Miscellaneous Paper 89-1
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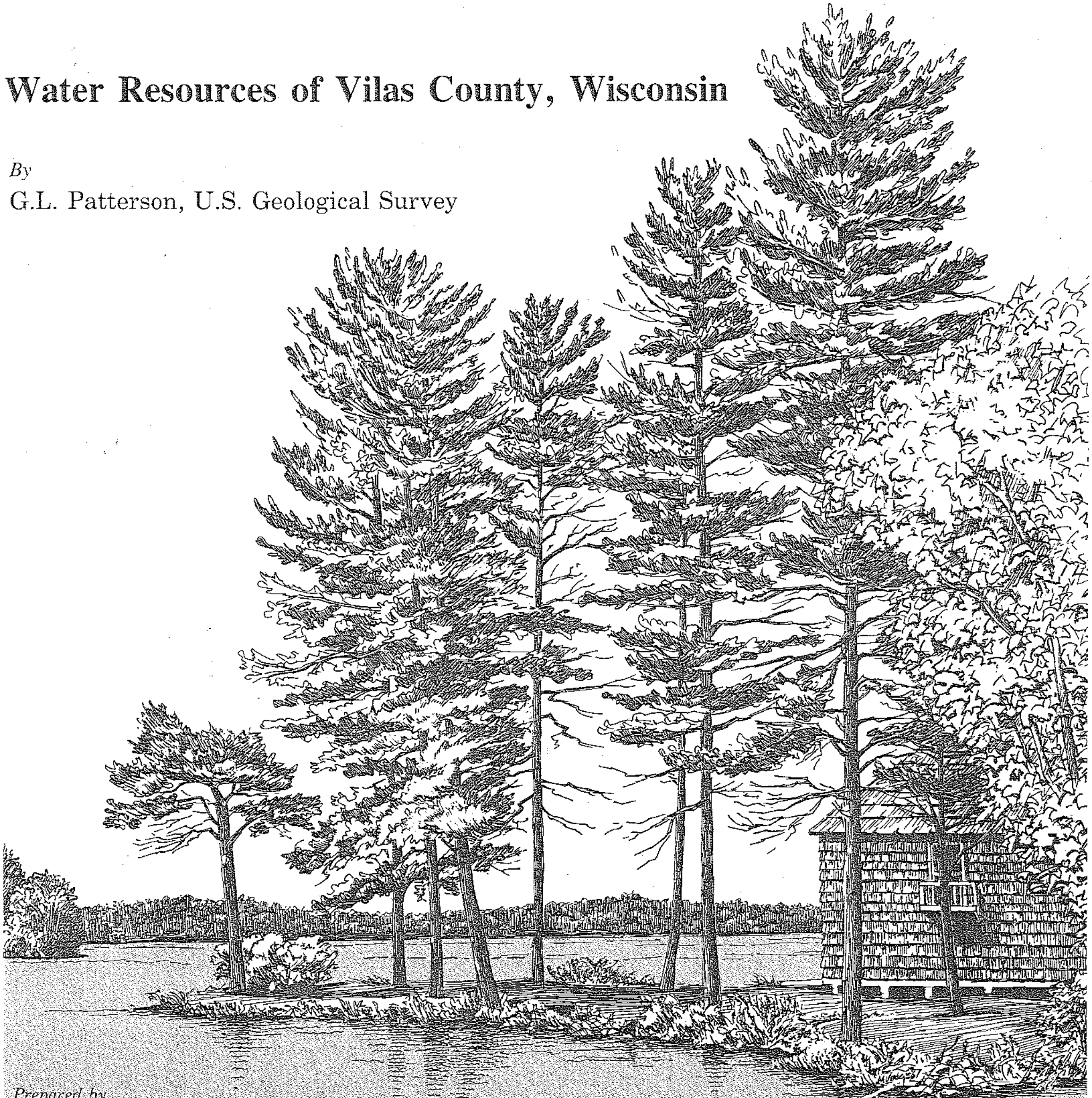
Water Resources of Vilas County, Wisconsin

By
G.L. Patterson, U.S. Geological Survey



Prepared by
United States Department of the Interior
Geological Survey

In cooperation with the
University of Wisconsin–Extension
Geological and Natural History Survey

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M.E. Ostrom, Director and State Geologist

This report is a product of the U.S. Geological Survey Water Resources Division and the University of Wisconsin–Extension, Geological and Natural History Survey.

The Wisconsin Geological and Natural History Survey Water Resources Program includes: systematic collection, analysis, and cataloging of basic water data; impartial research and investigation of Wisconsin's water resources and water problems; publication of technical and popular reports and maps; and public service and information. This report for the Survey's Water Resources Program is accomplished through state–federal cooperative cost sharing with the U.S. Geological Survey's Water Resources Division.

This report is available at: Wisconsin Geological and Natural History Survey, 3817 Mineral Point Road, Madison, Wisconsin, 53705.

CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC (INTERNATIONAL SYSTEM) UNITS

For the use of readers who prefer metric (International System) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound unit	*By*	*To obtain metric unit*
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (l)
	Mass	
ounce (oz)	0.0002835	milligram (mg)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (° F − 32)	degree Celsius (° C)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per second (ft/s)	0.3048	meter per second (m/s)
	Transmissivity	
square foot per second (ft^2/s)	0.09290	square meter per second (m^2/s)
	Concentration	
parts per million (ppm)	1.0	milligrams per liter (mg/L)

Other abbreviations:

micrograms per liter (μg/L) microequivalents per liter (μeq/L) milliequivalents per liter (meq/L)

The stratigraphic nomenclature used in this report is that of the Wisconsin Geological and Natural History Survey and does not necessarily follow usage of the U.S. Geological Survey.

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

WATER RESOURCES OF VILAS COUNTY, WISCONSIN

By
G. L. Patterson

ABSTRACT

This report describes the ground- and surface-water resources of Vilas County. The study was done by the U.S. Geological Survey, in cooperation with the Wisconsin Geological and Natural History Survey.

The Pleistocene drift in Vilas County, Wisconsin, consists of three types of material: till, debris-flow sediment, and fluvial sediment. The fluvial sediment consists of sand and gravel with little or no silt and clay. The till and debris-flow sediments are similar and consist of 60- to 80-percent sand, 15- to 30-percent silt, and 5- to 10-percent clay.

The water table generally is shallow and there is little water-level fluctuation throughout the county. The median depth to water in 80 observation wells varied from above land surface to 141.74 feet below land surface; however, only three wells had median depths to water of more than 50 feet. Fifty-six wells had median depths to water of less than 20 feet. The range of fluctuations was 0.5 to 7.36 feet.

Water-level altitudes at more than 175 wells and surface-water altitudes were used to prepare a ground-water-level contour map.

Horizontal hydraulic conductivity of the sand and gravel is on the order of 10^{-4} feet per second but that of the till and debris-flow sediment is on the order of 10^{-6} feet per second. Calculations of transmissivity indicate that the sand and gravel will yield sufficient quantities of water for most uses, but the till and debris-flow deposits will not.

The many lakes and wetlands in Vilas County store surface-water runoff and release it to the creeks and streams slowly over extended periods of time. Peak runoff is attenuated and high base flows are prolonged by the basin and wetland storage and from the shallow water table but are reduced during long drought periods because of evapotranspiration.

Ground-water quality in Vilas County is suitable for most purposes. Water samples collected from 50 observation wells in August 1982 indicate that calcium, magnesium, and bicarbonate are the major dissolved constituents in ground water. Samples from eight wells were significantly different from the rest of the samples. Sulfate was the primary anion in water from two wells and concentrations of sodium and chloride were elevated in water from six wells; the elevated concentrations of sodium and chloride are likely the result of contamination by road salt.

Dissolved-solids concentrations ranged from 31 to 453 mg/L (milligrams per liter), with a median concentration of 76 mg/L. Dissolved-solids concentrations generally were lower in Vilas County than in the surrounding area.

Alkalinity concentrations in Vilas County ranged from 2 to 152 mg/L, with a median concentration of 28 mg/L. The median concentration was much less than the 102 mg/L median for the surrounding area. The low alkalinity concentration in ground water in Vilas County indicates a limited capability to neutralize acid; this may increase the potential for degradation of lakes by acid precipitation.

Median concentrations of iron and manganese were 140 mg/L and 89 μg/L (micrograms per liter), respectively. These concentrations are greater than the median concentrations of 130 μg/L for iron and 45 μg/L for manganese in the surrounding area.

Alkalinity data for surface water were used to classify 546 lakes according to their sensitivity to acid precipitation. Five lakes are classified as ultra-sensitive, 108 lakes are classified as extremely sensitive, 185 lakes are classified as moderately sensitive, 89 lakes are classified as having low sensitivity, and 159 lakes are classified as not sensitive.

INTRODUCTION

BACKGROUND

Vilas County encompasses 867 mi² (square miles) in north-central Wisconsin adjacent to the Michigan border (fig. 1). The area is part of the Northern Highland Lake District (Martin, 1965) and is characterized by rolling topography and numerous lakes, swamps, and streams. Few parts of the world have the density of lakes found in Vilas County, where 15 percent of the surface is covered by water from more than 500 lakes and ponds. The county also contains large areas of the Northern Highlands State Forest and the Nicolet National Forest.

The primary industry is tourism and recreation, and, although the county has only about 17,000 full-time residents, as many as 2 or 3 times that number are transient summer residents and tourists.

PURPOSE AND SCOPE

This report describes the water resources of Vilas County with emphasis on the altitude and configuration of the water-table surface, ground-water movement and availability, ground-water use, and background water quality.

The surficial geology is discussed briefly in this report, only when necessary to describe the water resources. The reader is referred to "Pleistocene Geology of Vilas County, Wisconsin" (Attig, 1985) for detailed geologic information.

Data used for this study were obtained from 51 observation wells installed as part of this project, 11 observation wells installed as part of a ground-water study on the Lac du Flambeau Indian Reservation, 13 existing observation wells, more than 100 existing domestic wells, and numerous surface-water altitudes that represent ground-water levels.

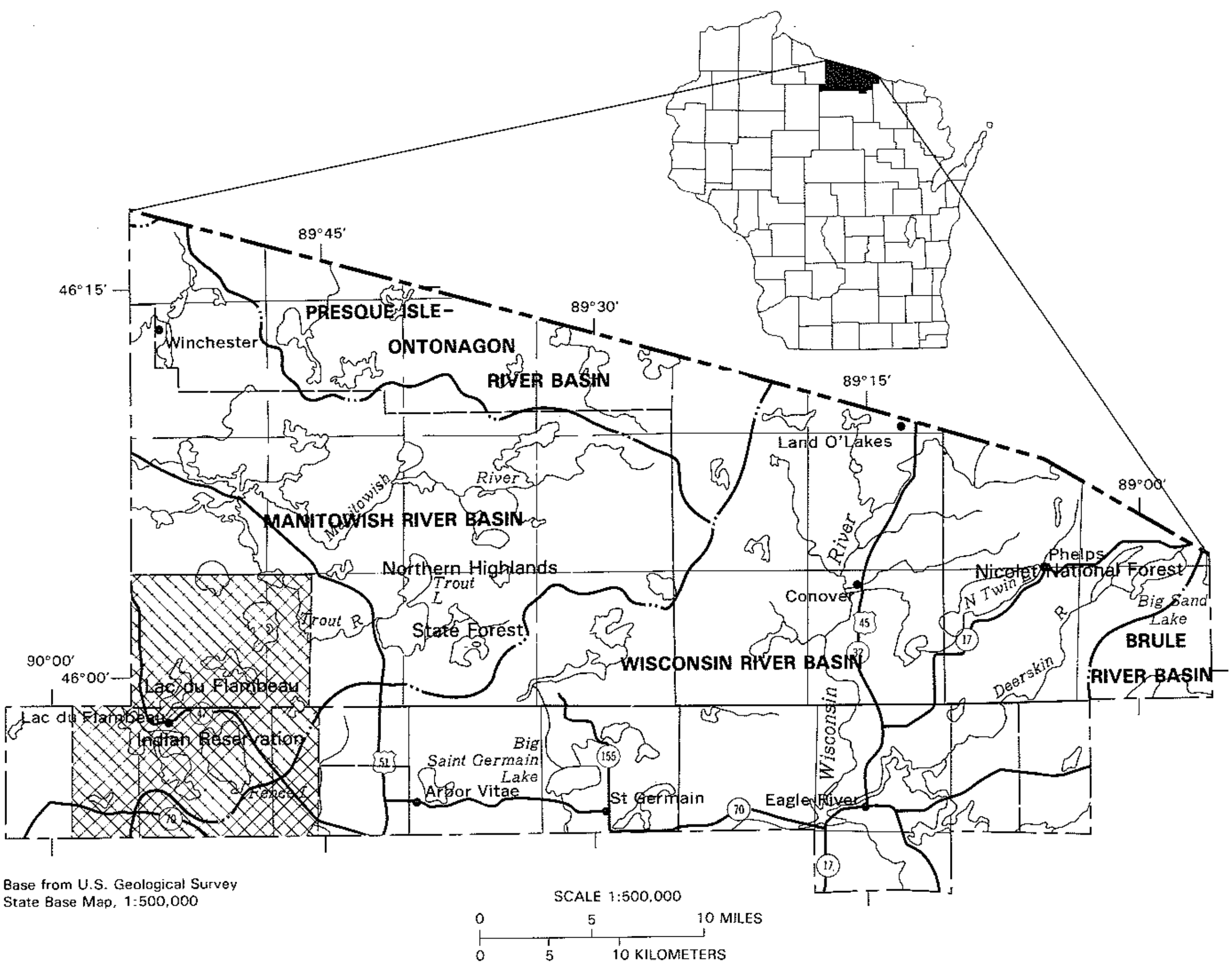

Figure 1. Location and major surface-water drainage basins of Vilas County, Wisconsin.

GEOLOGIC SETTING

The geology of Vilas County consists of Precambrian bedrock overlain by Pleistocene sediment. Rocks representing the hundreds of millions of years between the Precambrian Era and Pleistocene Epoch are absent because throughout this time Vilas County was part of a high, stable land mass where erosion was occurring.

BEDROCK TOPOGRAPHY

Well-construction logs, mineral-exploration-boring logs (Allen and Barrett, 1915), seismic data from Okwueze (1983), and data from 16 seismic lines run by the U.S. Geological Survey were used to construct a Precambrian bedrock topography map (fig. 2). The map shows a general slope in the bedrock surface from more than 1,600 ft (feet) in the northeast to less than 1,400 ft in the south. The contours suggest the presence of several pre-Pleistocene bedrock valleys on the erosional surface.

THICKNESS OF UNCONSOLIDATED MATERIALS

The bedrock topography data and topographic maps were used to prepare a depth-to-bedrock map (fig. 3). This map shows that the thickness of unconsolidated material ranges from more than 200 ft in the eastern and south-central parts of the county to less than 100 ft in the central and southeastern parts. The depth-to-bedrock map roughly resembles the bedrock topography map because the sediment generally is thicker near bedrock-surface lows and thinner near bedrock-surface highs.

COMPOSITION OF PLEISTOCENE MATERIALS

The Pleistocene material in Vilas County consists of three types: till, debris-flow sediment, and fluvial

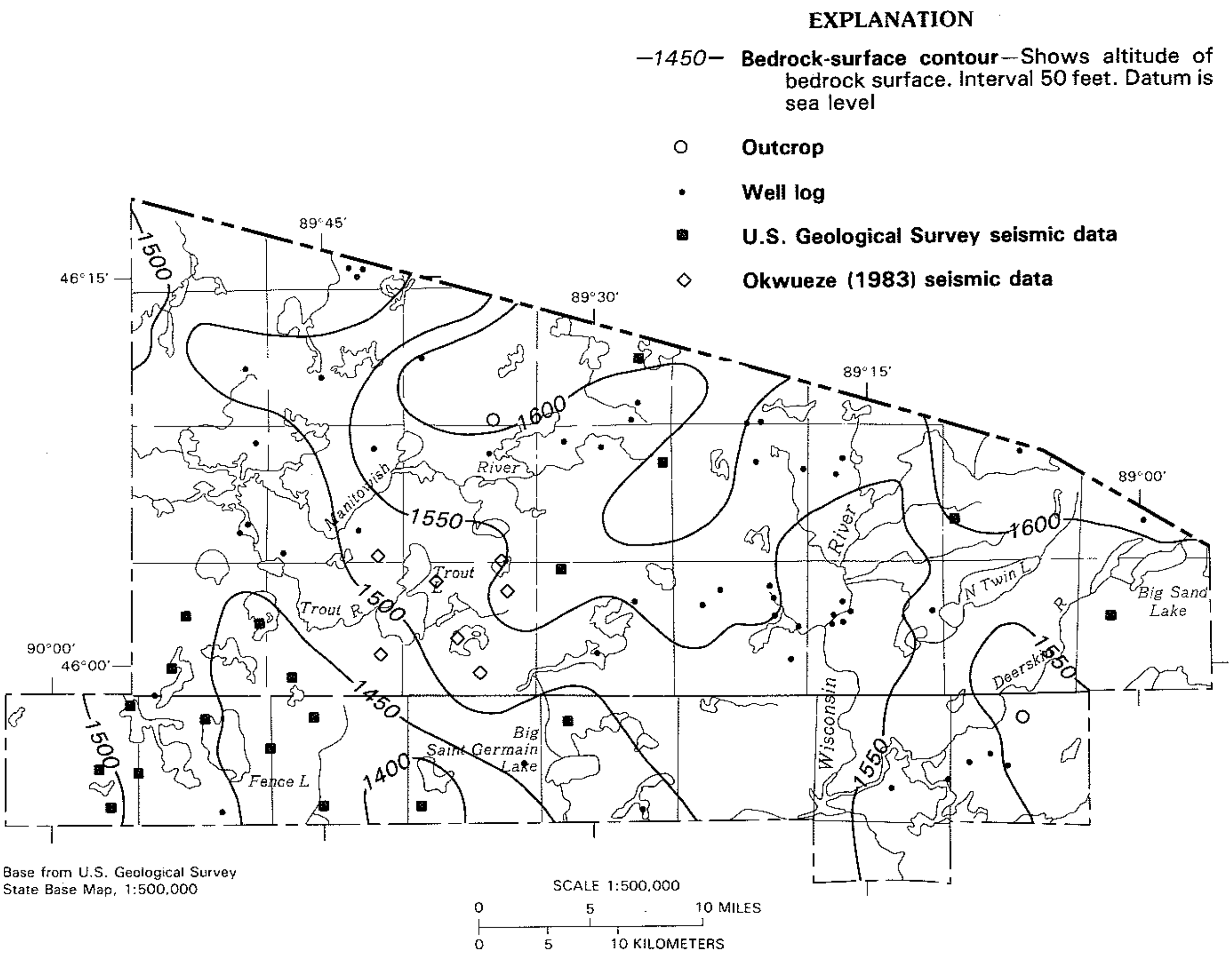

Figure 2. Altitude of the surface of Precambrian bedrock, Vilas County, Wisconsin.

