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U.S. Department of the Interior,
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Water and Bed-Sediment Quality in the Vicinity of Berlin Lake, Ohio, 2001

Water-Resources Investigations Report 02–4246

U.S. Department of the Interior
U.S. Geological Survey

Photos by Rob Darner, U.S. Geological Survey, 2001

A. USGS scientist prepares to collect a surface-water sample at the Mahoning River below Berlin Dam.
B. View of Berlin Dam from the left bank of the Mahoning River.
C. and D. USGS scientist collects a water sample (to be analyzed for chloride and bromide) at a culvert on the north side of Berlin Lake, then records field notes.

U.S. Department of the Interior
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By Robert A. Darner

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Columbus, Ohio
2002

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CONVERSION FACTORS, DATUMS, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot (ft)	5,280	miles
mile (mi)	1.609	kilometer
foot per mile (ft/mi)	0.1894	meter per kilometer
acre	0.4047	square hectometer
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
acre-foot	1,233	cubic meters
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second (ft^3/s)	28.32	liter
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

°F = 1.8(°C) + 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. Horizontial coordinate information is referenced to the North American Datum of 1983 (NAD83).

Abbreviated water-quality units used in this report: Water volumes and chemical concentrations referred to in water-quality discussions are given in metric units. Volume is given in milliliters (mL). Chemical concentration is given in milligrams per liter (mg/L), micrograms per liter (µg/L), or milliequivalents per liter (meq/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is approximately the same as for concentrations in parts per million. Milliequivalents per liter is the concentration in milligrams per liter divided by the equivalent weight of the ion of interest. Filter paper pore size is given in micrometers (µm). Instantaneous daily load is given in kilograms per day (kg/d).

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

Pore size of filters is given in micrometers (µm).

Other abbreviations used in this report:

Cl:Br	Chloride to Bromide
EWI	Equal-Width-Increment
MCF	Million Cubic Feet
MCL	Maximum Contaminant Level
NPL	National Priorities List
OEPA	Ohio Environmental Protection Agency
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

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Abstract

Berlin Lake, in northeast Ohio, was created by the U.S. Army Corps of Engineers in 1943 and is used primarily for flood control for the upper reaches of the Mahoning River. The area surrounding and under the lake has been tapped for oil and natural gas production. One of the by-products of oil and gas production is concentrated salt water or brine, which might have an effect on the chemical quality of area potable-water sources. This report presents the results of a U.S. Geological Survey baseline study to collect current (2001) water and sediment-quality data and to characterize water quality in the Berlin Lake watershed.

Chloride-to-bromide ratios were used to detect the presence of brine in water samples and to indicate possible adverse effects on water quality. Analyses of ground-water samples from domestic wells in the area indicate a source of chloride and bromide, but defining the source would require more data collection.

Analyses of specific conductance and dissolved solids indicate that 78 percent (14 of 18) of the ground-water samples exceeded the Secondary Maximum Contaminant Level for dissolved solids in public water supplies of 500 milligrams per liter (mg/L), compared to 6 percent of samples exceeding 500 mg/L in two nearby studies.

Surface water was analyzed twice, once each during low-flow and surface runoff conditions. A comparison of the 2001 data to historical chloride concentrations, accounting for seasonal changes, does not indicate an increase in chloride loads for surface water in the area of Berlin Lake.

Polycyclic aromatic hydrocarbons were found in bed-sediment samples collected from the mouths of major tributaries to Berlin Lake. Polycyclic aromatic hydrocarbons are produced during the incomplete combustion of organic carbon materials such as wood and fossil fuels, and they are components of petroleum products.

Introduction

As of 1999, records of the Ohio Department of Natural Resources (1999) indicated that 267,966 oil and gas wells were completed in Ohio, of which 63,122 were actively producing. During calendar year 2000, a total of 6,573,881 barrels of crude oil was produced, along with 98,550,667 million cubic feet of natural gas (Ohio Department of Natural Resources, 2000, p. 21). A side effect of oil and gas production can be degradation of water quality. Leaking well casings or spills of oil or brine can adversely affect water quality. The potential effects of oil and gas production on water quality are of current (2001) concern in the area surrounding Berlin Lake, in northeastern Ohio.

The Berlin Lake Project was authorized by the Flood Control Act of 1938 as 1 of 16 projects within the Pittsburgh District, U.S. Army Corps of Engineers. The Project, in Mahoning, Portage, and Stark Counties (fig. 1), covers some 7,984 acres, including both lake and land. The lake, which at the normal summer pool level covers 3,590 acres, has a drainage area above the dam of 249 mi^2 (U.S. Army Corps of Engineers, 2000).

Approximately 6,885 acres of the Project are owned

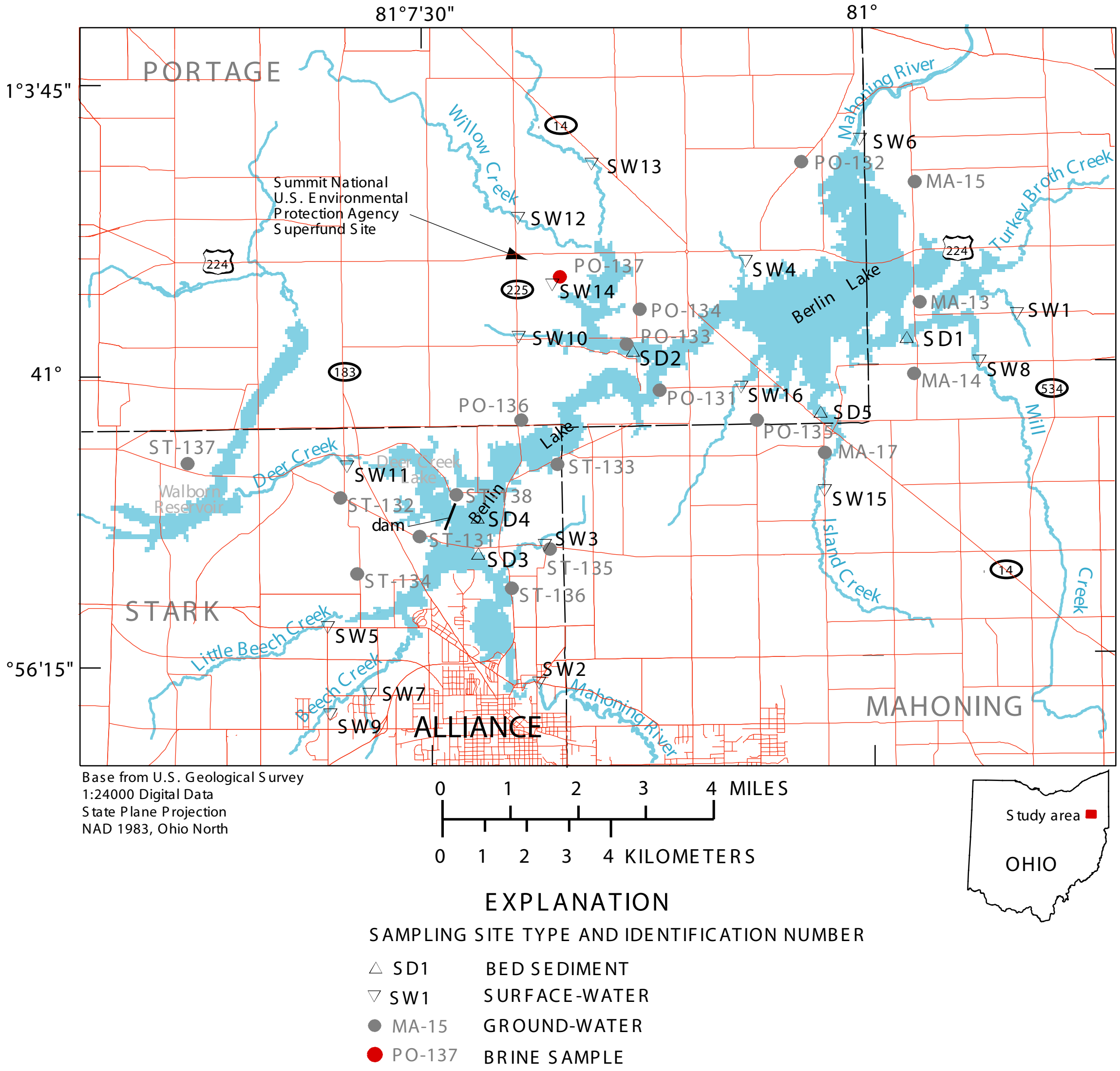


Figure 1. Location of sampling sites, Berlin Lake area, Ohio, 2001.

in fee by the Federal government, whereas the remaining 1,099 acres are flowage easements in which the surface and mineral ownership are non-Federal. In the early 1960s and mid-1980s, Federal oil and gas leases were issued for approximately 3,500 acres of the project. As of 1990, ten Federal oil and gas wells were operating on these leases. In late 1990, approximately 3,300 additional acres were offered for lease. After the 1990 leasing, 38 new Federal wells were drilled at the Project; 22 of these wells were on the Project and 16 were drilled directionally under the lake from adjacent private land (Becky Metz, Bureau of Land Management, written commun., 2002).

