup of materials at the conjunction of two ice lobes. In the valley along the Palmer fault, the maximum known thickness is 459 ft. Glacial deposits at Sands Plain can be divided into four general categories: till, transitional deposits, outwash and related drainage channel deposits, and lacustrine deposits. The composition of these deposits is illustrated by geologic cross sections that are located on figure 8 and shown on figure 9.

Till

Two types of till occur in the study area--ablation and basal till. Most is ablation till that was deposited when ice melted and sublimated. This till consists of a mixture of sand, silt, clay, and in some places, gravel. The following grain-size analyses are typical of ablation till:

	Percentage by weight	
Grain size	Well 8 (227-237 ft below land surface)	Well 21 (307-317 ft below land surface)
Very coarse sand	0.1	trace
Coarse sand	1.6	trace
Medium sand	14.6	14.0
Fine sand	45.8	38.0
Very fine sand	26.9	22.0
Silt and clay	11.0	26.0

These analyses show that the ablation till predominantly consists of clay to fine sand-sized particles. The thickest ablation till occurs beneath the Inner and Outer Marquette Moraines. Wells 2 and 21 (pl. 1) encountered at least 175 ft of this till.

Basal till, deposited directly from the bottom of the ice mass, consists of boulders, clay, silt, sand, and gravel. It was encountered in most wells drilled in the moraines; such as in wells 20 and 34 in the Outer Marquette Moraine. The presence of a boulder, gravel, sand, silt, and clay mixture at several altitudes indicates the ice sheet moved over previously deposited glacial material without excavating to bedrock. This situation occurred when the ice retreated and readvanced. Several basal tills were encountered while drilling well 34.

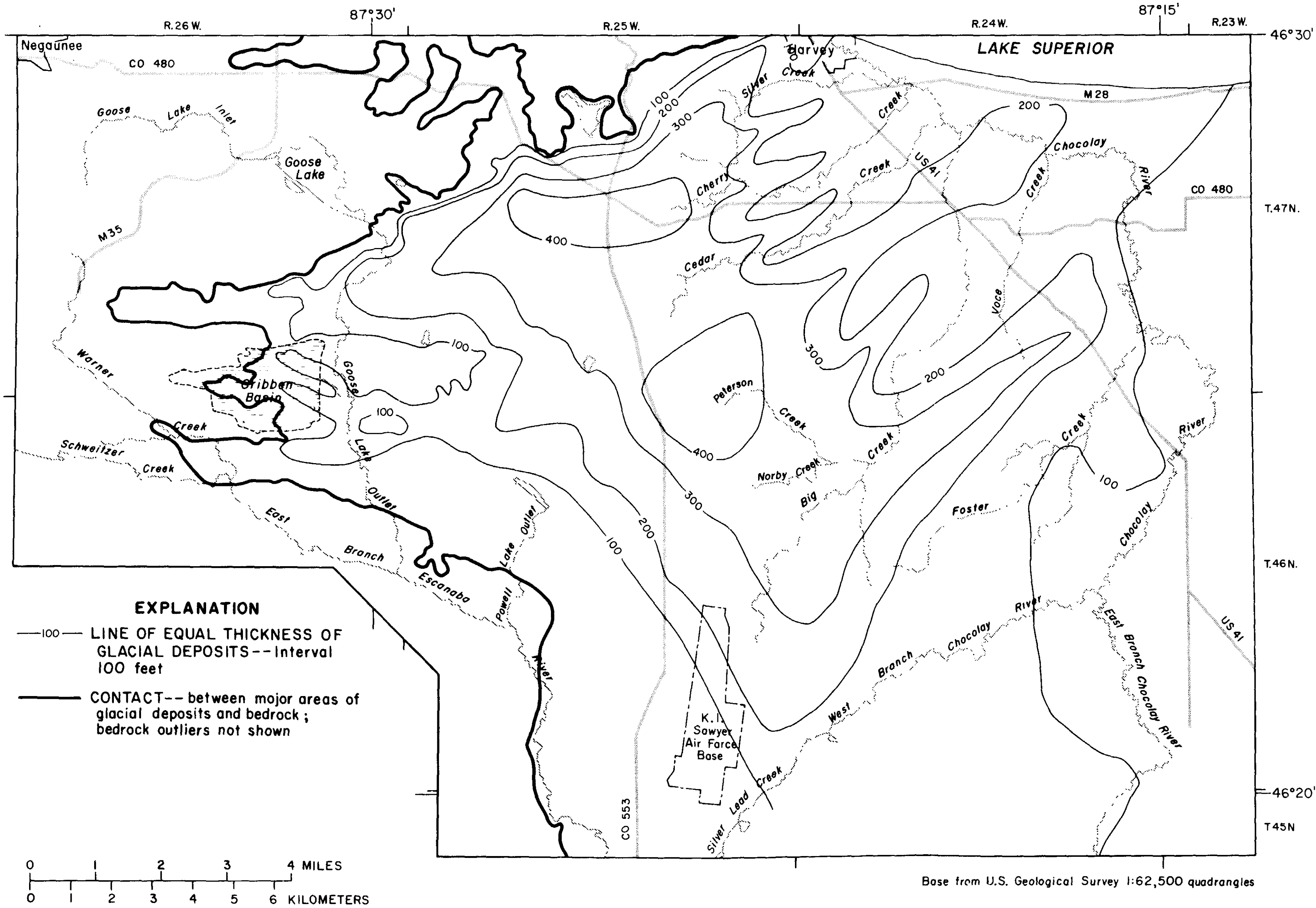


Figure 7.--Thickness of glacial deposits.

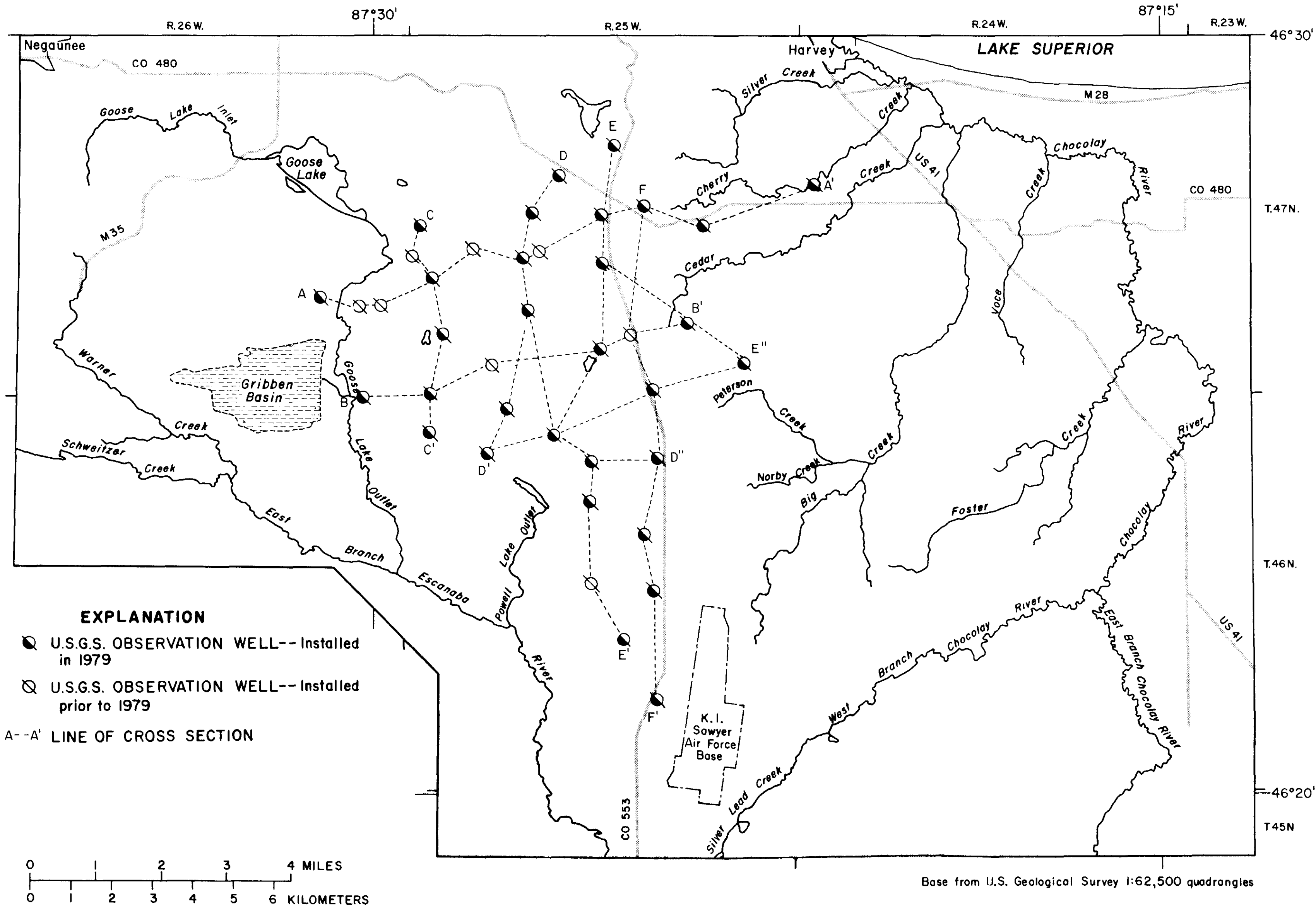


Figure 8.--Location of geologic cross sections.

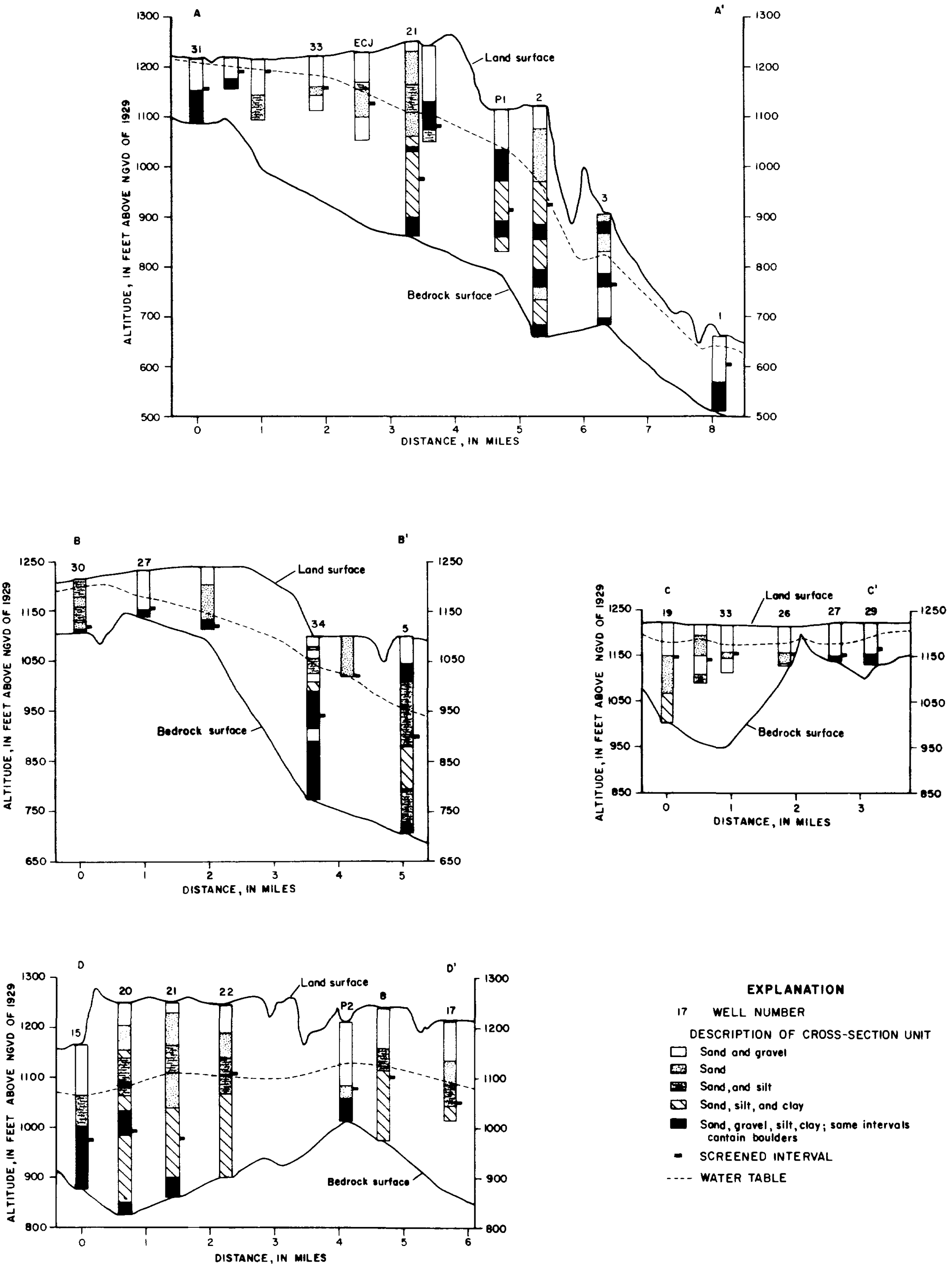


Figure 9.--Geologic cross sections showing thickness and lithologic character of glacial deposits (lines of section shown on figure 8).

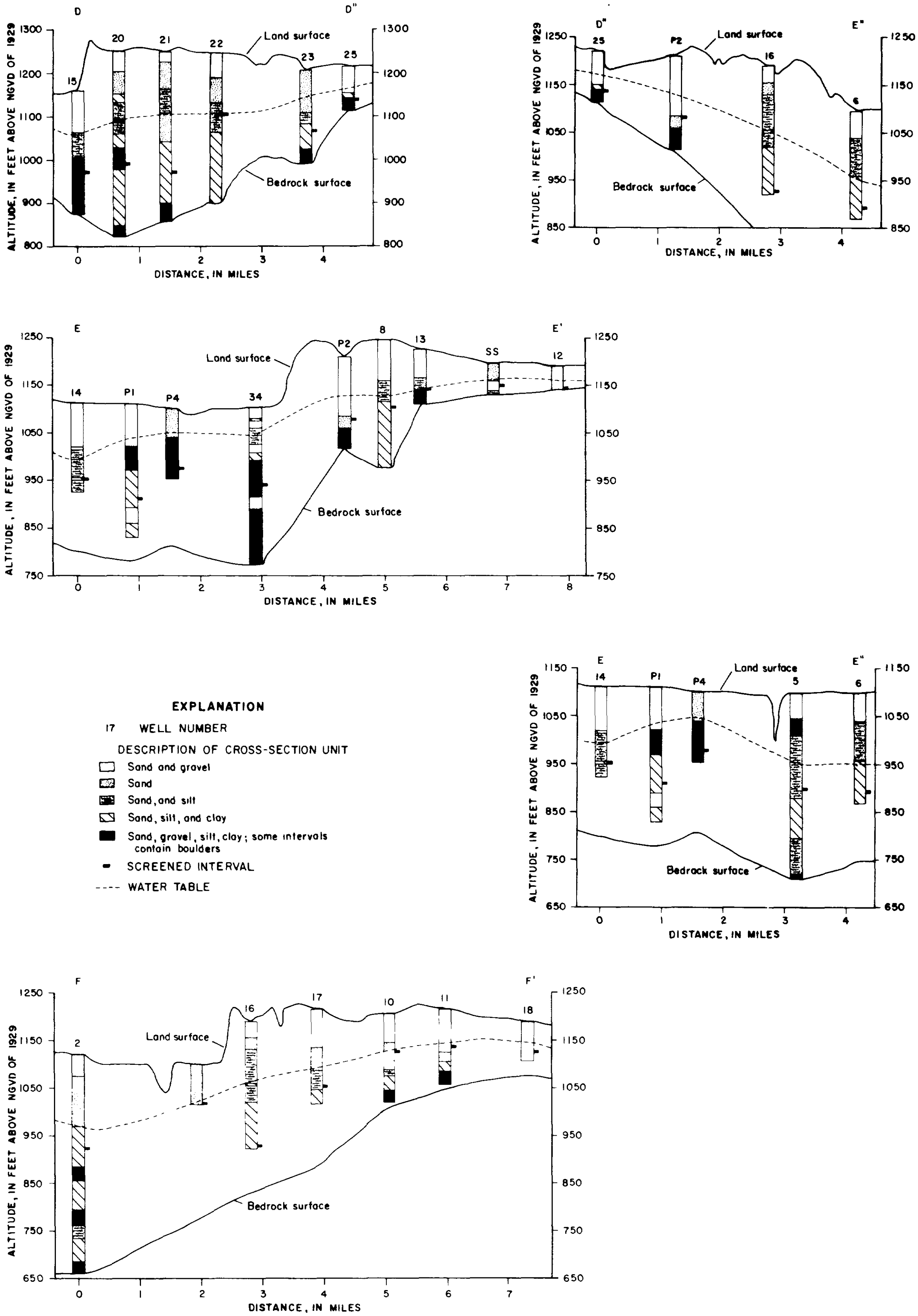


Figure 9.--Geologic cross sections showing thickness and lithologic character of glacial deposits (lines of section shown on figure 8) --continued

Transitional Deposits

Till interlayered with outwash is referred to in this report as a transitional deposit. It was deposited near the ice front and represents the transition between deposition of unstratified and stratified material. Most transitional deposits occur along the Outer Marquette Moraine. Near the western edge of the moraine, ice that built the moraine advanced and retreated short distances (probably less than one half mile) because of climatic or seasonal fluctuations. The resulting overlapping of ablation till and outwash left deposits that are illustrated by geologic cross section D-D' (fig. 9). Transitional deposits generally consist of mostly fine to medium sand with some very fine and coarse particles as shown by the following grain-size analyses:

Grain size	Percentage by weight		
	Well 21 (117-127 ft below land surface)	Well 22 (157-167 ft below land surface)	Well 23 (147-157 ft below land surface)
Gravel	0.6	0.3	0.1
Very coarse sand	2.2	2.7	1.5
Coarse sand	5.3	5.8	5.2
Medium sand	48.0	50.7	45.7
Fine sand	30.7	29.7	32.5
Very fine sand	9.3	8.6	10.8
Silt and clay	3.9	2.2	4.2

Some transitional deposits may have been deposited in water ponded between glacial ice and adjacent bedrock. This would explain why more transitional deposits were penetrated during drilling for well 30, which is located near Gribben Basin among large bedrock outcrops. Water may have been ponded near Strawberry Lake also, thus contributing to the greater amount of mixed silt and sand in wells 5 and 16. West of the Outer Marquette Moraine, transitional deposits are thin or do not exist because they were farther from the ice front during deposition.

Outwash

Outwash, deposited by water from melting glaciers flowing in braided streams, is composed mostly of fine to coarse sand with some gravel. Only small amounts of silt and clay are present because the meltwater carried these finer particles downstream. The following grain-size analyses are typical of outwash:

Grain size	Percentage by weight		
	Well 7 (27-37 ft below land surface)	Well 26 (57-67 ft below land surface)	Well 29 (57-67 ft below land surface)
Gravel	10.0	2.4	2.1
Very coarse sand	5.0	12.1	4.3
Coarse sand	17.0	14.1	10.7
Medium sand	52.0	38.6	55.6
Fine sand	13.0	28.3	23.2
Very fine sand	2.0	3.8	3.7
Silt and clay	1.0	.7	.4

The thickness of outwash (fig. 10) indicates that stratified sand and gravel covered most of the till as the glacial ice receded. Many features usually associated with moraines have been masked by this outwash. At depth, therefore, the moraines are broader than they are near the surface. This layer of outwash has created most of the flat-lying terrain by filling depressions in the bedrock and glacial deposits. During the final stages of glaciation, outwash was deposited primarily along stream drainage channels.

Lacustrine Deposits

Near Lake Superior, lacustrine deposits consisting mostly of sand with thin layers of clay or silt and clay, overlie till and outwash. Some sand and gravel forms beach ridges associated with Lake Nipissing.

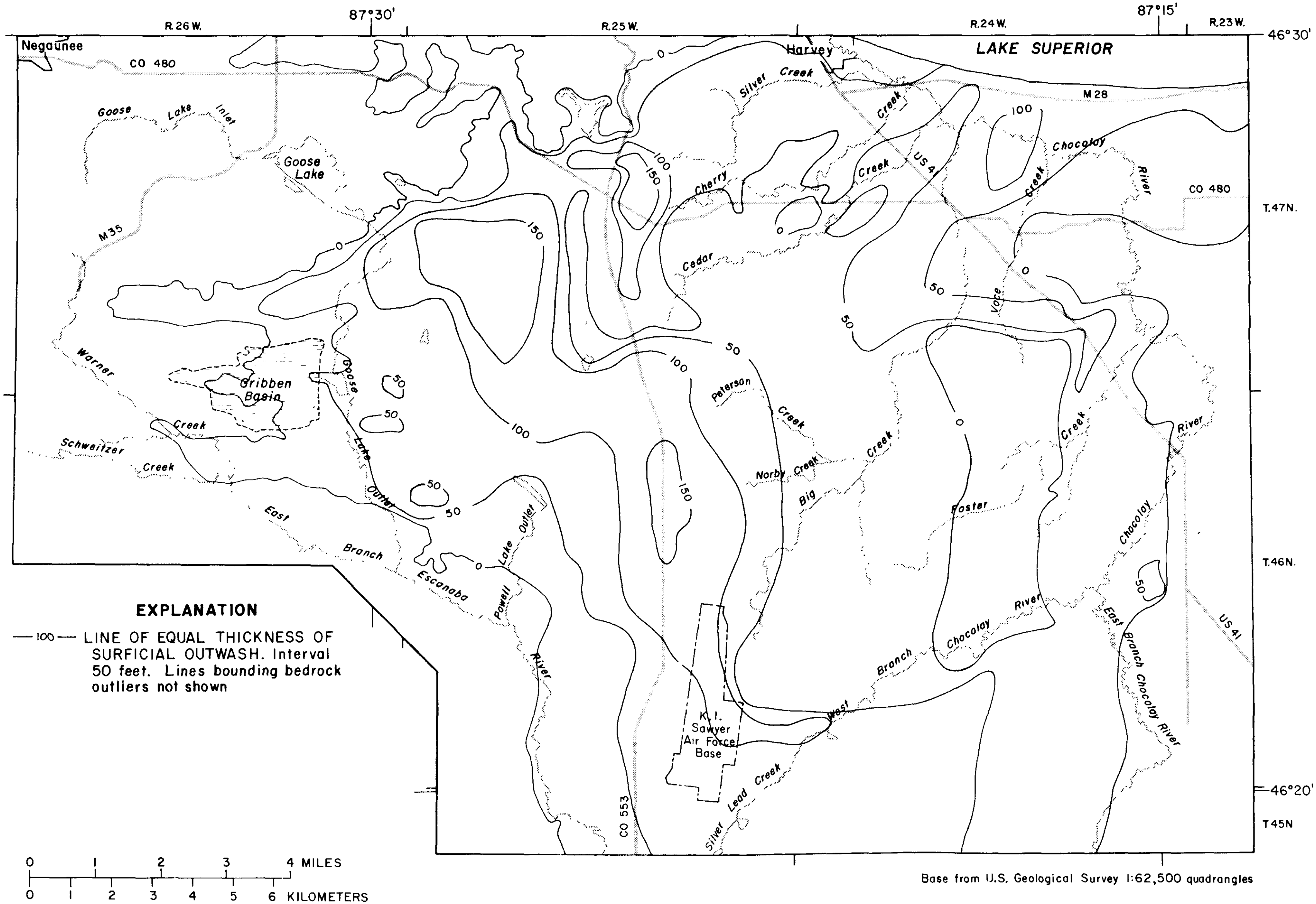


Figure 10.--Thickness of surficial sand and gravel.

HYDROLOGY

Water in the Sands Plain area, primarily derived from precipitation, is temporarily stored in streams, lakes, and in the ground. It is eventually discharged from the area as surface- or ground-water runoff and by evapotranspiration. Sandy soils facilitate infiltration of the precipitation, of which approximately 45 percent infiltrates the ground and percolates to the ground-water table. About 50 percent returns directly to the atmosphere by evaporation and plant transpiration. The remaining 5 percent flows to streams and lakes as surface runoff.

Surface Water

Sands Plain is drained by two major rivers--the Chocolay and East Branch Escanaba (fig. 11). Principal tributaries of the Chocolay River are Big Creek, which originates in the Outer Marquette Moraine, and Silver, Cherry, and Cedar Creeks, which originate as a series of seeps and springs in the Inner Marquette Moraine (fig. 6). The East Branch Escanaba River flows along the southwestern margin of the area and then south to Lake Michigan. Principal tributaries are Goose and Powell Lake Outlets and Warner Creek, which drains a small area south of Gribben Basin. Hourly gage heights were collected at the gaging stations and occasional discharge measurements were made at the miscellaneous sites shown on figure 11. Locations of the surface-water sites are given in table 4.

Variations in Streamflow

Streamflow in Michigan generally is greatest in spring and early summer and lowest in late summer and winter. It increases slightly after the first autumn frosts when evaporation decreases and vegetation dies. Streamflow in Goose Lake Outlet generally follows these seasonal variations (table 5). However, flow in tributaries to the Chocolay River show little seasonal variation. Nearly constant ground-water discharge maintains flow during periods of decreased precipitation. Sandy soils capture most rainfall not lost to evapotranspiration and little direct runoff occurs. Silver and Big Creeks have more surface runoff in the spring than Cherry and Cedar Creeks because more of their drainage area is directly underlain by less permeable till or bedrock. Comparing hydrographs of Big and Cherry Creeks (fig. 12), it can be seen that Big Creek has higher and longer responses to precipitation events than does Cherry Creek. The difference in the character of the hydrographs is caused in part by the size of the drainage area and in part by the less permeable glacial deposits in the Big Creek drainage area. In general, however, flood peaks in all four creeks dissipate quickly because stream gradients are steep, drainage areas are small, and sandy soils predominante. Data in table 6 show that there are only small differences between average discharge and flow duration for Big, Cedar, Cherry, and Silver Creeks. Baseflow separation of hydrographs for these creeks indicates that 95 percent of the average annual runoff is derived from ground-water flow to the stream channels. Average discharge per square mile ranges from 0.83 $(ft^3/s)/mi^2$ at site 33 to 4.19 $(ft^3/s)/mi^2$ at site 16. The discharge of Cherry Creek indicates a large ground-water component, since its discharge is equivalent to 57 in./yr falling on its drainage area (mean annual rainfall is 34 in./yr).

Table 4.--Description of locations of surface-water data collection sites [Station numbers are downstream order numbers used by the U.S. Geological Survey]

Site number	Station number	Description
1	04044554	Big Creek near Sands Station, MI (NE¼ sec.7, T.46 N., R.24 W., lat 46°24'07", long 87°20'47").
2	04044557	Peterson Creek near Sands Station, MI (SW¼ NW¼ sec.6, T.46 N., R.24 W., lat 46°24'44", long 87°21'53").
3	04044558	Norby Creek near Sands, MI (NE¼ NW¼ sec.7, T.46 N., R.24 W., lat 46°24'07", long 87°21'38").
4	04044559	Peterson Creek near Sands, MI (SW¼ SW¼ sec.5, T.46 N., R.24 W., lat 46°24'21", long 87°20'38").
5	04044560	Big Creek near Sands, MI (NW¼ SE¼ sec.5, T.46 N., R.24 W., lat 46°24'43", long 87°19'57").
6	04044561	Big Creek near Green Garden, MI (SW¼ NE¼ sec.32, T.47 N., R.24 W., lat 46°25'38", long 87°20'06").
7	04044563	Big Creek near Harvey, MI (SE¼ SW¼ sec.28, T.47 N., R.24 W., lat 46°26'04", long 87°19'04").
8	04044567	Big Creek near Beaver Grove, MI (SE¼ SW¼ sec.16, T.47 N., R.24 W., lat 46°27'55", long 87°19'07").
9	04044570	Cedar Creek near Sands, MI (SW¼ SW¼ sec.26, T.47 N., R.25 W., lat 46°26'11", long 87°24'20").
10	04044572	Cedar Creek near Gentian, MI (NE¼ SW¼ sec.24, T.47 N., R.25 W., lat 46°27'08", long 87°22'46").
11	04044573	Cedar Creek near Harvey, MI (NW¼ SW¼ sec.19, T.47 N., R.24 W., lat 46°27'20", long 87°21'42").
12	04044577	Cedar Creek near Beaver Grove, MI (SE¼ NE¼ sec.17, T.47 N., R.24 W., lat 46°28'23", long 87°19'46").
13	04044580	Cherry Creek near Cascade, MI (NW¼ NW¼ sec. 23, T.47 N., R.25 W., lat 46°27'43", long 87°24'20").
14	04044581	Cherry Creek near Sands, MI (NW¼ NE¼ sec.23, T.47 N., R.25 W., lat 46°27'47", long 87°23'31").
15	04044582	Cherry Creek near Gentian, MI (NW¼ SW¼ sec. 13, T.47 N., R.25 W., lat 46°28'02", long 87°22'52").
16	04044583	Cherry Creek near Harvey, MI (NE¼ SE¼ sec. 13, T.47 N., R.25 W., lat 46°27'57", long 87°21'53").
17	04044586	Cherry Creek near Beaver Grove, MI (SE¼ SW¼ sec.8, T.47 N., R.24 W., lat 46°28'45" long 87°20'18").
18	04044591	Silver Creek near Cascade, MI (SE¼ NW¼ sec.14, T.47 N., R.25 W., lat 46°28'22", long 87°23'48").
19	040445915	Silver Creek near Beaver Grove, MI (SW¼ NW¼ sec.13, T.47 N., R.25 W., lat 46°28'12", long 87°23'06").
20	04044592	Silver Creek near Sands, MI (SW¼ SW¼ sec.12, T.47 N., R.25 W., lat 46°28'48", long 87°23'07").
21	04044593	Unnamed tributary to Silver Creek near Harvey, MI (NW¼ SW¼ sec.12, T.47 N., R.25 W., lat 46°28'56", long 87°23'01").
22	04044595	Silver Creek at Harvey, MI (NW¼ NE¼ sec.12, T.47 N., R.25 W., lat 46°29'24", long 87°22'19").
23	04044597	Silver Creek near Harvey, MI (NE¼ NW¼ sec.8, T.47 N., R.24 W., lat 46°29'22", long 87°20'16").
24	04058360	Goose Lake Outlet 4.5 miles east of Palmer, MI (NW¼ sec.24, T.47 N., R.26 W., lat 46°27'32", long 87°30'09").
25	04058365	Goose Lake Outlet 4 miles east of Palmer, MI (NE¼ NW¼ sec.25, T.47 N., R.26 N., lat 46°26'49", long 87°30'09").
26	04058368	Goose Lake Outlet 3.6 miles east of Palmer, MI (NE¼ SE¼ sec.26, T.47 N., R.26 W., lat 46°26'26", long 87°30'39").
27	04058370	Goose Lake Outlet 3.7 miles east of Palmer, MI (NW¼ sec.36, T.47 N., R.26 W., lat 46°25'58", long 87°30'36").
28	04058371	Goose Lake Outlet 5 miles west of Sands, MI (NE¼ SE¼ sec.35, T.47 N., R.26 W., lat 46°25'37", long 87°30'45").
29	04058374	Unnamed tributary to Goose Lake Outlet near Sands Station, MI (SW¼ SW¼ sec.36, T.47 N., R.26 W., lat 46°25'16", long 87°30'30").
30	04058375	Goose Lake Outlet 4.8 miles west of Sands, MI (SW¼ SW¼ sec.36, T.47 N., R.26 W., lat 46°25'14", long 87°30'26").
31	04058380	Goose Lake Outlet 4.5 miles southeast of Palmer, MI (NW¼ SW¼ sec.1, T.46 N., R.26 W., lat 46°24'37", long 87°30'30").
32	04058390	Goose Lake Outlet 5.0 miles southwest of Sands, MI (SE¼ NW¼ sec.12, T.46 N., R.26 W., lat 46°24'04", long 87°30'06").
33	04058400	Goose Lake Outlet near Sands Station, MI (SE¼ SE¼ sec.12, T.46 N., R.26 W., lat 46°23'36", long 87°29'40").