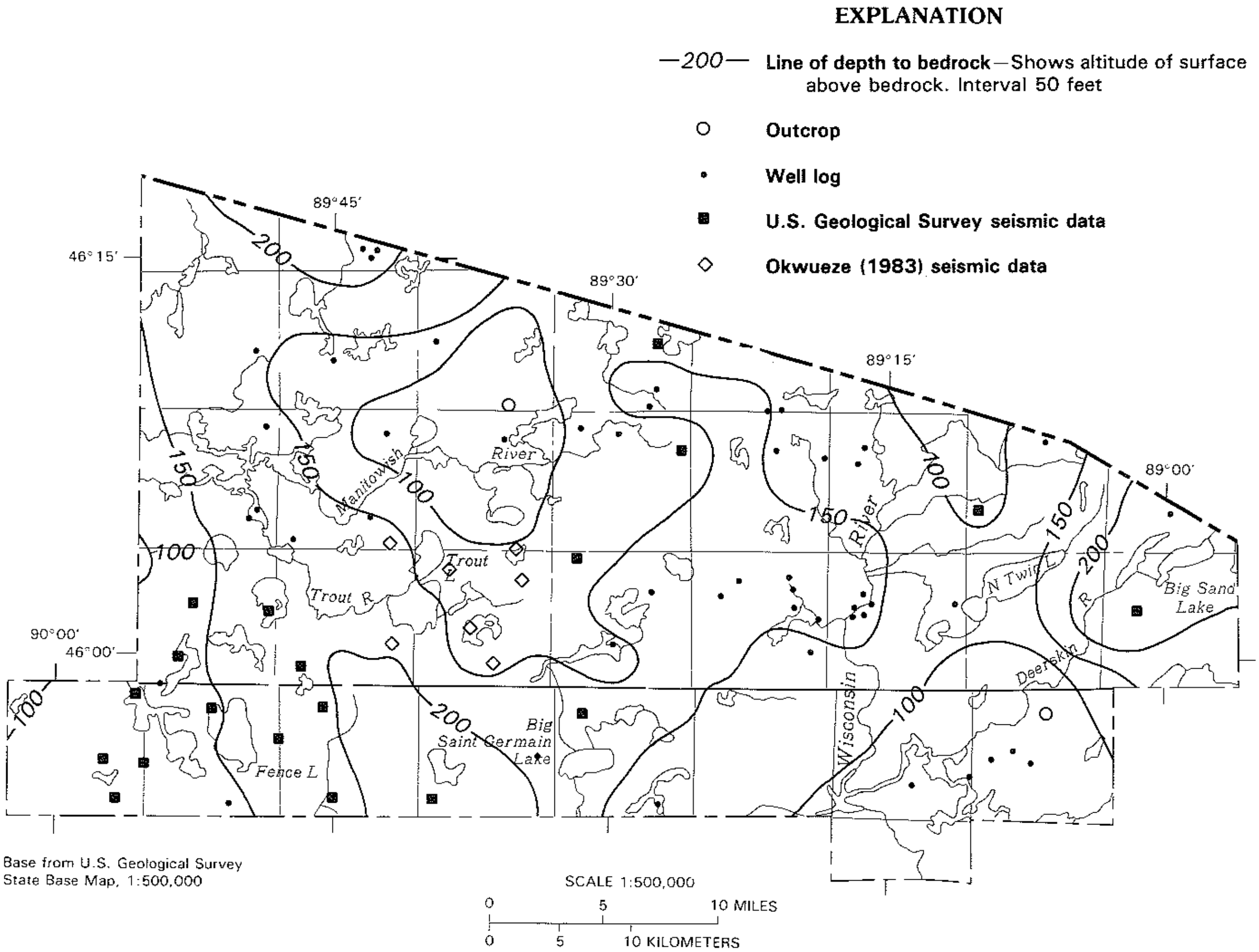

Figure 3. Depth to bedrock, Vilas County, Wisconsin.

Table 1. *Composition of Pleistocene material in Vilas County, Wisconsin*
[Modified from Attig (1985, table 2)]

Geologic member	Sediment type	Number of samples	Grain-size distribution of the <2 mm fraction (in percent)		
			Sand	Silt	Clay
Wildcat Lake	Till	16	71	21	8
	Debris-flow sediment	43	75	20	5
Nashville	Till	19	78	15	7
	Debris-flow sediment	40	79	15	6
Crab Lake	Till	19	61	30	9
	Debris-flow sediment	61	60	32	8

sediment (Attig, 1985). The fluvial sediment consists of sand and gravel with little or no silt or clay. Till and debris-flow sediment are similar (table 1) and consist of 60- to 80-percent sand, 15- to 30-percent silt, and 5- to 10-percent clay.

Three different till and debris-flow deposits are distinguished in Vilas County. They are part of the Crab Lake, Wildcat Lake, and Nashville Members of the Copper Falls Formation. Figure 4 shows a series of geologic sections from Attig (1985) that show that the till and debris-flow deposits are present throughout most of the county and are separated by relatively thick deposits of sand and gravel.

WATER RESOURCES

GROUND WATER

General Occurence and Movement

The source of all ground water is precipitation. When it rains or when snow melts the water takes the following paths:

1. Some wets the soil and is taken up by plants and trees.
2. Some runs off the surface and joins streams and lakes.
3. Some evaporates.
4. Some percolates downward to the water table and enters the ground-water reservoir.

Water that enters the ground-water reservoir fills numerous small openings, such as pores, fractures, and tiny cracks in the bedrock or unconsolidated surficial deposits.

Rocks not only store water, they also transmit it. After water reaches the ground-water reservoir, it flows laterally toward nearby streams and lakes. Because it is driven by gravity and the difference in pressure between high and low areas, ground water tends to flow toward low-lying areas. Most ground water discharges into lakes, streams, or springs within a few miles of where it originally fell to the ground as rain or snow.

An aquifer is a water-saturated rock unit that will yield sufficient quantities of water to wells or springs so that they can be used as practical sources of water supply. The most important aquifer in Vilas County is the water-table aquifer. The upper surface of the water in the aquifer is called the water table. At this surface, the water in the pores of the aquifer is at atmospheric pressure as if it were in an open tank. When a well is drilled into a water-table aquifer, the water in the well will stand near the level of the water table because the water in both the aquifer and the well is at atmospheric pressure.

Ground-Water Fluctuations

The water table fluctuates almost continuously, rising or falling within a relatively short period of time.

Water levels rise in the spring as a result of recharge from snowmelt and rainfall. Levels gradually fall throughout summer, when uptake by plants and evaporation exceeds precipitation and less water is available for infiltration to the water table. Commonly, a small rise occurs in the fall because of rainfall and a reduction in evapotranspiration. Water levels usually decline in winter when the frozen ground inhibits infiltration and precipitation is stored on the land surface as snow.

Monthly ground-water-level measurements were made at 74 observation wells (fig. 5) from August 1981 through November 1982, and at an additional 6 observation wells from August through November 1982. Table 2 lists the arithmetic mean, median, highest, and lowest water level, and the range of water-level fluctuation for each of these wells.

The median depth to water ranges from above land surface to 141.74 ft below land surface. Fifty-six wells had median depths to water of less than 20 ft. Only three wells had medians of more than 50 ft below land surface. The range of fluctuations was 0.5 to 7.36 ft. This is evidence of a very shallow depth to the water table and little water-level fluctuation throughout the county.

Relation to Precipitation

Figure 6 shows hydrographs of monthly precipitation and monthly ground-water levels from five precipitation stations and five nearby observation wells. The water-level hydrographs from wells 8107, 8124, 8128, and 8138 show the general trend of a falling water level from September 1981 through the winter. In March and April 1982, a sharp rise was caused by recharge from spring rainfall and snowmelt followed by a slight decrease through the summer months. In the autumn, increased rainfall and decreased evapotranspiration caused a rise in water levels from September through November. Well 8132 has a somewhat different hydrograph because the seasonal water-level fluctuation was not as great. The rises in water level in May, July, and November appear to be directly related to increased precipitation in April, July, and September.

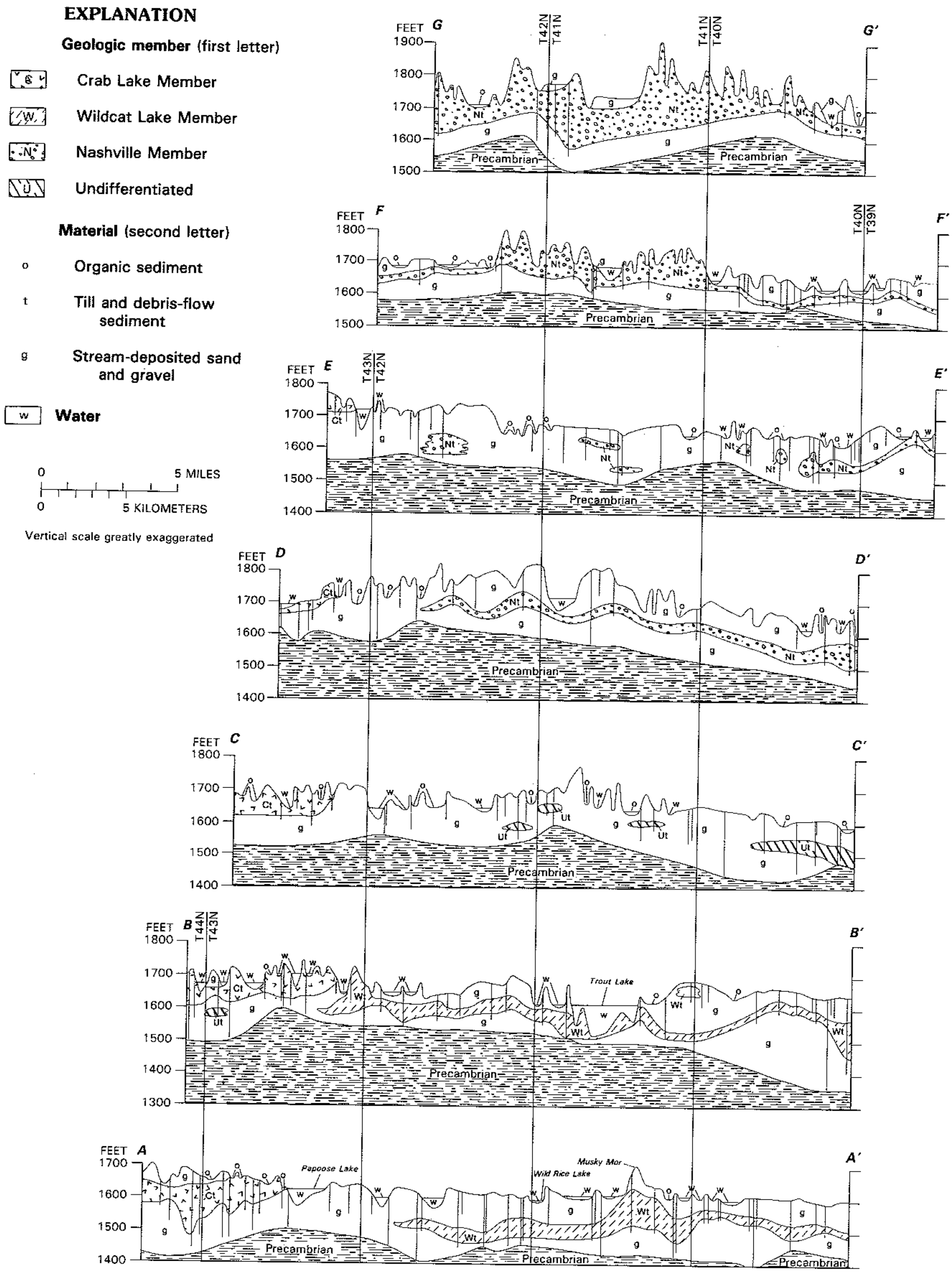

Figure 4. Geologic sections of the Copper Falls Formation, Vilas County, Wisconsin. (Attig, 1985)

Vertical Gradients

Ground water flows from higher pressure to lower pressure. The pressure gradient in recharge areas is downward from the surface and at discharge areas it is upward toward the surface. This is illustrated in figure 7. Well nest *A* is in the recharge area. Well *A*1 is open only at the water table and its water level is the level of the water table itself. Well *A*2 is not open at the water table but is open at some depth below. The water level in well *A*2 will be lower than that in well *A*1 because there is a downward gradient in recharge areas where the ground water flows both laterally and downward.

Well nest *C* is located in a discharge area. Well *C*1 is open only at the water table; thus, the water level in the well represents the water table itself. Well *C*2 is not open at the water table but is open at some depth below. The water level in well *C*2 is higher than that of well *C*1 because ground-water flow is lateral and upward in discharge areas.

Well nest *B* is located in the transition area between nests *A* and *C*; thus, it is in an area of essentially horizontal flow. The water level in water-table well *B*1 is the same as that of the deeper well *B*2.

Monitoring wells 8101–8102, 8107–8108, 8111–8112, 8125–8126, 8132–8133, and 8152A–8152B–8152*C* are nested together in groups with their screened intervals at different depths. Figure 8 shows the relation between hydrographs of these nests.

Wells 8101 and 8102 are screened at depths of 38 and 64 ft, respectively. Water-level hydrographs show a slightly lower water level in well 8102 throughout the period of record. Wells 8107 and 8108 are screened at depths of 30 and 37 ft, respectively, and the deeper well has a lower water level throughout the period of record. Well 8111 is 43 ft deep and well 8112 is 82 ft deep. Their hydrographs show a lower water level in the deeper well except for two brief reversals in April and July 1982. These reversals probably reflect the difference in time required for the deeper well to react to recharge events compared to that of the shallower well. Wells 8125 and 8126 are 28 and 49 ft deep, respectively. Their hydrographs show that the water level in the deeper well is lower throughout the monitoring period, but the gradient or difference is very small. This indicates that these wells are near the transition area between recharge and discharge. Wells 8132 and 8133 are 38 and 60 ft deep, respectively, and their hydrographs show a relation

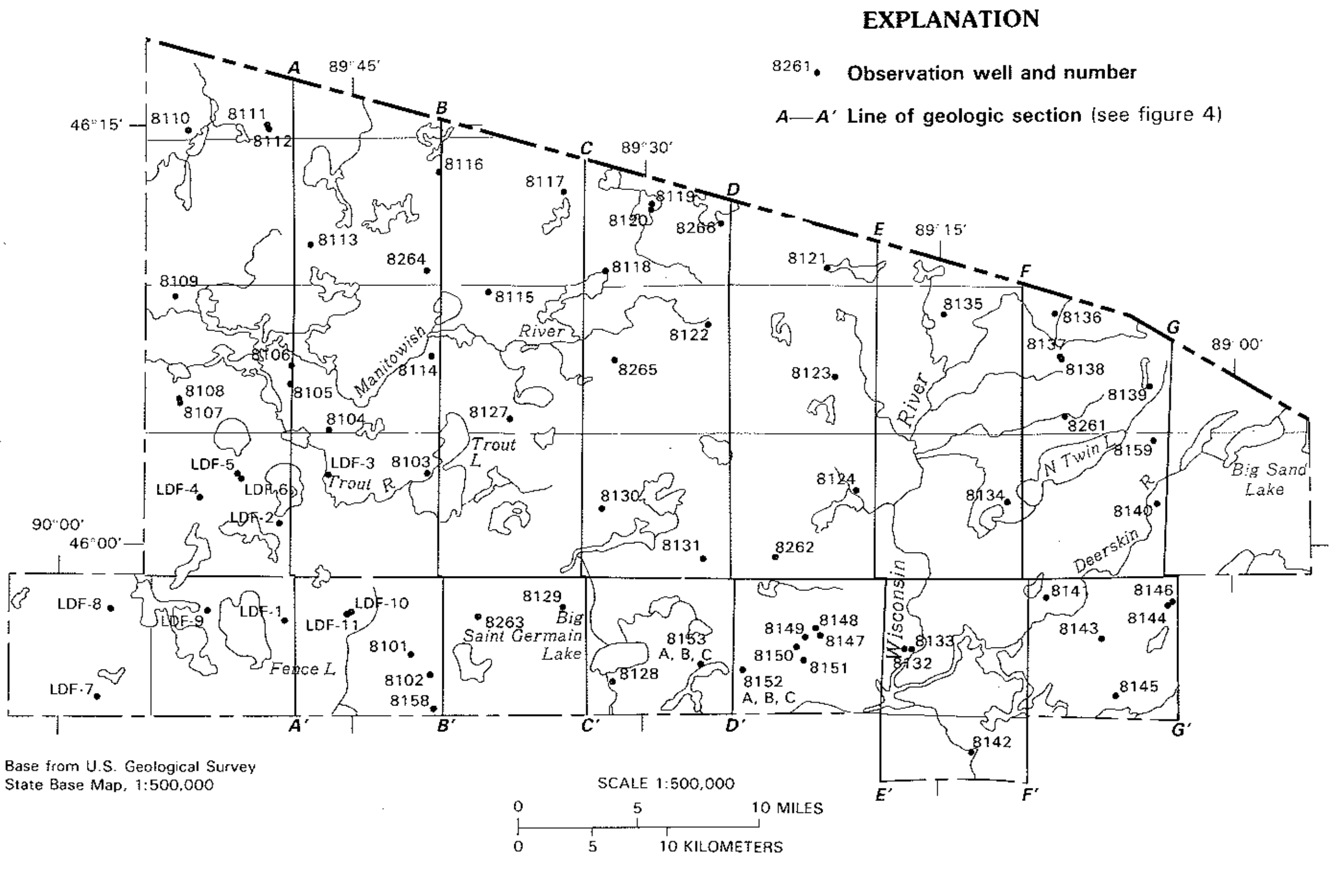

Figure 5. Observation-well locations and numbers, Vilas County, Wisconsin.

