GEOHYDROLOGY AND WATER QUALITY IN NORTHERN PORTAGE COUNTY, OHIO, IN RELATION TO DEEP-WELL BRINE INJECTION

By Sandra M. Eberts

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4158

Prepared in cooperation with the
CITY OF AKRON, OHIO, and the
OHIO WATER DEVELOPMENT AUTHORITY

Columbus, Ohio

1991

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
975 W. Third Avenue
Columbus, OH 43212-3192

Copies of this report can
can be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Box 25425, Federal Center
Building 810
Denver, CO 80225

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
barrel (bbl) (1 bbl = 42 gallons)	0.1590	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (^oF) can be converted to degrees Celsius (^oC) as follows:

$$^oF = 1.8\ (^oC) + 32$$

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."

PAGE 1 FOLLOWS

GEOHYDROLOGY AND WATER QUALITY IN NORTHERN PORTAGE COUNTY, OHIO, IN RELATION TO DEEP-WELL BRINE INJECTION

by Sandra M. Eberts

ABSTRACT

Geohydrology and water quality of the principal freshwater aquifers near oilfield and gasfield brine-injection wells in northern Portage County, Ohio, were evaluated. Since 1975, 13 wells in this part of the County have been used to dispose of more than 4.5 million barrels of brine by injection into Silurian carbonate and sandstone rocks that generally are greater than 3,500 feet below land surface. More than 3,000 feet of interbedded shales, sandstones, carbonates, and evaporites separate the freshwater aquifers from these brine-injection zones. The shallowest brine-injection zone is greater than 2,200 feet below sea level. Native fluids in the injection zones have dissolved-solids concentrations greater than 125,000 milligrams per liter and are hydraulically isolated from the freshwater aquifers. No known faults or fracture systems are present in northern Portage County, although abandoned oil and gas wells could exist and serve as conduits for migration of injected brine.

Pennsylvanian clastic units are freshwater bearing in northern Portage County, and two bedrock aquifers generally are recognized. The shallower bedrock aquifer (Connoquenessing Sandstone Member of the Pottsville Formation) principally consists of sandstone; this aquifer is separated from a deeper sandstone and conglomerate aquifer in the lower part of the Sharon Member (Pottsville Formation) by shale in the upper part of the Sharon Member that acts as a confining unit. The upper sandstone aquifer is the surficial aquifer where overlying glacial deposits are unsaturated in the uplands; glacial deposits comprise the surficial aquifer in buried valleys where the sandstone is absent. These two surficial aquifers are hydraulically connected and act as a single unit. The lower sandstone and conglomerate aquifer is the most areally extensive aquifer within the project area.

From November 1987 through August 1988, ground-water levels remained at least 60 feet higher in the upper sandstone aquifer than in the lower sandstone and conglomerate aquifer at a topographically high recharge area. Water levels in the surficial aquifers and the lower sandstone and conglomerate aquifer were nearly the same along the Cuyahoga River.

Ground water in the upper sandstone aquifer flows radially from topographically high recharge areas into the glacial deposits in the buried valleys. Much of the ground water in these surficial aquifers discharges into the Cuyahoga River.

Most ground water in the lower sandstone and conglomerate aquifer flows toward discharge areas near the Cuyahoga River and Eagle Creek. In June 1988, the Cuyahoga River gained 15.8 cubic feet per second of water from the aquifers between the northern edge of Portage County and State Route 303. Ground water may have discharged into the upstream end of Lake Rockwell but did not discharge into the downstream end of the Lake during most of the period from October 1987 through September 1988.

Measurements of the specific conductance of ground water sampled from areas near the 13 brine-injection wells and along the Cuyahoga River indicate no widespread ground-water contamination related to brine injection. Chemical analysis of water from 25 wells indicates that most ground waters are a calcium bicarbonate type. Water analyses show that four wells sampled contain water with chloride concentrations greater than 250 milligrams per liter. Sodium concentrations in water from these four wells ranged from 67 to 190 milligrams per liter. A mixing diagram constructed from bromide and chloride data was used to distinguish between the sources of elevated chloride concentrations in these four wells. Waters from two of the wells have been mixed with oilfield and gasfield brine, and waters from the other two wells have been mixed with a salt-solution brine such as that derived from diluted highway-deicing salts.

INTRODUCTION

The production of oil and gas usually is accompanied by the production of brine. Brine, defined as water having a total-dissolved-solids concentration greater than 100,000 mg/L (milligrams per liter) (Lloyd and Heathcote, 1985), can create environmental problems if it is disposed of improperly. The Northeast Ohio Brine Disposal Task Force (1984) estimated that one volume of brine produced in northeastern Ohio can raise the chloride content of about 800 volumes of freshwater above the Secondary Maximum Contaminant Level (SMCL) of 250 mg/L set by the U.S. Environmental Protection Agency (USEPA) (U.S. Environmental Protection Agency, 1989b). Diets restricted for health reasons limit sodium chloride intake to 22 mg/L (Northeast Ohio Brine Disposal Task Force, 1984). Brines in northeastern Ohio also contain toxic elements such as lead and mercury (Ohio Environmental Council, 1983). Long-term uptake of brine can result in death to plants and animals (Northeast Ohio Brine Disposal Task Force, 1984).

Ohio House Bill 501 (Ohio House of Representatives, 1985) specifies that brine may be disposed of in Ohio (1) by underground injection, including annular disposal; (2) in association with enhanced recovery of oil and gas; (3) through methods for testing or implementing a new technology or method of disposal;

or (4) by application to roads. (Brine application to roads is not permitted within the study area except in Nelson Township, where "spreading" hasn't occurred in recent years (Ohio Department of Natural Resources, Division of Oil and Gas, written commun., 1987).) The preferred and most environmentally acceptable method of brine disposal is deep-well injection (Ohio Environmental Council, 1983). If geologic and hydraulic conditions permit, however, brine can migrate from an injection zone into overlying freshwater aquifers through improperly constructed or improperly abandoned oil and gas wells or along natural fractures or fractures caused by over-pressuring injection wells. In addition, seepage of brine through corroded injection-well casing; leakage from wellheads, pumps, transport pipes, tank batteries, and brine-collection vaults; surface spills; and buried well cuttings have the potential to contaminate ground water and surface water at or near an injection site.

Because ground water accounts for 100 percent of withdrawals for public supply and more than 85 percent of withdrawals for rural domestic and livestock use within Portage County (Eberle and McClure, 1984), residents are concerned that brine-injection wells have contaminated or will contaminate their ground-water supplies (fig. 1). City of Akron officials also are concerned that brine injection will affect the Cuyahoga River, which drains much of northern Portage County and feeds Lake Rockwell (fig. 1), a major source of water for the City located in Summit County.

From April 1987 through April 1989, the U.S. Geological Survey (USGS), in cooperation with the City of Akron, the Ohio Water Development Authority, and numerous municipalities, conducted a study to determine the potential for containment of injected brine. General directions of ground-water flow and the relations between ground water, the Cuyahoga River, and Lake Rockwell also were to be determined. In addition, the study was designed to document current (1988) ground-water quality and determine if disposal of brine through deep-well injection has affected the freshwater aquifers and the Cuyahoga River. Results of this study contribute to the understanding of whether deep-well brine-injection successfully isolates oilfield and gasfield brine from potable water supplies.

Purpose and Scope

This report is a summary of the results of the investigation of the geohydrology and water quality in northern Portage County, Ohio, in relation to deep-well brine injection. Included in this report are discussions of the local geology in terms of the potential of formations to contain injected brine, the hydrology of the freshwater aquifers near the brine-injection wells, the quality of water in the freshwater aquifers, and the sources of elevated chloride concentrations in waters yielded by some wells.

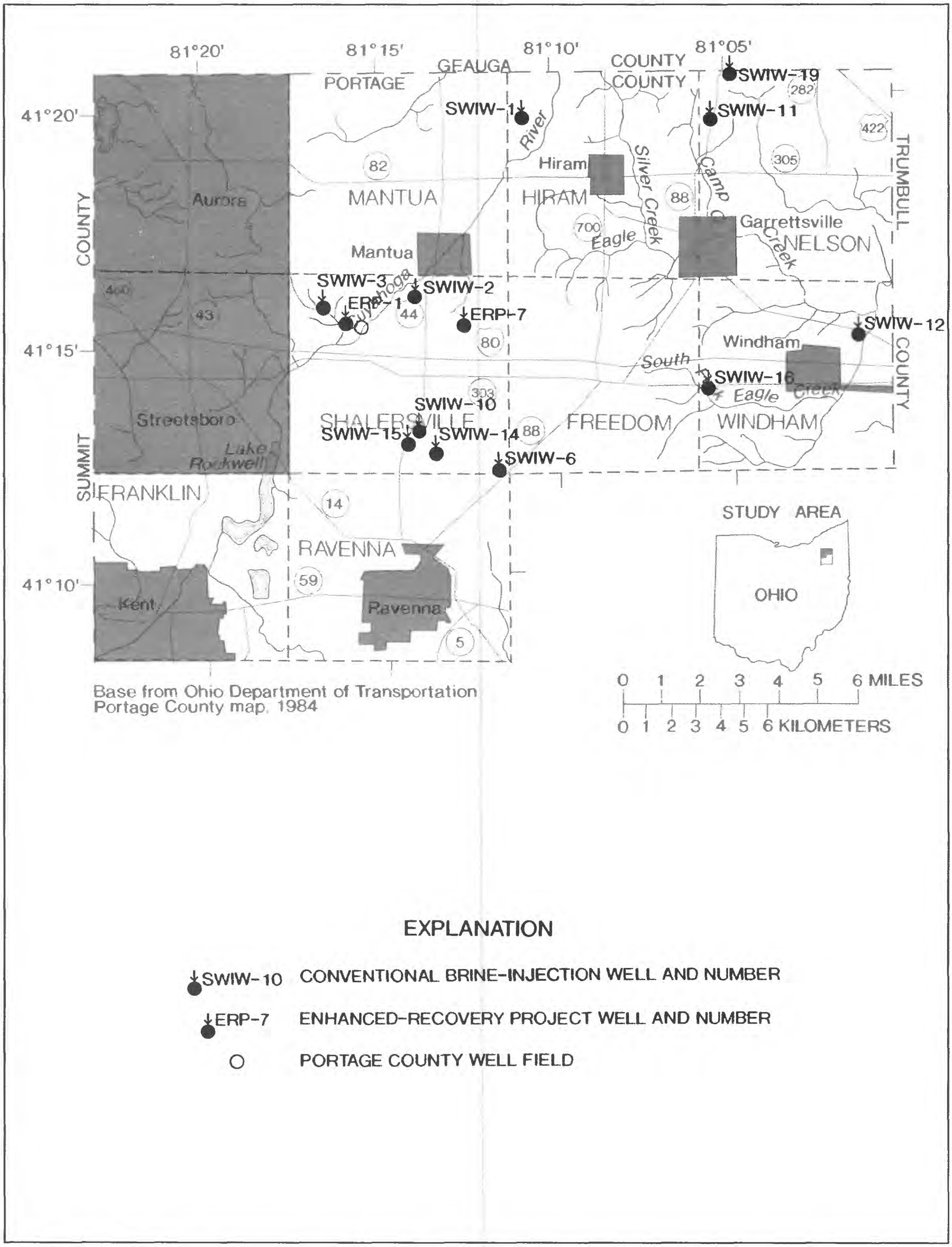


Figure 1.--Location of study area, conventional brine-injection wells, enhanced recovery project wells, and the Portage County well field.

Physical Setting

Northern Portage County, located in the northwestern part of the Glaciated Allegheny Plateau section of the Appalachian Plateaus physiographic province, is drained predominantly by the Cuyahoga River and Eagle Creek, a tributary to the Mahoning River. Remnants of preglacial topography are present in the study area, and local relief exceeds 300 ft (feet) (Winslow and White, 1966). The climate is humid; average annual precipitation is approximately 38 in. (inches) per year (Winslow and White, 1966).

Data Collection

The sites where ground-water levels, precipitation accumulations, and surface-water discharges were measured are shown in figure 2. Figure 3 shows the location of water wells that were sampled for detailed analysis of water chemistry. Most of the data collected during the study (1987-88) have been published in the USGS's annual water-data reports (Shindel and others, 1988-89).

Acknowledgments

The author appreciates the support and cooperation of the City of Akron; the Ohio Water Development Authority; the City of Aurora; the City of Streetsboro; Shalersville, Mantua, Hiram, Freedom, Windham, and Nelson Townships; the Village of Windham; the Akron Water Plant; the Portage County Sanitary Engineer's Lab; the Ohio Department of Natural Resources Division of Geology, Division of Oil and Gas, and Division of Water; and the homeowners who permitted access to their wells. The author especially appreciates the assistance of Art Youngblood[1], Superintendent of the Akron Watershed, who was instrumental in initiating this study. In addition, the author appreciates discussions regarding salinity-source identification with Donald Whittemore of the Kansas Geological Survey.

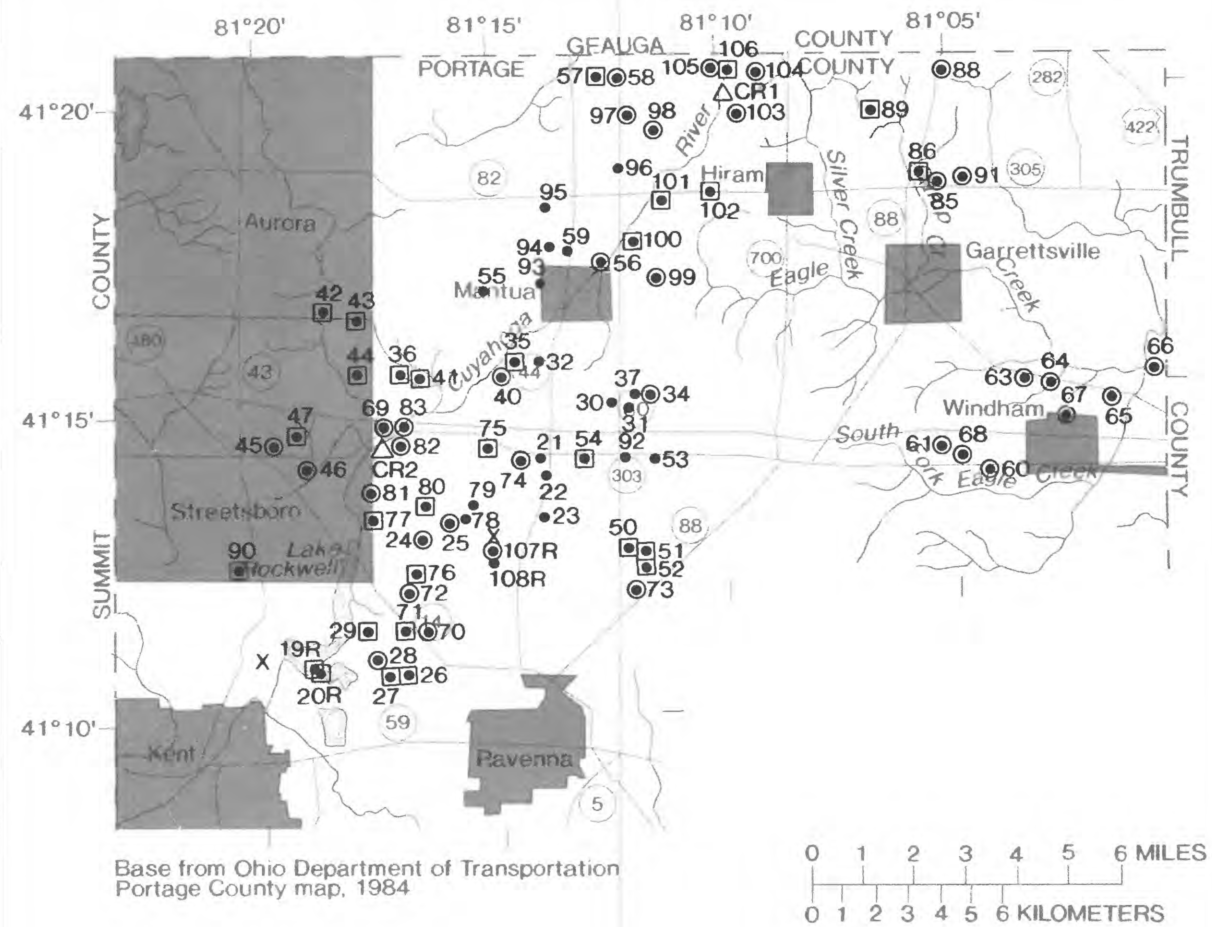
OVERVIEW OF DEEP-WELL BRINE INJECTION IN OHIO AND IN NORTHERN PORTAGE COUNTY

Oilfield and gasfield brines have been disposed of in Ohio through conventional brine-injection wells and injection wells associated with enhanced-recovery projects (fig. 4).[2] When brine

---

[1] Deceased December 6, 1989.

[2] An enhanced-recovery project involves the injection of fluids into a hydrocarbon-producing formation to increase reservoir pressure and enhance production of hydrocarbons in nearby production wells.



EXPLANATION

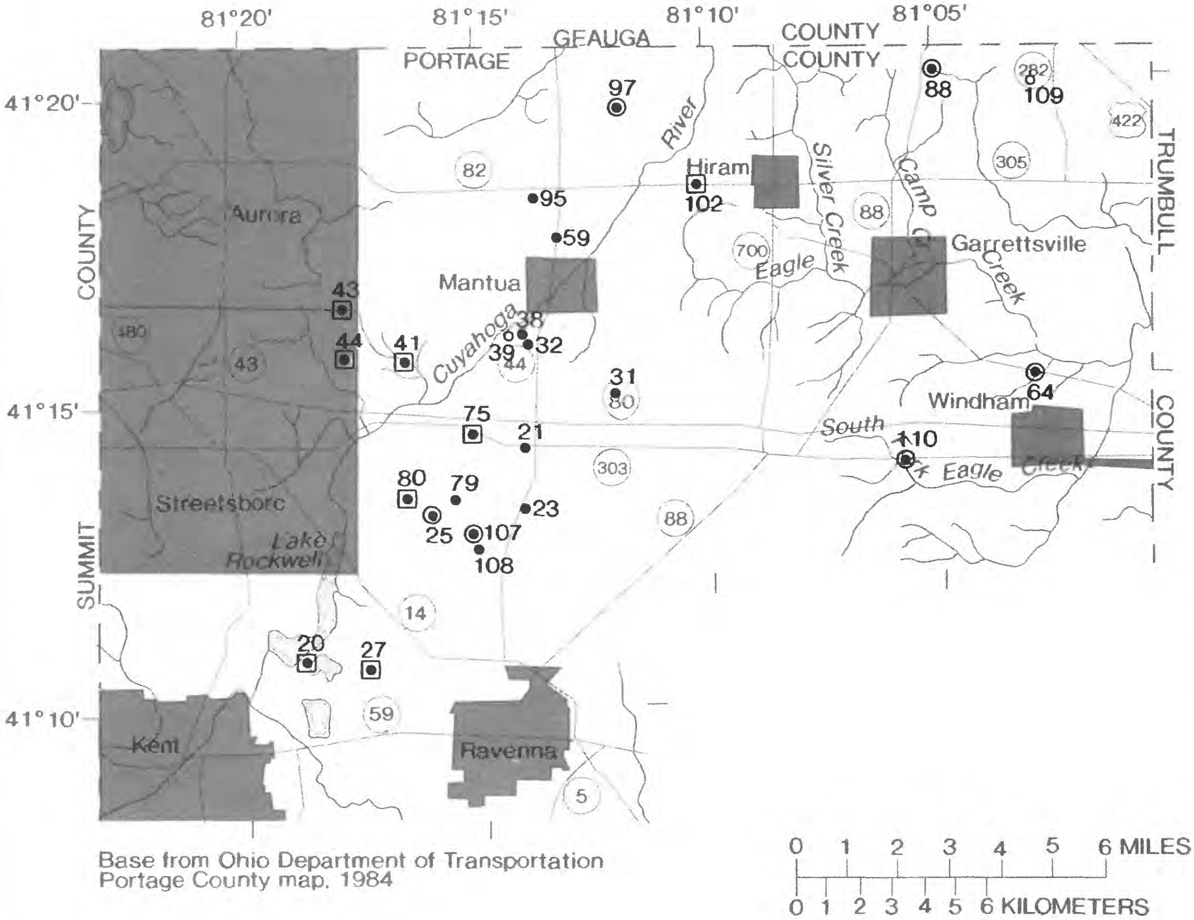
GROUND-WATER-LEVEL MEASUREMENT SITE AND NUMBER

- ▣90 Glacial deposits
- •21 Upper sandstone aquifer
- ◉34 Lower sandstone and conglomerate aquifer
- R Denotes piezometer or well instrumented to collect hourly ground-water-level data

△CR1 DISCHARGE-MEASUREMENT SITE AND NUMBER

X PRECIPITATION GAGE

Figure 2.--Data-collection network (the county prefix "Po-" has been omitted from well numbers).