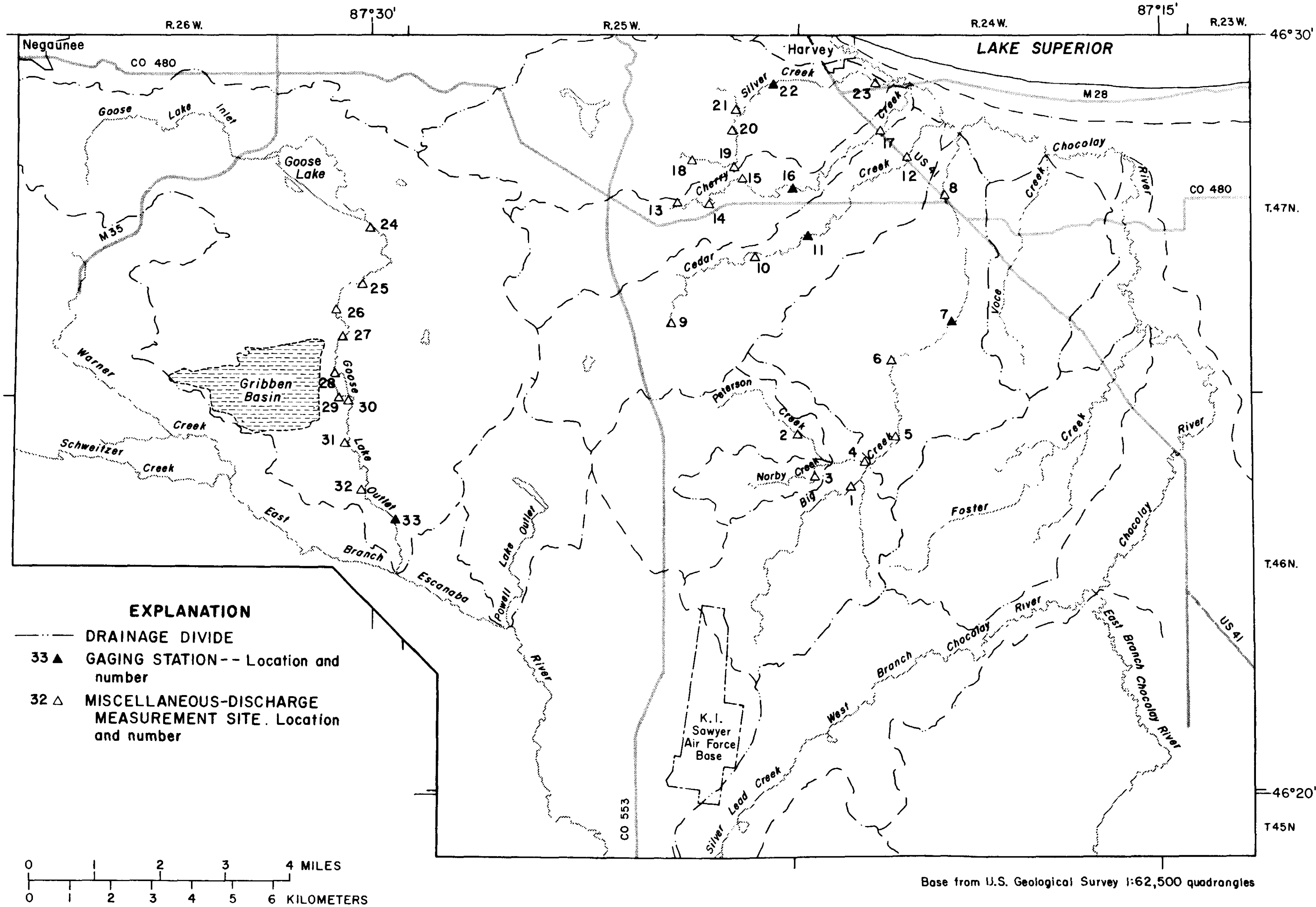


Figure 11.--Drainage basins.

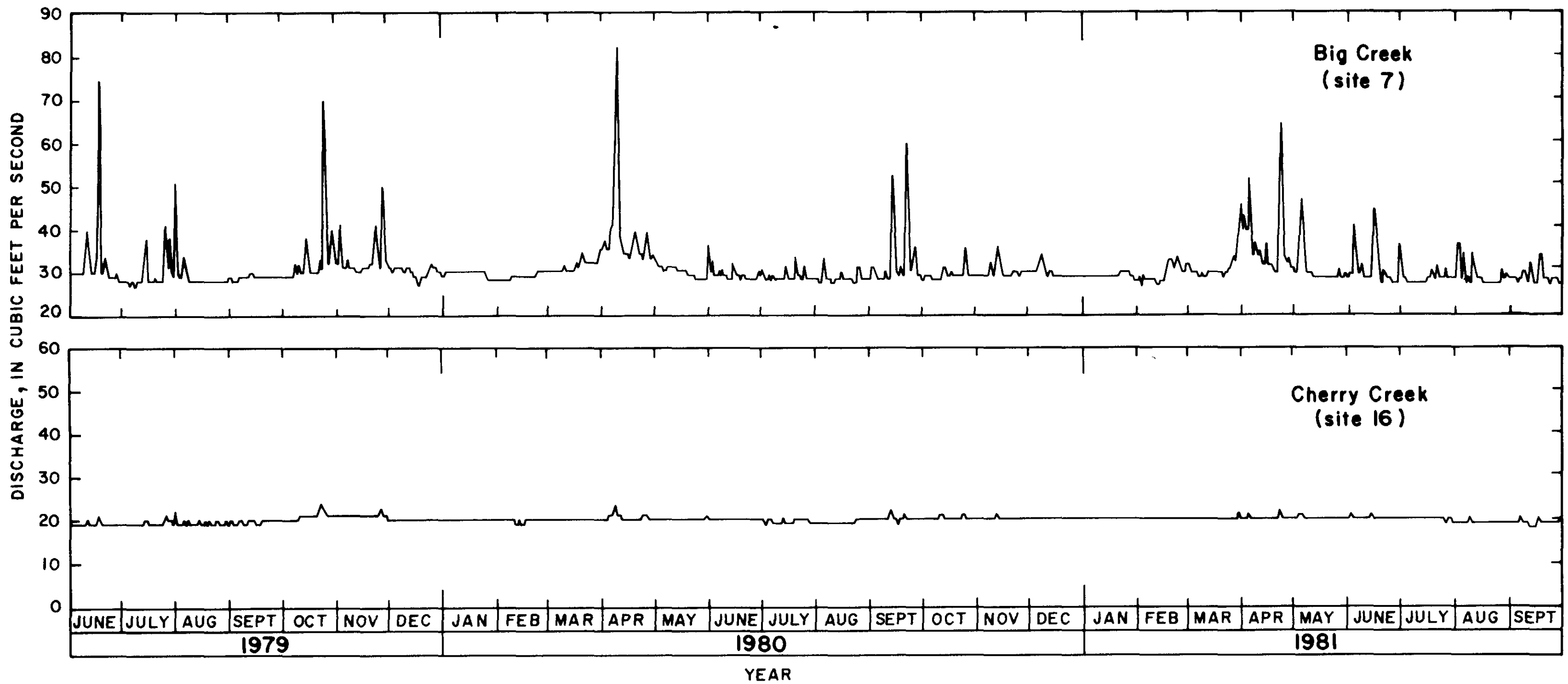


Figure 12.--Streamflow hydrographs of Big and Cherry Creeks.

Table 5.--Average monthly discharge at gaging stations

Site	Station	Discharge (ft³/s)											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
7	Big Creek	29.3	29.3	31.5	37.4	30.4	30.9	29.3	28.8	30.2	31.7	31.4	29.9
11	Cedar Creek	12.1	12.3	12.2	12.8	12.6	12.6	12.6	12.4	12.4	14.8	14.1	12.9
16	Cherry Creek	18.8	18.8	18.9	19.2	19.2	19.4	19.2	18.8	19.2	19.3	19.2	18.9
22	Silver Creek	9.34	9.31	9.87	11.6	9.62	9.61	9.44	9.16	9.42	9.90	9.57	9.27
33	Goose Lake Outlet	14.9	13.3	26.2	110.0	71.7	43.9	23.2	13.5	14.9	18.2	24.1	20.2

Table 6.--Streamflow characteristics at gaging stations

Site	Station	Period of analysis	Drainage area (mi^2)	Average discharge (ft^3/s)	Average discharge [(ft^3/s)/mi^2]	Maximum discharge (ft^3/s)	Discharge (ft^3/s) equaled or exceeded for the percentage of days indicated					
							10	25	50	70	90	95
7	Big Creek	1979-81	17.0	31	1.82	147	35	32	30	29	28	28
11	Cedar Creek	1979-81	9.17	13	1.42	34	15	14	13	12	12	12
16	Cherry Creek	1966-70, 1979-81	4.53	19	4.19	37	21	20	20	19	18	18
22	Silver Creek	1979-81	8.58	9.6	1.12	40	11	9.8	9.4	9.1	8.8	8.7
33	Goose Lake Outlet	1966-75	37.5	31	.83	458	66	33	19	14	10	9.0

Discharge was measured periodically at 33 stream sites between August 1979 and May 1982 (table 7). The measurements were made to determine variations of discharge throughout the reaches of each stream. Discharge of Big, Cedar, and Cherry Creeks consistently increased throughout their reaches in a downstream direction as a result of ground-water inflow. Discharge of Silver Creek and Goose Lake Outlet did not consistently increase downstream. For example, on October 1, 1980, between sites 24 and 25 on Goose Lake Outlet, water was lost into the adjacent aquifer at a rate of 10.1 ft^3/s. On this date, water also was lost between sites 25 and 27 at a rate of 0.7 ft^3/s. Below site 27, the stream consistently gained water from ground-water inflow. On August 24, 1981, the stream lost water in the same reaches discussed above, but, because inflow from the lake was less, the losses were less. On June 11, 1981, Goose Lake Outlet lost water only between sites 24 and 25; all reaches below site 25 gained water.

Goose Lake Outlet consistently loses water between sites 24 and 25. However, between sites 25 and 27, water was lost in autumn and spring when ground-water levels are usually lowest and streamflow is usually high. The Outlet gained water at these sites during late spring and early summer after ground-water levels had risen and stream levels had fallen.

Silver Creek loses water at rates varying from 0.6 to 1.2 ft^3/s between sites 18 and 20 (table 7). It also loses water between sites 22 and 23 at rates varying from 0.1 to 0.6 ft^3/s.

Table 7.--Discharge at sites on Big, Cedar, Cherry, and Silver Creeks, and on Goose Lake Outlet

		Discharge (ft³/s)						
	Site	Aug. 7, 1979	Oct. 17, 1979	May 20, 1980	May 21, 1980	July 15, 1980	Oct. 1, 1980	July 15, 1981
Big Creek	1	--	9.83	--	--	10.3	9.7	9.2
	2	2.24	2.06	--	--	2.05	2.53	2.02
	3	.14	.17	--	--	.14	.14	--
	4	2.97	2.54	--	2.76	2.68	2.89	2.41
	5	13.9	15.0	--	16.2	16.2	15.2	15.5
	6	20.5	21.2	--	--	21.3	23.8	--
	7	30.4	30.4	--	[a]29.0	27.5	28.5	28.4
	8	42.0	40.7	--	38.5	38.0	40.2	37.0
Cedar Creek	9	.23	.30	--	.25	.21	.26	.25
	10	9.78	10.9	--	--	8.31	10.5	10.1
	11	13.4	12.7	--	[a]13.0	13.4	13.7	12.4
	12	20.0	19.5	--	18.1	17.8	18.3	17.7
Cherry Creek	13	.04	.02	--	--	.02	.03	--
	14	5.88	5.44	5.30	--	5.26	5.79	5.65
	15	9.22	10.6	--	--	9.75	9.56	9.70
	16	20.3	19.7	[a]20.0	--	18.4	18.7	18.9
	17	26.8	26.6	25.8	--	25.3	25.5	25.4
Silver Creek	18	3.41	3.18	--	--	3.13	3.59	3.23
	19	--	--	--	--	2.58	2.89	--
	20	2.46	2.54	--	2.71	2.35	2.69	2.05
	21	.08	.06	--	--	.02	.04	--
	22	9.48	9.70	--	[a]9.30	8.92	8.94	8.75
	23	8.85	9.17	--	8.91	8.51	8.82	8.08

	Site	Oct. 1, 1980	June 11, 1981	Aug. 24, 1981	May 26, 1981
Goose Lake Outlet	24	21.5	15.5	2.38	--
	25	11.4	11.4	.93	20.2
	26	--	[b]12.04	--	23.2
	27	10.7	12.6	.64	24.4
	28	--	14.1	--	--
	29	.15	.20	.09	--
	30	15.5	15.4	2.38	--
	31	--	[c]19.8	[c]3.35	--
	32	--	[c]21.1	[c]5.0	--
	33	[c]28.5	[c]24.1	[c]7.2	[c]40.4

[a]Mean daily discharge
[b]Estimated based on discharge measurement of one channel
[c]Discharge adjusted for inflow from Gribben Basin

Ground Water

Ground water is water stored in the saturated zone of the ground from which wells, springs, and ground-water discharge are supplied. At Sands Plain, ground water generally flows toward Lake Superior from the south and west (fig. 13). Most ground water is contained and flows in the glacial deposits that are bounded on the north and west by relatively impermeable bedrock (fig. 7). The rock boundary forms a basin, the mouth of which is located at the lake. No ground water is known to flow across the basin boundaries; however, Wiitala and others (1967) suggested a hydraulic connection between the Chocolay and adjacent Carp River drainage areas at the gravel pit 1 mi west of Pelissier Lake. Although an interbasin connection is possible, it is thought to be unlikely based on the altitude of ponded water in gravel pits in the area. Ground-water flow is bounded on the south and east by Silver Lead Creek and Chocolay River; on the northeast it is bounded by Lake Superior.

Aquifers

The nature and size of pore spaces and other openings in rocks, such as fractures or solution channels, are primary factors controlling the movement and storage of ground water in aquifers. Outwash has large interconnected pore spaces; it readily transmits water and is a good aquifer. Till and transitional deposits have smaller pore spaces and the flow of water is restricted; these deposits are poorer aquifers than outwash. Glacial deposits, especially deposits of outwash, are the major aquifers in the Sands Plain area.

In igneous and metamorphic rocks, water generally is stored and transmitted in fractures. Fracturing, however, is not extensive enough in most places to allow large quantities of water to flow to wells even though it allows considerable water to flow to mines outside the study area. Fractures in the Palmer fault zone probably are more extensive and may allow water to move more freely. The amount of fracturing also affects ground-water flow in both the Jacobsville and the overlying Munising Sandstone. The size and interconnection of pore spaces in the Jacobsville Sandstone is quite variable, resulting in the formation being a good aquifer in some places and poor in others. Generally, the weathered upper part of the formation is most permeable. At depth, pore space is often filled with silica cement (Doonan and Van Alstine, 1982). Movement of water in the Trempealeau Formation depends primarily on the size and relation of solution channels. In places, where the channels are large and interconnected, the formation is a potentially good aquifer. Where the channels are small and poorly connected, the movement of water is greatly restricted.

Of the consolidated rocks in the study area, the Munising Sandstone and the Trempealeau Formation are the best aquifers (Doonan and Van Alstine, 1982). Their limited areal extent (fig. 4), however, makes them relatively unimportant when compared to the area's other aquifers. The Jacobsville Sandstone is areally extensive but it is only used as a source of water for domestic wells near Green Garden, Yalmer, and Skandia where glacial deposits are thin and poorly permeable.

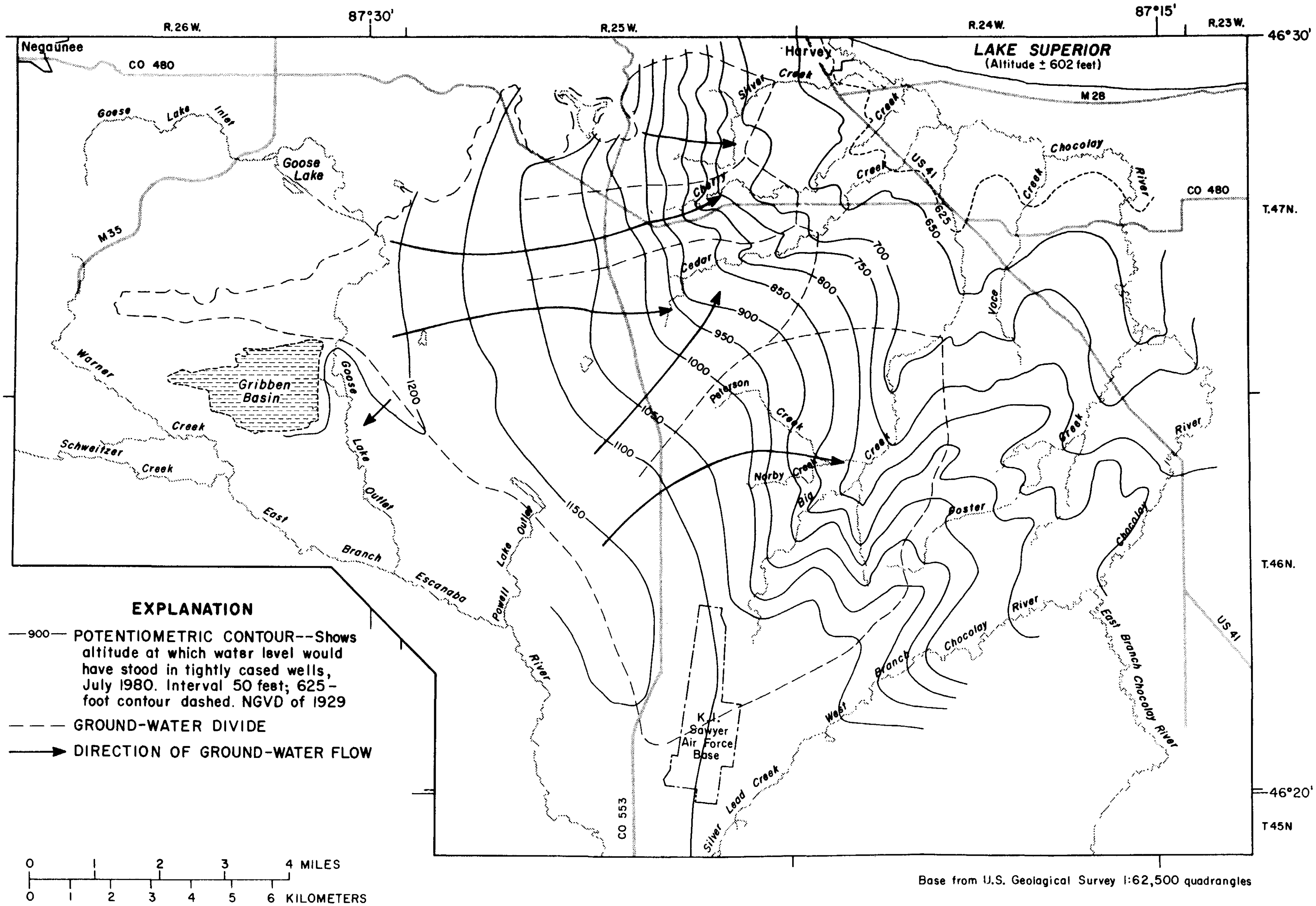


Figure 13.--Potentiometric surface July 1980 and ground-water divides.

Hydraulic characteristics of bedrock.--The hydraulic conductivity of metamorphic rocks depends almost entirely on the amount of fracturing in the rock. The degree of fracturing in metamorphic rocks at Sands Plain is thought to be insignificant enough to consider these rocks barriers to ground-water flow. Analysis of specific capacity tests of two wells completed in Jacobsville Sandstone near Green Garden indicate the horizontal hydraulic conductivity of this rock unit is less than 1 ft/d (Doonan and Van Alstine, 1982). Similar analysis of the Munising Sandstone and the Trempealeau Formation resulted in horizontal hydraulic conductivities of 8 and 10 ft/d respectively.

Hydraulic characteristics of glacial deposits.--Initial estimates of hydraulic conductivity and specific yield of aquifer material in glacial deposits were based on pumping tests at wells P2, P4, GL, and wells at K. I. Sawyer Air Force Base. Analysis of data from well GL indicated a range of hydraulic conductivities from 40 to 180 ft/d. Specific yield was estimated to be 0.16 (Wiitala and others, 1967). Analysis of pumping tests at wells P2 and P4 indicated horizontal hydraulic conductivities of 80 and 30 ft/d respectively. Storage coefficients of 0.01 and 0.0001 for wells P2 and P4, respectively, indicate that the aquifer is confined in some areas, particularly beneath the moraines. A pumping test conducted at K. I. Sawyer Air Force Base in 1965 indicated the aquifer has a horizontal hydraulic conductivity of 30 to 50 ft/d and a storage coefficient of 0.0001 to 0.007 in this area. In these analyses, the entire aquifer was assumed to have similar hydraulic properties, although aquifer materials may actually be interspersed with confining or semiconfining layers of silty sand or clay.

Specific capacity tests at 14 sites also were used to estimate hydraulic conductivity. Each test consisted of pumping the well at 2 to 10 gal/min for about an hour. Water levels obtained before, during, and after the pumping were analyzed according to a method described by Theis and others (1963). Results of these analyses indicate the general hydrologic properties of the glacial material, but are not as accurate as values determined by the pumping tests. The horizontal hydraulic conductivities were as follows:

Well number	Hydraulic conductivity	Well number	Hydraulic conductivity
12	35	27	16
15	8	30	7
17	38	31	50
19	2	34	194
21	7	P2	30
25	11	P4B	15
26	30		

The values obtained at wells P2 and P4B (located 150 ft from well P4) using this method resulted in hydraulic conductivity estimates that were about one half of the hydraulic conductivities obtained from the pumping test data.

Changes in Ground-Water Levels

Ground-water levels, measured periodically in Sands Plain since 1962, change depending on the amount of infiltrated precipitation, the ability of water to move through the aquifer, the amount of ground water pumped from wells, and, to a minor extent, changes in barometric pressure. Water levels generally fluctuate greater over shorter periods of time in the vicinity of aquifer boundaries and ground-water divides. Precipitation is the most important factor affecting ground-water levels in the Sands Plain area. Figure 14 shows the relation between precipitation and water levels in well SS; seasonal long-term effects are evident. During most years, water levels rose in the spring and declined from late summer through winter. A long-term general rise of about 7 ft occurred from 1964 to 1973. Levels generally declined by about 3 ft from 1973 to 1977; they increased again in 1978-79 and began to decrease in 1980. Water levels in wells G and ECJ show similar patterns (fig. 15), but fluctuate less seasonally and lag behind levels in well SS because they are more distant from the edge of the aquifer. For example, water levels in well SS were highest in 1972. In well ECJ, however, high levels did not occur until 1973; in well G the high did not occur until 1974. At any given point farther along the flow path, water levels will rise or fall as the infiltrated precipitation (now ground water) reaches and passes through the point. Assuming the aquifer has the same hydraulic properties from point to point, this effect is dampened in the downgradient direction as ground water from a larger area is integrated into the flow system. The more areally extensive the ground-water reservoir, the longer effect precipitation events will have on the amount of water stored in the reservoir.

Water levels in 40 observation wells were measured during 1979-81 (table 8). The water-level changes can be categorized according to position of the wells in the ground-water flow system. Water levels in wells nearest the ground-water divide south and west of the Outer Marquette Moraine (fig. 13) declined until June 1981, when they rose slightly (fig. 16). Water levels in wells nearer the moraine rose until June 1980, but then declined (fig. 17). Water levels in wells within the moraine rose until December 1980, but then declined (fig. 18). Water levels in wells near streams generally rose and fell as stream discharge increased or decreased, respectively, and showed greater seasonal variation than did levels in other wells (fig. 19). Other water levels that indicate the influence of nearby streams are shown in figure 20.