Text continues on p. 11

Table 2. *Arithmetic mean, median, highest, and lowest water level, and the range of water-level fluctuations in observation wells, Vilas County, Wisconsin*

[All values are in feet below land surface; negative values are above land surface]

Well number	Number of observations	Mean	Median	High	Low	Range
8101	18	34.10	34.29	31.92	34.67	2.75
8102	16	34.34	34.43	33.59	34.85	1.26
8103	21	28.62	28.69	27.38	29.20	1.82
8104	18	3.24	3.29	1.42	5.05	3.63
8105	16	3.63	3.45	2.07	5.81	3.74
8106	20	12.81	12.34	11.59	15.24	3.65
8107	18	4.34	4.39	3.10	5.24	2.14
8108	18	4.70	4.72	3.66	5.47	1.81
8109	18	12.06	11.74	10.65	14.09	3.44
8110	17	.37	.39	.07	.84	.77
8111	17	2.42	2.24	1.50	4.42	2.92
8112	18	2.90	2.64	1.62	5.02	3.40
8113	18	24.02	23.81	23.28	25.30	2.02
8114	19	17.85	17.53	16.77	19.42	2.65
8115	20	16.55	16.17	15.39	18.64	3.25
8116	14	10.88	10.84	10.50	11.29	.79
8117	18	6.53	6.51	6.10	7.06	.96
8118	18	2.68	2.64	2.48	2.98	.50
8119	17	35.75	35.72	35.00	36.24	1.24
8120	17	35.19	35.05	34.92	35.80	.88
8121	21	31.30	31.22	30.21	32.48	2.27
8122	15	10.67	10.37	9.92	12.36	2.24
8123	20	14.30	14.07	13.53	15.95	2.42
8124	18	10.82	10.57	9.50	12.84	3.34
8125	20	23.59	23.61	22.80	24.13	1.33
8126	21	23.49	23.50	22.70	24.03	1.33
8127	19	29.43	29.22	28.76	30.30	1.54
8128	21	31.91	31.76	31.04	33.08	2.04
8129	18	8.92	8.94	7.81	10.34	2.53
8130	18	4.06	4.01	3.74	4.43	.69
8131	18	14.90	14.69	14.06	16.25	2.19
8132	18	14.77	14.76	14.44	15.17	.73
8133	17	14.99	14.91	14.58	15.88	1.30
8134	20	9.79	10.14	7.66	12.16	4.50
8135	18	15.33	15.04	14.16	17.09	2.93
8136	17	7.17	6.78	6.06	9.17	3.11
8137	18	8.44	8.21	6.14	10.70	4.56
8138	18	10.28	10.28	7.98	11.97	3.99
8139	18	24.31	24.45	23.60	24.77	1.17

Table 2. *Arithmetic mean, median, highest, and lowest water level, and the range of water-level fluctuations in observation wells, Vilas County, Wisconsin—Continued*

[All values are in feet below land surface; negative values are above land surface]

Well number	Number of observations	Mean	Median	High	Low	Range
8140	17	3.10	3.08	2.56	3.60	1.04
8141	18	11.17	10.86	10.41	12.60	2.19
8142	17	4.63	4.61	3.93	5.70	1.77
8143	17	18.57	18.71	17.79	19.04	1.25
8144	17	16.32	16.35	14.44	18.98	4.54
8145	19	16.73	16.53	15.91	18.12	2.21
8146	13	141.40	141.74	135.65	143.01	7.36
8147	16	.75	.70	.08	1.54	1.46
8148	16	.38	.32	–.31	1.20	1.51
8149	16	8.38	8.23	7.87	9.00	1.13
8150	16	17.46	17.36	17.06	18.10	1.04
8151	16	5.32	5.15	4.52	6.35	1.83
8152A	16	6.00	5.77	5.66	6.85	1.19
8152B	16	6.28	6.13	5.84	7.06	1.22
8152C	16	6.34	6.18	6.00	7.07	1.22
8153A	15	.08	.01	–.16	.47	1.07
8153B	15	.05	–.03	–.18	.59	.63
8153C	16	.85	.67	.23	2.03	.77
8158	15	9.55	9.33	9.01	10.43	1.42
8261	3	12.80	12.81	12.65	12.94	—
8262	3	17.18	17.11	17.10	17.34	—
8263	3	19.96	19.91	19.84	20.12	—
8264	3	28.25	28.31	27.95	28.49	—
8265	1	18.00	18.00	18.00	18.00	—
8266	3	3.68	3.70	3.62	3.72	—
LDF1	10	17.49	17.62	16.26	18.33	1.80
LDF2	10	11.85	11.73	10.58	14.90	2.07
LDF3	10	9.18	9.99	6.38	10.55	4.32
LDF4	10	7.71	8.07	6.05	8.46	4.17
LDF5	10	3.56	3.66	2.76	4.21	2.14
LDF6	10	3.73	3.86	2.91	4.35	1.45
LDF7	10	40.08	39.94	39.50	40.61	1.44
LDF8	10	23.14	23.23	21.58	24.44	1.11
LDF9	10	10.10	10.53	8.02	11.39	3.37
LDF10	10	36.31	36.25	35.76	36.85	1.09
LDF11	10	37.04	37.00	36.44	37.53	1.09
LF17	18	31.46	31.42	30.74	32.05	1.31
LF17A	16	31.46	31.42	30.89	32.23	1.34
LFB5	16	22.50	22.42	22.24	22.99	.76
LFS10	17	51.76	51.74	51.07	52.37	1.30
LFS10A	18	52.31	52.29	51.62	52.84	1.22

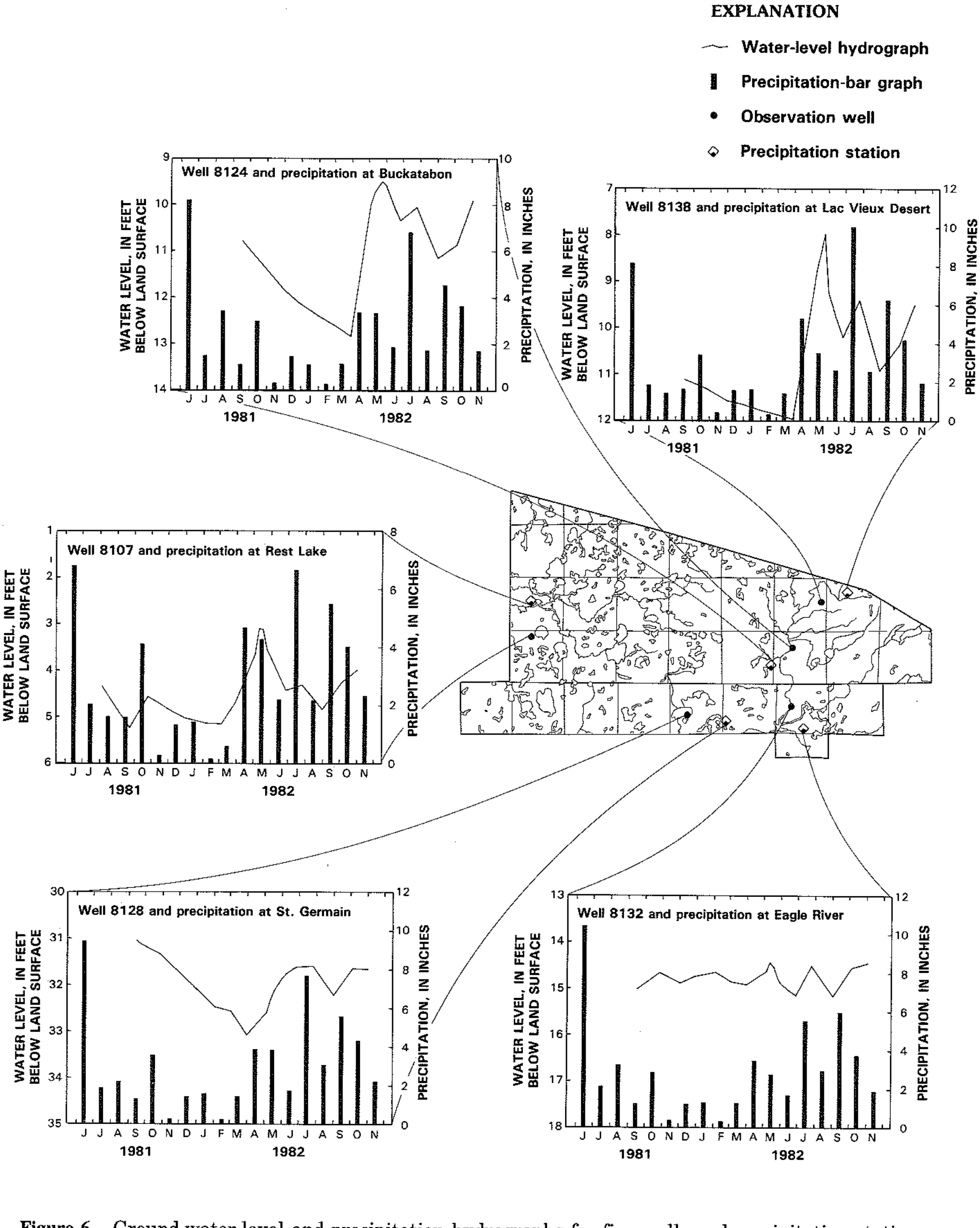

Figure 6. Ground-water-level and precipitation hydrographs for five wells and precipitation stations, Vilas County, Wisconsin.

similar to that of wells 8111 and 8112. There is a lower water level in the deeper well except for one reversal that occurred in May 1982.

Wells 8152*A*, *B*, and *C* are somewhat different because they are located adjacent to a large wetland area; their respective screen depths are 10, 25, and 45 ft below land surface. Hydrographs show that water levels in the two deeper wells were lower than in 8152*A*, but there was no difference in water levels between the deeper wells. This indicates a very shallow recharge condition in the upper part of the aquifer and generally lateral flow at depth. This is to be expected because of the close proximity to the wetland, which is a discharge area.

All of these nests are in recharge areas, as indicated by their hydrographs. The nest including wells 8152*A*, *B*, and *C* is very near to a discharge area, but none of these nests show the upwardly increasing gradient that would occur in a discharge area.

Estimated Recharge

Annual recharge to the water table can be estimated by multiplying the specific yield of the aquifer material by the cumulative rise in water level in a well during 1 year. Table 3 shows recharge estimates for 22 wells, 7 of which were installed in debris-flow materials and 15 in sand and gravel. Estimated specific yields of 0.20 for sand and gravel and 0.10 for debris-flow materials are from Walton (1970, p. 34). The geometric mean of recharge during 1982 for the 22 wells was 8.72 in. (inches). The geometric mean recharge for wells in sand and gravel was 9.94 in., and the geometric mean recharge for wells in debris-flow material was 6.6 in.

Ground-Water Levels

Water-level measurements from 51 observation wells installed as part of this project, 11 observation wells installed as part of a ground-water study on the Lac du Flambeau Indian Reservation, 13 existing observation wells, more than 100 existing domestic wells, and numerous surface-water altitudes that represent ground-water levels, were used to construct a general ground-water-level contour map (pl. 1). This map can be used to infer ground-water movement within the unconsolidated deposits in Vilas County. Recharge areas are generally areas of higher altitude and discharge areas are generally areas of lower altitude. Water moves from recharge areas toward discharge areas. Horizontal ground-water movement generally is perpendicular to the water-level contours. The water table generally resembles a subdued ver-

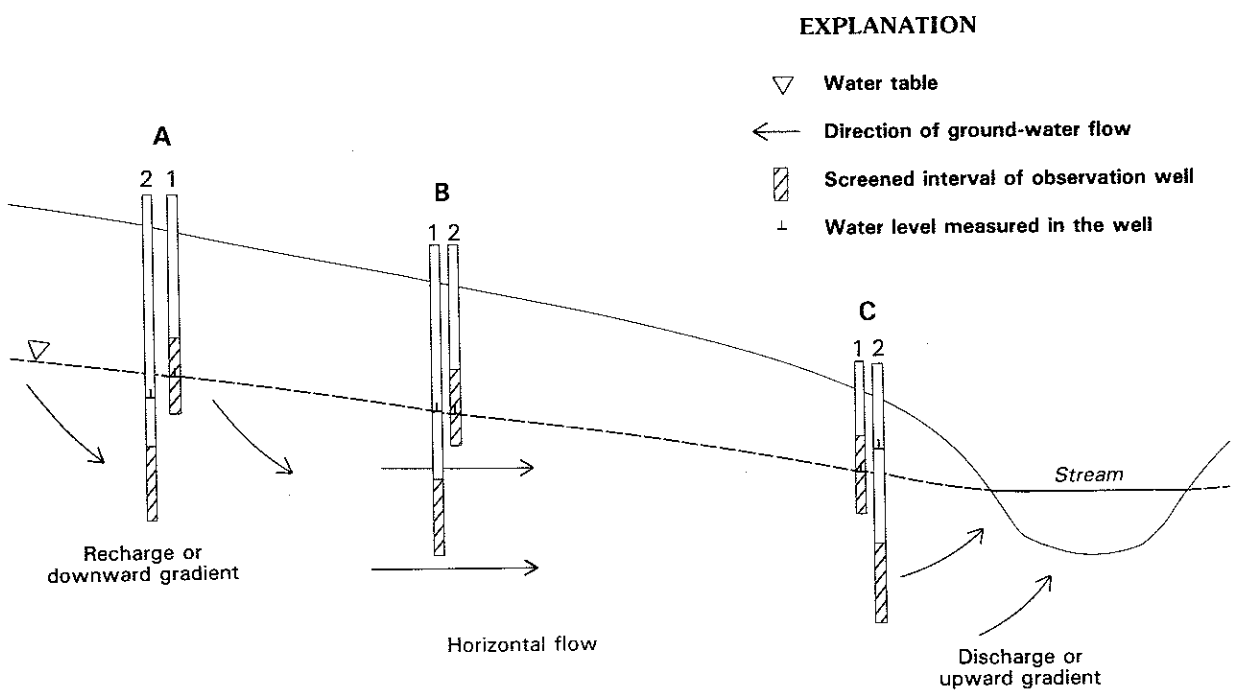

Figure 7. Hypothetical ground-water flow system showing downward and upward vertical hydraulic gradients.

sion of the topography; it is nearest the surface in valleys and low areas and deepest beneath the hills and ridges.

Most of the rivers and lakes in the county are surface expressions of the water table, but many wetland areas in northwestern and eastern Vilas County are not. In these areas, infiltration to the water table is inhibited by till and debris-flow deposits with low permeability. This is particularly prevalent in the interdrumlin wetlands near Phelps, Wis., where the wetlands are 80 to 100 ft above the regional water table.

Ground-Water Availability

The geologic sections in figure 4 show the general relation between the sand and gravel deposits and the till and debris-flow deposits. The sand and gravel deposits in Vilas County are aquifers but the till and debris-flow units, even when saturated, generally do not yield sufficient amounts of water for domestic use.

Table 4 describes the depth and geologic composition of the materials encountered when installing 51 observation wells shown in figure 5. Ten were screened in till or debris-flow sediment, 1 in lacustrine clayey sand, and 40 in fluvial sand and gravel. Till or debris-flow sediment were encountered at 23 of the sites during drilling.

