GROUND-WATER FLOW AND WATER QUALITY IN NORTHEASTERN UNION COUNTY, OHIO

By Karen S. Wilson

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4083

Prepared in cooperation with the
VILLAGE OF RICHWOOD, OHIO

Columbus, Ohio

1987

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For use of readers who prefer to use 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
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare
gallon per minute (gal/min)	0.0630	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
gallon per day per foot [(gal/d)/ft]	0.2070	liter per day per meter [(L/d)/m]

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 "Mean Sea Level of 1929."

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ABSTRACT

A study was done by the U.S. Geological Survey, in cooperation with the Village of Richwood, Ohio, to determine directions of ground-water flow, ground-water-level fluctuations, and water quality in the northeastern part of Union County.

The topography of the study area generally is featureless, and the land surface slopes gently eastward from 985 to 925 feet above sea level. Glacial deposits up to 48 feet thick cover the carbonate-bedrock aquifer. Three municipal wells and an adjoining abandoned landfill are located in an area previously excavated for clay deposits. An agricultural supply company is adjacent to the well field.

Ground water flows from west to east with local variation to the northeast and southeast because of the influence of Fulton Creek. Richwood Lake occupies an abandoned sand-and-gravel quarry. Water-level fluctuations indicate that the sand and gravel deposits beneath the lake may be hydraulically connected to the bedrock aquifer.

Water-quality data collected from 14 wells and Richwood Lake indicate that a hard to very hard calcium bicarbonate type water is characteristic of the study area. Dissolved solids ranged from 200 to 720 mg/L (milligrams per liter) throughout the study area.

Potassium ranged from 1.3 to 15 mg/L, with a median concentration of 2.0 mg/L. Concentrations of 10 and 15 mg/L at one municipal well were five to eight times greater than the median concentration.

Total organic carbon, ammonia, and organic nitrogen were present at every site. Concentrations of ammonia above 1 mg/L as nitrogen were found in water from two municipal wells and one domestic well. Total organic carbon was detected at a municipal well, a landfill well, and a domestic well at concentrations above 5 mg/L.

Ground-water quality is similar throughout the study area except in the vicinity of the municipal well field, where water from one well had elevated concentrations of ammonia, dissolved potassium, dissolved manganese, dissolved chloride, dissolved sodium, and total organic carbon.

INTRODUCTION

The community of Richwood in northeastern Union County, central Ohio (fig. 1), has measured elevated concentrations of ammonia and nitrite in the public ground-water supply for several years. In 1974, concentrations of 0.29 mg/L (milligrams per liter) of ammonia as nitrogen were detected; in 1980, concentrations reached 5.91 mg/L and, in 1981, 8.1 mg/L (Ohio Environmental Protection Agency, written commun., 1983). In late December 1984, nitrite concentrations in the public water supply of 10 to 11 mg/L were detected (F. Robinson, Richwood Division of Water, oral commun., 1985).

There is little information on the hydrogeology of Union County, especially the northern part. Although hydrogeologic studies of western Ohio incorporating Union County were conducted in the early 1970's by the Ohio Department of Natural Resources (ODNR) and the U.S. Geological Survey (Norris and Fidler, 1973; Norris, 1979), Union County was included only as a small part of those study areas.

A study was begun by the U.S. Geological Survey in July 1985, in cooperation with the Village of Richwood, to examine (1) ground-water flow direction and seasonal water-level fluctuations, and (2) temporal and areal variations in the quality of ground water in the northeastern Union County area.

Purpose and Scope

This report describes the ground-water hydrology and water quality of the study area and provides data necessary to evaluate the susceptibility of present and future water supplies to ground-water contamination.

To examine ground-water flow direction and seasonal water-level fluctuations, data were obtained from 38 wells selected for determination of water levels. Water samples were collected from 15 sites, including two municipal wells and a nearby landfill well, and were analyzed for general water chemistry. Water from Richwood Lake also was sampled and analyzed for general water chemistry. One municipal well and one domestic well upgradient of the Village were sampled for additional dissolved constituents, organic compounds, and pesticides. Data were collected from September 1985 through June 1986.

Description of Study Area

The study area encompasses the Village of Richwood, Claibourne Township, and the southwestern part of Jackson Township (fig. 1). Claibourne Township, including the Village of Richwood, has a total area of 33.4 square miles. The population of Richwood in 1980 was 2,180 (U.S. Bureau of the Census, 1981).

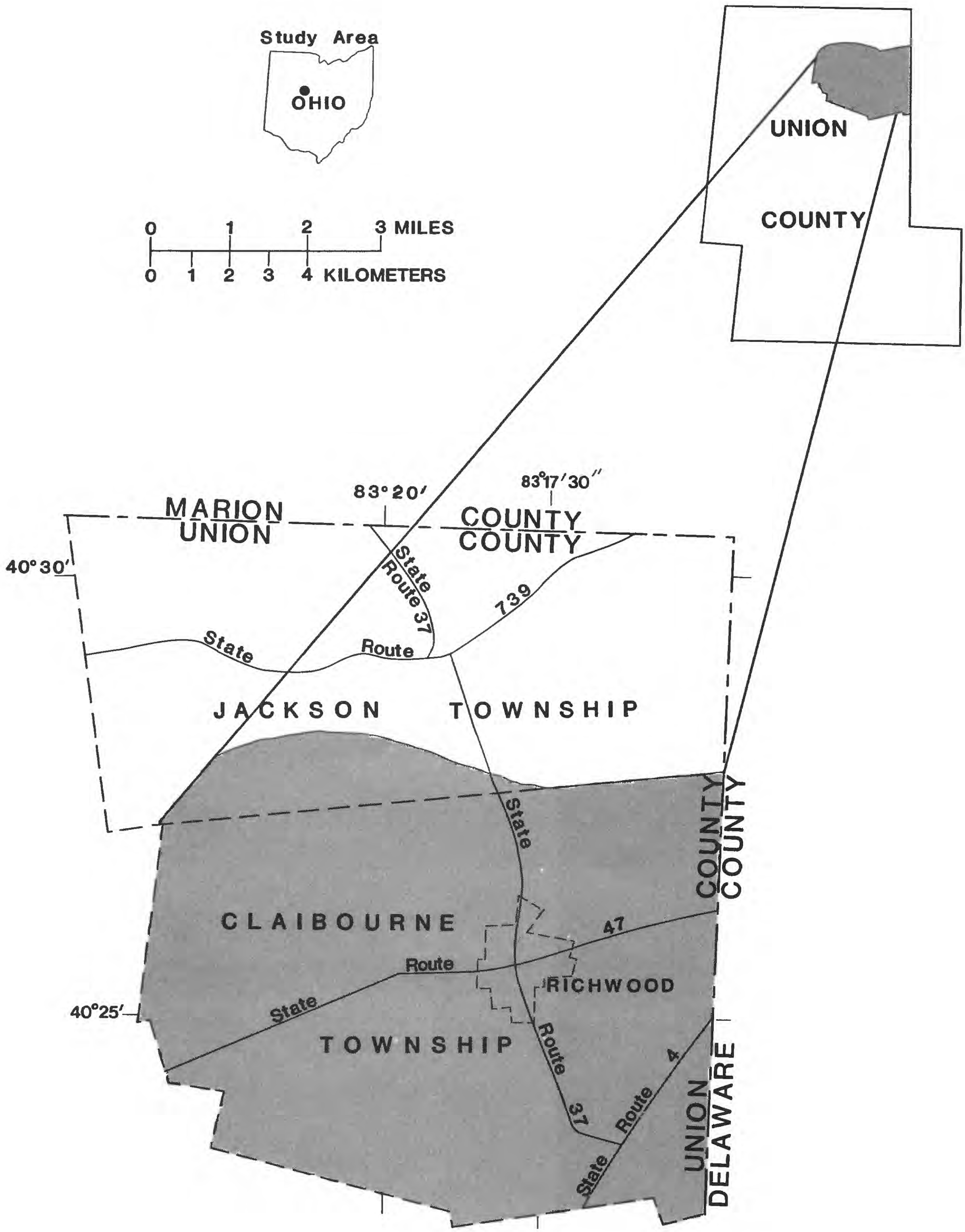


Figure 1.--Location of study area.

Richwood is a rural community, and farming is the principal land use in Claibourne and surrounding townships. Most of the land is used for corn and soybean production. Commercially important deposits of sand, gravel, and clay also were mined in the past. Richwood Lake and the surrounding recreational park were developed from an old sand-and-gravel quarry. Clay deposits once were mined for the production of brick and tile at the present site of the Richwood well field and an abandoned sanitary landfill located near the northeastern edge of the corporation limit.

The municipal well field has three wells, two of which were drilled in 1935. Well U-67 is 70 feet deep. Well U-68 was originally drilled to 60 feet, but was redrilled in May 1984 and is now 151 feet deep. Well U-69, drilled in 1950, is 120 feet deep. The municipal water plant, which uses a lime-soda treatment process, was constructed in 1974. The plant serves virtually the entire village, although there are a few isolated wells within the corporation limits that still are in use for nondomestic purposes. The village has a sewage-treatment plant at the southwestern corporation limit.

Surrounding the Richwood well field (fig. 2) is a residential section to the west; an agricultural supply company to the south (upon whose property are large liquid-nitrogen silos); and the Union County garage (which encompasses a salt-and-cinder storage area). Also to the south is a small strip of land that was once part of a small local dump. On this piece of land are four large storage tanks reported to contain bitumen. An abandoned sanitary landfill is 500 feet north of the water plant, outside the corporation limits.

Description of the Hydrogeologic System

Union County is in the Central Lowland physiographic province. Richwood lies on the glaciated Mississippi Valley Plain or Lexington peneplain at an altitude of 950 feet above sea level (Stout and others, 1943). The area is marked by broad, flat plains and rolling surfaces. North of the village is a small esker known as the Richwood esker. Fulton Creek drains approximately 20 square miles of land and lies about 0.75 mile south of Richwood (fig. 3).

Geology

Glaciers deposited a layer of unconsolidated material of varying thickness across Union County. The earliest glaciation occurred during the Illinoian age and was followed by the Wisconsin ice sheet (Stout and others, 1943). Both glaciers moved southward across Ohio, depositing great quantities of drift over carbonate bedrock of Silurian age (fig. 4).

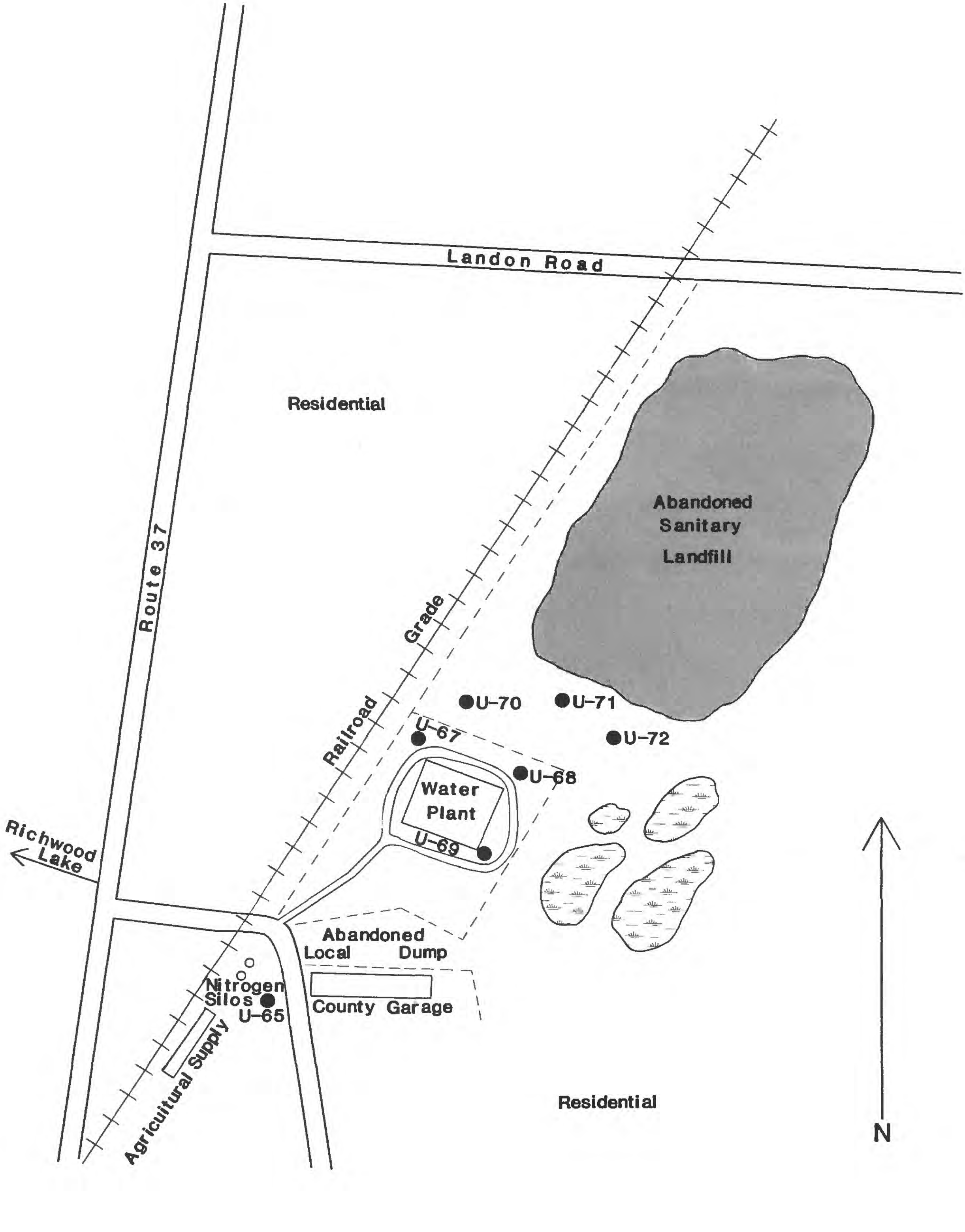
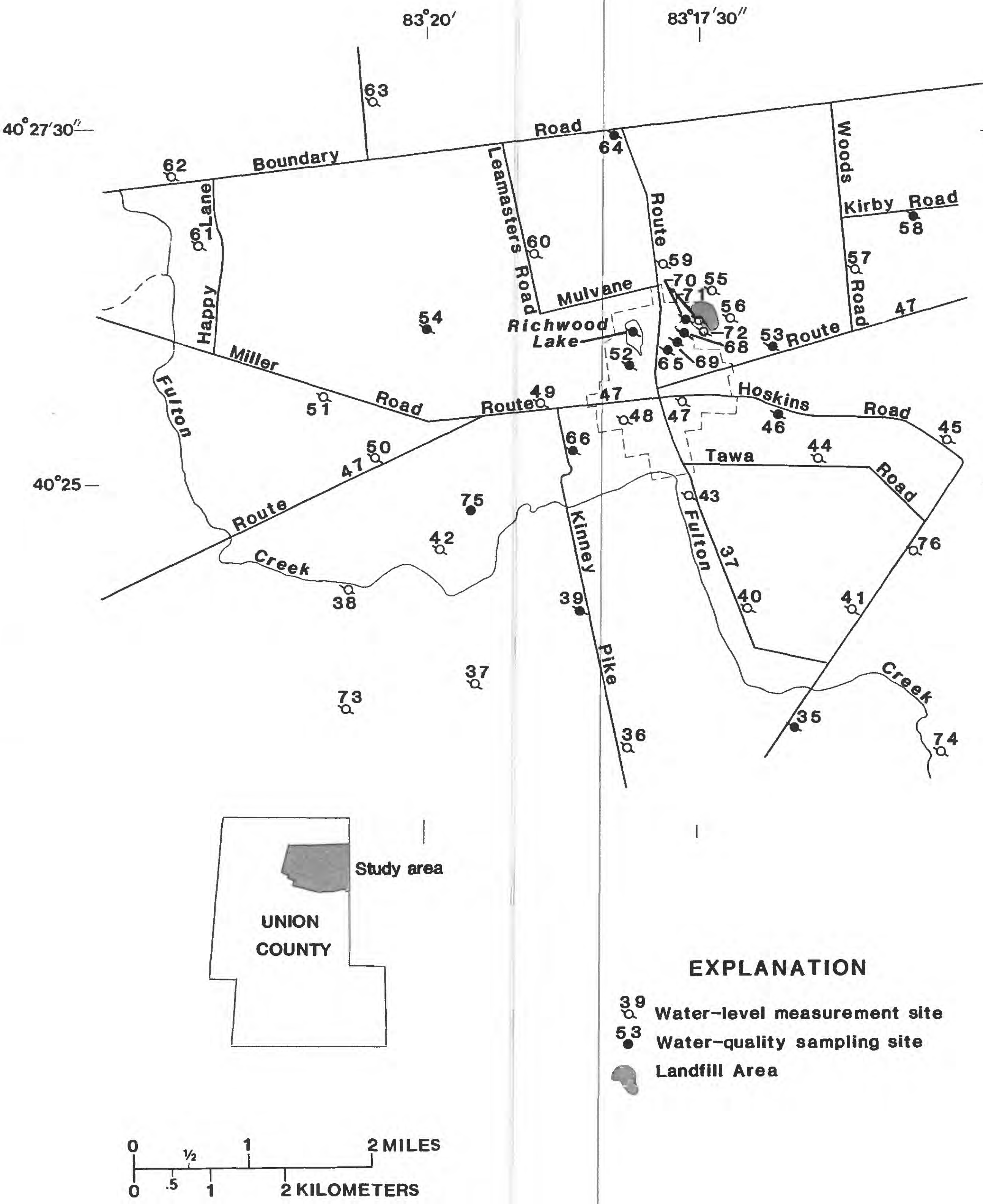