EXPLANATION

SAMPLING SITE AND NUMBER

- ▣20 Glacial deposits
- •21 Upper sandstone aquifer
- ◉97 Lower sandstone and conglomerate aquifer
- ○109 Multiple aquifers

Figure 3.--Location of ground-water-quality sampling sites (the county prefix "Po-" has been omitted from well numbers).

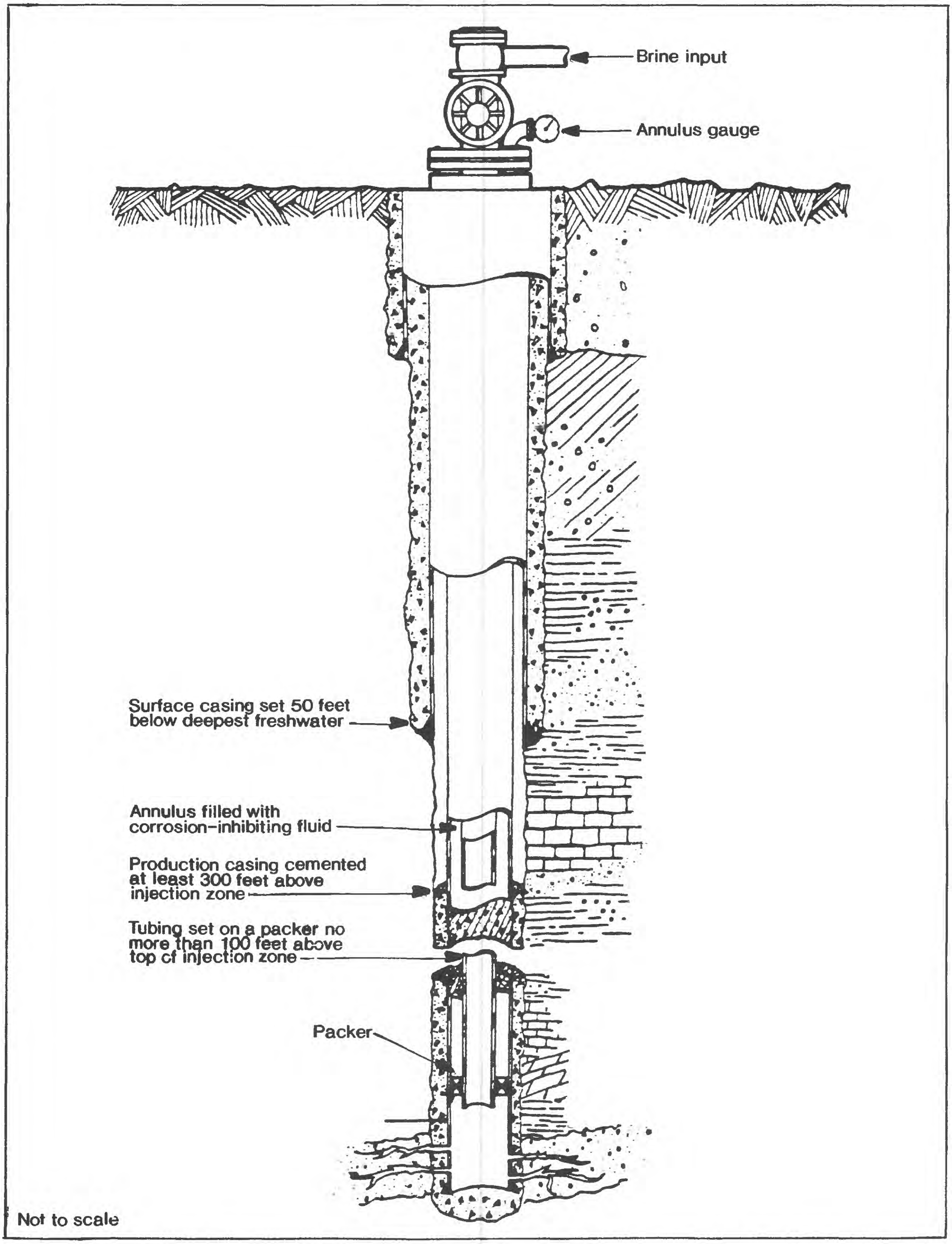


Figure 4.--Schematic drawing of a brine-injection well. (Adapted from McCormac, 1989, fig. 15.)

is injected, it displaces the native fluid present in the reservoir. The native fluid does not need to be displaced far to create enough storage space around the borehole to contain the injected brine (Clifford, 1975).

The number of conventional brine-injection wells in Ohio increased from 20 in 1964 to nearly 185 in 1988. One-hundred seventy-eight wells in Ohio were used for enhanced recovery of oil as part of 47 enhanced-recovery projects in 1988. The total volume of brine injected in 1988 was about 7.7 million barrels (McCormac, 1989). (One barrel is equivalent to 42 gallons.)

The "Clinton" zone, a drillers' term that refers to a discrete and laterally continuous porous rock sequence at the top of the Silurian Albion Sandstone (table 1), has been the most active productive zone since 1965. However, the Newburg zone, a drillers' term for any porous zone within the Silurian Lockport Dolomite (Tom Tomastik, Ohio Department of Natural Resources Division of Oil and Gas, oral commun., 1989) (table 1), is the primary brine-injection zone in Ohio (McCormac, 1988). The rates at which brine can be injected into the Newburg zone do not economically justify drilling a well specifically for disposal. Because the Newburg zone lies above the "Clinton" zone (table 1), abandoned "Clinton" production wells can be recompleted as Newburg injection wells at acceptable costs (Elmer E. Templeton and Associates, 1980). The "Clinton" zone ranks second to the Newburg zone in the volume of brine disposal in Ohio (McCormac, 1989).

Fifteen conventional brine-injection wells and three enhanced-recovery-project wells were operating in Portage County in 1988. The total volume of brine injected in Portage County in 1988 was about 1 million barrels (McCormac, 1989).

Since 1975, more than 4.5 million barrels of brine have been disposed of through the 11 conventional brine-injection wells and 2 enhanced-recovery-project wells located within the study area (fig. 1, table 2). Only one of the 13 wells was drilled for the purpose of brine injection (SWIW-19, fig. 1). The rest of the wells initially were drilled for production of hydrocarbons and later converted to brine-injection wells. In addition, SWIW-3 (fig. 1) had been used for annular disposal (fig. 5)[3] before the well was converted to a conventional brine-injection well. A few of the wells were no longer operating in 1987. By 1988, the surface facilities at SWIW-6 and SWIW-11 (fig. 1) had been removed and the sites had been restored.

---

[3] Annular disposal is a method of disposing of brine between the surface casing and the production casing of a producing oil or gas well. The protection of fresh ground water is from the surface casing only, which must be set 50 ft below the deepest freshwater formation and sealed to the surface.

Table 1.--General stratigraphic column of the consolidated rocks in northern Portage County, Ohio

Pennsylvanian

Pottsville Formation
- Homewood Sandstone Member
- Mercer Member
- Connoquenessing Sandstone Member (upper sandstone aquifer)
- Sharon Member
  - Shale unit (confining unit)
  - Conglomerate unit (lower sandstone and conglomerate aquifer)

Mississippian

Cuyahoga Group
Berea Sandstone

Mississippian and Devonian

Undifferentiated shale

Devonian

Undifferentiated limestone, dolomite, and sandstone

Silurian

Bass Islands Dolomite
Salina Formation
Lockport Dolomite (Newburg zone[1])
Clinton Formation
Albion Sandstone ("Clinton" zone[1])

[1] Drillers' or informal name

Table 2.--General information pertaining to the brine-injection wells in northern Portage County, Ohio

[--, data not available. Locations of wells are shown in figure 1.]

Well number	Township	Date permitted	Injection zone	Length of open inter-val(s) (feet)	Estimated average poros-ity of injec-tion inter-val(s) (percent)	Approximate volume of brine injected[1] (barrels)
SWIW-1	Hiram	02-15-75	Newburg	59	6.6	1,110,000 (1978-1986)
SWIW-2	Shalersville	12-02-80	Newburg	52 38	--	752,000
SWIW-3	Shalersville	05-04-79	Newburg	26 54	8 5	533,000
SWIW-6	Shalersville	11-04-82	"Clinton"	33	--	--
SWIW-10	Shalersville	06-01-83	"Clinton"	58	6.8	249,000 (1983-1986)
SWIW-11	Nelson	09-14-83	"Clinton"	100	--	523,000
SWIW-12	Windham	11-30-84	Newburg	10	7	283,000
SWIW-14	Shalersville	07-16-84	"Clinton"	74	6.8	23,000
SWIW-15	Shalersville	10-11-85	Newburg	40	6.6	272,000
SWIW-16	Windham	10-21-85	Newburg	210	5.7	190,000
SWIW-19	Nelson	01-02-85	Newburg	6 16	--	334,000
ERP-1	Shalersville	06-01-79	"Clinton"	48	--	200,000
ERP-7	Shalersville	08-09-84	"Clinton"	32	6.5	78,000

[1]From date of initial injection through March 1987, unless otherwise noted.

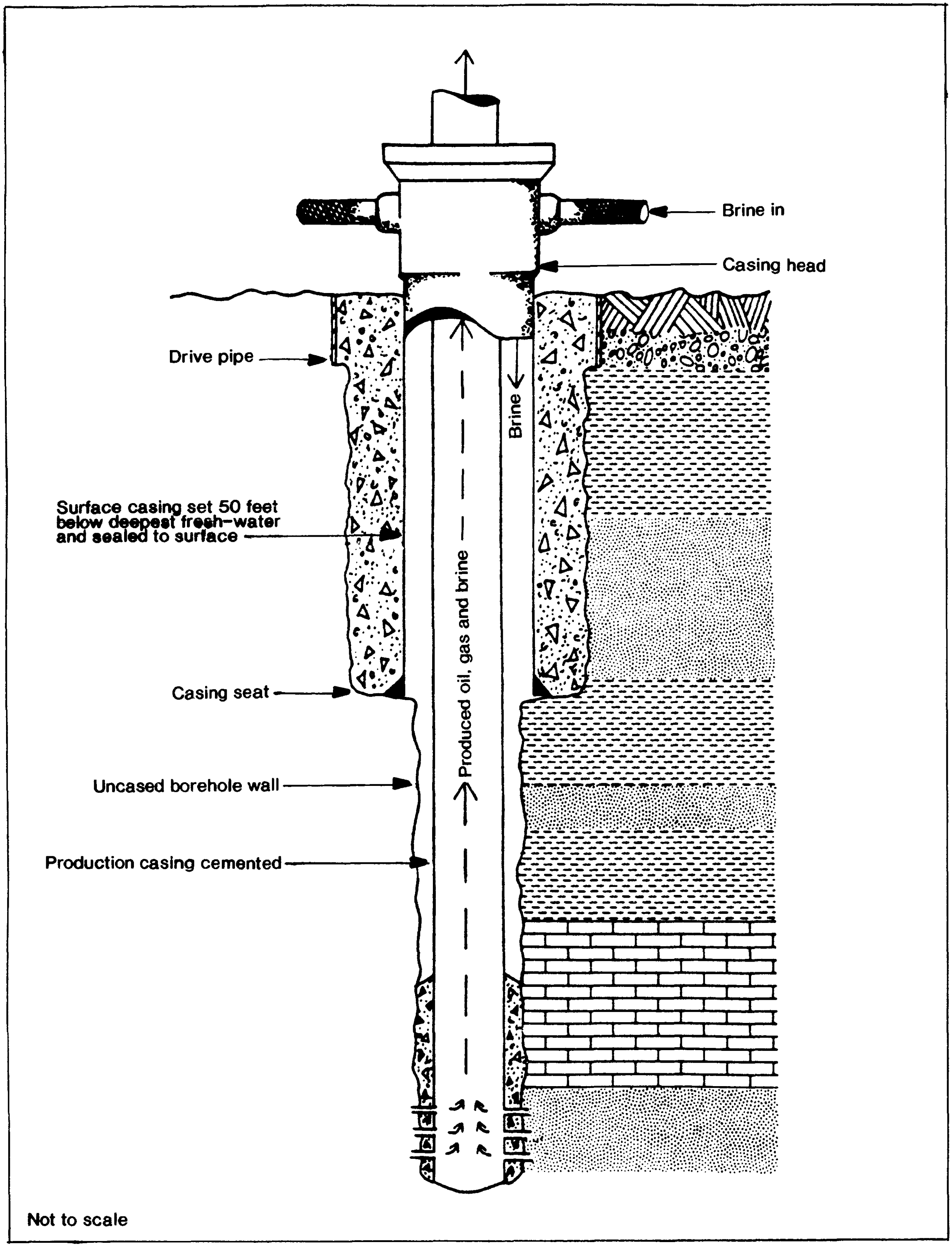


Figure 5.--Schematic drawing of an annular-disposal well. (Adapted from McCormac, 1989, fig. 22.)

Seven of the 13 brine-injection wells have been used to inject brine into the Newburg zone, and 6 of the wells have been used to inject brine into the "Clinton" zone (table 2). The average length of the open interval of the wells used to inject brine into the Newburg zone is approximately 70 ft. The average length of the open interval of the "Clinton" brine-injection wells is about 60 ft.

The following conditions have been recorded by State inspectors (Unpublished data on file with the Ohio Department of Natural Resources, Division of Oil and Gas, Columbus, Ohio) and observed by USGS personnel at brine-injection sites in the study area: (1) separation of dump pads from dikes, which resulted in brine flowing freely onto the ground; (2) overflows of brine from above-ground storage tanks; (3) dikes constructed of permeable material and of insufficient size to hold tank overflows; and (4) leakage of brine at pumps and injection wellheads. Grass kills and elevated chloride levels in soil and water samples also have been noted by State inspectors (Unpublished data on file with the Ohio Department of Natural Resources, Division of Oil and Gas, Columbus, Ohio).

In October 1979 and again in March 1981, water from the No. 3 well in the County well field was contaminated with chloride. Chloride concentrations which are typically near 150 mg/L reached 243 mg/L and 1,634 mg/L, respectively (Portage County Sanitary Engineering Department, written commun., 1987). Serna (1986) traced the contamination to two plumes of oilfield brine within the freshwater aquifers just north of the well field. The source of the largest plume was brine from the above-ground storage tanks at a production well just north of the well field. The source of the second plume was brine that migrated up and formed a puddle around an abandoned oil well. This upward migration of brine could have been due to the increased reservoir pressure caused by the injection of brine at a nearby enhanced-recovery-project well (ERP-1), which is less than 1,000 ft from the County well field.

GEOHYDROLOGY

Geology

Four geologic sections were constructed to illustrate the stratigraphic relations between the freshwater aquifers and the brine-injection zones (fig. 6 and pls. 1-3). The glacial geology and post-Devonian bedrock geology presented on the four sections was modified from a bedrock geologic map and geologic sections in Winslow and White (1966) on the basis of more recent maps showing bedrock topography (Risser, 1983a), drift thickness (Risser, 1983b), and structure on the Berea Sandstone (Gray, 1981).

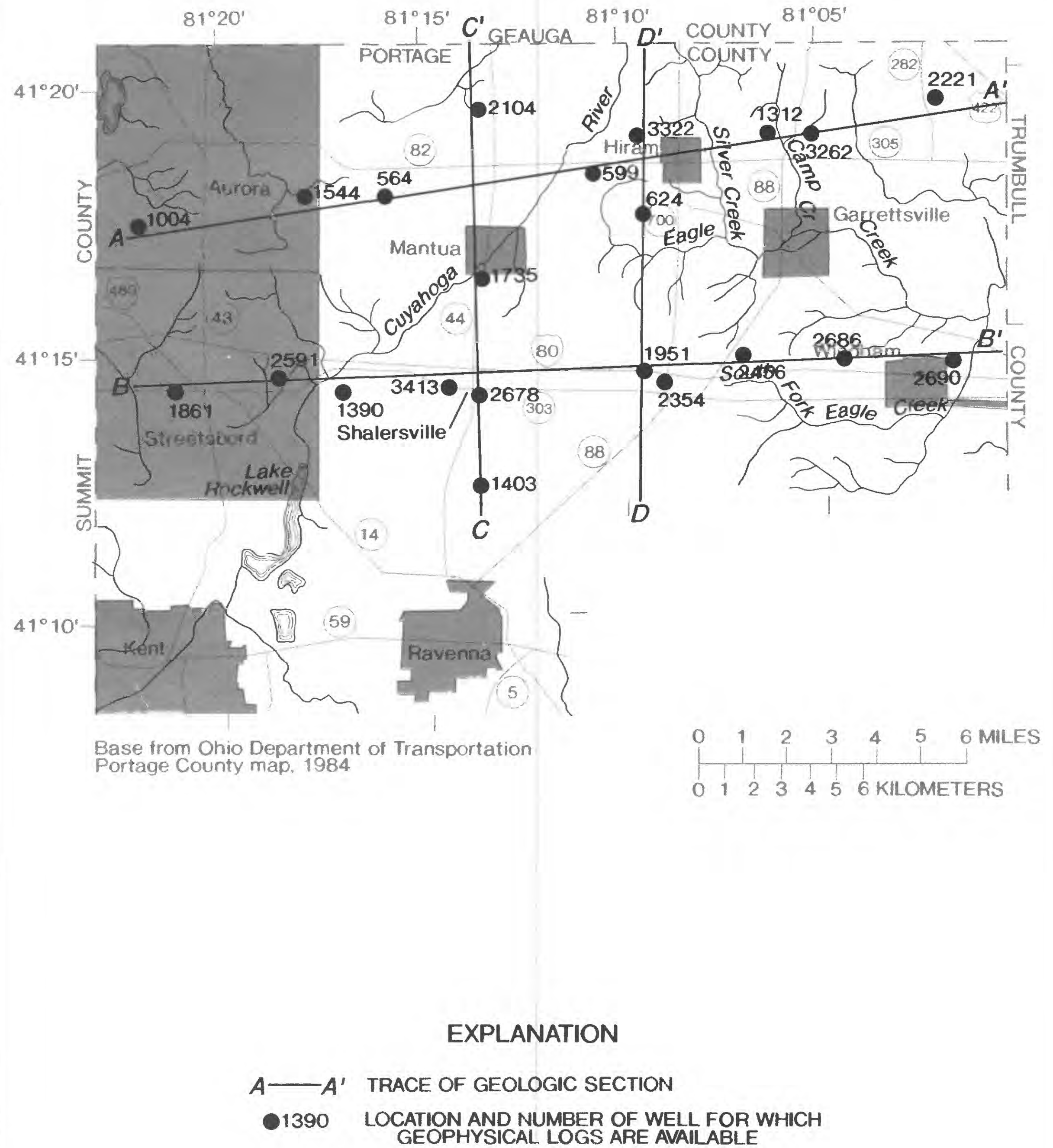


Figure 6.--Location of geologic sections (sections are shown on plates 1-3).