Table 4 also shows the results of tests performed on 49 of the wells to estimate horizontal hydraulic conductivity, which is a measure of the rate that water will flow through the material adjacent to the well screen. The test involved inserting a rod of

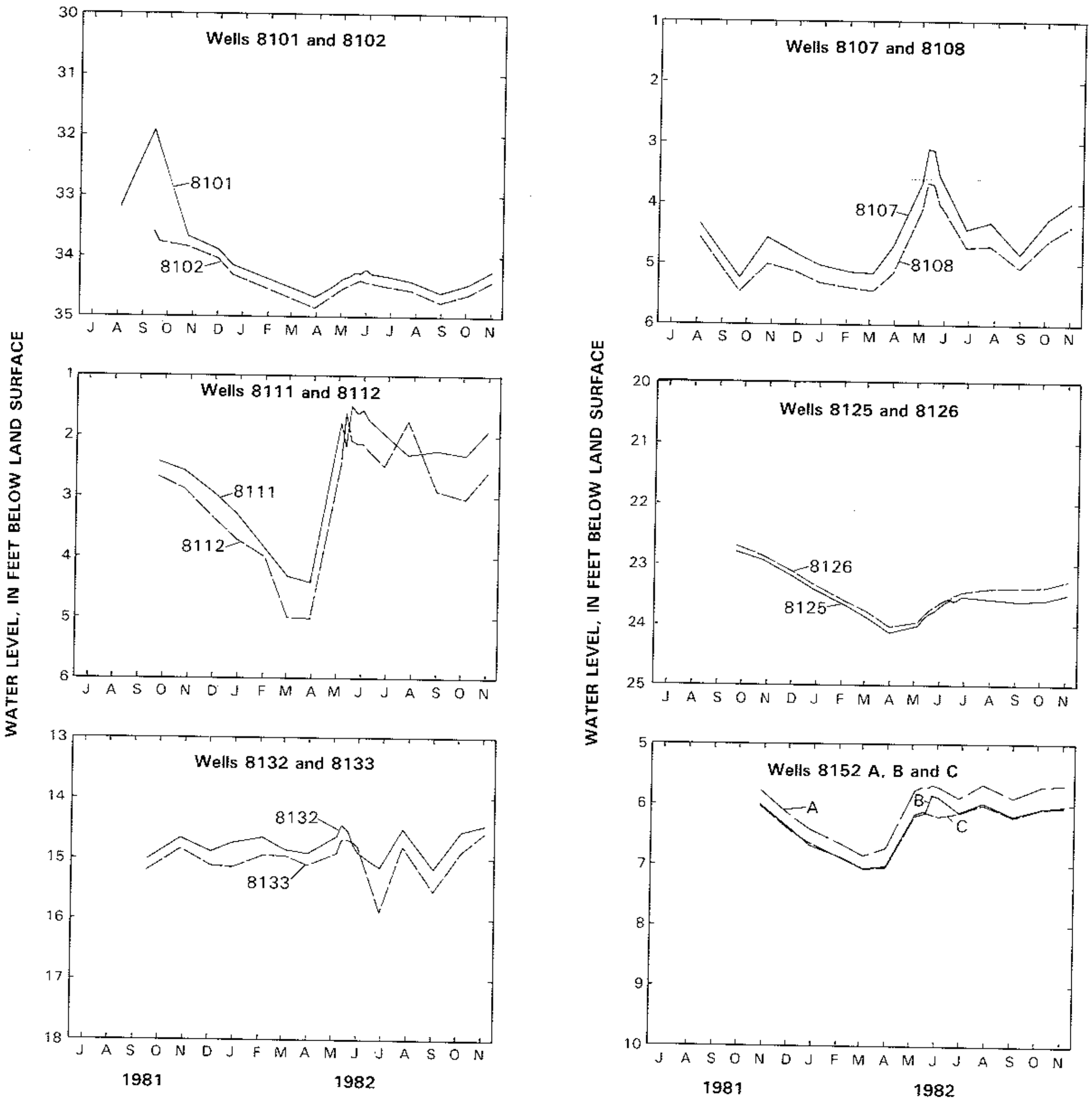

Figure 8. Hydrographs of nested wells.

known volume into a well below the water table. After the water level returned to its original level, the rod was rapidly removed from the water and the rate at which the water level returned to normal was measured using a transducer in the well. These measurements were then used in calculations as described by Bouwer and Rice (1976).

The geometric mean of hydraulic conductivities from 31 of the 39 wells finished in sand and gravel is 2.8×10^{-4} ft/s (feet per second) and the geometric mean of hydraulic conductivities from the 10 wells finished in till or debris-flow materials is 2.73×10^{-6} ft/s.

The transmissivity of an aquifer is defined as the rate at which water will flow through a vertical strip of aquifer 1-ft wide extending through the full saturated thickness. It is calculated by multiplying the horizontal hydraulic conductivity by the aquifer thickness. Aquifers with transmissivities greater than 0.016 ft^2/s (square feet per second) are likely sources of water for municipal, industrial, or irrigation purposes; aquifers with transmissivities of 0.0016 ft^2/s will provide only enough water for limited domestic use (Universal Oil Products Company, 1972).

Transmissivity estimates can be made for the aquifers in Vilas County using the equation

$$T = Kb,$$

where T is the transmissivity,
K is the hydraulic conductivity, and
b is the aquifer thickness.

For example, wells 8101 and 8102 are both finished in sand and gravel (table 4) that extends from the surface to at least 68 ft below land surface. The lowest water level measured in 1981 and 1982 was about 35 ft below land surface. Subtracting 35 from 68 ft yields the minimum saturated aquifer thickness of 33 ft. Multiplying this by the horizontal hydraulic conductivity of well 8101 (5×10^{-4} ft/s) (table 4) gives

Table 3. *Recharge estimates for 22 wells*

Well number	Recharge (inches)	Specific yield	Geometric mean (inches)
	Wells finished in debris-flow materials		
8105	8.75	0.10	
8124	7.3	.10	
8134	10.6	.10	
8137	9.4	.10	6.6
8141	6.0	.10	
8149	2.8	.10	
8151	5.1	.10	
	Wells finished in sand and gravel		
8106	14.8	.20	
8111	13.4	.20	
8112	15.0	.20	
8113	8.4	.20	
8115	12.2	.20	
8117	4.4	.20	
8118	5.6	.20	
8121	10.6	.20	9.94
8122	10.4	.20	
8127	9.6	.20	
8128	9.0	.20	
8129	11.2	.20	
8135	12.4	.20	
8142	9.8	.20	
8145	9.4	.20	
		Total	8.72

Text continues on p. 16

Table 4. *Geologic log and horizontal estimates of hydraulic conductivity for observation wells, Vilas County, Wisconsin*

Well no.	Well depth (feet)	Horizontal hydraulic conductivity (feet per second)	Geologic log	
8101	38	5×10^{-4}	0– 38 ft	Sand and gravel
8102	64	6×10^{-4}	0– 64 ft	Sand and gravel
8103	50	1×10^{-4}	0– 12 ft	Boulder till
			12– 50 ft	Sand
8104	57	7×10^{-5}	0– 25 ft	Sand and gravel
			25– 30 ft	Sandy till
			30– 50 ft	Sand and gravel
			50– 57 ft	Sandy till
8105	44	4×10^{-6}	0– 40 ft	Sand and gravel
			40– 44 ft	Sandy till
8106	26	3×10^{-4}	0– 3 ft	Sand and gravel
			3– 7 ft	Sandy till
			7–103 ft	Fine to medium sand
8107	30	1×10^{-5}	0– 8 ft	Medium sand
			8– 16 ft	Coarse sand
			17– 23 ft	Sandy till
			23– 27 ft	Medium sand
			27– 30 ft	Coarse sand and gravel
8108	37	1×10^{-5}	0– 8 ft	Medium sand
			8– 16 ft	Coarse sand
			17– 23 ft	Sandy till
			23– 27 ft	Medium sand
			27– 37 ft	Coarse sand and gravel
8109	33	3×10^{-4}	0– 33 ft	Medium to coarse sand
8110	23	1×10^{-6}	0– 12 ft	Organic mud and peat
			12– 23 ft	Silty till
8111	43	4×10^{-4}	0– 43 ft	Graded sand
8112	82	7×10^{-5}	0– 83 ft	Graded sand
8113	38	7×10^{-4}	0– 15 ft	Clayey silty till
			15– 38 ft	Sand and gravel
8114	53	4×10^{-4}	0– 18 ft	Medium sand
			18– 23 ft	Silty sand
			23– 53 ft	Medium sand
8115	100	1×10^{-4}	0–100 ft	Sand and gravel
8116	25	3×10^{-6}	0– 25 ft	Sandy till
8117	33	3×10^{-5}	0– 8 ft	Sand and gravel
			8– 27 ft	Silty till
			27– 33 ft	Sand and gravel

Table 4. *Geologic log and horizontal estimates of hydraulic conductivity for observation wells, Vilas County, Wisconsin—Continued*

Well no.	Well depth (feet)	Horizontal hydraulic conductivity (feet per second)	Geologic log	
8118	18	2×10^{-4}	0– 5 ft	Silty till
			5–18 ft	Coarse sand and gravel
8119	54	9×10^{-7}	0– 4 ft	Fine sand
			4–19 ft	Sandy till
			19–35 ft	Medium sand (red)
			35–48 ft	Medium sand (gray)
			48–54 ft	Silty sandy till
8120	42	Not available	0– 4 ft	Fine sand
			4–19 ft	Sandy till
			9–35 ft	Medium sand (red)
			5–42 ft	Medium sand (gray)
8121	53	1×10^{-4}	0–18 ft	Sand and gravel
			18–53 ft	Medium sand
8122	28	3×10^{-4}	0–28 ft	Medium sand
8123	28	7×10^{-4}	0–28 ft	Medium sand
8124	23	7×10^{-5}	0–10 ft	Sand and gravel
			10–23 ft	Silty sand
8125	28	3×10^{-4}	0–28 ft	Medium sand
8126	49	4×10^{-4}	0–49 ft	Medium sand
8127	38	5×10^{-4}	0–38 ft	Medium sand
8128	50	3×10^{-6}	0–50 ft	Sand and gravel
8129	23	1×10^{-4}	0– 8 ft	Sand and gravel
			8–17 ft	Sandy till
			17–23 ft	Coarse sand
8130	18	3×10^{-4}	0– 4 ft	Medium sand
			4–18 ft	Sand and gravel
8131	28	7×10^{-5}	0–28 ft	Sand and gravel
8132	38	3×10^{-4}	0–38 ft	Sand and gravel
8133	60	1×10^{-4}	0–60 ft	Sand and gravel
8134	23	5×10^{-6}	0– 8 ft	Coarse sand
			8–15 ft	Sand and gravel
			15–23 ft	Sandy till
8135	33	4×10^{-4}	0–33 ft	Medium sand
8136	23	2×10^{-4}	0– 10 ft	Coarse gravel
			10–23 ft	Sand and gravel
8137	23	1×10^{-6}	0– 7 ft	Medium sand
			7–23 ft	Sandy till
8138	48	Not available	0– 7 ft	Medium sand
			7– 25 ft	Fine sand and silt
			26–48 ft	Clayey sand

Table 4 continues

Table 4. *Geologic log and horizontal estimates of hydraulic conductivity for observation wells, Vilas County, Wisconsin—Continued*

Well no.	Well depth (feet)	Horizontal hydraulic conductivity (feet per second)	Geologic log	
8139	38	2×10^{-4}	0– 7 ft	Bouldery till
			7– 38 ft	Sand and gravel
8140	23	2×10^{-4}	0–23 ft	Medium sand
8141	28	2×10^{-6}	0–17 ft	Sand and gravel
			17–28 ft	Silty till
8142	19	2×10^{-4}	0– 4 ft	Organic mud, silt, and sand
			4–12 ft	Silty till
			12–19 ft	Fine sand
8143	78	1×10^{-4}	0–36 ft	Sand and gravel
			36–47 ft	Silty till
			47–78 ft	Sand and gravel
8144	33	4×10^{-4}	0– 3 ft	Topsoil
			3– 8 ft	Silty till
			8–13 ft	Sand and gravel
			13–33 ft	Sand and gravel
8145	33	2×10^{-4}	0–33 ft	Sand and gravel
8261	33	1×10^{-6}	0–15 ft	Bouldery till
			15–33 ft	Sandy till
8262	30	5×10^{-4}	0–30 ft	Sand and gravel
8263	28	4×10^{-4}	0–28 ft	Medium sand
8264	42	8×10^{-5}	0–17 ft	Silty till
			17–42 ft	Sand and gravel
8265	31	1×10^{-4}	0–31 ft	Medium sand
8266	22	3×10^{-6}	0–11 ft	Medium sand
			11–22 ft	Silty till

a transmissivity of 0.017 ft²/s, which indicates that the aquifer probably could yield enough water for municipal, industrial, or irrigation purposes.

Conversely, well 8110 is finished in silty till to 23 ft deep. The lowest water-level measurement was about 1 ft below land surface, so the saturated thickness is at least 22 ft. Multiplying this by the horizontal hydraulic conductivity of 1×10^{-6} ft/s yields a transmissivity of 0.000022 ft²/s, which indicates that the material would not be adequate for domestic supply.

The horizontal hydraulic conductivities of the sand and gravel wells are on the order of 1×10^{-4} ft/s. Rearranging equation 1 to

$$b=\frac{T}{K}$$

and using 0.016 ft²/s as T and dividing by 1×10^{-4} shows that the aquifer with a hydraulic conductivity of 1×10^{-4} ft/s would need to be about 160 ft thick to be sufficient as a high-capacity water supply. Using a T value of 0.0016 ft²/s shows that this same aquifer would only have to be 16 ft thick to be adequate for a domestic supply.

Using a K value of 1×10^{-6} to represent the wells finished in till or debris-flow sediment shows that the thickness of these materials would need to be 160 ft for most domestic purposes and 1,600 ft for municipal purposes. Although the above calculations are estimates and presented as informational tools only, this information indicates that where the sand and gravel deposits are thick enough, they probably will yield sufficient amounts of water for most purposes. The till and debris-flow deposits, however, probably are not reliable sources of water.

Ground-Water Pumpage and Use

About 546 million gallons of ground water were pumped in Vilas County in 1980 (Lawrence and Ellefson, 1982) and in 1984 (B. R. Ellefson, U.S. Geological Survey, written commun., 1986) the amount had increased to about 599 million gallons. This water was used for residential, industrial, commercial, irrigation, and municipal purposes, as shown below.

Water use	Amount pumped in 1980 (gallons)	Amount pumped in 1984 (gallons)
Residential, public	22,000,000	26,300,000
Residential, private	255,700,000	318,500,000
Industrial, public and private	9,000,000	630,000
Commercial, public and private	156,000,000	149,100,000
Irrigation, private	12,000,000	26,800,000
Municipal and other	91,300,000	78,100,000
TOTAL	546,000,000	599,400,000

Residential water use includes all household uses and farm use, such as watering stock and washing equipment. Public-supply residential use is water used by residences on a public or private water-distribution system serving five or more homes. Private-supply residential use includes homes and farms with their own private wells.

Commercial use refers to water used by businesses that do not produce a product. Examples include filling stations, retail stores, and restaurants.

Industrial use refers to water used in plants that manufacture products. Industrial water is used for cooling, sanitation, air conditioning, irrigation of plant grounds, and production.

Irrigation use is water used for sprinkling golf courses and irrigating crops. Some public-supply water is used for lawn sprinkling but is included in municipal use.

Municipal water use is pumped by municipalities but not sold to customers. It includes water used to flush water lines, fight fires, sprinkling, use in municipal buildings and institutions, and water lost in the distribution system through leaks or broken mains.

SURFACE WATER

The four major surface-water drainage basins in the county are shown in figure 1. The Manitowish River drains much of the western part of the county and eventually joins the Chippewa River and then the Mississippi River. The Wisconsin River drains the central part of the county and eventually discharges into the Mississippi River. The northern part of the county is drained by the Presque Isle and the Ontonagon Rivers, which discharge into Lake Superior, and the extreme eastern part of the county is drained by the Brule River, which eventually discharges into Lake Michigan.

Surface-Water Discharge

The many lakes and wetlands in Vilas County store surface-water runoff and release it to the creeks and streams slowly over extended periods of time. Peak runoff is reduced and high base flows are prolonged by the basin and wetland storage and from the shallow water table. Base flows are reduced during long drought periods because of evapotranspiration.

Flood-flow characteristics for two partial-record stations located in Vilas County (Muskrat Creek at Conover and Mishonagon Creek near Woodruff) and two long-term gaging stations (Wisconsin River at Tomahawk in Oneida County and Prairie River at Merrill in Lincoln County) are listed in table 5. Most of the drainage area upstream from the long-term station on the Wisconsin River is located in Vilas County, and the Prairie River is included for comparison. All four stations are within the Wisconsin River basin.

The probabilities of occurrence listed in table 6 represent the results of a log-pearson regression analysis. A probability of occurrence of 50 percent means that the corresponding discharge has a 50-percent chance of occurring within any given year. A probability of occurrence of 20 percent means that the corresponding discharge has a 20-percent chance of occurring within any given year. The 1- and 2-percent-probability discharges represent major floods.

The Prairie River at Merrill is included in the table because its drainage area does not include the many lakes and wetlands in Vilas County. Comparison of the discharge per square mile for the 4-, 2-, and 1-percent-probability discharges (table 6) shows that the peak flows are much lower in the Vilas County basins.

Low-flow measurements were made on the Manitowish River in western Vilas County and the Deerskin River in eastern Vilas County (fig. 1). The discharge per square mile (table 5) is believed to represent base-flow conditions because there had been no measurable precipitation for the preceding 12 days. The base-flow discharge of 0.68 and 0.86 $(ft^3/s)/mi^2$ (cubic feet per second per square mile) of drainage area for Vilas County streams is much higher than the 0.46 $(ft^3/s)/mi^2$ discharge for the Prairie River at Merrill.

GENERAL HYDROLOGIC BUDGET OF VILAS COUNTY

Assuming that precipitation in Vilas County that enters the ground-water reservoir eventually discharges to the nearby lakes and streams and exits the county as runoff, the general water budget can be expressed as

$$P = ET \pm Q = e$$

where P = precipitation,
ET = evapotranspiration,
Q = runoff, and
e = error

The average annual precipitation of Vilas County is approximately 34 in. and the average annual runoff is approximately 13.5 in. (U.S. Geological Survey, 1985, p. 487).