Figure 2.--Sketch of area surrounding the Richwood well field and water plant. (not to scale)



Base from U.S. Geological Survey
Richwood Quadrangle, 1961

Figure 3.--Water-level measurement and water-quality sampling sites (the county prefix U- has been deleted from the well numbers).

Series	Group	Formation	Lithology and typical thickness (feet)
Pleistocene		Glacial drift	Clay, sand, and gravel (35)
Upper Silurian	Bass Islands	Tymochtee Formation	Dolomite, thin to massive bedded, gray to brown (65)
		Greenfield Dolomite	Dolomite, thin to massive bedded, gray to brown (70)
Middle Silurian	Lockport	Guelph Dolomite	Dolomite, light, massive, very pure (50)
		Goat Island Dolomite	Dolomite, chert-bearing, slightly silty, light brown to grayish brown (30)
		Gasport Dolomite	Dolomite, medium to dark gray (20)
		Rochester Formation	Gray-green dolomitic shale and argillaceous dolomite (22)
		Dayton Formation	Dolomite, limey, gray to drab, medium bedded (50)

Figure 4.--Generalized stratigraphic column for the study area (modified from Janssens, 1977).

Glacial deposits consist of clayey till, sand, and gravel. In the study area, glacial deposits range from 12 to 48 feet in thickness.

Beneath the glacial cover, the Tymochtee Formation of the Bass Islands Group of Late Silurian age is approximately 65 feet thick. The underlying Greenfield Dolomite of the Bass Islands Group is approximately 70 feet thick. The underlying Lockport Group (Janssens, 1977) is divided into the Guelph Dolomite at a depth of 170 feet, the Goat Island Dolomite at 220 feet, and the Gasport Dolomite at 250 feet. Where the Lockport is undifferentiated it is referred to as the Lockport Dolomite. The Rochester Formation is at 270 feet and the Dayton Formation at 292 feet.

Hydrology

The Bass Islands Group and the Lockport Group (Janssens, 1977) or Lockport Dolomite together comprise the principal carbonate-rock aquifer in the study area. This aquifer is confined because of poorly permeable glacial till that overlies the bedrock (Norris and Fidler, 1973). Yields in excess of 1,000 gallons per minute have been developed from the Bass Islands Group and Lockport Group at depths ranging from 190 to 270 feet. The transmissivity of the combined aquifer has been determined to be 7,486 feet squared per day with a 24-hour specific capacity of 66.75 gallons per minute per foot; if corrected for well loss, the 24-hour specific capacity is 70.30 gallons per minute per foot (Ohio Department of Natural Resources, unpublished data on file in the Ohio District office of the U.S. Geological Survey, 1971).

The highest yields are from the Bass Islands Group, because the Bass Islands rocks generally are more permeable than the Lockport Group (Norris and Fidler, 1973). However, the Lockport Dolomite also is a good source of ground water. Farm and domestic supplies of 10 to 15 gallons per minute usually are obtained at depths of less than 125 feet (Schmidt, 1978). Historically, thin sand and gravel deposits throughout the drift were a source of water; however, clay till generally is less permeable and not a source of water.

Acknowledgments

The author acknowledges the cooperation of the Village of Richwood, Division of Water, and also expresses thanks to area businesses and to homeowners for permitting access to their wells.

Table 1.--Records of selected wells in northeastern Union County, Ohio

[Depth of well: Taken from drillers' logs or measured (M). Altitude of land surface is in feet above sea level. Interpolated from U.S. Geological Survey 7.5-minute topographic maps, contour interval 5 feet, and surveyed January 14-17, 1986. Casing material: P, PVC; S, steel. Water use: L, livestock; D, domestic; C, commercial; M, municipal; U, unused; a dash indicates no data are available.]

Well number	Latitude	Longitude	Depth of well (feet)	Altitude of land surface (feet)	Year completed	Casing material	Casing diameter (inches)	Casing length (feet)	Water use	Water-quality site?
U-35	40 23 13	83 16 33	62.0	940	1984	P	6	26	L	Yes
U-36	40 23 03	83 18 05	82.0	953	1971	S	4.5	55	D	
U-37	40 23 30	83 19 29	43.0	972	1949	S	4	28	D	
U-38	40 24 11	83 20 40	35.0	957	1957	S	4	32	D	
U-39	40 24 02	83 18 28	32.0	945	1984	S	6	20	D	Yes
U-40	40 24 05	83 17 01	44.5	937	1964	S	4	19	D	
U-41	40 24 01	83 15 57	--	931	--	S	--	--	D	
U-42	40 24 29	83 19 49	38.0	959	1978	S	5.5	29.5	D	
U-43	40 24 52	83 17 29	33.0M	941	--	S	4	--	D	
U-44	40 25 07	83 16 19	44.5M	937	--	S	4	--	D	
U-45	40 25 16	83 15 11	49.0	932	1961	S	4.5	30	D	
U-46	40 25 29	83 16 41	85.0M	937	--	S	4	--	D	Yes
U-47	40 25 36	83 17 33	29.0	941	1956	S	4	23.5	U	
U-48	40 25 22	83 18 09	32.0	942	1978	S	5	24	L	
U-49	40 25 29	83 19 00	20.0M	948	--	S	--	--	U	
U-50	40 25 05	83 20 26	42.0M	974	--	S	4	--	D	
U-51	40 25 35	83 20 56	76.0	975	1964	S	5	29	D	
U-52	40 25 47	83 18 03	44.0	946	1958	S	4	21.5	U	Yes
U-53	40 25 54	83 16 44	55.0M	939	--	S	5.25	--	C	Yes
U-54	40 26 02	83 19 56	68.0	964	1969	S	4.5	47	D	Yes

METHODS OF STUDY

A network of privately owned wells was developed to provide data on ground-water levels in the study area. To define the potentiometric surface and direction of flow, 38 wells were selected on the basis of accessibility and good connection with the aquifer (fig. 3, table 1). All wells were completed in the bedrock aquifer of the Bass Islands Group and ranged from 20 to 151 feet deep. Most wells were cased through the unconsolidated glacial deposits and were left as open hole into the dolomite. Potentiometric-surface maps were constructed from water-level measurements made in September 1985, December 1985, March 1986, and June 1986.

Water-level recorders were installed on well U-65 and at Richwood Lake (fig. 3) to measure continuous changes in water levels. Richwood Lake was included in the study to examine the general ground-water/surface-water interaction in the study area. A series of streamflow measurements along Fulton Creek were made to provide additional data concerning the ground-water/surface-water interaction.

Fourteen wells and Richwood Lake were sampled for analysis of water quality (fig. 3, table 1). Well selection was based primarily on the direction of ground-water flow as determined from the September 1985 potentiometric surface. Samples from two unused wells (U-65, U-70) were collected with a submersible pump. Samples from all other wells were collected from a tap. To ensure a sample representative of the aquifer, water had been withdrawn until specific conductance, temperature, and pH had stabilized.

The 15 sites were sampled on October 30 through November 1, 1985, and April 1 through 3, 1986, for constituents used to describe the general chemical quality of the ground water. Field measurements of temperature, specific conductance, alkalinity, pH, and dissolved oxygen were made. Two of the fifteen sites also were sampled on April 9 and June 20, 1986, for selected organic compounds, pesticides, and dissolved constituents (table 2).

Samples collected for analyses of dissolved constituents were filtered in the field. All samples were treated and preserved in compliance with established procedures and methods (Federal Interagency Work Groups, 1977; and U.S. Geological Survey, 1983) and analyzed at the U.S. Geological Survey National Water-Quality Laboratory (Fishman and Friedman, 1985; Wershaw and others, 1983).

Table 1.--Records of selected wells in northeastern Union County, Ohio--Continued

Well number	Latitude	Longitude	Depth of well (feet)	Altitude of land surface (feet)	Year completed	Casing material	Casing diameter (inches)	Casing length (feet)	Water use	Water-quality site?
U-55	40 26 16	83 17 22	50.0	948	1984	S	6	31	D	
U-56	40 26 07	83 17 09	35.0M	954	--	S	4	--	D	
U-57	40 26 31	83 16 03	54.0	938	1963	S	4.25	30	D	
U-58	40 26 54	83 15 27	36.0	940	1982	S	4.25	34	D	Yes
U-59	40 26 29	83 17 47	45.0M	955	--	S	4	--	D	
U-60	40 26 38	83 19 01	57.0	948	1964	S	4.25	28	D	
U-61	40 26 35	83 22 08	60.0M	981	--	S	4	--	U	
U-62	40 27 03	83 22 30	52.0M	980	--	S	5	--	D	
U-63	40 27 37	83 20 31	72.0M	960	--	S	5	--	D	
U-64	40 27 26	83 18 15	78.0	951	1978	S	5	43	D	Yes
U-65	40 25 55	83 17 42	49.0M	949	--	S	4	--	U	Yes
U-66	40 25 08	83 18 35	114.0	946	1982	S	8	27	C	Yes
U-67	40 26 00	83 17 40	70.0	947	1935	S	10	--	M	
U-68	40 25 59	83 17 38	151.0	947	1935	S	10	105	M	Yes
U-69	40 25 58	83 17 39	120.0	949	1950	S	10	40	M	Yes
U-70	40 26 01	83 17 38	36.0	946	1974	P	2	33.6	U	Yes
U-71	40 25 59	83 17 38	35.0	947	1974	P	2	31.6	U	
U-72	40 25 58	83 17 37	33.0	946	1974	P	2	26.6	U	
U-73	40 23 17	83 20 40	--	976	--	P	4	--	D	
U-74	40 23 00	83 15 04	52.0	930	1959	S	5	22	D	
U-75	40 14 43	83 19 33	42.0	956	1956	S	4	22	D	Yes
U-76	40 24 29	83 15 28	50.0M	930	--	S	4	--	D	

Table 2.--Organic compounds, pesticides, and dissolved constituents analyzed for

[Samples collected April 9 and June 20, 1986]

Organic compounds and pesticides	
Dichlorobromomethane, total	Trans-1,3-Dichloropropene, total
Carbontetrachloride, total	Cis-1,3-Dichloropropene, total
1,2-Dichloroethane, total	Perthane, total
Bromoform, total	Vinyl cloride, total
Chlorodibromomethane, total	Trichloroethylene, total
Chloroform, total	Naphthalenes, polychlorinated
Toluene, total	Aldrin, total
Benzene, total	Lindane, total
Chlorobenzene	Chlordane
Chloroethane	DDD, total
Ethylbenzene	DDE, total
Methyl-bromide	DDT, total
Methyl chloride, total	Dieldrin, total
Methyl-ene-chloride	Endosulfan, total
Tetra-chloroethylene	Endrin, total
Trichlorofluoromethane	Ethion, total
1,1-Dichloroethane, total	Toxaphene, total
1,1 Dichloroethylene	Heptachlor, total
1,1,1 Trichloroethane	Heptachlor epoxide, total
1,1,2 Chloroethane	Methoxychlor, total
1,1,2,2 Tetrachloroethane	PCB, total
1,2-Di-Chlorobenzene, total	Malathion, total
1,2-Dichloropropane	Parathion, total
1,2-Transdichloroethylene	Diazinon, total
1,3-Dichloropropane	Methyl parathion, total
1,3-Di chlorobenzene, total	Mirex, total
1,4-Di-chlorobenzene, total	Trithion, total
2-Chloroethylvinyl- ether	Methyl trithion, total
Dichlorodifluoromethane, total	

Dissolved constituents	
Antimony	Lead
Arsenic	Mercury
Beryllium	Nickel
Cadmium	Selenium
Chromium	Silver
Copper	Zinc
Cyanide	