The older bedrock sequence (Silurian and Devonian) was interpreted from borehole-geophysical logs on file with the Ohio Department of Natural Resources, Division of Geological Survey. Bulk-density, gamma-ray, and neutron logs were used. For clarity of presentation, only the bulk-density and gamma-ray logs are shown on the geologic sections (pls. 1-3). Drillers' logs for numerous oil- and gas-production wells and the brine-injection wells were used to identify specific geologic units, including the "Clinton" and Newburg brine-injection zones.

General Stratigraphy and Lithology

The oldest stratigraphic unit considered in this investigation is the Albion Sandstone of Silurian age (table 1, pls. 1-3). The Albion Sandstone is composed predominantly of sandstone but contains some shale (Multer, 1963). The uppermost sandstone units within the Albion Sandstone are equivalent to the drillers' "Clinton" zone, as noted on the geologic sections in plates 1 through 3. The drillers' "Clinton" has been described as a white, gray, brown, or red fine-grained sandstone cemented with silica, calcite, or clay (Multer, 1963).

The drillers' "Clinton" zone is within rock older than and not equivalent to the Clinton Formation recognized by the USGS (table 1, pls. 1-3). The Clinton Formation recognized by the USGS overlies the Albion Sandstone and is also Silurian in age. In this report, the term "Clinton" within quotation marks is used to refer to the permeable zone within the Albion Sandstone and not to the Clinton Formation.

The Clinton Formation is overlain by the Silurian Lockport Dolomite (table 1, pls. 1-3). Geologic sections included with this report (pls. 1-3) show the Lockport Dolomite is more than 400 ft thick. The Lockport Dolomite often occurs as a microcrystalline dolomite; however, it contains porous crystalline intervals of sugary dolomite (Multer, 1963) that are referred to by drillers as the Newburg zone.

The Lockport Dolomite is overlain by the Silurian Salina Formation (table 1, pls. 1-3). The Salina Formation is composed of dolomite and shale interbedded with anhydrite, gypsum, and halite. Halite beds generally are less than 50 ft thick, and the aggregate thickness of the halite beds generally is less than 200 ft (Norris, 1978).

The Bass Islands Dolomite overlies the Salina Formation and is approximately 150 ft thick in northern Portage County (table 1, pls. 1-3). This unit marks the top of the Silurian rock sequence within the study area. Devonian carbonate rock and sandstones that overlie the Bass Islands Dolomite are undifferentiated on the geologic sections (pls. 1-3). These units are overlain by approximately 2,000 ft of Devonian and Mississippian shales (table 1, pls. 1-3).

The Berea Sandstone (Mississippian) ranges from 10 to 30 ft in thickness within the study area. The Cuyahoga Group includes the shale and interbedded sandstone that lie between the Berea Sandstone and the overlying Pottsville Formation (table 1, pls. 1-3).

The Pottsville Formation (Pennsylvanian) is the youngest bedrock unit in the study area (table 1, pls. 1-3). In ascending order, the Pottsville is divided into the Sharon, the Connoquenessing Sandstone, the Mercer, and the Homewood Sandstone Members. The conglomerate unit of the Sharon Member is a porous, coarse- to medium-grained, gray-white to light-tan-brown orthoquartzite with a basal quartz-pebble conglomerate that was deposited in a broad channel cut into the underlying Mississippian rocks (Winslow and White, 1966). The shale unit of the Sharon Member overlies the conglomerate unit and is as much as 90 ft thick.

The Connoquenessing Sandstone Member overlies the shale unit of the Sharon Member and underlies the Mercer Member (table 1, pls. 1-3). The Connoquenessing is a coarse- to medium-grained micaceous sandstone that contains more feldspar and clay than the conglomerate unit of the Sharon Member (Winslow and White, 1966). In addition, the Connoquenessing Member is dissected more extensively by buried valleys than is the conglomerate unit of the Sharon Member (pls. 1-3). The areal extent of the Mercer and the Homewood Members is limited within the study area (table 1, pls. 1-3).

The material overlying the bedrock is of glacial origin and consists of clay, silt, sand, and gravel. These glacial deposits cover the uplands and fill the buried valleys (pls. 1-3).

Potential for Containment of Injected Brine

Isolation of injected brine from freshwater aquifers depends on a number of geologic factors. A subsurface reservoir used for brine disposal should have the following characteristics: (1) a sufficient volume of porous and permeable reservoir rock; (2) surrounding rocks that can prevent migration of waste fluid from reservoir rock; and (3) isolation from potable ground water and from the surface environment (Lloyd and Reid, 1986).

Lloyd and Reid (1986) suggest that 5-percent porosity is the minimum for reservoir rock (sandstone, dolomite, or limestone), that at least 100 ft of confining rock (shale, or evaporite), should overlie and underlie reservoir rock, and that the top of reservoir rock in the Appalachian Basin should be at least 1,000 ft below sea level. Clifford (1975) suggests that the native fluid present in reservoir rock should have a total-dissolved-solids concentration of at least 10,000 mg/L because high natural salinity in the Appalachian Basin indicates that the fluid is slow-moving and that it is probably isolated from surface and subsurface sources of freshwater. Clifford also states that shale and evaporites (halite and anhydrite) are the best confining units because they are able to flow slightly and seal fractures and small faults when compressed at depth. The geologic structure in the area of disposal wells should be unfractured because vertical conduits could allow the migration of injected fluids. Seismic activity of the deep-well-injection area should be low (Clifford, 1975).

The drillers' Newburg and "Clinton" zones have the characteristics suggested by Lloyd and Reid (1986) and Clifford (1975) for successful isolation of injected brine from freshwater aquifers. On the basis of bulk-density and neutron logs of the brine-injection wells, the Newburg and "Clinton" zones were determined to have average porosities of 5 to 8 percent and 6.5 to 6.8 percent, respectively (table 2). About 200 ft of evaporite deposits and 2,000 ft of shale separate the reservoir rocks from the freshwater aquifers (pls. 1-3). In addition, at least 100 ft of confining rock underlies the Newburg zone (pls. 1-3) above the "Clinton" zone. No data were available that indicate the nature of the rock units underlying the Albion Sandstone, which contains the "Clinton" zone. The top of the Newburg zone, which is the uppermost brine-injection zone, is at least 2,200 ft below sea level.

The native fluids in the Newburg and "Clinton" zones have total dissolved-solids concentrations of more than 250,000 mg/L (Stith, 1979) and 125,000 mg/L (Breen and others, 1984), respectively. Both concentrations greatly exceed the suggested minimum of 10,000 mg/L for reservoir rock (Clifford, 1975).

No faults have been documented for northern Portage County, and none were detected during construction of the geologic sections (pls. 1-3). Undetected fracture systems, however, could be present in the area. If improperly constructed or improperly abandoned oil and gas wells are present, they also could provide pathways for migration of injected brine from the reservoir rocks to the overlying freshwater aquifers. The Ohio Department of Natural Resources, Division of Oil and Gas, reviews the area around a potential brine-injection well to locate improperly abandoned oil and gas wells before issuing a permit for injection.

Some seismic activity has been noted in northeastern Ohio in past years. At least three earthquakes have occurred in Portage County since 1885. Epicenters and intensities of these earthquakes were not determined (Hansen, 1986).

Hydrology

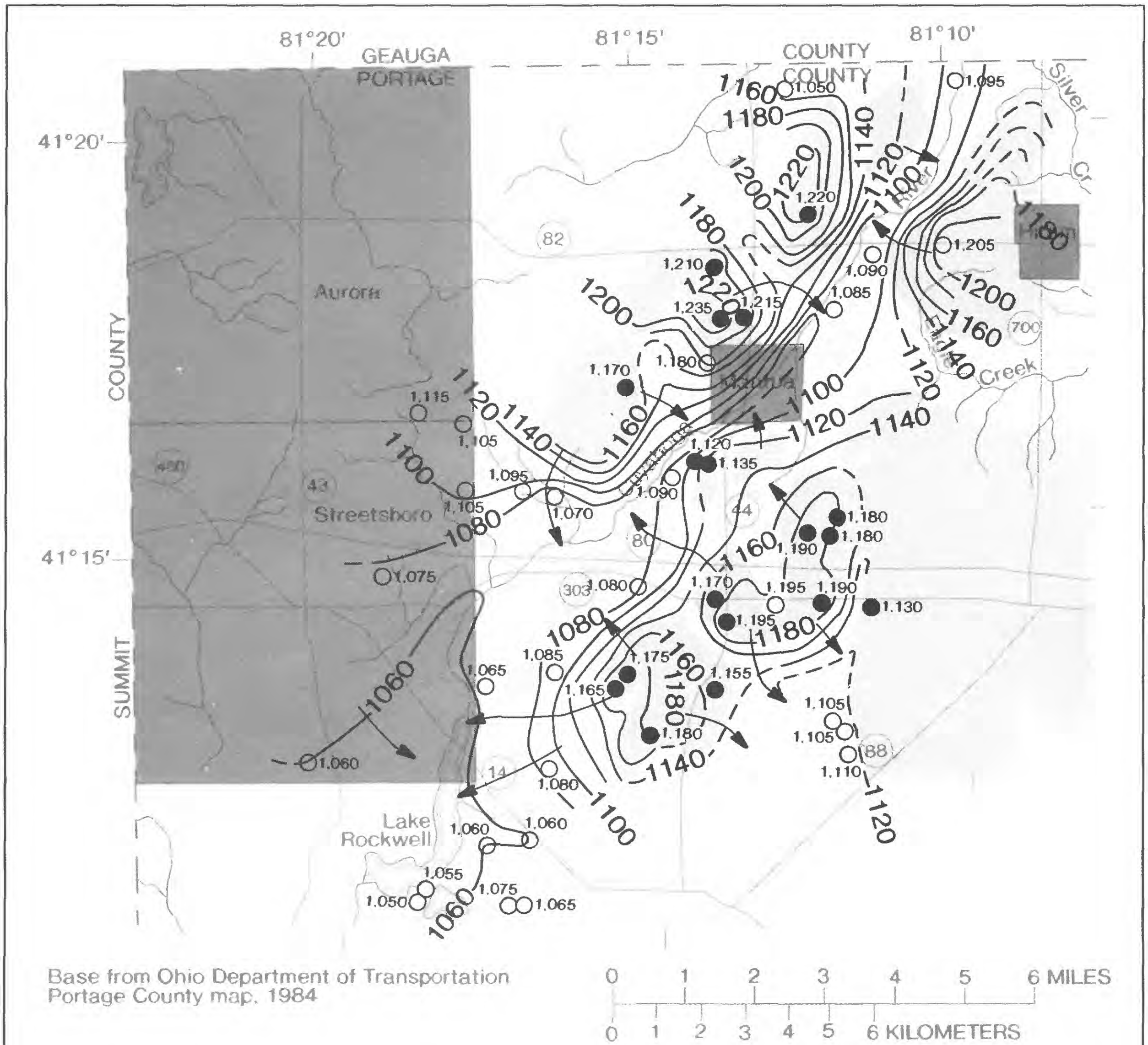
Freshwater Aquifers

Two bedrock aquifers in rocks of Pennsylvanian age are generally recognized within the study area. The shallowest bedrock aquifer (Connoquenessing Sandstone Member of the Pottsville Formation) (table 1, pls. 1-3) is principally a coarse- to medium-grained sandstone. Yields from wells in this aquifer are typically less than 50 gal/min (gallons per minute) (Winslow and White, 1966). Quartz sandstone and conglomerate in the Sharon Member of the Pottsville Formation (table 1, pls. 1-3), comprises the deeper bedrock aquifer. This aquifer is the most areally extensive in the study area. Typical well yields range from 5 to 200 gal/min (Winslow and White, 1966). These two bedrock aquifers are generally separated by a shale bed in the Sharon Member (table 1, pls. 1-3), which acts as a confining unit. Glacial deposits are used as a source of water primarily in the buried valleys where the deposits are the thickest and the bedrock aquifers are absent or deeply buried (pls. 1-3).

Water levels

Water levels were measured in 78 wells in September 1987 and in 74 of the same wells in April 1988 (table 3, at back of report; fig. 2). Wells PO-107 and PO-108 were completed in the lower sandstone and conglomerate aquifer and the upper sandstone aquifer, respectively (fig. 2), and instrumented to collect hourly water-level data. These data provide information on vertical hydraulic gradients between the two bedrock aquifers at a topographically high recharge area. Piezometers PO-19 and PO-20 were screened in the glacial deposits along the southern shore of Lake Rockwell (fig. 2) and instrumented to collect hourly water-level data to obtain information on vertical hydraulic gradients near the lake. Each well selected for water-level measurement produces water from a single aquifer. Drillers' logs were obtained for all wells selected for water-level measurement.

Ground-water-level maps (figs. 7 and 8) were constructed from measurements made during September 1987 (table 3). Water levels in wells that tap the upper sandstone aquifer and the glacial deposits are depicted in figure 7. The upper sandstone aquifer is the surficial aquifer where glacial deposits are unsaturated (in the uplands); the glacial deposits comprise the surficial aquifer in the valleys where the sandstone is absent. The two aquifers are hydraulically connected and act as a single unit. Because the upper sandstone aquifer is not laterally continuous, water-level measurements in wells tapping this aquifer were concentrated near Shalersville Township in the central part of the study area. In general, the shape of the water-level surface in the surficial aquifers (upper sandstone aquifer and glacial deposits) is a subdued reflection of the land surface.



EXPLANATION

APPROXIMATE EXTENT OF THE CONNOQUENESSING SANDSTONE MEMBER--from Winslow and White, 1966

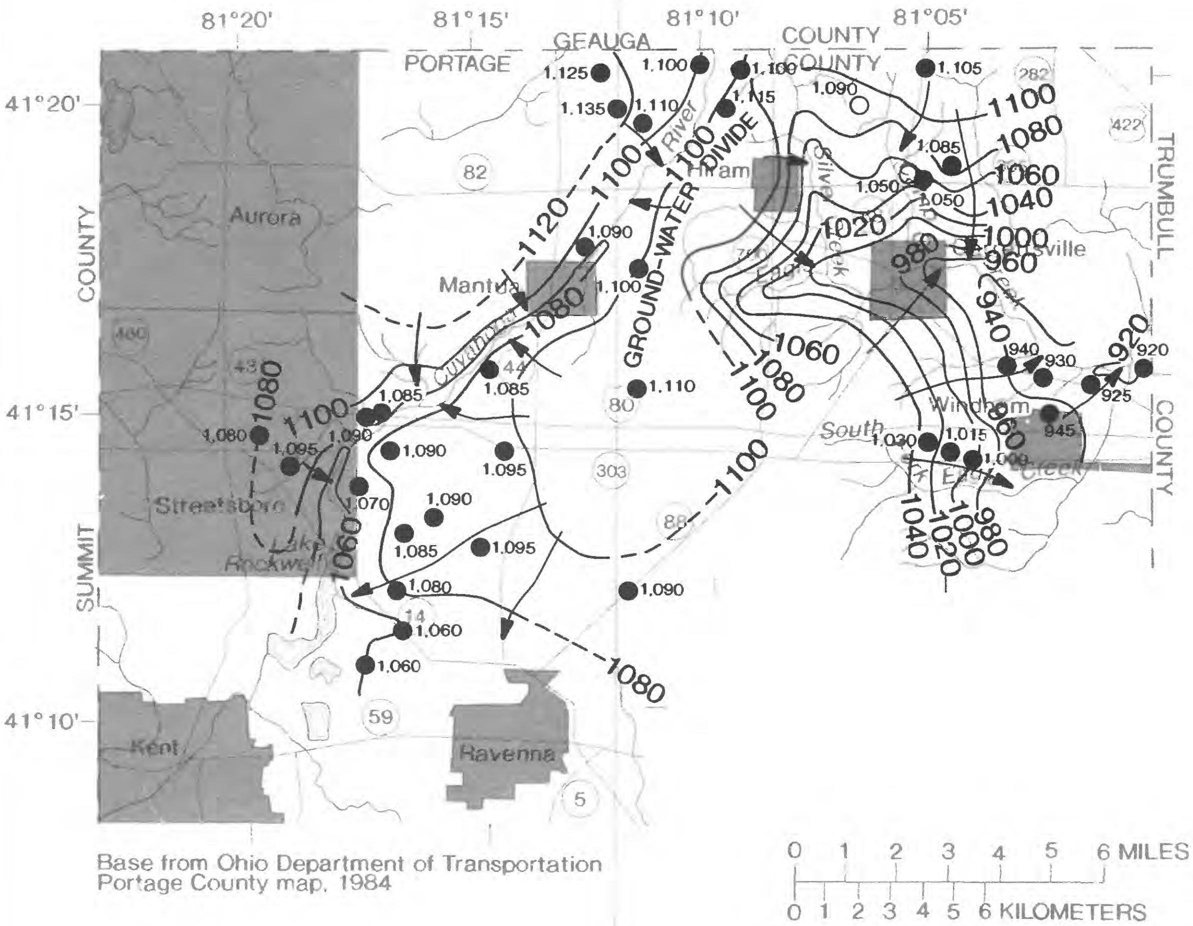
—1100— LINE OF EQUAL ALTITUDE OF WATER-LEVEL--Dashed where approximately located. Interval 20 feet. Datum is sea level

GENERAL DIRECTION OF GROUND-WATER FLOW

●1,165 MEASURED WATER-LEVEL ALTITUDE IN THE UPPER SANDSTONE AQUIFER

○1,050 MEASURED WATER-LEVEL ALTITUDE IN THE GLACIAL DEPOSITS

Figure 7.--Ground-water levels and general directions of ground-water flow in the upper sandstone aquifer and the glacial deposits, September 1987.



EXPLANATION

—1100— LINE OF EQUAL ALTITUDE OF WATER-LEVEL--Dashed where approximately located. Interval 20 feet. Datum is sea level

→ GENERAL DIRECTION OF GROUND-WATER FLOW

● 1,060 MEASURED WATER-LEVEL ALTITUDE IN THE LOWER SANDSTONE AND CONGLOMERATE AQUIFER

○ 1,050 MEASURED WATER-LEVEL ALTITUDE IN THE GLACIAL DEPOSITS WHERE THE LOWER SANDSTONE AND CONGLOMERATE AQUIFER IS ABSENT

Figure 8.--Ground-water levels and general directions of ground-water flow in the lower sandstone and conglomerate aquifer, September 1987

Ground-water levels measured in the lower sandstone and conglomerate aquifer in September 1987 generally indicate confined conditions and are illustrated in figure 8. The shape of the potentiometric surface in this aquifer is less influenced by topography than is the water-level surface in the surficial aquifers.

Water-level measurements from wells PO-107 and PO-108 are shown in figure 9. Water levels in PO-108, which produces from the upper sandstone aquifer, fluctuated less than 5 ft from November 1987 to September 1988, except when the well was pumped for sampling in April and May 1988. Water levels in well PO-107, which produces from the lower sandstone and conglomerate aquifer, fluctuated as much as 20 ft from November 1987 to August 1988. No explanation is apparent for the sharp water-level rise in February 1988. (This water-level rise was verified in the field and is not an artifact of faulty instrumentation.) The sharp water-level decline in April 1988 occurred as a result of pumping for the collection of a water-quality sample.

Water levels in well PO-107 were at least 60 ft lower than water levels in well PO-108 from November 1987 through August 1988. This indicates that there is a downward hydraulic gradient at this topographically high recharge area and that the intervening shale serves as a confining unit that impedes the vertical flow of ground water from the upper sandstone aquifer to the lower sandstone and conglomerate aquifer. Water levels in the upper sandstone aquifer and the lower sandstone and conglomerate aquifer were nearly the same near discharge areas along the Cuyahoga River (figs. 7 and 8).