As of July 2002, approximately 5,450 acres of the Project remains under lease with a total of 48 Federal oil and gas wells in production. Numerous private oil and gas wells adjacent to the Project participate in Federal Communications Agreements, which ensures that the Federal government is compensated for the Federal portion of the oil and gas drained through these private wells. Most of these wells were drilled after the 1990 leasing (Becky Metz, Bureau of Land Management, written commun., 2002).

The counties surrounding Berlin Lake have been peppered with oil and gas production wells, as well as test borings and abandoned production wells (fig. 2). In Stark and Portage Counties (Mahoning County data are unavailable at the time of report publication), the oil and gas drilling often is close to domestic water wells that are used for drinking water (fig. 3). The effects of extensive development of oil and gas on the surface- and ground-water quality

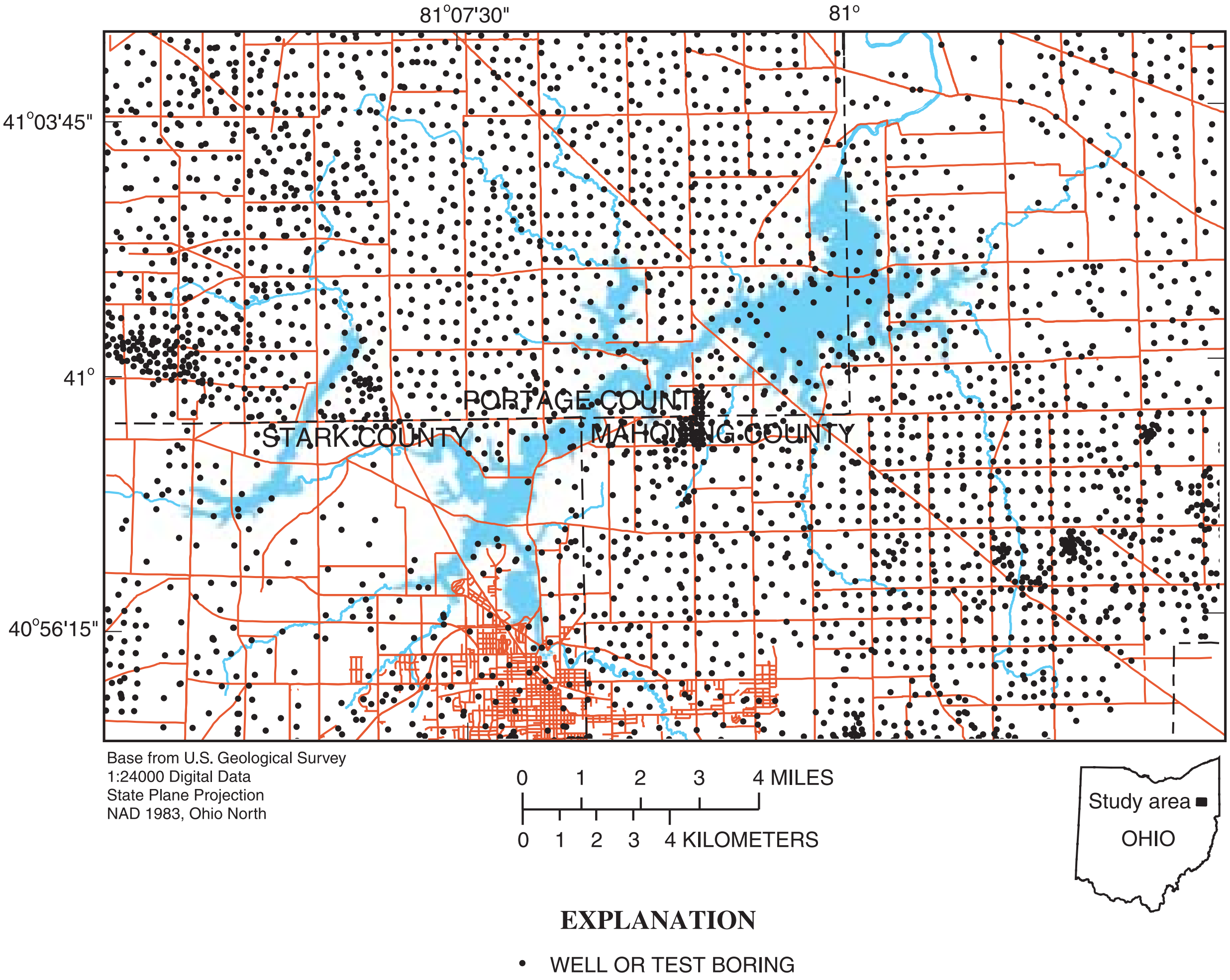


Figure 2. Location of oil and gas wells and test borings in the vicinity of Berlin Lake, Ohio.

has yet to be studied in this area. In 2000, 42 new oil and gas wells were drilled in Mahoning County, 33 in Stark County, and 14 in Portage County (Ohio Department of Natural Resources, 2000).

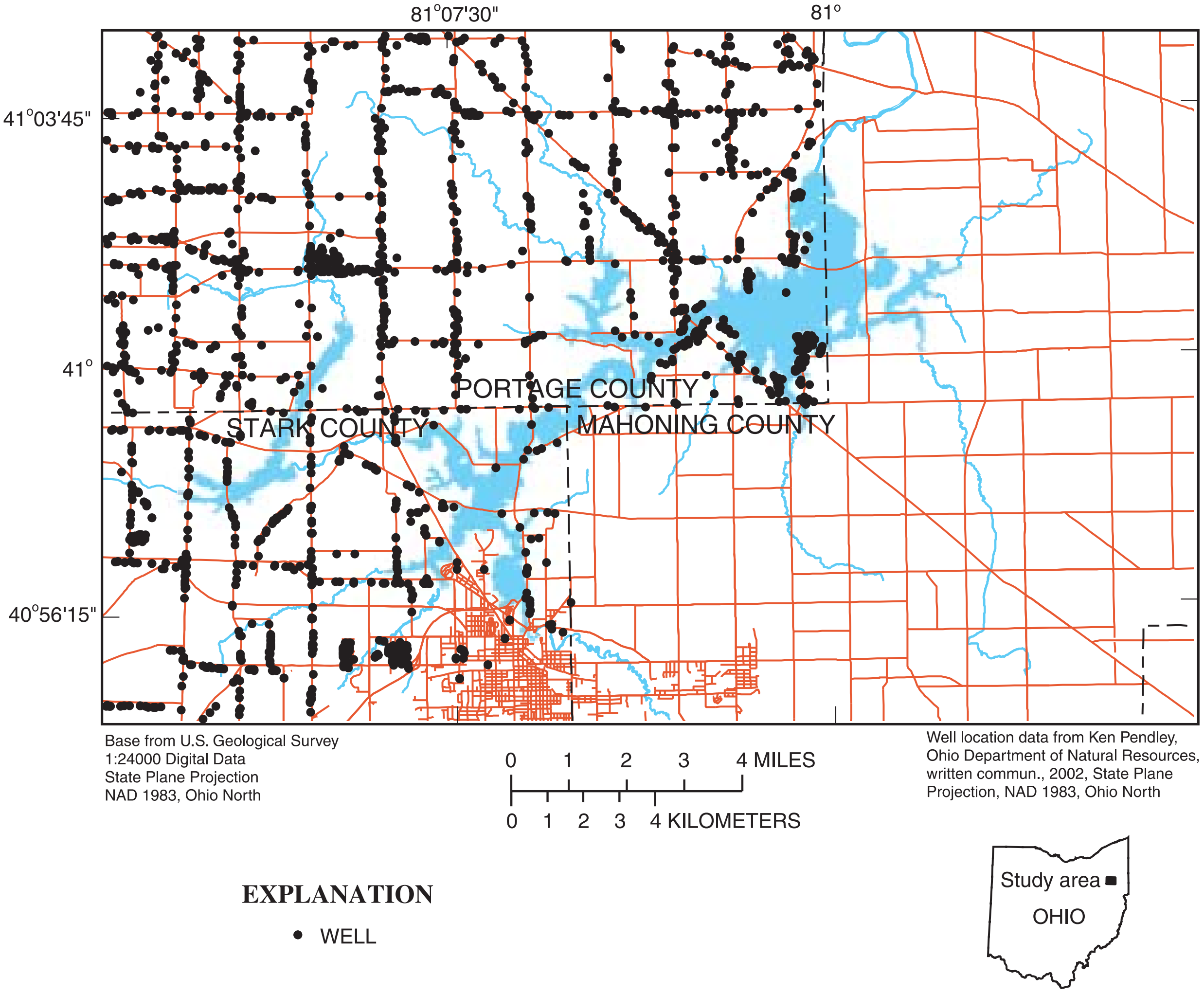
Few water-quality data are available for the area surrounding Berlin Lake, as are related data on chemical quality of streambed sediments near the lake. Therefore, the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Interior, Bureau of Land Management, investigated the water and sediment quality in the vicinity of Berlin Lake to provide baseline data before further oil and gas production takes place. The chemical analyses included properties and constituents related to oil and gas production, including pH, specific conductance, major ions in water, and polycyclic aromatic hydrocarbons (PAHs) in streambed and lakebed sediment.