Table 8.--Ground-water levels and well data

Well	Location	Altitude of land surface, above NGVD of 1929 (ft)	Depth drilled (ft)	Screened interval (ft)	Highest water level measured, below land surface (ft)	Date of highest measured water level	Lowest water level measured, below land surface (ft)	Date of lowest measured water level
				Wells drilled in 1979				
1	47N24W18CAC	660	157	56-61	21.41	Sep. 12, 1980	22.15	Dec. 05, 1979
2	47N25W22ABA	1,121	459	198-203	152.67	Sep. 15, 1981	153.83	Dec. 05, 1979
3	47N25W23ACB	906	227	138-143	85.26	Sep. 15, 1981	87.43	Dec. 05, 1979
5	47N25W26CDC	1,097	389	198-203	138.70	Oct. 24, 1979	139.90	Nov. 03, 1980
6	47N25W36BCD	1,096	227	202-207	142.10	Nov. 14, 1979	143.16	Jan. 26, 1981
7	46N25W02ADB	1,133	207	178-183	107.51	Oct. 24, 1979	108.50	Nov. 03, 1980
8	46N25W04DDC	1,243.23	267	138-143	115.37	Nov. 04, 1981	117.26	June 16, 1980
10	46N25W15ABA	1,203	187	78-83	69.29	Nov. 04, 1981	71.58	Apr. 28, 1980
11	46N25W15DDD	1,214	159	72-77	64.32	Sep. 15, 1981	68.18	Oct. 24, 1979
12	46N25W22CDA	1,189.06	51	42-47	28.23	May 19, 1981	32.28	Dec. 05, 1979
13	46N25W09DAB	1,224.51	115	78-83	82.35	Jan. 26, 1981	--	--
14	47N25W15BBD	1,111.68	187	156-161	116.03	July 09, 1981	118.93	Dec. 05, 1979
15	47N25W16CAA	1,160.47	280	178-183	97.82	Nov. 04, 1981	100.29	July 24, 1980
16	47N25W34DDB	1,187.52	267	258-263	181.65	Nov. 14, 1979	185.26	Sep. 15, 1981
17	46N25W03DDA	1,213.54	197	158-163	121.18	Oct. 24, 1979	122.66	Nov. 03, 1980
18	46N25W27ADD	1,188	82.5	58.5-63.5	38.63	Aug. 04, 1981	42.07	Dec. 05, 1979
19	47N25W19BCA	1,226	227	78-83	34.07	Apr. 14, 1981	41.39	Dec. 03, 1979
20	47N25W20AAA	1,250	423	258-263	161.86	Oct. 23, 1979	165.57	Nov. 04, 1981
21	47N25W20DDC	1,248.28	389	208-273	139.57	Nov. 04, 1981	141.68	Nov. 13, 1979
22	47N25W29DAA	1,245.45	343	136-141	138.16	Nov. 13, 1979	139.86	Nov. 03, 1980
23	46N25N05ABB	1,209	220	138-143	64.05	Nov. 04, 1981	66.33	Apr. 28, 1980
24	46N25W08DCD	1,205	18	--	--	--	--	--
25	46N25W05CCD	1,218	104	78-83	45.54	May 19, 1981	50.58	Nov. 13, 1979
26	47N25W31ABB	1,217	84	58-63	32.40	Apr. 14, 1981	35.85	Dec. 03, 1979
27	47N25W31CDD	1,230.66	91	73-78	45.30	June 14, 1981	50.42	Dec. 03, 1979
28	47N25W32BBA	1,239.50	207	98-103	94.00	Dec. 15, 1981	96.21	June 16, 1980
29	46N25W06BDD	1,224.08	92	58-63	21.79	Apr. 14, 1981	26.70	Dec. 03, 1979
30	47N26W36CDD	1,214	104	90-95	14.30	Mar. 09, 1981	16.65	Dec. 03, 1979
31	47N26W26ACD	1,217.12	130	58-63	3.84	Sep. 10, 1980	7.02	Apr. 29, 1980
33	47N25W30BAC	1,220.91	107	63-68	40.10	Nov. 04, 1981	42.46	Dec. 03, 1979
34	47N25W33AAD	1,101.19	328	157-162	55.12	Nov. 14, 1979	55.84	Nov. 03, 1980
P1	47N25W22BCB	1,112.36	282	196-201	73.70	Nov. 12, 1981	75.03	Nov. 03, 1980
P2	46N25W04CAB	1,211.38	169	128-148	82.24	Dec. 15, 1981	84.61	Nov. 03, 1980
P4	47N25W22CCD	1,100.40	147	119-123	48.93	Nov. 13, 1979	52.30	Sep. 01, 1980
				Wells drilled prior to 1979				
ECJ	47N25W20CBC	1,229.78	177	101-103	78.47	June 21, 1965	90.58	Oct. 10, 1973
L	47N26W27BCC	1,280	37	28-31	+3.40	Oct. 22, 1969	10.07	Apr. 26, 1979
GL	47N26W36BBC	1,210	59	38-56	3.60	Mar. 11, 1977	8.82	Apr. 15, 1979
G	47N25W32BDC	1,239.59	125	116-118	83.58	Oct. 28, 1964	100.02	Apr. 23, 1976
SS	46N25W16DDA	1,195	65	44-46.5	27.11	May 12, 1964	37.68	July 16, 1969
C1[1]	46N26W02CBC	1,205.68	20	17-20	2.70	Nov. 9, 1978	9.80	Mar. 18, 1977
C2[1]	46N26W02CAC	1,202.81	13	10-13	.76	Apr. 14, 1980	7.90	Mar. 18, 1977
C3[1]	46N26W02ADA	1,200.47	15.5	12.5-15.5	3.59	Apr. 14, 1980	6.80	Mar. 18, 1977
C4[1]	47N26W35DDD	1,202.50	14	11-14	1.97	Oct. 30, 1979	10.60	Oct. 25, 1977
C5[1]	47N26W35DAB	1,202.80	--	--	.93	Oct. 30, 1979	7.70	Mar. 18, 1977
C6[1]	47N26W35AAC	1,205.39	10	7-10	+.06	Oct. 30, 1979	4.83	Oct. 25, 1977
C7[2]	47N26W35CDC	1,214.08	10.5	7.5-10.5	.93	Apr. 15, 1981	7.04	Mar. 18, 1977
C8[1]	47N26W26AAD	1,219.49	21	18-21	+1.16	Oct. 30, 1979	9.30	Mar. 18, 1977
C10[1]	47N26N33DDC	1,234.73	14	11-14	1.18	Nov. 1, 1979	5.50	Oct. 25, 1977
C11[1]	46N26W04AAA	1,234.54	14.5	11.5-14.5	1.90	Oct. 25, 1977	8.04	Mar. 18, 1977
C12[1]	46N26W03DBB	1,205	17	14-17	--	--	6.00	Jan. 29, 1976
C13	47N26W27CBB	1,280	--	--	Flow	--	Flow	--

[1]Data provided by Cleveland-Cliffs Iron Company
[2]Data provided by Cleveland-Cliffs Iron Company, water levels measured by U.S. Geological Survey during 1979-81

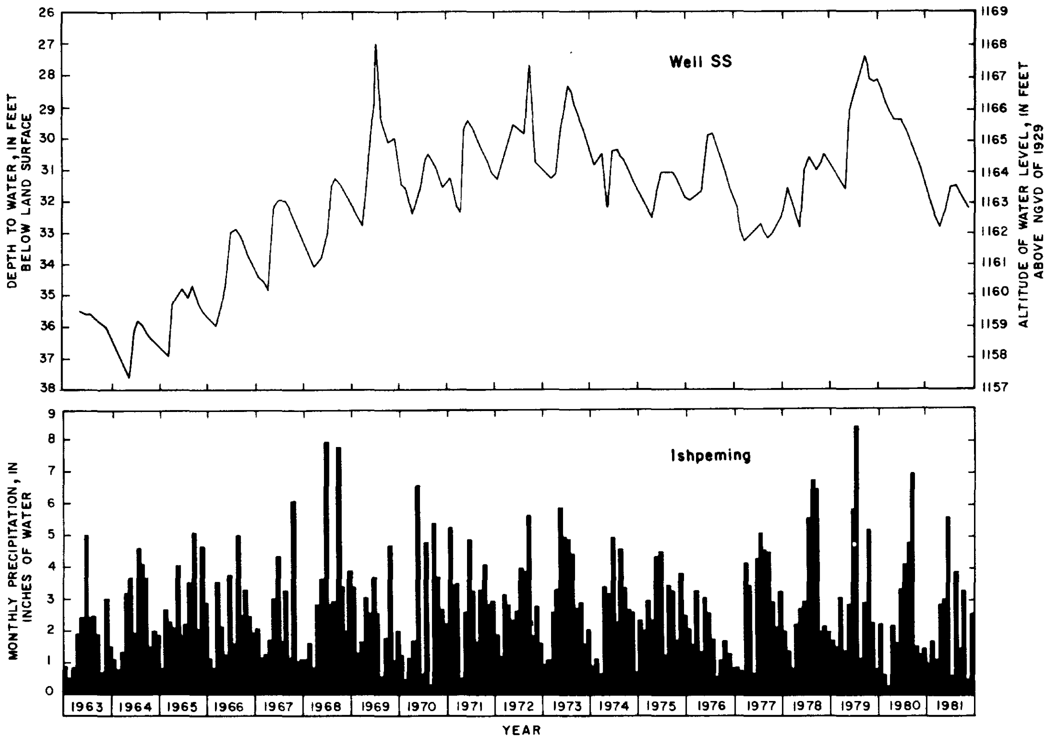


Figure 14.--Relation of precipitation at Ishpeming to water levels in well SS.

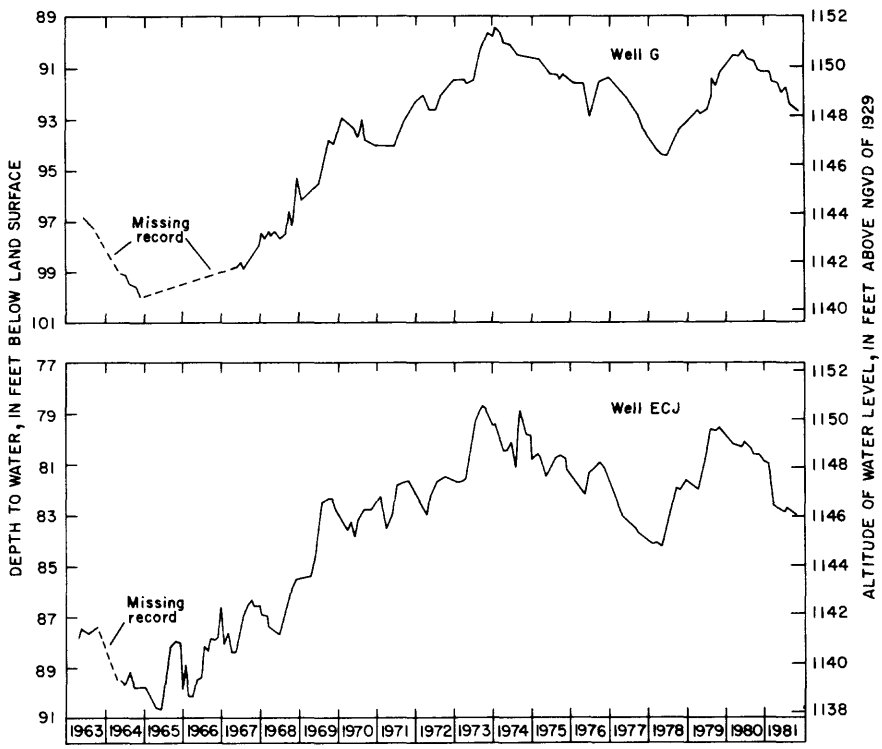


Figure 15.--Water levels in wells G and ECJ.

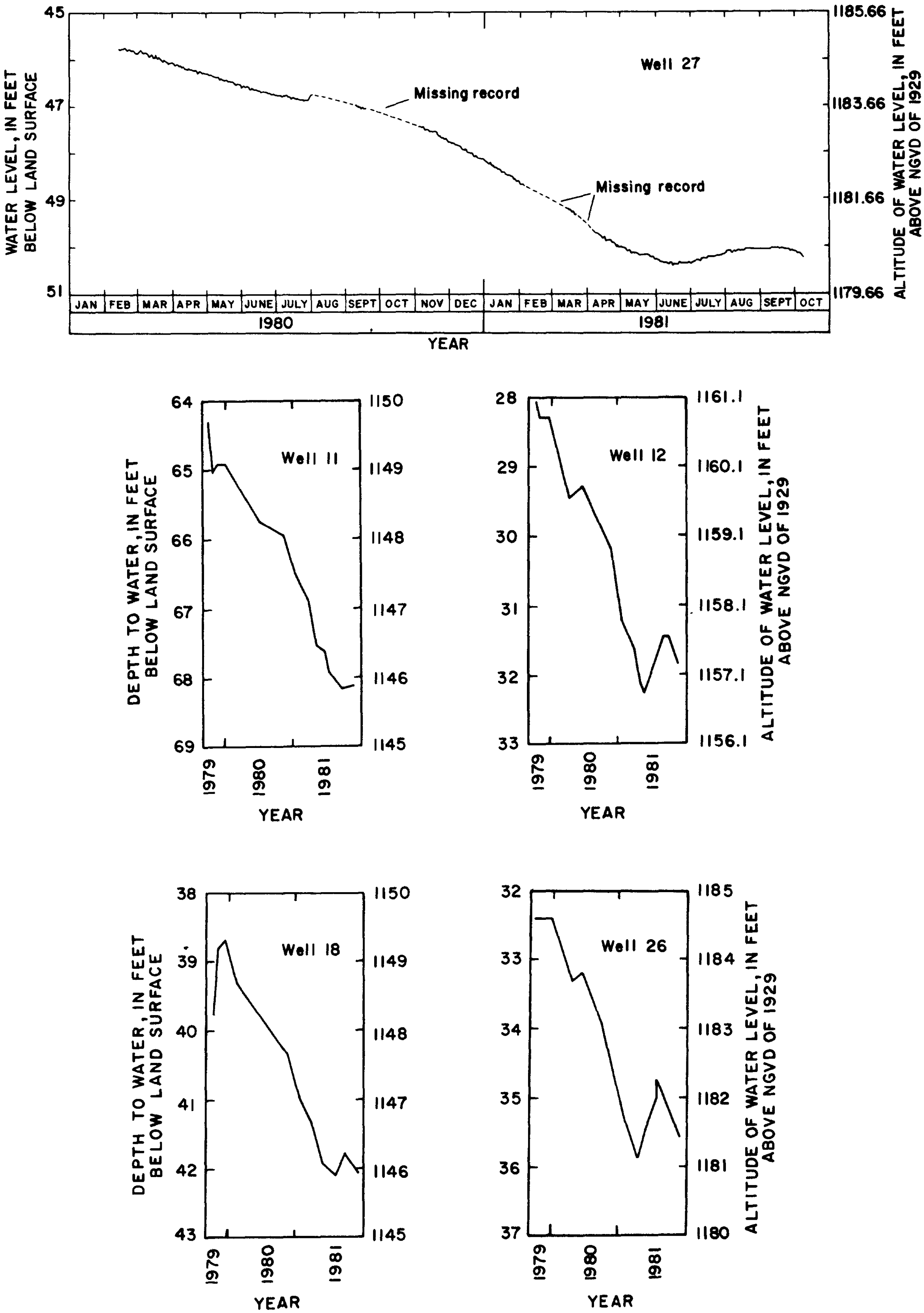


Figure 16.--Water levels in wells near the ground-water divide south and west of the Outer Marquette Moraine.

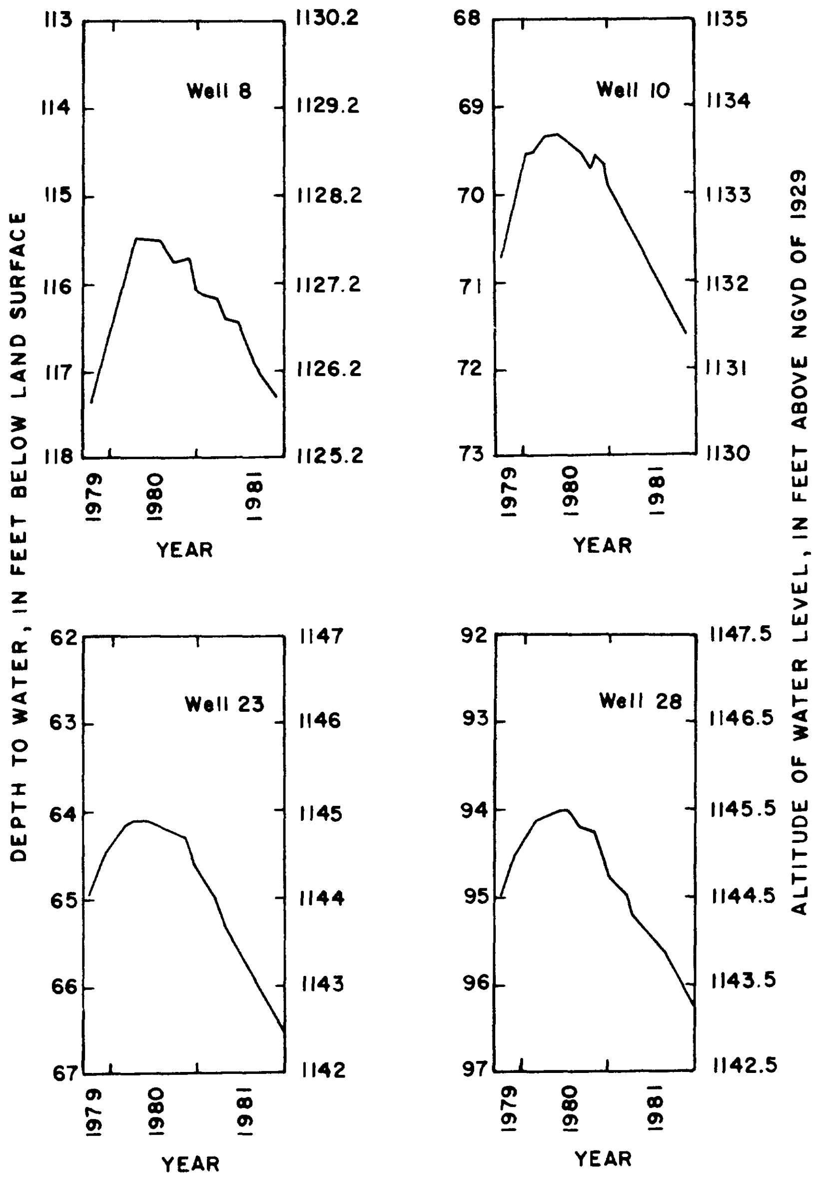


Figure 17.--Water levels in wells near the Outer Marquette Moraine.

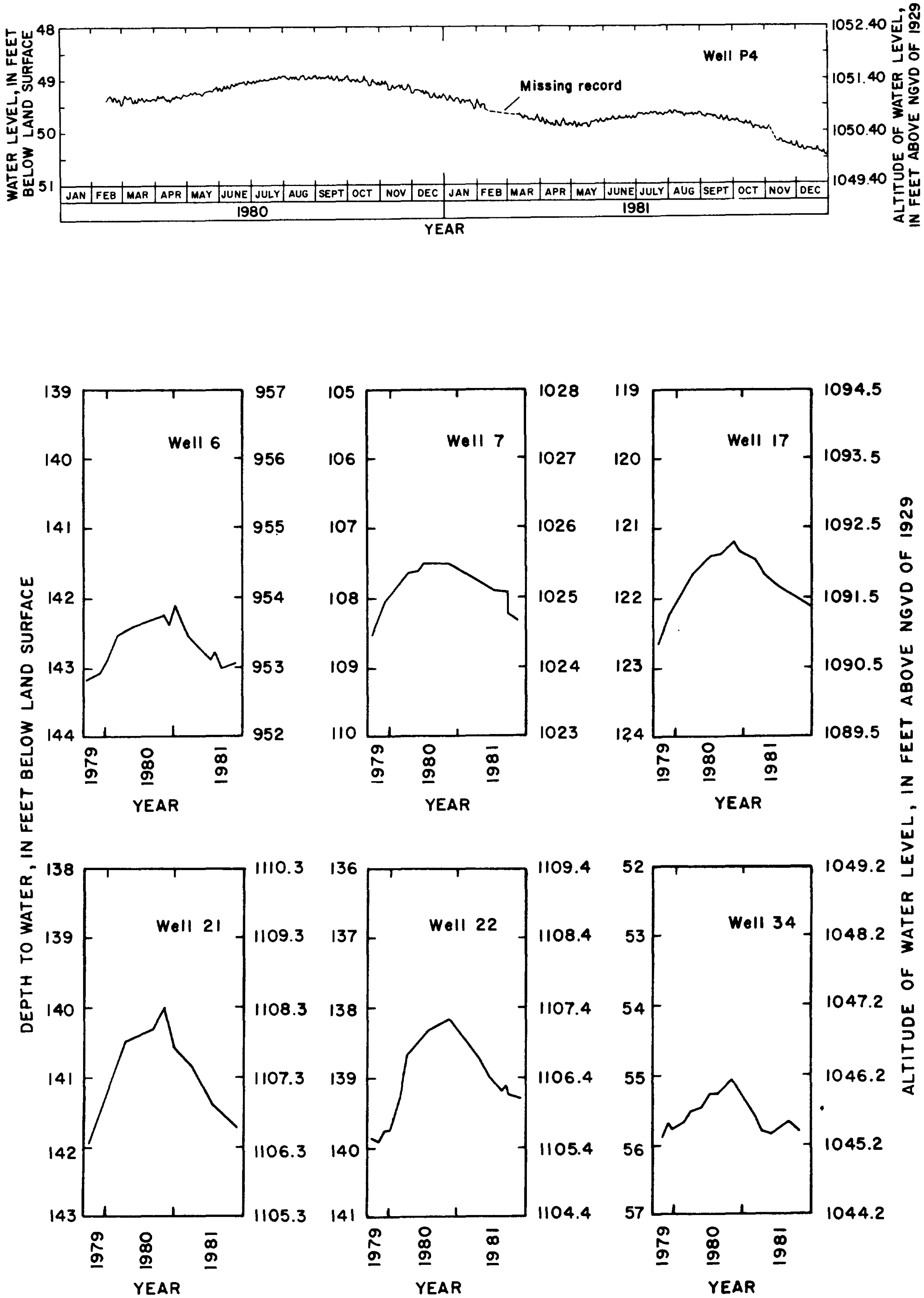


Figure 18.--Water levels in wells in the Outer Marquette Moraine.

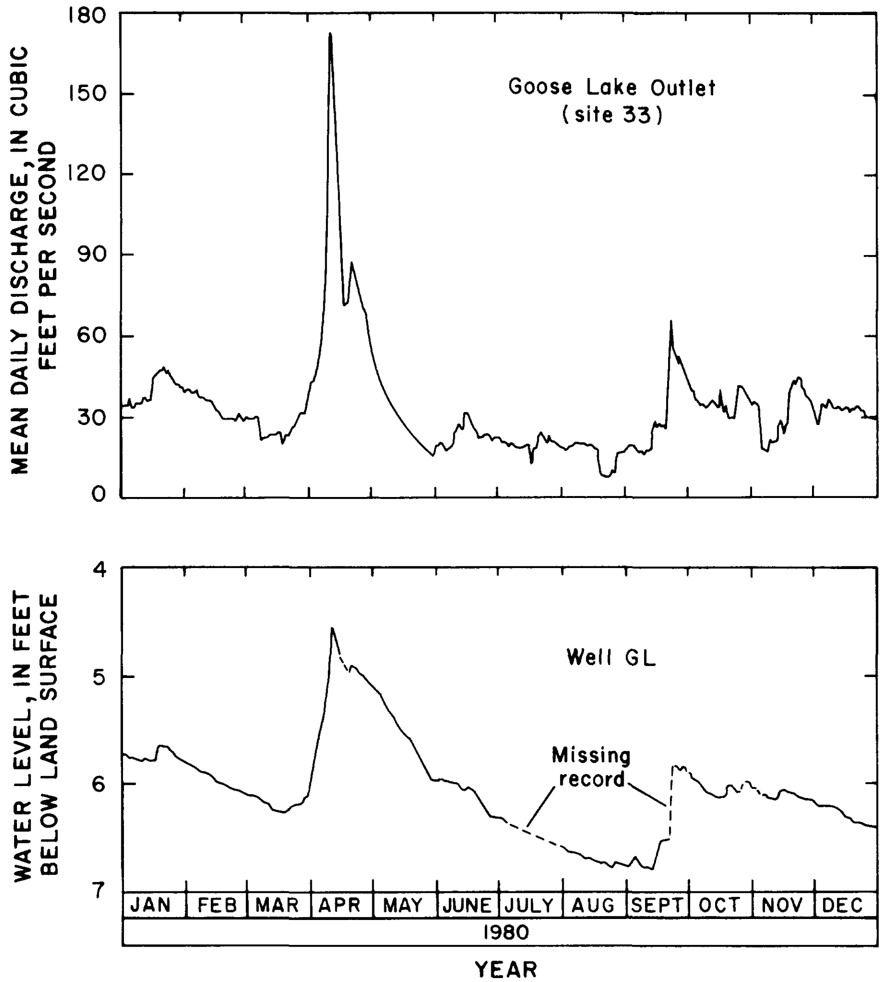


Figure 19.--Water levels in well GL and discharge in nearby Goose Lake Outlet.

Recharge

Ground-water recharge in the Sands Plain area is about 15 in./yr. This was determined by solving a general water-balance equation that may be expressed as:

$$R = Q_g \pm E + S_g \pm U \qquad (1)$$

where R is ground-water recharge, Q_g is ground-water runoff, E is ground-water evapotranspiration, S_g is the change in ground-water storage, and U is ground-water flow into or out of the ground-water reservoir. Over several years, the additions to S_g balance the losses and it can be assumed that $S_g = 0$. This assumption can be applied during the period of data collection because rainfall, which was above average in 1979, below average in 1980, and about average in 1981, would roughly balance the changes in ground-water storage (S_g). Because depth to ground water in all of the study area is generally deeper than the root

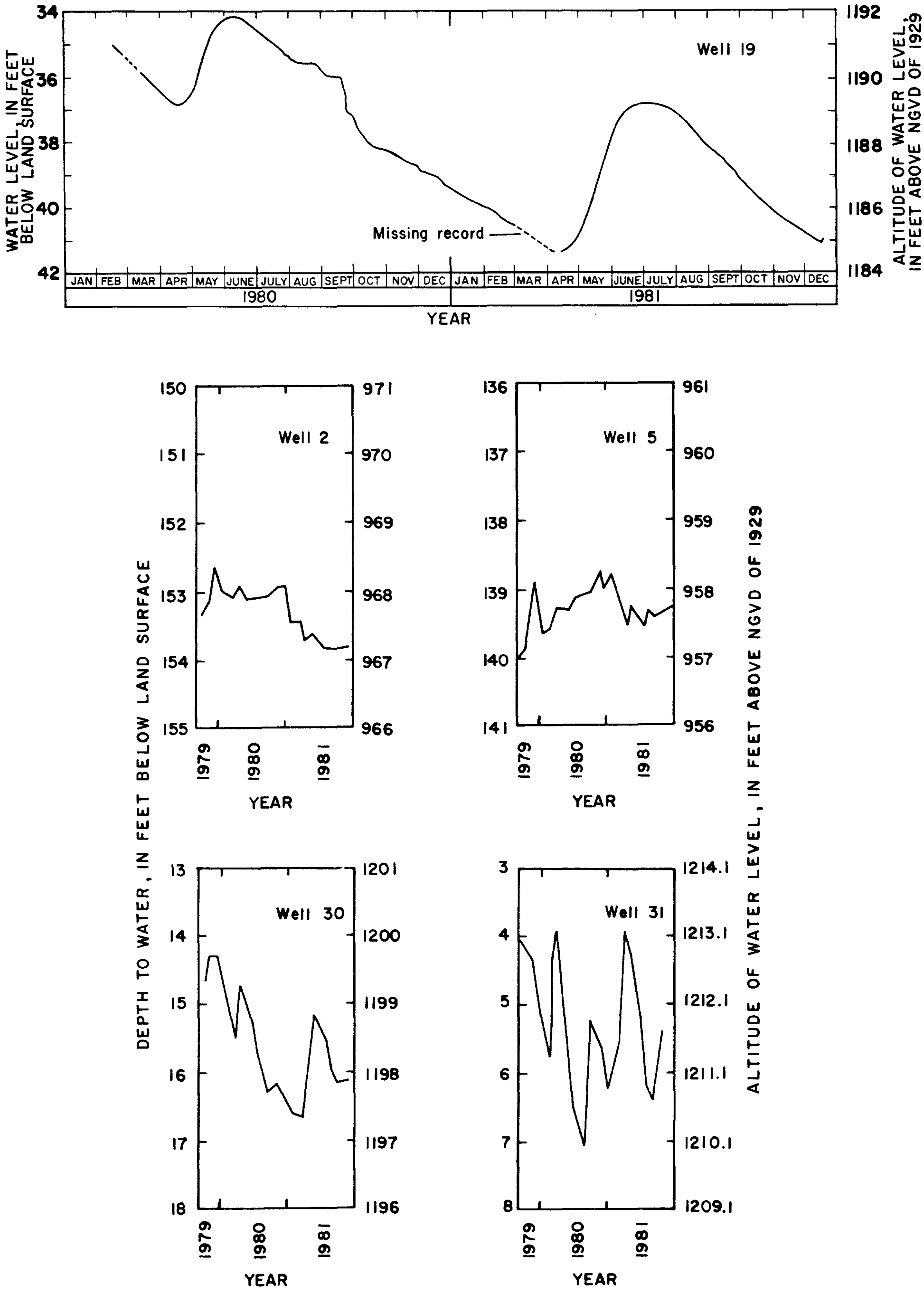


Figure 20.--Water levels in wells near streams.

depths of plants (except near streams, which cover a small percentage of the area), E is assumed to be negligible. Long-term recharge of the aquifer, therefore, was based on ground-water runoff adjusted for interbasin ground-water flow, or

$$R = Q_g \pm U \qquad (2)$$

Ground-water runoff of Silver, Cherry, Cedar, and Big Creeks was determined by baseflow separation. A combined discharge of 70 ft^3/s at the four gaging stations was considered to be from ground-water inflow. Comparison of gaging station records with low-flow measurements on these streams during 1962-70 indicates that the gaging station data for the period 1979-81 accurately represents the flow characteristics of these streams for longer time intervals. For example, combined discharge of the four streams in July 1963 (the third year for drought conditions), was 64 ft^3/s, or 92 percent of the estimated average ground-water runoff.

The ground-water reservoir also is recharged by streamflow losses in the upper reaches of Goose Lake Outlet. Based on correlations between periodic discharge measurements and gaging station records of Goose Lake Outlet, the average loss is estimated to be 9 ft^3/s on an annual basis (2 in./yr). This amount was deducted from the net ground-water discharge to give a recharge of 61 ft^3/s.

Applying equation 2 to a ground-water reservoir area of 56 mi^2 (fig. 13), recharge is 15 in./yr or about 45 percent of average annual precipitation. For comparison, Stark and others (1982) also calculated a recharge rate of 15 in./yr for a sand and gravel aquifer in Iosco County, Michigan.

Ground-water recharge was calculated for the period from October 1979 to September 1981 (1980-81 water years) by adding net ground-water runoff to the average change in ground-water storage with the following equation:

$$R = Q_g \pm S_g + U \qquad (3)$$

Baseflow was determined by conventional methods of separating streamflow hydrographs for four of the Chocolay River tributaries. Average monthly baseflow was calculated and summed. Ground-water recharge from Goose Lake Outlet, based on measured streamflow losses and correlations, was subtracted from average monthly baseflow in the Chocolay tributaries to give net ground-water runoff in the Chocolay tributaries. Ground-water evapotranspiration was considered negligible. Average monthly change in ground-water storage was determined by averaging water-level changes in 34 observation wells and multiplying the result by a specific yield of 0.1. Ground-water recharge, determined by applying equation 3, was 16.0 and 13.5 in., respectively, for 1980 and 1981 (table 9). The value of specific yield used for these calculations was lower than the value derived from pumping test analysis (0.16) because some wells were completed in finer grained deposits than at the pumping test site. However, similar calculations with a specific yield of 0.15 resulted in recharge of 16.09 in. for 1980 and 12.69 in. for 1981 which does not differ greatly from the previous calculation.

Table 9.--Ground-water recharge from precipitation
[Calculated from net ground-water runoff of the Chocolay River tributaries and from changes in ground-water storage]

	Precipitation[1] (in.)		Ground-water discharge to streams[2] (in.)		Change in ground-water storage[3] (in.)		Ground-water recharge[4] (in.)	
	1980	1981	1980	1981	1980	1981	1980	1981
October	5.88	2.01	1.37	1.32	[5]0.16	-0.03	1.53	1.29
November	2.13	1.41	1.30	1.32	.17	-.36	1.47	.96
December	1.14	1.79	1.30	1.33	.38	-.17	1.68	1.16
January	2.72	1.45	1.32	1.32	-.19	-.17	1.13	1.15
February	1.17	1.96	1.31	1.32	.03	-.19	1.34	1.13
March	.43	1.49	1.33	1.24	.05	-.20	1.38	1.04
April	3.24	3.24	1.17	.99	.05	.02	1.22	1.01
May	1.52	2.63	1.33	1.03	.03	.02	1.36	1.05
June	2.47	5.34	1.35	1.21	-.06	-.12	1.29	1.09
July	3.08	.82	1.34	1.32	-.06	-.04	1.28	1.28
August	3.09	3.21	1.31	1.31	-.32	-.13	.99	1.18
September	6.74	1.62	1.33	1.33	-.03	-.18	1.30	1.15
Total	33.61	26.97	15.76	15.04	0.21	-1.55	15.97	13.49

[1]Average of data from six sites.
[2]Average values calculated from streamflow hydrographs by baseflow separation.
[3]Average from 34 observation wells using specific yield of 0.1.
[4]Sum of ground-water discharge to streams and change in ground-water storage.
[5]Based on water-level changes in three wells.