GROUND-WATER FLOW

Direction of Flow

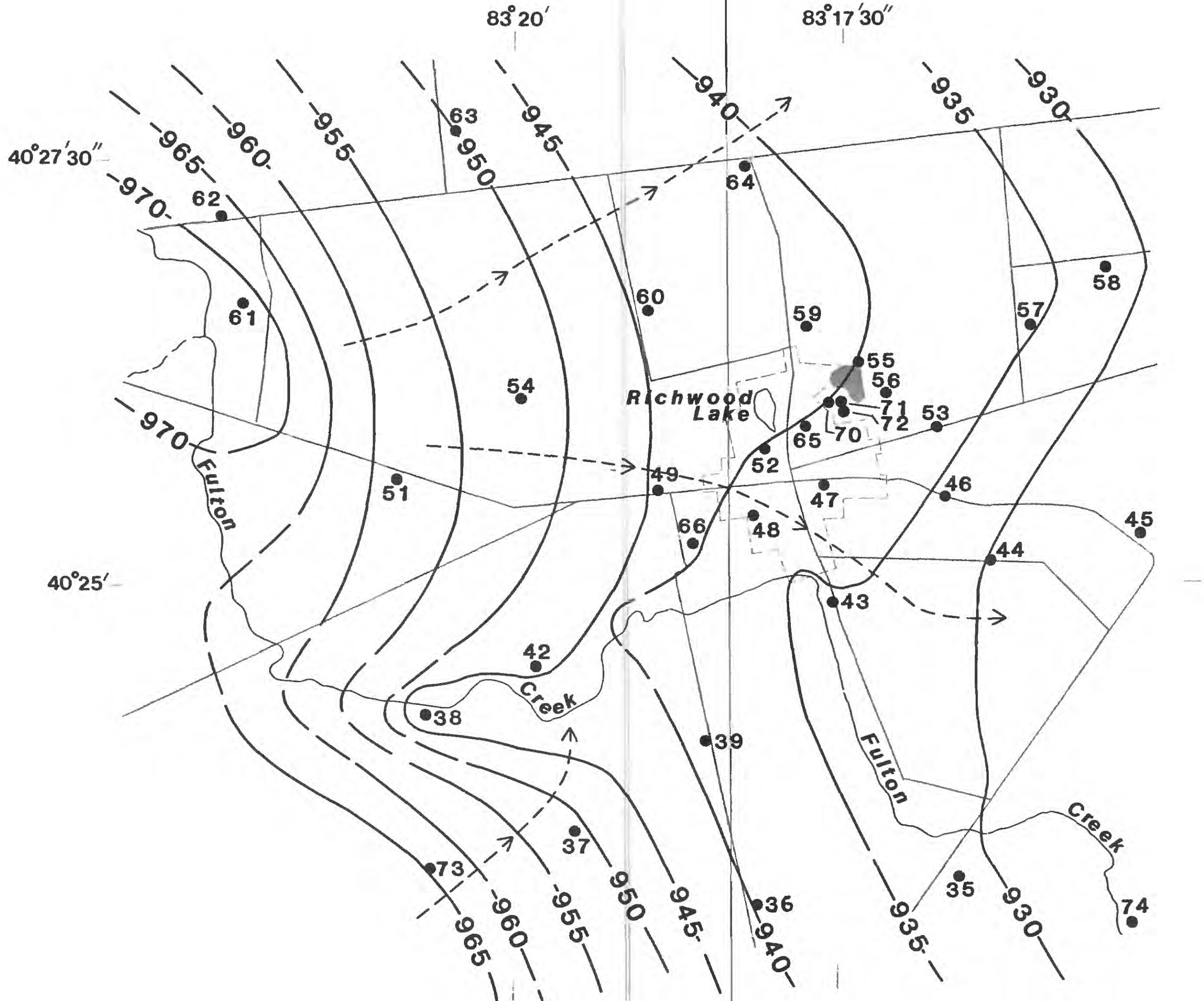
Water enters the ground and moves slowly to points of lower elevation under the influence of gravity. The direction of ground-water flow is determined from the gradient indicated by the potentiometric surface. The potentiometric surface is the level to which water will rise in a cased well. Ground water moves along paths at right angles to potentiometric contour lines (fig. 5).

In the study area, the land surface slopes generally eastward from 985 to 925 feet above sea level. Regional ground-water flow is from west to east, with local variation to the northeast or southeast due to the influence of Fulton Creek. The potentiometric contours on figure 5 are generalized because most wells open in the consolidated rock aquifers are cased to the top of the bedrock aquifer in the Bass Islands Group and are drilled as an open hole for the remainder of the well depth. The water level in such a well represents an integration of the heads in the different water-yielding zones that contribute to the well (Norris and Fidler, 1973).

Ground water moves from areas of recharge (where water enters the system) to points of natural discharge (where water leaves the system). The quantity of recharge and discharge depends on distribution and intensity of rainfall, plant cover, altitude, slope and roughness of terrain, the character of the geologic materials through which the water moves, and other hydrologic factors.

Because bedrock is not exposed in the study area, water enters the ground-water system by infiltration through overlying glacial deposits, as well as from points of recharge upgradient of the study area. Points of natural discharge within the study area are along Fulton Creek.

The direction of ground-water flow also is affected by pumping wells. The drawdown of the water surface in the aquifer under pumping conditions changes the gradient of the potentiometric surface locally. For example, water levels in wells U-70, U-71, and U-72, which are located near the landfill north of the municipal well field, are higher than water levels in U-65 south of the municipal well field, even though the land-surface altitude of U-65 is higher than that of the landfill wells (fig. 6; table 3, at back of report). A cone of depression from the withdrawal of water by the municipal wells might induce flow from the vicinity of the landfill towards the municipal wells. However, water levels of the municipal wells were not available, and the direction of flow in the immediate vicinity of the municipal wells and the landfill wells is not clearly understood.



EXPLANATION

39 • Water-level measurement site

-940- Line of equal altitude of water surface, dashed where uncertain. Interval, 5 feet.

- - -> Direction of ground-water flow

Landfill area

Base from U.S. Geological Survey
Richwood Quadrangle, 1961

Figure 5.--Potentiometric surface and flow lines for March 1986 (the county prefix U- has been deleted from well number).

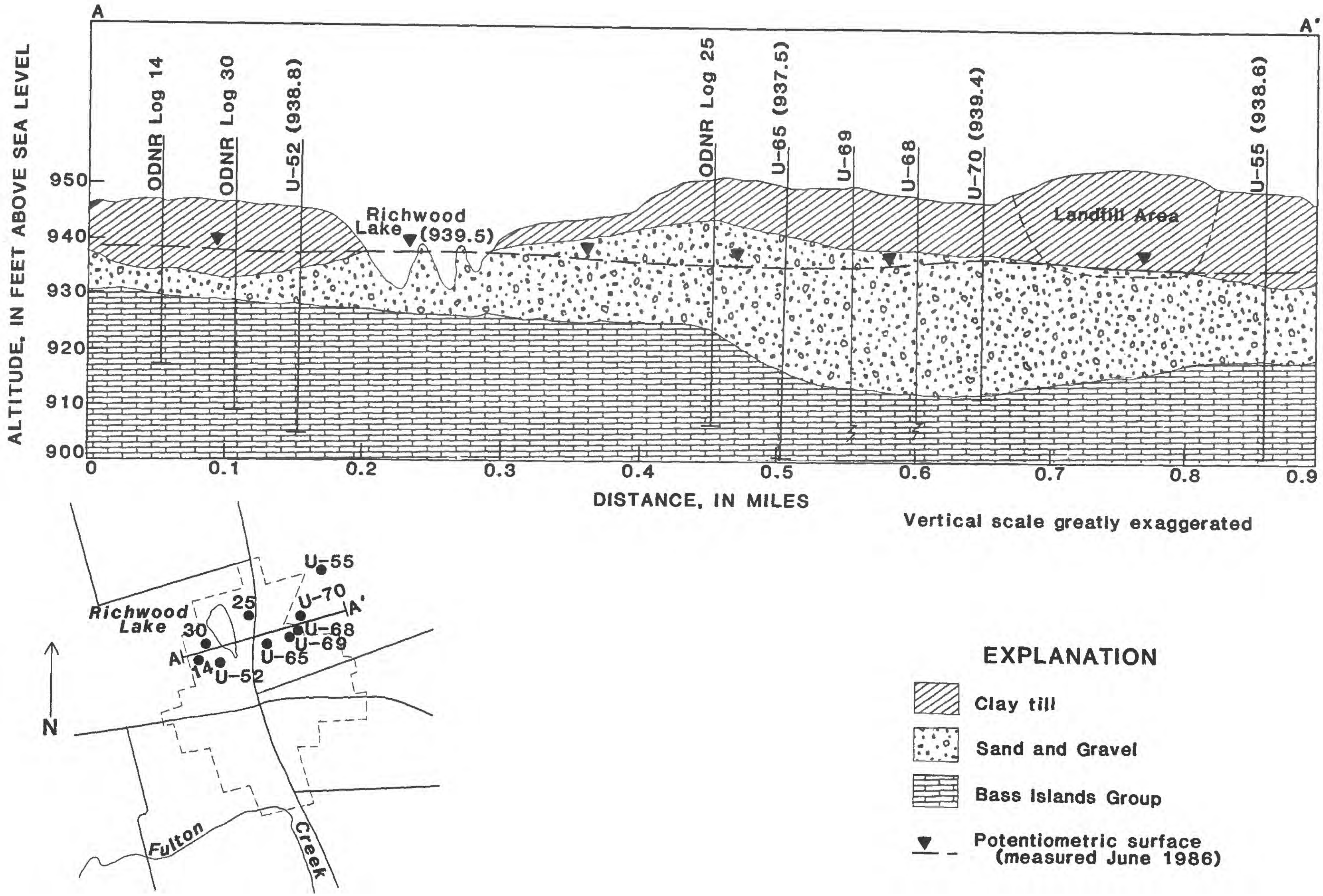


Figure 6.—Geologic Cross-section A - A'.

Water-Level Fluctuations

Water-level fluctuations result from a wide variety of hydrologic conditions such as ground-water recharge, evapotranspiration, bank-storage effects near streams, atmospheric pressure effects, and ground-water pumpage. For the period of study, ground-water levels were the lowest in September 1985 and were the highest during March 1986 (table 3, at back of report).

Water levels at well U-65 were recorded hourly from October 1985 through June 1986. Precipitation records were obtained from a site 2 miles east of the study area in Prospect, Ohio (National Oceanic and Atmospheric Administration, 1985-86) and were compared to the ground-water fluctuations at U-65 (fig. 7; tables 4 and 5, at back of report). Comparison of water-level fluctuations and precipitation data indicate that fluctuation of water levels in the aquifer was directly related to rainfall.

Evapotranspiration, a combination of evaporation from land surfaces and transpiration from the soil by plants, also affects ground-water levels where the water table is near the land surface. In a farmed area such as Claibourne Township, evapotranspiration has the greatest effect from April through September, as reflected by the water-level data for well U-65 (fig. 7). As the plants develop and use water, ground-water levels tend to decline; as temperature decreases, crops mature and are harvested, evapotranspiration ceases, and water levels increase.

Ground-Water/Surface-Water Interaction

The streams in the study area generally are gaining streams, that is, streams whose flow is increased by inflow of ground water. This is suggested by the potentiometric contours which, with respect to Fulton Creek, have a "V" pattern pointing upstream. This is typical of areas where ground-water flow is toward the stream (fig. 5). Stream-surface altitudes were used to construct contour lines near Fulton Creek. A series of seepage measurements was made to confirm that Fulton Creek is a gaining stream. During low-flow conditions, Fulton Creek was measured at four sites and at three inflowing tributaries (fig. 8). Results of the streamflow measurements indicate that there is an increase of flow downstream that cannot be attributed to tributary inflow; therefore, the increase is likely inflow of ground water to the stream (table 6). This indicates that the stream is a natural area of ground-water discharge.

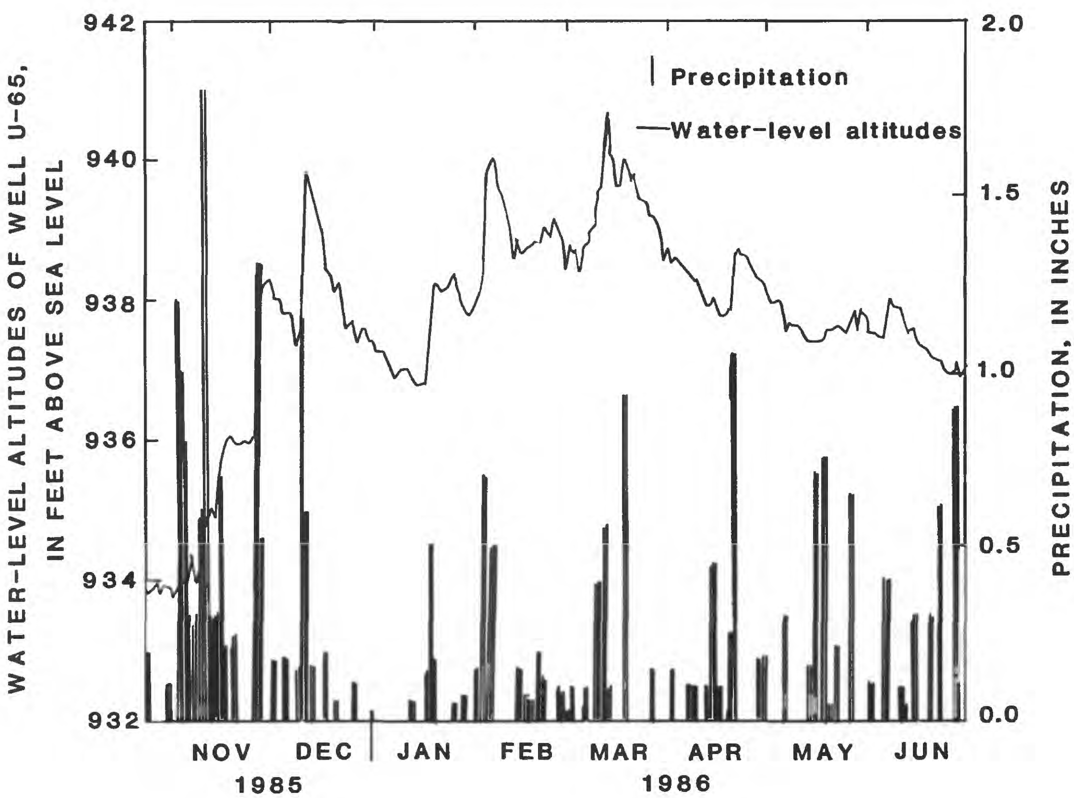


Figure 7.--Daily precipitation at Prospect, Ohio, and water-level altitudes at well U-65.