Purpose and scope

The purpose of this report is to present current (2001) water and sediment-quality data and to briefly characterize water quality in the Berlin Lake watershed. Emphasis is on providing baseline water quality that may be useful in assessing effects of past and continuing oil and gas production in the area.

The USGS collected 18 ground-water samples from domestic wells that were representative of aquifers within the watershed. One brine sample from an oil and gas well also was analyzed for major ions. To determine the quality of surface water, 14 samples were collected during low flow and 16 samples during periods of surface runoff; all samples were analyzed for major ions. The USGS collected five streambed- or lakebed-sediment (referred to simply as "bed sediment" hereafter) samples to be analyzed for PAHs.

The results of the analyses are used herein to characterize area water quality with respect to historical data and probable sources of contamination. A comparison to historical data at three surface water sites is used to examine



Base from U.S. Geological Survey
1:24000 Digital Data
State Plane Projection
NAD 1983, Ohio North

Well location data from Ken Pendley, Ohio Department of Natural Resources, written commun., 2002, State Plane Projection, NAD 1983, Ohio North

Figure 3. Location of several domestic water wells in Stark and Portage Counties in the vicinity of Berlin Lake, Ohio. (Data for Mahoning County are unavailable).

temporal effects of urbanization and oil and gas production. An analysis of chloride to bromide (Cl:Br) ratios is used to determine the possible sources that affect current (2001) water quality.

Acknowledgments

The author thanks the 20 homeowners who allowed USGS personnel to collect water samples from their wells. The personnel from the U.S. Army Corps of Engineers Office at Berlin Lake deserve special recognition for supplying local knowledge and assistance.

Description of study area

The study area lies entirely in the glaciated part of the Appalachian Plateaus. The area consists primarily of gentle slopes and moderate relief that typically does not exceed 100 ft/mi (DeLong and White, 1963). Modification of the pre-Pleistocene surface by glacial erosion and the deposition of glacial drift have resulted in the current topography (Winslow and White, 1966). The thickness of the glacial deposits can be more than 200 ft in the buried valleys but nonexistent on the bedrock hills (DeLong and White, 1963).

The upper part (Pennsylvanian) of the bedrock produces potable water. The lower bedrock formations consist of laterally stacked, discontinuous statigraphic traps that may contain gas and oil (U.S. Department of Interior, Bureau of Land Management, 1990).

Berlin Lake hydrology

The construction of Berlin Lake was authorized by the Flood Control Act of 1938. Berlin Dam, which has been in continuous operation since July 1943, is a concrete gravity dam with a controlled center spillway and random, rolled earth embankments. The overall length of the dam is 5,750 ft, and the maximum height is 96 ft above the streambed (U.S. Army Corps of Engineers, 2000). The dam is on the Mahoning River, 11 mi upstream from Lake Milton and 35 mi upstream from Warren, Ohio.

For flood-storage purposes, the lake level is held below 1,016.6 ft from late August through late March. Between late March and early May, the pool level is allowed to rise to 1,024.0 ft. The pool is held at 1,024.0 ft until late June. At a full pool elevation of 1,032.0 ft, Berlin Lake covers 5,510 acres and has a storage capacity of 91,150 acre-ft (U.S. Army Corps of Engineers, 2000). The lake has the capability to store 6.9 in. of precipitation over its 249-mi^2 drainage area.

Mean annual precipitation at the National Weather Service station at the Akron-Canton Regional Airport (about 20 mi southwest of Berlin Lake) for 1961–90 was 36.82 in. For the same period, mean annual precipitation at the National Weather Service station at the Youngstown Regional Airport (about 25 mi northeast of Berlin Lake) was 37.32 in. (National Oceanographic and Atmospheric Administration, National Data Center, 2001).

Berlin Lake's congressionally authorized purposes include

- flood control
- low-flow augmentation
- water-quality control
- indirect water-supply, flow augmentation
- fish and wildlife enhancement
- recreation

Fish and wildlife enhancement and recreation are the only purposes that do not have storage allocations. The primary effort during operation is to maximize the flood-storage capability and provide water-supply augmentation (U.S. Army Corps of Engineers, 2000). Berlin Lake does not directly supply water to any municipality, but the city of Alliance withdraws water from Deer Creek, Walborn and Westville Reservoirs, which are all in the Mahoning River watershed upstream from Berlin Lake. Also in the Mahoning River watershed, just downstream from Berlin Lake, is Lake Milton, which supplies water to Youngstown, Ohio.

The watershed upstream from Berlin Lake is mostly rural, dominated by forest and agriculture (fig. 4). In the early 1990s, the majority of the watershed (58 percent) was being used for agriculture. Agricultural activities can generate nonpoint sources for many contaminants, including but not limited to septic-system leachates, fertilizers, and pesticides. The next largest land use category in the Berlin Lake watershed is forest at 29 percent, followed by low-intensity residential and wetlands at 4 percent each. Commercial, industrial, and transportation classifications make up about 1 percent of the watershed; most of the industrial development is along the Mahoning River in Alliance, Ohio, just upstream from Berlin Lake. Steel mills, textile production, and other manufacturing facilities have used the Mahoning River and Mill Creek as a source of water since the mid-1800s.

The U.S. Environmental Protection Agency (USEPA) (1998) listed the following possible sources of contamination of Berlin Lake:

- industrial point sources
- municipal point sources
- agriculture
- hydro modification
- atmospheric deposition
- spills

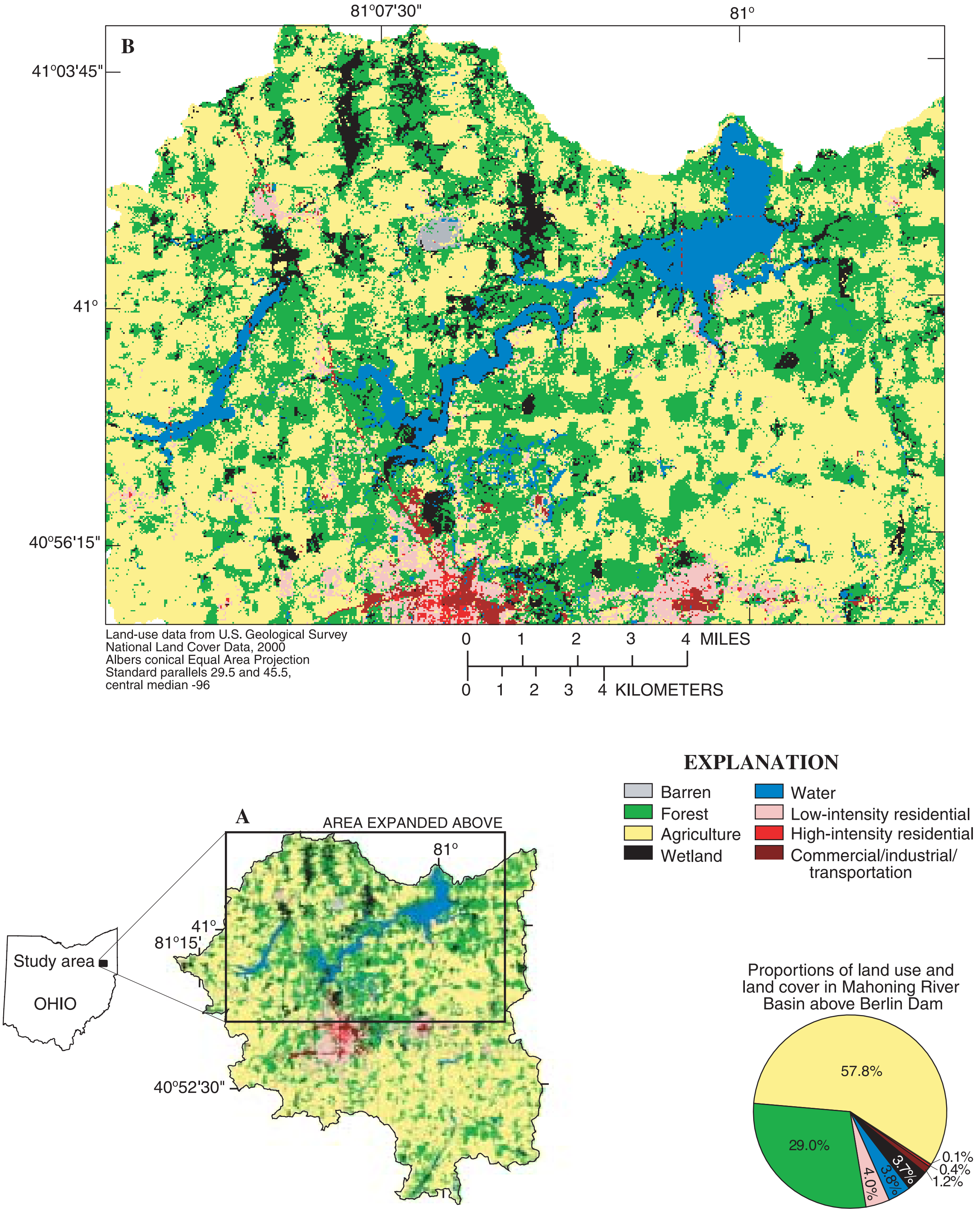
and the following sources of contamination to Mill Creek, an input to Berlin Lake:

- municipal point sources
- combined sewer overflows
- agriculture
- urban runoff
- channelization
- dam construction
- flow regulation/modification

The USEPA National Priorities List (NPL) is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The NPL is intended primarily to guide the USEPA in determining which sites warrant further investigation (U.S. Environmental Protection Agency, 2000a). A USEPA NPL Superfund site is in the drainage of Berlin Lake at the intersection of U.S. Route 224 and State Route 225 (fig. 1). The site, known as Summit National (USEPA identification number OHD980609994), is a former coal surface mine containing a coal wash pond and a coal stockpile. For 5 years in the mid-1970s, the site was used as a waste-disposal facility and received such wastes as oils, resins, paint, metal-plating sludges, flammable solvents, and chlorinated solvents. The ground water, soil, and surface water were contaminated with volatile organic compounds (VOCs), phenols, phthalates, polychlorinated biphenyls (PCBs) and heavy metals, including arsenic, chromium, and cadmium (U.S. Environmental Protection Agency, 2000a).