Evapotranspiration can be divided into two components—free water-surface evaporation (from lake and stream surfaces) and land-surface evapotranspiration. The annual free water-surface evaporation is estimated to be about 25 in. (Veihmeyer, 1964, p. 9) and the annual land evapotranspiration is estimated to be approximately 75 percent of the free water-surface evaporation (Douglas Clark, Wisconsin State Climatologist, oral commun., 1987). Thus, assuming that 15 percent of Vilas County is actually free water surface, evapotranspiration can be calculated using the following equation:

$$ET \frac{\text{inches}}{\text{year}} = 0.15 \left(25 \frac{\text{inches}}{\text{year}}\right) + 0.85\ (0.75)\ \left(25 \frac{\text{inches}}{\text{year}}\right)$$

$$ET = 19.69 \text{ inches per year.}$$

Using these estimates the budget equation yields

$$34 \frac{\text{inches}}{\text{year}} = 19.69 \frac{\text{inches}}{\text{year}} \times 13.5 \frac{\text{inches}}{\text{year}} \pm e$$

or

$$34 \frac{\text{inches}}{\text{year}} = 33.19 \frac{\text{inches}}{\text{year}} \pm \text{error}$$

The error is a reflection of several factors, including difficulties in measuring evapotranspiration and runoff.

WATER QUALITY

GROUND-WATER QUALITY

The analyses of ground-water samples indicate that the quality of ground water in Vilas County is generally good and suitable for most uses. Ground-water samples were collected from 50 observation wells in August 1982, and from 12 wells in August 1983. Three to five well volumes of water were removed from each well prior to the sample collection to obtain a sample representative of the water in the aquifer. The samples were collected with a stainless-steel sampling pump or a PVC bailer. The samples were then sent to the U.S. Geological Survey Central Laboratory for analysis for common inorganic constituents, trace metals, and nutrients.

The results of analysis for each well are listed in table 7. The arithmetic mean, median, lowest concentration, and highest concentration for all samples collected in 1982 for each constituent are listed in table 8. The median value of ground-water-quality characteristics of samples and water-quality standards from ground-water-province III (Kammerer, 1984) also is listed in table 8. Ground-water-province III (fig. 9), which includes Vilas County, is the area where the sand-and-gravel aquifer overlies Precambrian bedrock. The medians listed are obtained from all available analyses within province III for each constituent.

Table 5. *Base-flow characteristics at three surface-water-monitoring sites*

Gaging station	Drainage area (square miles)	Discharge, August 24, 1981 (cubic feet per second)	Discharge per square mile, August 24, 1981 (cubic feet per square mile)
Manitowish River	250	170	0.68
Deerskin River	65	56	.86
Prairie River at Merrill	184	85	.46

Calcium, magnesium, and bicarbonate are the major dissolved constituents in ground water in Vilas County. Figure 10 shows trilinear diagrams for the analyses from the 50 wells sampled in Vilas County and for analyses of ground water for the entire province. Trilinear diagrams are graphic representations of the major cation and major anion composition in water. The diagrams were constructed by converting the concentrations of the cations (calcium, magnesium, and sodium plus potassium) and the anions (sulfate, chloride, and bicarbonate plus carbonate) from milligrams per liter (mg/L) to milliequivalents per liter (meq/L). The percentage of each cation was plotted on the triangle at the lower left and the percentage of each anion was plotted in the triangle at the lower right of the diagram. A line was then drawn parallel to the outer edge of each triangle through the diamond at the top. The intersection of those two lines is a representation of the total cation-anion composition of the water.

The diagrams on figure 10 show that calcium and magnesium together comprise more than 80 percent of the cations, and carbonate and bicarbonate comprise more than 75 percent of the anions in Vilas

Table 6. *Probabilities of occurrence of peak surface-water discharges at four streamflow-gaging stations*

[ft^3/s = cubic foot per second; $(ft^3/s)/mi^2$ = cubic foot per second per square mile]

Probability of occurrence (percent)	Discharge (ft^3/s)	Discharge per square mile [$(ft^3/s)/mi^2$]
	Muskrat Creek at Conover, Wis. (15 years of record, 10.2-mi^2 drainage area)	
50	66.2	6.5
20	90.6	8.9
10	106	10.4
4	125	12.3
2	138	13.5
1	121	14.8
	Mishanagon Creek near Woodruff, Wis (27 years of record, 17.6-mi^2 drainage area)	
50	68.6	3.9
20	86.5	4.9
10	97.3	5.5
4	110	6.3
2	119	6.8
1	127	7.2
	Wisconsin River at Rainbow Lake, Tomahawk, Wis. (48 years of record, 757-mi^2 drainage area)	
50	1,780	2.4
20	1,2500	2.3
10	2,940	3.9
4	3,450	4.6
2	3,810	5.0
1	4,140	5.5
	Prairie River at Merrill, Wis. (52 years of record, 184-mi^2 drainage area)	
50	1,420	7.7
20	2,200	12.0
10	2,740	14.9
4	3,450	18.8
2	4,000	21.7
1	4,550	24.7

County and in the entire province. Water samples from Vilas County that greatly differ from the majority are from wells 8125, 8131, 8132, 8133, 8142, 8152*A*, 8261, and 8266. The cation-anion percentages for these wells and the median percentages for each group of wells are listed in table 9. The median concentration is a better representation of the general background concentration than the arithmetic mean because the mean may be affected by a few very high or low values. Comparison of the data for each well with those of the median values clearly points out the differences. Water from wells 8152*A* and 8261 had higher sulfate percentages and water from wells 8125, 8131, 8132, 8133, 8142, and 8266 had higher percentages of sodium, potassium, and chloride. These wells are located near roads, and it seems likely that the use of road salt has degraded the ground water.

With the exception of the wells discussed above, the concentrations of the common inorganic constituents fall well within the range of those found throughout province III and, in most cases, are much lower than elsewhere in the province.

pH and Specific Conductance

The pH is a measure of the hydrogen-ion activity of water and is used to express relative acidity or alkalinity on a scale of 1 through 14. A pH of 7.0 is neutral; values less than 7.0 express acidic conditions and values greater than 7.0 represent alkaline conditions.

pH values of ground water in Vilas County ranged from 5.3 to 8.3 and had a median of 6.8 (table 8). Samples from wells 8131, 8134, 8140, 8142, 8152*A*, and 8266 had pH values below 6, indicating relatively acidic conditions. Samples from wells 8137 and 8138 exhibited pH values of 8.0 and above, indicating relatively alkaline conditions. All remaining samples were within the range of 6 to 8.

Specific conductance is the ability of a substance to conduct an electric current (Hem, 1985). The presence of charged ions in water makes it conductive and, as the concentrations increase, the conductance of the water increases. The conductance measurement, therefore, provides a relative indication of total ion concentration.

Specific-conductance values ranged from 46 to 1,100 μS/cm (microsiemens per centimeter at 25 °C), with a median value of 104 μS/cm. The median value for all samples from province III is 222 μS/cm.

Dissolved Solids

Dissolved-solids concentration is a measure of the total amount of material dissolved in the water. The major constituents that comprise dissolved solids in ground water in Vilas County are calcium, magnesium, and bicarbonate.

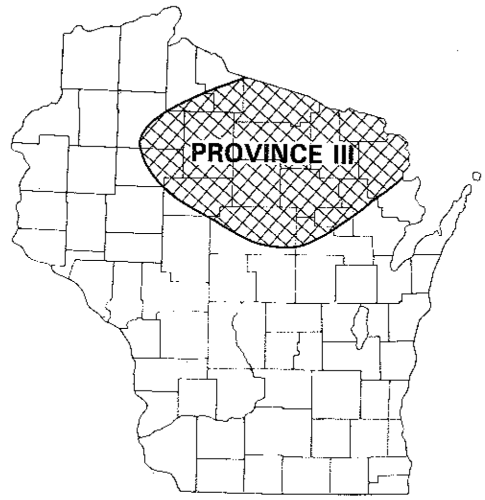

Figure 9. Ground-water-province III.

Dissolved solids in Vilas County ranged from 31 to 453 mg/L, with a median of 76 mg/L (table 8). Concentrations from 5 of the 50 wells sampled exceeded 200 mg/L; the highest were 302 mg/L in well 8132 and 453 mg/L in well 8131. None of the wells sampled exceeded the 500 mg/L State drinking-water standard (Wisconsin Department of Natural Resources, 1978), and the median value for the wells in Vilas County was much less than the 146-mg/L median value for the entire province (Kammerer, 1984).

Hardness

Hardness ($CaCO_3$) of water is caused by the presence of calcium and magnesium; it may be described by the following classification scheme (Durfor and Becker, 1964, p. 27):

Hardness range (mg/L as calcium carbonate)	Hardness description
0–60	Soft
61–120	Moderately hard
121–180	Hard
>180	Very hard

Water from wells 8108 and 8116 is classified as being hard, and samples from 11 other wells are classified as being moderately hard; samples from 37 wells are classified as being soft. The hardness values range from 5 to 160 mg/L and the median for Vilas County is 35.6 mg/L compared to 111 mg/L for the entire province (P. A. Kammerer, U.S. Geological Survey, written commun., 1985).

Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of solutes contained in water and is primarily caused by the presence of bicarbonate.

The alkalinity values in Vilas County water ranged from 2 to 152 mg/L (table 8). The median value of 28 mg/L is much less than the 102-mg/L median value for province III (P. A. Kammerer, U.S. Geological Survey, written commun., 1985). The very low alkalinity values reflect the lack of carbonate minerals in the Precambrian bedrock and Pleistocene deposits. The low alkalinity values indicate that the acid-neutralizing capability of these materials is limited, which can increase the potential for water-quality degradation by acid precipitation.

Calcium

Calcium concentrations ranged from 1.3 to 44 mg/L and had a median value of 10.1 mg/L. The median concentration for province III is 28 mg/L (P. A. Kammerer, U.S. Geological Survey, written commun., 1985). Calcium is normally the predominant cation in ground water, as indicated by the trilinear diagrams (fig. 10).

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin*

[μS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Sodium, dissolved (mg/L as Na)	Alkalinity lab (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
8101	08-03-82	75	6.1	16.0	25	7.0	1.8	0.50	2.1	22	3.0
8102	08-03-82	104	6.5	18.0	28	7.1	2.4	.10	1.6	18	4.0
8102	08-24-83	910	6.9	13.0	—	—	—	—	—	—	—
8103	08-03-82	122	8.2	16.0	45	12	3.7	.50	2.2	47	8.0
8104	08-03-82	268	7.4	15.0	100	33	5.1	.70	2.1	110	2.0
8105	08-04-82	252	7.5	13.0	120	39	4.9	.70	2.0	122	<1.0
8106	08-04-82	138	6.9	10.0	55	16	3.7	.40	1.9	37	8.0
8107	08-04-82	62	6.6	13.0	22	6.7	1.3	.20	1.1	19	3.0
8108	08-04-82	352	6.8	11.0	130	41	6.3	1.3	2.1	137	1.0
8108	08-24-83	390	6.9	15.0	—	—	—	—	—	—	—
8109	08-04-82	120	7.4	11.0	48	11	5.1	.50	1.6	46	5.0
8111	08-04-82	175	6.5	12.0	46	13	3.3	.40	1.8	51	<1.0
8111	08-24-83	172	6.8	15.0	—	—	—	—	—	—	—
8112	08-04-82	226	7.0	13.0	100	35	3.2	.50	1.9	103	1.0
8113	08-04-82	180	6.6	13.0	63	16	5.5	.40	2.0	52	5.0
8113	08-24-83	128	6.7	13.0	—	—	—	—	—	—	—
8114	08-05-82	119	7.8	14.0	49	14	3.4	.50	1.7	44	5.0
8115	08-05-82	165	7.7	11.0	76	25	3.2	.30	1.6	76	<1.0
8116	08-05-82	359	7.3	18.0	160	44	12	.70	4.6	152	<1.0
8117	08-05-82	178	6.8	13.0	74	21	5.2	.60	2.6	68	8.0
8117	08-25-83	197	7.4	12.5	—	—	—	—	—	—	—
8118	08-05-82	118	6.7	13.0	42	11	3.5	1.0	2.0	35	10
8120	08-17-82	295	7.2	9.0	100	31	5.7	1.7	4.3	118	4.0
8121	08-17-82	100	6.5	11.5	37	11	2.3	.70	3.0	35	10
8122	08-23-82	61	6.4	11.0	20	5.2	1.7	.50	1.0	24	3.0
8123	08-23-82	87	7.5	11.0	34	9.1	2.8	.60	1.3	36	5.0
8124	08-23-82	46	6.2	11.0	11	3.3	.7	.40	1.1	13	6.0
8125	08-18-82	230	6.2	10.5	50	14	3.6	1.6	13	16	4.0
8126	08-23-82	53	7.8	10.0	18	4.7	1.6	.30	1.1	20	5.0
8127	08-05-82	71	6.9	13.0	27	7.6	2.0	.30	1.6	24	5.0
8128	08-23-82	74	7.5	9.0	25	7.0	1.8	.50	1.7	26	6.0

Table 7 continues

Magnesium

Magnesium concentrations ranged from 0.3 to 12 mg/L and had a median concentration of 2.9 mg/L. The median concentration for province III is 10 mg/L (P. A. Kammerer, U.S. Geological Survey, written commun., 1985). Magnesium had the second highest cation concentration in all but seven wells.

Sodium

Sodium concentrations ranged from 0.3 to 170 mg/L, but the median value of only 1.9 mg/L indicates that most concentrations were low. The median value for samples in province III is 3.0 mg/L (P. A. Kammerer, U.S. Geological Survey, written commun., 1985).

Relatively high sodium values are present only in the aforementioned wells where contamination from road salt is suspected. Drinking water with less than 20 mg/L of sodium is recommended for persons on sodium-restricted diets (National Academy of Sciences, National Academy of Engineering, 1973, p. 88). Sodium concentrations in wells 8131, 8132, and 8133 exceed that recommended limit.

Potassium

Potassium concentrations ranged from 0.1 to 2.2 mg/L in Vilas County and had a median value of 0.6

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin—Continued*

[µS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Potassium, dissolved (mg/L as K)	Sodium, dissolved (mg/L as Na)	Alkalinity lab (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
8130	08-23-82	138	6.9	12.0	41	11	3.3	.80	1.7	41	6.0
8131	08-18-82	1,100	5.7	12.0	25	7.5	1.5	2.2	170	20	18
8132	08-24-82	520	6.3	9.0	86	24	6.4	1.2	59	17	6.0
8132	08-25-83	240	6.2	18.0	—	—	—	—	—	23	—
8133	08-17-82	435	7.1	12.5	110	29	8.5	1.7	28	68	16
8134	08-18-82	65	5.5	11.0	21	5.1	2.0	1.6	2.1	18	5.0
8134	08-25-83	48	5.8	18.0	—	—	—	—	—	—	—
8135	08-23-82	76	7.7	9.0	30	8.5	2.1	<.10	1.3	31	1.0
8136	08-24-82	64	6.6	8.5	25	6.8	2.0	.70	1.8	24	8.0
8137	08-24-82	160	8.0	10.0	72	20	5.3	.90	3.2	70	7.0
8138	08-24-82	196	8.3	9.0	89	24	7.1	.70	3.0	85	2.0
8139	08-18-82	80	6.0	12.0	17	4.8	1.1	.60	1.6	23	7.0
8139	08-25-83	44	6.2	11.0	—	3.3	—	—	—	15	—
8140	08-17-82	60	5.3	13.0	—	—	—	—	—	9	4.0
8140	08-25-83	46	5.6	18.0	17	5.4	.93	.90	1.1	9	4.0
8141	08-24-82	184	7.8	11.0	84	21	7.6	.30	2.9	86	5.0
8142	08-18-82	100	5.7	10.5	24	6.1	2.1	.80	8.5	12	9.0
8143	08-24-82	75	7.0	8.0	29	6.7	2.9	.30	1.9	28	7.0
8144	08-24-82	78	6.7	8.0	31	6.6	3.4	.30	2.6	28	8.0
8144	08-25-83	76	6.6	12.0	—	—	—	—	—	—	—
8145	08-24-82	81	6.4	8.0	28	7.5	2.3	.40	2.6	20	3.0
8152A	08-25-82	83	5.8	17.0	5	1.3	.42	.90	.30	2.0	12
8152B	08-16-82	70	6.4	14.5	19	5.3	1.5	.20	1.7	17	7.0
8152C	08-25-82	51	7.8	11.0	16	5.8	.31	.20	1.1	18	3.0
8261	08-24-82	57	6.2	8.0	19	5.6	1.1	.60	1.4	11	11
8262	08-25-82	48	6.4	11.0	12	3.4	.85	.50	1.1	17	6.0
8263	08-25-82	60	7.1	9.0	21	5.7	1.6	.40	1.4	11	6.0
8263	08-23-82	64	6.9	9.0	21	5.8	1.6	.80	1.2	21	7.0
8264	08-05-82	162	6.8	11.0	66	19	4.4	.70	1.9	72	3.0
8266	08-05-82	420	5.7	13.0	43	13	2.5	.90	28	16	14

mg/L. The median value for province III is 1.0 mg/L (P. A. Kammerer, U.S. Geological Survey, written commun., 1985).

Iron

Iron concentrations ranged from <3 to 28,000 μg/L (micrograms per liter) and had a median value of 140 μg/L. The median value is slightly higher than the 130-μg/L median value for province III (Kammerer, 1984).

Table 7 shows that 15 of the wells in Vilas County had iron concentrations greater than the recommended 300 μg/L maximum concentration for drinking water (Wisconsin Department of Natural Resources, 1978).

Iron is abundant and widely distributed in rocks and soils, but the chemical and biological processes that affect the chemistry of iron in ground water are complex and rapid. This complicates collection and interpretation of analytical data as well as the description of the occurrence and movement of iron in ground water.