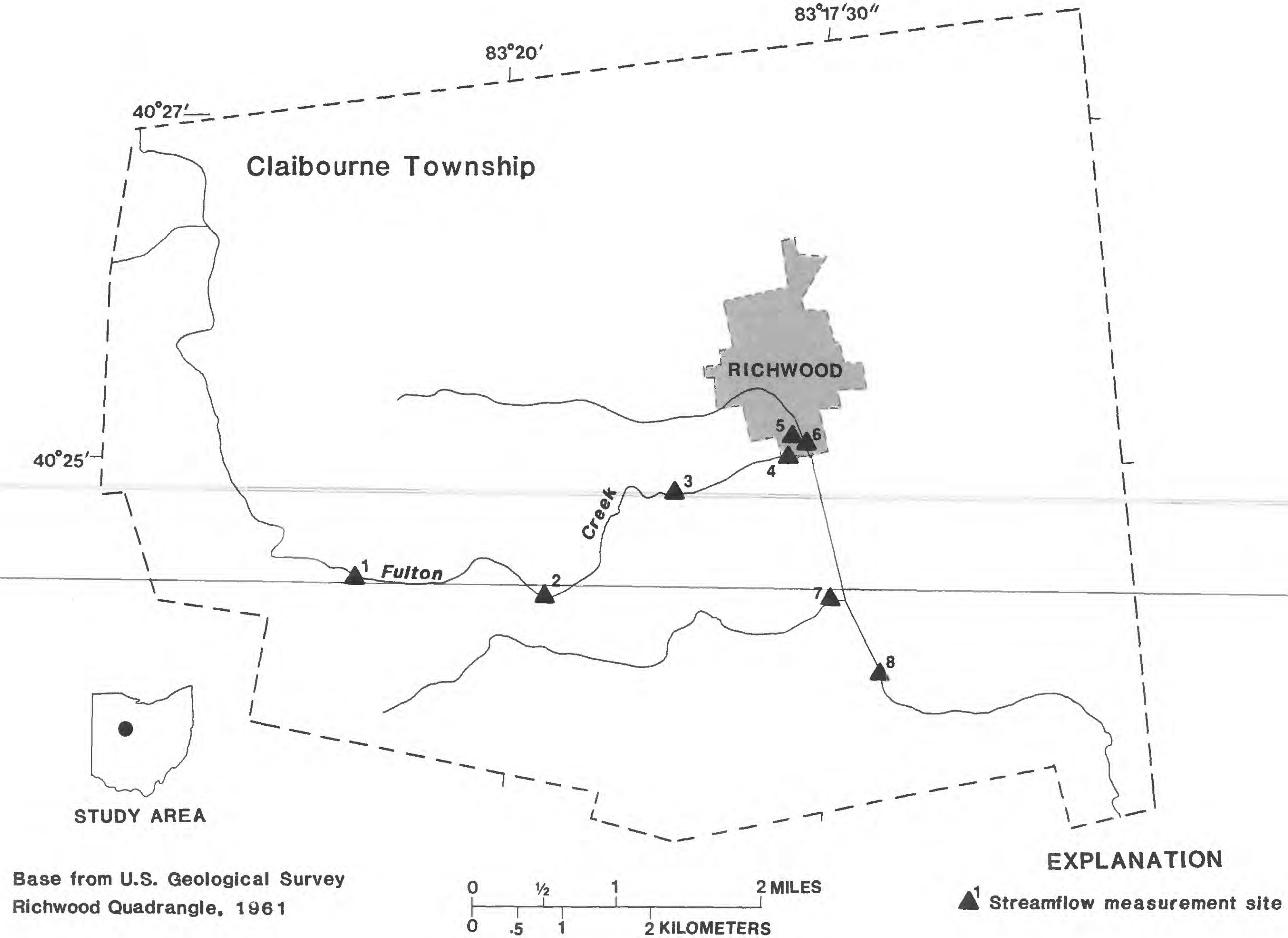


Figure 8.--Location of streamflow measurement sites on Fulton Creek and its tributaries.

Table 6.--Streamflow measurements on Fulton Creek and its tributaries, June 4, 1986

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

Site number	Identification number	Site name	Discharge (ft^3/s)
1	402416083211400	Fulton Creek----------------------	1.91
2	402409083194000	Fulton Creek----------------------	2.40
3	402447083183700	Fulton Creek ---------------------	2.50
4	402502083174300	Fulton Creek----------------------	2.80
[a]5	---------------	Sewage-treatment plant discharge--	.75
6	402504083173800	Unnamed Tributary to Fulton Creek----------------------------	.55
7	402410083172300	Unnamed Tributary to Fulton Creek----------------------------	.33
8	402343083170300	Fulton Creek----------------------	4.27

[a]The sewage-treatment plant discharge was calculated by using the 30-day average for the period April 1986.

Ground-water/surface-water interaction also was examined using water-level measurements of Richwood Lake (table 7, at back of report). In general, the water-level fluctuations of the lake are similar to the water-level fluctuations of well U-65, which is approximately 0.2 mile downgradient. As mentioned previously, the lake occupies an old sand-and-gravel quarry and is approximately 13 acres in area. There is no surface-water inlet or outlet associated with the lake; therefore, lake-level changes are influenced by precipitation and evaporation. Well U-65 is 49 feet deep and completed in the dolomite aquifer of the Bass Islands Group.

Although the magnitude of the fluctuations is not the same, figure 9A illustrates the similarity in water-level changes between the lake and well U-65 (during a rainfall event). A change in water levels will not occur at the same magnitude because well U-65 represents a confined system, whereas the lake is a free-water surface. Figure 9B shows actual daily water-level altitudes from October 1985 through June 1986. The geologic setting and water-level fluctuations indicate that the lake may be hydraulically connected to the underlying carbonate aquifer.

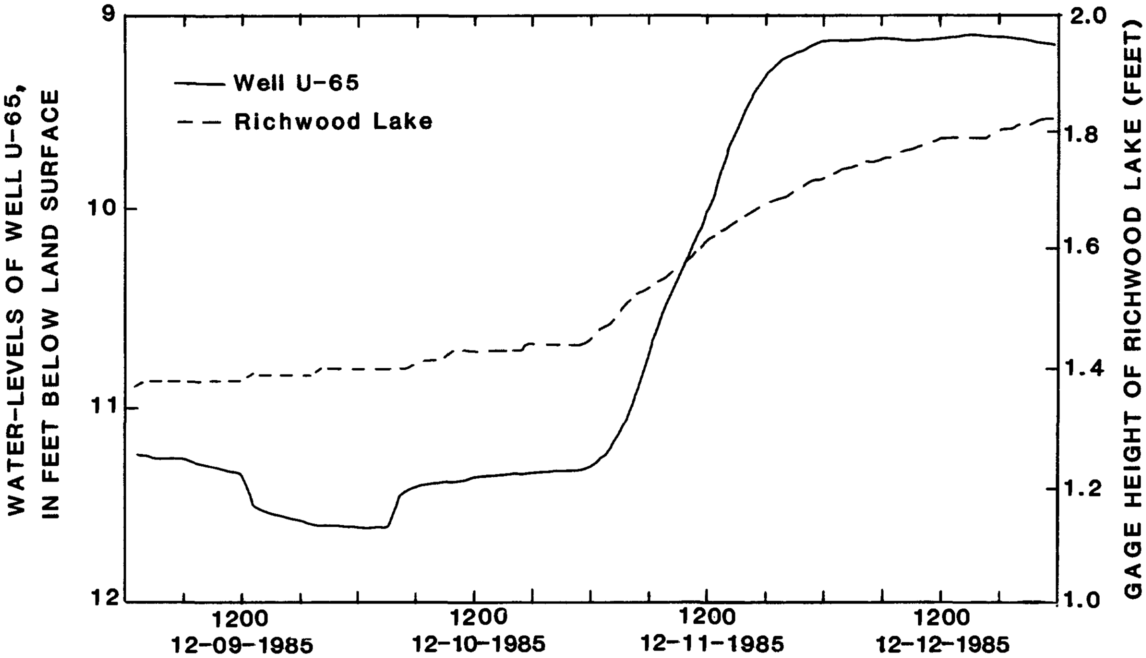
WATER QUALITY

Water samples were collected in October 1985 and April 1986 from 14 wells and Richwood Lake (fig. 3). Municipal wells U-68 and U-69 were included in the 14 well sites. The discussion of the water quality in this report includes the major inorganic constituents, selected minor constituents, organics and pesticides. The chemical analyses for samples from each well are presented in tables 8 and 9 (at back of report). Well numbers are reported in approximate order from upgradient sites to downgradient sites across the study area.

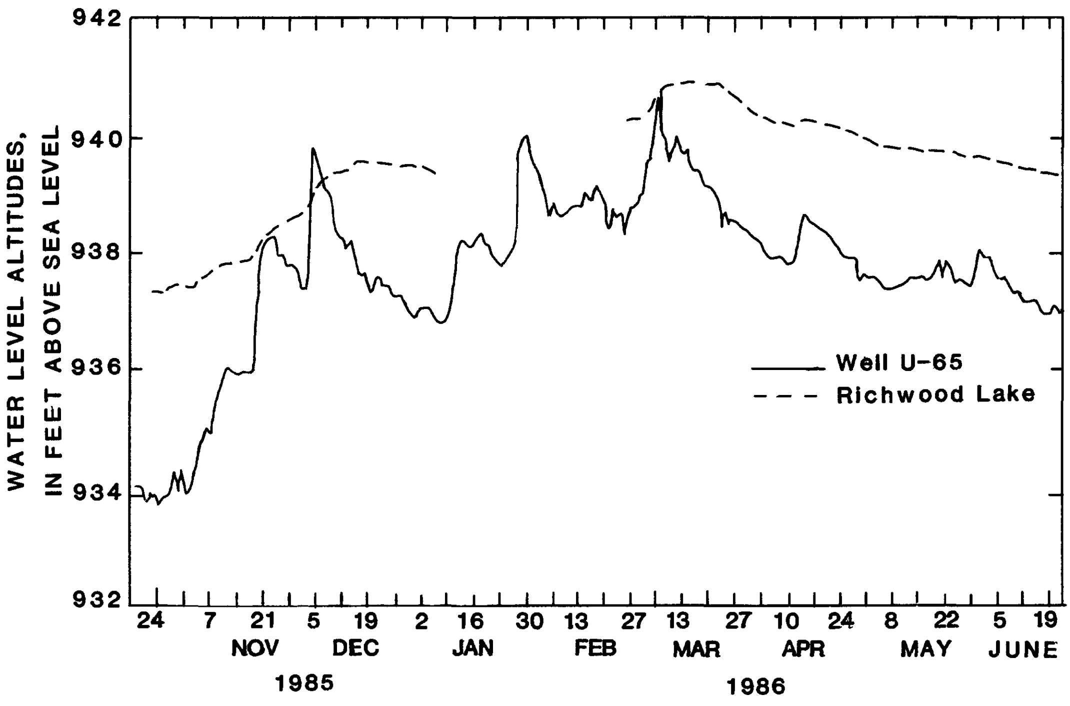
Areal Variation

Typical of water from a dolomite aquifer, ground water of northeastern Union County is a very hard calcium bicarbonate type (fig. 10); that is, calcium is the predominant cation and bicarbonate the predominant anion. Water from Richwood Lake also is of the bicarbonate type. The similar water type in the lake and the aquifer supports the view that the lake is hydraulically connected to the carbonate aquifer. The pH ranged from 7.0 to 7.5 with a median value of 7.3 for ground-water sites. The mean pH for Richwood Lake was 9.2.

For acceptable aesthetic and taste characteristics, the U.S. Environmental Protection Agency (1986) recommended a concentration limit for dissolved solids of 500 mg/L for domestic water supplies. The range of dissolved solids in 29 analyses from this study was from 200 mg/L at Richwood Lake to 720 mg/L at municipal well U-68 with a median value of 510 mg/L.



A.--Continuous water levels at well U-65 and gage heights at Richwood Lake from December 9 through December 12, 1985



B.--Water level altitudes at well U-65 and Richwood Lake from October 25, 1985 through June 30, 1986.

Figure 9.--Water-level comparisons of well U-65 and Richwood Lake.

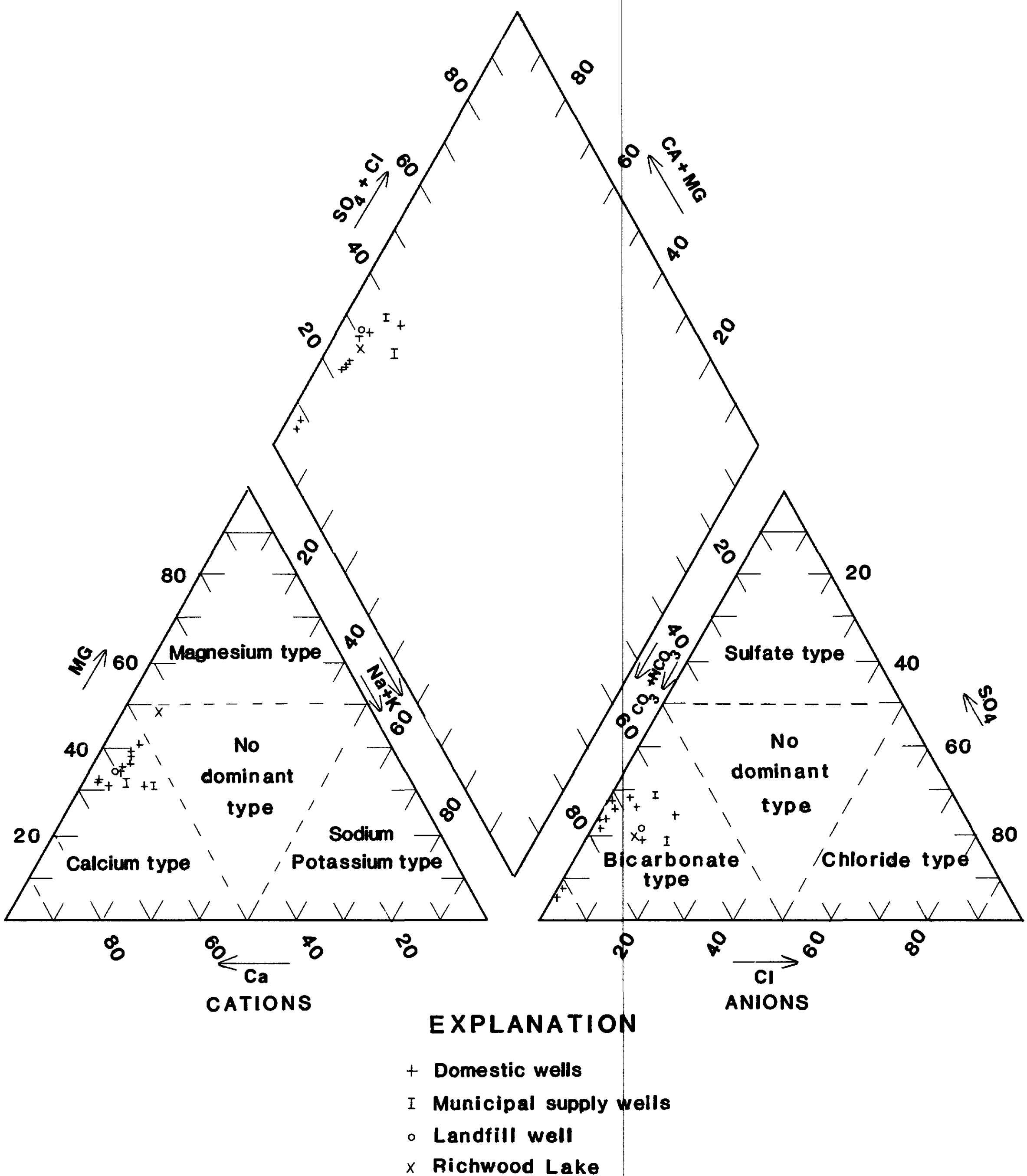


Figure 10.--Water-quality diagram showing the distribution of constituents in ground water and surface water within the study area.

The measured hardness of water (as $CaCO_3$) ranged from 170 to 540 mg/L; the median value for 29 analyses was 430 mg/L. Any concentration above 300 mg/L is classified as "very hard" water (U.S. Environmental Protection Agency, 1986). Analyses for two wells (U-46 and U-53) and Richwood Lake were below 300 mg/L and are considered "hard" water.