Geology

The bedrock generally dips to the south at between 5 and 10 ft/mi but may change locally because of slight flexures in the beds (Winslow and White, 1966, p. 8). The study area is covered by glacial deposits that are generally less than 20 ft thick. Although water can be found in localized areas of the glacial deposits, it is generally not considered an aquifer in the area surrounding Berlin lake. The glacial deposits



Land-use data from U.S. Geological Survey
National Land Cover Data, 2000
Albers conical Equal Area Projection
Standard parallels 29.5 and 45.5,
central median -96

Figure 4. Land use and land cover based on 30-meter Landsat thematic mapper data (1987-94): (A) Mahoning River Basin above Berlin Dam and (B) Berlin Lake area, Ohio.

are underlain by a series of sandstone and shale layers (table 1).

Bedrock. The oldest and deepest rock unit of interest in this study is the Albion Group, a layer of sandstone that constitutes the primary oil and gas producing zone in Ohio. Most oil and gas wells in the vicinity of Berlin Lake are finished in the upper sands of the Albion Group. Local drillers' terminology for the upper sandstone part of the Albion Group is the "Clinton," not to be confused with the overlying Clinton Group (Delong and White, 1963). In this report, "Albion Group" will be used to refer to the entire Albion Group; caution should be used when referring to other regional reports that mention the "Clinton" of the drillers.

The Clinton Group overlies the Albion Group and is made up of dolomite and the "Packer Shell" of the drillers (Delong and White, 1963). The Lockport Group includes the Lockport Dolomite and Guelph Dolomite and consists primarily of dolomite. The porous crystalline portion of this group is called the "Second Water" by drillers. The Bass Island and Salina Groups constitute the upper part of the Silurian-age rocks and are included in the drillers' "Big Lime." These groups are made up of interbedded dolomite, gypsum, salt, and shale.

The Silurian rocks are overlain by Devonian-age shale, sandstone, and limestone. The limestone sequence consists of the Helderberg Limestone, Oriskany Sandstone (drillers' "First Water"), and the Onondaga Limestone

Table 1. Summary of geologic units and associated properties, Berlin Lake area, Ohio

[Modified from Winslow and White, 1966, and Delong and White, 1963; >, greater than.]

System	Geologic unit	Approximate maximum thickness (in feet)	Character of deposits	Properties
Quaternary (Pleistocene)	Glacial deposits	400	Clay, silt, sand, and gravel; deposited by ice and meltwater.	Few domestic wells; sand and gravel may yield 5 to 20 gallons per minute. Well must be drilled to bedrock when sand and gravel is thin or missing.
Pennsylvanian	Pottsville Formation:		Sandstone; contains local channels of conglomerate and some shale where not removed by erosion.	Occasionally yield 100 gallons per minute but maximum reliable yield is closer to 25 gallons per minute.
	Homewood Sandstone Member	0-100		
	Mercer Member	0-90		
	Connoquenessing Sandstone Member	0-140		
	Sharon Member	0-340		
Mississippian	Cuyahoga Formation	0-250	Shale, siltstone, fine-grained sandstone conglomerate	Leaky confining unit on a regional scale; poorly productive aquifer on a local scale.
	Sunbury Shale	15-95	Black to dark-gray shale	
	Berea Sandstone	10-100	White to light-gray, fine- to very fine grained sandstone	Saline to brackish water, reported to contain some gas.
	Bedford Shale	2-10	Light- to medium-gray silty shale	
	Cussewago Sandstone	0-20	Fine- to coarse-grained loosely cemented rock	Small amounts of gas and oil have been produced from the sandstone.
Devonian	Ohio Shale	1,600-2,400	Light gray shale increasing to black with depth, interbedded with shaly siltstone	
	Onondaga Limestone	170-245	Hard, dense, finely crystalline rock	
	Oriskany Sandstone	0-40	Loose, medium-grained sandstone	Referred to by drillers as "First Water." In this area the water is brine of weak to strong concentration (Stout and others, 1943).
	Helderberg Limestone	100-200	Dense, very fine crystalline limestone	
Silurian	Bass Island and Salina Group	655-850	Interbedded dolomite, gypsum, salt, and shale	
	Lockport Group	255-340	White to light-gray dolomite	Referred to by drillers as "Second Water"; also a brine-producing zone.
	Clinton Group	120-230	Gray dolomitic shales and the "Packer Shell" limestone	
	Albion Group ("Clinton")	25-175	Top - "Clinton" sandstone; bottom - shale and silty shale	Principal gas-producing zone in Ohio.

(table 1). The two limestones form a part of the drillers' "Big Lime" section. (Delong and White, 1963). The top of the Devonian consists of 1,600 to 2,400 ft of the Ohio Shale (table 1). Where the Mississippian Cussewago Sandstone is present, the Devonian-Mississippian contact is definite; but elsewhere, the Bedford Shale of Mississippian age is so similar to the Ohio Shale that the units are indistinguishable.

The oldest members of the Mississippian-age bedrock that underlie the region are the Cussewago Sandstone and the Bedford Shale. The Cussewago Sandstone is described as poorly cemented medium- to coarse-sized quartz grains (Winslow and White, 1966 p. 9). The Bedford Shale primarily is shale interbedded with thin layers of sandstones and limy siltstones. In Stark County, just south of the study area, the Cussewago Sandstone produces small amounts of gas and oil.

In pockets of the study area, the Sunbury Shale, a black to dark gray shale, overlies the Berea Formation. Overlying the Bedford Shale is the Berea Sandstone. Water in the Berea Sandstone may be expected to be saline to brackish (Winslow and White, 1966, p. 9). The Berea Sandstone also is an oil- and gas-producing unit, although the hydrocarbon potential in Berlin Lake area is meager (DeLong and White, 1963, p. 102).

The uppermost Mississippian unit is the Cuyahoga Formation, which consists primarily of shale to silty shale but may contain some fine-grained silty sandstone. This formation may contain some water, but most wells that do not provide sufficient water in the overlying glacial deposits or Pottsville Formation are drilled through to the units below the Cuyahoga.

The Pottsville Formation, of Pennsylvanian age, is the uppermost bedrock in the study area. This unit is mostly sandstone with a few discontinuous shale lenses and is the most extensively developed fresh-water aquifer in the area (table 1). The wells withdrawing water from the bedrock generally are cased through the glacial deposits into the top of the bedrock and then left open hole through the total depth of the well.

Glacial. The study area is predominately within the bounds of the Hiram Till (fig. 5). In the vicinity of Berlin Lake the glacial deposits typically are less than 15 ft thick; throughout its extent, the Hiram Till averages 6 ft in thickness (Totten and White, 1987).

The Hiram Till is clay rich with sparse pebbles, few cobbles, and few boulders (Winslow and White, 1966, p. 34). The average composition of the till is 10 percent sand, 48 percent silt, and 42 percent clay (Totten and White, 1987). Sand or gravel lenses are rare but where present can produce 5 to 20 gal/min of freshwater (Walker, 1979). The glacial deposits only produce sufficient quantities of water in limited areas; therefore, most domestic water wells in the area are completed in the bedrock below, primarily in the Pottsville Formation.

Soils

Most soils near Berlin Lake formed in glacial till, and their permeabilities are low. For the most part, the soils are poorly to moderately well drained. The low permeability of the major soils in this area is a severe limitation for septic-system filter fields.

Berlin Lake is bounded from the west to east around the north side of the lake by the Remsen-Geeburg-Trumbull association. This association consists of nearly level to gently sloping, moderately well drained to poorly drained soils that formed in the fine-textured glacial till (Ritchie and others, 1978). To the south, the lake is bounded by the Mahoning-Ellsworth association, consisting of nearly level to sloping, poorly drained and moderately well drained soils that formed mostly in moderately fine-textured glacial till (Lessig and others, 1971). To the southwest, in Stark County, a small section of the Remsen association bounds the lake. The Remsen is defined as deep, mainly nearly level to gently sloping, poorly drained soils that are dominated by clayey subsoil; Remsen soils formed in silty clay glacial till (Christman and others, 1971).

Poorly drained Lorain soils, poorly drained Sebring, Holly, and Montgomery soils; moderately well drained Bogart, soils and well-drained Chili soils are interspersed within the primary soil types and represent about 25 percent of the area (Ritchie and others, 1978).