Ground Water - Surface Water Interactions

Ground water in the Sands Plain area is mainly derived from precipitation infiltrating the sandy surface soils which cover most of the study area. Most of the water that reaches the water table moves to stream channels or lakes where it is discharged and becomes surface water. Some ground water flows to the East Branch Escanaba River or its tributaries, but most flows to the Chocolay River and its tributaries. En route, most of this ground water passes through the Marquette moraines. Glacial materials of lower hydraulic conductivity in the moraines slow the rate of flow and raise the potentiometric surface in the area west and southwest of the moraines (fig. 13). The amount of ground water discharged to stream channels accounts for about 95 percent of the total flow in Silver, Cherry, Cedar, and Big Creeks. Because of the geologic setting of these four streams, their ground-water divide does not coincide with their surface-water divide. Rather, the ground-water drainage area is about 17 mi^2 (44 percent) larger than the surface-water drainage area.

In addition to infiltrated precipitation, streams in a few areas recharge the aquifer by losing water from their channels into the aquifer. Water is lost from the upper reaches of Goose Lake Outlet at an average rate of 8 to 10 ft^3/s. This water flows as ground water toward Lake Superior and emerges in creeks tributary to Chocolay River.

Between sites 18 and 20, the channel of Silver Creek is not as deeply incised as that of nearby Cherry Creek. Because of this, water from Silver Creek infiltrates the ground and flows as ground water to Cherry Creek.

QUALITY OF WATER

As water moves through the hydrologic cycle, its physical and chemical properties change because of interactions with surrounding matter. Water vapor condensing in the atmosphere may incorporate gases and solid particulates that, in time, are carried to the ground by precipitation. Factors affecting the quality of precipitation are wind direction and duration, intensity and duration of precipitation, and materials being transported in the atmosphere.

Some of the precipitation infiltrates the land surface and percolates to the ground-water reservoir. The quality of ground water at any specific site is determined by precipitation, surrounding rock type, the time water is in contact with the rocks, temperature, land use, and ground-water recharge from surface-water sources. Human activity and waste products may also have an impact on the quality of ground water. Water at shallow depths is more likely to be affected by human activity than that at greater depths. Aquifers overlain by impermeable materials commonly are protected from contaminants infiltrating from the land surface.

The quality of streamflow generally is determined by the composition of precipitation and dry fallout, the type of soil and rock materials in the drainage area, the quality of ground-water inflow, and human activity. In the Sands Plain area, the quality of streamflow is primarily determined by ground-water inflow.

Precipitation

Chemical and physical characteristics of rain, snow, and dry fallout were measured at Sporley Lake and at Cherry Creek (pl. 1). Analyses are shown in tables 10, 11, and 12 for the period 1979-81. The following data indicate that quality characteristics of rain and snow are similar at both sites:

	Concentration (Mean values)	
Characteristic	Sporley Lake	Cherry Creek
Specific conductance (μmhos)	23	24
pH (units)	4.0	4.1
Sulfate, SO_4 (mg/L)	2.4	2.5
Ammonia, NH_4 as N (mg/L)	.35	.31
Nitrate, NO_3 as N (mg/L)	.32	.37

Based on data from both sites, specific conductance of precipitation ranged from 10 to 50 μmhos, and pH ranged from 3.6 to 4.5. The low pH values suggest that precipitation on the Sands Plain area is consistently acidic. Hydrogen is the principal cation; sulfate and nitrate are the principal anions. In general, sulfate, nitrate, and ammonia increase and pH decreases as specific conductance increases.

Table 10.--Chemical and physical characteristics of rain and snow at Sporley Lake
[Analyses by U.S. Geological Survey]

Date	Precipitation (in.) Rain	Precipitation (in.) Snow	Specific conductanc (μmhos)	pH (units)	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)	Nitrogen, ammonia total (mg/L as N)
July 25, 1979	0.60	--	50	3.8	--	--	--	--	6.3	--	0.59
July 30, 1979	1.65	--	23	4.1	--	--	--	--	.9	--	.14
Aug. 28, 1979	2.08	--	22	3.8	--	--	--	--	1.5	--	.26
Oct. 24, 1979	--	[a]0.90	12	4.3	--	--	--	--	.1	--	.05
Jan. 8, 1980	--	7.00	22	3.8	0.2	0.0	0.1	0.1	1.5	0.3	.32
April 10, 1980	2.67	--	38	4.0	--	--	--	--	.0	--	.67
June 2, 1980	.49	--	17	4.0	--	--	--	--	1.3	--	.11
Aug. 5, 1980	.55	--	27	3.6	--	--	--	--	3.3	--	.24
Sept. 13, 1980	1.79	--	31	3.6	.2	.1	.3	.0	3.3	.3	.32
Dec. 24, 1980	--	--	13	4.1	.1	.0	.1	.1	1.6	.8	--
Jan. 29, 1981	--	1.50	14	4.3	--	--	--	--	1.1	--	.09
April 14, 1981	.76	--	26	4.0	--	--	--	--	2.0	--	.26
April 23, 1981	1.90	--	16	4.0	--	--	--	--	1.3	--	.10
June 3, 1981	1.04	--	31	4.0	--	--	--	--	9.4	--	.35
Oct. 6, 1981	.55	--	10	4.3	--	--	--	--	1.9	--	.11

Date	Nitrogen, organic total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, total (mg/L as N)	Phosphorus, ortho total (mg/L as P)	Phosphorus, total (mg/L as P)	Hardness, (mg/L as $CaCO_3$)	Solids, residue at 180°C dissolved (mg/L)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)
July 25, 1979	--	<0.01	0.51	--	<0.01	<0.01	--	--	--	--
July 30, 1979	--	<.01	.27	--	<.01	<.01	--	--	--	--
Aug. 28, 1979	--	<.01	.18	--	<.01	<.01	--	--	--	--
Oct. 24, 1979	--	.00	.13	--	.00	.00	--	--	--	--
Jan. 8, 1980	--	.00	.78	--	.00	.01	1	1	0	20
April 10, 1980	0.33	.01	.71	1.7	.01	.03	--	--	--	--
June 2, 1970	.09	.00	.23	.43	.00	.00	--	--	--	--
Aug. 5, 1980	.00	.01	.16	.39	.00	.00	--	--	--	--
Sept. 13, 1980	--	.00	.41	--	.00	.00	1	2	1	100
Dec. 24, 1980	--	--	--	--	--	--	0	3	1	8
Jan. 29, 1981	.01	<.01	.16	.26	<.01	<.01	--	--	--	--
April 14, 1981	.08	<.01	.19	.53	<.01	<.01	--	--	--	--
April 23, 1981	.10	<.01	.21	.41	<.01	<.01	--	--	--	--
June 3, 1981	.08	<.01	.33	.76	<.01	<.01	--	--	--	--
Oct. 6, 1981	.18	<.01	.17	.46	<.01	<.01	--	--	--	--

Date	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 (mg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Mercury, dissolved (μg/L as Hg)	Zinc, dissolved (μg/L as Zn)
July 25, 1979	--	--	--	--	--	--	--	--	--
July 30, 1979	--	--	--	--	--	--	--	--	--
Aug. 28, 1979	--	--	--	--	--	--	--	--	--
Oct. 24, 1979	--	--	--	--	--	--	--	--	--
Jan. 8, 1980	1	<10	0	3	20	10	5	0.1	5
April 10, 1980	--	--	--	--	--	--	--	--	--
June 2, 1980	--	--	--	--	--	--	--	--	--
Aug. 5, 1980	--	--	--	--	--	--	--	--	--
Sept. 13, 1980	0	<10	0	2	20	7	10	.1	30
Dec. 24, 1980	1	10	0	0	10	4	2	<.1	8
Jan. 29, 1981	--	--	--	--	--	--	--	--	--
April 14, 1981	--	--	--	--	--	--	--	--	--
Apirl 23, 1981	--	--	--	--	--	--	--	--	--
June 3, 1981	--	--	--	--	--	--	--	--	--
Oct. 6, 1981	--	--	--	--	--	--	--	--	--

[a]Water equivalent

Table 11.--Chemical and physical characteristics of rain and snow at Cherry Creek
[Analyses by U.S. Geological Survey]

Date	Precipitation (in.) Rain	Precipitation (in.) Snow	Specific conductance (µmhos)	pH (units)	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)	Nitrogen, ammonia total (mg/L as N)
July 24, 1979	1.32	--	48	3.9	--	--	--	--	7.7	--	0.52
July 31, 1979	2.42	--	14	4.3	--	--	--	--	1.4	--	.07
Aug. 28, 1979	.78	--	21	4.0	--	--	--	--	1.8	--	.24
Oct. 24, 1979	[a]3.65	--	18	4.2	--	--	--	--	.6	--	.20
Jan. 8, 1980	--	7.00	22	3.8	0.2	0.0	0.2	0.1	1.1	0.3	.21
April 9, 1980	2.53	--	28	4.2	--	--	--	--	2.2	--	.34
June 2, 1980	1.32	--	18	4.0	--	--	--	--	1.3	--	.12
Aug. 5, 1980	1.58	--	50	3.7	--	--	--	--	6.3	--	1.10
Sept. 15, 1980	3.10	--	16	3.9	.3	.1	.3	.0	1.4	.1	.19
Dec. 24, 1980	--	--	17	4.1	.1	.0	.1	.1	2.1	.8	--
Jan. 30, 1981	--	1.50	39	3.9	--	--	--	--	4.3	--	.19
April 14, 1981	.54	--	18	4.5	--	--	--	--	3.0	--	.58
April 23, 1981	1.82	--	15	4.1	--	--	--	--	1.1	--	.11
June 4, 1981	1.23	--	20	3.9	--	--	--	--	--	--	.36
Oct. 7, 1981	--	--	15	4.3	--	--	--	--	1.2	--	.06

Date	Nitrogen, organic total (mg/L as N)	Nitrogen, nitrite total (mg/L as N)	Nitrogen, nitrate total (mg/L as N)	Nitrogen, total (mg/L as N)	Phosphorus, ortho total (mg/L as P)	Phosphorus, total (mg/L as P)	Hardness, (mg/L as $CaCO_3$)	Solids, residue at 180°C, dissolved (mg/L)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)
July 24, 1979	--	<0.01	0.43	--	<0.01	<0.01	--	--	--	--
July 31, 1979	--	<.01	.12	--	<.01	<.01	--	--	--	--
Aug. 28, 1979	--	<.01	.21	--	<.01	<.01	--	--	--	--
Oct. 24, 1979	--	.00	.16	--	.00	.01	--	--	--	--
Jan. 8, 1980	--	.00	.58	--	.00	.01	1	1	1	20
April 9, 1980	0.00	.01	.42	0.64	.02	.01	--	--	--	--
June 2, 1980	.12	.00	.21	.45	.00	.01	--	--	--	--
Aug. 5, 1980	.20	.00	.87	2.2	.01	.03	--	--	--	--
Sept. 15, 1980	--	.00	.21	--	.00	.00	1	2	2	100
Dec. 24, 1980	--	--	--	--	--	--	0	6	1	10
Jan. 30, 1981	.07	<.01	.89	1.2	<.01	<.01	--	--	--	--
April 14, 1981	.12	.01	.32	1.0	<.01	.01	--	--	--	--
April 23, 1981	.18	<.01	.21	.50	<.01	<.01	--	--	--	--
June 4, 1981	.07	<.01	.32	.75	<.01	<.01	--	--	--	--
Oct. 7, 1981	.82	<.01	.16	1.0	.03	<.01	--	--	--	--

Date	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 (mg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Zinc, dissolved (µg/L as Zn)
July 24, 1979	--	--	--	--	--	--	--	--	--
July 31, 1979	--	--	--	--	--	--	--	--	--
Aug. 28, 1979	--	--	--	--	--	--	--	--	--
Oct. 24, 1979	--	--	--	--	--	--	--	--	--
Jan. 8, 1980	0	10	0	3	30	7	3	0.1	90
April 9, 1980	--	--	--	--	--	--	--	--	--
June 2, 1980	--	--	--	--	--	--	--	--	--
Aug. 5, 1980	--	--	--	--	--	--	--	--	--
Sept. 15, 1980	0	<10	0	2	60	4	10	.1	10
Dec. 24, 1980	0	10	0	0	1	6	1	<.1	10
Jan. 30, 1981	--	--	--	--	--	--	--	--	--
April 14, 1981	--	--	--	--	--	--	--	--	--
April 23, 1981	--	--	--	--	--	--	--	--	--
June 4, 1981	--	--	--	--	--	--	--	--	--
Oct. 7, 1981	--	--	--	--	--	--	--	--	--

[a]Rain and snow

Table 12.--Chemical and physical characteristics of leachable dry fallout
[Analyses by U.S. Geological Survey]

Sporley Lake near Little Lake, Michigan (Lat 46°19'46", long 87°20'53")

Date	Specific conductance (μmhos)	pH (units)	Calcium, dissolved (mg/L as Ca)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Nitrogen, ammonia dissolved (mg/L as N)
Oct. 26, 1979	11	6.5	0.9	2.6	0.7	0.77
April 10, 1980	--	--	--	32	--	5.7
Nov. 3, 1980	--	--	--	--	--	.01
April 14, 1981	--	--	--	13	--	2.1

Date	Nitrogen, organic dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, dissolved (mg/L as N)	Phosphorus, ortho dissolved (mg/L as P)	Phosphorus, dissolved (mg/L as P)
Oct. 26, 1979	--	--	--	--	--	0.16
April 10, 1980	--	--	--	--	--	.06
Nov. 3, 1980	--	<0.01	--	--	0.02	--
April 14, 1981	0.00	<.01	3.0	4.9	.05	.07

Cherry Creek near Harvey, Michigan (Lat 36°28'03",long 87°21'54")

Date	Specific conductance (μmhos)	pH (units)	Calcium, dissolved (mg/L as Ca)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Nitrogen, ammonia dissolved (mg/L as N)
Oct. 26, 1979	125	5.2	10	41	2.2	1.8
April 10, 1980	--	--	--	16	--	2.1
Nov. 3, 1980	--	--	--	--	--	--
April 14, 1981	--	--	--	18	--	1.7

Date	Nitrogen, organic dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, dissolved (mg/L as N)	Phosphorus, ortho dissolved (mg/L as P)	Phosphorus, dissolved (mg/L as P)
Oct. 26, 1979	--	--	--	--	--	0.28
April 10, 1980	--	--	--	--	--	.03
Nov. 3, 1980	--	--	--	--	--	--
April 14, 1981	0.20	<0.01	1.6	3.5	0.03	.05

The amount of dissolved nitrogen and sulfate deposited by rain and snow each year on the Sands Plain area has been estimated by assuming a mean annual precipitation of 32 in. during 1979-81. Deposition rates computed from data obtained at both sites follow:

Substance	Nitrogen (as N) and sulfate (as SO_4) deposition: lb/acre/yr	(tons/mi^2)/yr
Ammonia	2.1	0.67
Nitrate	2.6	.83
Organic nitrogen	1.2	.38
Total dissolved nitrogen	5.8	1.9
Sulfate	17.4	5.6

The above amounts do not differ appreciably from amounts found at other locations in northern Michigan, but are about half those found in lower parts of the state. For example, Cummings (1978) reported ammonia, nitrate, and organic nitrogen loads of 4.0, 4.8, and 3.4 lb/acre/yr, respectively, at Hillsdale, Michigan. Other studies undertaken in the north central part of Michigan's Lower Peninsula (Pecor and others, 1973) reported inorganic and organic nitrogen in precipitation at Houghton Lake to be 6.8 lb/acre/yr during 1972. Richardson and Merva (1976) reported 4.3 and 2.8 lb/acre/yr of nitrate and ammonia, respectively, at Pellston; they reported 2.9 and 1.9 lb/acre/yr at Houghton. Although organic nitrogen was not determined in the study by Richardson and Merva, their nitrate and ammonia loads suggest that total nitrogen deposition does not differ greatly from that at Sands Plain. The relative proportions of nitrogen compounds in precipitation in the Sands Plain area are also similar to those found at other locations, although the load of organic nitrogen is slightly less.

Sulfate deposition (17.4 lb/acre/yr) is also similar to that found at sites away from industrialized areas. At Pellston, Richardson and Merva found 16.3 lb/acre/yr.

Wind direction may also affect the chemical and physical characteristics of rain and snowfall, particularly in areas where urban and industrial development is not extensive. In the Sands Plain area, storms moving from the south would be expected to transport greater amounts of nitrogen and sulfate because of atmospheric emissions from industrial activity in Lower Michigan, Ohio, Pennsylvania, Indiana, and Illinois (Hileman, 1981). Data obtained during this study suggest that an effect is detectable. For example, at Sporley Lake, precipitation had the following characteristics on the indicated dates:

Date	Wind direction prior to precipitation	Specific conductance (μmhos)	pH (units)	Chemical characteristics	
				Sulfate (mg/L)	Nitrate (mg/L)
July 25, 1979	South	50	3.8	6.3	0.51
July 30, 1979	Northwest	23	4.1	.9	.27

Comparisons of results obtained on other dates were less suggestive than those cited above. The amount of precipitation, storm intensity, variable wind conditions, and other factors mask relations between wind direction and quality of precipitation. A general grouping of data, based on prevailing monthly wind direction, does indicate a general relation between wind direction and chemical and physical characteristics of rain and snow. From July to October, when winds from the south are likely, the average specific conductance was about 26 μmhos, the average pH was 3.99, and the average sulfate concentration was 2.7 mg/L. During the remainder of the year, when winds from the north prevail, the average specific conductance was 21 μmhos, the average pH was 4.09, and the average sulfate concentration was 2.2 mg/L.

Dry fallout was collected at 4- to 6-month intervals with an automatic sampler that opened or closed in response to precipitation (table 12). Material accumulated in a sampling bucket which, when removed, was rinsed clean with a known volume of deionized water and allowed to stand 24 hours. The resultant suspension was filtered through a 0.45 micron filter, and then analyzed. Analyses given in table 12 thus represent the leachable substances under the specified conditions. A rough estimate of dry fallout, in grams for the period of collection, was also made by drying and weighing all material that could be removed from the sampling buckets. Average accumulation during 1979-81 was about 0.03 grams of dry fallout per square foot per month. Because of the difficulty in removing stubbornly adhering material from bucket walls, and the possibility that small amounts were not recovered, this value should be considered a minimum for the Sands Plain area.

A comparison of dry fallout data with that of rainfall and snow indicates that the proportion of sulfate in dry fallout is lower. The relation of nitrate to ammonia in dry fallout is about the same as that of rain or snow. Phosphorus, present near the detection limit in rain and snow, was a larger component of dry fallout.

Surface Water

Analyses of water from Silver, Cherry, Cedar, and Big Creeks are given in tables 13 to 15 at the back of the report. Plate 1 shows the locations of sampling sites. Because most flow in these streams is ground-water inflow, the chemical characteristics of water from each does not vary appreciably. Silver and Cherry Creeks have the highest dissolved-solids concentrations; Cedar Creek has the lowest. Water of Cherry Creek has a higher dissolved-solids concentration because a substantial amount of its flow is derived from the more highly mineralized ground water in glacial deposits west of site 13 (pl. 1). For example, dissolved solids concentrations were 240, 177, and 165 mg/L, respectively, for water from wells 15, 21, and P1. Average dissolved-solids concentration for water from 20 sites on Silver, Cherry, Cedar, and Big Creeks during October 1979 was 110 mg/L. Measurements of specific conductance of water at sites on Goose Lake Outlet on August 24, 1981, indicate that its mineralization is higher and more variable than that of Cedar, Cherry, Big, and Silver Creeks. Specific conductance ranged from 225 μmhos at site 27 to 955 μmhos at site 31, just downstream from the entrance of drainage from the Gribben tailings basin. At sites 24 and 25, where surface water infiltrates the aquifer, specific conductance was 280 μmhos.

Calcium and bicarbonate are the principal dissolved substances at all sites on the Chocolay tributaries (table 13). Calcium ranged from 18 to 34 mg/L; bicarbonate ranged from 62 to 140 mg/L. Sulfate ranged from 82 to 143 mg/L. Total nitrogen ranged from 0.12 to 1.2 mg/L. The mean concentrations of total nitrogen (0.40 mg/L) and nitrate (0.20 mg/L) do not differ significantly from the mean concentrations for ground water (0.38 mg/L and 0.15 mg/L). The similarity would be expected because of the interrelationship of ground water and surface water in the Sands Plain area. Mean total phosphorus concentration (0.014 mg/L) in surface water was about half that in ground water. In general, concentrations of trace metals in surface water do not differ greatly from those in ground water. Cadmium, chromium, and mercury, however, were slightly higher in surface water.

Chemical analyses of water from four lakes are given in table 16. Dissolved-solids concentrations in each was lower than found in water from streams, and lower than found in most ground water. Pelissier Lake, which had the highest concentration (69 mg/L) is in the area where more highly mineralized ground water occurs. Harvey, Powell, and Strawberry Lakes, whose dissolved-solids concentrations ranged from 22 to 49 mg/L, are in an area where ground water has a lower mineralization. The lower amount of mineralization indicates that these lakes have small local flow systems and do not discharge water from the regional ground-water flow system whose principal discharge area is the Chocolay tributaries. Water from each lake was of a calcium bicarbonate type. Mean total dissolved nitrogen for the four lakes was 0.50 mg/L, slightly higher than found in other surface waters and in ground water, but less than in precipitation. Organic nitrogen constituted more than 80 percent of the total.

Table 16.--Chemical and physical characteristics of water from lakes [Analyses by U.S. Geological Survey; results in milligrams per liter except as indicated]

Lake	Date	Sampling depth (ft)	Specific conductance (μmhos)	Temperature (°C)	pH (units)	Iron, dissolved (Fe)	Iron, toal recoverable (Fe)	Manganese, dissolved (Mn)	Manganese, total (Mn)
Powell	June 5, 1981	2.0	31	22.0	6.8	90	280	0	20
Strawberry	Sept. 3, 1981	3.0	57	21.0	6.8	20	170	<10	10
Harvey	June 2, 1981	--	23	22.0	6.4	80	490	4	10
Pelissier	Aug. 31, 1981	3.0	102	20.5	7.6	40	300	<10.	10

Lake	Date	Calcium, dissolved (Ca)	Magnesium, dissolved (Mg)	Sodium, dissolved (Na)	Potassium, dissolved (K)	Bicarbonate, field (HCO_3)	Carbonate, field (CO_3)	Carbon dioxide dissolved (CO_2)	Chloride, dissolved (Cl)
Powell	June 5, 1981	3.7	1.1	0.7	0.4	12	0	3.0	0.5
Strawberry	Sept. 3, 1981	7.0	1.8	.7	.3	27	0	6.5	.6
Harvey	June 2, 1981	2.3	.6	.8	.2	8	0	5.1	.5
Pelissier	Aug. 31, 1981	13	3.9	1.0	.6	55	0	2.2	.9

Lake	Date	Sulfate, dissolved (SO_4)	Fluoride, dissolved (F)	Nitrogen, dissolved (as N)	Nitrogen, ammonia dissolved (as N)	Nitrogen, nitrite dissolved (as N)	Nitrogen, dissolved nitrite plus nitrate (as N)	Nitrogen, organic dissolved (as N)	Phosphorus, ortho, dissolved (as P)
Powell	June 5, 1981	4.1	0.1	0.51	0.08	<0.01	0.01	0.42	<0.01
Strawberry	Sept. 3, 1981	3.2	.1	.40	.04	<.01	.02	.34	<.01
Harvey	June 2, 1981	2.4	.1	.57	.04	<.01	.02	.51	<.01
Pelissier	Aug. 31, 1981	6.4	.1	.52	.04	<.01	.04	.44	<.01

Lake	Date	Phosphorus, dissolved (as P)	Solids, residue at 180° C, dissolved	Hardness, (as $CaCO_3$)	Hardness, noncarbonate (as $CaCO_2$)	Potassium 40, dissolved (as K40)
Powell	June 5, 1981	<0.01	34	14	4	0.30
Strawberry	Sept. 3, 1981	<.01	49	25	3	--
Harvey	June 2, 1981	<.01	22	8	1	.20
Pelissier	Aug. 31, 1981	<.01	69	49	4	.40

Ground Water

Chemical and physical characteristics of ground water are given in tables 17 (at back of report), 18, and 19. At most locations, calcium and bicarbonate are the principal dissolved ions; however, wells 18 and C7 yield water of the sodium bicarbonate type and well C3 yields water of the calcium sulfate type. Hardness of water ranges from 15 mg/L (soft) to 200 mg/L (very hard); dissolved-solids concentrations range from 38 to 288 mg/L.

Areas of highest dissolved-solids concentrations occur in water east of Goose Lake Outlet and south of Cedar Creek; lowest concentrations occur southeast of Gribben Basin (fig. 21). Wiitala and others (1967) found that surface water entering Goose Lake via Goose Lake Inlet had a specific conductance as great as 632 µmhos, which is equivalent to a dissolved-solids concentration of about 400 mg/L. Calcium and sulfate were the principal ions in solution. Calcium and sulfate concentrations are also greater in the more highly mineralized ground water east of the losing reaches of Goose Lake Outlet (fig. 22). Surface water from Goose Lake Outlet infiltrates the aquifer and moves eastward to be discharged in the Chocolay tributaries. Between the point of infiltration and the point of discharge, the chemical characteristics of the water are altered by dilution from precipitation that has infiltrated the aquifer.

Water moving into glacial deposits from bedrock may also account for some of the more highly mineralized water east of Goose Lake Outlet, particularly along the Palmer fault. No wells were drilled in bedrock along the fault, but water from a flowing well drilled in the Negaunee Iron-formation (Well C13) had a dissolved-solids concentration of 288 mg/L--the highest concentration sampled during this study.

Specific conductance of water in wells 19, 27, and P4 was measured at hourly intervals during 1980-81 to determine natural variations in mineralization, and to establish baseline conditions against which future changes can be judged. Specific conductance of water in wells P4 and 27 varied less than 20 µmhos during 1980-81 (fig. 23). During the same period, water levels in well P4 varied seasonally but generally fell about 1 ft; in well 27 water levels had less seasonal variation and generally fell about 5 ft. There is no direct relation between water levels and specific conductance of water in these two wells (fig. 23).