The U.S. Environmental Protection Agency (1986) has set a recommended limit of 250 mg/L for both chloride and sulfate in domestic water supplies. No analyses exceeded these limits. Sulfate ranged from 16 to 190 mg/L; the median concentration was 97 mg/L. Chloride ranged from 2.3 to 84 mg/L with a median concentration of 20 mg/L. Municipal well U-68 had concentrations of 67 and 84 mg/L of chloride, and well U-65 had concentrations of 77 and 72 mg/L. The concentrations are below the recommended limit; however, the concentrations are elevated in comparison to the other wells in the study area.

Sodium ranged from 3.0 to 39 mg/L with a median concentration of 13 mg/L. The U.S. Environmental Protection Agency (1986) recommends a maximum sodium content of 20 mg/L in water for sodium-restricted diets and 270 mg/L for moderately restricted diets. Sodium levels for domestic water supplies have no set criteria. The concentrations of sodium in municipal well U-68 were 39 and 32 mg/L, and in well U-65 the concentrations were 34 and 35 mg/L. The similar concentrations of both sodium and chloride in municipal well U-68 and well U-65 (upgradient from and south of the well field) may indicate contamination, although the source is not known.

Potassium--a primary nutrient used in fertilizers--has no set criteria in domestic water supplies. Potassium is reported as having little or no significant concentration in water from the Bass Islands Group, and the average range in natural or background water is 3 to 5 mg/L (Ohio Department of Natural Resources, 1970). Potassium concentrations ranged from 1.3 to 15 mg/L with a median value of 2.0 mg/L. Municipal well U-68 had potassium values five to eight times greater than the median value (fig. 11).

In the study area, ammonia is the most common form of nitrogen in the water, although nitrogen also is found in the form of nitrate, nitrite, and organic nitrogen. Organic nitrogen, as well as ammonia, were the nitrogen forms that were most commonly detected. These forms were detected at all 15 sites on each sampling date (fig. 12). Organic nitrogen ranged from 0.03 to 0.57 mg/L with a median of 0.15 mg/L. Ammonia was found at higher concentrations, and ranged from 0.03 to 15 mg/L as nitrogen with a median value of 0.18 mg/L. The most elevated levels of ammonia were at U-68 and U-69 (municipal wells) and also at U-52. The concentrations at U-68 and U-69 are elevated above background levels based on concentrations at the other wells. Ammonia concentrations in the three municipal wells have sporadically ranged from less than 0.05 to 34.60 mg/L since 1983 (Village of Richwood, written commun., 1986) (fig. 13).

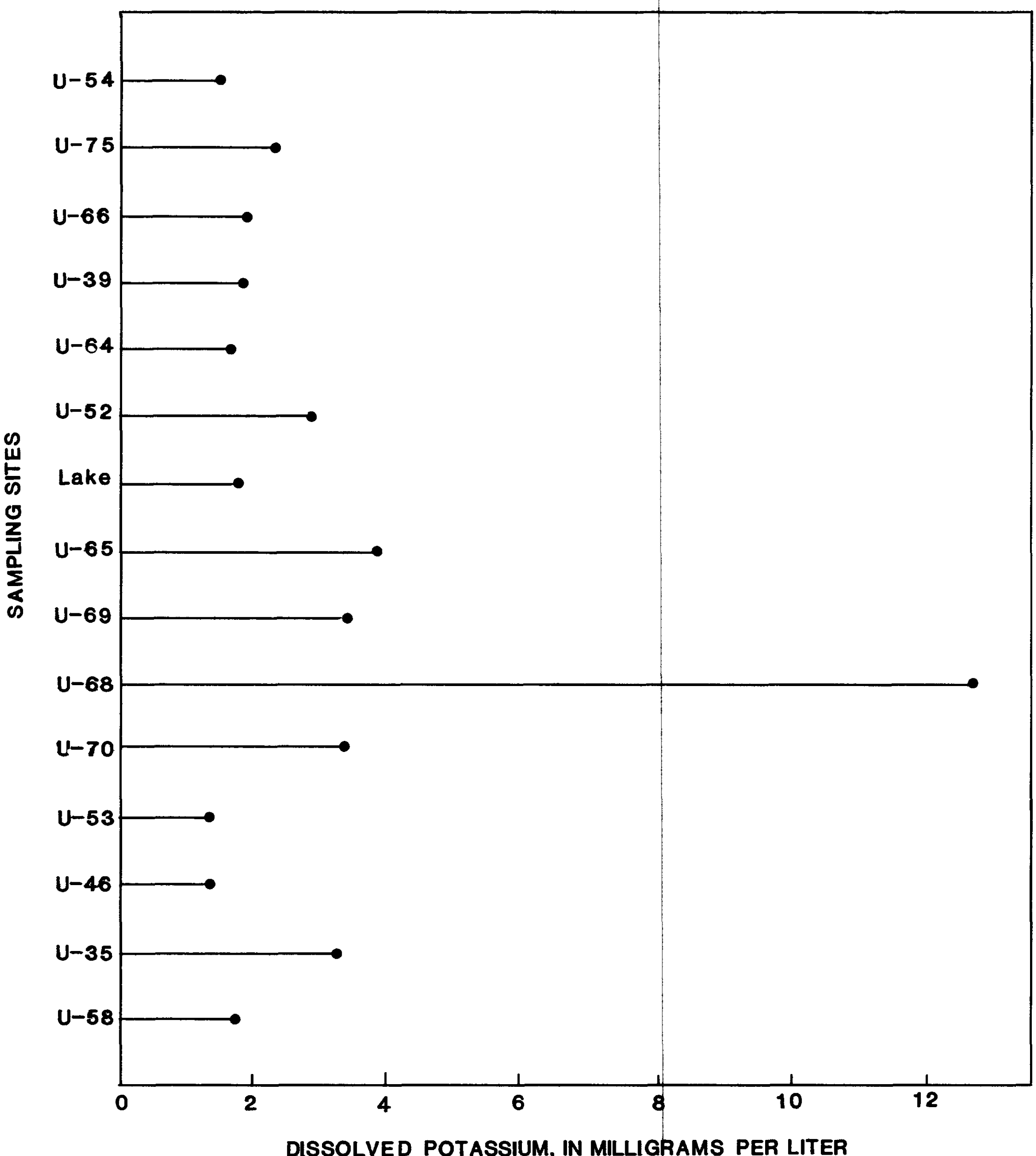


Figure 11.—Mean concentrations of dissolved potassium in water sampled October 1985 and April 1986 for 15 sites in the study area.

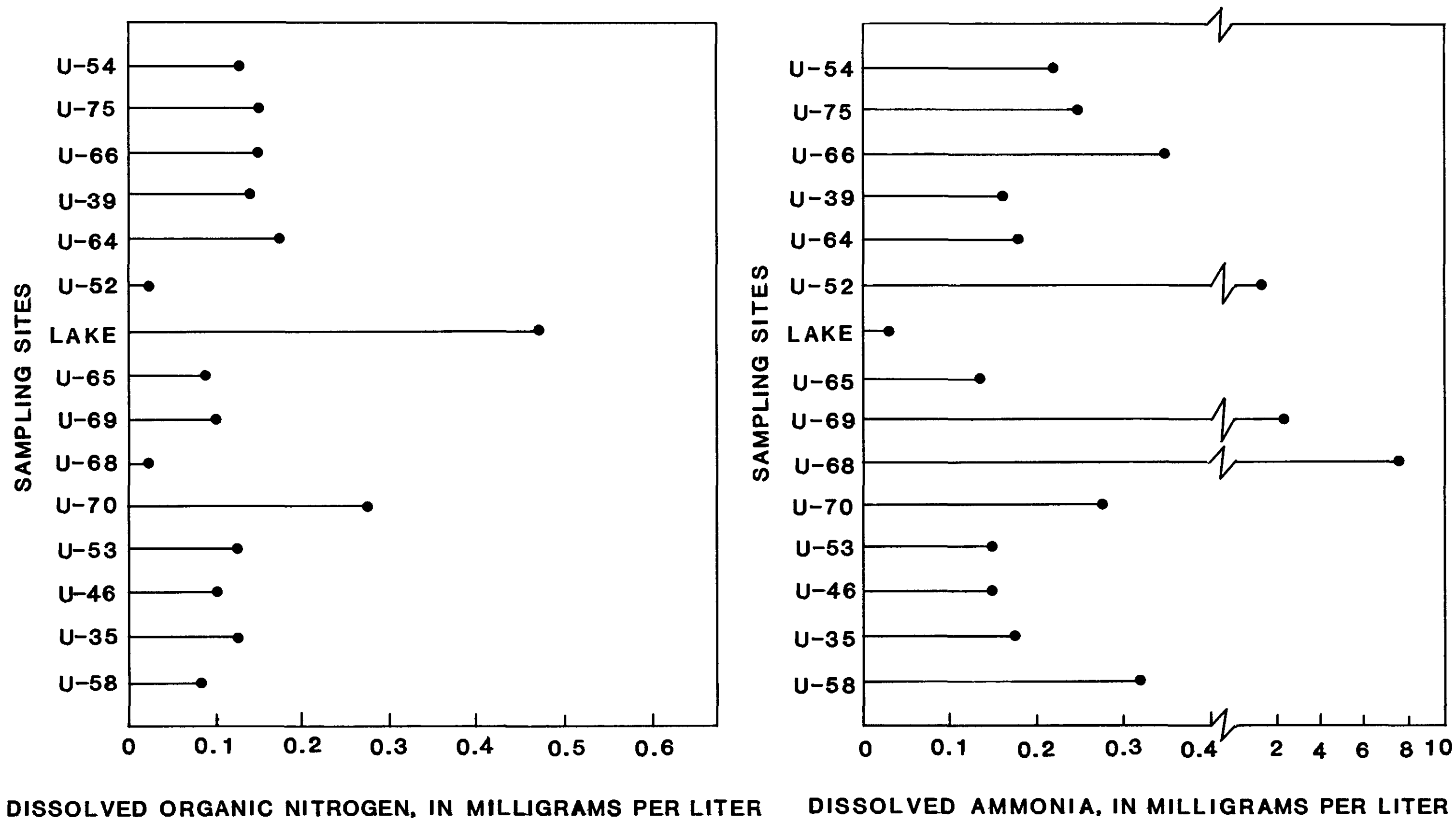


Figure 12.--Mean concentrations of dissolved organic nitrogen and ammonia in water sampled October 1985 and April 1986 for 15 sites in the study area.

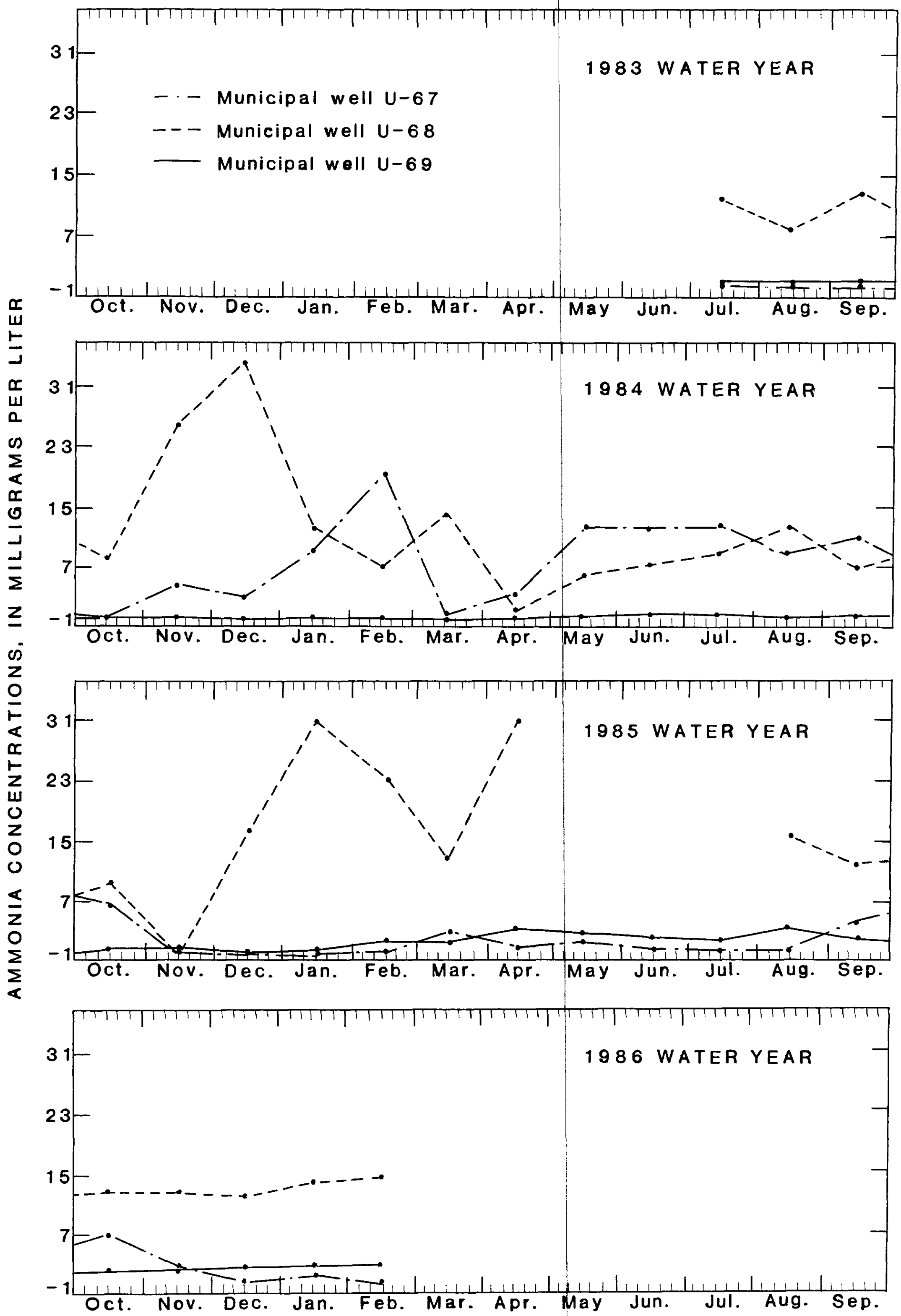


Figure 13.--Ammonia concentrations from Richwood municipal wells (analyses provided by the Village of Richwood, 1986).

The recommended limit for nitrate in public water supplies is 10 mg/L as N (U.S. Environmental Protection Agency, 1986). The level of nitrate considered to be above natural or background levels has not been defined; however, in ground water, concentrations greater than about 3 mg/L of nitrate-nitrogen are considered indicative of human activity (Madison and Brunett, 1985). No criteria have been set for other forms of nitrogen in water supplies. Nitrate was only detected in the study area at levels ranging from 0.10 mg/L in Richwood Lake to 2.79 mg/L in U-70 (landfill well). Nitrate was detected in three other wells: U-66, 0.12 mg/L; U-46, 1.50 mg/L; and U-35, 0.12 mg/L.