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin—Continued*

[μS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Carbon, organic dissolved (mg/L as C)	Phosphorus, dissolved (mg/L as P)
8101	08-03-82	3.9	<.10	12	50	<.10	.100	.60	—	.020
8102	08-03-82	1.3	<.10	25	70	<.10	1.20	.90	3.3	.020
8102	08-24-83	—	—	—	—	—	—	—	—	—
8103	08-03-82	.30	<.10	19	72	<.10	.040	.30	1.2	.050
8104	08-03-82	.60	<.10	31	143	.76	.220	.70	3.1	.050
8105	08-04-82	.50	<.10	36	150	<.10	.110	.30	—	.040
8106	08-04-82	5.9	<.10	19	89	1.1	.020	.30	.80	.010
8107	08-04-82	.50	<.10	17	50	1.1	.050	.20	—	.020
8108	08-04-82	.60	.10	45	193	.16	.530	.50	8.0	.050
8108	08-24-83	—	—	—	—	—	—	—	—	—
8109	08-04-82	.20	<.10	12	58	<.10	.040	.10	—	.040
8111	08-04-82	.60	<.10	27	80	<.10	.110	.20	—	.030
8111	08-24-83	—	—	—	—	—	—	—	—	—
8112	08-04-82	.90	<.10	25	143	<.10	.110	.80	3.6	.020
8113	08-04-82	7.7	<.10	22	101	<.10	.060	<.10	.50	<.010
8113	08-24-83	—	—	—	—	—	—	—	—	—
8114	08-05-82	2.7	<.10	15	84	.15	.030	1.1	—	.010
8115	08-05-82	.40	<.10	24	108	<.10	.140	.30	2.0	.040
8116	08-05-82	5.3	<.10	25	203	.15	.070	.20	—	.060
8117	08-05-82	.30	<.10	21	117	.62	.020	<.10	.90	<.010
8117	08-25-83	—	—	—	—	—	—	—	—	—
8118	08-05-82	.90	<.10	26	93	<.10	.030	.20	3.1	.020
8120	08-17-82	2.8	<.10	36	157	.35	1.40	13	—	.120
8121	08-17-82	2.2	<.10	9.9	62	.10	.100	3.0	7.9	.020
8122	08-23-82	.90	<.10	8.6	36	<.10	.040	.20	1.1	.010
8123	08-23-82	.70	<.10	15	58	<.10	.010	.50	—	.020
8124	08-23-82	.90	<.10	13	34	<.10	.020	<.10	.50	<.010
8125	08-18-82	35	<.10	9.3	165	—	—	—	—	—
8126	08-23-82	.80	<.10	13	40	<.10	.030	<.1	.30	.020
8127	08-05-82	.30	<.10	17	53	<.10	.010	<.10	—	.010
8128	08-23-82	1.7	<.10	14	55	<.10	.060	.30	1.4	<.010

Table 7 continues

Ground water with a pH of 6 to 8 can be sufficiently reducing to retain as much as 50,000 μg/L of ferrous iron at equilibrium if bicarbonate does not exceed 61 mg/L (Hem, 1985). Wells that yield water of this type may appear to be erratically distributed, and the causes are difficult to explain because of complicated oxidation-reduction relations.

Manganese

Concentrations of manganese ranged from <1 to 1,100 μg/L and had a median of 89 μg/L. The median is nearly twice as high as the 45-μg/L median for all of province III (Kammerer, 1984). Thirty-four of the Vilas County wells yielded water with concentrations that exceed the 50 μg/L drinking-water standard (Wisconsin Department of Natural Resources, 1978).

The chemical processes affecting manganese concentrations, although different, are as complex as those that affect iron concentrations.

Sulfate

Sulfate concentrations in Vilas County ranged from 1 to 18 mg/L and had a median value of 5 mg/L. The median for all samples in province III is 7.2 mg/L

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin—Continued*

[μS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, ammonia + organic dissolved (mg/L as N)	Carbon, organic dissolved (mg/L as C)	Phosphorus, dissolved (mg/L as P)
8130	08-23-82	1.9	<.10	28	92	<.10	.110	.50	2.8	.020
8131	08-18-82	240	<.10	12	453	.33	.070	3.9	—	.030
8132	08-24-82	120	<.10	19	302	1.4	<.010	.10	.90	.010
8132	08-25-83	—	—	—	—	—	—	—	—	—
8133	08-17-82	68	<.10	18	263	<.10	.100	2.7	—	<.010
8134	08-18-82	2.0	<.10	15	83	.11	.180	4.9	—	.070
8134	08-25-83	—	—	—	—	—	—	—	—	—
8135	08-23-82	<.10	.10	13	52	<.10	<.010	<.10	.70	.040
8136	08-24-82	.60	<.10	18	58	<.10	<.010	<.10	—	.010
8137	08-24-82	1.0	.10	17	109	<.10	.030	<.10	—	.060
8138	08-24-82	7.0	<.10	18	128	.12	<.010	<.10	.30	.040
8139	08-18-82	1.5	<.10	11	47	.24	.100	.40	—	.060
8139	08-25-83	—	—	—	—	—	—	—	—	—
8140	08-17-82	.90	<.10	—	47	2.5	<.010	.60	1.6	<.010
8140	08-25-83	.40	<.10	11	50	—	—	—	—	—
8141	08-24-82	.30	.10	30	128	<.10	<.010	.20	1.3	.030
8142	08-18-82	13	<.10	15	61	<.10	.010	4.8	1.9	.010
8143	08-24-82	.30	<.10	17	60	<.10	<.010	<.10	—	.010
8144	08-24-82	<.10	.10	21	62	<.10	<.010	<.10	.50	<.010
8144	08-25-83	—	—	—	—	—	—	—	—	—
8145	08-24-82	5.9	<.10	19	76	1.2	<.010	<.10	<.30	.020
8152A	08-25-82	1.1	<.10	7.2	86	<.10	.040	.30	—	.030
8152B	08-16-82	1.6	<.10	15	56	.14	.020	1.1	2.3	<.010
8152C	08-25-82	2.0	<.10	.4	31	<.10	<.010	.30	—	.01
8261	08-24-82	.30	<.10	15	52	<.10	<.010	<.10	2.0	<.010
8262	08-25-82	.20	.10	11	41	<.10	<.010	.20	.80	.030
8263	08-25-82	.60	.20	16	54	<.10	<.010	3.6	1.3	.030
8263	08-23-82	.30	<.10	12	45	<.10	.040	<.10	.60	<.010
8264	08-05-82	.60	<.10	18	100	.16	.110	.20	—	.010
8266	08-05-82	77	<.10	24	297	<.10	1.80	2.0	20	.040

(Kammerer, 1984). These concentrations are much lower than the 250-mg/L drinking-water standard (Wisconsin Department of Natural Resources, 1978) and indicate no apparent sulfate problems in ground water in the county.

Chloride

Chloride concentrations ranged from <0.1 to 240 mg/L and had a median value of 0.9 mg/L. The low median value indicates that most wells have low chloride concentrations. Those wells with water containing elevated chloride concentrations are the same wells that contain elevated sodium concentrations. These elevated concentrations are probably caused by road salt contamination.

The median concentration for all samples in province III is 2.2 mg/L (Kammerer, 1984). None of the samples exceeded the 250-mg/L drinking-water standard (Wisconsin Department of Natural Resources, 1978).

Fluoride

Fluoride concentrations ranged from <0.1 to 0.2 mg/L and had a median value of <0.1 mg/L. The median concentration for all wells in province III is 0.20 mg/L (P. A. Kammerer, U.S. Geological Survey,

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin—Continued*

[μS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Arsenic dis-solved (μg/L as As)	Barium, dis-solved (μg/L as Ba)	Cad-mium dis-solved (μg/L as Cd)	Chro-mium, dis-solved (μg/L as Cr)	Copper, dis-solved (μg/L as Cu)	Iron, dis-solved (μg/L as Fe)	Lead, dis-solved (μg/L as Pb)	Manga-nese, dis-solved (μg/L as Mn)	Stron-tium, dis-solved (μg/L as Sr)	Zinc, dis-solved (μg/L as Zn)
8101	08-03-82	—	—	—	—	—	94	—	120	21	—
8102	08-03-82	1	18	3	3	4	7,800	3	120	17	1,100
8102	08-24-83	—	—	—	—	—	7,900	—	—	—	750
8103	08-03-82	<1	10	2	<1	2	85	1	4	17	17
8104	08-03-82	2	37	2	6	4	3,600	2	390	53	38
8105	08-04-82	—	—	—	—	—	250	—	700	42	—
8106	08-04-82	1	12	1	<1	1	12	<1	350	35	14
8107	08-04-82	—	—	—	—	—	50	—	66	17	—
8108	08-04-82	2	88	4	10	1	20,000	2	560	68	5,200
8108	08-24-83	—	—	—	—	—	20,000	—	—	—	7,200
8109	08-04-82	—	—	—	—	—	200	—	70	12	—
8111	08-04-82	—	—	—	—	—	18,000	—	220	22	—
8111	08-24-83	—	—	—	—	—	16,000	—	220	—	190
8112	08-04-82	1	150	2	5	2	230	2	520	35	20
8113	08-04-82	1	24	<1	<1	1	1,800	1	110	23	860
8113	08-24-83	—	—	—	—	—	1,500	—	—	—	500
8114	08-05-82	—	—	—	—	—	42	—	8	20	—
8115	08-05-82	2	24	2	3	2	230	2	240	27	11
8116	08-05-82	—	—	—	—	—	24	—	180	56	—
8117	08-05-82	<1	38	2	<1	2	160	3	89	24	2,700
8117	08-25-83	—	—	—	—	—	130	—	23	—	750
8118	08-05-82	1	15	<1	4	5	420	5	380	26	48
8120	08-17-82	—	—	—	—	—	4,900	—	1,100	42	—
8121	08-17-82	1	17	<1	<1	6	14	3	500	27	210
8122	08-23-82	1	6	<1	20	1	1,100	2	85	14	22
8123	08-23-82	—	—	—	—	—	17	—	<1	15	—
8124	08-23-82	1	4	2	20	7	1,200	2	23	18	1,900
8125	08-18-82	—	—	—	—	—	5	—	14	84	—
8126	08-23-82	<1	6	1	20	1	19	3	25	10	380
8127	08-05-82	—	—	—	—	—	220	—	19	18	—

Table 7 continues

written commun., 1985). These values are below the 2.2-mg/L drinking-water standard (Wisconsin Department of Natural Resources, 1978).

Nitrogen

Nitrate plus nitrite concentrations ranged from <0.1 to 2.5 mg/L as N and had a median value of <0.1. The median value for all wells in province III is 0.20 mg/L (Kammerer, 1984). These concentrations are below the 10 mg/L as N drinking-water standard (Wisconsin Department of Natural Resources, 1978).

Ammonia nitrogen and ammonia plus organic nitrogen concentrations ranged from <0.01 to 1.8 mg/L and from <0.1 to 13 mg/L, respectively. The difference between the ammonia plus organic nitrogen concentration and the ammonia nitrogen concentration is the concentration of organic nitrogen for each sample.

Elevated nitrate-nitrogen concentrations in ground water generally are indications of contamination from septic systems, agricultural fertilizers, livestock wastes, and/or waste-disposal sites (Kammerer, 1984).

Table 7.—*Ground-water quality from 50 observation wells, Vilas County, Wisconsin—Continued*

[μS/cm = microsiemens per centimeter at 25 °C; °C = degrees Celsius; mg/L = milligrams per liter; < = less than; — indicates not sampled]

Well	Date of sample (m-d-yr)	Arsenic dis-solved (μg/L as As)	Barium, dis-solved (μg/L as Ba)	Cad-mium dis-solved (μg/L as Cd)	Chro-mium, dis-solved (μg/L as Cr)	Copper, dis-solved (μg/L as Cu)	Iron, dis-solved (μg/L as Fe)	Lead, dis-solved (μg/L as Pb)	Manga-nese, dis-solved (μg/L as Mn)	Stron-tium, dis-solved (μg/L as Sr)	Zinc, dis-solved (μg/L as Zn)
8128	08-23-82	<1	7	1	20	3	140	4	84	18	880
8130	08-23-82	1	23	2	20	2	11,000	6	450	28	61
8131	08-18-82	—	—	—	—	—	85	—	49	54	—
8132	08-24-82	<1	35	1	5	2	9	3	4	130	61
8132	08-25-83	—	—	—	—	—	60	—	57	—	59
8133	08-17-82	—	—	—	—	—	1,200	—	430	100	—
8134	08-18-82	—	—	—	—	—	1,100	—	890	23	—
8134	08-25-83	—	—	—	—	—	—	—	—	—	180
8135	08-23-82	1	6	<1	4	5	16	2	12	15	7
8136	08-24-82	—	—	—	—	—	44	—	19	20	—
8137	08-24-82	—	—	—	—	—	13	—	160	49	—
8138	08-24-82	2	30	<1	6	2	15	3	150	59	9
8139	08-18-82	—	—	—	—	—	1,300	—	190	36	—
8139	08-25-83	—	—	—	—	—	350	—	—	—	5,800
8140	08-17-82	1	—	—	—	—	—	—	—	—	—
8140	08-25-83	1	48	<1	<1	—	96	2	37	28	—
8141	08-24-82	3	11	1	2	1	85	2	640	42	<4
8142	08-18-82	1	42	<1	<1	12	<3	1	6	42	11
8143	08-24-82	—	—	—	—	—	110	—	22	17	—
8144	08-24-82	3	7	24	5	1	3	4	7	18	6
8144	08-25-83	—	—	4	—	—	69	—	—	—	49
8145	08-24-82	<1	11	<1	6	3	16	2	150	40	26
8152A	08-25-82	—	—	—	—	—	19,000	—	220	9	—
8152B	08-16-82	1	29	<1	3	5	2,500	6	42	24	120
8152C	08-25-82	—	—	—	—	—	300	—	72	20	—
8261	08-24-82	<1	10	<1	5	3	70	4	63	29	15
8262	08-25-82	<1	31	<1	8	3	95	2	65	35	3,800
8263	08-25-82	<1	9	2	3	4	62	3	33	23	2,500
8263	08-23-82	1	12	1	20	2	170	3	54	15	1,100
8264	08-05-82	—	—	—	—	—	150	—	360	33	—
8266	08-05-82	<1	35	6	20	2	28,000	9	220	50	8,600

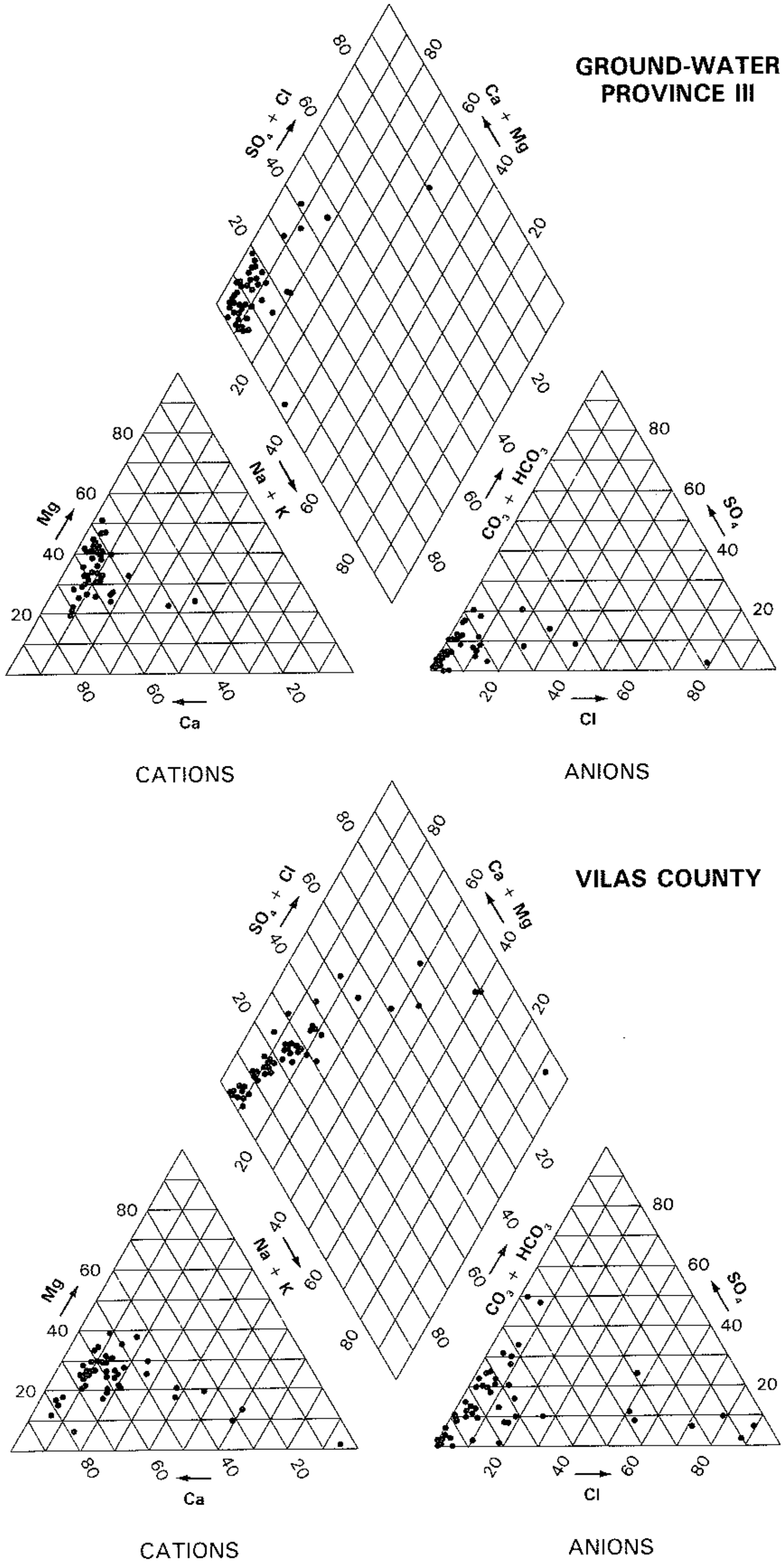

Figure 10. Cation and anion composition of ground water from ground-water province III (from Kammerer, 1984) and Vilas County, Wisconsin.