General directions of ground-water flow

Ground-water-level maps (figs. 7 and 8) were used to determine general directions of ground-water flow in the principal aquifers. Ground water moves from areas of high water levels to areas of low water levels, generally perpendicular to lines of equal water-level altitude. Generally, the direction of ground-water flow in the upper sandstone aquifer (fig. 7) is radial, away from topographically high areas. Much of the ground water in upper sandstone aquifer flows into the glacial deposits in the buried valley beneath the Cuyahoga River and discharges into the Cuyahoga River. Most ground water in the lower sandstone and conglomerate aquifer flows toward discharge areas near the Cuyahoga River or Eagle Creek (fig. 8). A ground-water divide between these two drainage basins is illustrated in figure 8.

The ground-water-flow directions illustrated in figures 7 and 8 are regional in nature but provide a general indication of probable migration paths in the event of brine contamination of

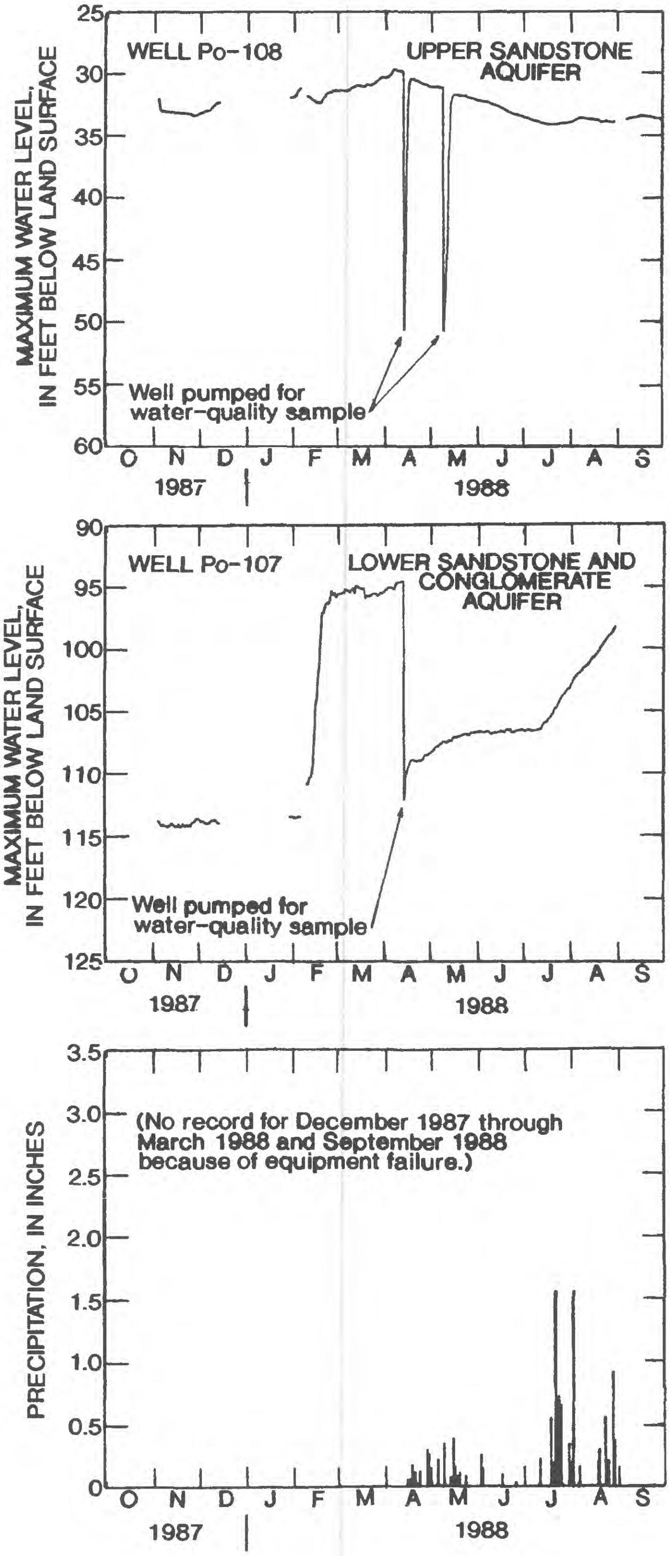


Figure 9.--Water levels at well Po-108 and well Po-107 and daily precipitation from April 8, 1988 through August 30, 1988 at the well site.

the freshwater aquifers. Site-specific water-level data are necessary to determine migration paths near areas of brine contamination, however.

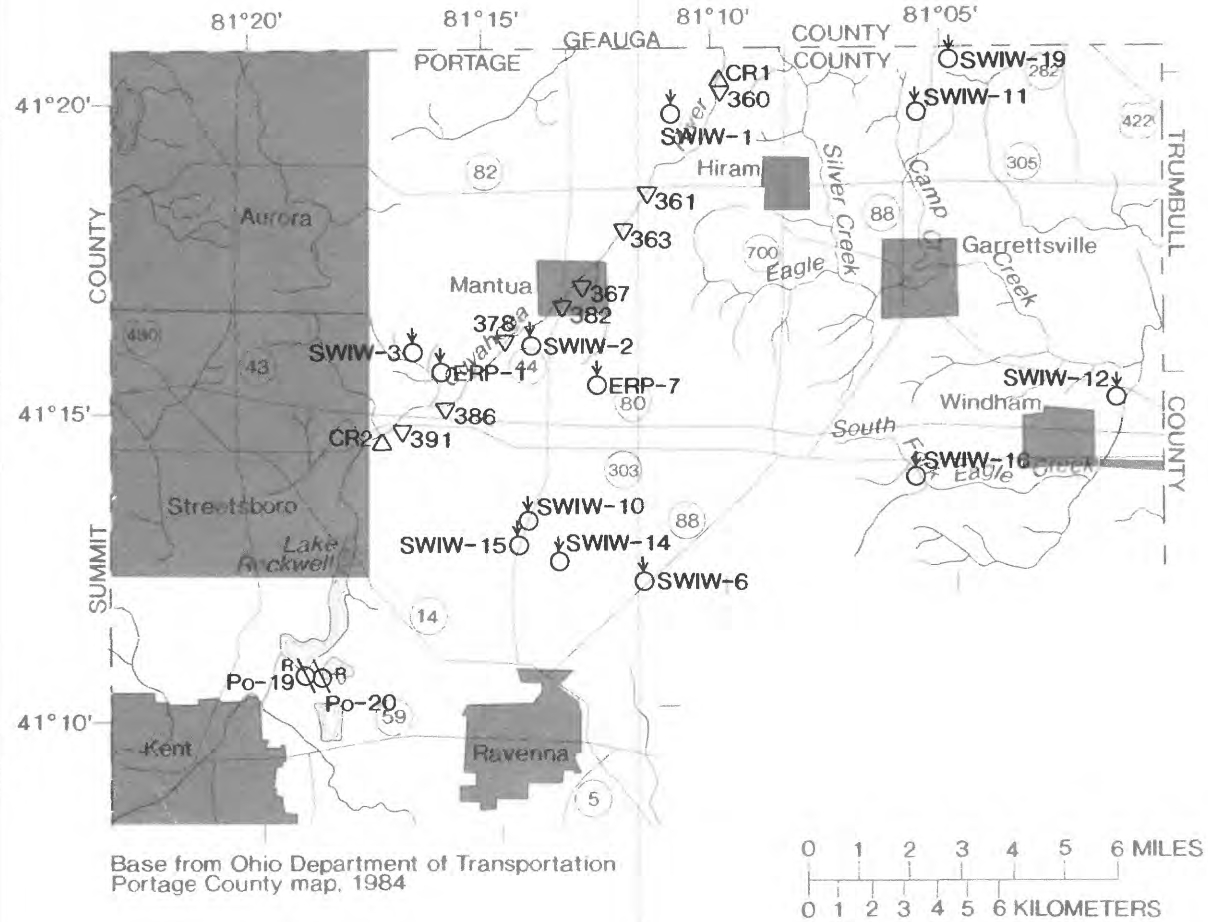
Ground-Water/Surface-Water Relations

Much of the ground water in northern Portage County flows toward discharge areas along the Cuyahoga River (figs. 7 and 8). In June 1988, a gain/loss study was conducted on the Cuyahoga River to quantify the relation between ground water and the Cuyahoga River in the study area. The daily flow duration along this reach of the Cuyahoga River was 85 to 90 percent (flow that is exceeded 85 to 90 percent of the time) during the time of measurement. Data from the study are interpreted to indicate that the Cuyahoga River is gaining 15.8 ft^3/s (cubic feet per second) of water from the aquifers between sites CR1 and CR2 (fig. 10). Assuming a measurement error of 5 percent, the gain could range from 10.1 ft^3/s to 21.3 ft^3/s.

The relation between ground water and Lake Rockwell was studied by comparing daily lake levels and ground-water levels at piezometers PO-20 and PO-19 along the southern shore of Lake Rockwell (fig. 2). The data are plotted in figure 11. Except for a short period in November 1987 and April, June, and August 1988, the water level in Lake Rockwell was higher than the ground-water levels in the piezometers. Ground-water levels in the shallow piezometer (PO-20) were higher than ground-water levels in the deep piezometer (PO-19). These data indicate that ground water did not discharge into the downstream end of Lake Rockwell during most of the 1988 water year. Rather, water in Lake Rockwell, which is a regulated water-supply reservoir, recharged the glacial aquifer that underlies the Lake at this location. No relation was determined between the glacial aquifer and Lake Rockwell at its upstream end.

WATER QUALITY

Drinking-water regulations established by the USEPA (1988a, 1988b, 1988c, 1988d, and 1989b) set limitations on the quality of water that may be supplied for public consumpion. Maximum Contaminant-Level Goals (MCLGs) are nonenforceble health-based standards set at a level to prevent known or anticipated adverse effects with an adequate margin of safety. Maximum Contaminant Levels (MCLs) are enforceable standards set as close to the MCLGs as feasible on the basis of water-treatment technologies and costs. MCLs have been established for substances that can affect human health. Secondary MCLs (SMCLs) have been established for substances that affect the aesthetic quality of water by imparting taste and odor and by staining fixtures. These regulations are not used to regulate the quality of water produced from individual domestic wells but serve as guidelines with which to evaluate domestic supplies.



EXPLANATION

△CR1	GAIN/LOSS MEASUREMENT SITE AND NUMBER
Po-19 R	OBSERVATION WELL EQUIPPED WITH A RECORDER
SWIW-1	BRINE-INJECTION WELL AND NUMBER
ERP-1	ENHANCED-RECOVERY PROJECT WELL AND NUMBER
▽367	SPECIFIC CONDUCTANCE OF CUYAHOGA RIVER, IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS

Figure 10.--Data-collection network for determining ground-water/surface-water relations and specific conductance of the Cuyahoga River, June 1988.

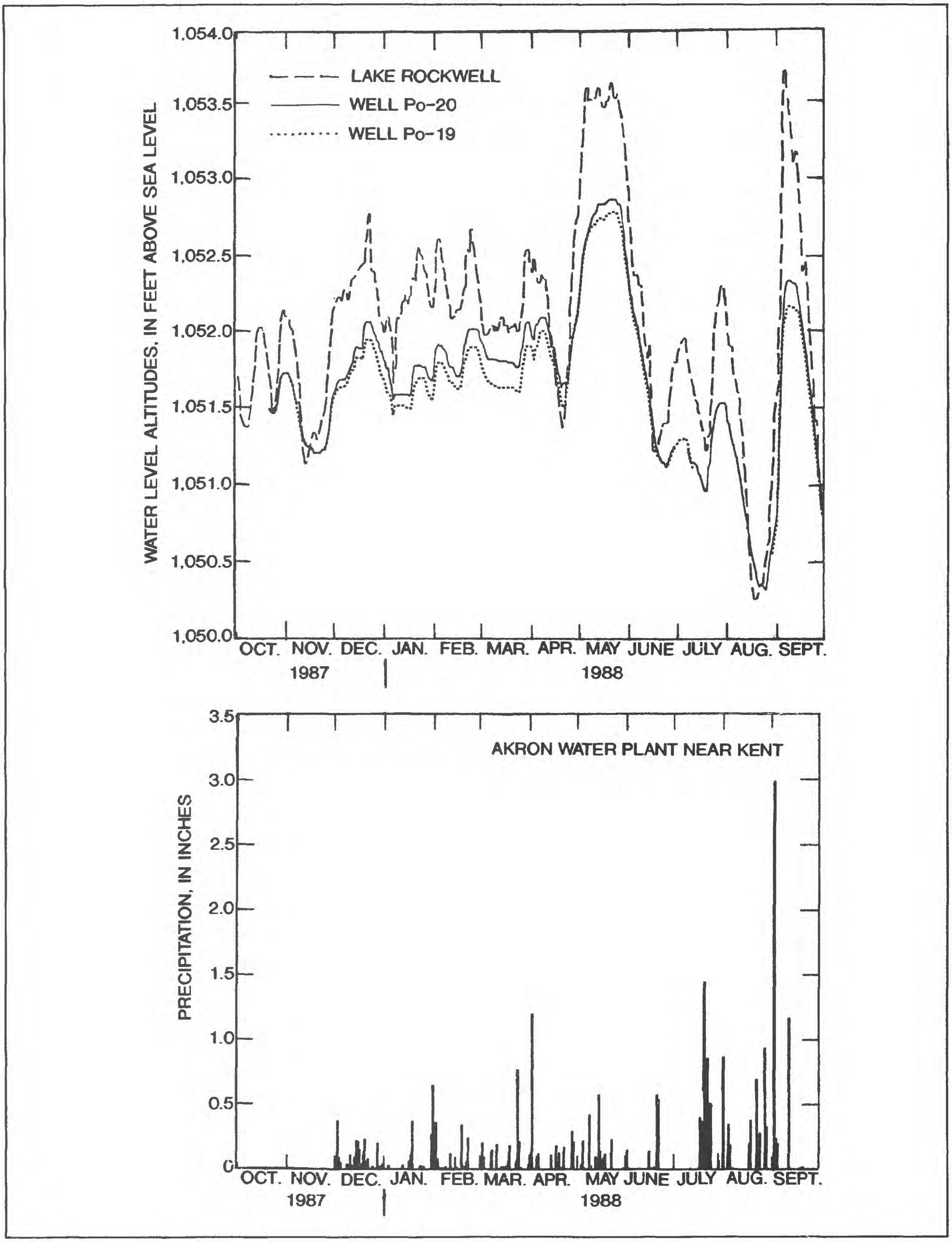


Figure 11.--Water levels at Lake Rockwell, well Po-20, and well Po-19, and daily precipitation at the Akron Water Plant.

Specific-Conductance Survey of Water from the Freshwater Aquifers and the Cuyahoga River

Specific conductance can be used to estimate the dissolved-solids concentration of a water sample because specific conductance generally is directly related to dissolved-solids concentration (Hem, 1985). Water-quality data collected by the USGS in neighboring Geauga County indicate that, for the glacial and Pottsville aquifers, a specific conductance of 800 μS/cm (microsiemens per centimeter at 25 degrees Celsius) approximately corresponds to a dissolved-solids concentration of 500 mg/L (Eberts and others, 1990)--the SMCL set by the USEPA for public water supplies.

Because freshwater mixed with brine contains elevated concentrations of dissolved solids, specific conductance was measured in ground water from all accessible domestic wells within one-quarter mile of each brine-injection well to determine if widespread contamination of the freshwater aquifers has occurred as a result of brine injection. The specific-conductance data were used to identify domestic wells near the brine-injection wells to be sampled for detailed analysis of water chemistry.

A specific conductance greater than 800 μS/cm was detected in six of the nearly 100 wells sampled. Only four of these six wells (PO-38, PO-39, PO-41, and PO-110) (fig. 3) were sampled for detailed water chemistry because of well-access problems. Wells PO-38 and PO-39 were sampled twice, and wells PO-41 and PO-110 were sampled once. One additional well (PO-109) was sampled because of previous reports of anomalous water quality.

A specific-conductance reconnaissance survey was conducted along the Cuyahoga River at low flow (June 1988) to determine if the ground-water component of the river (base flow) has been affected by oilfield and (or) gasfield brine. The highest value of specific conductance measured in the Cuyahoga River was 391 μS/cm (fig. 10). As a result, the Cuyahoga River was not sampled for detailed analysis of water chemistry.

Ground-Water Quality in the Freshwater Aquifers

Twenty additional wells were sampled, once only, to determine ground-water quality in the three aquifers within the study area (fig. 3). Each of these 20 wells produces water from a single aquifer. Wells PO-38, PO-41, and PO-110 also yield water from a single aquifer, whereas wells PO-39 and PO-109 yield water from multiple aquifers.

The plumbing system at each well was inspected to ensure that samples were unaffected by water-treatment systems. The volume of water in the well bore and the volume of water in the pressure tank (if the pressure tank could not be bypassed) was purged three times before a sample was collected at each well.

Well discharge was volumetrically estimated, and a portable meter with a fully enclosed flow chamber was used to monitor pH, dissolved-oxygen concentration, specific conductance, and water temperature. Samples were collected when purging was complete and when successive readings of the four characteristics stabilized. An in-line filter equipped with a 0.45-micrometer membrane filter was used to collect samples for dissolved metals.

Samples were preserved as required and analyzed by the USGS National Water Quality Laboratory in Denver, Colo. Properties and constituents for which all ground-water samples were analyzed are listed in table 4. Water from wells PO-38, PO-39, PO-41, PO-110, PO-23, PO-32, PO-109, and a brine sample from SWIW-2 (fig. 1) were analyzed by gas chromatography with a flame-ionization detector. Bromide concentrations were determined by use of method I-2129-85, which accounts for common-ion interference from iodide (Fishman and Friedman, 1985). Specific conductance, pH, water temperature, and concentrations of dissolved oxygen and alkalinity were determined in the field. Bicarbonate concentration was calculated from the field-determined alkalinity concentration.

Glacial Deposits

Eight wells completed in the glacial deposits were sampled in April or May 1988 (table 5, at back of report). The location of these wells is shown in figure 3. Concentrations of major cations (calcium, magnesium, and sodium) and anions (bicarbonate, sulfate, and chloride) in the waters provide a means of classifying and distinguishing the waters by type (fig. 12). Ground water from glacial deposits ranges from a calcium bicarbonate to a calcium sodium bicarbonate chloride water type (fig. 12). Calcium bicarbonate is the dominant water type, whereas only water from PO-41 contains chloride as a dominant anion. Well PO-41 is near brine-injection well SWIW-3 (figs. 1 and 3).

Summary statistics of chemical data for waters from the glacial deposits are listed in table 6. Median concentrations for the principal cations are: Dissolved calcium, 82 mg/L; dissolved magnesium, 22 mg/L; and dissolved sodium, 15 mg/L. Median concentrations for the principal anions are: Bicarbonate, 232 mg/L; dissolved sulfate, 74 mg/L; and dissolved chloride, 24 mg/L. Water from well PO-44 had the highest concentration of dissolved calcium (150 mg/L), dissolved magnesium (69 mg/L), bicarbonate (410 mg/L), and dissolved sulfate (350 mg/L). The highest concentrations of dissolved sodium (83 mg/L) and dissolved chloride (230 mg/L) were found in water from well PO-41.