Nitrite may be produced by oxidation of ammonia in a process referred to as nitrification. Nitrite was detected at concentrations of 0.01 mg/L for two domestic wells (U-39 and U-52) and 0.02 mg/L for the landfill well U-70. These concentrations are not considered elevated, and are much less than the levels of 10 to 11 mg/L reported in 1984 in the community's water system. The elevated nitrite concentrations detected in 1984 have been attributed to a contaminated redwood aerator, according to the Richwood Division of Water (F. Robinson, Richwood Division of Water, oral commun., 1985). The elevated nitrite concentrations were detected from water within the community system and not in the raw water from the municipal wells.

In an area that is predominantly agricultural, nitrogen contamination could be attributed to nitrogen fertilizers or livestock wastes. Ammonia is used to manufacture such nitrogenous products as fertilizers and can potentially produce ammonia as a contaminant. Constituents leached from a chemical fertilizer production area near production wells at an agricultural chemical plant in Illinois created a contamination plume with elevated ammonia concentrations in the underlying aquifer (Naymik and Barcelona, 1981).

Both ammonia and potassium were detected at levels above background concentrations at municipal well U-68. The source may be the abandoned landfill, where waste from a local lawn-care chemical production company was reportedly discarded. Because overlying clay deposits have been excavated from the site of the present municipal well field and the landfill, the area is highly susceptible to infiltration of any contaminant from the land surface. This, along with the fact that eyewitness accounts state that sand and gravel was exposed during operation of the landfill, suggests an avenue of flow for contaminants from the landfill through the sand and gravel deposits to the underlying carbonate aquifer. Pumping the municipal wells could induce flow from the vicinity of the landfill to the municipal wells.

Infiltration from the land surface and the effect of pumping the municipal wells also are important when considering the abandoned liquid-nitrogen silos at the agricultural supply company and the small strip of land next to the well field that was once a dump. It is unknown what might have been deposited in the dump; and one of the nitrogen silos leans, which indicates the possibility of a leak.

Although a source of ammonia and potassium was not determined, it can be said that the well field is in an area highly susceptible to contamination from several sources.

Concentrations of dissolved iron ranged from 13 to 2,300 µg/L (micrograms per liter) with a median value of 910 ug/L; 24 of the 29 analyses exceed the U.S. Environmental Protection Agency water-quality standard of 300 µg/L for iron. The recommended limit of 300 µg/L is to prevent objectionable tastes or laundry staining, thus, levels found in the study area that exceeded the standard are not necessarily harmful to human health (U.S. Environmental Protection Agency, 1976a). The sites where the standard was not exceeded include Richwood Lake, U-70 (landfill well), and one analysis from U-35. These are the only wells that are cased with PVC instead of steel, which may indicate that, in many wells, corrosion of the iron casing adds iron to the water pumped from them (Hem, 1985).

Concentrations of manganese range from <1 to 230 µg/L, and five analyses (at U-70, U-68, and U-39) exceed the U.S. Environmental Protection Agency standards of 50 µg/L for manganese (fig. 14).

Arsenic, lead, mercury, aluminum, sulfide, phosphorus, and orthophosphorus were present in trace amounts only (table 8).

The amount of organic material present in most waters is small compared to that of inorganic material. The amount of organic carbon in water can be an indicator of the presence of organic contaminants. Total organic carbon (TOC) is the sum of dissolved organic carbon (DOC) and suspended organic carbon (SOC). Leenheer and others (1974) suggest that concentrations of DOC exceeding 5 mg/L would indicate ground-water contamination by organics. In ground water, since most constituents are in the dissolved state with little or no suspended particles, the concentration of TOC measured in this study can be assumed to be equivalent to the concentration of DOC.

Concentrations of total organic carbon ranged from 1.2 to 8.2 mg/L with a median of 2.1 mg/L. Three of twenty-seven ground-water analyses of total organic carbon exceeded 5 mg/L (table 8). Elevated concentrations were found at U-70 (landfill well), U-68 (municipal well), and U-64 (a domestic well upgradient and to the north of the municipal well field) (fig. 15).

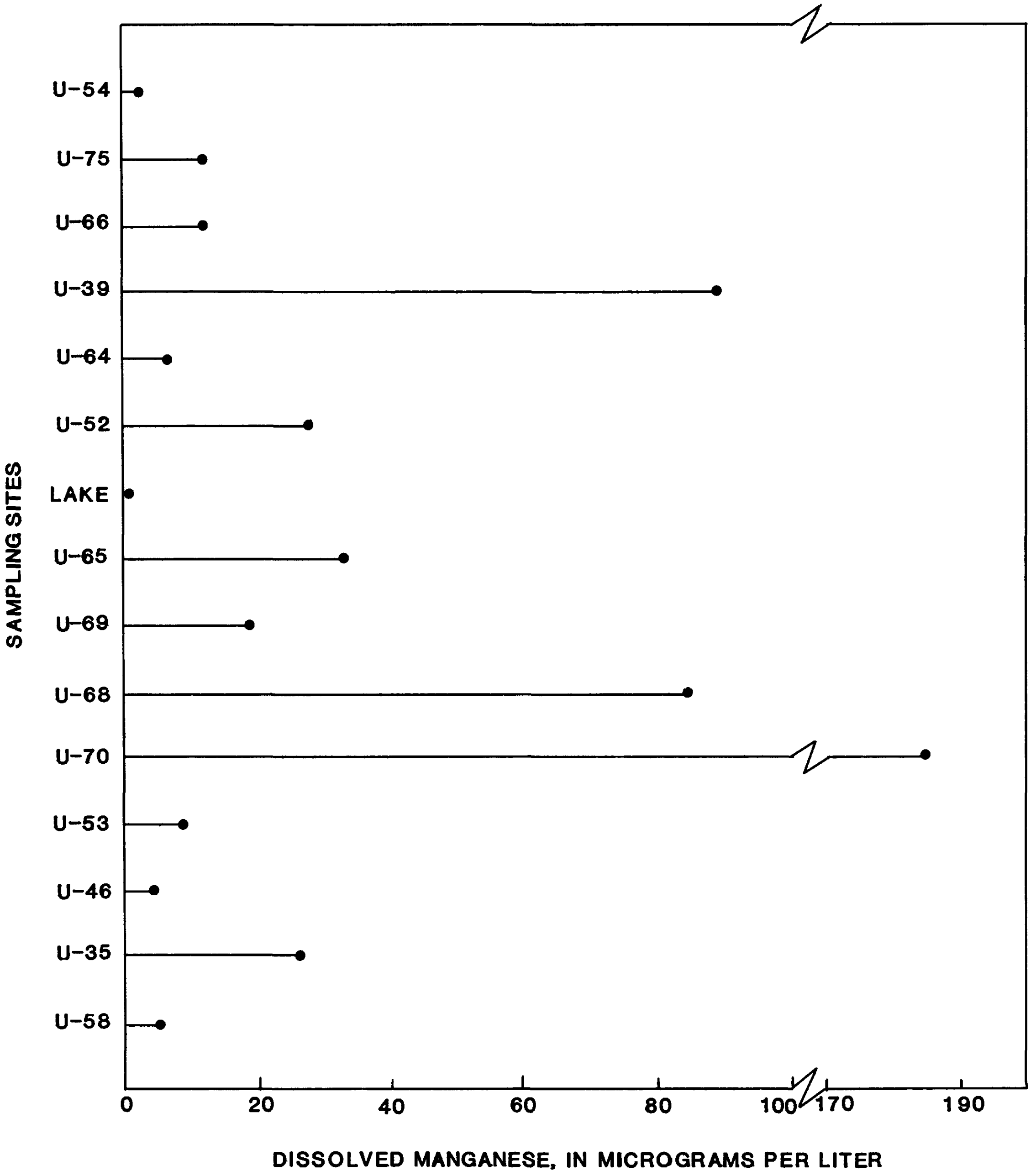


Figure 14.—Mean concentrations of dissolved manganese in water sampled October 1985 and April 1986 for 15 sites in the study area.

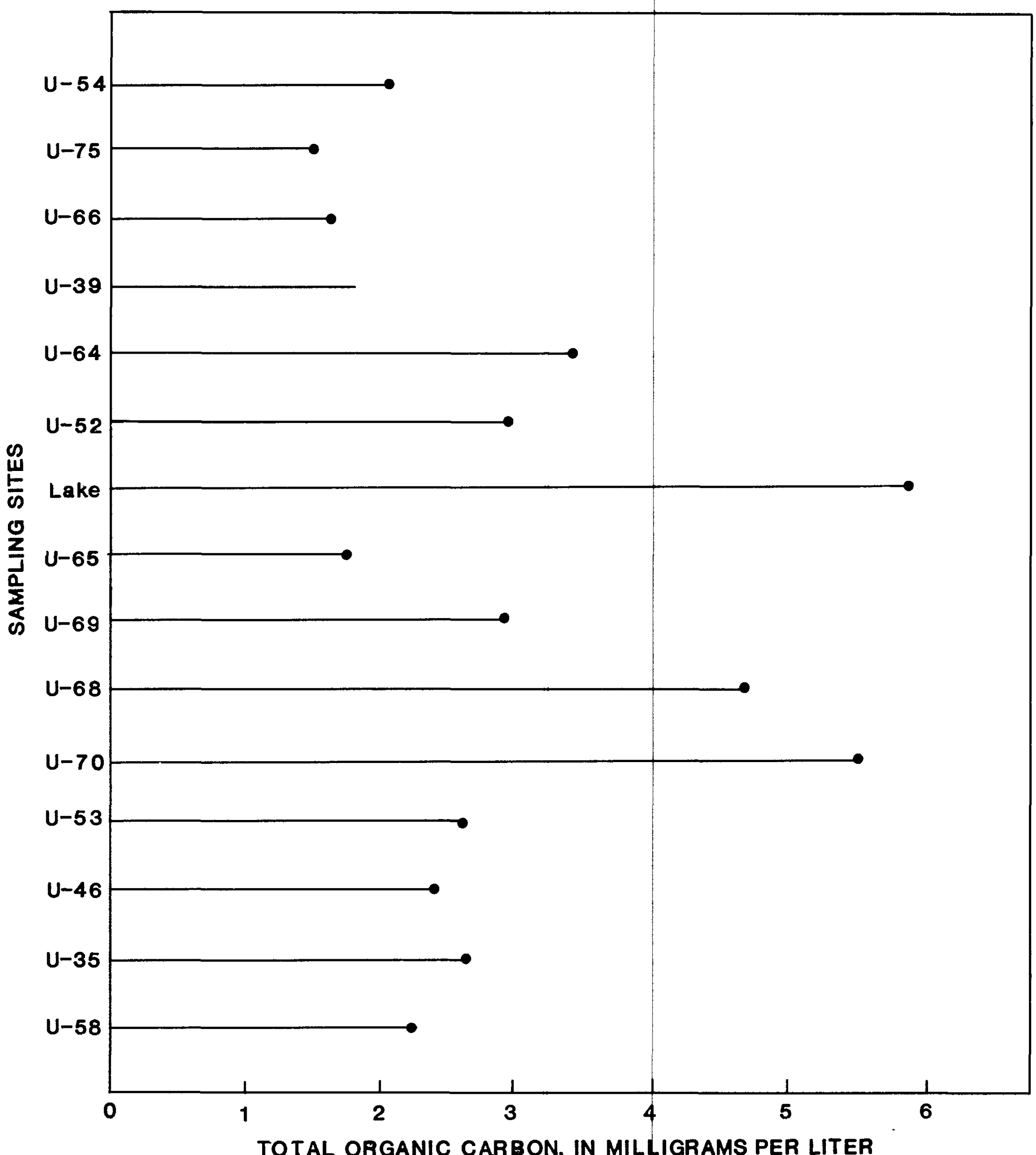


Figure 15.--Mean concentrations of total organic carbon in water sampled October 1985 and April 1986 for 15 sites in the study area.

The similar concentrations of 8.2 mg/L in U-70 and 6.6 mg/L in U-68 in October may indicate that both wells are affected by leachate from the landfill. The source of 5.2 mg/L of organic carbon in U-64 sampled in April is not known. Levels of total organic carbon in Richwood Lake exceeded 5 mg/L, but this is not an uncommon concentration for surface water.

Ground-water quality is similar throughout the study area, except in the vicinity of the well field. Municipal well U-68 reflects elevated levels of ammonia, dissolved potassium, dissolved sodium, dissolved chloride, dissolved manganese, and total organic carbon when compared to other wells in the study area. Elevated concentrations of ammonia in the past and concern about possible contaminants from the landfill next to the municipal supply led to additional data collection from U-68. Well U-54, located upgradient of the municipal well field, was selected as a comparison site. Water samples from both wells were analyzed for 57 organic compounds and pesticides (table 2). The wells were sampled in April and June 1986, but no detectable concentrations of any of the 57 constituents were found in either well.

The water also was analyzed for selected dissolved trace constituents (table 9). Lead, copper, nickel, zinc, and arsenic were present in trace amounts below the contamination limits (table 9). The other constituents were not detected.

Temporal Variation

From October 1985 to April 1986, concentrations of constituents generally did not vary widely at any site. Ammonia concentrations at municipal well U-68 reflected the most extreme change between samplings--from 0.15 to 15 mg/L. Fluctuating concentrations of ammonia (fig. 13) have been documented by the Richwood Division of Water since 1983 (Village of Richwood, written commun., 1986).

Ground water is in continuous motion, although it often flows at slow rates. Ground-water velocities depend on local hydrogeologic conditions; normal rates range from 2 meters per year to 2 meters per day (Todd, 1980). However, the rate of ground-water flow through fractures and solution cavities in dolomite can be as fast as surface-water streamflow. Because the rate of ground-water flow is slow, the quality of ground water generally changes slowly, especially in deep aquifers.

A major cause of cyclic fluctuations of concentrations of dissolved constituents, such as those reflected by ammonia in the municipal wells, could be intermittent infiltration of water-soluble substances (Pettyjohn, 1976). Soluble constituents infiltrate during periods of recharge (precipitation) and migrate towards points of discharge, such as pumping wells. When precipitation stops, infiltration ceases, and the constituent is no longer introduced into the ground-water system.

Later, another period of recharge flushes the soluble constituents into the ground-water system again. Factors affecting cyclic fluctuations include laminar flow conditions, pumpage, and differences in specific gravity, temperature, and viscosity between the constituent and the native ground water.

SUMMARY

The hydrology and ground-water quality in the vicinity of Richwood, northeastern Union County, were studied using data from 38 wells and 1 surface-water site, Richwood Lake. The study consisted of preparation of a potentiometric-surface map and collection and interpretation of water-quality data.

In the study area, which included Claibourne Township and the southwestern part of Jackson Township, the topography is featureless due to glaciation, and the land surface slopes gently eastward from 985 to 925 feet above sea level. Glacial deposits that consist of clay till, sand, and gravel are up to 48 feet thick and cover the carbonate bedrock aquifer, the Bass Islands Group of Late Silurian age. The predominant land use outside the village is agriculture.

A potentiometric-surface map based on water-level data from 34 wells measured in March 1986 shows that ground water flows from west to east. Local variations to the northeast and southeast are caused by the influence of Fulton Creek. Fulton Creek is a gaining stream as a result of ground-water discharge. Richwood Lake occupies an abandoned sand-and-gravel quarry and reflects similar water-level fluctuations as those of well U-65, which indicates that the sand and gravel deposits beneath Richwood Lake are hydraulically connected to the carbonate aquifer.