Methods of study

A variety of environmental samples were collected during the study, including ground water, bed sediment, surface water during low-flow conditions, and surface-water runoff. Procedures used for each sample type are described below.

Collection and analyses of ground water samples

Ground-water samples were collected July 24 through August 9, 2001, from 18 domestic wells and 1 oil and gas well (fig. 1). Four quality-control duplicates were collected during this time period. Well selection was based on spatial distribution, completion of the well in a single unit, and access. An attempt was made to locate wells open to the glacial deposits, but only two wells were located that were accessible.

Domestic samples were collected from household spigots supplied by household plumbing and well-pump systems. Well owners identified spigots that bypassed water softeners, and USGS personnel inspected 15 of the 18 systems that were sampled.

Water samples were collected in accordance with USGS protocol for ground-water sampling of water-supply

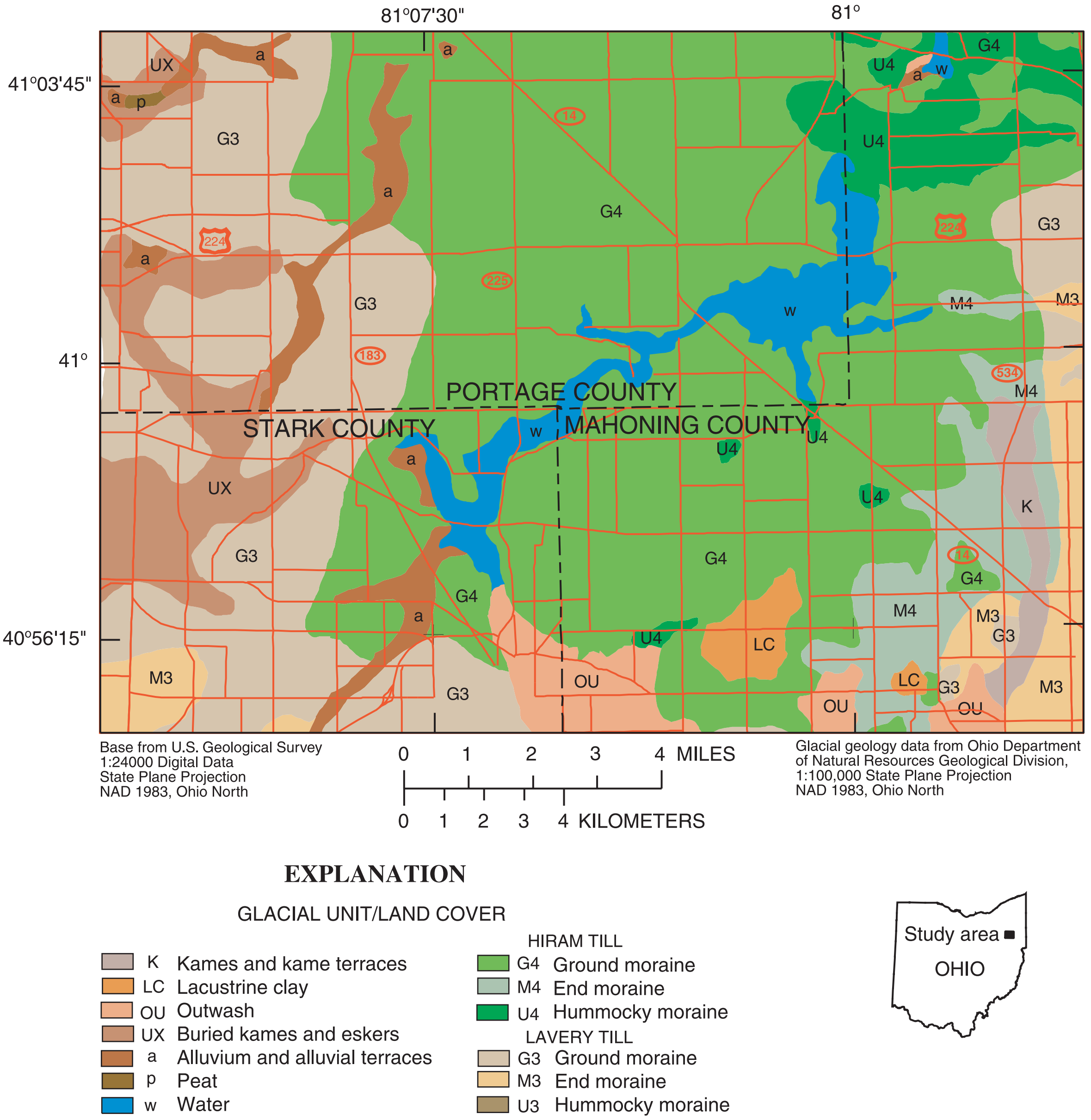


Figure 5. Glacial geology of the Berlin Lake area, Ohio.

wells as described in Wilde and others (1999a). Measurements of pH, specific conductance, water temperature, and dissolved oxygen were made with a multiparameter probe that was field calibrated and fitted with a flowthrough cell. Most wells were purged by removing three times the standing volume of water in the well. In some cases, the owner requested that as little water as possible be withdrawn from the well. If the well was recently pumped through normal use, the judgement of the personnel onsite and the stability of pH, specific conductance, dissolved oxygen, and water temperature measured with the multiparameter probe were used to indicate the purge volume necessary to ensure that the samples reflected the water chemistry in the aquifer.

Hoses, flowthrough chamber, and filtration equipment were decontaminated between each sample. Decontamination consisted of scrubbing and soaking the equipment in a detergent-water mixture and then rinsing with deionized water.

A different procedure was used to collect the sample from the oil and gas well (PO-137). The sample was collected from the discharge from a crude oil holding tank. A small amount of the brine was allowed to run into a holding tank to purge the pipes, and then the brine was collected in a clean sampling container. This unique sampling opportunity did not allow for multiparameter monitoring or water-level measurement, so the analysis was used only to determine the brine endpoint of a Cl:Br ratio analyses.

Samples that required filtration were filtered through a 0.45-µm inline plate filter, and samples that required preservation were acidified by use of nitric acid (Wilde and others, 1999b). Alkalinity was determined in the field by means of the incremental titration method (Wilde and Radtke, 1998). All other properties and constituents were determined by the USGS National Water-Quality Laboratory in Denver, Colo.

Collection and analyses of surface water samples

Surface-water samples were collected under two different hydrologic conditions. The initial effort consisted of 14 samples that were collected during low (base)-flow conditions, July 18–26, 2001. An effort was made to sample all the surface-water inputs to Berlin Lake. An additional 16 samples were collected during a period of rainfall that produced surface runoff, November 27–29, 2001. The original 14 sites were sampled, and 2 additional sites were added to obtain better coverage of the area (fig. 1).

The flow condition was determined by examining the discharge at the nearby USGS gaging station at Eagle Creek near Phalanx Station, Ohio (fig. 6.) The low-flow standard was set at 80 percent duration or 15 ft^3/s; the surface runoff samples were collected during a rain event that produced a daily mean flow of 146 ft^3/s for Eagle Creek, near the 50-percent duration of 153 ft^3/s. Eagle Creek near Phalanx Station was used as the index station for this study because it is the closest gaging station with real-time capabilities and, therefore, granted the best opportunity to sample a surface runoff event. It should be noted that the surface runoff samples collected below Berlin Dam and on Deer Creek above Deer Creek Reservoir were actually at a lower flow than the low-flow sample. The inputs to the lakes were picking up surface runoff; but because the area had been in drought, the reservoirs were low and the gates at the dams were restricted in an effort to resupply the reservoirs.

Surface-water samples were collected in accordance with USGS protocol for equal-width-increment (EWI) sampling methods, as described in Wilde and others (1999a). Measurements of pH, specific conductance, water temperature, and dissolved oxygen were made with a field-calibrated multiparameter probe.

Sampling devices and filtration equipment were decontaminated between each sample. Decontamination consisted of scrubbing and soaking the equipment in a detergent-water mixture and then rinsing with deionized water. Twenty 1-L sampling containers and nozzles were cleaned prior to sampling, and a separate set was used for each site. The surface-water samples were processed in the same manner as the ground-water samples and sent to the USGS National Water-Quality Laboratory in Denver, Colo.

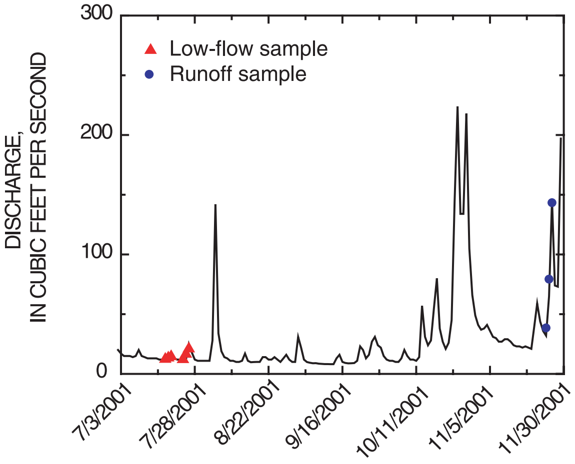


Figure 6. Daily mean discharge and surface-water sampling dates at Eagle Creek near Phalanx Station, Ohio. (Exact dates and times of sampling are listed in table 5).