In addition to calcium, magnesium, sodium, bicarbonate, sulfate, and chloride, Reid and others (1974) list potassium, bromide, and iodide as constituents normally found in oilfield and gasfield brines. The median concentration of dissolved potassium in waters from the glacial deposits in northern

Table 4.--Properties and constituents selected for determination in ground-water samples

FIELD DETERMINATIONS	
Specific conductance	Water temperature
pH	Oxygen, dissolved
MAJOR CATIONS AND ANIONS	
Hardness, as $CaCO_3$	Bicarbonate
Noncarbonate hardness, as $CaCO_3$	Alkalinity, as $CaCO_3$
Calcium	Sulfate
Magnesium	Chloride
Sodium	Potassium
OTHER CONSTITUENTS	
Barium	Fluoride
Iron	Bromide
Manganese	Silica
Strontium	Total dissolved solids
ORGANIC COMPOUNDS	
Organic carbon, dissolved	Compounds detectable by gas chromatography with a flame-ionization detector

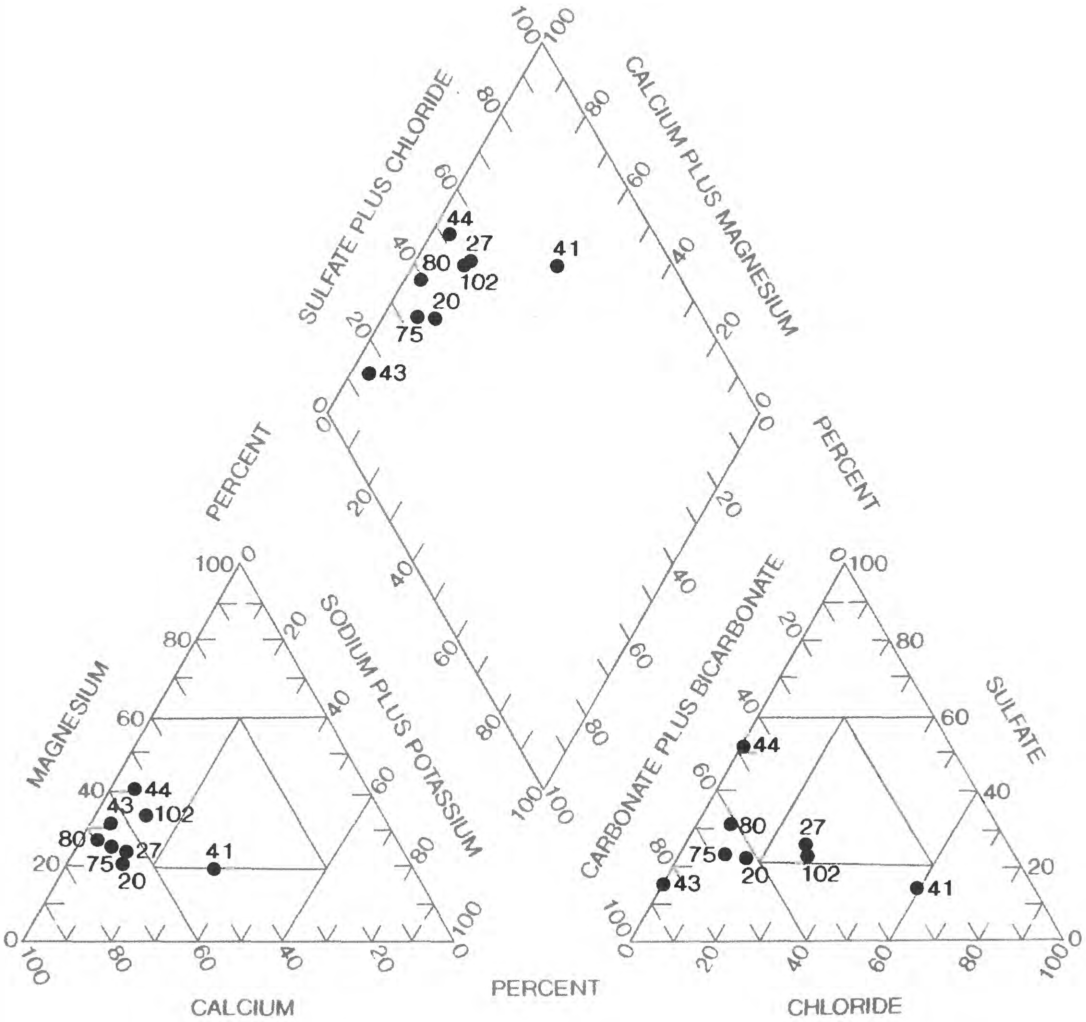


Figure 12.--Piper diagram showing variation in the chemical character of water from wells completed in glacial deposits in northern Portage County, Ohio (the county prefix "Po-" has been omitted from well numbers).

Table 6.--Statistical summary of water-quality data for wells in the glacial deposits

[Number of observations is 8 unless otherwise indicated]

Constituent or property	Mean	Median	Standard deviation	Minimum	Maximum	25th percentile	75th percentile
Specific conductance (μS/cm)	742	580	282	478	1,140	533	1,080
pH (standard units)	7.3	7.3	.18	7.0	7.6	7.1	7.3
Oxygen, dissolved (mg/L)	0	0	0	0	0	0	0
Hardness, total (mg/L as $CaCO_3$)	350	300	140	230	660	270	420
Hardness, noncarbonate (mg/L as $CaCO_3$)	140	120	95	23	320	68.5	200
Calcium (mg/L)	94	82	26	69	150	78	110
Magnesium (mg/L)	28	22	18	13	69	17	36
Sodium (mg/L)	22	15	26	4.3	83	7.2	24
Potassium (mg/L)	1.4	1.4	.37	.90	2.0	1.0	1.7
Bicarbonate (mg/L)	258	232	85.4	171	410	182	331
Alkalinity (mg/L as $CaCO_3$)	211	190	69.8	140	336	150	271
Sulfate (mg/L)	110	74	100	48	350	58	106
Chloride (mg/L)	58	24	78	.7	230	5.6	97
Fluoride (mg/L)	.2	.2	.1	.1	.3	.1	.2
Bromide (mg/L)	.20	.045	.44	.021	1.3	.030	.079
Silica (mg/L)	12	11	4.6	5.9	20	9.8	17
Total dissolved solids (mg/L)	455	345	192	289	813	325	627
Barium (μg/L)	69	54	50	15	160	28	110
Iron (μg/L)	1,000	720	1,000	10	2,600	180	2,200
Strontium (μg/L)	230	140	260	110	870	110	190
Organic carbon, dissolved (mg/L)[1]	1.1	.6	.9	.5	2.7	.5	1.9

[1]Six observations.

Portage County is 1.4 mg/L, whereas the median concentration of dissolved bromide is 0.045 mg/L (table 6). Water from well PO-44 had the highest concentration of dissolved potassium (2.0 mg/L), and water from well PO-41 had the highest concentration of dissolved bromide (1.3 mg/L). Iodide concentrations were not reported for the samples collected as part of this investigation.

Pottsville Formation

Upper sandstone aquifer

Nine wells completed in the upper sandstone aquifer were sampled in April or May 1988 (table 5, fig. 3). Eight of the wells were sampled once; well PO-38 was sampled twice in April. Calcium bicarbonate is the dominant type of water produced from these nine wells (fig. 13). Chloride is the dominant anion in waters from wells PO-21 and PO-38; these waters contain the highest concentration of dissolved solids, and do not reflect native water quality in the upper sandstone aquifer. Well PO-21 is 1 of the 20 wells sampled to help determine water quality in the principal aquifers. Well PO-38 was selected for sampling because a high specific conductance was measured during the reconnaissance survey near brine-injection well SWIW-2 (fig. 1).

Summary statistics of chemical data for waters from the upper sandstone aquifer are listed in table 7. The median concentrations of dissolved calcium, dissolved magnesium, dissolved sodium, and dissolved potassium are 73, 18, 8.1, and 1.8 mg/L, respectively. The median concentration of bicarbonate is 225 mg/L, and the median concentrations of dissolved sulfate and dissolved chloride are 49 and 15 mg/L, respectively. Water from well PO-21 had the highest concentrations of calcium (140 mg/L), magnesium (35 mg/L), sodium (190 mg/L), and chloride (420 mg/L). Two samples collected from well PO-38 had an average dissolved bromide concentration of 3.2 mg/L, whereas the median concentration of dissolved bromide for waters from the nine wells that produce from the upper sandstone aquifer is 0.024 mg/L.

Lower sandstone and conglomerate aquifer

Six wells that produce water from the lower sandstone and conglomerate aquifer were sampled in April or May 1988 (table 5, fig. 3). Calcium bicarbonate is the dominant water type in this aquifer (fig. 14). None of the wells produced water in which sodium was the dominant cation or chloride was the dominant anion.

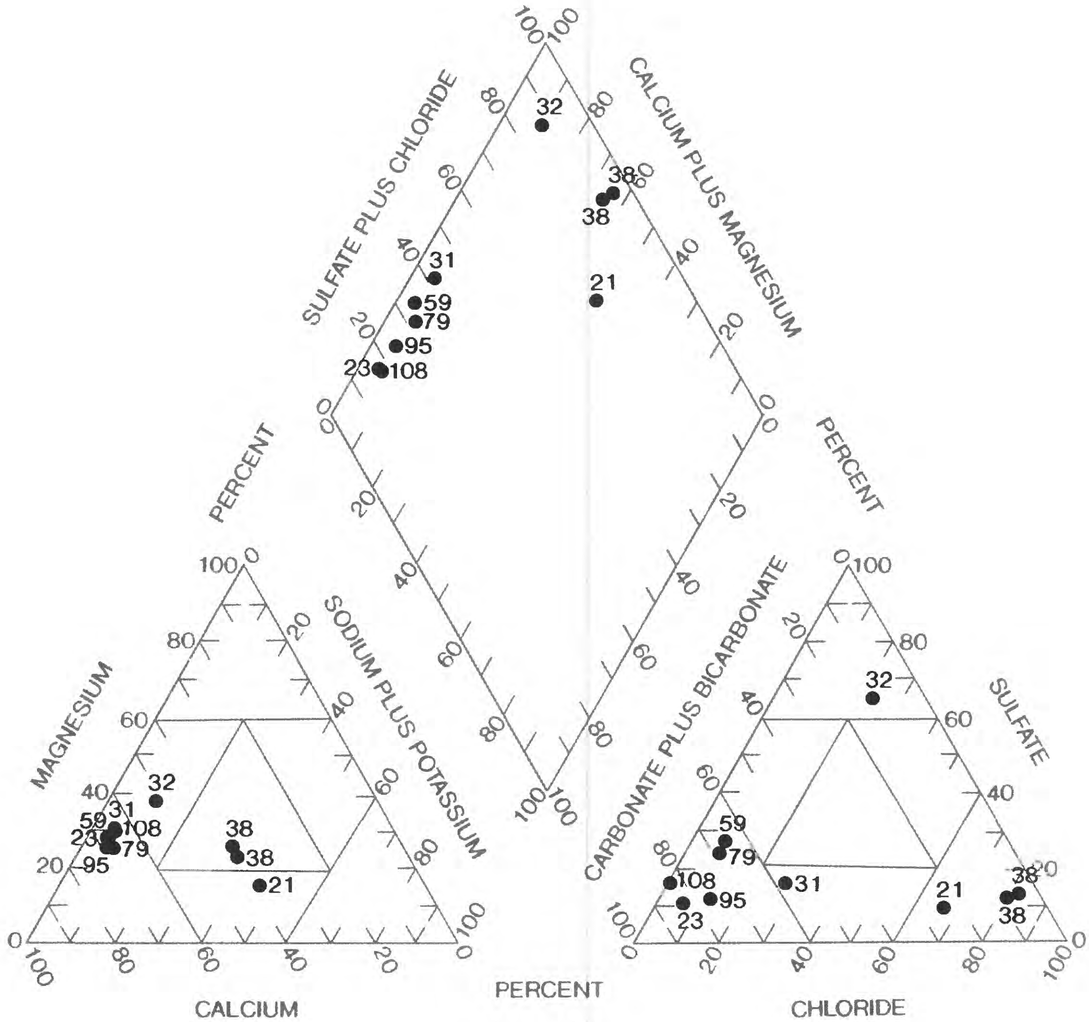


Figure 13.--Piper diagram showing variation in the chemical character of water from wells completed in the upper sandstone aquifer in northern Portage County, Ohio (the county prefix "Po-" has been omitted from well numbers).

Table 7.--Statistical summary of water-quality data for wells in the upper sandstone aquifer

[Number of observations is 9 unless otherwise indicated]

Constituent or property	Mean	Median	Standard deviation	Minimum	Maximum	25th percentile	75th percentile
Specific conductance (µS/cm)	673	486	552	245	2,030	357	800
pH (standard units)	6.9	7.0	.68	5.8	7.5	6.2	7.4
Oxygen, dissolved (mg/L)[1]	3.0	1.0	3.8	0	9.4	0	6.8
Hardness, total (mg/L as $CaCO_3$)	260	260	110	99	490	180	310
Hardness, noncarbonate (mg/L as $CaCO_3$)	110	72	99	20	280	36	190
Calcium (mg/L)	70	73	33	23	140	49	84
Magnesium (mg/L)	20	18	8.4	10	35	12	26
Sodium (mg/L)	34	8.1	63	3.0	190	4.0	41
Potassium (mg/L)	1.7	1.8	.80	.90	3.2	.90	2.2
Bicarbonate (mg/L)	185	225	105	9	332	86.0	247
Alkalinity (mg/L as $CaCO_3$)	151	184	86.4	7	272	70.0	202
Sulfate (mg/L)	48	49	18	24	80	31	62
Chloride (mg/L)	92	15	150	1.1	420	8.6	170
Fluoride (mg/L)	.3	.3	.1	.1	.4	.2	.4
Bromide (mg/L)	.39	.024	1.0	.010	3.2	.016	.096
Silica (mg/L)	12	12	1.5	11	16	11	13
Total dissolved solids (mg/L)	401	304	304	171	1,100	205	519
Barium (µg/L)	38	36	25	4	76	19	60
Iron (µg/L)	1,700	730	2,400	7	6,200	9	3,700
Strontium (µg/L)	150	110	90	54	300	79	240
Organic carbon, dissolved (mg/L)	.8	.7	.4	.5	1.6	.5	.9

[1]Eight observations.

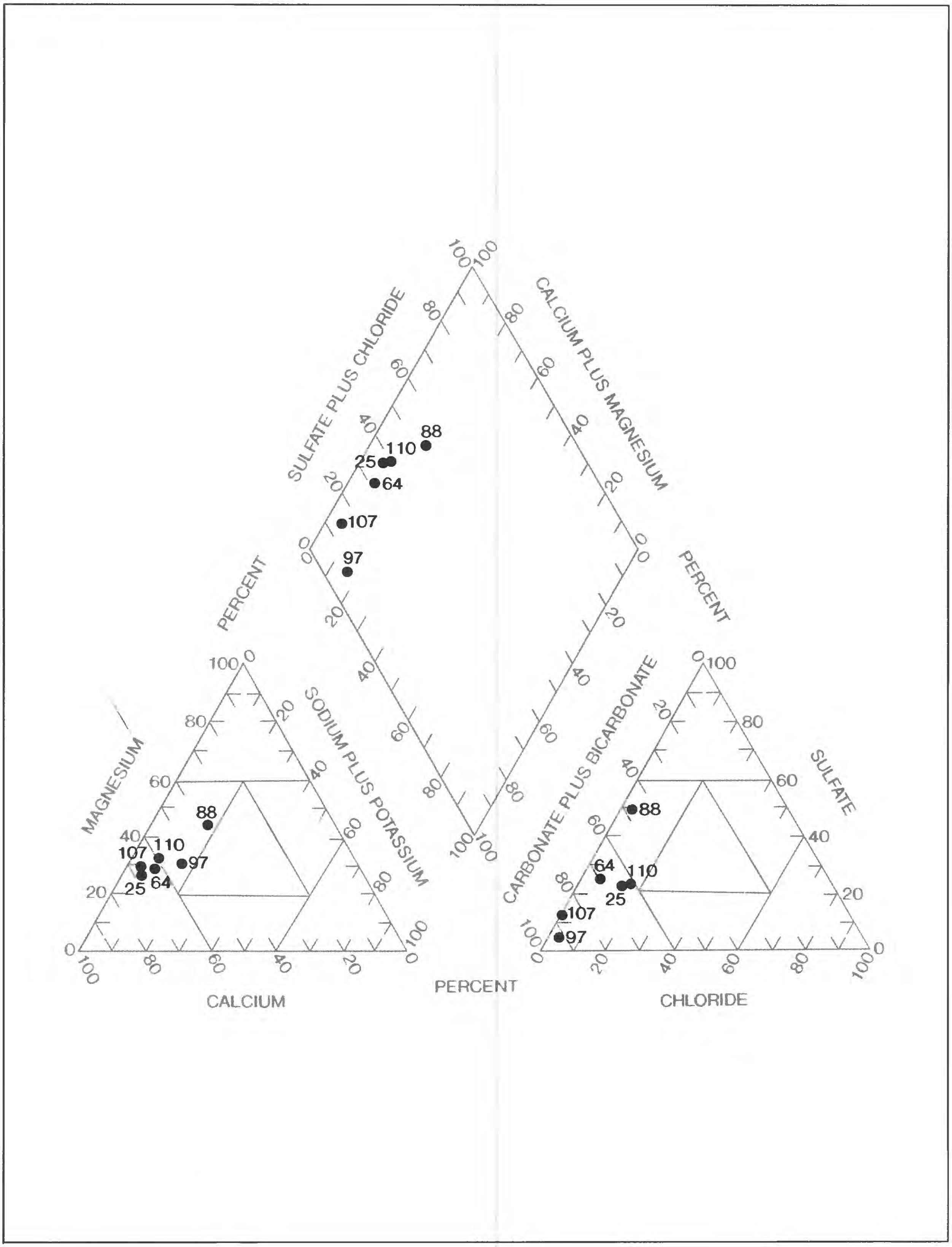


Figure 14.--Piper diagram showing variation in the chemical character of water from wells completed in the lower sandstone and conglomerate aquifer in northern Portage County, Ohio (the county prefix "Po-" has been omitted from well numbers).

Summary statistics of chemical data for waters from the lower sandstone and conglomerate aquifer are listed in table 8. The median concentrations for the principal cations are: Calcium, 66 mg/L; magnesium, 18 mg/L; sodium, 8.2 mg/L; and potassium, 1.6 mg/L. The median concentration for bicarbonate is 247 mg/L, whereas the median concentrations for sulfate and chloride are 58 mg/L and 6.0 mg/L, respectively. The median concentration for dissolved bromide is 0.030 mg/L.

Water from well PO-110 had the highest concentration of calcium (100 mg/L), magnesium (32 mg/L), sodium (16 mg/L), sulfate (90 mg/L), chloride (46 mg/L), and bromide (0.051 mg/L). The concentrations of sodium, chloride, and bromide in well PO-110 were much lower than the maximum concentrations of these constituents detected in samples from the other aquifers. Water from well PO-107 had the highest concentration of bicarbonate (336 mg/L) from the lower sandstone and conglomerate aquifer. Water from well PO-97 had the highest concentration of potassium (4.9 mg/L).

Ground-Water Quality near Brine-Injection Wells

Most ground waters in northern Portage County, Ohio, are calcium bicarbonate-type waters (figs. 12-14). Samples that had chloride concentrations greater than 250 mg/L were either a calcium magnesium sodium chloride (PO-38 and PO-39), calcium sodium chloride (PO-21), or sodium chloride (PO-109) water type (table 5). (Data from wells PO-39 and PO-109 are not plotted in figures 12-14 because these wells produce water from multiple aquifers.)

Mixing curves for fresh ground waters, oilfield and gasfield brine, and salt-solution brine (such as derived from diluted highway-deicing salts), constructed on a diagram of bromide:chloride (Br:Cl) ratios plotted against chloride concentrations, are used to differentiate between sources of salinity in ground waters with dissolved-solids concentrations less than 10,000 mg/L (Whittemore, 1984 and 1988). Because bromide and chloride are two conservative constituents in natural ground water, this technique is not subject to error from ion-exchange processes, mineral precipitation, or oxidation-reduction reactions (Whittemore, 1988).