During the period of study (September 1985 through June 1986), ground-water levels were lowest during September 1985 and highest during March 1986. The bedrock aquifer responded to rainfall events with a rise in water levels, which indicates that recharge to the ground-water system is from precipitation. From April through June 1986, evapotranspiration caused a lowering of ground-water levels.

Water-quality data were collected from 14 wells and Richwood Lake. Hard to very hard calcium bicarbonate type water is characteristic of the study area. Concentrations of dissolved solids were near the U.S. Environmental Protection Agency's recommended level of 500 mg/L at most sites. Dissolved manganese was present at concentrations greater than 50 µg/L in water from wells U-68 (municipal well), U-70 (landfill well), and U-39 (domestic well).

Although organic carbon was present at every site, only 3 analyses of 27 for the 14 ground-water sites had concentrations of TOC that exceeded 5 mg/L: U-70 (landfill well), 8.2 mg/L; U-68 (municipal well), 6.6 mg/L; and U-64 (a domestic well upgradient and to the north of the municipal well field), 5.2 mg/L.

Potassium ranged from 1.3 to 15 mg/L with a median value of 2.0 mg/L. Concentrations of 15 and 10 mg/L from municipal well U-68 were elevated compared to concentrations from the other wells.

Both ammonia and organic nitrogen were detected at all sites; ammonia concentrations at municipal wells U-68 and U-69 and domestic well U-52 exceeded 1 mg/L as nitrogen. The direction of ground-water flow in the vicinity of the municipal wells is not well defined; therefore, the source of elevated ammonia concentrations, as well as potassium concentrations, was not determined.

Additional water-quality samples were collected at well U-68 and analyzed for organic compounds, pesticides, and dissolved constituents. Well U-54 was sampled for comparison purposes. No contaminants were detected at either well.

Municipal well U-68 had elevated concentrations of dissolved solids, ammonia, dissolved potassium, dissolved manganese, dissolved chloride, dissolved sodium, and total organic carbon, whereas the other sites had only one or two constituents with elevated concentrations based on levels from other wells.

Several factors are potentially related to the elevated concentrations of constituents found in the municipal wells and those in the vicinity of the well field:

1. The site where the well field and landfill are located was at one time excavated for clay deposits; this makes the underlying sand and gravel and carbonate aquifer susceptible to infiltration from the land surface.

2. Infiltration of precipitation is the source of recharge to the aquifer and may be related to the fluctuation of concentrations of constituents.

3. Upgradient from and about 100 yards southwest of the well field is an agricultural supply company with liquid-nitrogen silos that may have leaked.

4. An abandoned landfill is north of the well field.

5. Adjacent to the well field is part of an abandoned community dump.

6. The development of a cone of depresssion around the municipal wells might induce ground-water flow from any or all of the potential sources of contamination.

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Table 3.--Water-level data collected in Union County from September 1985 through June 1986

[Altitudes in feet above sea level]

Well number	Date measured	Water-level altitude (feet)	Land-surface altitude (feet)
U-35	9/16/85	930.3	940
	12/10/85	933.0	
	3/06/86	933.9	
	6/17/86	932.8	
U-36	9/17/85	936.9	953
	12/09/85	939.5	
	3/05/86	939.9	
	6/17/86	939.3	
U-37	9/18/85	948.7	972
	12/10/85	951.5	
	3/05/86	952.4	
	6/17/86	951.4	
U-38	9/16/85	941.6	957
	12/10/85	943.2	
	3/05/86	943.9	
	6/17/86	942.9	
U-39	9/23/85	935.1	945
	12/09/85	938.0	
	3/03/86	938.6	
	6/17/86	937.7	
U-40	9/23/85	926.9	937
U-41	9/25/85	924.8	931
U-42	9/25/85	944.5	959
	12/10/85	947.0	
	3/05/86	947.8	
	6/17/86	946.7	
U-43	9/23/85	929.9	941
	12/10/85	932.5	
	3/06/86	933.5	
	6/17/86	932.0	
U-44	9/25/85	926.2	937
	12/10/85	929.4	
	3/05/86	930.0	
	6/18/86	929.0	

Table 3.--Water-level data collected in Union County from September 1985 through June 1986--Continued

Well number	Date measured	Water-level altitude (feet)	Land-surface altitude (feet)
U-45	9/16/85	921.3	932
	12/10/85	924.0	
	3/05/86	924.7	
U-46	9/24/85	930.9	937
	12/09/85	933.3	
	3/05/86	933.9	
	6/18/86	932.8	
U-47	9/17/85	934.9	941
	12/09/85	937.3	
	3/05/86	938.0	
	6/18/86	936.9	
U-48	9/18/85	935.0	942
	12/09/85	937.5	
	3/06/86	938.5	
	6/17/86	937.0	
U-49	9/17/85	940.6	948
	12/10/85	942.8	
	3/06/86	944.3	
	6/17/86	942.6	
U-50	9/24/85	952.2	974
	6/17/86	954.5	
U-51	9/17/85	953.8	975
	12/10/85	955.5	
	3/06/86	957.3	
	6/17/86	955.9	
U-52	9/24/85	937.0	946
	12/09/85	938.7	
	3/05/86	940.0	
	6/17/86	938.9	
U-53	9/17/85	934.4	939
	12/09/85	935.6	
	3/05/86	936.7	
	6/18/86	935.4	
U-54	9/20/85	950.0	964
	12/09/85	952.1	
	3/06/86	953.7	
	6/20/86	952.1	

Table 3.--Water-level data collected in Union County from September 1985 through June 1986--Continued

Well number	Date measured	Water-level altitude (feet)	Land-surface altitude (feet)
U-55	9/17/85	935.9	948
	12/10/85	938.8	
	3/05/86	940.4	
	6/17/86	938.6	
U-56	9/20/85	934.9	954
	12/09/85	937.8	
	3/05/86	939.2	
	6/18/86	937.4	
U-57	9/16/85	931.4	938
	12/09/85	933.8	
	3/05/86	935.2	
	6/18/86	933.9	
U-58	9/25/85	927.8	940
	12/10/85	930.8	
	3/05/86	932.2	
	6/18/86	930.8	
U-59	9/18/85	936.2	955
	12/09/85	938.9	
	3/05/86	940.6	
	6/17/86	938.9	
U-60	9/17/85	938.2	948
	12/09/85	940.5	
	3/06/86	941.8	
	6/17/86	940.2	
U-61	9/24/85	968.7	981
	12/10/85	971.6	
	3/06/86	973.4	
	6/17/86	971.4	
U-62	9/24/85	965.1	980
	12/10/85	967.4	
	3/06/86	969.3	
	6/17/86	967.3	
U-63	9/20/85	944.9	960
	12/09/85	947.6	
	3/10/86	950.4	
	6/17/86	947.4	
U-64	9/16/85	937.2	951
	12/09/85	936.2	
	3/05/86	942.3	
	6/17/86	940.5	

Table 3.--Water-level data collected in Union County from September 1985 through June 1986--Continued

Well number	Date measured	Water-level altitude (feet)	Land-surface altitude (feet)
U-65	12/09/85	937.7	949
	3/05/86	938.4	
	6/17/86	937.5	
U-66	12/09/85	941.0	946
	3/05/86	941.6	
	6/17/86	940.5	
U-70	12/09/85	939.7	946
	3/05/86	941.2	
	6/17/86	939.4	
U-71	12/09/85	938.6	947
	3/05/86	939.4	
	6/17/86	938.3	
U-72	12/09/85	938.8	946
	3/05/86	940.2	
	6/17/86	938.5	
U-73	3/03/86	965.3	976
U-74	3/06/86	921.5	930
	6/17/86	920.2	
U-76	6/18/86	919.7	930

Table 4.--Daily maximum water-level altitudes from well U-65, October 1985 through June 1986

[Dash indicates no data available]

	Daily maximum water levels, in feet above sea level								
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1	--	933.75	938.29	937.40	937.88	938.46	938.73	938.13	937.69
2	--	933.87	937.98	937.42	937.97	938.79	938.55	937.97	937.52
3	--	933.90	937.98	937.25	938.09	938.65	938.62	937.92	937.56
4	--	933.99	938.00	937.25	938.35	938.71	938.55	937.95	937.51
5	--	934.30	937.78	937.26	939.79	938.39	938.49	937.96	937.48
6	--	933.96	937.79	937.10	939.98	938.80	938.45	937.92	937.48
7	--	934.37	937.79	936.96	940.02	938.78	938.40	937.56	937.88
8	--	933.92	937.77	936.88	939.78	938.81	938.35	937.68	938.05
9	--	933.98	937.39	937.02	939.59	938.98	938.27	937.61	937.89
10	--	934.42	937.39	937.04	939.47	939.04	938.28	937.62	937.89
11	--	934.74	937.75	937.03	939.21	939.55	938.15	937.62	937.90
12	--	934.85	939.87	937.06	939.05	939.61	938.04	937.53	937.70
13	--	935.03	939.59	936.92	938.63	940.19	937.93	937.50	937.56
14	--	934.93	939.38	936.80	938.88	940.68	937.93	937.39	937.56
15	--	935.04	939.22	936.78	938.67	940.07	938.01	937.38	937.60

Table 4.--Daily maximum water-level altitudes from well U-65, October 1985 through June 1986--Continued

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
	Daily maximum water levels, in feet above sea level								
16	--	935.49	939.04	936.82	938.67	939.98	937.93	937.41	937.47
17	--	935.77	938.95	936.85	938.74	939.59	937.79	937.43	937.35
18	--	935.99	938.40	937.01	938.76	939.68	937.76	937.44	937.33
19	--	936.05	938.34	937.55	938.83	940.03	937.79	937.48	937.30
20	--	935.96	938.29	938.22	938.83	939.90	937.90	937.60	937.18
21	--	935.96	938.09	938.22	938.81	939.69	938.59	937.59	937.17
22	--	935.94	938.24	938.09	939.03	939.78	938.71	937.59	937.16
24	--	935.98	937.74	938.17	938.91	939.40	938.65	937.61	937.02
25	933.86	935.97	937.60	938.29	939.14	939.40	938.62	937.55	936.98
26	933.86	936.10	937.66	938.36	939.03	939.33	938.49	937.59	936.96
27	933.97	937.28	937.47	938.18	938.91	939.17	938.45	937.74	936.97
28	933.79	937.96	937.34	938.13	938.83	939.16	938.34	937.87	937.12
29	933.94	938.21	937.58	937.90	--	939.08	938.25	937.54	936.89
30	933.89	938.27	937.58	937.82	--	938.95	938.23	937.87	937.08
31	933.90	--	937.44	937.79	--	938.56	--	937.81	--
Maximum	--	938.27	939.87	938.36	940.02	940.68	938.73	938.13	938.05

Water Year 1986: Mean, 937.71; high, 933.75 (Nov. 1); low, 940.68 (Mar. 14)

Table 5.--Precipitation at Prospect, Ohio, October 1985 through June 1986

[Data from National Oceanic and Atmospheric Administration, 1985 and 1986. Dash indicates no precipitation recorded]

	Precipitation, in inches								
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1	0.30	--	--	--	--	--	--	0.19	--
2	--	--	.17	--	.15	--	.15	--	0.11
3	--	1.20	--	--	--	.10	--	--	--
4	--	1.00	--	--	.70	--	--	--	--
5	--	.80	--	--	.40	--	--	--	--
6	--	.20	.18	--	.10	--	--	--	.40
7	--	.20	--	--	.50	.10	.10	.30	.40
8	--	.30	--	--	--	--	--	--	--
9	--	--	--	--	--	--	.10	--	--
10	--	.60	.15	--	--	--	--	--	--
11	--	1.80	1.15	--	--	.40	--	--	.10
12	--	.40	.60	--	--	.10	--	--	.05
13	.25	.30	--	.05	--	.55	.10	--	--
14	.45	.30	.16	--	--	.10	--	.15	--
15	.30	.15	--	--	.15	--	.45	--	.30

Table 5.--Precipitation at Prospect, Ohio, October 1985 through June 1986--Continued

	Precipitation, in inches								
Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
16	--	0.70	--	--	--	--	--	0.70	--
17	--	.22	--	--	.07	--	.10	--	--
18	--	--	.19	.15	--	--	--	.25	--
19	--	--	--	.50	.06	.93	--	.75	--
20	.10	.25	--	.18	--	--	.25	--	.30
21	.20	--	.05	--	.20	--	1.05	.05	--
22	--	--	--	--	.12	--	--	.05	--
23	--	--	--	--	--	--	--	.22	.62
24	.90	--	--	--	--	--	--	--	--
25	.20	--	--	--	--	--	--	--	--
26	--	.40	--	.05	--	--	--	--	--
27	--	1.30	.10	--	.10	.15	--	.65	.90
28	--	.52	--	--	.08	--	--	--	--
29	--	--	--	.07	--	--	.17	--	--
30	--	--	--	--	--	--	--	--	--
31	.10	--	--	--	--	--	--	--	--
Total	2.80	10.64	2.75	1.00	2.63	2.43	2.47	3.31	3.18

Table 7.--Daily mean water-level altitudes at Richwood Lake, October 1985 through June 1986

[Dash indicates no data available]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
	Daily mean water-level elevation, in feet above sea level								
1	--	937.36	938.45	939.56		--	940.76	940.17	939.74
2	--	937.36	938.49	939.55		--	940.74	940.14	939.71
3	--	937.43	938.51	939.53		--	940.68	940.11	939.69
4	--	937.46	938.55	939.51		--	940.64	940.08	939.66
5	--	937.46	938.59	939.51		940.28	940.60	940.05	939.65
6	--	937.46	938.64	939.51		940.30	940.56	940.03	939.68
7	--	937.46	938.67	939.51		940.32	940.52	940.02	939.72
8	--	937.45	938.70	939.51		940.31	940.47	940.00	939.72
9	--	937.45	938.73	939.50		940.31	940.44	939.97	939.69
10	--	937.52	938.76	939.47		940.33	940.39	939.94	939.67
11	--	937.61	938.95	939.46		940.39	940.35	939.91	939.66
12	--	937.64	939.12	939.43		940.42	940.32	939.88	939.65
13	--	937.67	939.21	939.43		940.60	940.29	939.86	939.62
14	--	937.71	939.28	939.43		940.74	940.27	939.83	939.60
15	--	937.73	939.28	--		940.81	940.28	939.82	939.60

Table 7.--Daily mean water-level altitudes at Richwood Lake, October 1985 through June 1986--Continued

Daily mean water-level elevation, in feet above sea level

16	--	937.80	939.35	--		940.84	940.26	939.84	939.59
17	--	937.83	939.42	--		940.86	940.24	939.83	939.56
18	--	937.84	939.42	--		940.87	940.22	939.81	939.53
19	--	937.87	939.42	--		940.89	940.20	939.85	939.50
20	--	937.88	939.42	--		940.89	940.23	939.84	939.48
21	--	937.89	939.42	--		940.90	940.30	939.81	939.46
22	--	937.90	939.46	--		940.90	940.30	939.81	939.44
23	--	937.91	939.55	--		940.90	940.28	939.80	939.45
24	--	937.92	939.56	--		940.90	940.27	939.78	939.42
25	--	937.93	939.56	--		940.90	940.25	939.76	939.38
26	--	938.02	939.56	--		940.90	940.24	939.75	939.35
27	--	938.17	939.56	--		940.90	940.23	939.80	939.33
28	--	938.27	939.57	--		940.90	940.22	939.79	939.38
29	--	938.33	939.57	--		940.90	940.20	939.78	939.36
30	937.38	938.39	939.57	--		940.90	940.18	939.78	939.34
31	937.38	--	939.57	--		940.88	--	939.76	--
Mean	--	937.76	939.16	--		--	940.36	939.89	939.55
Maximum	--	938.39	939.57	--		--	940.76	940.17	939.74
Minimum	--	937.36	938.45	--		--	940.18	939.75	939.33

Table 8.--Water-quality data collected in October 1985 and April 1986

[Recommended limits at the bottom of each column are taken from U.S. Environmental Protection Agency water quality criteria (1986) and drinking water standards (1976b). Sites are in order from upgradient to downgradient across the study area. Abbreviations used: C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; a dash indicates no data are available or not applicable.]