Table 18.--Nitrogen and phosphorus in ground water
[Analyses by U.S. Geological Survey; results in milligrams per liter; nitrogen values are reported as N; phosphorus values are reported as P]

Well	Date	Nitrogen, total	Nitrogen, dissolved	Nitrogen, ammonia, total	Nitrogen, ammonia, dissolved	Nitrogen, nitrite, total	Nitrogen, nitrite, dissolved	Nitrogen, nitrate, total	Nitrogen, nitrate, dissolved	Nitrogen, organic, total	Nitrogen, organic, dissolved	Phosphorus, total	Phosphorus, dissolved	Phosphorus, ortho, total	Phosphorus, ortho, dissolved
1	July 23, 1980	0.14	--	0.00	--	0.00	--	0.14	--	0.00	--	0.04	--	0.03	--
2	July 23, 1980	--	0.17	--	0.01	--	0.00	--	0.13	--	0.03	--	0.01	--	0.00
5	July 24, 1980	.47	--	.00	--	.00	--	.42	--	.05	--	.03	--	.04	--
6	July 24, 1980	--	--	--	--	--	--	--	--	--	--	--	.02	--	--
7	Sept. 3, 1981	--	.90	--	.11	--	.05	--	.18	--	.56	--	--	--	--
8	June 5, 1981	.15	--	.02	--	<.01	--	.04	--	.08	--	.02	--	.02	--
10	July 21, 1980	.13	--	.00	--	.00	--	.07	--	.06	--	.03	--	.00	--
12	July 21, 1980	--	.25	--	.01	--	.00	--	.20	--	.04	--	.02	--	.00
14	July 23, 1980	.14	--	.00	--	.00	--	.06	--	.08	--	.04	--	.03	--
	Aug. 31, 1981	--	.35	--	<.01	--	<.01	--	.17	--	.16	--	.02	--	<.01
15	July 24, 1980	--	1.20	--	.00	--	.00	--	1.20	--	.01	--	.01	--	.00
	June 3, 1981	1.30	--	.01	--	<.01	--	.95	--	.31	--	<.01	--	.01	--
17	July 24, 1980	--	.05	--	.00	--	.00	--	.03	--	.02	--	.02	--	.00
18	June 1, 1981	--	.17	--	.05	--	<.01	--	.06	--	.05	--	.04	--	.04
19	July 30, 1980	.09	--	.00	--	.00	--	.08	--	.01	--	.02	--	.00	--
	June 3, 1981	--	.41	--	.01	--	<.01	--	.27	--	.12	--	<.01	--	<.01
21	July 25, 1980	.19	--	.00	--	.00	--	.19	--	.00	--	.02	--	.00	--
	Sept. 1, 1981	--	.45	--	<.01	--	.01	--	.24	--	.19	--	.01	--	<.01
22	Sept. 1, 1981	--	1.40	--	.13	--	.09	--	.11	--	1.10	--	.20	--	.15
23	June 4, 1981	.22	--	.02	--	<.01	--	.11	--	.08	--	.01	--	.01	--
25	July 29, 1980	--	.09	--	.01	--	.00	--	.09	--	.00	--	.01	--	.01
26	July 22, 1980	--	.02	--	.02	--	.00	--	.00	--	.00	--	.02	--	.01
	June 2, 1981	--	.12	--	.02	--	<.01	--	.01	--	.08	--	.01	--	.02
27	July 29, 1980	.13	--	.00	--	.00	--	.11	--	.02	--	.06	--	.02	--
	June 2, 1981	--	.26	--	.03	--	<.01	--	.09	--	.13	--	<.01	--	<.01
28	July 25, 1980	--	.29	--	.00	--	.00	--	.28	--	.01	--	.02	--	.01
29	June 2, 1981	.36	--	.00	--	<.01	--	.08	--	.27	--	.02	--	.02	--
30	July 22, 1980	--	.05	--	.00	--	.00	--	.04	--	.01	--	.01	--	.01
	Sept. 1, 1981	.23	--	<.01	--	<.01	--	--	--	--	--	.02	--	.02	--
31	July 30, 1980	.07	--	.00	--	.00	--	.00	--	.07	--	.01	--	.01	--
34	July 25, 1980	--	.07	--	.00	--	.00	--	.07	--	.00	--	.01	--	.00
	Sept. 8, 1981	.23	--	.03	--	<.01	--	.03	--	.16	--	<.01	--	<.01	--
P1	Aug. 31, 1981	.46	--	.02	--	<.01	--	.15	--	.28	--	.03	--	<.01	--
P2	July 29, 1980	.01	--	.03	--	.00	--	.00	--	.00	--	.02	--	.01	--
	June 4, 1981	--	.20	--	.04	--	<.01	--	<.01	--	.15	--	.01	--	<.01
P4	July 24, 1980	.16	--	.00	--	.00	--	.04	--	.12	--	.03	--	.01	--
C2	Sept. 2, 1981	.90	--	.25	--	.03	--	.02	--	.60	--	.10	--	.02	--
C3	Sept. 2, 1981	--	.62	--	.04	--	<.01	--	.01	--	.56	--	<.01	--	<.01
C7	Sept. 8, 1981	--	2.00	--	.14	--	.02	--	.00	--	1.90	--	.04	--	.04
C13	Sept. 2, 1981	--	.31	--	.05	--	<.01	--	<.01	--	.25	--	.01	--	<.01

Table 19.--Trace metals in ground water
[Analyses by U.S. Geological Survey; results in micrograms per liter]

Well	Date	Aluminum, total recoverable (Al)	Arsenic, total (As)	Barium, total recoverable (Ba)	Beryllium, total recoverable (Be)	Boron, total recoverable (B)	Cadmium, total recoverable (Cd)	Chromium, total recoverable (Cr)	Cobalt, total recoverable (Co)	Copper, total recoverable (Cu)	Gallium, dissolved (Ga)	Germanium, dissolved (Ge)	Lead, total recoverable (Pb)	Lithium, total recoverable (Li)
1	July 23, 1980	50	6	<50	10	10	0	10	0	3	<30	30	3	10
5	July 24, 1980	10	2	100	0	20	1	10	0	3	<30	50	3	10
8	June 5, 1981	140	1	100	0	0	3	10	5	2	--	--	9	0
10	July 21, 1980	60	1	<50	0	10	0	--	--	2	<30	<30	6	10
11	June 1, 1981	100	1	100	0	0	1	10	1	6	--	--	2	0
14	July 23, 1980	20	2	<50	0	6	0	10	0	18	<30	<30	7	10
15	June 3, 1981	180	1	100	10	0	1	10	1	5	--	--	1	0
19	July 30, 1980	40	1	<50	0	90	0	10	0	0	<30	70	1	0
21	July 25, 1980	60	0	100	0	70	0	20	0	3	<30	100	1	0
23	June 4, 1981	120	2	100	10	0	2	20	3	1	--	--	8	0
27	July 29, 1980	140	1	100	0	7	0	<10	0	1	50	70	2	0
29	June 2, 1981	90	1	100	10	0	1	10	1	6	--	--	6	0
30	Sept. 1, 1981	40	4	100	<10	10	<1	<10	1	2	--	--	10	<10
31	July 30, 1980	40	0	<50	0	70	0	<10	1	1	30	70	6	10
34	Sept. 8, 1981	40	1	<50	30	20	<1	10	<1	2	--	--	<1	<10
P1	Aug. 31, 1981	20	1	100	<10	90	3	10	2	3	--	--	9	<10
P2	July 29, 1980	30	2	<50	0	20	0	10	0	1	<30	70	1	0
P4	July 24, 1980	40	1	100	10	6	0	10	0	1	<30	<30	0	0

Well	Date	Mercury, total recoverable (Hg)	Molybdenum, total recoverable (Mo)	Nickel, total recoverable (Ni)	Selenium, total recoverable (Se)	Silver, total recoverable (Ag)	Strontium, total recoverable (Sr)	Tin, dissolved (Sn)	Titanium, dissolved (Ti)	Uranium, dissolved extraction (U)	Vanadium, dissolved (V)	Zinc, total recoverable (Zn)	Zirconium, dissolved (Zr)
1	July 23, 1980	<0.1	2	0	0	0	70	<50	<5	--	<10	10	<5
5	July 24, 1980	.1	2	2	0	0	50	<50	<5	--	<10	10	<5
8	June 5, 1981	<.1	4	9	0	0	20	--	--	0.03	--	10	--
10	July 21, 1980	.2	1	0	0	0	--	100	<5	--	<10	10	<5
11	June 1, 1981	.2	2	5	0	0	40	--	--	.15	--	20	--
14	July 23, 1980	.1	1	2	0	0	40	<50	<5	--	<10	20	<5
15	June 3, 1981	.3	1	9	0	0	70	--	--	.48	--	10	--
19	July 30, 1980	<.1	2	1	0	0	100	70	<5	.11	<10	10	<5
21	July 25, 1980	<.1	2	0	0	0	80	50	<5	--	<10	20	<5
23	June 4, 1981	<.1	4	3	0	0	20	--	--	.09	--	10	--
27	July 29, 1980	<.1	1	1	0	0	30	100	<5	.11	<10	10	5
29	June 2, 1981	.2	2	25	0	0	30	--	--	.08	--	40	--
30	Sept. 1, 1981	<.1	3	3	<1	<1	50	--	--	.23	--	10	--
31	July 30, 1980	<.1	1	6	0	0	140	70	<5	.05	<10	10	<5
34	Sept. 8, 1981	<.1	5	<1	<1	<1	50	--	--	.11	--	30	--
P1	Aug. 31, 1981	.2	3	2	<1	2	80	--	--	.20	--	10	--
P2	July 29, 1980	<.1	1	2	0	0	70	70	<5	.21	<10	10	<5
P4	July 24, 1980	<.1	1	1	0	0	40	<50	<5	.08	<10	10	<5

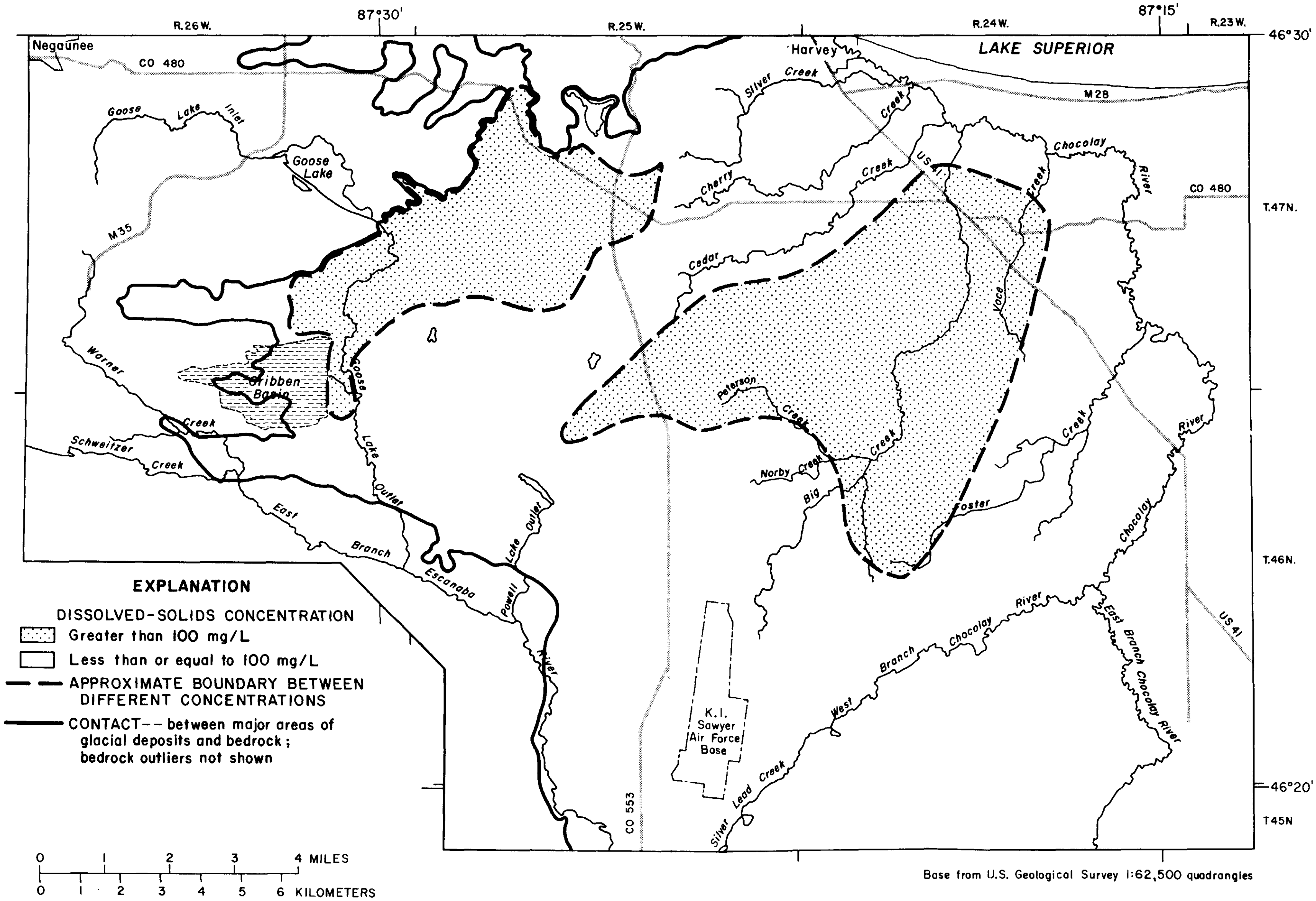


Figure 21.--Dissolved-solids concentrations in ground water from glacial deposits.

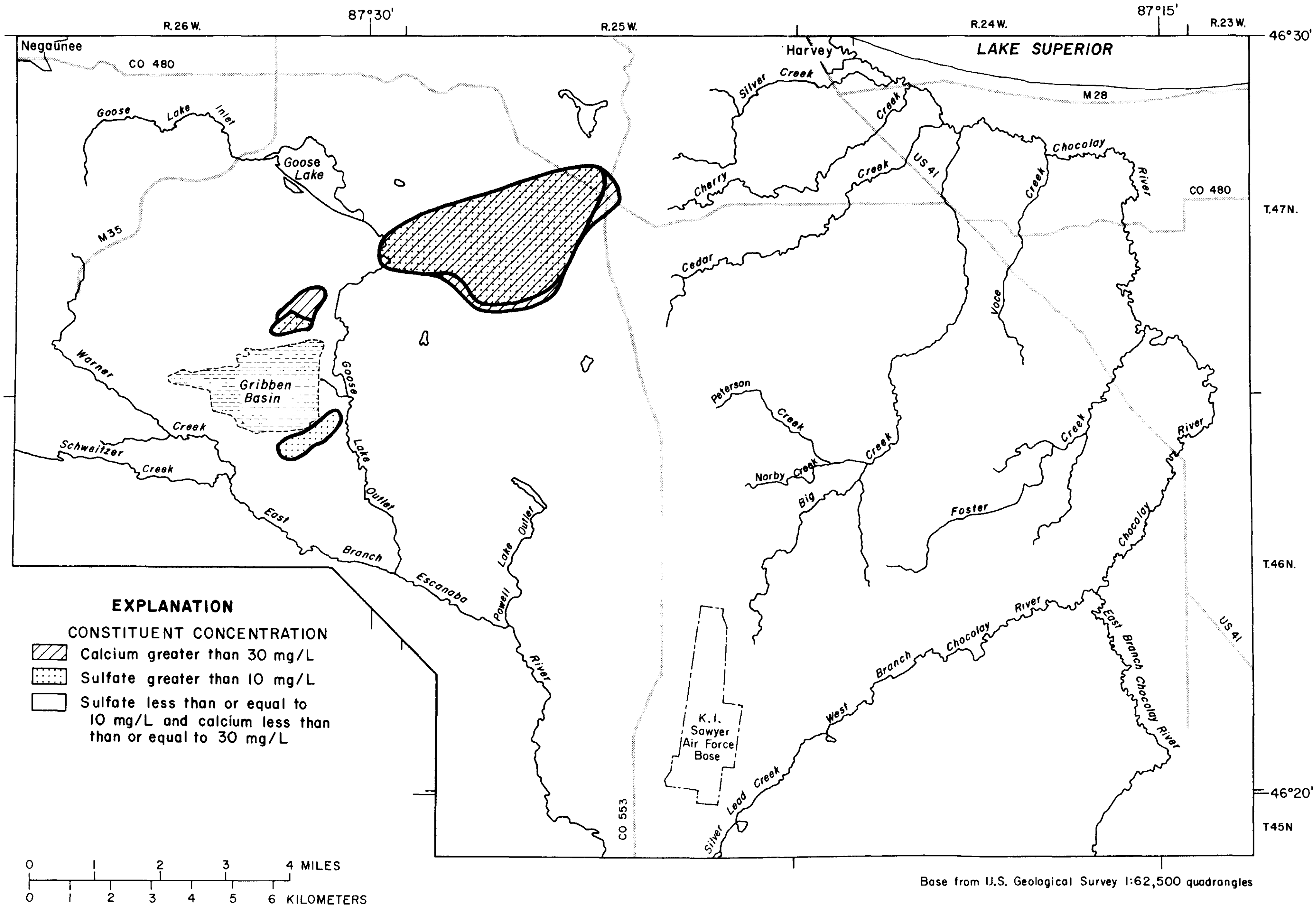
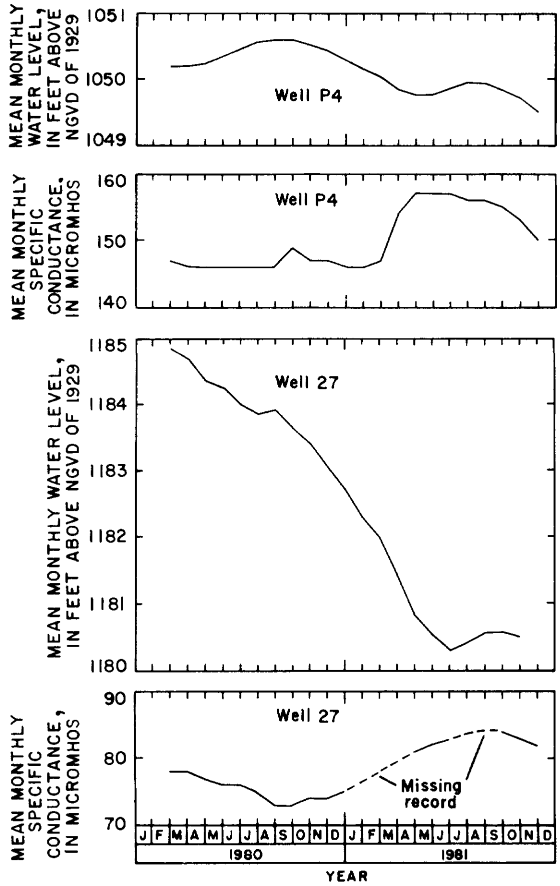


Figure 22.--Calcium and sulfate concentrations in water from glacial deposits.

Figure 23.--Relation of specific conductance and water levels in wells P4 and 27.



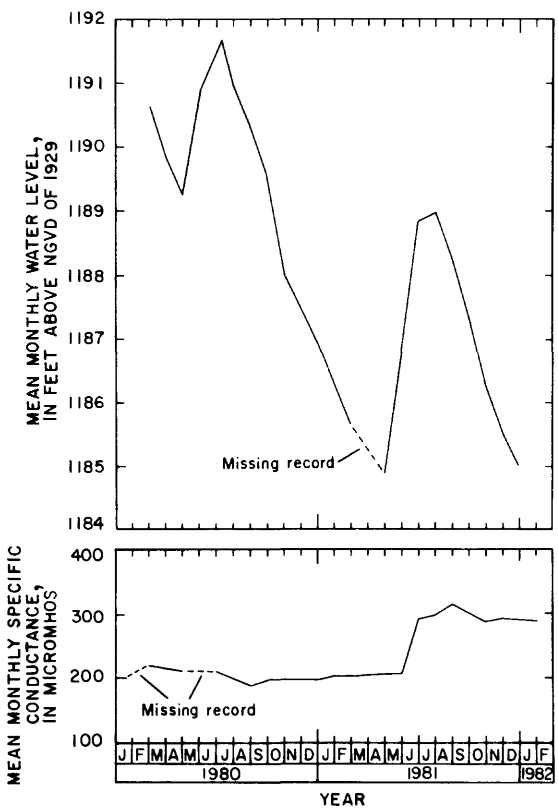


Figure 24.--Relation of specific conductance and water levels in well 19.

Specific conductance of water in well 19 varied about 100 μmhos during 1980-81 (fig. 24). There is an apparent correlation between rising water levels in April, May, and June 1981 and the rise in specific conductance. About one month after water levels began rising, specific conductance of the water in well 19 began rising. The rise in water level in the well was due to snowmelt, rainfall, and higher stages in Goose Lake Outlet. The rise in specific conductance was probably caused by increased inflow to the aquifer from Goose Lake Outlet, the stage of which was increasing during spring runoff.

Sparse water quality data is available from 11 shallow wells around Gribben Basin. The wells, with screened intervals ranging from 7 to 21 ft below land surface, were drilled in 1976 to monitor water levels and quality of ground water outside of the basin dikes. Dissolved-solids concentrations of water from these wells varied more than that from other parts of the study area (fig. 25). Specific conductance varied from less than 50 to 500 μmhos, and showed no consistent trend. Water from most of the wells had increased specific conductance during 1977. This could have been caused by disturbed surface conditions and dewatering during basin construction. Water from wells C4 and C7 showed only slight increases in specific conductance during 1977 but, during 1979-82, specific conductance increased by 360 and 260 μmhos in wells C4 and C7, respectively. There are several possible explanations for these increases, including the delayed effects of tailings-basin construction, the proximity of Goose Lake Outlet, and leakage from the tailings basin. Because these wells are in sand and gravel and have shallow depths to water, infiltrating precipitation or surface water reaches the water table rapidly and may change the chemical character of water in the wells. In November 1978, water stood 0 to 5 ft below land surface in the basin-perimeter wells.

Most dissolved substances in ground water were within the range typical of natural water (Cummings, 1980). Exceptions include iron, which was high in both dissolved and total forms in water from three wells (22, C3, and C7), all of which are screened near the water table. Phenol concentrations, which ranged from 0 to 80 μg/L, are higher than in most ground waters in Michigan. In an attempt to verify the natural occurrence of phenols, well 10 was resampled after pumping for 2 hours. The concentration was lower, but phenol was still present. Values of pH ranged from 4.9 to 9.1, both higher and lower than common in most natural ground waters.

Analyses of nitrogen and phosphorus in ground water are shown in table 18. Nitrate and organic nitrogen constitute more than 90 percent of the nitrogen in water. Based on all samples collected, the mean concentration of nitrate (0.15 mg/L) is about half that found in precipitation; total nitrogen also is about half. The mean concentration of total phosphorus (0.03 mg/L) in ground water, although low, was about three times the mean for precipitation.

Trace-metal analyses of water from 18 wells are given in table 19. Concentrations are low, and values for only three substances--gallium (50 μg/L), germanium (100 μg/L), and tin (100 μg/L)--exceed the maximum values found in a study of natural ground waters in Michigan (Cummings, 1980). Although the U.S. Environmental Protection Agency (1977a, 1977b) has not established drinking-water standards for all of the substances, none of the concentrations exceeded those that have been set.

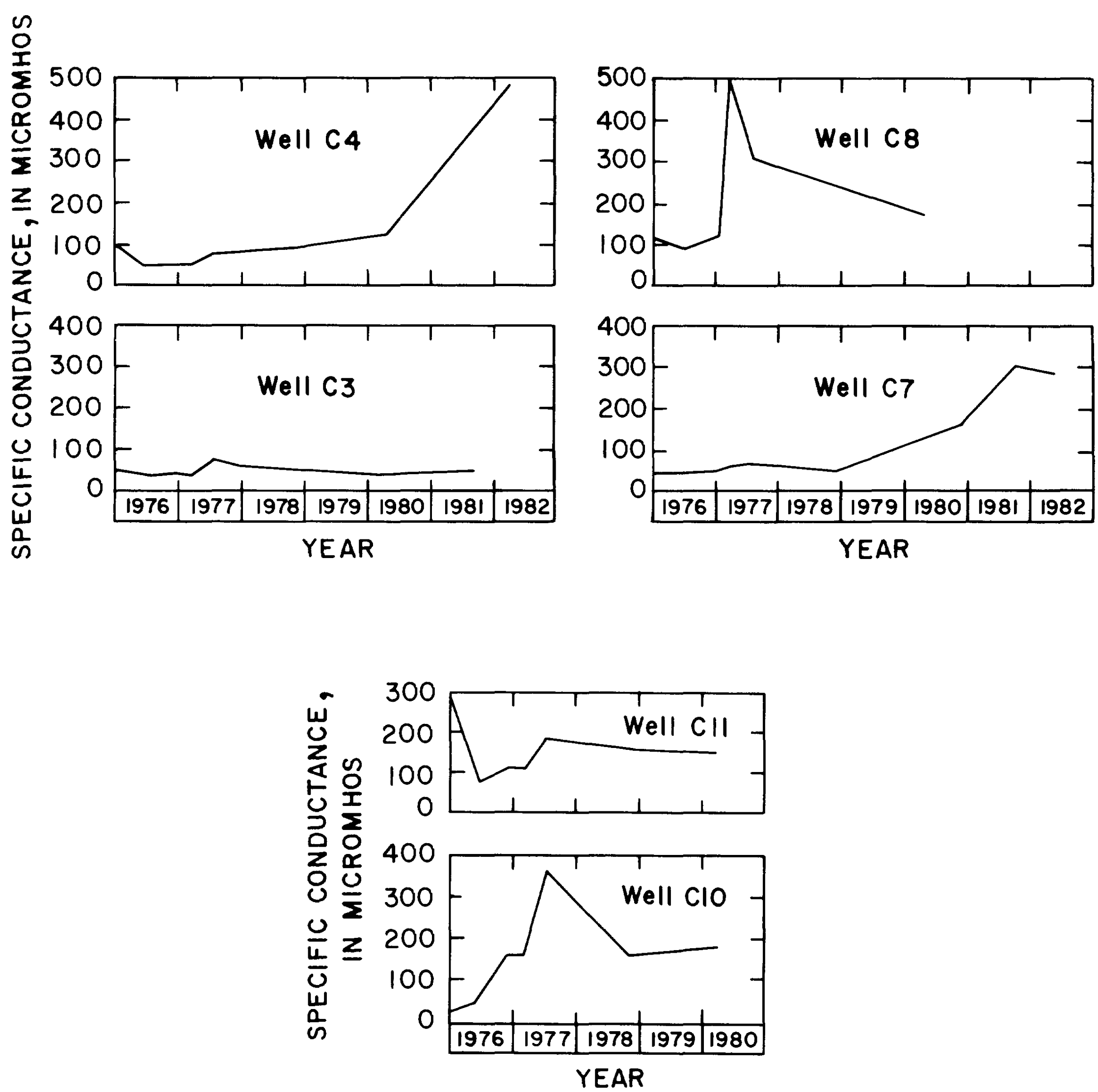


Figure 25.--Specific conductance of water from wells bounding Gribben Basin.

GROUND-WATER FLOW MODEL

Analysis of ground-water flow at Sands Plain was aided by a digital model that simulates the hydraulics of the aquifer-stream system. Ground-water flow directions, the potentiometric surface in the aquifer, ground-water flow to or from streams, and the effects of Gribben Basin as well as hypothetical tailings basins were simulated with the model. The digital model approximates a solution to the ground-water flow equation (a mathematical model) using boundaries and features of the aquifer-stream system as expressed in a conceptual model.

Conceptual Model

A conceptual model of the aquifer in Sands Plains area was developed by evaluating the hydrogeologic data described earlier in this report. It expresses, in general terms, the aquifer's boundaries, hydraulic properties, and stresses. The basic assumptions of the conceptual model are:

1. Ground-water flow principally occurs in the glacial deposits. This assumption is considered valid because the igneous and metamorphic rocks that subcrop in the area have poor properties for transmitting and storing water and the sandstones with good aquifer properties underlie only a small part of the study area.

2. No water flows into the aquifer through the igneous and metamorphic bedrock that forms the northwestern boundary of the aquifer. The remaining boundaries for the aquifer are hydrologic--to the northeast, Lake Superior; to the south and southeast, the Chocolay River or its tributaries; to the west and southwest, the Escanaba River or its tributaries. It is assumed that no water moves into the aquifer from outside of these surface-water boundaries.

3. The aquifer is assumed to consist of all of the glacial deposits including till, outwash, and transitional deposits. Although outwash has better aquifer properties than the other types of glacial deposits, it is unsaturated in some parts of the area, especially in the Outer Marquette Moraine, and therefore, is not a factor in horizontal water movement at some locations. Till and transitional deposits have significant permeability because of included sand and gravel lenses, because their predominant grain size is sandy silt, and because they have sufficient saturated thickness to conduct significant horizontal ground-water flow.

4. Ground-water flow in saturated glacial deposits is essentially horizontal and the aquifer is assumed to be isotropic. These assumptions are considered to be reasonably valid from available hydrogeologic information.

5. Most recharge to the aquifer is uniformly distributed. This assumption is considered valid because surface soils in the area are predominantly sand and gravel. Most of the area underlain by till at depth is mantled by some permeable sand and gravel (fig. 10). Recharge is greater in the northwestern part of the Sands Plain area because surface runoff from bedrock outcrops infiltrates the aquifer where it laps upon the bedrock. The aquifer is also recharged by leakage from Goose Lake Outlet.

6. Water levels in all streams are considered to be constant. This assumption is considered valid because the greatest measured difference in gage height at the four gaging stations on the Chocolay River tributaries is about 2 ft. At the gaging station on Goose Lake Outlet, the maximum gage height difference is about 4.5 ft. These differences are insignificant compared to a total head difference of about 600 ft between Goose Lake Outlet and Lake Superior.

7. Water will pond in tailings basins during operation and after they are abandoned. This assumption is considered valid because slurry is pumped into the basins during operation, and precipitation will collect in the basins after operations cease.

8. Pumpage in the study area consists of domestic water use (most of which is returned to the aquifer from septic tanks) which is assumed to be negligible, and some pumpage at K. I. Sawyer Air Force Base (about 1 ft^3/s). Only pumpage at the Air Force Base was incorporated in the model.

9. Most ground water is assumed to be discharged from the area by leakage to streams and lakes. The streams are tributary to East Branch Escanaba or Chocolay Rivers. Small amounts of ground water are discharged to Pelissier, Harvey, Strawberry, and Powell Lakes where it evaporates. Ground water is also discharged to Lake Superior.

10. Steady-state ground-water flow conditions were assumed to be reasonably approximated by average ground-water levels and stream discharge during the period of data collection. This assumption is considered valid because above-average precipitation in 1979 was mostly offset by below-average precipitation in 1980 and average precipitation in 1981. Average water levels during 1979-81 in wells SS, G, and ECJ are fairly representative of the average water levels in these wells from 1970-81 (figs. 14 and 15). Ground-water runoff did not vary significantly over the period of data collection and was only about 10 percent greater than low-flow measurements collected during drought conditions in 1964.

Although these assumptions do not always represent actual conditions in the aquifer-stream system, the deviations probably do not produce significant errors in the simulation process.

Mathematical Model

For a confined aquifer, the basic two-dimensional ground-water flow equation that is approximated in the model is:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \qquad (4)$$

where

T_{xx} and T_{yy} are the principal components of the transmissivity tensor (L^2/t)

h is hydraulic head (L)

S is the storage coefficient (dim)

t is time

x,y are the rectangular coordinates along the principal major and minor flow axes

W (x,y,t) is the volumetric flux of recharge or withdrawal per unit surface of the aquifer (L/t).

For flow in an unconfined aquifer, the ground-water flow equation is:

$$\frac{\partial}{\partial x} \left(K_{xx} b \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y} \left(K_{yy} b \frac{\partial h}{\partial y}\right) = S_y \frac{\partial h}{\partial t} + W(x,y,t) \qquad (5)$$

where

K_{xx} and K_{yy} are the principal components of the hydraulic conductivity tensor (L/t)

S_y is the specific yield of the aquifer (dim)

b is the saturated thickness (L).