Br:Cl ratios were computed for the data from the 25 wells sampled as part of this investigation and for data from 21 wells that produce from the same aquifers in Geauga County (Eberts and others, 1990), which is immediately north of Portage County. These Br:Cl ratios were plotted against their corresponding chloride concentrations (fig. 15). Mixing curves representing the boundaries of various mixtures of oilfield and gasfield brines and salt-solution brines with local fresh ground waters were calculated and plotted. The zones delineated by these curves are used to identify mixtures of local fresh ground waters

Table 8.--Statistical summary of water-quality data for wells in the lower sandstone and conglomerate aquifer

[Number of observations is 6]

Constituent or property	Mean	Median	Standard deviation	Minimum	Maximum	25th percentile	75th percentile
Specific conductance (µS/cm)	484	462	161	334	757	342	597
pH (standard units)	7.1	7.1	.52	6.2	7.6	6.8	7.6
Oxygen, dissolved (mg/L)	.87	0	2.1	0	5.2	0	1.3
Hardness, total (mg/L as $CaCO_3$)	240	240	110	100	380	140	320
Hardness, noncarbonate (mg/L as $CaCO_3$)	45	17	57	0	140	5.2	100
Calcium (mg/L)	62	66	31	19	100	36	87
Magnesium (mg/L)	19	18	7.4	12	32	13	24
Sodium (mg/L)	9.8	8.2	3.8	6.4	16	6.8	14
Potassium (mg/L)	2.2	1.6	1.6	.80	4.9	1.0	3.8
Bicarbonate (mg/L)	233	247	84.5	110	336	148	308
Alkalinity (mg/L as $CaCO_3$)	191	202	69.2	90	275	122	252
Sulfate (mg/L)	57	58	32	9.5	90	32	90
Chloride (mg/L)	16	6.0	18	2.1	46	4.1	33
Fluoride (mg/L)	.3	.3	.1	.1	.5	.2	.4
Bromide (mg/L)	.034	.030	.012	.020	.051	.024	.046
Silica (mg/L)	12	12	3.7	6.8	18	10	15
Total dissolved solids (mg/L)	284	258	108	187	468	198	365
Barium (µg/L)	110	84	94	4	270	37	170
Iron (µg/L)	6,600	700	13,000	14	34,000	160	12,000
Strontium (µg/L)	220	130	270	32	760	68	340
Organic carbon, dissolved (mg/L)	.7	.7	.1	.6	.8	.6	.8

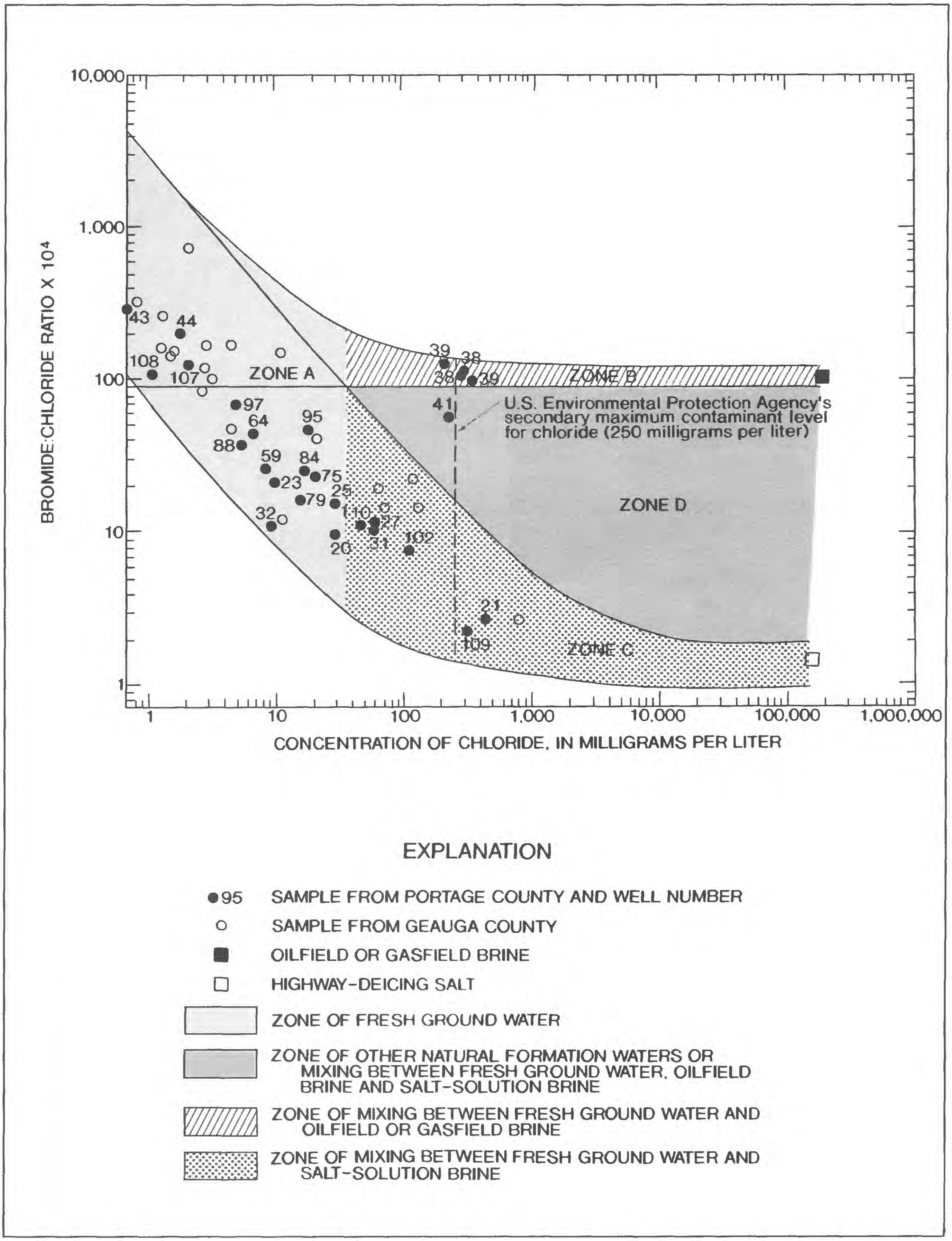


Figure 15.--Bromide:chloride ratios for fresh ground water and brine-mixing zones.

(zone A; fig. 15) with oilfield brine and salt-solution brine. These curves are based on the following mixing equation (Whittemore, 1988):

$$C_{mix} = C_1V + C_2(1-V), \quad (1)$$

where C_{mix} is the concentration of bromide (or chloride) in the mixture,
C_1 is the concentration of bromide (or chloride) in the first end-point water,
C_2 is the concentration of bromide (or chloride) in the second end-point water, and
V is the volume fraction of the first end-point water.

The endpoints for the upper and lower boundaries of zone A were selected so that all of the measured Br:Cl ratios fall within the boundaries. The endpoints for the upper and lower boundaries of zone B, which represents mixtures of oilfield and (or) gasfield brine with local ground waters, were computed as ±15 percent of the bromide concentration of three oilfield and gasfield brine samples from Geauga and Summit Counties (Eberts and others, 1990). The endpoints for the upper and lower boundaries of zone C, which represents mixtures of salt-solution brine with local ground waters, were selected to bracket the measured Br:Cl ratios from highway-deicing salts used in northeastern Ohio (D.O. Whittemore, Kansas Geological Survey, oral commun., 1989). Zone D represents waters that are either a mixture of local ground water with oilfield brine and salt-solution brine or other local natural-formation waters.

Waters from most of the wells sampled in northern Portage County plot within zone A and represent unmixed fresh ground waters. The waters from samples collected at wells PO-38 and PO-39 plot within zone B, which represents a mixture of local ground waters and oilfield and (or) gasfield brine. The chloride concentration in three of the four samples slightly exceeds the USEPA's SMCL for chloride (U.S. Environmental Protection Agency, 1989b). These wells (PO-38 and PO-39) are located near brine-injection well SWIW-2 (fig. 1).

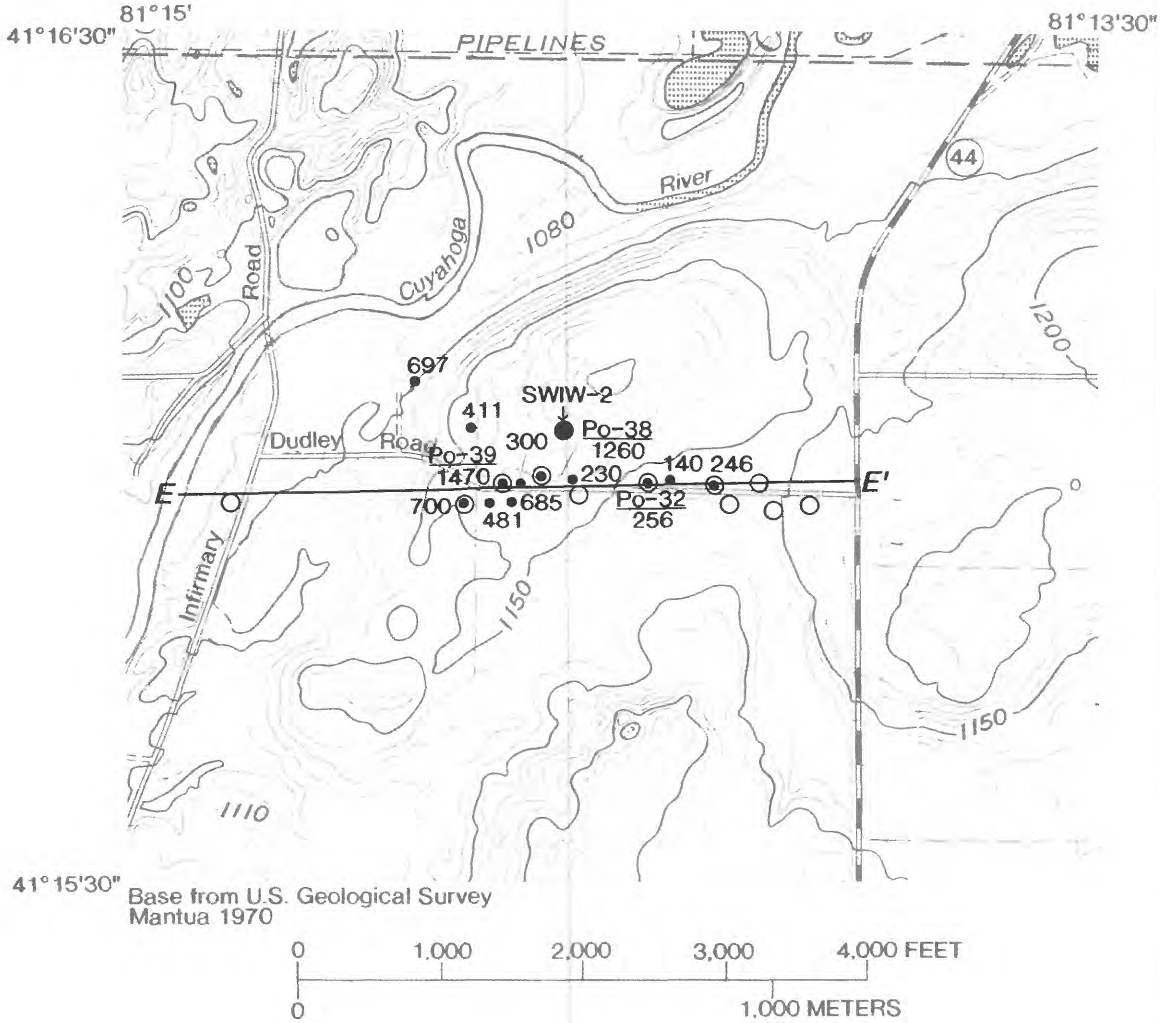
The waters from wells PO-110, PO-27, PO-31, PO-102, PO-109, and PO-21 plot within zone C, which represents a mixture of local ground water and salt-solution brine. Wells PO-109 and PO-21 have chloride concentrations that exceed the SMCL for chloride. Well PO-21 is located across the street from a storage pile of highway-deicing salt.

Well PO-41 plots within zone D, which indicates that its water is a three-component mixture of local ground water, oilfield and (or) gasfield brine, and salt-solution brine, or that it has a component of other natural-formation waters, such as from the upwelling of waters from the underlying shales or sandstones. Well PO-41 is located near SWIW-3 (fig. 1), which was used for annular disposal of brine before it was converted to a conventional brine-injection well. Well PO-41 produces water from glacial deposits in a buried valley near the outcrop of the underlying shales of the Cuyahoga Group and plots within the zone of mixing of fresh ground water and Cuyahoga Group waters on a mixing diagram constructed by Knuth and others (1990).

Oil, dissolved organic substances, and dissolved gases are common in oilfield brine (Reid and others, 1974). Gas chromatograph/flame-ionization detector analysis can be used to screen samples for the presence of organic substances. Use of the flame-ionization detector confirms the presence of organic substances. Sites where substances have been detected with a flame-ionization detector can then be reanalyzed with a mass spectrometer to identify and measure concentrations of individual organic substances.

Water from wells where high specific conductance was measured (PO-38, PO-39, PO-41, and PO-110), water from PO-109 (reported to contain elevated concentrations of dissolved solids), and water from wells that produce (unaffected) fresh ground water (PO-23 and PO-32) were analyzed by gas chromatography with a flame-ionization detector. No peaks great enough to be identified with a mass spectrometer were detected in water from any well except well PO-38. This well is affected by oilfield and gasfield brine (fig. 15).

Wells PO-38 and PO-39 are the only domestic wells near a brine-injection well (SWIW-2; fig. 1) that were shown to be affected by oilfield and gasfield brine. These wells produced waters with specific conductances of 1,260 and 1,470 µS/cm, respectively, in August 1987 (fig. 16). Specific conductances of water from each well within one-quarter-mile of SWIW-2 (measured in August 1987) are plotted in figure 16. Drillers' logs are not available for most of these domestic wells; therefore, the aquifer or aquifers represented by the specific-conductance values is (are) not known. Specific conductances of water from wells west of SWIW-2 generally are higher than specific conductances of water from wells east of SWIW-2 (fig. 16). Regional ground-water flow is generally east to west in this part of Portage County (figs. 7 and 8).



EXPLANATION

E——*E'* TRACE OF GEOLOGIC SECTION--Shown in figure 17

—1150— LINE OF EQUAL ALTITUDE OF LAND SURFACE--Interval 10 feet

• Po-32 / 256 OBSERVATION WELL--Upper number is local well number where available. Lower number is specific conductance, in microsiemens per centimeter at 25 degrees Celsius, where available

○ WELL USED IN CONSTRUCTION OF GEOLOGIC SECTION

SWIW-2 BRINE-INJECTION WELL AND NUMBER

Figure 16.--Specific conductance of ground water along Dudley Road, Portage County, Ohio and location of wells used to construct geologic section *E–E'* (section is shown in fig. 17).

Locally, ground water in the upper sandstone aquifer southwest of SWIW-2 is believed to be downgradient of SWIW-2 because the shape of the water-level surface in the surficial aquifers is a subdued reflection of the topography, and ground water generally flows perpendicular to lines of equal water-level altitude (fig. 16). Wells PO-38 and PO-39 produce some or all of their water from the surficial aquifer immediately southwest of SWIW-2 (figs. 16 and 17).

The well located between PO-38 and PO-39 (fig. 16) produced water with a specific-conductance of 300 μS/cm (August 1987). Although no driller's log was available for this well, the homeowner reports that the well is deeper than the neighboring wells. The well between PO-38 and PO-39 is thought to produce water strictly from the lower sandstone and conglomerate aquifer. The overlying shale unit has been shown to impede the flow of ground water between the upper sandstone aquifer and the lower sandstone and conglomerate aquifer. This is one explanation for the differences in chemistry observed between waters produced from PO-38 and PO-39 and water produced from the well between them.

The elevated specific conductance of water from the surficial aquifer immediately downgradient of SWIW-2 as compared with water from the lower sandstone and conglomerate aquifer at the same location and from all of the aquifers in a general upgradient direction is consistent with a surface source of brine contamination. Possible sources of contamination include leakage of brine from the wellhead, pump, transport pipes, tank batteries, and the concrete vault used to collect spills during the unloading of brine trucks. Spills directly onto the ground surface and burial of well cuttings are also possible sources of the contamination. Collection of additional ground-water samples and water-level data would be necessary to determine the extent of brine contamination near well SWIW-2 and to confirm ground-water-flow paths and the direction of brine flow.

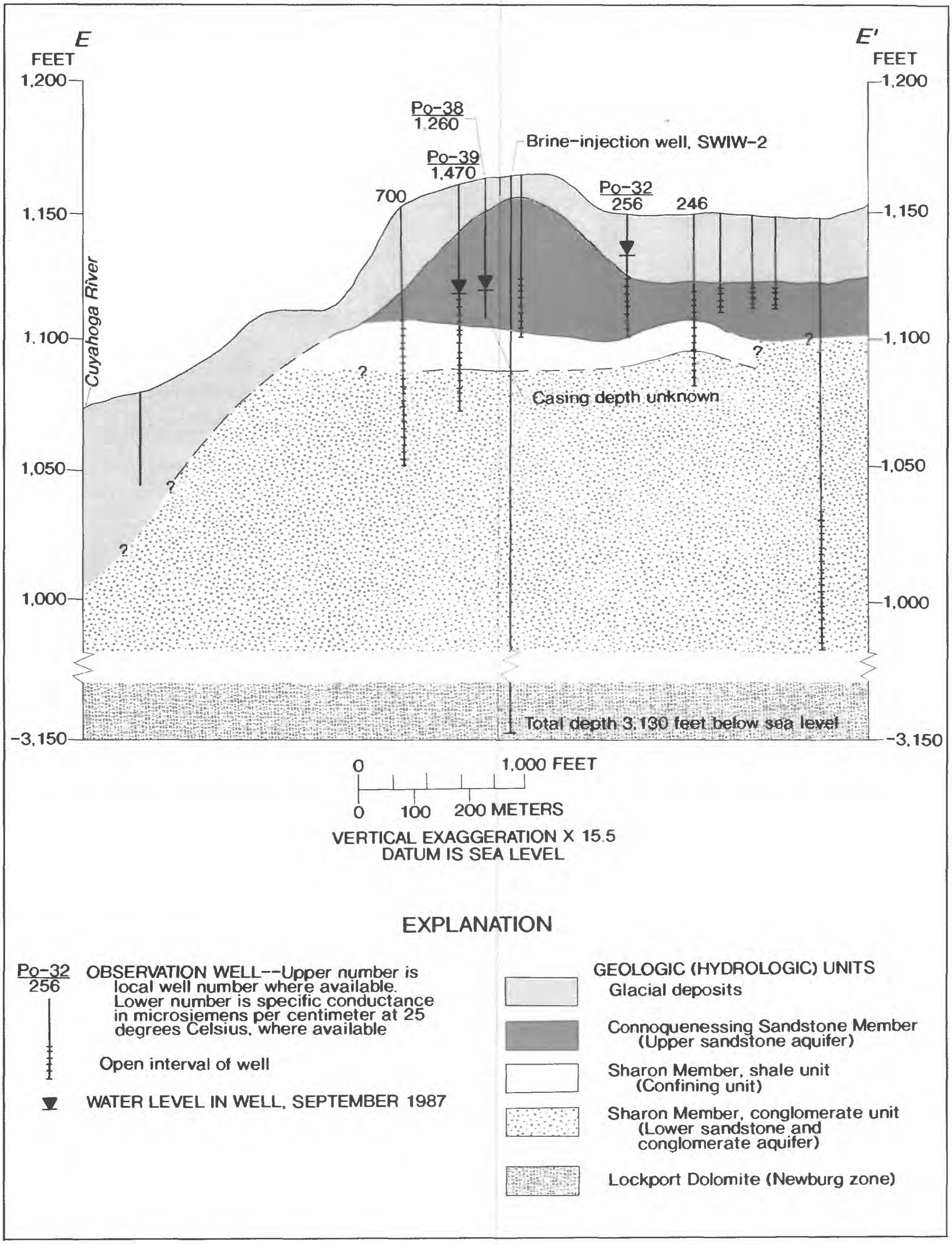


Figure 17.--Geologic section *E-E'* along Dudley Road.