Collection and analyses of bed-sediment samples

Five bed-sediment samples were collected September 18 and 19, 2001, near the mouths of the major inputs to Berlin Lake (fig. 1). These areas include the Mahoning River, Mill Creek, Deer Creek, Island Creek, and Willow Creek. The bed-sediment samples were collected and processed in the field in accordance with USGS protocol for streambed-sediment sampling as described in Radtke (1997).

The samples were collected with a stainless-steel core sampler driven to a depth of 15 to 18 in. The material was gathered in a stainless-steel bucket and thoroughly mixed with a stainless-steel spoon. The mixture then was run through a 2-mm stainless-steel sieve directly into the sample container. The samples were then chilled on ice and shipped to the USGS National Water Quality Laboratory in Denver, Colo., for analyses for PAHs.

Water and bed-sediment quality

Physical characteristics of domestic wells and location of the surface-water and sediment sites are listed in tables 2 and 3, respectively. The chemical analyses of the ground water, surface water, and streambed sediment are listed in tables 4, 5, and 6, respectively (at back of report). Information on concentration limits and water use implications for drinking water are given in table 7. Statistical summaries of the water-quality data are presented in the form of boxplots in figure 7.

Every reasonable attempt was made to ensure that ground-water samples from domestic sources bypassed any

Table 2. Physical characteristics of wells sampled in the vicinity of Berlin Lake, Ohio, July and August 2001

[--, unavailable for this well.]

Map identifier	Site identifier	Latitude	Longitude	Casing diameter (in inches)	Land surface datum (in feet above sea level)	Measuring point height (in feet above land surface)	Primary geologic unit	Open interval (in feet below land surface)	
								Top	Bottom
ST-131	405753081073900	40°57′53"	81°07′39"	5	1,046	--	glacial	56	56
ST-132	405824081085900	40°58′24"	81°08′59"	4	1,100	--	Pottsville	35	202
ST-133	405847081051800	40°58′47"	81°05′18"	4.2	1,060	1.6	Pottsville	76	138
ST-134	405725081084300	40°57′25"	81°08′43"	5	1,086	1.25	Pottsville	47	111
ST-135	405742081052700	40°57′42"	81°05′27"	5	1,060	.85	Pottsville	57	115
ST-136	405712081060600	40°57′12"	81°06′06"	5.5	1,072	--	glacial	89	89
ST-137	405852081113400	40°58′52"	81°11′34"	4	1,140	2.2	Pottsville	69	100
ST-138	405825081070100	40°58′25"	81°07′01"	5	1,040	1.65	Pottsville	170	186
PO-131	405943081033200	40°59′43"	81°03′32"	6	1,048	1.65	Pottsville	123	175
PO-132	410238081010400	41°02′38"	81°01′04"	5	1,077	--	Pottsville	32	124
PO-133	410019081040500	41°00′19"	81°04′05"	5	1,044	1.9	Pottsville	38	114
PO-134	410046081035100	41°00′46"	81°03′51"	6	1,050	2.1	Pottsville	30	100
PO-135	405919081015400	40°59′19"	81°01′54"	5.5	1,058	1.0	Pottsville	29	67
PO-136	405922081055400	40°59′22"	81°05′54"	5	1,059	1.4	Pottsville	75	105
PO-137	405805080543100	40°58′05"	80°54′31"	--		--	Albion Group		
MA-13	410048080590600	41°00′48"	80°59′06"	6	1,050	1.6	Pottsville	22	151
MA-14	405953080591300	40°59′53"	80°59′13"	4	1,088	1.2	Pottsville	182	203
MA-15	410221080590900	41°02′21"	80°59′09"	6	1,050	1.55	Pottsville	114	175
MA-17	405853081004500	40°58′53"	81°00′45"	5	1,074	1.3	Pottsville	40	315

Table 3. Location of surface-water and bed-material sites where samples were collected in the vicinity of Berlin Lake, Ohio, July and August 2001

Map identifier	Site identifier	Station name	Latitude	Longitude
		Surface-water sites		
SW1	410037080572800	Unnamed tributary to Turkey Broth Creek at Berlin Station	41°00′37"	80°57′28"
SW2	03086500	Mahoning River at Alliance	41°02′54"	81°00′05"
SW3	405744081053300	Unnamed tributary at Greenbower Road	40°57′44"	81°05′33"
SW4	410121081020400	Unnamed tributary to Berlin Lake near Deerfield	41°01′21"	81°02′04"
SW5	405643081091500	Little Beech Creek at SR 619	40°56′43"	81°09′15"
SW6	03090500	Mahoning River below Berlin Dam near Berlin Center	41°00′01"	80°58′07"
SW7	405551081083400	Tributary to Beech Creek at Vine Street	40°55′55"	81°08′34"
SW8	03089500	Mill Creek near Berlin Center	40°55′58"	81°05′41"
SW9	405536081091400	Beech Creek at Freshley Ave	40°55′36"	81°09′14"
SW10	410025081055600	Unnamed tributary at SR 225 near Fewtown Road	41°00′25"	81°05′56"
SW11	405847081085300	Deer Creek above Deer Creek Reservoir at Limaville	40°58′47"	81°08′53"
SW12	410157081055500	Willow Creek at SR 225	41°01′57"	81°05′55"
SW13	410238081043900	Unnamed tributary at Notman Road	41°02′38"	81°04′39"
SW14	410105081052100	Tributary near Portage-Stark Range	41°01′05"	81°05′21"
SW15	405823081004700	Island Creek near North Benton	41°58′23"	81°00′47"
SW16	405944081021000	Unnamed tributary at Wagner Road	40°59′44"	81°02′10"
		Bed-material sites		
SD1	410021080592000	Berlin Lake near the Mouth of Mill Creek	41°00′21"	80°59′20"
SD2	410014081035900	Willow Creek at Berlin Lake	41°00′14"	81°03′59"
SD3	405739081064000	Mahoning River at Rockhill Road	40°57′39"	81°06′40"
SD4	405807081064000	Deer Creek Below Deer Creek Dam	40°58′07"	81°06′40"
SD5	405924081004900	Island Creek at Berlin Lake	40°59′24"	81°00′49"

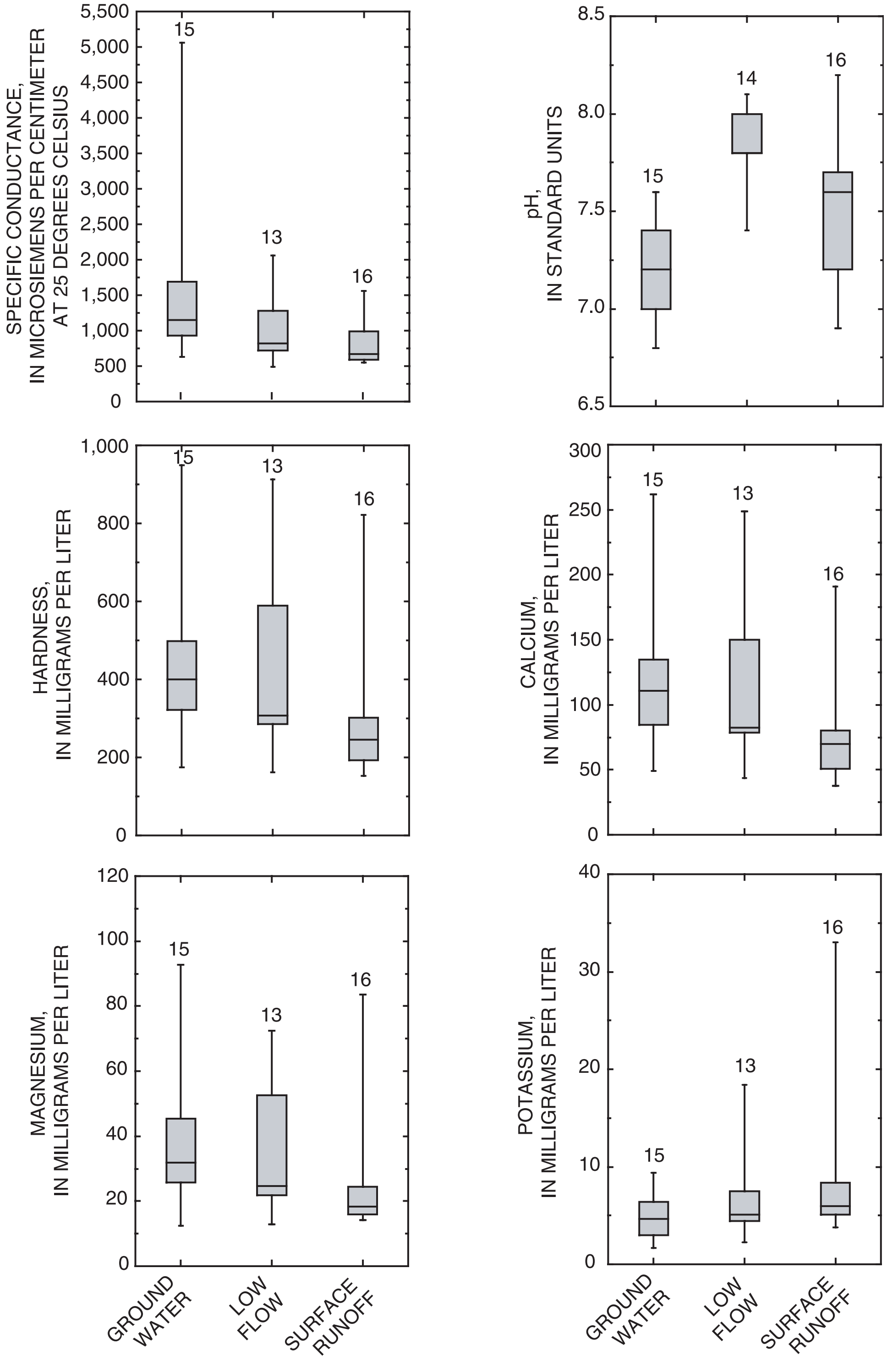


Figure 7. Chemical constituents delineated by sample types, Berlin Lake area, Ohio.