Digital Model

The area simulated using the digital model (fig. 26) coincides with the hydrologic boundaries and not with the study area. The modeled area was divided into a grid consisting of 4,736 cells, each 1,000 ft on a side. The center of each cell is called a node. The computer program approximated a solution to equation 4 or 5 at each node. Numbers were assigned to each cell to define the boundaries and hydrologic properties of the aquifer in the cell by superimposing the grid over maps of bedrock altitude (fig. 5), glacial deposits (fig. 6), and topography (fig. 2). Ground-water flow to or from Silver, Cherry, Cedar, and Big Creeks, as well as East Branch Escanaba River and its tributaries, was simulated as moving through leaky confining streambeds. Harvey, Strawberry, Powell, and Pelissier Lakes and Gribben Basin were simulated as having leaky lakebeds. Water in the stream or lake is separated from the aquifer by a leaky confining layer representing material deposited in the streambed or lakebed. The grid cells representing the river or lake are approximately, but not exactly, in the same location as the bodies of water (fig. 26). Altitudes of the stream- or lake-water surface were determined by interpolating between contour lines on topographic maps whose contour interval is 20 ft. The vertical hydraulic conductivity of the confining layer was initially estimated to be one-tenth of the horizontal conductivity of the cell. Thickness of the layer was assumed to be 5 ft in the streams, 10 ft in the lakes, and either 25, 55, or 85 ft in the tailings basins. Because the area of the streambed is smaller than the cell representing it in the model, the streambed hydraulic conductivity was reduced proportionally.

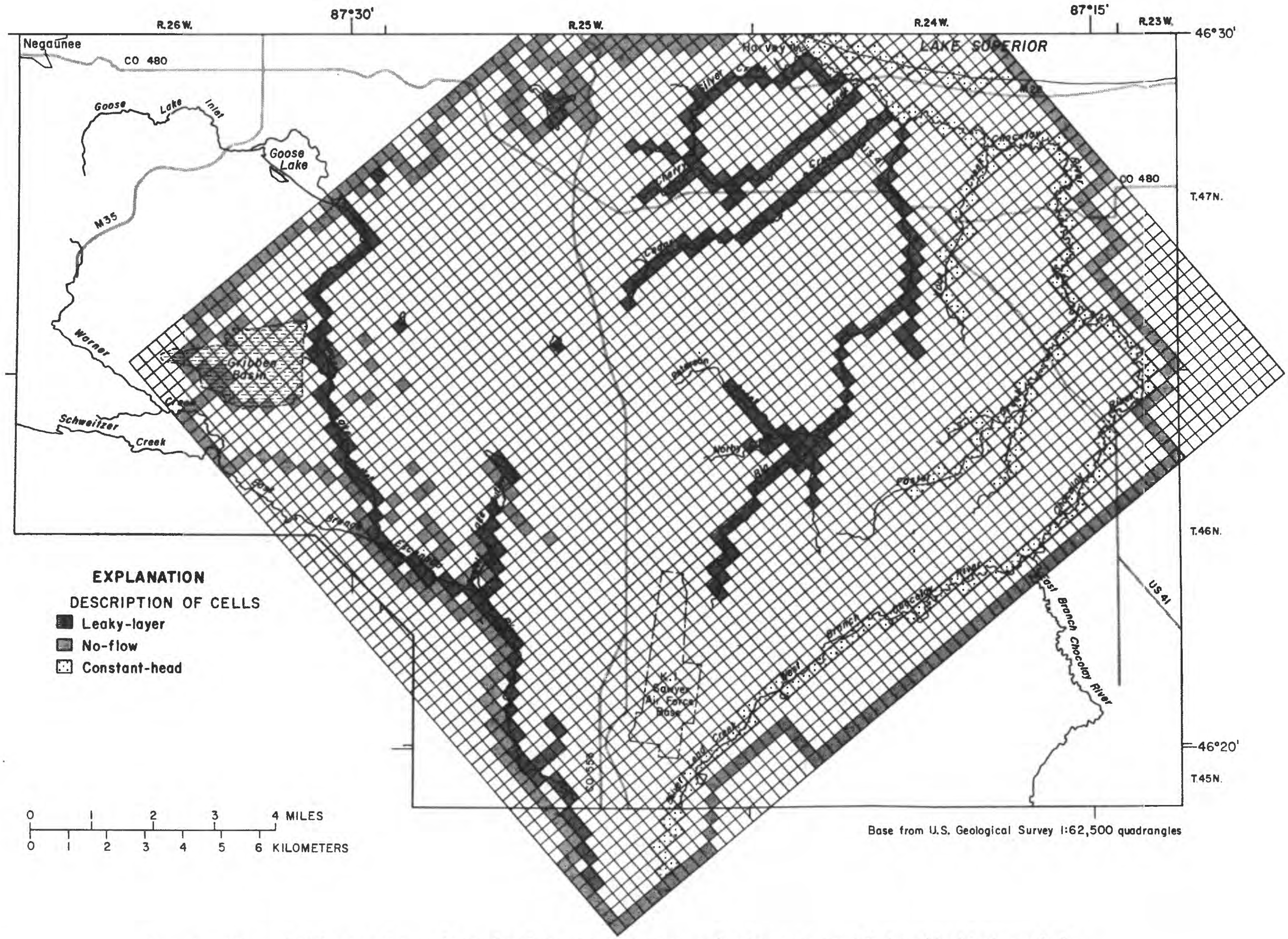


Figure 26.--Grid spacing, boundaries, and trace of streams used in digital model.

Silver Lead, Voce, and Foster Creeks, as well as the Chocolay River and Lake Superior were simulated as a series of constant head nodes. Altitudes of the water surface were determined by interpolating between contour lines on topographic maps.

Calibration

Before the ground-water flow model can be used reliably to simulate imposed stresses on the aquifer, the model must be calibrated--that is, it must be capable of simulating known hydrologic conditions. For example, before the model can be programmed to simulate tailings basins, it should be capable of simulating measured water levels and ground-water runoff. The calibration of the model consisted of comparing model output with field measurements of water levels in observation wells and discharge measurements of the area's streams. Calibration consisted of two phases, steady-state and transient.

Steady-state calibration.--A model that simulates steady-state hydrologic conditions assumes that, over a long period of time, water entering the system equals that being discharged and there is no change in the amount of ground water in storage. Model output consisted of head values in the aquifer and ground-water discharge to or from specified stream reaches. When the match between measured and simulated data was poor, estimates of the hydraulic conductivity of the aquifer were changed within plausible limits and simulations were continued until the match was considered satisfactory. Comparison of the simulated and average water levels in the observation wells are as follows:

Well number	Water level: Observed, average	Water level: Simulated (ft)	Well number	Water level: Observed, average	Water level: Simulated (ft)
1	638.2	643	22	1106.6	1110
2	967.7	967	23	1144.1	1142
3	820.4	817	25	1169.9	1171
5	957.8	961	26	1182.7	1180
6	953.3	960	27	1182.8	1186
7	1025.2	1024	28	1144.6	1140
8	1127.0	1128	29	1199.7	1200
10	1132.9	1130	30	1198.4	1196
11	1147.7	1143	31	1211.8	1214
12	1158.8	1160	33	1179.6	1183
13	1141.5	1142	34	1045.6	1053
14	994.2	999	P1	1038.0	1039
15	1061.6	1063	P2	1128.1	1124
17	1091.7	1088	P4	1049.9	1047
18	1147.5	1146	ECJ	1148.9	1149
19	1188.9	1185	G	1148.4	1142
20	1087.4	1090	SS	1164.5	1165
21	1107.4	1105			

Comparison of the simulated and estimated steady-state ground-water runoff are as follows:

Site number	Ground-water runoff Estimated (ft^3/s)	Simulated (ft^3/s)
7	29.0	29.3
11	12.8	13.0
16	19.2	19.1
22	9.2	9.2
33	11.0	10.4

In the early stages of calibration, the vertical hydraulic conductivity of the streambeds, the altitude of bedrock, and the interpolated values of stream altitude also were given minor adjustments. The range of horizontal hydraulic conductivity values in the calibrated model is 0.5 ft/d in parts of the moraines to 120 ft/d in outwash; the vertical hydraulic conductivity of the streambeds was 0.6 ft/d. The aquifer was recharged at a rate of 15 in./yr except near major bedrock outcrops as discussed previously. At these locations, recharge was increased proportionately to the area between the edge of the aquifer and the surface-water divide. Contours of the potentiometric surface from the steady-state calibration are shown on figure 27.

The calibrated steady-state model represents ground-water flow conditions prior to the construction of Gribben Basin, a tailings basin that covers 2.5 mi^2 west of Goose Lake Outlet. Although most of the water-level and streamflow data used for the calibration were collected after the Basin was constructed, it is believed that most of the wells are hydraulically separated from the Basin by Goose Lake Outlet. The operation of Gribben Basin is considered to affect only ground-water discharge to Goose Lake Outlet and not the Chocolay River tributaries. Analysis of streamflow data for Goose Lake Outlet was made for the period prior to basin construction.

A series of steady-state simulations were made to test the sensitivity of the model to recharge, hydraulic conductivity, and stream leakage. Increasing recharge from 15 to 18 in./yr caused total ground-water runoff at the gaging stations on the Chocolay River tributaries to increase from 70 to 80 ft^3/s. During this simulation, water levels in the observation wells rose 7 ft on the average. Increasing hydraulic conductivity of the aquifer by 25 percent increased the simulated ground-water runoff from 70 to 76 ft^3/s; while causing water levels in the observation wells to decline 8 ft on the average. Decreasing hydraulic conductivity of the aquifer by 25 percent decreased ground-water runoff from 70 to 64 ft^3/s; while causing water levels in the observation wells to rise 11 ft on the average. Increasing the vertical hydraulic conductivity of the streambeds by 25 percent caused ground-water runoff to increase by less than 0.5 ft^3/s and caused little change in water levels. These simulations indicate that the model is more sensitive to recharge and aquifer hydraulic conductivity than it is to the hydraulic properties of the streambeds. Because the estimated recharge is considered to be fairly accurate due to the high component of baseflow in the area's streams, it is believed that the calibration procedure (which primarily involved adjusting aquifer hydraulic conductivity values) is reasonably accurate.

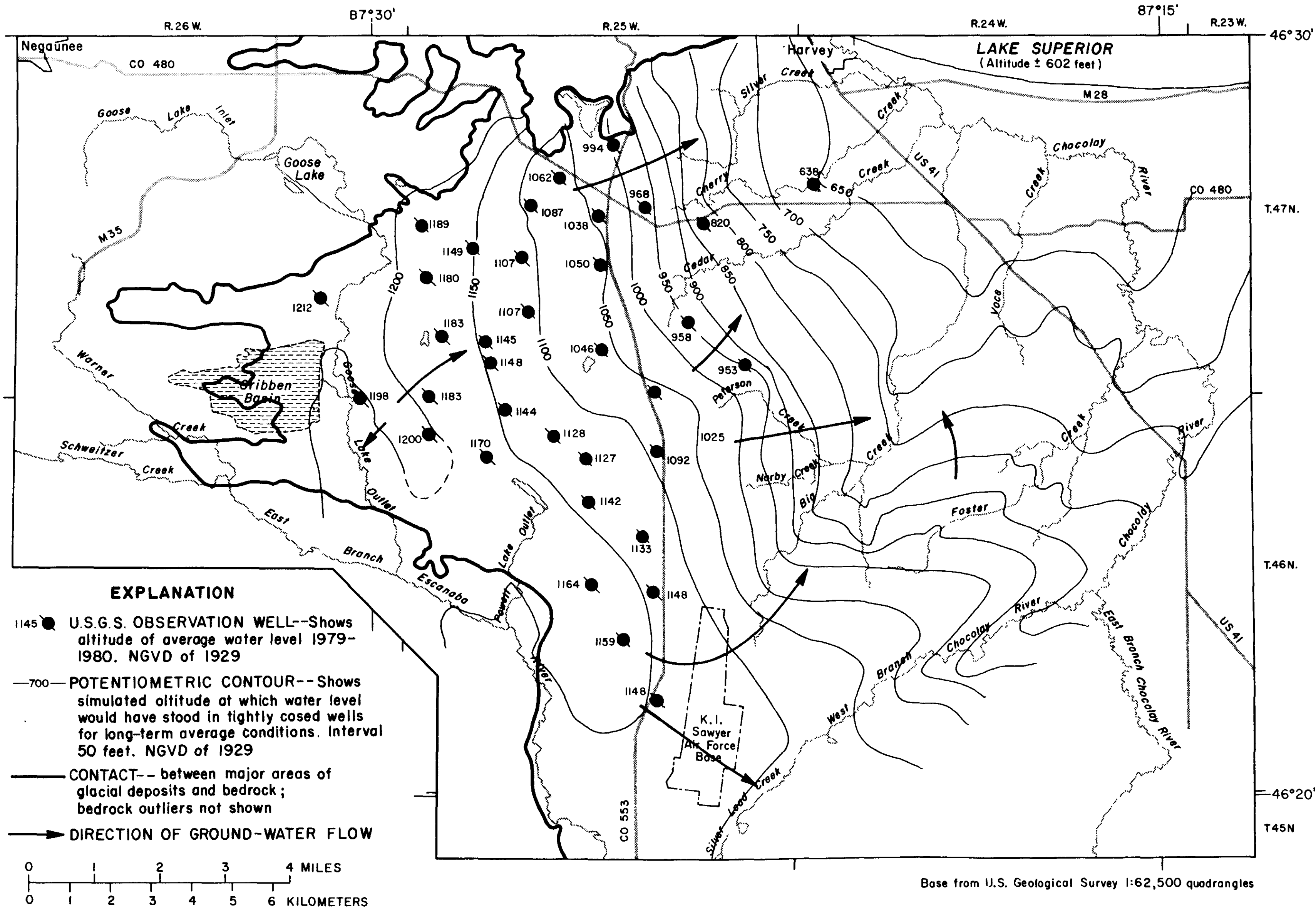


Figure 27.--Results of model simulation under steady-state conditions.

Transient Calibration.--Because steady-state conditions did not exist during the period of data collection, a transient model was developed to confirm that the steady-state model reasonably approximated ground-water flow in the Sands Plain area. The period October 1979 through September 1981 was used for transient calibration because recharge, water level, and streamflow data were most accurately known for this period (tables 8 and 9). The calibration period was broken into seven seasonal recharge periods based on grouping of monthly recharge estimates (table 9). Target ground-water levels were chosen at or near the end of each recharge period. Head values calculated by the steady-state model were used as the initial heads for the transient simulation. Because the hydrologic system was not at steady-state prior to beginning the transient simulation, the transient model did not approach the trend of the observed water levels as well in the first several recharge periods as it did in the later period (fig. 28). For example, calculated water levels in well 21 did not follow the trend of measured water levels during 1979-80 but more accurately followed them during 1981.

Because the aquifer is confined in a limited area beneath the Marquette moraines, the transient model was used to simulate the aquifer as confined beneath the moraines but unconfined away from them. A storage coefficient of 0.001 and a specific yield of 0.16 were used. The steady-state model simulated the entire aquifer as unconfined. The confined/unconfined model, when simulating a long enough period of time to approach steady-state, simulated water levels and ground-water runoff that were nearly identical to the steady-state model. Depending on initial conditions, steady-state ground-water flow was approached after simulating flow for about one year. Near the headwaters of Cherry Creek, minor adjustments in hydraulic conductivity in the transient model were made to improve the match between observed and simulated heads; the values were raised from 10 to 16 ft/d in 8 cells and from 50 to 100 ft/d in 8 cells. The increases in hydraulic conductivity were necessary to adjust for the decreased saturated thickness due to simulating the aquifer as confined. The transient model confirmed that the steady-state model, which simulated the entire aquifer as being unconfined, was a reasonably accurate description of ground-water flow in the Sands Plain area.

Predictive Simulations

Using the steady-state model, predictive simulations were made to determine the effects of continued operation of the present tailings basin and of several assumed operational conditions that might occur in the future. Such conditions could include the addition of several new tailings basins.

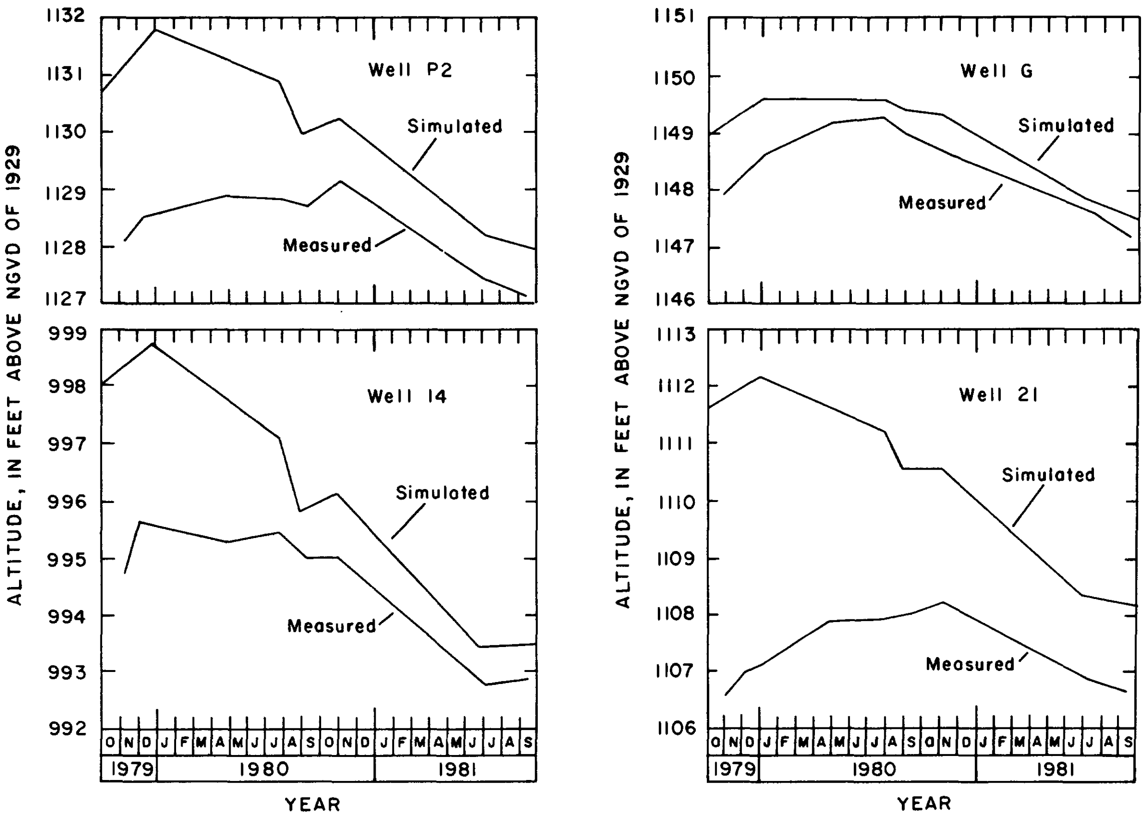


Figure 28.--Relation of measured and simulated water levels in wells 14, 21, G, and P2.

Gribben Basin Simulation

Gribben Basin was constructed during 1976-77 in the western part of the study area. The boundary of the Basin consists of a series of outcrops of Compeau Creek Gneiss that are connected by cement-bentonite slurry walls beneath the original ground surface and dikes with clay liners above the surface (fig. 29). The slurry walls are 2 ft thick and extend downward, in

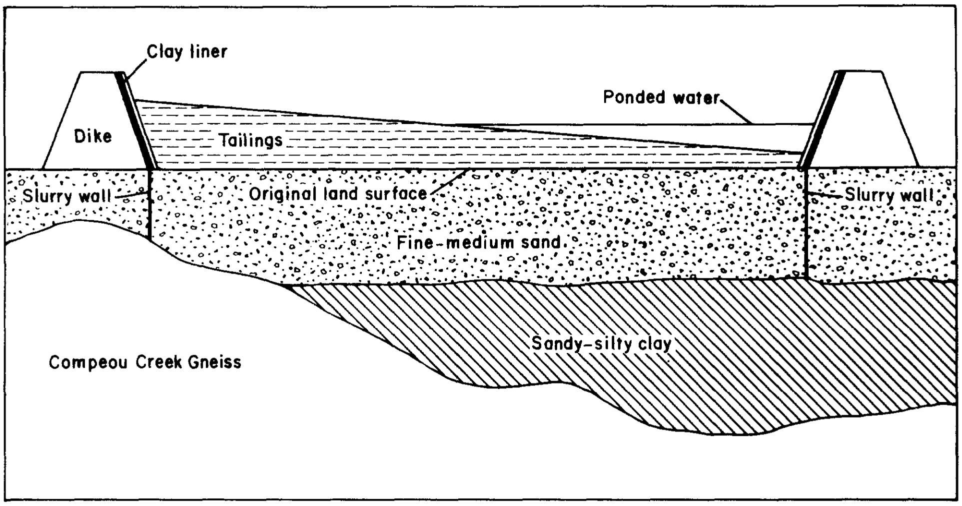


Figure 29.--Schematic diagram of section through Gribben Basin showing geologic conditions and construction characteristics. (Data provided by Cleveland-Cliffs Iron Co.)

some places as much as 80 ft, to a sandy, silty clay layer or to bedrock, whichever is shallower. Dikes extend above the slurry walls to an altitude of 1,270 ft. The basin covers an area of 2.5 mi^2 and can presently hold 2.6 x 10^9 ft^3 of tailings (60,000 acre-ft). Tailings began filling the basin in November 1977. The elevation of standing water in the basin is controlled by a drop-inlet type decanting system that carries water from the basin to a clarifier from which it is discharged to Goose Lake Outlet by an open channel. In 1979-80, an average of 10 ft^3/s was discharged.

The difference between the head of standing water in the basin and that of ground or surface water outside the basin indicates that water might flow out of the basin. However, the slurry wall; the sandy, silty clay layer; and the bedrock restricts this outward flow. Laboratory tests of undisturbed samples of the slurry wall material, collected six months after wall implacement, indicate that hydraulic conductivity of the cement-bentonite mixture ranges from 0.01 to 0.04 ft/d (Meier and Rettberg, 1978). Hydraulic conductivity of the sandy, silty clay layer is estimated to range from 0.01 to 9.4 ft/d (Harza Engineering Company, 1976). The sandy, silty clay layer averages 30 ft thick but varies from 0 at bedrock outcrops to 75 ft under the eastern boundary of the basin adjacent to Goose Lake Outlet (Harza Engineering Company, 1976).

Laboratory analyses of tailings from the Tilden Mine indicate that the hydraulic conductivity of the tailings ranges from 0.02 to 0.03 and averages 0.028 ft/d (Henry V. Greenwood, The Cleveland-Cliffs Iron Co., written communication). The boundary of Gribben Basin was simulated in the model by reducing the hydraulic conductivity of the cells used to represent the basin dikes; slurry walls; and sandy, silty clay layer. For example, the horizontal hydraulic conductivity of a cell that, prior to construction was defined as outwash, was reduced from 80 ft/d to either 0.01 or 1.0 ft/d. This range of hydraulic conductivity reasonably accounts for the uncertainty in the hydraulic properties of the dikes; slurry walls; and sandy, silty clay layer. Because the model represents ground-water flow in two dimensions, it was not possible to separate the hydrologic properties of the dikes; slurry walls; or sandy, silty clay layer in cells representing the basin boundary. Rather, the boundary was treated as one hydrologic unit with an average conductivity value. The values used for hydraulic conductivity were 0.01 and 1.0 ft/d. The value of 0.01 ft/d is probably too low for the sandy, silty clay unit; but may be reasonable for the slurry wall; 1.0 ft/d may be more reasonable for the sandy, silty clay unit but is two orders of magnitude higher than estimates of hydraulic conductivity for the slurry wall. Cells containing large bedrock outcrops were not altered from the calibrated model since they already were defined as no-flow cells. Tailings in the basin were considered to act as a confining layer with overlying ponded water.

Steady-state model simulations were used to determine the effects of Gribben Basin on ground-water flow. The model was run to determine the effects of a growing pile of tailings and, therefore, ponded water at higher altitudes. Simulations were made for three thicknesses of tailings that were considered to represent incremental increases in tailings thickness and ponded-water altitude. The third value is 5 ft less than the ultimate proposed dike altitude.

Analysis of the results indicates that construction and operation of Gribben Basin has only affected ground-water flow to Goose Lake Outlet and Warner Creek. Flow to Warner Creek increased slightly, whereas flow to Goose Lake Outlet decreased. Ground-water leakage from the basin, calculated by the model, ranged from 0.0 to 1.7 ft^3/s. Differences between estimated ground-water runoff, shown in table 20, are mostly due to differences in the calculated amount of leakage from the basin into the aquifer. The aquifer directly beneath the basin is now being recharged only by basin leakage. If the amount of leakage is low, the basin effectively reduces recharge. If basin leakage increases, recharge increases and the reduction in ground-water runoff is less. Additional study is necessary before accurate estimates of basin leakage can be made.

Simulations for Hypothetical Tailings Basins

As iron-ore mining from the Marquette Iron Range continues, it is likely that some parts of Sands Plain will be used for disposal of tailings. To assess the effects of increased tailings deposition on the hydrologic environment, model simulations were made by increasing the number of tailings basins. The

Table 20.--Estimated effects on ground-water runoff caused by operating Gribben Basin

Altitude of standing water in tailings basin, above NGVD of 1929 (ft)	Assumed average tailings thickness (ft)	Assumed horizontal hydraulic conductivity of basin boundaries[1] (ft/d)	Calculated by model		
			Ground-water discharge to streams (ft^3/s)		Total basin leakage (ft^3/s)
			Goose Lake Outlet	Warner Creek	
Prior to basin construction	--	--	10.4	1.8	--
1235	25	0.01	8.8	2.0	0.0
		1.0	9.5	2.0	.5
1265	55	.01	8.9	2.0	.02
		1.0	10.0	2.1	1.2
1295	85	.01	8.9	2.1	.03
		1.0	10.5	2.1	1.7

[1]Assumed vertical hydraulic conductivity of tailings, 0.028 ft/d.

additional hypothetical basins, and their locations, are assumed for the purpose of this study to be south and east of the existing basin (basins 2, 3, 4, and 5 on figure 30). The total area covered by the four assumed basins is about 11 mi^2. Model simulations were run for all basins using the same assumptions as for Gribben Basin. Gribben Basin and basins 2, 3, 4, and 5 were simulated by successively adding a new basin to the previous simulation. Recharge in all simulations was 15 in./yr. The aquifer beneath the basins was recharged only by leakage through the tailings. Simulations for basin 5 also were run without a slurry wall beneath the dikes. For these simulations, vertical hydraulic conductivity of the tailings was reduced from 0.028 to 0.001 ft/d to simulate additional bottom sealing. Results of the predictive simulations on ground-water flow to streams are presented in table 21. For comparison, ground-water flow to streams calculated by the model is also shown for a steady-state simulation without any tailings basins. Results of some of the Gribben Basin simulations are duplicated in tables 20 and 21 to put all similar data in one table. These results have been discussed in the previous section.

Hypothetical basin 2 covers about 2 mi^2 south of and adjacent to Gribben Basin. Simulated operation of basin 2 and Gribben Basin only affects ground-water flow to Warner Creek and Goose Lake Outlet. Ground-water runoff was 1.7 ft^3/s less when the basin boundaries were simulated with hydraulic conductivity equal to 0.01 ft/d than when the boundaries were simulated using 1.0 ft/d. The difference in ground-water runoff is primarily due to the amount of basin leakage.

Basin 3, also about 2 mi^2, would cover the area presently occupied by Harvey Lake. Operation of this basin, together with basin 2 and Gribben Basin, would affect ground-water flow to the four Chocolay River tributaries as well as Goose Lake Outlet and Warner Creek. Ground-water runoff was 2 ft^3/s less when the basin boundaries were simulated with a hydraulic conductivity of 0.01 ft/d than when they were simulated with 1.0 ft/d. The difference in ground-water runoff is due primarily to basin leakage.

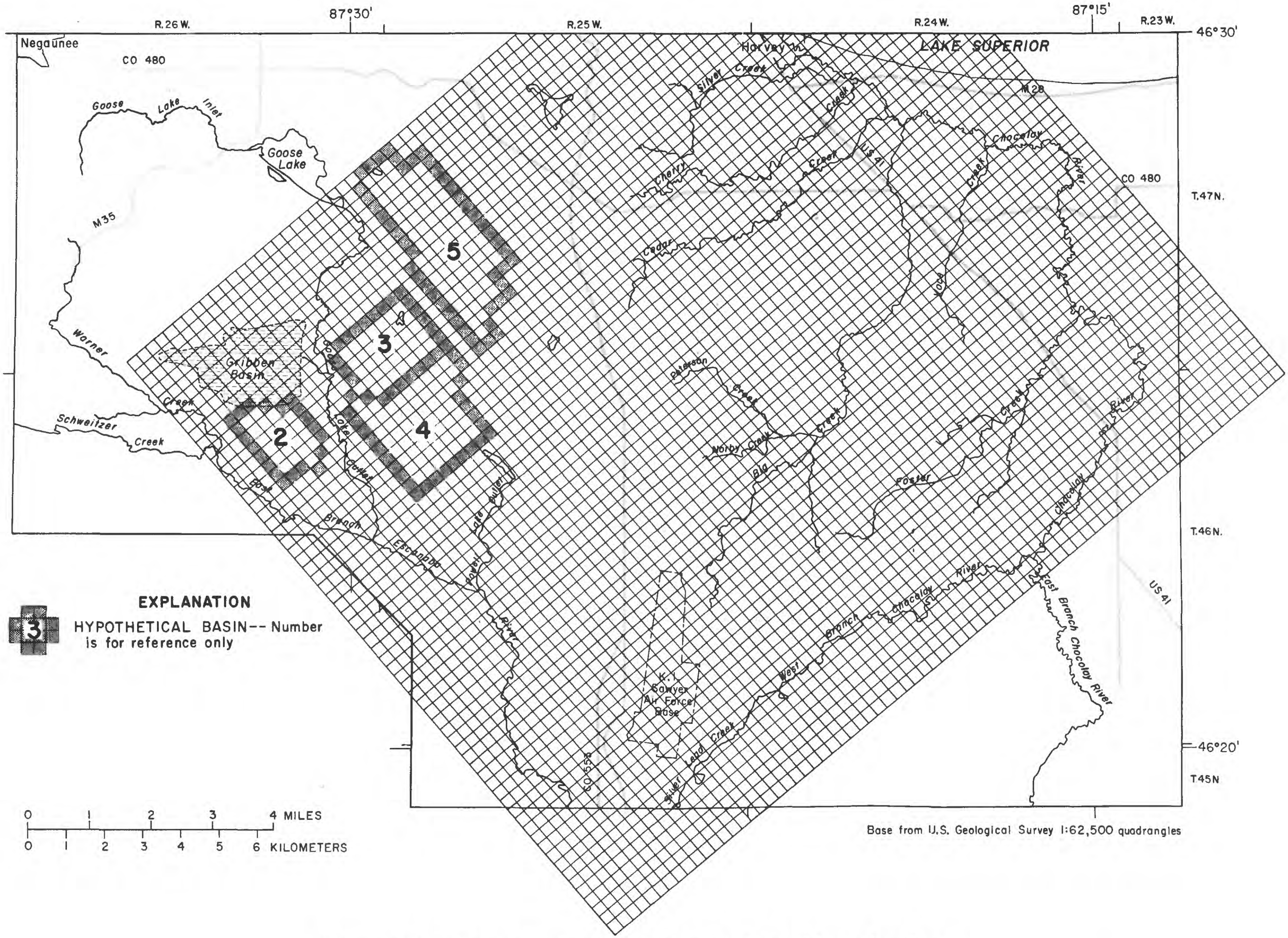


Figure 30.--Locations of hypothetical tailings basins.