SUMMARY AND CONCLUSIONS

Geohydrology and water quality of the principal freshwater aquifers near oilfield and gasfield brine-injection wells in northern Portage County, Ohio, were evaluated. Since 1975, 13 wells have been used to dispose of more than 4.5 million barrels of brine by injection into deep geologic units known to drillers as the "Clinton" and Newburg zones. (The "Clinton" zone is a drillers' term for the permeable zone at the top of the Silurian Albion Sandstone and is not equivalent to the Clinton Formation recognized by the USGS. The Newburg zone is a drillers' term that refers to any porous interval in the Silurian Lockport Dolomite.) Twelve disposal wells were initially drilled for production of oil and gas and later converted to brine-injection wells, and one well was drilled for the purpose of brine injection. This was done because the rates at which brine can be injected into the Newburg zone, the principal brine-injection zone, do not economically justify drilling a well specifically for disposal.

More than 3,000 ft of interbedded shales, sandstones, carbonates, and evaporites separate the freshwater aquifers and the geologic units used for brine disposal. The top of the uppermost brine-injection zone (Newburg zone) is at least 2,200 ft below sea level. The native fluids present in the "Clinton" and Newburg zones have a total-dissolved-solids concentration greater than 125,000 mg/L; the fluids are slow-moving and hydraulically isolated from the freshwater aquifers. No faults are known in northern Portage County through which injected brine might migrate from brine-injection zones. However, improperly abandoned oil and gas wells in the area could provide avenues of upward migration for brine. Some seismic activity has been noted in Portage County.

An upper sandstone aquifer is separated from a more areally extensive lower sandstone and conglomerate aquifer by shale that acts as a confining unit. Glacial deposits also serve as a source of ground water and comprise the surficial aquifer where the bedrock aquifers are absent or deeply buried. The upper sandstone aquifer is the surficial aquifer where glacial deposits are unsaturated. These two surficial aquifers are hydraulically connected and act as a single unit.

In general, the shape of the water-level surface in the surficial aquifers (upper sandstone aquifer and glacial deposits) corresponds to topography. Ground-water in the upper sandstone aquifer generally flows radially away from topographically high recharge areas into glacial deposits in the buried valleys. Much of the ground water in the surficial aquifers discharges into the Cuyahoga River. The shape of the water-level surface in the lower sandstone and conglomerate aquifer is influenced less by topography than is the water-level surface in the surficial aquifers. Most ground water in the lower sandstone and conglomerate aquifer flows toward discharge areas near the Cuyahoga River or toward Eagle Creek.

The Cuyahoga River gained 15.8 ft^3/s of water from the aquifers between the northern edge of Portage County and State Route 303 in June 1988. Ground water did not discharge into the downstream end of Lake Rockwell during most of the period from October 1987 through September 1988 but may have discharged into the upstream end.

Sampling for detailed analysis of water chemistry provided data on median concentrations of major cations and anions in each of the three principal freshwater aquifers. In addition, median concentrations of potassium and bromide (constituents normally found in oilfield and gasfield brine) were determined for each of the aquifers. Water-quality data indicate that most ground waters in northern Portage County are a calcium bicarbonate type.

Results of a specific-conductance reconnaissance survey of the aquifers near the 13 brine-injection wells and along the Cuyahoga River indicate that widespread contamination has not occurred in northern Portage County because of brine injection. Water chemistry shows that four wells produce waters with chloride concentrations greater than 250 mg/L--the USEPA's SMCL for chloride in drinking water.

A three-component mixing diagram of fresh ground waters, oilfield and gasfield brine, and salt-solution brine (such as derived from diluted highway-deicing salt), constructed on the basis of Br:Cl ratios plotted as a function of chloride concentrations, was used to differentiate between the sources of elevated chloride concentrations in these four wells. Water from two of the wells plotted in the zone of mixing between fresh ground water and salt-solution brine, whereas water from the additional two wells plotted in the zone of mixing between fresh ground waters and oilfield and gasfield brine. Water from a fifth well had a chloride concentration of 230 mg/L and plotted in the zone that indicates (1) a three-component mixture of fresh ground water, oilfield and (or) gasfield brine, and salt-solution brine, or (2) other natural-formation waters of unknown origin.

The two wells that plotted in the zone of mixing of fresh ground water and oilfield and gasfield brine produce some or all of their water from the surficial aquifer immediately downgradient from brine-injection well SWIW-2. Because water produced by these two wells had higher specific conductances than water produced from the lower sandstone and conglomerate aquifer at the same location and water produced from all of the aquifers in a general upgradient direction, the brine affecting these waters probably is from a shallow source near SWIW-2. Possible sources of the brine include leakage from the injection facilities, surface spills, and buried well cuttings.

Collection of additional ground-water samples and water-level data would be necessary to determine the extent of brine contamination near SWIW-2 and to confirm ground-water-flow paths and the direction of brine flow.

REFERENCES CITED

Breen, K.J., Angelo, C.G., Masters, R.W., and Sedam, A.C., 1984, Chemical and isotopic characteristics of brines from three oil- and gas-producing sandstones in eastern Ohio, with applications to the geochemical tracing of brine sources: U.S. Geological Survey Water-Resources Investigations Report 84-4314, 58 p.

Clifford, M.J., 1975, Subsurface liquid-waste injection in Ohio: Ohio Geological Survey Information Circular 43, 27 p.

Eberle, Michael, and McClure, J.A., 1984, Water use in Ohio, 1980: U.S. Geological Survey Water-Resources Investigations Report 84-4024, 34 p.

Eberts, S.M., Bair, E.S., and deRoche, J.T., 1990, Variations in ground-water quality and simulation of regional ground-water flow and increased ground-water development, Geauga County, Ohio: U.S. Geological Survey Water-Resources Investigations Report 90-4026, 117 p.

Elmer E. Templeton and Associates, Inc., 1980, Environmentally acceptable disposal of salt brines produced with oil and gas, a report for the Ohio Water Development Authority: Marietta, Ohio, 85 p.

Fishman, M.J., and Friedman, L.C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Open-File Report 85-495, 709 p.

Gray, J.D., 1981, Structure on the Berea Sandstone in eastern Ohio, Portage County: Ohio Geological Survey Open-File Map 151, 1 sheet, scale 1:62,500.

Hansen, M.C., 1986, The January 1986 northeastern Ohio earthquake: Ohio Geology, Summer 1986, 5 p.

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

Knuth, M., Jackson, J.L., and Whittemore, D.O., 1990, An integrated approach to identifying the salinity source contaminating a ground-water supply: Ground Water, v. 28, no. 3, p. 202-214.

Lloyd, J.W., and Heathcote, J.A., 1985, Natural inorganic hydrochemistry in relation to groundwater, an introduction: Oxford, Clarendon Press, p. 143.

Lloyd, O.B., Jr., and Reid, M.S., 1986, Evaluation of liquid waste-storage potential based on porosity distribution in the Paleozoic rocks in central and southern parts of the Appalachian basin: U.S. Geological Survey Open-File Report 86-0478, 50 p.

McCormac, M.P., 1988, Summary of Ohio oil and gas developments in 1987: Ohio Department of Natural Resources, Division of Oil and Gas, 50 p.

----- 1989, 1988 Ohio oil and gas developments: Ohio Department of Natural Resources, Division of Oil and Gas, 56 p.

Multer, H.G., 1963, Geology of the Silurian producing zones in the Moreland oil pool, Wayne County, northeastern Ohio: Ohio Geological Survey Report of Investigations 46, 48 p.

Norris, S.E., 1978, Hydrologic environment of the Silurian salt deposits in parts of Michigan, Ohio, and New York: U.S. Geological Survey Open-File Report 78-684, 31 p.

Northeast Ohio Brine Disposal Task Force, 1984, Brine disposal in northeast Ohio, a report on the problem and recommendations for action: Cleveland, Ohio, 21 p.

Ohio Environmental Council, 1983, Brine disposal in Ohio, an overview: Columbus, Ohio, 27 p.

Ohio House of Representatives, 1985, Provisions of Ohio's new brine disposal law: House Bill 501, 12 p.

Reid, G.W., Streebin, L.E., Canter, L.W., and Smith, J.R., 1974, Brine disposal treatment practices relating to the oil production industry: U.S. Environmental Protection Agency, EPA-660/2-74-037, 275 p.

Risser, M.L., 1983a, Top-of-rock map of Portage County, Ohio: Ohio Geological Survey Open-File Map 204, 1 sheet, scale 1:62,500.

----- 1983b, Drift thickness map of Portage County, Ohio: Ohio Geological Survey Open-File Map 205, 1 sheet, scale 1:62,500.

Serna, C.J., 1986, An investigation of groundwater contamination due to oil field brines in Portage County, Ohio: Oxford, Ohio, Miami University, unpublished Master's thesis, 98 p.

Shindel, H.L., and others, 1988-89, Water resources data for Ohio, water years 1987-88--volume 2: U.S. Geological Survey Water Data Reports OH-87-2 and OH-88-2 (published annually).

Stith, D.A., 1979, Brine analyses, 1972-1974: Ohio Geological Survey Open-File Report 79-1.

U.S. Environmental Protection Agency, 1989b, Proposed rule, National primary and secondary drinking-water regulations: (sections 141.50, 141.51, 141.61, and 141.62 of part 141 and 143.3 of part 143) U.S. Federal Register, v. 54, no. 97, May 22, 1989, p. 22,062-22,160.

----- 1988a, Maximum contaminant levels (subpart B of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 530-533.

----- 1988b, Maximum contaminant level goals (subpart F of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 585-586.

----- 1988c, National revised primary drinking-water regulations: Maximum contaminant levels (subpart G of part 141, National interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 586-587.

----- 1988d, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1988, p. 608.

Whittemore, D.O., 1984, Geochemical identification of salinity sources in R.H. French, Salinity in watercourses and reservoirs: Boston, Massachusetts, Ann Arbor Science, Butterworth Publishers, p. 505-514.

Whittemore, D.O., 1988, Bromide as a tracer in ground-water studies, geochemistry and analytical determination in Ground Water Geochemistry Conference, Proceedings: Denver, Colorado, Association of Ground Water Scientists and Engineers, p. 339-359.

Winslow, J.D., and White, G.W., 1966, Geology and ground-water resources of Portage County, Ohio: U.S. Geological Survey Professional Paper 511, 80 p.

Table 3.--Records of selected wells in northern Portage County, Ohio

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-21	41°14'18"	081°14'12"	Upper sandstone aquifer	1,200	09-10-87 04-12-88	31.45 28.81
PO-22	41°14'04"	081°13'55"	Upper sandstone aquifer	1,225	09-10-87 04-12-88	29.15 18.79
PO-23	41°13'19"	081°14'14"	Upper sandstone aquifer	1,180	09-11-87 04-12-88	24.25 22.51
PO-24	41°12'58"	081°16'53"	Lower sandstone and conglomerate aquifer	1,140	09-11-87 04-12-88	54.20 53.63
PO-25	41°13'11"	081°16'16"	Lower sandstone and conglomerate aquifer	1,130	09-11-87 04-12-88	42.10 43.90
PO-26	41°10'41"	081°17'21"	Glacial deposits	1,080	09-14-87 04-11-88	14.84 14.56
PO-27	41°10'40"	081°17'28"	Glacial deposits	1,075	09-14-87 04-11-88	2.03 0.63
PO-28	41°10'49"	081°17'45"	Lower sandstone and conglomerate aquifer	1,110	09-14-87 04-11-88	51.70 51.43
PO-29	41°11'26"	081°17'59"	Glacial deposits	1,120	09-15-87 04-11-88	62.08 60.47
PO-30	41°15'09"	081°12'33"	Upper sandstone aquifer	1,220	09-10-87 04-13-88	27.66 26.20
PO-31	41°15'08"	081°12'08"	Upper sandstone aquifer	1,210	09-10-87 04-12-88	31.29 26.98
PO-32	41°15'58"	081°14'10"	Upper sandstone aquifer	1,150	09-10-87 04-12-88	14.08 11.56

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-34	41°15'17"	081°11'42"	Lower sandstone and conglomerate aquifer	1,180	09-11-87 04-13-88	71.06 70.63
PO-35	41°15'50"	081°14'49"	Glacial deposits	1,105	09-11-87 04-12-88	14.50 11.40
PO-36	41°15'41"	081°17'13"	Glacial deposits	1,110	09-11-87	16.04
PO-37	41°15'12"	081°12'05"	Upper sandstone aquifer	1,205	09-15-87 04-13-88	26.72 21.36
PO-40	41°15'40"	081°15'01"	Lower sandstone and conglomerate aquifer	1,095	09-15-87 04-12-88	12.09 9.49
PO-41	41°15'39"	081°16'46"	Glacial deposits	1,090	09-15-87 04-12-88	17.96 15.57
PO-42	41°16'35"	081°18'55"	Glacial deposits	1,160	09-16-87	45.63
PO-43	41°16'31"	081°18'15"	Glacial deposits	1,200	09-16-87 04-12-88	96.98 89.38
PO-44	41°15'39"	081°18'08"	Glacial deposits	1,165	09-16-87 04-12-88	60.70 72.82
PO-45	41°14'32"	081°20'01"	Lower sandstone and conglomerate aquifer	1,155	09-16-87 04-15-88	76.43 76.99
PO-46	41°14'05"	081°19'22"	Lower sandstone and conglomerate aquifer	1,145	09-16-87 04-13-88	52.40 47.77

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-47	41°14'41"	081°19'34"	Glacial deposits	1,150	09-16-87 04-13-88	74.08 74.57
PO-50	41°12'43"	081°12'11"	Glacial deposits	1,150	09-14-87 04-11-88	43.40 42.49
PO-51	41°12'42"	081°12'06"	Glacial deposits	1,155	09-14-87 04-11-88	52.05 55.01
PO-52	41°12'27"	081°11'57"	Glacial deposits	1,150	09-14-87 04-11-88	38.88 38.02
PO-53	41°14'17"	081°11'41"	Upper sandstone aquifer	1,165	09-14-87 04-13-88	37.02 36.38
PO-54	41°14'18"	081°13'13"	Glacial deposits	1,200	09-15-87 04-14-88	6.72 2.85
PO-55	41°17'01"	081°15'26"	Upper sandstone aquifer	1,200	09-15-87 04-13-88	29.96 27.05
PO-56	41°17'29"	081°12'46"	Lower sandstone and conglomerate aquifer	1,110	09-15-87 04-13-88	22.05 22.85
PO-57	41°20'33"	081°12'49"	Glacial deposits	1,165	09-15-87 04-13-88	13.63 10.41
PO-58	41°20'33"	081°12'26"	Lower sandstone and conglomerate aquifer	1,150	09-15-87 04-13-88	23.50 21.86
PO-59	41°17'41"	081°13'24"	Upper sandstone aquifer	1,245	09-15-87 05-11-88	31.19 30.49

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-60	41°14'05"	081°04'14"	Lower sandstone and conglomerate aquifer	1,010	09-16-87 04-14-88	10.54 9.83
PO-61	41°14'23"	081°05'08"	Lower sandstone and conglomerate aquifer	1,105	09-16-87 04-14-88	77.02 77.87
PO-63	41°15'36"	081°03'28"	Lower sandstone and conglomerate aquifer	950	09-16-87 04-14-88	10.60 8.94
PO-64	41°15'28"	081°02'44"	Lower sandstone and conglomerate aquifer	940	09-16-87 04-14-88	10.62 9.58
PO-65	41°15'15"	081°01'32"	Lower sandstone and conglomerate aquifer	940	09-16-87 04-14-88	14.40 13.93
PO-66	41°15'34"	081°00'33"	Lower sandstone and conglomerate aquifer	930	09-16-87 04-14-88	11.52 9.07
PO-67	41°14'52"	081°02'33"	Lower sandstone and conglomerate aquifer	960	09-16-87 04-14-88	16.20 13.77
PO-68	41°14'09"	081°04'44"	Lower sandstone and conglomerate aquifer	1,105	09-16-87 04-14-88	88.84 91.92
PO-69	41°14'50"	081°17'41"	Lower sandstone and conglomerate aquifer	1,100	09-16-87 04-12-88	9.29 8.78
PO-70	41°11'19"	081°16'51"	Lower sandstone and conglomerate aquifer	1,060	09-15-87 04-11-88	1.19 0.95
PO-71	41°11'25"	081°17'08"	Glacial deposits	1,070	09-15-87 04-11-88	9.41 8.68
PO-72	41°12'05"	081°17'07"	Lower sandstone and conglomerate aquifer	1,090	09-15-87 04-11-88	9.41 9.54

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-73	41°11'55"	081°11'57"	Lower sandstone and conglomerate aquifer	1,125	09-15-87 04-11-88	33.80 32.62
PO-74	41°14'18"	081°14'38"	Lower sandstone and conglomerate aquifer	1,120	09-15-87 04-12-88	24.52 23.85
PO-75	41°14'35"	081°15'18"	Glacial deposits	1,100	09-15-87 04-14-88	18.20 17.45
PO-76	41°12'09"	081°16'59"	Glacial deposits	1,105	09-16-87 04-11-88	27.26 27.26
PO-77	41°13'17"	081°17'56"	Glacial deposits	1,075	09-16-87 04-12-88	11.66 11.23
PO-78	41°13'15"	081°15'51"	Upper sandstone aquifer	1,190	09-16-87 04-12-88	24.41 19.90
PO-79	41°13'25"	081°15'44"	Upper sandstone aquifer	1,200	09-16-87 04-12-88	23.88 18.70
PO-80	41°13'27"	081°16'49"	Glacial deposits	1,095	09-16-87 04-12-88	10.67 9.89
PO-81	41°13'44"	081°17'55"	Lower sandstone and conglomerate aquifer	1,080	09-16-87 04-12-88	8.90 8.15
PO-82	41°14'27"	081°17'21"	Lower sandstone and conglomerate aquifer	1,110	09-16-87	20.93
PO-83	41°14'48"	081°17'21"	Lower sandstone and conglomerate aquifer	1,110	09-16-87 04-12-88	22.65 23.01
PO-85	41°18'40"	081°05'22"	Lower sandstone and conglomerate aquifer	1,095	09-17-87 04-14-88	45.72 43.88

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-86	41°18'57"	081°05'43"	Glacial deposits	1,080	09-17-87	30.92
					04-14-88	30.20
PO-88	41°20'31"	081°05'17"	Lower sandstone and conglomerate aquifer	1,170	09-17-87	66.38
					04-14-88	63.76
PO-89	41°19'56"	081°06'44"	Glacial deposits	1,120	09-17-87	27.57
					04-13-88	26.46
PO-90	41°12'21"	081°20'51"	Glacial deposits	1,130	09-16-87	70.96
					04-11-88	71.51
PO-91	41°18'51"	081°04'44"	Lower sandstone and conglomerate aquifer	1,160	09-17-87	74.20
					04-14-88	74.73
PO-92	41°14'18"	081°12'21"	Upper sandstone aquifer	1,205	09-23-87	17.10
					04-13-88	11.23
PO-93	41°17'09"	081°14'08"	Upper sandstone aquifer	1,195	09-22-87	15.04
					04-13-88	14.32
PO-94	41°17'43"	081°13'54"	Upper sandstone aquifer	1,290	09-22-87	55.07
					04-13-88	57.92
PO-95	41°18'24"	081°14'00"	Upper sandstone aquifer	1,240	09-22-87	30.72
					04-13-88	28.41
PO-96	41°18'58"	081°12'26"	Upper sandstone aquifer	1,230	09-22-87	12.42
					04-13-88	9.20
PO-97	41°19'54"	081°12'06"	Lower sandstone and conglomerate aquifer	1,185	09-22-87	51.25
					04-13-88	52.27
PO-98	41°19'39"	081°11'36"	Lower sandstone and conglomerate aquifer	1,150	09-22-87	42.03
					04-13-88	40.05

Table 3.--Records of selected wells in northern Portage County, Ohio--Continued

Well number	Latitude	Longitude	Aquifer	Altitude of land surface (feet)	Date of water-level measurement	Water level, depth below land surface (feet)
PO-99	41°17'14"	081°11'35"	Lower sandstone and conglomerate aquifer	1,130	09-23-87 04-13-88	32.29 31.18
PO-100	41°17'52"	081°12'08"	Glacial deposits	1,100	09-23-87	16.00
PO-101	41°18'34"	081°11'28"	Glacial deposits	1,120	09-23-87 04-13-88	27.48 26.68
PO-102	41°18'37"	081°10'20"	Glacial deposits	1,230	09-23-87 04-13-88	22.90 19.22
PO-103	41°19'56"	081°09'41"	Lower sandstone and conglomerate aquifer	1,145	09-23-87 04-14-88	28.09 25.88
PO-104	41°20'34"	081°09'19"	Lower sandstone and conglomerate aquifer	1,120	09-23-87 04-13-88	20.07 14.12
PO-105	41°20'41"	081°10'16"	Lower sandstone and conglomerate aquifer	1,110	09-23-87 04-13-88	9.89 8.89
PO-106	41°20'40"	081°10'10"	Glacial deposits	1,110	09-23-87 04-13-88	12.17 12.17

Table 5.--Water-quality records for ground water in northern Portage County, Ohio

[mm, millimeters; °C, degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; μS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available.]