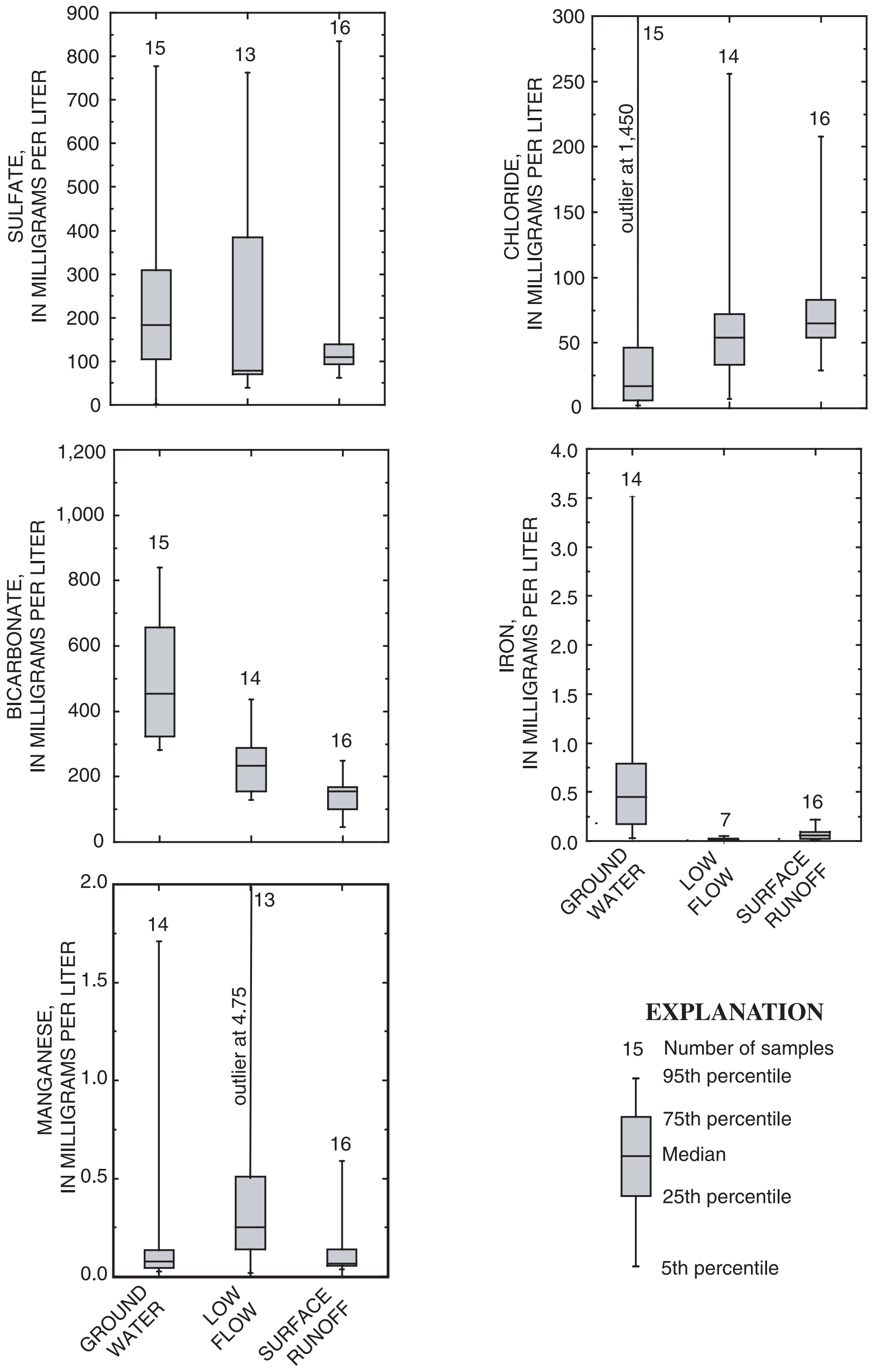


Figure 7. Chemical constituents delineated by sample types, Berlin Lake area, Ohio—Continued.

water-treatment system. However, in some cases the homeowner was not available or did not wish for USGS personnel to inspect the system. The samples from wells ST-134, PO-133, MA-14, and PO-137, had significantly different concentrations of various constituents as compared to samples from other wells in the study. Samples from these wells may have passed through a water-treatment system. More information on this possibility is given below.

For wells ST-134, PO-133, and MA-14, concentrations of hardness, calcium, and magnesium all were less than the concentrations found in other samples (table 4). Water that has been softened by ion-exchange methods can result in the replacement of calcium, magnesium, and iron by sodium (Driscoll, 1986). Therefore, it is possible that these three samples were softened and, therefore, not representative of the aquifer water. For this reason, the sample results are not included in the following discussions, but the data are presented in table 4 and figure 8.

The sample from well PO-137 is a brine sample that is used to determine an end-member for a CL:Br ratio analysis. The sample results were not used for any other comparison, but the data are presented in table 4 and figure 8.

To compare the quality of water in the vicinity of Berlin Lake to other regional waters, the data collected from this study were compared to data from other studies in northeastern Ohio. A report by Barton and others (1998) on the Mosquito Creek is similar in scope to this report, with comparable data; furthermore, Mosquito Creek is only about 25 mi northeast of Berlin Lake. Jagucki and Darner (2001) studied the ground-water quality on a countywide basis for Geauga County, Ohio, due north of Portage County. A study by Eberts (1990) in northern Portage County covered water quality in relation to deep-well brine injection.

pH

The pH of water sampled from all domestic wells ranged from 6.8 to 7.6, with a median value of 7.2 (table 4). Water from the two wells completed in the glacial deposit (ST-136 and ST-131) had a pH of 6.8 and 7.1. Barton and others (1998) reported pH ranges of 6.8 to 8.1 for similar wells in the area of nearby Mosquito Creek, Trumbull County, Ohio. The brine sample from the oil and gas well (PO-137) had a pH of 3.2. The pH of three brine samples collected from wells completed in the Albion Group in nearby Trumbull County were reported by Barton and others (1998) as ranging from 3.7 to 4.5.

The pH of surface-water samples collected during low flow ranged from 7.4 to 8.1 and during surface runoff ranged from 6.9 to 8.2 (table 5). Barton and others (1998) reported that pH for similar streams in northeastern Ohio ranged from 7.1 to 10.1. Surface-water samples collected during low-flow and surface-runoff conditions were more alkaline than the ground water, and the ground water was more alkaline than the brine (fig. 7).

Specific conductance

Specific conductance for ground water from domestic wells ranged from 630 to 5,060 µS/cm. The maximum specific conductance was at MA-17 a well completed at 315 ft. The specific conductance of the brine sample (PO-137) was 212,000 µS/cm. Specific conductances of water samples collected from the glacial deposits (ST-131 and ST-136) were 1,100 and 1,590 µS/cm, respectively.

Specific conductance often is used as an estimator for dissolved solids concentration (Hem, 1992). In a USGS study in nearby Geauga County, it was found that a specific conductance of 800 µS/cm correlates with a dissolved-solids concentration of 500 mg/L (Eberts, 1990). The U.S. Environmental Protection Agency (2002) Secondary Maximum Contaminant Level (SMCL) for dissolved solids in public water supplies is 500 mg/L.

A ground-water study in northern Portage County (Eberts, 1990) found that 6 of nearly 100 samples (6 percent) from domestic wells had specific conductances that exceeded 800 µS/cm. Another study in Geauga County (Jagucki and Darner, 2001) found that 1 of 18 samples (6 percent) collected from the glacial deposits and the Pottsville Formation had specific conductance that exceeded 800 µS/cm. Of the 18 domestic-well samples in this study, 14 samples (78 percent) had a specific conductance that exceeded 800 µS/cm. The same 14 samples also had dissolved-solids concentrations greater than 500 mg/L.

Specific conductance in low-flow surface-water samples ranged from 489 to 2,060 µS/cm (table 5), with a median of 867 µS/cm. In samples collected during surface-runoff conditions, specific conductance ranged from 550 to 1560 µS/cm (table 5), with a median of 705 µS/cm. Barton and others (1998) reported specific conductance values for similar streams in northeastern Ohio as ranging from 240 to 2,210 µS/cm.