Table 21.--Ground-water runoff calculated by computer model
[Steady-state conditions, altitude of standing water in the basins is 1265 ft above NGVD of 1929; tailings thickness is 55 ft for all simulations, vertical hydraulic conductivity of tailings is 0.028 ft/d]

Tailings basin being operated	Horizontal hydraulic conductivity of basin boundaries, assumed (ft/d)	Ground-water discharge to streams (ft^3/s)					
		Goose Lake Outlet	Warner Creek	Silver Creek	Cherry Creek	Cedar Creek	Big Creek
None	--	10.4	1.8	9.2	19.1	13.0	29.3
Gribben	0.01	8.9	2.0	9.2	19.1	13.0	29.3
	1.0	10.0	2.1	9.2	19.1	13.0	29.3
Gribben and basin 2	.01	7.9	1.2	9.2	19.1	13.0	29.3
	1.0	9.4	1.4	9.2	19.1	13.0	29.3
Gribben and basins 2 and 3	.01	7.9	1.2	8.9	18.9	12.0	29.2
	1.0	9.5	1.4	8.9	18.9	12.2	29.2
Gribben and basins 2, 3, and 4	.01	6.5	1.6	8.7	18.8	11.3	28.8
	1.0	9.0	1.7	8.8	18.8	11.6	28.9
Gribben and basins 2, 3, 4, and 5	.01	10.2	1.6	3.8	15.7	4.7	28.6
	1.0	13.4	1.7	6.5	17.4	9.1	28.9
	[a].01	6.4	1.6	8.8	18.6	11.3	28.8
	[a]1.0	9.0	1.7	8.8	18.8	11.7	28.9

[a]No slurry wall was simulated beneath the basin dikes of basin 5. Instead, the vertical hydraulic conductivity of the tailings was reduced to 0.001 ft/d to simulate bottom sealing.

Basin 4 covers about 3 mi^2 south of basin 3. Operation of basin 4, together with Gribben Basin and basins 2 and 3, caused ground-water flow to Goose Lake Outlet and Warner, Silver, Cherry, Cedar, and Big Creeks to be reduced in all simulations. Ground-water runoff was 3.1 ft^3/s less when the basin boundaries were simulated with a hydraulic conductivity of 0.01 ft/d than when they were simulated with 1.0 ft/d. Operation of these basins also would have an effect on the level of Strawberry Lake.

Basin 5 covers about 4 mi^2 between Goose Lake Outlet and county road 480. It overlies the buried bedrock valley associated with the Palmer fault. Simulated operation of basin 5, together with Gribben Basin and basins 2, 3, and 4 caused ground-water runoff in Silver and Cedar Creeks to be reduced by 30 to 60 percent. Depending on the hydraulic conductivity of the basin boundaries, flow to Goose Lake Outlet and Warner Creek increased or decreased. For example, with hydraulic conductivity set at 1.0 ft/d, ground-water runoff to Goose Lake Outlet was increased by 3.0 ft^3/s; for hydraulic conductivity set at 0.01 ft/d, ground-water runoff to Goose Lake Outlet was increased by 3.0 ft^3/s; for hydraulic conductivity set at 0.01 ft/d, flow was decreased by 0.2 ft^3/s.

Simulations were also made for basin 5 without slurry walls but with vertical hydraulic conductivity of the tailings set at 0.001 ft/d to represent bottom sealing. The other four basins were simulated as having slurry walls. Basin 5 was treated differently from the other basins because it is located between Goose Lake Outlet and the Chocolay River tributaries and over the thickest part of the aquifer. Constructing a slurry wall at the basin boundaries would significantly reduce the ability of the aquifer to transmit ground water. The slurry wall would cause the ground-water gradient to reverse between basin 5 and Goose Lake Outlet. This would change the upper reaches of Goose Lake Outlet from a losing to a gaining stream. Whether or not it is practical to seal the bottom of this and other basins rather than use slurry walls is beyond the scope of this study; but as shown by the last two simulations (table 21), it is a technique that could more closely maintain the present rates of streamflow. However, bottom seals may result in considerable leakage from the basins; leakage from basin 5 was about 3 ft^3/s when using 0.001 ft/d for vertical hydraulic conductivity of the tailings. A more complete evaluation of alternatives can be accomplished by using the ground-water model prepared for this study.

In general, predictive simulations indicate that construction and operation of new tailings basins in the Sands Plain area probably will produce a net reduction in ground-water flow to streams. The magnitude of these reductions will depend on engineering decisions about the method of basin construction and a better understanding of the hydraulic properties of the materials used to seal the basin perimeters. Under some conditions, ground-water flow to Warner Creek and Goose Lake Outlet will be increased by leakage from tailings basins.

The maximum total reduction of ground-water runoff due to construction and operation of 11 mi^2 of tailings basins would be about 18 ft^3/s and total basin leakage would be about 0.7 ft^3/s. However, if a bottom seal were used in basin 5, instead of a slurry wall, the total maximum reduction would be 7.5 ft^3/s. Total leakage from basin 5 would be 2.8 ft^3/s and from all basins about 3.0 ft^3/s.

The minimum total reduction of ground-water runoff due to the operation of all five basins would be 3.9 ft^3/s. Basin 5 would leak about 3.0 ft^3/s and leakage from all basins would be about 7 ft^3/s.

SUMMARY AND CONCLUSIONS

The Sands Plain study area consists of 225 mi^2, the central part of which is a relatively flat-lying sandy plain covering about 40 mi^2. Part of the plain is a potential site for future basins to dispose of iron-ore tailings.

Bedrock consists mostly of metamorphic and sedimentary rocks. Erosion of bedrock formed two major and at least two minor bedrock valleys that have been buried by glacial deposits. The thickest glacial deposits are located along the trace of the Palmer fault, a major northeast trending fault that weakened bedrock and increased its susceptibility to erosion.

Two major moraines and associated outwash plains were deposited during the last glacial advance. Lacustrine deposits from glacial lakes were deposited near Lake Superior. Glacial deposits are as much as 500 ft thick and constitute the main aquifer at Sands Plain.

Most ground water flows toward Lake Superior, discharging in a series of nearly parallel tributaries to the Chocolay River. Ninety five percent of the discharge of these streams is from ground-water inflow. The aquifer is also recharged by streamflow losses from the upper reaches of Goose Lake Outlet. Some ground water in the western part of the area flows to the East Branch Escanaba River and its tributaries.

Water levels during the period of study generally fell in wells near ground-water divides; rose and then fell in wells near the moraines; and had no general fluctuation pattern in wells near streams.

Precipitation, collected at two sites, had mean pH values of 4.0 and mean dissolved concentrations for sulfate and nitrate of 2.4 and 0.35 mg/L, respectively. Sulfate and total dissolved nitrogen were estimated to be deposited by precipitation at rates of 11.4 and 5.8 lb/acre/yr, respectively.

Quality of water data indicate that, of the Chocolay tributaries, Silver and Cherry Creeks have the highest dissolved-solids concentrations; Cedar Creek has the lowest. Calcium and bicarbonate were the principal dissolved substances at all sites. Dissolved solids ranged from 82 to 143 mg/L; sulfate ranged from 4.2 to 10 mg/L. Mean concentrations of total nitrogen in surface water (0.40 mg/L) do not differ significantly from the mean concentrations for ground water (0.38 mg/L), nor do trace-metal concentrations differ significantly. Water from four lakes in the area had dissolved-solids concentrations lower than water from streams and most ground water.

Highest dissolved-solids concentrations in water from wells in glacial deposits were found in a zone east of Goose Lake Outlet along the general trace of the Palmer fault. The higher concentrations were caused by streamflow losses to the aquifer in the upper reaches of Goose Lake Outlet and probably some inflow of ground water along the fault. Dissolved-solids concentrations in water from wells in glacial deposits ranged from 0.9 to 53 mg/L. Trace-metal concentrations in water from 19 wells were less than any established as standards for drinking water.

A two-dimensional digital model of ground-water flow was developed to simulate the hydraulics of the aquifer-stream system. The model was used to simulate water levels and ground-water runoff under both steady-state and transient conditions. Recharge for the steady-state model was 15 in./yr. Recharge for the transient simulations was varied seasonally. The specific yield was 0.16 where the aquifer is unconfined and the storage coefficient was 0.001 in a confined part of the aquifer beneath the moraines.

Predictive simulations using the steady-state model were run to determine the effects of continued operation of Gribben tailings basin and the operation of additional tailings basins. Model simulations indicate that operation of Gribben Basin has reduced steady-state ground-water flow to Goose Lake Outlet by 0.9 to 1.6 ft^3/s, compared to that calculated prior to basin construction. Ground-water flow to Warner Creek has slightly increased by 0.2 to 0.3 ft^3/s. Continued filling of Gribben Basin to its designed tailings capacity is expected to cause only a slight increase in leakage from the basin to Goose Lake Outlet. Only streamflow of Goose Lake Outlet and Warner Creek are affected by Gribben Basin operations.

Four hypothetical tailings basins were simulated using the steady-state model. The basins were simulated to cover a total area of 11 mi^2. A range of aquifer properties was used to approximate the basin boundaries. The model also was used to simulate one of the hypothetical basins without slurry walls but with more effective bottom sealing.

Depending on the location in the path of ground-water flow and the hydraulic properties assigned the basin boundaries, the basins would, in most simulations, reduce ground-water flow to streams. The reductions ranged from 0.2 to 4.0 ft^3/s in Goose Lake Outlet; 0.1 to 0.6 ft^3/s in Warner Creek; 0.0 to 5.4 ft^3/s in Silver Creek; 0.0 to 3.4 ft^3/s in Cherry Creek; 0.0 to 8.3 ft^3/s in Cedar Creek; and 0.0 to 0.7 ft^3/s in Big Creek. Results of two simulations indicate that operation of Gribben Basin has increased ground-water flow to Warner Creek by 0.2 to 0.3 ft^3/s. Simulated operation of a basin located over the Palmer fault valley indicates that slurry wall construction would increase ground-water flow to Goose Lake Outlet and reduce flow to the Chocolay River tributaries more than any of the other hypothetical basins. Based on assumed construction techniques, the maximum probable basin leakage from all five basins would be about 7 ft^3/s; the minimum probable leakage would be about 0.7 ft^3/s. Bottom sealing of the basin overlying the Palmer fault valley would more closely preserve the present rates of streamflow, but basin leakage would probably increase. As decisions are made concerning basin location, size, and construction technique, the model can be utilized to predict changes in ground-water flow to streams. The model also can be used to predict the hydrologic effects of other possible developments in the area.

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DEFINITION OF TERMS

Altitude. Vertical distance of a point or line above or below the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

Aquifer. A geologic 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. Also called a ground-water reservoir.

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

Bedrock. Designates consolidated rocks, commonly called "ledge".

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).

Confining bed. A body of relatively impermeable material stratigraphically adjacent to one or more aquifers.

Contour. An imaginary line connecting points of equal altitude, whether the points are on the land surface, on a formation surface, or on a potentiometric surface.

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

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 its water; a ground-water divide is a line on a potentiometric surface on each side of which the potentiometric surface slopes downward away from the line.

Dry fallout. Particulate matter transported by air circulation and deposited during periods when no condensed water is falling.

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

Fracture. A structural break or opening in bedrock.

Grain size. The classification range for the diameter of particles, in millimeters, is as follows:

Gravel	>2.0
Sand, very coarse	1.0 - 2.0
Sand, coarse	0.5 - 1.0
Sand, medium	0.25 - 0.5
Sand, fine	0.125 - 0.25
Sand, very fine	0.0625 - 0.125
Silt and clay	<0.0625

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

Ground-water discharge. The discharge of water from the saturated zone by 1) natural processes such as ground-water runoff and ground-water evapotranspiration and 2) artificial discharge through wells and other man-made structures.

Ground-water evapotranspiration. Ground water discharged into the atmosphere in the gaseous state either by direct evaporation or by the transpiration of plants.

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

Hardness of water. Commonly refers to concentration of $CaCO_3$. The classification range for hardness; in milligrams per liter (mg/L) of $CaCO_3$, is as follows:

Very Hard -- more than 180
Hard -- 121 to 180
Moderately hard -- 61 to 120
Soft -- 0 to 60

Head. The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

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.

Hydraulic gradient.--The change in static head per unit distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decrease in head.

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

Potentiometric surface. In aquifers, the levels to which water will rise in tightly cased wells.

Recharge. The process by which water is infiltrated and added to the zone of saturation. 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 was 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 micromhos (μmhos) per centimeter at 25°C. Because the specific conductance is related to amount and type of dissolved material, it can be 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 micromhos) is in the range 0.5 to 0.8.

Specific yield. The ratio of the volume of water which rock, after being saturated, will yield by gravity, to the volume of rock.

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. In an unconfined aquifer, the storage coefficient is equal to the specific yield.

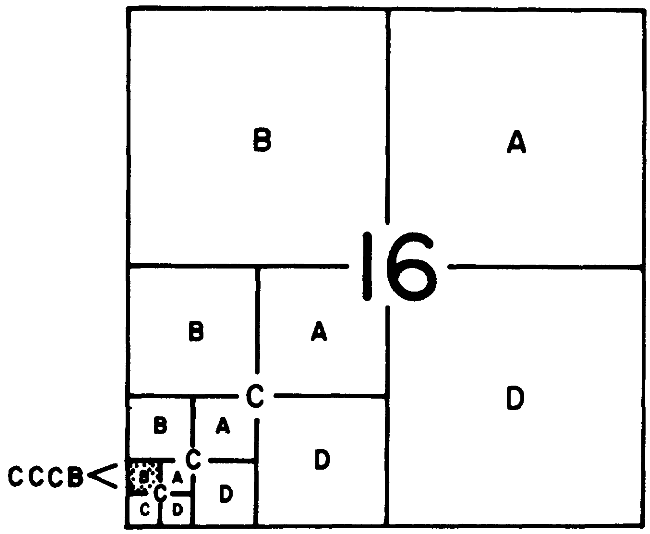
Subcrop. In this report, a bedrock formation or rock unit that directly underlies the glacial deposits and would be exposed if all glacial deposits were removed.

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. In general, the term refers to the ability of aquifer material to transmit water. It is equal to the product of hydraulic conductivity and aquifer thickness, and is expressed in units of length squared per unit time (L^2/t).

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 having shallow penetration into saturated materials.

LOCAL WELL NUMBERING SYSTEM

The local well number indicates the location of wells within the rectangular subdivision of land with reference to the Michigan meridian and base line. The first two segments of the well number designate township and range, the third segment of the number designates the section, and the letters A through D designate successively smaller subdivisions of the sections as shown below. Thus, a well designated as 45N25W16CCCB would be located within a 2.5 acre area, as indicated by the shaded area in section 16.



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TABLES

Table 13.--Chemical and physical characteristics of surface water
[Analyses by U.S. Geological Survey]

Date	Instantaneous discharge (ft³/s)	Specific conductance (µmhos)	Temperature (deg. C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Turbidity (NTU)	Color (platinum-cobalt units)	pH (units)	Iron, dissolved (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)
Site 1. Big Creek near Sands Station										
Oct. 17, 1979	9.8	164	7.0	11.2	94	1.0	10	7.9	50	160
July 15, 1980	10	175	14.0	9.6	96	1.0	6	8.0	50	230
July 14, 1981	9.2	171	11.0	10.4	96	--	--	8.1	20	--
Site 2. Peterson Creek near Sands Station										
Oct. 17, 1979	2.1	160	7.0	11.6	98	1.0	5	8.0	10	60
July 15, 1980	2.1	170	9.0	10.8	96	--	--	7.9	10	--
July 14, 1981	2.0	177	8.0	11.3	99	--	--	7.7	180	--
Site 3. Norby Creek near Sands										
Oct. 17, 1979	0.16	142	7.0	11.2	94	--	--	7.9	30	--
Site 5. Big Creek near Sands										
Oct. 18, 1979	15	172	4.0	12.1	95	--	--	8.0	50	--
July 16, 1980	16	175	12.0	9.6	91	--	--	7.8	40	--
July 15, 1981	16	174	9.0	10.3	91	--	--	7.9	10	--
Site 7. Big Creek near Harvey										
Oct. 17, 1979	30	168	7.5	11.0	93	1.0	5	7.9	30	120
July 16, 1980	27	180	11.0	9.7	90	.75	2	7.9	20	170
July 15, 1981	28	171	9.0	11.0	97	--	--	8.1	<10	--
Site 8. Big Creek near Beaver Grove										
Oct. 18, 1979	41	162	5.5	11.6	94	--	--	7.7	30	--
July 16, 1980	38	187	11.5	10.2	94	--	--	7.9	--	--
Site 9. Cedar Creek near Sands										
Oct. 17, 1979	0.30	150	7.0	10.6	90	1.0	5	8.0	10	60
July 15, 1980	.21	137	8.0	10.6	93	.30	2	7.9	0	90
Site 10. Cedar Creek near Gentian										
Oct. 18, 1979	11	148	5.0	11.9	96	--	--	8.0	10	--
July 15, 1980	8.3	152	9.0	10.7	95	--	--	7.8	180	--
July 14, 1981	10	149	9.5	10.8	96	--	--	8.0	<10	--
Site 11. Cedar Creek near Harvey										
Oct. 17, 1979	13	145	7.0	11.2	94	1.0	5	7.8	10	80
July 15, 1980	13	158	10.0	10.1	92	.45	0	7.8	10	140
July 14, 1981	12	146	9.0	11.0	97	--	--	7.7	<10	--
Site 12.--Cedar Creek near Beaver Grove										
Oct. 18, 1979	19	135	4.0	11.8	91	--	--	7.7	20	--
July 16, 1980	18	152	10.0	11.0	100	--	--	7.9	--	--

Table 13.--Chemical and physical characteristics of surface water--continued

Date	Instantaneous discharge (ft³/s)	Specific conductance (µmhos)	Temperature (deg. C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Turbidity (NTU)	Color (platinum-cobalt units)	pH (units)	Iron, dissolved (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)
Site 13. Cherry Creek near Cascade										
Oct. 17, 1979	0.02	115	6.5	8.1	68	4.0	50	7.3	130	2,100
July 15, 1980	.02	159	13.0	6.3	62	--	--	7.2	100	--
Site 14. Cherry Creek near Sands										
July 15, 1980	5.3	216	8.0	9.9	87	.40	1	8.0	--	110
July 14, 1981	5.6	222	8.0	10.7	93	--	--	7.7	<10	--
Site 15. Cherry Creek near Gentian										
Oct. 17, 1979	11	220	7.5	11.0	93	--	--	8.0	20	--
July 15, 1980	9.8	219	9.0	10.5	93	--	--	7.7	70	--
July 15, 1981	9.7	211	7.0	10.4	88	--	--	8.0	<10	--
Site 16. Cherry Creek near Harvey										
Oct. 17, 1979	20	188	7.0	11.0	92	1.0	5	7.9	10	80
July 15, 1980	18	195	10.5	10.4	95	.25	1	7.9	0	140
July 15, 1981	19	198	8.0	11.2	97	--	--	8.0	<10	--
Site 17. Cherry Creek near Beaver Grove										
Oct. 18, 1979	27	188	5.0	11.4	90	--	--	8.0	10	--
July 16, 1980	25	192	9.0	10.4	92	--	--	7.9	--	--
July 15, 1981	25	192	9.0	11.2	98	--	--	8.0	<10	--
Site 18. Silver Creek near Cascade										
Oct. 17, 1979	3.2	193	7.0	11.3	95	1.0	5	8.0	10	90
July 15, 1980	3.1	204	10.0	10.6	97	.65	1	7.9	--	170
July 14, 1981	3.2	198	8.0	11.4	99	--	--	8.1	<10	--
Site 20. Silver Creek near Sands										
Oct. 17, 1979	2.5	195	7.5	11.5	97	--	--	8.0	20	--
July 15, 1980	2.4	209	11.0	10.4	96	--	--	7.9	70	--
July 14, 1981	2.1	200	9.0	10.8	96	--	--	8.1	<10	--
Site 21. Unnamed tributary to Silver Creek near Harvey										
Oct. 17, 1979	0.06	222	7.5	8.5	72	--	--	7.6	30	--
July 15, 1980	.02	214	11.5	7.5	70	--	--	7.3	140	--
Site 22. Silver Creek at Harvey										
Oct. 17, 1979	9.7	207	7.5	11.0	92	1.0	10	7.9	50	110
July 15, 1980	8.9	216	11.0	9.8	91	.80	1	8.0	10	170
July 15, 1981	8.8	222	8.0	11.2	97	--	--	8.0	<10	--
Site 23. Silver Creek near Harvey										
Oct. 17, 1979	9.8	218	7.5	11.3	96	--	--	8.0	30	--
July 15, 1980	8.5	224	13.0	10.0	97	--	--	7.9	--	--

Table 13.--Chemical and physical characteristics of surface water--continued

Date	Manganese, dissolved (μg/L as Mn)	Manganese, total recoverable (μg/L as Mn)	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)	Bicarbonate, field (mg/L as HCO_3)	Carbonate, field (mg/L as CO_3)	Chloride, dissolved (mg/L as Cl)
Site 1. Big Creek near Sands Station										
Oct. 17, 1979	5	10	9.7	26	4.7	1.1	.7	94	0	2.0
July 15, 1980	6	10	9.5	26	4.8	1.3	.6	100	0	1.2
July 14, 1981	2	--	--	27	5.2	1.5	.6	100	0	1.6
Site 2. Peterson Creek near Sands Station										
Oct. 17, 1979	1	0	10	26	4.5	1.1	.7	88	0	2.3
July 15, 1980	1	--	--	25	4.6	1.3	.6	96	0	1.8
July 14, 1981	<1	--	--	26	4.7	1.2	.6	90	0	2.2
Site 3. Norby Creek near Sands										
Oct. 17, 1979	4	--	--	23	3.8	1.0	.8	76	0	.8
Site 5. Big Creek near Sands										
Oct. 17, 1979	0	--	--	26	5.0	1.4	.7	92	0	1.7
July 16, 1980	2	--	--	26	5.0	1.3	.7	100	0	1.3
July 15, 1981	<1	--	--	26	5.2	1.4	.7	90	0	1.2
Site 7. Big Creek near Harvey										
Oct. 17, 1979	1	10	11	26	5.3	1.4	.8	98	0	1.0
July 16, 1980	3	10	10	25	5.5	1.5	.7	100	0	1.1
July 15, 1981	<1	--	--	26	5.7	1.7	.7	92	0	.9
Site 8. Big Creek near Beaver Grove										
Oct. 18, 1979	1	--	--	26	5.6	1.6	.8	100	0	1.7
July 16, 1980	--	--	--	--	--	--	--	110	0	--
Site 9. Cedar Creek near Sands										
Oct. 17, 1979	0	0	7.4	18	3.3	5.6	.7	66	0	11
July 15, 1980	1	10	7.4	18	3.4	5.9	.7	66	0	11
Site 10. Cedar Creek near Gentian										
Oct. 18, 1979	0	--	--	22	4.4	1.9	.6	82	0	3.3
July 15, 1980	10	--	--	21	4.5	2.1	.6	86	0	3.3
July 14, 1981	<1	--	--	21	4.4	2.2	.6	80	0	3.2
Site 11. Cedar Creek near Harvey										
Oct. 17, 1979	0	10	9.5	22	4.4	1.7	.6	87	0	2.1
July 15, 1980	2	10	8.9	21	4.5	1.8	.6	92	0	2.3
July 14, 1981	<1	--	--	21	4.6	2.0	.6	86	0	2.4
Site 12. Cedar Creek near Beaver Grove										
Oct. 18, 1979	2	--	--	21	4.5	1.8	.7	86	0	2.3
July 16, 1980	--	--	--	--	--	--	--	88	0	--

Table 13.--Chemical and physical characteristics of surface water--continued

Date	Manganese, dissolved (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	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)	Bicarbonate, field (mg/L as HCO_3)	Carbonate, field (mg/L as CO_3)	Chloride, dissolved (mg/L as Cl)
Site 13. Cherry Creek near Cascade										
Oct. 17, 1979	6	250	8.7	18	3.2	3.3	.5	62	0	8.3
July 15, 1980	20	--	--	21	3.8	4.1	.6	80	0	7.6
Site 14. Cherry Creek near Sands										
July 15, 1980	--	30	--	--	--	--	.7	120	0	6.3
July 14, 1981	1	--	--	31	6.8	3.5	.7	110	0	6.2
Site 15. Cherry Creek near Gentian										
Oct. 17, 1979	7	--	--	31	6.4	2.6	.7	110	0	5.6
July 15, 1980	5	--	--	29	6.5	2.8	.7	120	0	5.8
July 15, 1981	<1	--	--	30	6.8	3.3	.7	110	0	5.7
Site 16. Cherry Creek near Harvey										
Oct. 17, 1979	1	10	10	28	5.9	2.3	.7	110	0	4.6
July 15, 1980	2	20	10	28	6.1	2.4	.7	120	0	3.9
July 15, 1981	2	--	--	28	6.1	2.5	.7	110	0	3.8
Site 17. Cherry Creek near Beaver Grove										
Oct. 18, 1979	4	--	--	27	5.6	2.4	.8	110	0	4.2
July 16, 1980	--	--	--	--	--	--	.8	110	0	4.0
July 15, 1981	4	--	--	27	6.2	3.5	.8	110	0	3.9
Site 18. Silver Creek near Cascade										
Oct. 17, 1979	0	0	9.4	30	6.3	1.2	.6	120	0	3.3
July 15, 1980	4	10	8.9	28	--	1.3	.5	120	0	3.1
July 14, 1981	<1	--	--	30	6.7	1.5	.6	120	0	3.3
Site 20. Silver Creek near Sands										
Oct. 17, 1979	3	--	--	30	6.0	1.2	.6	110	0	2.8
July 15, 1980	7	--	--	29	6.2	1.2	.6	120	0	3.5
July 14, 1981	<1	--	--	30	6.6	1.4	.6	120	0	3.2
Site 21. Unnamed tributary to Silver Creek near Harvey										
Oct. 17, 1979	10	--	--	34	6.1	1.2	.8	120	0	3.0
July 15, 1980	70	--	--	30	5.5	1.2	1.1	120	0	3.5
Site 22. Silver Creek at Harvey										
Oct. 17, 1979	1	0	10	33	7.1	1.4	.7	130	0	2.7
July 15, 1980	2	20	9.7	31	7.0	1.4	.7	140	0	2.9
July 15, 1981	1	--	--	32	7.5	1.6	.7	130	0	2.9
Site 23. Silver Creek near Harvey										
Oct. 17, 1979	1	--	--	32	6.9	1.4	.8	130	0	3.0
July 15, 1980	--	--	--	--	--	--	--	130	0	--

Table 13.--Chemical and physical characteristics of surface water--continued

Date	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180 dig. C dissolved (mg/L	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Carbon, organic dissolved (mg/L as C)	Cyanide total (mg/L as Cn)	Phenols (µg/L)
Site 1. Big Creek near Sands Station									
Oct. 17, 1979	7.5	.0	98	106	84	7	5.5	.00	0
July 15, 1980	5.6	.1	99	107	85	3	3.7	.00	0
July 14, 1981	5.9	--	--	106	89	7	--	--	--
Site 2. Peterson Creek near Sands Station									
Oct. 17, 1979	8.1	.1	96	108	84	11	3.6	.00	0
July 15, 1980	6.7	--	--	106	81	3	--	--	--
July 14, 1981	7.2	--	--	100	84	10	--	--	--
Site 3. Norby Creek near Sands									
Oct. 17, 1979	7.8	--	--	87	73	11	--	--	--
Site 5. Big Creek near Sands									
Oct. 18, 1979	7.0	--	--	119	86	10	--	--	--
July 16, 1980	5.8	--	--	113	86	4	--	--	--
July 15, 1981	5.5	--	--	104	86	12	--	--	--
Site 7. Big Creek near Harvey									
Oct. 17, 1979	6.7	.1	101	110	87	6	2.4	.00	0
July 16, 1980	5.5	.1	99	112	85	3	7.2	.00	0
July 15, 1981	5.4	--	--	101	88	13	--	--	--
Site 8. Big Creek near Beaver Grove									
Oct. 18, 1979	6.3	--	--	115	88	6	--	--	--
July 16, 1980	--	--	--	--	--	--	--	--	--
Site 9. Cedar Creek near Sands									
Oct. 17, 1979	5.7	.1	85	83	59	4	3.8	.00	0
July 15, 1980	4.5	.0	84	92	59	5	2.5	.00	0
Site 10. Cedar Creek near Gentian									
Oct. 18, 1979	5.7	--	--	96	73	6	--	--	--
July 15, 1980	5.2	--	--	95	71	0	--	--	--
July 14, 1981	4.3	--	--	93	71	5	--	--	--
Site 11. Cedar Creek near Harvey									
Oct. 17, 1979	5.4	.1	89	92	73	2	3.6	.00	0
July 15, 1980	4.2	.1	89	97	71	0	4.3	.00	0
July 14, 1981	4.2	--	--	90	71	0	--	--	--
Site 12. Cedar Creek near Beaver Grove									
Oct. 18, 1979	5.4	--	--	82	71	0	--	--	--
July 16, 1980	--	--	--	--	--	--	--	--	--