Date	Time	Water level, depth below land surface (feet)	Depth of well, total (feet)	Altitude of land-surface datum (feet above sea level)	Barometric pressure (mm of Hg)	Specific conductance (μS/cm)	pH	Temperature, air (°C)	Temperature, water (°C)	Oxygen, dissolved (mg/L)
Glacial Deposits										
411038081190201 PO-20 USGS SHALLOW PIEZOMETER NR KENT OH (LAT 41 10 38N LONG 081 19 02W)										
April 13, 1988	1700	3.45	16	1,055	733	478	7.2	20.0	8.5	0
411040081172800 PO-27 HILGERT NR RAVENNA OH (LAT 41 10 40N LONG 081 17 28W)										
April 28, 1988	1700	1.00	42	1,075	734	599	7.3	6.0	12.0	0
411327081164900 PO-80 DANTONE NR RAVENNA OH (LAT 41 13 27N LONG 081 16 49W)										
April 20, 1988	1415	8.94	58	1,095	732	561	7.3	10.0	11.0	0
411435081151800 PO-75 LAING NR SHALERSVILLE OH (LAT 41 14 35N LONG 081 15 18W)										
April 15, 1988	0930	17.41	38	1,100	735	525	7.3	4.0	11.5	0
411539081164600 PO-41 HARMON NR MANTUA OH (LAT 41 15 39N LONG 081 16 46W)										
April 20, 1988	1030	16.44	60	1,090	734	1,140	7.3	4.0	11.0	0
411539081180800 PO-44 MILLER NR STREETSBORO OH (LAT 41 15 39N LONG 081 18 08W)										
April 29, 1988	1000	64.06	118	1,165	735	1,130	7.1	6.0	11.0	0
411631081181500 PO-43 HIENTON NR MANTUA OH (LAT 41 16 31N LONG 081 18 15W)										
April 18, 1988	1630	93.60	253	1,200	725	557	7.6	5.0	11.0	0
411837081102000 PO-102 PHILLIPS NR HIRAM OH (LAT 41 18 37N LONG 081 10 20W)										
April 20, 1988	1200	19.35	47	1,230	731	950	7.0	8.0	11.0	0

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Time	Water level, depth below land surface (feet)	Depth of well, total (feet)	Elevation of land-surface datum (feet above sea level)	Barometric pressure (mm of Hg)	Specific conductance (µS/cm)	pH	Temperature, air (°C)	Temperature, water (°C)	Oxygen, dissolved (mg/L)
Upper Sandstone Aquifer										
411239081151401 PO-108 USGS SHALLOW WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)										
May 12, 1988	1030	33.24	71	1,210	739	579	7.5	18.0	14.5	--
411319081141400 PO-23 MELLINGER NR RAVENNA OH (LAT 41 13 19N LONG 081 14 14W)										
May 10, 1988	1730	21.55	88	1,180	731	404	7.5	20.0	11.5	0
411325081154400 PO-79 WILLIAMS NR MANTUA OH (LAT 41 13 25N LONG 081 15 44W)										
April 12, 1988	1300	18.57	71	1,200	732	486	7.4	19.0	12.0	0.3
411418081141200 PO-21 HILLSIDE CEM NR SHALERSVILLE OH (LAT 41 14 18N LONG 081 14 12W)										
April 27, 1988	1400	30.64	73	1,200	728	2,030	7.3	15.0	11.0	5.5
411508081120800 PO-31 KUBE NR MANTUA OH (LAT 41 15 08N LONG 081 12 08W)										
April 12, 1988	1000	18.98	63	1,210	732	625	7.0	12.0	11.0	0
411558081141000 PO-32 FORREST NR MANTUA OH (LAT 41 15 58N LONG 081 14 10W)										
April 13, 1988	1430	11.61	50	1,150	733	245	5.8	19.5	9.0	9.4
411559081142100 PO-38 HUNTER NR MANTUA OH (LAT 41 15 59N LONG 081 14 21W)										
April 11, 1988	1500	42.69	--	1,160	734	833	6.0	18.5	12.0	5.0
April 28, 1988	1400	39.29	--	1,160	730	1,120	5.7	8.0	12.0	9.5
411741081132400 PO-59 HAMMEL NR MANTUA OH (LAT 41 17 41N LONG 081 13 24W)										
May 11, 1988	1000	30.49	46	1,245	737	311	6.6	12.0	11.5	0
411824081140000 PO-95 CHIANCONE NR MANTUA OH (LAT 41 18 24N LONG 081 14 00W)										
May 11, 1988	1400	31.81	81	1,240	737	405	7.0	14.0	11.5	1.7

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Time	Water level, depth below land surface (feet)	Depth of well, total (feet)	Elevation of land-surface datum (feet above sea level)	Barometric pressure (mm of Hg)	Specific conductance (µS/cm)	pH	Temperature, air (°C)	Temperature, water (°C)	Oxygen, dissolved (mg/L)
Lower Sandstone and Conglomerate Aquifer										
411239081151400 PO-107 USGS DEEP WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)										
April 14, 1988	1115	91.01	181	1,210	728	528	7.2	13.5	11.0	0
411311081161600 PO-25 COOLEY NR RAVENNA OH (LAT 41 13 11N LONG 081 16 16W)										
April 12, 1988	1600	41.03	82	1,130	733	544	7.6	19.0	11.0	0
411404081053900 PO-110 LONG NR WINDHAM OH (LAT 41 14 04N LONG 081 05 39W)										
April 21, 1988	1730	37.52	--	1,080	734	757	7.0	12.5	11.5	5.2
411528081024400 PO-64 ISLER NR WINDHAM OH (LAT 41 15 28N LONG 081 02 44W)										
April 19, 1988	1415	9.70	50	940	736	334	7.0	4.0	11.5	0
411954081120600 PO-97 HERBOLD NR MANTUA OH (LAT 41 19 54N LONG 081 12 06W)										
April 14, 1988	1600	51.30	98	1,185	729	395	7.6	15.5	11.0	0
412031081051700 PO-88 KLER NR GARRETTSVILLE OH (LAT 41 20 31N LONG 081 05 17W)										
April 19, 1988	1600	63.78	97	1,170	729	344	6.2	5.0	11.5	0
Multiple Aquifers										
411559081142400 PO-39 MAYLE NR MANTUA OH (LAT 41 15 59N LONG 081 14 24W)										
April 13, 1988	1030	41.57	90	1,160	734	924	6.2	22.5	11.5	8.8
28, 1988	1000	41.96	90	1,160	730	1,220	5.8	1.0	11.5	9.4
412019081030100 PO-109 HRACH NR GARRETTSVILLE OH (LAT 41 20 19N LONG 081 03 01W)										
April 21, 1988	1400	9.20	--	1,130	731	1,130	5.0	19.0	10.0	7.9

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Glacial Deposits										
411038081190201 PO-20 USGS SHALLOW PIEZOMETER NR KENT OH (LAT 41 10 38N LONG 081 19 02W)										
April 13, 1988	230	65	69	13	14	1.7	196	161	55	29
411040081172800 PO-27 HILGERT NR RAVENNA OH (LAT 41 10 40N LONG 081 17 28W)										
April 28, 1988	270	130	78	17	17	0.90	171	140	73	59
411327081164900 PO-80 DANTONE NR RAVENNA OH (LAT 41 13 27N LONG 081 16 49W)										
April 20, 1988	290	100	84	20	4.3	1.0	232	190	96	17
411435081151800 PO-75 LAING NR SHALERSVILLE OH (LAT 41 14 35N LONG 081 15 18W)										
April 15, 1988	270	79	78	18	10	1.6	232	190	65	20
411539081164600 PO-41 HARMON NR MANTUA OH (LAT 41 15 39N LONG 081 16 46W)										
April 20, 1988	350	200	98	25	83	1.4	178	146	75	230
411539081180800 PO-44 MILLER NR STREETSBORO OH (LAT 41 15 39N LONG 081 18 08W)										
April 29, 1988	660	320	150	69	16	2.0	410	336	350	1.8
411631081181500 PO-43 HIENTON NR MANTUA OH (LAT 41 16 31N LONG 081 18 15W)										
April 18, 1988	300	23	81	24	6.3	1.2	341	279	48	0.7
411837081102000 PO-102 PHILLIPS NR HIRAM OH (LAT 41 18 37N LONG 081 10 20W)										
April 20, 1988	440	190	110	40	27	1.4	301	246	110	110

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Upper Sandstone Aquifer										
411239081151401 PO-108 USGS SHALLOW WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)										
May 12, 1988	310	35	83	24	8.1	2.0	332	272	52	1.1
411319081141400 PO-23 MELLINGER NR RAVENNA OH (LAT 41 13 19N LONG 081 14 14W)										
May 10, 1988	210	20	58	16	3.8	3.2	233	191	24	9.6
411325081154400 PO-79 WILLIAMS NR MANTUA OH (LAT 41 13 25N LONG 081 15 44W)										
April 12, 1988	260	72	73	18	8.2	0.90	225	184	63	15
411418081141200 PO-21 HILLSIDE CEM NR SHALERSVILLE OH (LAT 41 14 18N LONG 081 14 12W)										
April 27, 1988	490	280	140	35	190	1.8	261	214	80	420
411508081120800 PO-31 KUBE NR MANTUA OH (LAT 41 15 08N LONG 081 12 08W)										
April 12, 1988	310	120	84	25	8.3	1.3	231	189	49	59
411558081141000 PO-32 FORREST NR MANTUA OH (LAT 41 15 58N LONG 081 14 10W)										
April 13, 1988	99	92	23	10	4.2	2.5	9	7	36	9.1
411559081142100 PO-38 HUNTER NR MANTUA OH (LAT 41 15 59N LONG 081 14 21W)										
April 11, 1988	290	270	74	26	75	2.0	28	23	61	280
28, 1988	310	260	73	30	72	1.8	51	42	58	290
411741081132400 PO-59 HAMMEL NR MANTUA OH (LAT 41 17 41N LONG 081 13 24W)										
May 11, 1988	150	37	40	11	3.0	0.90	132	108	43	8.2
411824081140000 PO-95 CHIANCONE NR MANTUA OH (LAT 41 18 24N LONG 081 14 00W)										
May 11, 1988	200	37	58	14	5.3	0.90	203	166	26	18

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Lower Sandstone and Conglomerate Aquifer										
411239081151400 PO-107 USGS DEEP WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)										
April 14, 1988	300	7	82	22	6.9	1.8	336	275	39	2.1
411311081161600 PO-25 COOLEY NR RAVENNA OH (LAT 41 13 11N LONG 081 16 16W)										
April 12, 1988	290	91	83	19	8.7	1.1	238	195	70	29
411404081053900 PO-110 LONG NR WINDHAM OH (LAT 41 14 04N LONG 081 05 39W)										
April 21, 1988	380	140	100	32	16	1.3	298	244	90	46
411528081024400 PO-64 ISLER NR WINDHAM OH (LAT 41 15 28N LONG 081 02 44W)										
April 19, 1988	150	23	42	12	6.4	0.80	161	132	46	6.7
411954081120600 PO-97 HERBOLD NR MANTUA OH (LAT 41 19 54N LONG 081 12 06W)										
April 14, 1988	190	0	49	16	13	4.9	256	210	9.5	4.8
412031081051700 PO-88 KLER NR GARRETTSVILLE OH (LAT 41 20 31N LONG 081 05 17W)										
April 19, 1988	100	11	19	13	7.8	3.5	110	90	90	5.4
Multiple Aquifers										
411559081142400 PO-39 MAYLE NR MANTUA OH (LAT 41 15 59N LONG 081 14 24W)										
April 13, 1988	250	240	66	21	67	2.1	17	14	60	210
28, 1988	320	310	83	27	88	2.5	11	9	66	320
412019081030100 PO-109 HRACH NR GARRETTSVILLE OH (LAT 41 20 19N LONG 081 03 01W)										
April 21, 1988	140	130	39	9.9	170	5.0	10	8	58	310

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, residue at 180 °C (mg/L)	Barium, dissolved (µg/L as Ba)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Carbon, organic, dissolved (mg/L as C)
Glacial Deposits									
411038081190201 PO-20 USGS SHALLOW PIEZOMETER NR KENT OH (LAT 41 10 38N LONG 081 19 02W)									
April 13, 1988	0.1	0.028	5.9	289	27	56	650	130	1.6
411040081172800 PO-27 HILGERT NR RAVENNA OH (LAT 41 10 40N LONG 081 17 28W)									
April 28, 1988	0.2	0.068	14	339	160	740	130	120	--
411327081164900 PO-80 DANTONE NR RAVENNA OH (LAT 41 13 27N LONG 081 16 49W)									
April 20, 1988	0.2	0.043	9.9	351	110	710	120	110	0.5
411435081151800 PO-75 LAING NR SHALERSVILLE OH (LAT 41 14 35N LONG 081 15 18W)									
April 15, 1988	0.2	0.047	11	321	31	10	210	110	0.6
411539081164600 PO-41 HARMON NR MANTUA OH (LAT 41 15 39N LONG 081 16 46W)									
April 20, 1988	0.1	1.3	9.8	660	97	550	96	140	0.5
411539081180800 PO-44 MILLER NR STREETSBORO OH (LAT 41 15 39N LONG 081 18 08W)									
April 29, 1988	0.3	0.036	20	813	15	2,600	180	870	--
411631081181500 PO-43 HIENTON NR MANTUA OH (LAT 41 16 31N LONG 081 18 15W)									
April 18, 1988	0.2	0.021	18	336	65	2,600	240	200	0.5
411837081102000 PO-102 PHILLIPS NR HIRAM OH (LAT 41 18 37N LONG 081 10 20W)									
April 20, 1988	0.2	0.083	11	528	44	1,100	290	170	2.7

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, residue at 180 °C (mg/L)	Barium, dissolved (µg/L as Ba)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Carbon, organic, dissolved (mg/L as C)
Upper Sandstone Aquifer									
411239081151401 PO-108 USGS SHALLOW WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)									
May 12, 1988	0.3	0.012	16	350	44	2,300	680	110	1.6
411319081141400 PO-23 MELLINGER NR RAVENNA OH (LAT 41 13 19N LONG 081 14 14W)									
May 10, 1988	0.4	0.020	13	229	75	820	82	300	0.5
411325081154400 PO-79 WILLIAMS NR MANTUA OH (LAT 41 13 25N LONG 081 15 44W)									
April 12, 1988	0.2	0.024	12	304	15	730	190	76	0.5
411418081141200 PO-21 HILLSIDE CEM NR SHALERSVILLE OH (LAT 41 14 18N LONG 081 14 12W)									
April 27, 1988	0.4	0.11	13	1,100	76	44	16	210	1.1
411508081120800 PO-31 KUBE NR MANTUA OH (LAT 41 15 08N LONG 081 12 08W)									
April 12, 1988	0.3	0.061	11	361	4	7	3	110	0.7
411558081141000 PO-32 FORREST NR MANTUA OH (LAT 41 15 58N LONG 081 14 10W)									
April 13, 1988	0.1	0.010	11	171	43	9	2	160	0.7
411559081142100 PO-38 HUNTER NR MANTUA OH (LAT 41 15 59N LONG 081 14 21W)									
April 11, 1988	0.1	3.0	12	643	34	4,400	2,600	300	0.6
28, 1988	0.1	3.3	12	712	39	5,700	3,900	260	--
411741081132400 PO-59 HAMMEL NR MANTUA OH (LAT 41 17 41N LONG 081 13 24W)									
May 11, 1988	0.3	0.021	13	182	26	6,200	470	54	0.7
411824081140000 PO-95 CHIANCONE NR MANTUA OH (LAT 41 18 24N LONG 081 14 00W)									
May 11, 1988	0.4	0.083	12	233	23	10	20	82	0.5

Table 5.--Water-quality records for ground water in northern Portage County, Ohio--Continued

Date	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, residue at 180 °C (mg/L)	Barium, dissolved (µg/L as Ba)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Carbon, organic, dissolved (mg/L as C)
Lower Sandstone and Conglomerate Aquifer									
411239081151400 PO-107 USGS DEEP WELL NR SHALERSVILLE OH (LAT 41 12 39N LONG 081 15 14W)									
April 14, 1988	0.3	0.026	18	307	110	850	58	200	0.8
411311081161600 PO-25 COOLEY NR RAVENNA OH (LAT 41 13 11N LONG 081 16 16W)									
April 12, 1988	0.2	0.044	14	331	140	550	140	120	0.7
411404081053900 PO-110 LONG NR WINDHAM OH (LAT 41 14 04N LONG 081 05 39W)									
April 21, 1988	0.3	0.051	11	468	59	14	<1	140	0.7
411528081024400 PO-64 ISLER NR WINDHAM OH (LAT 41 15 28N LONG 081 02 44W)									
April 19, 1988	0.1	0.029	13	202	48	4,200	1,000	80	0.8
411954081120600 PO-97 HERBOLD NR MANTUA OH (LAT 41 19 54N LONG 081 12 06W)									
April 14, 1988	0.5	0.032	6.8	208	270	210	18	760	0.6
412031081051700 PO-88 KLER NR GARRETTSVILLE OH (LAT 41 20 31N LONG 081 05 17W)									
April 19, 1988	0.3	0.020	11	187	4	34,000	3,100	32	0.6
Multiple Aquifers									
411559081142400 PO-39 MAYLE NR MANTUA OH (LAT 41 15 59N LONG 081 14 24W)									
April 13, 1988	0.1	2.7	14	562	33	160	180	500	0.7
28, 1988	0.1	3.1	14	715	44	490	280	650	--
412019081030100 PO-109 HRACH NR GARRETTSVILLE OH (LAT 41 20 19N LONG 081 03 01W)									
April 21, 1988	0.2	0.069	9.7	679	32	37	470	130	1.1

☆U.S. Government Printing Office: 1991 — 550-354