Well number	Date	Water level below land surface (feet)	Depth of well (feet)	Temperature (°C)	Temperature, air (°C)	Oxygen, dissolved (mg/L)	pH (standard units)	Specific conductance (µS/cm)
U-54	11-01-85	12.70	68.0	12.0	13.0	0.4	7.3	730
	04-09-86	10.96		11.5	11.0	< .1	7.3	823
U-75	04-02-86	--	42.0	11.5	16.0	.1	7.3	850
U-66	10-31-85	7.40	114.0	12.0	16.5	.3	7.0	765
	04-09-86	5.03		11.0	11.0	.1	7.3	860
U-39	10-31-85	9.70	32.0	13.0	16.0	.3	7.1	810
	04-03-86	6.74		11.0	22.0	.1	7.2	785
U-64	10-31-85	14.80	78.0	12.0	10.5	.2	7.3	700
	04-03-86	8.78		12.0	21.5	.1	7.4	685
U-52	10-30-85	9.50	44.0	14.0	14.0	4.0	7.2	730
	04-09-86	5.92		12.0	11.0	1.5	7.3	800
LAKE	10-31-85	--	--	11.5	10.5	9.3	9.6	335
	04-02-86	--	--	14.0	14.5	10.8	8.8	360
U-65	10-30-85	15.10	49.0	12.0	10.5	.6	7.1	1,020
	04-01-86	10.12		13.5	25.0	.2	7.1	1,020
U-69	10-31-85	--	120.0	11.0	10.0	5.8	7.5	836
	04-02-86	--		11.5	19.0	3.2	7.2	840
U-68	10-31-85	--	151.0	12.0	11.0	2.1	7.1	1,180
	04-09-86	--		12.0	11.0	--	7.3	1,100
U-70	10-30-85	11.25	33.0	14.0	14.0	.3	7.0	860
	04-01-86	4.42		12.0	26.0	.1	7.1	755
U-53	11-01-85	6.30	55.0	12.5	15.0	.3	7.4	514
	04-03-86	2.30		12.5	11.5	.1	7.2	525
U-46	11-01-85	6.93	85.0	12.0	16.5	.3	7.4	498
	04-02-86	3.31		12.0	15.0	.1	7.2	495
U-35	10-31-85	10.12	62.0	11.5	16.5	4.0	7.1	852
	04-03-86	6.80		12.0	24.0	5.0	7.3	935
U-58	10-30-85	12.70	36.0	12.0	13.0	.4	7.3	730
	04-01-86	7.86		12.5	26.0	.1	7.3	735
Recommended limit		--	--	--	--	--	--	800-1,200

Table 8.--Water-quality data collected in October 1985 and April 1986--Continued

Well number	Date	Solids, sum of constituents, dissolved (mg/L)	Alkalinity, field (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
U-54	11-01-85	510	411	410	0	100	39
	04-09-86	490	344	440	90	110	39
U-75	04-02-86	560	374	490	110	110	52
U-66	10-31-85	530	363	440	81	110	41
	04-09-86	530	350	440	92	110	41
U-39	10-31-85	570	433	480	48	110	50
	04-03-86	530	386	470	89	110	48
U-64	10-31-85	480	359	380	24	99	33
	04-03-86	470	305	410	110	110	33
U-52	10-30-85	500	358	390	32	95	37
	04-09-86	480	293	410	110	100	39
LAKE	10-31-85	200	100	170	72	21	29
	04-02-86	280	208	230	17	44	29
U-65	10-30-85	660	400	480	81	120	44
	04-01-86	690	383	540	150	140	47
U-69	10-31-85	590	360	430	71	110	38
	04-02-86	590	335	460	120	120	39
U-68	10-31-85	720	505	490	--	120	46
	04-09-86	620	361	470	110	120	42
U-70	10-30-85	580	395	470	78	120	42
	04-01-86	440	274	430	150	110	38
U-53	11-01-85	310	288	290	6	78	24
	04-03-86	320	296	300	4	80	24
U-46	11-01-85	310	278	290	8	75	24
	04-02-86	280	241	280	37	75	23
U-35	10-31-85	610	370	480	110	120	43
	04-03-86	650	428	510	76	120	50
U-58	10-30-85	500	411	360	--	90	34
	04-01-86	450	312	380	66	97	34
Recommended limit		500-750	+20	300	--	--	--

Table 8.--Water-quality data collected in October 1985 and April 1986--Continued

Well number	Date	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Sodium, dissolved (mg/L as Na)
U-54	11-01-85	2.0	2.9	92	1.0	14	11
	04-09-86	2.1	2.7	100	.9	15	12
U-75	04-02-86	2.3	10	130	1.0	16	16
U-66	10-31-85	1.8	3.9	120	1.3	16	13
	04-09-86	2.0	3.8	130	1.3	16	13
U-39	10-31-85	1.9	8.9	110	1.0	17	13
	04-03-86	2.0	6.8	100	.9	16	13
U-64	10-31-85	1.8	39	70	.5	14	10
	04-03-86	1.9	36	76	.5	15	10
U-52	10-30-85	3.0	29	93	.3	9.9	15
	04-09-86	2.7	21	110	.4	11	14
LAKE	10-31-85	1.7	24	58	.2	0	8.0
	04-02-86	1.8	21	54	.2	.2	7.5
U-65	10-30-85	3.7	77	130	.3	11	34
	04-01-86	4.0	72	150	.3	12	35
U-69	10-31-85	3.1	33	150	1.1	11	21
	04-02-86	3.7	36	150	1.0	12	19
U-68	10-31-85	15	84	96	.4	10	39
	04-09-86	10	67	97	.3	10	32
U-70	10-30-85	4.1	44	110	.2	7.1	15
	04-01-86	2.6	30	83	.2	6.5	9.8
U-53	11-01-85	1.3	2.8	17	.7	12	3.4
	04-03-86	1.5	2.4	16	.6	13	3.4
U-46	11-01-85	1.3	3.0	19	.5	12	3.1
	04-02-86	1.5	2.3	18	.5	12	3.0
U-35	10-31-85	2.4	5.4	190	1.4	13	12
	04-03-86	4.1	20	170	1.4	15	15
U-58	10-30-85	1.7	6.2	92	1.5	18	11
	04-01-86	1.9	5.8	94	1.5	19	11
Recommended limit		--	250	250	1.8	--	--

Table 8.--Water-quality data collected in October 1985 and April 1986--Continued

Well number	Date	Sodium adsorption ratio	Percent sodium	Carbon, organic, total (mg/L as C)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Sulfide, total (mg/L as S)
U-54	11-01-85	0.2	5	1.8	<0.01	<0.01	<0.1
	04-09-86	.3	6	3.4	.05	--	.2
U-75	04-02-86	.3	7	1.5	--	.01	.1
U-66	10-31-85	.3	6	1.7	.02	.01	.7
	04-09-86	.3	6	1.6	.01	< .01	.3
U-39	10-31-85	.3	6	1.2	< .01	< .01	< .1
	04-03-86	.3	6	2.4	.03	< .01	< .1
U-64	10-31-85	.2	5	1.7	< .01	< .01	< .1
	04-03-86	.2	5	5.2	< .01	< .01	< .1
U-52	10-30-85	.3	8	3.3	< .01	< .01	< .1
	04-09-86	.3	7	2.6	.03	< .01	< .1
LAKE	10-31-85	.3	9	7.4	.01	< .01	< .1
	04-02-86	.2	7	4.2	.03	< .01	--
U-65	10-30-85	.7	13	1.6	.02	< .01	< .1
	04-01-86	.7	12	1.9	< .01	< .01	< .1
U-69	10-31-85	.5	10	1.6	.01	.01	.3
	04-02-86	.4	8	4.2	.02	< .01	< .1
U-68	10-31-85	.8	14	6.6	.05	< .01	< .1
	04-09-86	.7	13	2.6	.01	--	< .1
U-70	10-30-85	.3	6	8.2	.01	< .01	< .1
	04-01-86	.2	5	2.8	.03	< .01	.2
U-53	11-01-85	.1	2	2.1	< .01	< .01	< .1
	04-03-86	.1	2	3.2	.02	< .01	< .1
U-46	11-01-85	.1	2	2.1	.01	< .01	< .1
	04-02-86	.1	2	2.7	.03	< .01	< .1
U-35	10-31-85	.2	5	1.5	< .01	< .01	.3
	04-03-86	.3	6	1.8	.02	< .01	.2
U-58	10-30-85	.3	6	1.2	< .01	< .01	< .1
	04-01-86	.3	6	3.3	< .01	< .01	< .1
Recommended limit		--	-	--	--	-----	--

Table 8.--Water-quality data collected in October 1985 and April 1986--Continued

Well number	Date	Nitrogen, organic, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)
U-54	11-01-85	0.19	0.21	<0.01	<0.10
	04-09-86	.07	.23	< .01	< .10
U-75	04-02-86	.15	.25	< .01	< .10
U-66	10-31-85	.04	.26	< .01	< .10
	04-09-86	.26	.44	< .01	.12
U-39	10-31-85	.12	.18	.01	< .10
	04-03-86	.16	.14	< .01	< .10
U-64	10-31-85	.03	.17	< .01	< .10
	04-03-86	.32	.18	< .01	< .10
U-52	10-30-85	0	1.60	.01	< .10
	04-09-86	.05	.65	.02	< .10
LAKE	10-31-85	.57	.03	< .01	< .10
	04-02-86	.37	.03	< .01	.10
U-65	10-30-85	--	.13	< .01	< .10
	04-01-86	.17	.13	< .01	< .10
U-69	10-31-85	0	2.00	< .01	< .10
	04-02-86	.2	2.90	< .01	< .10
U-68	10-31-85	.05	.15	< .01	< .10
	04-09-86	--	15.0	< .01	< .10
U-70	10-30-85	.25	.45	< .01	< .10
	04-01-86	.3	.10	.01	2.79
U-53	11-01-85	--	.15	< .01	< .10
	04-03-86	.25	.15	< .01	< .10
U-46	11-01-85	.05	.15	< .01	1.50
	04-02-86	.15	.15	< .01	< .10
U-35	10-31-85	.1	.20	< .01	< .10
	04-03-86	.15	.15	< .01	.12
U-58	10-30-85	.08	.32	< .01	< .10
	04-01-86	.08	.32	< .01	< .10
Recommended limit		--	--	-----	10

Table 8.--Water-quality data collected in October 1985 and April 1986--Continued

Well number	Date	Arsenic, dissolved (μg/L as As)	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Mercury dissolved (μg/L as Hg)	Aluminum, dissolved (μg/L as Al)
U-54	11-01-85	<1	430	<10	3	<0.1	<100
	04-09-86	<1	400	1	4	< .1	10
U-75	04-02-86	<1	2300	<10	12	< .1	20
U-66	10-31-85	2	1400	<10	11	< .1	<100
	04-09-86	3	1200	<10	14	< .1	<10
U-39	10-31-85	5	2700	<10	46	< .1	<100
	04-03-86	3	1300	<10	130	< .1	<10
U-64	10-31-85	<1	1400	--	7	.1	<100
	04-03-86	<1	1600	<10	6	< .1	10
U-52	10-30-85	<1	620	<10	33	.1	<100
	04-09-86	<1	850	<10	24	< .1	<10
LAKE	10-31-85	3	18	<10	2	< .1	<100
	04-02-86	<1	13	<10	<1	< .1	20
U-65	10-30-85	<1	1800	<10	32	< .1	<100
	04-01-86	<1	1900	<10	34	< .1	<10
U-69	10-31-85	<1	1100	<10	18	< .1	<100
	04-02-86	<1	910	<10	21	< .1	10
U-68	10-31-85	<1	2200	<10	74	< .1	<100
	04-09-86	<1	1700	1	91	< .1	20
U-70	10-30-85	3	220	<10	230	< .1	11
	04-01-86	<1	18	<10	140	< .1	20
U-53	11-01-85	2	400	<10	8	.1	<100
	04-03-86	<1	390	<10	8	< .1	10
U-46	11-01-85	<1	810	<10	5	< .1	<100
	04-02-86	<1	720	<10	3	< .1	10
U-35	10-31-85	<1	310	<10	23	< .1	<100
	04-03-86	<1	190	<10	32	< .1	10
U-58	10-30-85	3	1300	<10	5	< .1	<100
	04-01-86	4	1300	<10	6	< .1	10
Recommended limit		50	300	50	50	20	--

Table 9.--Additional water-quality data collected in April and June 1986

[Recommended limits from U.S. Environmental Protection Agency drinking water standards (1976) and water-quality criteria (1986) are listed at the bottom of each column. Abbreviations used: mg/L, milligrams per liter; µg/L, micrograms per liter; a dash indicates no data are available.]

Local number	Date	Arsenic, dissolved (µg/L as As)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Lead, dissolved (µg/L as Pb)
U-68	04-09-86	<1	<0.5	<1	<10	<1	1
	06-20-86	<1	< .5	<1	<10	1	<5
U-54	04-09-86	<1	< .5	<1	<10	1	1
	06-20-86	<1	< .5	<1	<10	2	<5
Recommended limit		50 µg/L	0 --	10 µg/L	50 µg/L	1,000 µg/L	50 µg/L

Local number	Date	Zinc, dissolved (µg/L as Zn)	Antimony, dissolved (µg/L as Sb)	Selenium, dissolved (µg/L as Se)	Mercury, dissolved (µg/L as Hg)	Cyanide, dissolved (mg/L as CN)	Nickel, dissolved (µg/L as Ni)	Silver, dissolved (µg/L as Ag)
U-68	04-09-86	6	<1	<1	<0.1	--	2	<1
	06-20-86	9	<1	<1	< .1	< .01	2	<1
U-54	04-09-86	8	<1	<1	< .1	--	1	<1
	06-20-86	75	<1	<1	< .1	< .01	<1	<1
Recommended limit		5,000 µg/L	146 µg/L	10 µg/L	2 µg/L	.200 µg/L	632 µg/L	50 µg/L

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