Table 13.--Chemical and physical characteristics of surface water--continued

Date	Sulfate, dis- solved (mg/L as SO_4)	Fluo- ride, dis- solved (mg/L as F)	Solids, sum of consti- tuents, dis- solved (mg/L)	Solids, residue at 180 dig. C dis- solved (mg/L	Hard- ness (mg/L as $CaCO_3$)	Hard- ness, noncar- bonate (mg/L $CaCO_3$)	Carbon, organic dis- solved (mg/L as C)	Cyanide, total (mg/L as Cn)	Phenols (µg/L)
Site 13. Cherry Creek near Cascade									
Oct. 17, 1979	5.3	.0	78	94	58	7	11	.00	0
July 15, 1980	5.2	--	--	110	68	3	--	--	--
Site 14. Cherry Creek near Sands									
July 15, 1980	9.0	.1	75	143	--	--	3.4	.00	0
July 14, 1981	10	--	--	125	110	20	--	--	--
Site 15. Cherry Creek near Gentian									
Oct. 17, 1979	9.8	--	--	122	100	10	--	--	--
July 15, 1980	8.5	--	--	138	99	1	--	--	--
July 15, 1981	8.9	--	--	126	100	10	--	--	--
Site 16. Cherry Creek near Harvey									
Oct. 17, 1979	8.7	.1	115	123	94	4	3.8	.00	0
July 15, 1980	6.9	.1	117	120	95	0	3.0	.00	0
July 15, 1981	7.4	--	--	107	95	5	--	--	--
Site 17. Cherry Creek near Beaver Grove									
Oct. 18, 1979	7.5	--	--	108	91	1	--	--	--
July 16, 1980	6.1	--	--	126	--	--	--	--	--
July 15, 1981	6.4	--	--	105	93	3	--	--	--
Site 18. Silver Creek near Cascade									
Oct. 17, 1979	6.1	.1	116	120	100	2	3.0	.00	0
July 15, 1980	4.8	.1	68	127	--	--	5.3	--	0
July 14, 1981	4.8	--	--	117	100	2	--	--	--
Site 20. Silver Creek near Sands									
Oct. 17, 1979	6.0	--	--	109	100	10	--	--	--
July 15, 1980	5.2	--	--	128	98	0	--	--	--
July 14, 1981	4.5	--	--	116	100	2	--	--	--
Site 21. Unnamed tributary to Silver Creek near Harvey									
Oct. 17, 1979	9.9	--	--	124	110	12	--	--	--
July 15, 1980	8.6	--	--	135	98	0	--	--	--
Site 21. Silver Creek at Harvey									
Oct. 17, 1979	6.8	.0	126	129	110	3	7.9	.00	0
July 15, 1980	5.4	.1	127	138	110	0	9.2	--	0
July 15, 1981	5.5	--	--	124	110	3	--	--	--
Site 23. Silver Creek near Harvey									
Oct. 17, 1979	7.1	--	--	124	110	3	--	--	--
July 15, 1980	--	--	--	--	--	--	--	--	--

Table 14.--Nitrogen and phosphorus in surface water
[Analyses by U.S. Geological Survey; results in milligrams per liter; nitrogen values are reported as N; phosphorus values are reported as P]

Date of Sample	Nitrogen, total	Nitrogen, ammonia, total	Nitrogen, nitrite, total	Nitrogen, nitrate, total	Nitrogen, organic, total	Phosphorus, total	Phosphorus, ortho, total
Site 1. Big Creek near Sands Station							
Oct. 17, 1979	0.69	0.02	0.02	0.42	0.23	0.01	0.01
July 15, 1980	.53	.02	.01	.45	.05	.01	.00
July 14, 1981	--	.01	<.01	.50	--	<.01	<.01
Site 2. Peterson Creek near Sands Station							
Oct. 17, 1979	.60	.03	.01	.58	.00	.01	.01
July 15, 1980	--	.00	.00	.59	--	.01	.01
July 14, 1981	--	.01	<.01	.55	--	.01	.01
Site 3. Norby Creek near Sands							
Oct. 17, 1979	--	.02	.00	.29	--	.01	.01
Site 5. Big Creek near Sands							
Oct. 18, 1979	--	.03	.01	.42	--	.01	.01
July 16, 1980	--	.01	.01	.46	--	.02	.01
July 15, 1981	--	<.01	<.01	.48	--	<.01	<.01
Site 7. Big Creek near Harvey							
Oct. 17, 1979	1.2	.00	.01	.44	.76	.01	.00
July 16, 1980	.68	.00	.00	.46	.22	.01	.01
July 15, 1981	--	<.01	<.01	.48	--	.01	<.01
Site 8. Big Creek near Beaver Grove							
Oct. 18, 1979	--	.02	.01	.43	--	.01	--
Site 9. Cedar Creek near Sands							
Oct. 17, 1979	.29	.01	.00	.01	.27	.01	.01
July 15, 1980	.34	.00	.00	.03	.31	.01	.01
Site 10. Cedar Creek near Gentian							
Oct. 18, 1979	--	.04	.01	.00	--	.01	.01
July 15, 1980	--	.00	.00	.03	--	.01	.00
July 14, 1981	--	<.01	<.01	.04	--	<.01	<.01
Site 11. Cedar Creek near Harvey							
Oct. 17, 1979	.21	.00	.00	.07	.14	.01	.00
July 15, 1980	.21	.02	.00	.09	.10	.01	.01
July 14, 1981	--	.01	<.01	.10	--	.01	<.01
Site 12. Cedar Creek near Beaver Grove							
Oct. 18, 1979	--	.02	.00	.18	--	.01	.00
Site 13. Cherry Creek near Cascade							
Oct. 17, 1979	.57	.00	.00	.01	.56	.05	.00
July 15, 1980	--	.02	.00	.03	--	.08	.00

Table 14.--Nitrogen and phosphorus in surface water--continued

Date of Sample	Nitrogen, total	Nitrogen, ammonia, total	Nitrogen, nitrite, total	Nitrogen, nitrate, total	Nitrogen, organic, total	Phosphorus, total	Phosphorus, ortho, total
			Site 14. Cherry Creek near Sands				
July 15, 1980	0.28	0.02	0.00	0.10	0.16	0.00	0.00
July 14, 1981	--	<.01	<.01	.11	--	<.01	<.01
			Site 15. Cherry Creek near Gentian				
Oct. 17, 1979	--	.01	.00	.06	--	.01	.01
July 15, 1980	--	.00	.00	.09	--	.02	.00
July 15, 1981	--	<.01	<.01	.09	--	<.01	<.01
			Site 16. Cherry Creek near Harvey				
Oct. 17, 1979	.14	.03	.02	.02	.07	.01	.01
July 15, 1980	.12	.00	.00	.06	.06	.00	.00
July 15, 1981	--	.02	<.01	.08	--	.01	<.01
			Site 17. Cherry Creek near Beaver Grove				
Oct. 18, 1979	--	.03	.00	.15	--	.02	.02
July 16, 1980	--	.02	.01	.15	--	.04	.03
July 15, 1981	--	.02	<.01	.15	--	.03	.01
			Site 18. Silver Creek near Cascade				
Oct. 17, 1979	.22	.04	.01	.11	.06	.01	.01
July 15, 1980	.20	.01	.00	.15	.04	.04	.04
July 14, 1981	--	.01	<.01	.15	--	<.01	<.01
			Site 20. Silver Creek near Sands				
Oct. 17, 1979	--	.01	.00	.09	--	.01	.00
July 15, 1980	--	.01	.00	.14	--	.01	.01
July 14, 1981	--	.01	<.01	.15	--	.01	.01
			Site 21. Unnamed tributary to Silver Creek near Harvey				
Oct. 17, 1979	--	.01	.00	.08	--	.01	.00
July 15, 1980	--	.01	.00	.13	--	.01	.00
			Site 22. Silver Creek at Harvey				
Oct. 17, 1979	.25	.01	.00	.13	.11	.01	.00
July 15, 1980	.23	.01	.00	.15	.07	.01	.00
July 15, 1981	--	.01	<.01	.18	--	<.01	<.01
			Site 23. Silver Creek near Harvey				
Oct. 17, 1979	--	.02	.01	.11	--	.01	--

Table 15.--Trace metals in surface water
[Analyses by U.S. Geological Survey;
results in micrograms per liter]

Date	Aluminum, dissolved (Al)	Arsenic, dissolved (As)	Barium, dissolved (Ba)	Beryllium, dissolved (Be)	Boron, dissolved (B)	Cadmium, dissolved (Cd)	Chromium, dissolved (Cr)	Cobalt, dissolved (Co)	Copper, dissolved (Cu)
Site 1. Big Creek near Sands Station									
Oct. 17, 1979	100	1	3	0	0	0	<10	1	0
July 15, 1980	200	0	30	0	6	3	10	0	0
July 14, 1981	--	1	30	--	--	<1	10	0	<10
Site 2. Peterson Creek near Sands Station									
Oct. 17, 1979	100	1	20	0	10	1	10	1	0
July 15, 1980	--	1	30	--	--	4	10	0	0
July 14, 1981	--	1	30	--	--	<1	40	0	<10
Site 3. Norby Creek near Sands									
Oct. 17, 1979	--	1	0	--	--	0	<10	0	0
Site 5. Big Creek near Sands									
Oct. 18, 1979	--	1	30	--	--	1	<10	1	2
July 16, 1980	--	1	40	--	--	1	10	0	0
July 15, 1981	--	2	30	--	--	<1	<10	0	<10
Site 7. Big Creek near Harvey									
Oct. 17, 1979	100	2	10	0	10	2	<10	0	3
July 16, 1980	200	2	40	0	6	3	10	0	0
July 15, 1981	--	2	30	--	--	<1	40	0	<10
Site 8. Big Creek near Beaver Grove									
Oct. 18, 1979	--	1	10	--	--	1	10	0	0
Site 9. Cedar Creek near Sands									
Oct. 17, 1979	100	1	30	0	20	0	<10	0	0
July 15, 1980	0	0	20	0	20	4	<10	0	1
Site 10. Cedar Creek near Gentian									
Oct. 18, 1979	--	1	20	--	--	0	20	0	2
July 15, 1980	--	1	40	--	--	4	10	0	4
July 14, 1981	--	1	30	--	--	<1	10	0	<10
Site 11. Cedar Creek near Harvey									
Oct. 17, 1979	100	1	40	1	0	0	10	0	0
July 15, 1980	100	2	30	0	2	4	30	0	0
July 14, 1981	--	2	30	--	--	<1	<10	0	<10
Site 12. Cedar Creek near Beaver Grove									
Oct. 18, 1979	--	2	0	--	--	0	<10	2	0

Table 15.--Trace metals in surface water--continued

Date	Aluminum, dissolved (Al)	Arsenic, dissolved (As)	Barium, dissolved (Ba)	Beryllium, dissolved (Be)	Boron, dissolved (B)	Cadmium, dissolved (Cd)	Chromium, dissolved (Cr)	Cobalt, dissolved (Co)	Copper, dissolved (Cu)
				Site 13. Cherry Creek near Cascade					
Oct. 17, 1979	200	1	30	1	20	0	10	1	17
July 15, 1980	--	0	40	--	--	6	10	0	0
				Site 14. Cherry Creek near Sands					
July 15, 1980	100	2	--	--	10	--	20	0	--
July 14, 1981	--	1	40	--	--	<1	<10	0	<10
				Site 15. Cherry Creek near Gentian					
Oct. 17, 1979	--	1	1	--	--	0	<10	1	2
July 15, 1980	--	1	40	--	--	2	10	0	0
July 15, 1981	--	2	30	--	--	<1	20	0	<10
				Site 16. Cherry Creek near Harvey					
Oct. 17, 1979	100	1	20	0	0	0	<10	0	0
July 15, 1980	100	1	30	0	4	3	10	0	0
July 15, 1981	--	1	40	--	--	<1	10	0	<10
				Site 17. Cherry Creek near Beaver Grove					
Oct. 18, 1979	--	1	30	--	--	1	<10	0	0
July 16, 1980	--	1	--	--	--	--	10	0	--
July 15, 1981	--	2	40	--	--	<1	20	0	<10
				Site 18. Silver Creek near Cascade					
Oct. 17, 1979	200	1	20	0	0	0	10	2	1
July 15, 1980	100	2	40	0	0	2	30	0	12
July 14, 1981	--	1	30	--	--	<1	<10	0	<10
				Site 20. Silver Creek near Sands					
Oct. 17, 1979	--	1	70	--	--	0	<10	0	0
July 15, 1980	--	1	40	--	--	3	10	0	0
July 14, 1981	--	1	30	--	--	<1	10	0	<10
				Site 21. Unnamed tributary to Silver Creek near Harvey					
Oct. 17, 1979	--	1	20	--	--	1	<10	0	2
July 15, 1980	--	1	30	--	--	4	10	0	0
				Site 22. Silver Creek at Harvey					
Oct. 17, 1979	100	2	0	0	10	0	<10	1	0
July 15, 1980	0	2	30	0	0	5	20	0	0
July 15, 1981	--	1	40	--	--	<1	10	0	<10
				Site 23. Silver Creek near Harvey					
Oct. 17, 1979	--	1	0	--	--	0	10	2	1

Table 15.--Trace metals in surface water--continued

Date	Lead, dis-solved (Pb)	Lithium, dis-solved (Li)	Mercury, dis-solved (Hg)	Molyb-denum, dis-solved (Mo)	Nickel, dis-solved (Ni)	Sele-nium, dis-solved (Se)	Silver, dis-solved (Ag)	Stron-tium, dis-solved (Sr)	Zinc, dis-solved (Zn)
Site 1. Big Creek near Sands Station									
Oct. 17, 1979	0	1	.3	0	0	0	0	30	0
July 15, 1980	0	2	.1	2	0	0	0	30	2
July 14, 1981	1	--	.1	--	--	--	--	--	<4
Site 2. Peterson Creek near Sands Station									
Oct. 17, 1979	0	2	.3	0	1	0	0	30	7
July 15, 1980	0	--	<.1	--	--	--	--	--	4
July 14, 1981	2	--	.1	--	--	--	--	--	5
Site 3. Norby Creek near Sands									
Oct. 17, 1979	0	--	.3	--	--	--	--	--	5
Site 5. Big Creek near Sands									
Oct. 18, 1979	0	--	.3	--	--	--	--	--	4
July 16, 1980	0	--	<.1	--	--	--	--	--	0
July 15, 1981	2	--	<.1	--	--	--	--	--	7
Site 7. Big Creek near Harvey									
Oct. 17, 1979	0	2	.3	4	0	0	0	40	20
July 16, 1980	0	2	<.1	0	0	0	0	40	7
July 15, 1981	3	--	<.1	--	--	--	--	--	<4
Site 8. Big Creek near Beaver Grove									
Oct. 18, 1979	0	--	.3	--	--	--	--	--	7
Site 9. Cedar Creek near Sands									
Oct. 17, 1979	0	2	.3	1	0	0	0	20	0
July 15, 1980	0	1	<.1	0	0	0	0	20	1
Site 10. Cedar Creek near Gentian									
Oct. 18, 1979	0	--	.3	--	--	--	--	--	4
July 15, 1980	0	--	.4	--	--	--	--	--	30
July 14, 1981	1	--	<.1	--	--	--	--	--	<4
Site 11. Cedar Creek near Harvey									
Oct. 17, 1979	0	1	.3	12	1	0	0	30	10
July 15, 1980	0	2	<.1	0	0	0	0	30	5
July 14, 1981	1	--	<.1	--	--	--	--	--	5
Site 12. Cedar Creek near Beaver Grove									
Oct. 18, 1979	0	--	.3	--	--	--	--	--	0

Table 15.--Trace metals in surface water--continued

Date	Lead, dis-solved (Pb)	Lithium, dis-solved (Li)	Mercury, dis-solved (Hg)	Molyb-denum, dis-solved (Mo)	Nickel, dis-solved (Ni)	Sele-nium, dis-solved (Se)	Silver, dis-solved (Ag)	Stron-tium, dis-solved (Sr)	Zinc, dis-solved (Zn)
Site 13. Cherry Creek near Cascade									
Oct. 17, 1979	0	1	.3	3	1	0	0	20	10
July 15, 1980	1	--	.2	--	--	--	--	--	20
Site 14. Cherry Creek near Sands									
July 15, 1980	0	--	<.1	0	0	0	0	--	--
July 14, 1981	2	--	.5	--	--	--	--	--	8
Site 15. Cherry Creek near Harvey									
Oct. 17, 1979	0	--	.3	--	--	--	--	--	5
July 15, 1980	0	--	.3	--	--	--	--	--	8
July 15, 1981	1	--	.1	--	--	--	--	--	7
Site 16. Cherry Creek near Harvey									
Oct. 17, 1979	0	2	.5	0	0	0	0	40	0
July 15, 1980	0	2	<.1	2	0	0	0	40	3
July 15, 1981	1	--	.2	--	--	--	--	--	<4
Site 17. Cherry Creek near Beaver Grove									
Oct. 18, 1979	0	--	.3	--	--	--	--	--	8
July 16, 1980	0	--	.1	--	--	--	--	--	--
July 15, 1981	2	--	.2	--	--	--	--	--	7
Site 18. Silver Creek near Cascade									
Oct. 17, 1979	0	2	.3	0	0	0	0	30	4
July 15, 1980	1	2	<.1	0	0	0	0	29	15
July 14, 1981	1	--	.1	--	--	--	--	--	10
Site 20. Silver Creek near Sands									
Oct. 17, 1979	0	--	.3	--	--	--	--	--	0
July 15, 1980	0	--	.2	--	--	--	--	--	1
July 14, 1981	1	--	.1	--	--	--	--	--	4
Site 21. Unnamed tributary to Silver Creek near Harvey									
Oct. 17, 1979	0	--	.4	--	--	--	--	--	1
July 15, 1980	0	--	.4	--	--	--	--	--	5
Site 22. Silver Creek at Harvey									
Oct. 10, 1979	0	2	<.1	3	5	0	0	40	7
July 15, 1980	0	2	<.1	0	0	0	0	40	3
July 15, 1981	1	--	.2	--	--	--	--	--	<4
Site 23. Silver Creek near Harvey									
Oct. 17, 1979	0	--	.3	--	--	--	--	--	3

Table 17.--Chemical and physical characteristics of ground water
[Analyses by U.S. Geological Survey]

Well	Date	Specific conductance (µmhos)	Turbidity (NTU)	Color (platinum-cobalt units)	pH (units)	Iron, dissolved (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Manganese, total recoverable (µg/L as Mn)	Silica, dissolved (mg/L as SiO_2)
1	July 23, 1980	125	17	7	8.4	--	540	--	10	--
2	July 23, 1980	156	--	--	8.0	10	1,700	20	50	--
5	July 24, 1980	153	.40	1	8.2	--	90	--	10	--
6	July 24, 1980	187	--	--	8.3	10	260	10	10	--
7	Sept. 3, 1981	125	--	--	7.1	800	41,000	180	890	--
8	June 5, 1981	71	1.5	2	8.6	<10	80	<1	10	6.5
10	July 21, 1980	70	.85	0	8.9	10	110	10	10	5.9
	Oct. 28, 1980	70	--	--	9.0	--	--	--	--	--
11	June 1, 1981	132	220	4	8.2	<10	120	4	10	6.4
12	July 21, 1980	72	--	--	9.1	0	390	1	0	--
14	July 23, 1980	160	1.2	3	6.8	--	120	--	10	--
	Aug. 31, 1981	144	--	--	6.4	<10	160	<10	10	--
15	July 24, 1980	391	--	--	7.8	0	570	3	20	--
	June 3, 1981	384	4.4	2	7.7	10	240	2	10	9.8
17	July 24, 1980	73	--	--	9.0	10	240	0	10	--
18	June 1, 1981	122	--	--	8.6	60	800	4	10	--
19	July 30, 1980	200	.25	3	7.3	--	50	--	10	--
	June 3, 1981	288	--	--	7.0	10	80	2	10	--
21	July 25, 1980	338	1.5	1	8.2	--	90	--	40	--
	Sept. 1, 1981	272	--	--	7.7	30	100	<10	10	--
22	Sept. 1, 1981	196	--	--	7.9	25,000	84,000	810	2,200	--
23	June 4, 1981	74	1.5	2	8.7	10	50	1	10	8.0
25	July 29, 1980	78	--	--	8.8	10	80	2	10	--
26	July 22, 1980	110	--	--	8.4	10	100	50	50	--
	June 2, 1981	105	--	--	8.1	20	540	60	60	--
27	July 29, 1980	76	2.2	3	8.7	--	150	--	10	--
	June 2, 1981	82	--	--	8.7	<10	80	<1	10	--
28	July 25, 1980	105	--	--	8.8	0	90	0	10	--
29	June 2, 1981	76	1.2	3	8.7	<10	110	<1	10	6.7
30	July 22, 1980	68	--	--	9.0	0	100	0	0	--
	Sept. 1, 1981	70	.30	<1	8.5	<10	40	<10	10	8.1
31	July 30, 1980	224	.50	40	7.8	--	1,300	--	150	--
	Oct. 28, 1980	206	--	--	7.7	--	--	--	--	--
34	July 25, 1980	97	--	--	8.8	0	90	1	10	--
	Sept. 8, 1981	93	.30	<1	8.8	<10	90	<10	<10	6.6
P1	Aug. 31, 1981	245	.40	<1	7.7	20	130	30	40	8.9
P2	July 29, 1980	210	.20	4	8.0	--	70	--	110	--
	June 4, 1981	194	--	--	7.8	30	110	100	110	--
P4	July 24, 1980	134	.50	2	8.5	--	50	--	10	--
C3	Sept. 2, 1981	53	--	--	4.9	3,300	3,400	60	70	--
C7	Sept. 8, 1981	320	--	--	5.6	8,600	8,600	70	80	--
C13	Sept. 2, 1981	456	--	--	7.3	1,000	1,100	150	150	--

Table 17.--Chemical and physical characteristics of ground water--continued

Well	Date	Calcium, dis-solved (mg/L) as Ca)	Magne-sium, dis-solved (mg/L as Na)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Bicar-bonate, field (mg/L as HCO_3)	Car-bonate, field (mg/L as CO_3)	Chlo-ride, dis-solved (mg/L as Cl)	Sulfate, dis-solved (mg/L as SO_4)	Fluo-ride, dis-solved (mg/L as F)
1	July 23, 1980	16	5.0	3.0	1.2	80	1	0.5	1.9	0.1
2	July 23, 1980	24	4.2	1.2	.9	100	0	.4	3.0	.1
5	July 24, 1980	21	5.0	1.0	.7	91	0	.6	3.6	.1
6	July 24, 1980	24	5.8	3.8	1.4	120	0	.7	3.7	.1
7	Sept. 3, 1981	18	9.0	3.6	1.6	--	--	1.1	3.0	<.1
8	June 5, 1981	9.5	1.7	.7	.3	30	3	.1	2.7	<.1
10	July 21, 1980	10	1.8	1.0	.4	42	5	.3	3.5	.0
	Oct. 28, 1980	--	--	--	--	--	--	--	--	--
11	June 1, 1981	19	3.4	.9	.3	71	0	.7	8.5	<.1
12	July 21, 1980	10	1.7	1.5	.4	32	5	.4	5.2	.0
14	July 23, 1980	23	5.0	1.0	.5	95	0	.7	5.6	.0
	Aug. 31, 1981	20	3.8	1.2	.5	78	0	.8	7.3	<.1
15	July 24, 1980	51	15	2.9	1.2	210	0	13	9.8	.1
	June 3, 1981	50	15	4.0	.7	205	0	14	13	<.1
17	July 24, 1980	8.9	1.8	1.7	.5	43	4	.4	3.1	.0
18	June 1, 1981	5.7	1.2	21	1.0	57	3	.6	7.7	<.1
19	July 30, 1980	24	5.7	3.8	1.3	78	0	3.4	26	.1
	June 3, 1981	35	8.3	4.8	1.1	77	0	8.8	53	<.1
21	July 25, 1980	47	10	3.0	1.0	140	0	5.6	48	.1
	Sept. 1, 1981	37	7.8	2.6	1.5	106	0	5.2	37	<.1
22	Sept. 1, 1981	26	5.9	--	4.3	--	--	3.7	10	<.1
23	June 4, 1981	10	2.4	1.0	.4	33	3	.2	2.6	<.1
25	July 29, 1980	8.9	2.1	1.6	.6	38	2	.3	3.0	.1
26	July 22, 1980	16	2.5	.9	.5	60	1	.5	2.8	.1
	June 2, 1981	17	2.6	1.0	.4	62	0	.4	3.9	<.1
27	July 29, 1980	10	1.8	.6	.5	37	1	.3	3.6	.1
	June 2, 1981	12	2.1	.8	.3	34	4	.4	5.2	<.1
28	July 25, 1980	15	2.9	.7	.4	70	1	.5	5.3	.1
29	June 2, 1981	11	1.7	.9	.3	32	4	.4	3.5	<.1
30	July 22, 1980	8.5	1.9	1.3	.6	33	5	.5	1.3	.1
	Sept. 1, 1981	9.0	2.2	1.3	1.4	36	1	.4	2.7	<.1
31	July 30, 1980	32	5.9	1.8	.7	136	0	.9	3.2	.1
	Oct. 28, 1980	--	--	--	--	--	--	--	--	--
34	July 25, 1980	13	2.8	.7	.5	52	3	.5	3.9	.1
	Sept. 8, 1981	12	2.0	.8	.1	50	4	.2	3.3	<.1
P1	Aug. 31, 1981	34	5.9	2.5	.6	130	0	1.7	19	<.1
P2	July 29, 1980	30	5.2	1.2	.6	130	0	.5	2.0	.1
	June 4, 1981	29	5.1	1.4	.5	120	0	.4	.9	<.1
P4	July 24, 1980	19	5.0	1.0	.6	99	1	.5	4.9	.1
C3	Sept. 2, 1981	4.0	1.1	.9	.9	10	0	1.0	13	<.1
C7	Sept. 5, 1981	6.0	1.8	63	2.3	130	0	36	28	<.1
C13	Sept. 2, 1981	74	4.6	5.2	4.1	180	0	1.2	81	1.1

Table 17.--Chemical and physical characteristics of ground water--continued

Well	Date	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180°C, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Carbon, organic, dissolved (mg/L as C)	Cyanide total (mg/L as Cn)	Phenols (µg/L)	Potassium 40, dissolved (PCI/L as K40)
1	July 23, 1980	69	--	61	0	1.0	0.00	36	--
2	July 23, 1980	90	109	77	0	--	--	--	--
5	July 24, 1980	84	--	73	0	2.1	.00	39	--
6	July 24, 1980	--	103	84	0	--	--	--	--
7	Sept. 3, 1981	--	101	82	--	--	--	--	--
8	June 3, 1981	41	49	31	1	3.0	--	0	.20
10	July 21, 1980	49	--	32	3	1.2	.00	30	--
	Oct. 28, 1980	--	--	--	--	--	--	4	--
11	June 1, 1981	74	68	61	3	3.4	<.01	16	.20
12	July 21, 1980	--	48	32	0	--	--	--	--
14	July 23, 1980	89	--	78	0	1.6	.00	80	--
	Aug. 31, 1981	--	86	66	2	--	--	--	.40
15	July 24, 1980	206	246	190	17	--	--	--	--
	June 3, 1981	203	240	190	22	3.0	<.01	24	.50
17	July 24, 1980	--	47	30	0	--	--	--	--
18	June 1, 1981	--	89	19	0	--	--	--	.70
19	July 30, 1980	109	--	83	19	4.6	.00	6	--
	June 3, 1981	160	194	120	57	--	--	--	.80
21	July 25, 1980	190	--	160	44	8.5	.00	9	--
	Sept. 1, 1981	--	177	120	33	--	--	--	1.1
22	Sept. 1, 1981	--	120	89	--	--	--	--	3.2
23	June 4, 1981	44	--	35	3	<.3	--	0	.30
25	July 29, 1980	--	42	31	0	--	--	--	--
26	July 22, 1980	--	56	50	0	--	--	--	--
	June 2, 1981	--	54	53	2	--	--	--	.30
27	July 29, 1980	43	--	32	0	4.0	.00	4	--
	June 2, 1981	--	52	39	4	--	--	--	.20
28	July 25, 1980	67	82	49	0	--	--	--	--
29	June 2, 1981	44	51	34	1	--	--	0	.20
30	July 22, 1980	42	--	29	0	--	--	--	--
	Sept. 1, 1981	47	--	32	1	--	<.01	<1	1.0
31	July 30, 1980	120	--	100	0	7.0	.00	0	--
	Oct. 28, 1980	--	--	--	--	--	--	4	--
34	July 25, 1980	--	55	44	0	--	--	--	--
	Sept. 8, 1981	48	50	38	0	.9	<.01	--	--
P1	Aug. 31, 1981	139	165	110	3	--	<.01	77	.40
P2	July 29, 1980	111	--	96	0	1.7	.00	11	--
	June 4, 1981	--	112	93	0	--	--	--	.40
P4	July 24, 1980	88	--	68	0	4.8	.00	39	--
C3	Sept. 2, 1981	38	48	15	7	--	--	--	.70
C7	Sept. 8, 1981	208	--	22	0	--	--	--	--
C13	Sept. 2, 1981	--	288	200	52	--	--	--	3.1

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