The concentrations of all the nitrogen species analyzed are low and do not indicate a problem in Vilas County.

Phosphorus

Phosphorus concentrations ranged from <0.01 to 0.12 mg/L and had a median value of 0.02 mg/L. These concentrations of phosphorus are sufficiently low to indicate no apparent problems from excessive phosphorus concentrations. The presence of elevated phosphorus concentrations can indicate contamination from landfills or sewage-treatment facilities.

Dissolved Organic Carbon

Dissolved organic carbon samples were collected from 30 wells (table 7). The concentrations ranged from <0.3 to 20 mg/L and had a median value of 1.3 mg/L.

Participation of dissolved organic matter in metal-oxide reduction may explain increased manganese

Table 8.—*Statistical data on water-quality analyses (from 1982 analyses)*

[μg/cm = micrograms per centimeter; mg/L = milligrams per liter]

Constituent	Arithmetic mean	Low	High	Median	Province III median[1]	Wisconsin drinking-water standard[2]
Specific conductance (μs/cm)	165	46	1,100	104	[3]222	
pH (standard units)	6.8	5.3	8.3	6.8		
Temperature (°C)	12	8	18	11		
Hardness (mg/L as $CaCO_3$)	49	5	160	36	[3]111	
Calcium (mg/L)	14.0	1.3	44.0	10.1	[3]28.0	
Magnesium (mg/L)	6.4	.3	12.0	2.9	[3]10.0	
Potassium (mg/L)	.7	<.1	2.2	.6	[3]1.0	
Sodium (mg/L)	7.8	.3	170.0	1.9	[3]3.0	
Alkalinity (mg/L as $CaCO_3$)	43	2	152	28	[3]102	
Sulfate (mg/L)	5.8	1.0	18.0	5.0	7.2	250.0
Chloride (mg/L)	12.2	<.1	240.0	.9	2.2	250.0
Fluoride (mg/L)	<.1	<.1	.2	<.1	[3].2	2.2
Silica (mg/L)	18.5	.4	45.0	17.0		
Dissolved solids (mg/L)	103	31	453	76	146	500
Nitrate plus nitrite (mg/L as N)	.25	<.1	2.50	<.1	.20	10.00
Ammonia (mg/L as N)	.15	<.01	1.80	.04		
Ammonia plus organics (mg/L as N)	1.0	<.1	13.0	.3		
Organic carbon (mg/L)	2.5	<.3	20.0	1.3		
Phosphorus (mg/L)	.03	<.01	.12	.02		
Arsenic (μg/L)	1	<.1	3	1		50
Barium (μg/L)	26	4	150	16		1,000
Cadmium (μg/L)	2	<.1	24	1		10
Chromium (μg/L)	8	<.1	20	5		50
Copper (μg/L)	3	1	12	2		1,000
Iron (μg/L)	2,534	<.3	28,000	140	130	300
Lead (μg/L)	3	<.1	9	3		50
Manganese (μg/L)	208	<.1	1,100	89	45	50
Strontium (μg/L)	34	9	130	26		
Zinc (μg/L)	1,031	2	8,600	55		5,000

[1] Kammerer, 1984.

[2] Wisconsin Department of Natural Resources, 1978.

[3] Kammerer, written commun., 1986.

and/or iron concentrations in water near organic-carbon sources. An elevated dissolved organic-carbon concentration might also indicate ground-water contamination from landfills.

A summary of 317 carbon analyses from Wisconsin wells (Kammerer, 1981) reveals a minimum concentration of 0.1 mg/L and a maximum concentration of 41 mg/L. Of the wells sampled in Vilas County, only water from wells 8108, 8121, and 8266 contain concentrations of dissolved organic carbon that exceed the statewide median value of 4.4 mg/L.

Silica

Concentrations of silica ranged from 0.4 to 45 mg/L and had a median value of 17 mg/L.

The range of silica concentrations in natural waters is from 1 to about 30 mg/L, although concentrations as high as 100 mg/L are not infrequent in some areas (Hem, 1985, p. 73). Davis (1964) cites a median value for silica in ground water of 17 mg/L. This is the same median value as that from the Vilas County wells.

Trace Elements

Trace elements included in the analyses are arsenic, barium, cadmium, chromium, copper, lead, strontium, and zinc. The lowest, highest, and median values are shown in table 8. The median values for each constituent are less than the State drinking-water standards; however, the maximum values for cadmium and for zinc exceed the standards.

The cadmium concentration in water from well 8144 was 24 μg/L and the second highest value was 6 μg/L. Well 8144 was resampled in August 1983 and the cadmium value was only 4 μg/L.

Zinc concentrations exceeded the State standard in wells 8108, 8139, and 8266. The highest concentrations of zinc were found in wells with steel casings. Although precautions were taken, such as pumping several volumes of water from the well before samples were collected, it seems likely that the elevated zinc concentrations were derived from the steel well casings.

SURFACE-WATER QUALITY

Acid Sensitivity of Lakes

The possible damage to lakes from the effects of acid precipitation is a major national concern. Acid precipitation is caused by the conversion, in the atmosphere, of gaseous air pollutants into sulfuric and nitric acids. These acids then return to the earth with rain, snow, sleet, or hail and can cause serious damage to the ecosystems on which they fall. The Wisconsin Department of Natural Resources uses the following simple system of classifying the sensitivity of lakes based on their alkalinity (Sheffy, 1984).

Class	Alkalinity (microequivalents per liter)
I Ultrasensitive	0
II Extremely sensitive	0–39
III Moderately sensitive	40–199
IV Low sensitivity	200–499
V Not sensitive	>500

Alkalinity data from 546 lakes in Vilas County are summarized in "Surface-Water Resources of Vilas

Table 9. *Chemical composition of cations and anions in water-quality samples from eight wells in Vilas County, Wisconsin*

Well no.	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Carbonate plus bicarbonate (CO_3+HCO_3)	Sulfate (SO_4)	Chloride (Cl)
8125	44	18	38	23	6	71
8131	5	2	93	5	6	89
8132	27	13	60	10	3	87
8133	42	21	37	38	9	53
8142	35	20	45	30	24	46
8152A	48	26	26	46	48	6
8261	63	20	17	48	50	2
8266	31	10	59	12	10	78
Median (Vilas County)	60	28	12	79	17	4
Median (province III; Kammerer, 1984)	58	35	7	90	7	3

County" (Black and others, 1963). These data were converted from methyl-orange alkalinity values to the present gran method alkalinity by the following formula (Joseph Eilers, Wisconsin Department of Natural Resources. written commun., 1985):

$$\left[\text{Methyl Orange Alkalinity } \left(\frac{\text{Milligrams}}{L}\right) \times \left(19.98\ \frac{\text{microequivalents}}{\text{milligram}}\right) - 15 = \text{gran alkalinity } \left(\frac{\text{microequivalents}}{\text{L}}\right)\right]$$

These results and 75 alkalinity values from samples collected by the Wisconsin Department of Natural Resources in 1982 (Joseph Eilers, written commun., 1982) are listed in table 10. Table 10 also lists the sensitivity of each lake according to the classification scheme presented above. Of the 546 lakes for which data were available, 5 are in Class I, 108 are in Class II, 185 are in Class III, 89 are in Class IV, and 159 are in Class V. Data for 1982 were used for the classification of lakes for which data were available.

SUMMARY

The general geology of Vilas County consists of 100 to 200 ft of Pleistocene sediment overlying Precambrian bedrock. The Pleistocene drift consists of three types of material: till, debris-flow sediment, and fluvial sediment. The fluvial sediment is sand and gravel with little or no silt and clay. The till and debris-flow sediment are similar and consist of 60- to 80-percent sand, 15- to 30-percent silt, and 5- to 10-percent clay.

The water table is shallow in most areas and there is little seasonal water-level fluctuation throughout the county. The median depth to water in 80 observation wells varied from above land surface to 141.74 ft below land surface; however, only three wells had median depths to water of greater than 50 ft. Fifty-six wells had median depths to water of less than 20 ft. The range of fluctuations was 0.5 to 7.36 ft.

Water-level measurements in more than 175 wells and numerous surface-water altitudes were used to prepare a ground-water-level contour map. The contour map shows that the water table generally is nearest the surface in valleys and low areas and deepest beneath hills and ridges. Many wetland areas in northwestern and eastern Vilas County are perched above the regional water table, particularly the interdrumlin wetlands near Phelps, Wis.

Hydrographs of monthly water-level measurements show a general trend of declining water levels through winter, a sharp rise in March and April from snowmelt and spring rain, a slight decline through the summer because of increased evapotranspiration, and a general rise in the fall because of decreased evapotranspiration and fall rains.

The results of slug tests indicate that the hydraulic conductivity of the sand and gravel is on the order of 10^{-4} ft/s, but that of the till and debris-flow sediment is on the order of 10^{-6} ft/s. Calculations of transmissivity using the aquifer thickness and hydraulic conductivity values indicate that the sand and gravel will yield sufficient quantities of water for most uses. The till and debris-flow deposits, however, probably are not adequate sources of water for domestic supply.

The many lakes and wetlands in Vilas County store surface-water runoff and release it to the creeks and streams slowly over extended periods of time. Peak runoff is attenuated and high base flows are prolonged by storage in the basin and wetlands and because the water table is shallow; however, base flows are reduced during long drought periods because of evapotranspiration.

Water samples collected from 50 observation wells in August 1982 indicate that calcium, magnesium, and bicarbonate are the major dissolved constituents in ground water in Vilas County. Calcium and magnesium comprise more than 80 percent of the cations and carbonate and bicarbonate comprise more than 75 percent of the anions. Samples from eight wells were significantly different from the others. Sulfate was the primary anion in two wells, and concentrations of sodium and chloride were elevated in six wells. The six wells with elevated sodium and chloride concentrations are near roads and are thought to be contaminated by road salt.

Dissolved-solids concentrations ranged from 31 to 453 mg/L and had a median concentration of 76 mg/L. Dissolved solids generally were lower in Vilas County than in the surrounding ground-water-province III, where ground water had a median dissolved-solids concentration of 146 mg/L.

Alkalinity concentrations in Vilas County ranged from 2 to 152 mg/L and had a median concentration of 28 mg/L. The median concentration was much less than the 102 mg/L median for the surrounding ground-water-province III. The low alkalinity in ground water in Vilas County implies a limited capability to neutralize acid; this may increase the potential for degradation by acid precipitation.

Concentrations of iron and manganese had median values of 140 and 89 μg/L, respectively. These concentrations are higher than the 130-μg/L median concentration for iron and 45-μg/L median concentration for manganese in the surrounding ground-water-province III.

Alkalinity data were used to classify 546 lakes according to their sensitivity to the effects of acid precipitation. Five lakes are classified as ultrasensitive, 108 lakes are classified as extremely sensitive, 185 lakes are classified as moderately sensitive, 89 lakes are classified as having low sensitivity, and 159 lakes are classified as not sensitive.

REFERENCES

Allen, R. C., and Barrett, L. P., 1915, Contributions to the Precambrian geology of northern Michigan and Wisconsin: Michigan Geological and Biological Survey, Publication 18, Geological Series 15, 189 p.

Attig, J. W., 1985, Pleistocene geology of Vilas County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 50, 32 p.

Black, J. J., Andrews, L. M., and Threinen, C. W., 1963, Surface water resources of Vilas County: Wisconsin Conservation Department, Madison, Wis., 317 p.

Bouwer, Herman, and Rice, R. C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423–428.

Davis, S. N., 1964, Silica in streams and ground water: American Journal of Science, v. 262, p. 870–891.

Durfor, C. N., and Becker, E., 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Hem, J. D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Johnson Division, Universal Oil Products Company, 1972, Ground water and wells, 440 p.

Kammerer, P. A., Jr., 1984, An overview of ground-water quality data in Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 83–4239, 58 p.

____ 1981, Ground-water-quality atlas of Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 39, 39 p.

Lawrence, C. L., and Ellefson, B. R., 1982, Water use in Wisconsin, 1979: U.S. Geological Survey Water-Resources Investigations Report 82–444, 98 p.

Martin, Lawrence, 1965, The physical geography of Wisconsin: Madison, University of Wisconsin Press, 608 p.

National Academy of Sciences, National Academy of Engineering, 1973 [1974], Water-quality criteria, 1972: U.S. Government Printing Office, 594 p.

Okwueze, E. E., 1983, Geophysical investigations of the bedrock and the ground water-lake flow system in the Trout Lake region of Vilas County, northern Wisconsin: Madison, University of Wisconsin, unpublished Ph. D. thesis.

Sheffy, Thomas, 1984, What does it all mean?, *in* Taylor, J. W., ed., The acid test: Wisconsin Department of Natural Resources, p. 29–32.

U.S. Geological Survey, 1986, National water summary, 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, 506 p.

Veihmeyer, F. J., 1964, Evapotranspiration, *in* Handbook of applied hydrology: New York, McGraw-Hill, sec. 11, p. 1–38.

Walton, W. C., 1970, Groundwater resource evaluation: New York, McGraw-Hill Book Company, 664 p.

Wisconsin Department of Natural Resources, 1978, Wisconsin administrative code, Chapter NR109, Safe drinking water: Register, February 1978, No. 266, Environmental Protection.

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Adams	8	40	10	15		II
Adelade	32	44	5	145		III
Afterglow	26	42	11	105		III
Aimer, Lower	5	43	7	45		III
Aimer, Upper	5	43	7	45		III
Alder	25	42	5	644		V
Allequash	16	41	7	764		V
Alma	36	40	8	105	88	III
Alva	28	42	8	265		IV
Ambleside	22	43	6	245		IV
Amik	19	40	4	564		V
Anderson	12	40	8	25		II
Anderson	35	43	9	425		IV
Annabelle	13	43	6	165		III
Anne	30	43	6	65		III
Anne	36	44	5	385		IV
Anvil	23	40	11	345		IV
Apeekwa	7	40	4	425		IV
Arbor Vitae, Big	29	40	7	994	1,027	V
Arbor Vitae, Little	33	40	7	1,074	1,046	V
Armour	11	43	6	325		IV
Arrowhead	36	40	6	744		V
Aspen	9	40	9	25		II
Aurora	19	41	8	784		V
Averill	17	43	6	1,224		V
Baker	3	41	9	385	337	IV
Baker	22	41	11	45		III
Ballard	9	41	8	544		V
Balsam	12	42	8	205		IV
Bambi	36	43	7	45		III
Basin	31	44	7	225		IV
Bass	29	40	11	704		V
Bass, Little	15	40	8	25		II
Bass, Little	35	40	6	85		III
Bass, Red	19	43	7	45		III
Bateau, Little	30	43	10	235		IV
Battine	8	43	7	45		III
Bay, West	19	43	9	964		V
Bear	36	43	6	2,404		V
Beatrice	18	44	5	145		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Beatrice	20	40	11	45		III
Beaver	13	40	8	45		III
Beaver	14	43	7	604		V
Beaver, Brown	29	44	6	25		II
Belle	13	43	6	145		III
Bena	17	44	5	185		III
Benedict	17	40	7	25	25	II
Bennett	5	41	10	85		III
Benny	26	43	8	45		III
Benson	7	42	5	704		V
Big	23	43	8	1,104		V
Big	6	42	6	1,194		V
Bills	22	40	4	5		II
Birch	14	43	5	704		V
Birch, White	5	41	8	524		V
Birch, Yellow	22	40	10	584	471	IV
Bittersweet	27	40	7	95	70	III
Blueberry	23	41	7	25		II
Blueberry	1	41	9	15		II
Bluebill	19	43	7	225		IV
Bodidosh	26	41	5	31		II
Bobs	6	41	8	584		V
Bolin	27	42	5	185		III
Bolton	12	40	5	844		V
Boot	11	40	9	445	511	V
Boot	33	44	6	5		II
Borden	23	43	6	155		III
Boulder	18	42	7	604		V
Boygan	2	42	9	245		IV
Bragonier	32	40	9	65		III
Brandy	35	40	6	704		V
Brazell	2	40	9	485		IV
Broken Bow	27	40	4	15		II
Buck	9	43	7	105		III
Buckatabon, Lower	23	41	9	544	536	V
Buckatabon, Upper	27	41	9	584	565	V
Bug	17	40	7	85		III
Bug	8	43	7	65		III
Bullfrog	28	40	9	45		III
Camp	27	41	6	25		II

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Camp One	10	41	11	65		III
Camp Two	34	42	11	25		II
Camp Five	21	42	9	185		III
Camp Ten	33	41	9	25	24	II
Camp Twelve	33	41	9	85		III
Camp Twelve	33	41	9	65		III
Canoe, Lost	35	42	7	405		IV
Canteen	8	43	7	45		III
Carlin	20	43	6	85		III
Carpenter	19	40	11	265	169	III
Caspian	36	41	10	45		III
Catfish	36	40	10	664		V
Cathaline	31	44	6	45		III
Catherine	4	41	12	145		III
Cedar	4	40	4	25		II
Cedar	12	42	8	205		IV
Chamberlain	29	42	10	55		III
Chickaree	34	40	9	25		II
Chub	17	42	5	65		III
Circle Lily	6	42	5	704		V
Clair	22	42	9	105		III
Clear	12	42	5	644		V
Cleveland	30	43	9	65		III
Cloud, Little	13	40	7	15		II
Cloud, Moving	36	41	5	5		II
Cochran	20	43	8	664		V
Coffee	26	43	8	744		V
Constance	30	44	5	105		III
Content	29	40	8	504		V
Cooks	1	40	9	125		III
Corn, Great	5	41	6	125		III
Corn, Little	32	42	6	245		IV
Corrine	20	43	8	205		IV
Crab	24	43	6	405		IV
Crab, Little	26	43	6	105		III
Crab, North	15	43	6	445		IV
Crampton	15	43	8	85		III
Cranberry	31	40	11	604	408	IV
Crawford	31	44	6	55		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Croker	7	40	10	145		III
Crooked, Big	15	41	5	165		III
Crooked, Big	7	42	7	285		IV
Crooked, Little	1	42	6	984		V
Crystal	28	41	7	15		II
Crystal	1	43	10	674		V
Curve	11	42	10	145		III
Dads	31	41	9	145	190	III
Dalzell	22	43	8	65		III
David	35	40	5	45		III
Day	2	41	6	35		II
Deadmans	2	40	8	25		II
Deadwood	15	43	8	75		III
Decker	9	41	9	35		II
Deep	36	41	9	25		II
Deer	32	40	9	65		III
Deer	30	42	10	105		III
Deer	10	43	5	185		III
Deerfoot	18	42	5	25		II
Deerpath	23	43	8	0		I
Deerskin	6	40	11	524	429	IV
Denton	34	42	10	0		I
Devils	29	43	8	25		II
Devine	4	40	6	844		V
Dewey	32	41	12	35		II
Diamond	11	41	6	25		II
Doe	9	43	7	85		III
Dog	7	42	5	65		III
Dollar	26	40	10	45		III
Dollar	26	43	9	1,563		V
Donahue	22	42	10	45		III
Donahue, Big	36	43	9	55		III
Donahue, Little	30	43	10	25		II
Dorothy	30	43	8	85		III
Dorothy Dunn	27	42	8	504		V
Drott	31	42	9	35		II
Dry	17	40	7	405		IV
Duck	22	40	10	824	476	IV
Dunn	13	43	7	1,124		V
Eagle	26	40	10	764	473	IV

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Eagle	14	41	5	5	473	IV
Edith	10	43	7	45		III
Edith	26	42	6	25		II
Eleanore	5	42	11	245		IV
Elizabeth	16	42	7	45		III
Ellerson, East	28	41	6	185		III
Ellerson, Middle	29	41	6	15		II
Ellerson, West	29	41	6	944		V
Ellen	8	41	12	35		II
Eloise	25	42	8	255		IV
Elsie	30	41	6	25		II
Emerald	33	41	7	15		II
Emil	10	42	9	724		V
Emily	8	40	4	644		V
Erickson	16	40	7	465	431	IV
Erwin	36	43	8	45		III
Escanaba	2	41	7	485		IV
Ethel	1	42	9	245		IV
Etna	18	44	5	345		IV
Ewald	20	40	9	25		II
Fallison	33	41	7	15		II
Favil	9	40	4	425		IV
Fawn	30	40	8	684	691	V
Fawn	12	42	5	664		V
Fence	22	40	5	604		V
Findler	30	44	5	85		III
Finger	12	40	10	205		IV
Finley	31	40	9	105	99	III
Firefly	28	41	7	45		III
Fishtrap	11	42	7	1,404		V
Flambeau	12	40	4	824		V
Flora	30	43	7	145		III
Forest	4	42	9	584		V
Found	14	40	8	385	389	IV
Fox	19	44	5	65		III
Franchian	18	44	5	65		III
Frank	13	41	7	185		III
Frost	12	40	9	624		V
Gail	15	41	12	25		II
Gateway	35	43	10	704		V

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Gem	17	42	5	5		II
Gene	26	40	4	65		III
Genevieve	34	44	5	205		IV
George	30	44	5	145		III
George	1	42	9	425		IV
Gibson, Big	7	42	8	165		III
Gibson, Little	7	42	8	335		IV
Gilbert	14	43	8	25		II
Goodall	33	42	11	45		III
Gordon	10	39	10	15		II
Grassy	4	42	7	744		V
Gresham, Lower	9	41	6	724		V
Gresham, Middle	4	41	6	724		V
Gresham, Upper	4	41	6	764		V
Gretchen	18	44	5	65		III
Gross	27	41	11	5		II
Gunlock	35	40	5	684	718	V
Halls	21	40	6	864		V
Hardin	30	43	9	85		III
Harmony	13	40	10	65	4	II
Harriet	33	40	6	265		IV
Harris	35	44	5	764		V
Harvey	5	43	5	345		IV
Haskell	31	40	5	744	903	V
Head Flyer	27	41	5	145		III
Heart	10	43	6	145		III
Heart	29	42	10	145		III
Helen	32	44	5	105		III
Helen	30	43	9	1,074		V
Hells Kitchen	23	43	6	105		III
Helmet	20	43	7	95		III
Henning	32	42	9	65		III
Hiawatha	23	43	5	305		IV
High	31	43	8	1,603		V
Hillis	35	40	6	15		II
Hobo	28	41	8	15		II
Homestead	31	42	5	25		II
Honeysuckle	10	40	9	5		II
Horsehead	2	43	6	405		IV
Horsehead, Little	35	44	6	704		V

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*
[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Horseshoe	30	42	9	105		III
Hungry	35	40	6	25		II
Hunter	25	41	9	145	125	III
Hurrah	8	40	7	185		III
Hurst, Big	28	43	6	105		III
Hurst, Little	28	43	6	15		II
Ike Walton	24	41	5	25		II
Ila	34	40	6	374		IV
Imogene	32	41	12	65		III
Indian	18	42	9	185		III
Inkpot	26	43	9	45		III
Interlocken, Long	8	40	5	544		V
Irving	3	41	8	485		IV
Island	18	42	6	724		V
Jag	35	42	6	25		II
Jean	26	42	8	305		IV
Jenny	24	43	6	115		III
Jerms	33	40	5	85		III
John	5	43	7	65		III
John, Little	29	41	7	874		V
John Jr., Little	29	41	7	25		II
Johnson	8	42	8	445		IV
Johnson	35	40	6	884		V
Jones	29	43	8	65		III
Joyce	15	42	9	25	2	II
Jute	33	43	8	85		III
Jute, Little	33	43	8	25		II
Kasomo	18	40	8	0		I
Katinka	18	43	6	85		III
Keego	33	43	6	65		III
Kentuck	34	41	12	704		V
Kenu	12	42	9	385		IV
Kildare	19	42	11	564		V
Kitten, Big	33	43	7	1,344		V
Klondike	4	40	7	0		I
Knife	7	43	7	25		II
Korth	13	39	10	185		III
Kuehn	15	40	8	35		II
Lac des Fluers	15	42	10	45		III
Lac du Lune	17	42	9	75		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Lac View Desert	11	42	11	624		V
Lake O' Pines	9	42	10	305		IV
Lake of the Hills	34	41	10	624	631	V
Lake of the Woods	8	42	9	145		III
Landing	32	43	10	684	717	V
Langley	8	41	9	335		IV
Laura	12	41	8	485	457	IV
Lawler	27	42	10	65		III
Lewis	28	41	9	25		II
Lonewood	30	43	10	45		III
Long	8	41	12	664	647	V
Loon	4	39	10	85		III
Lost	10	40	8	385	591	V
Lotus	26	40	9	25		II
Lucky	35	40	5	85		III
Lynx	15	40	10	67		III
Lynx	19	43	7	145		III
Mabel	21	43	7	105		III
Mamie	21	43	9	1,114		V
Mamie, Little	33	40	8	5		II
Manitowish	23	42	5	704		V
Mann	32	41	7	1,084		V
Manuel	22	41	11	65	32	II
Maple	10	42	6	75		III
Maple, Sugar	24	42	11	45		III
Marion	30	44	5	465		IV
Marlands	13	40	5	45		III
Marsh	3	42	10	85		III
Marshall	27	42	9	744		V
Mary	32	44	5	105		III
Mary, Lake	35	40	9	5		II
McCabe	9	42	5	145		III
McCullough	24	43	7	584		V
McDonald	32	40	9	25	18	II
McKinney	8	42	5	205		IV
McLeod	34	41	9	225	178	III
Mermaid	3	43	6	125		III
Merrill	34	43	9	45		III
Meta	1	39	10	95	64	III
Midge	25	41	6	125		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Mielke	28	40	7	25		II
Mill	33	43	10	934	788	V
Minette	3	40	4	25		II
Minnow	9	39	10	185		III
Minonk	32	44	6	25		II
Mirror	7	43	8	325		IV
Mitten	15	40	4	385		IV
Moccasin	11	42	9	494		IV
Monahan	28	42	9	524		V
Moon	25	40	8	15	105	III
Moraine	19	44	6	1,204		V
Morton	24	43	7	844		V
Moss	8	40	5	465		IV
Mud	13	40	8	345		IV
Mud	35	41	9	824		V
Mud	27	43	7	125		III
Murphey	29	44	6	65		III
Muskeg	10	41	11	25		II
Muskellunge	17	40	9	544		V
Muskellunge, Big	28	41	7	405		IV
Muskesin	19	41	5	15		II
Muskie, Little	26	40	6	NA	792	V
Myrtle	35	42	9	85	246	IV
Mystery	1	41	7	285		IV
Nebish	11	41	7	325		IV
Nell	27	44	5	45		III
Nellie	26	42	7	105		III
Nelson	22	40	9	165		III
Nelson	31	42	6	405	80	III
Nichols	24	42	6	25		II
Nine Mile, Lower	34	40	11	744		V
Nine Mile, Upper	36	40	11	884		V
Nine Web	19	42	9	5		II
Nixon	30	42	8	814		V
No Man	20	44	5	465		IV
Norwood	20	42	12	65	10	II
Noseeum	24	43	5	85		III
Noseeum	2	41	11	105		III
Nudist	2	41	9	25		II
Oak, Black	36	43	9	744		V

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Oberlin	22	40	7	25		II
Osceola	13	42	9	1,344		V
Oswego	10	42	7	105		III
Otter	23	40	10	824	468	V
Oxbow	36	44	6	335		IV
Pallette	3	41	7	245		IV
Palmer	21	43	8	1,054		V
Papoose	25	43	5	924		V
Papoose, Little	25	43	5	864		V
Partridge	33	42	8	944		V
Patterson	33	40	5	65		III
Pauto	2	40	6	5		II
Perch	4	42	10	25		II
Perch	36	40	9	65		III
Perry	35	43	8	45		III
Pickel	16	41	12	105		III
Pickeral	5	40	9	704		V
Pier	19	42	5	245		IV
Pike, Dead	29	42	5	584		V
Pincherry	18	40	9	25		II
Pine	30	41	9	724		V
Pine Island	35	41	10	65		III
Pine, Little	16	40	10	45		III
Pine, Lone	16	43	7	305		IV
Pinkeye	16	42	10	25		II
Pioneer	24	41	10	774	723	V
Pleasant, Lake	22	42	10	25		II
Plum	32	41	8	974		V
Plummer	8	40	6	385	367	IV
Plymouth	15	41	12	25		II
Pokegama	33	41	5	924		V
Pollack	24	41	9	5		II
Portage, Big	18	42	10	235		IV
Portage, Little	9	42	10	704	722	V
Potfish	14	42	11	45		III
Poupart	30	41	5	415		IV
Presque Isle	8	43	6	1,244		V
Presque Isle, Little	3	43	7	1,543		V
Prong	27	40	7	85		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Punch	35	41	6	15		II
Rade	2	40	10	724	90	III
Rainbow	3	43	5	644		V
Rainbow Springs	29	41	9	624		V
Range Line	12	40	9	65	41	III
Raven	3	41	5	5		II
Razorback	29	41	8	365	322	IV
Red	29	43	6	85		III
Reiter	30	42	5	125		III
Reservoir	36	41	12	744		V
Rest	16	42	5	724		V
Rice	34	43	6	85	521	V
Rice	14	40	9	584	521	V
Rice, Little	21	42	7	405		IV
Rice, Scattering	24	40	10	994	689	V
Rice, Wild	6	41	6	724		V
Roach	7	43	8	65		III
Roach	9	40	7	85		III
Robinson	13	41	12	25		II
Rock	33	44	5	584		V
Rock, Little	36	41	6	45		III
Rosalind	30	43	6	65		III
Rose	32	44	5	165		III
Ross	15	40	7	554	572	V
Ross Allen	11	40	4	5		II
Round	35	43	6	1,024		V
Rudolph	26	42	6	15		II
Rudolph	18	43	7	85		III
Rush	1	42	7	1,593		V
Russett	22	43	7	25		II
St. Germain, Big	21	40	8	724	675	V
St. Germain, Little	35	40	8	724		V
Salsich	14	41	8	265	248	IV
Sanborn	19	43	8	1,084		V
Sand, Big	3	41	12	664		V
Sand, Little	23	41	5	1,084		V
Sand, White	27	42	7	694		V
Sand, White	27	41	5	784		V
Sanford	25	43	6	235		IV
Scaffold	9	40	7	305		IV

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Scat	16	40	10	5		II
Secret	22	41	12	55		III
Seneca	25	40	9	25		II
Seventeen, Lake	17	39	10	0		I
Sherman	31	42	5	245		IV
Signal	30	41	5	524		V
Silver	28	40	10	205	215	IV
Sime	32	43	8	25		II
Smoky	36	42	12	205	190	III
Snake	36	40	6	1,484		V
Snipe	22	40	9	145	147	III
Snort	5	41	6	185		III
Snyder	20	41	9	65		III
Soleit	23	41	9	125		III
Sparkling	26	41	6	814		V
Spectacle	29	41	12	55		III
Spider	14	42	5	724		V
Spider, Little	11	40	6	724	710	V
Spirit	12	40	10	65	18	II
Spread	4	43	6	1,184		V
Spring	27	43	9	1,683		V
Spring	11	39	10	165		III
Spruce	7	42	9	285		IV
Spruce	12	41	7	145		III
Squaw, White	20	42	9	585		V
Star	22	41	8	624	565	V
Star, Little	22	42	5	664	690	V
Star, Little	10	41	8	704	690	V
Starrette	24	41	7	85		III
Statehouse	5	42	5	65		III
Stateline	26	44	6	1,044		V
Statenaker	32	41	6	544		V
Stearns	31	41	6	115		III
Stella	2	40	8	604		V
Stewart	20	41	9	65		III
Stone	14	42	5	724		V
Stone, Crawling	21	40	5	544		V
Stone, Little Crawling	30	40	52	464.50		IV
Stone #1, Stepping	21	42	5	105		III
Stone #2, Stepping	21	42	5	105		III

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Stone #3, Stepping	21	42	5	105		III
Stormy	12	41	9	265		IV
Street	26	42	6	25		II
Stub Walsh	13	41	11	15		II
Sturgeon	8	42	5	824		V
Sugarbush, Little	22	41	5	365		IV
Sugarbush, Lower	18	41	5	784		V
Sugarbush, Middle	20	41	5	844		V
Sugarbush, Upper	16	41	5	904		V
Sumach	28	40	6	225	280	IV
Sunfish	22	41	5	125		III
Sunset	26	40	9	15	26	II
Tamarack	10	43	5	624		V
Tamarack, Little	35	42	9	544	541	V
Tambling	19	40	11	684		V
Tank	26	40	4	25		II
Taylor	35	40	10	105		III
Tellefson	36	41	9	85		III
Tenderfoot	18	43	8	824		V
Tepee	12	40	9	544	664	V
Tinsel	29	40	11	95		III
Tippecanoe	23	40	4	85		III
Torch	20	41	10	25	3	II
Toulish	6	40	6	504		V
Towanda	23	40	6	245	149	III
Tower	13	42	8	385		IV
Tree, Lone	9	41	8	65		III
Trilby	14	40	6	5		II
Trostel	30	44	5	85		III
Trout	17	41	7	524		V
Trout, Little	35	42	5	305		IV
Turtle, North	5	43	5	544		V
Turtle, South	20	43	5	704		V
Twin, North	18	41	11	984		V
Twin, South	18	41	11	684	788	V
Twin, North Placid	26	40	5	305		IV
Twin, South Placid	26	40	5	325		IV
Twin Island	11	43	7	1,623		V
Vance	9	42	5	724		V
Vandercook	36	41	6	5	39	II

Table 10. *Alkalinity values and estimated sensitivity to acid precipitation of 546 Vilas County Lakes—Continued*

[Values are in microequivalents per liter]

Name	Section	Township (North)	Range (East)	Alkalinity (1961-62)[1]	Alkalinity (1982)[2]	Sensitivity class[3]
Van Vliet	21	43	6	1,284		V
Verna	10	40	6	425	542	V
Vista	26	41	11	15		II
Wabasso	5	40	4	45		III
Wakefield	36	40	8	25		II
Warrior	18	40	6	165		III
Warvet	28	42	11	25		II
Watersmeet	31	40	10	624	577	V
Weber	27	42	11	104		III
Wharton	25	41	8	25		II
Whispering	35	41	11	5		II
Whitefish	34	40	5	425		IV
Whitney	15	42	6	425		IV
Wildcat	34	43	7	1,294		V
Wildwood	33	41	7	15		II
Williams	20	42	10	25		II
Wilson	19	41	9	25		II
Winifred	9	43	7	65		III
Wishow	18	40	6	25		II
Witches, East	3	40	7	85	67	III
Witches, West	3	40	7	85	58	III
Wolf	32	43	7	1,763		V
Wolf	26	42	10	125		III
Wood	34	43	9	5		II
Wool	14	42	6	125		III
Wyandock	27	40	5	25		II
Yolanda	32	44	5	45		III
Zee	10	41	5	25		II

[1]Data from Black and others, 1963.

[2]Data from Joseph Eilers, Wisconsin Department of Natural Resources, written commun., 1985.

[3]Sensitivity classes are those of Sheffy (1984).