Major anions and cations

Water with a hardness concentration of greater than 180 mg/L is considered very hard water (table 7). The median hardness concentration for ground-water samples in this study is 400 mg/L (fig. 7). Surface-water samples also were very hard, with median concentrations for low-flow and surface runoff conditions of 311 mg/L and 262 mg/L, respectively. Boxplots for calcium and magnesium (fig. 7) are similar in composition to the hardness boxplot, because hardness is based primarily on calcium and magnesium concentrations (Hem, 1992).

The character or type of water with regard to proportions of major anions and cations can be assessed by the use of trilinear diagrams, constructed by converting concentrations of anions and cations to milliequilavents per liter (meq/L) and plotting relative percentages of the major cations on the lower left equilateral triangle and the major anions on the lower right equilateral triangle (Hem, 1992). Each corner on the triangles represents 100 percent of a particular type (or types) of ion(s). The cation and anion compositions then are projected along a line parallel to the outer edge of the equilateral triangles until the cation and anion projections intersect on a third, diamond-shaped diagram. A trilinear diagram representing all samples collected for this study is shown in figure 8.

The trilinear diagram does not indicate a single water type for the area but rather a wide range of waters. The first pattern to note in the trilinear diagram is the three groundwater samples that appear to be softened, ST-134, PO-133, and MA-14, located near the bottom point of the diamond. The position of these samples on the diagram correlates with softened samples diagrammed in Jagucki and Darner (2001). The brine sample (PO-137) plots to the far right of the anion triangle. The sample from well MA-17 plots in a similar position on the anion triangle, indicating a possible influence of brine.

The composition of the cation triangle is similar to what Jagucki and Darner (2001) found in nearby Geauga County, Ohio. A common natural process that supports this trend is dissolution of carbonate minerals combined with cation exchange (Eberts and others, 1990; Lesney, 1992). In cation exchange, calcium and magnesium ions are removed from solution and replaced by sodium ions on exchangeable sites in clay minerals. As the reaction proceeds, the ratio of calcium ions to sodium ions remaining in solution decreases (Jagucki and Darner, 2001). The longer the residence time, the greater the effect of the process on calcium and sodium concentrations.

Chloride-to-bromide ratios

A method developed by Whittemore (1988) for characterizing waters with respect to sources and mixing was used by and described in Jagucki and Darner (2001) and was modified for this study. Simple binary mixing curves (fig. 9) were prepared to show how the Cl:Br ratio of dilute groundwater changes with the addition of increasing amounts of three concentrated solutions: saturated halite solution, oilfield brine, and domestic sewage. These solutions, as well as the dilute, unaffected ground water, are referred to as "end-members" because they represent the starting and stopping points of the possible mixing process.

The sample from well ST-137 was chosen as the dilute ground water end-member because it had the lowest Cl:Br ratio and the lowest chloride concentration. The Cl:Br ratio of the brine end-member was estimated as the mean of PO-137 and three samples of brine collected by Eberts and others (1990) from oil and gas wells in Geauga County. Upper and lower limits were added to the ground-water-plus-brine mixing curve by adding 15 percent to the end-member value to account for natural variation and analytical error.

The Cl:Br ratio of the saturated halite solution was computed as the mean of three samples of road salt applied in northeastern Ohio (collected by Knuth and others, 1990). The Cl:Br ratio of the domestic sewage end-member was selected as the midpoint of the range (300-600) reported by Davis and others (1998), based on limited analyses of urban sewage from England and the United States. The chloride concentration of the sewage end-member was estimated as the midpoint of the range 37-101 mg/L, reported by Peavy (1978; cited in Canter and Knox, 1986).

The shaded area designated as dilute ground water in figure 9 is based on Cl:Br ratios reported by Davis and others (1998) and on chloride concentrations reported by Jones and Sroka (1997). Davis and others (1998) reported that shallow ground water, unaffected or only minimally affected by dissolution of halite, generally has a Cl:Br ratio of 100 to 200. Davis and others (1998) also reported that Cl:Br ratios of atmospheric precipitation are generally between 50 and 150, with ratios highest near the coast and decreasing inland. Jones and Sroka (1997) estimated that water samples from shallow wells in Ohio that were unaffected by halite dissolution had chloride concentrations less than 10 mg/L.

Ground water. Waters that have Cl:Br ratios exceeding 400 and plot near or between the mixing lines may indicate effects of road salt or sewage from malfunctioning septic systems (Jagucki and Darner, 2001). An example is the sample from well MA-13, which plots near the sewage-plus-halite mixing line with a Cl:Br ratio of 1,017. MA-13 is 151 ft deep and completed in a sandstone member of the Pottsville Formation. The casing length is 22 ft and, if the well was not properly constructed or has been damaged, would be a relatively short path (compared to natural flowpaths) for water at land surface to affect ground water near the well.

Five other samples plot outside the dilute groundwater area and between the brine and ground-water-plus-sewage mixing lines. Samples from these wells may be affected by a combination of brine and infiltration from malfunctioning septic-systems. The two wells completed in the glacial deposits (ST-131 and ST-136) are included in this group. The glacial-deposit wells are completed to depths of 56 and 89 ft, respectively.

The samples from two wells, ST-133 and ST-135, plot along the mixing curve between dilute ground water and brine. Both wells are completed in a shale member of the Pottsville Formation at depths of 138 ft and 115 ft, respectively. The sample from PO-131 plots very close to the mixing line; the well is completed at a depth of 175 ft and penetrates a shale member of the Pottsville Formation.

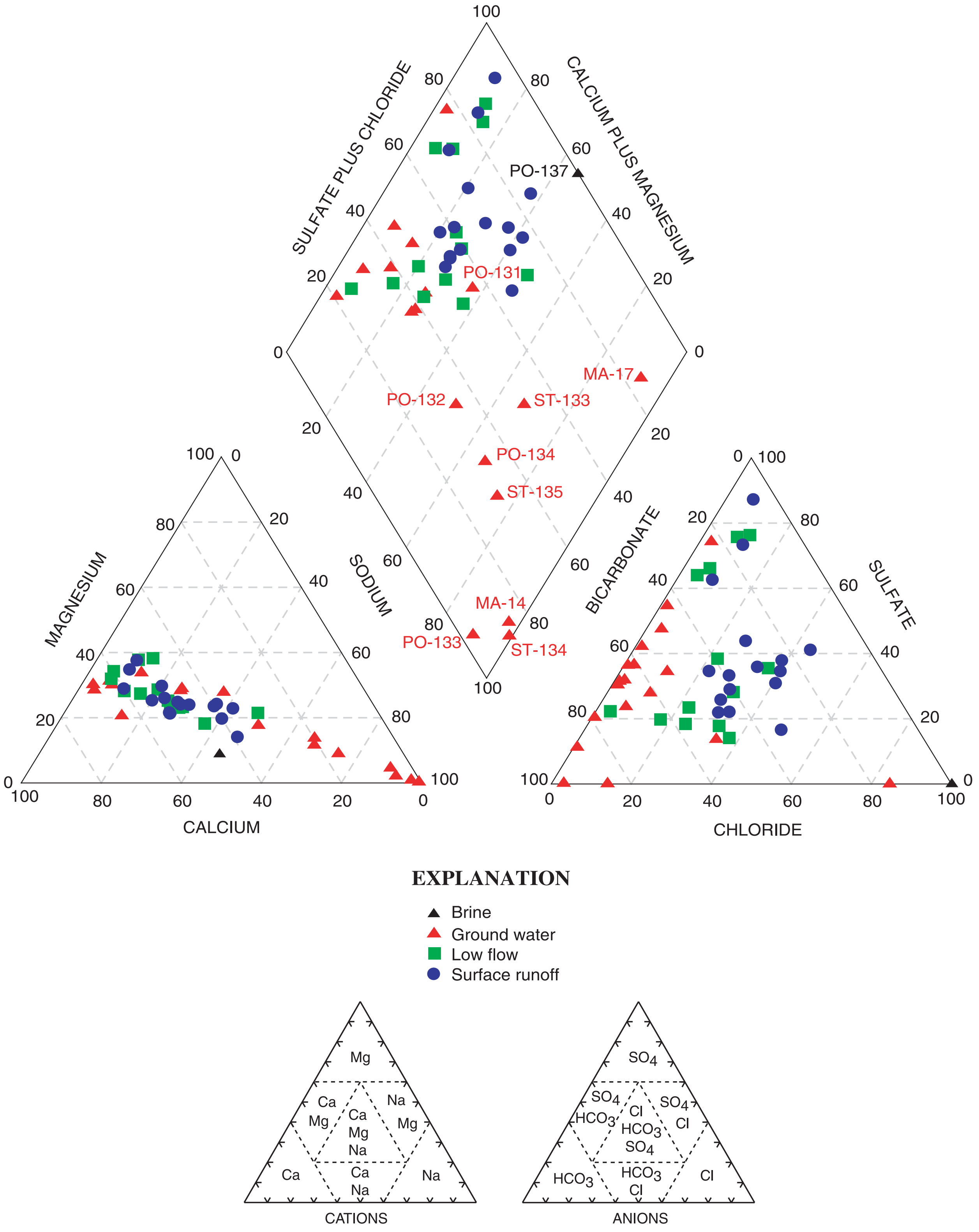


Figure 8. Trilinear diagram of chemical differences in water samples collected in the Berlin Lake area, Ohio, July, August, and November 2001.

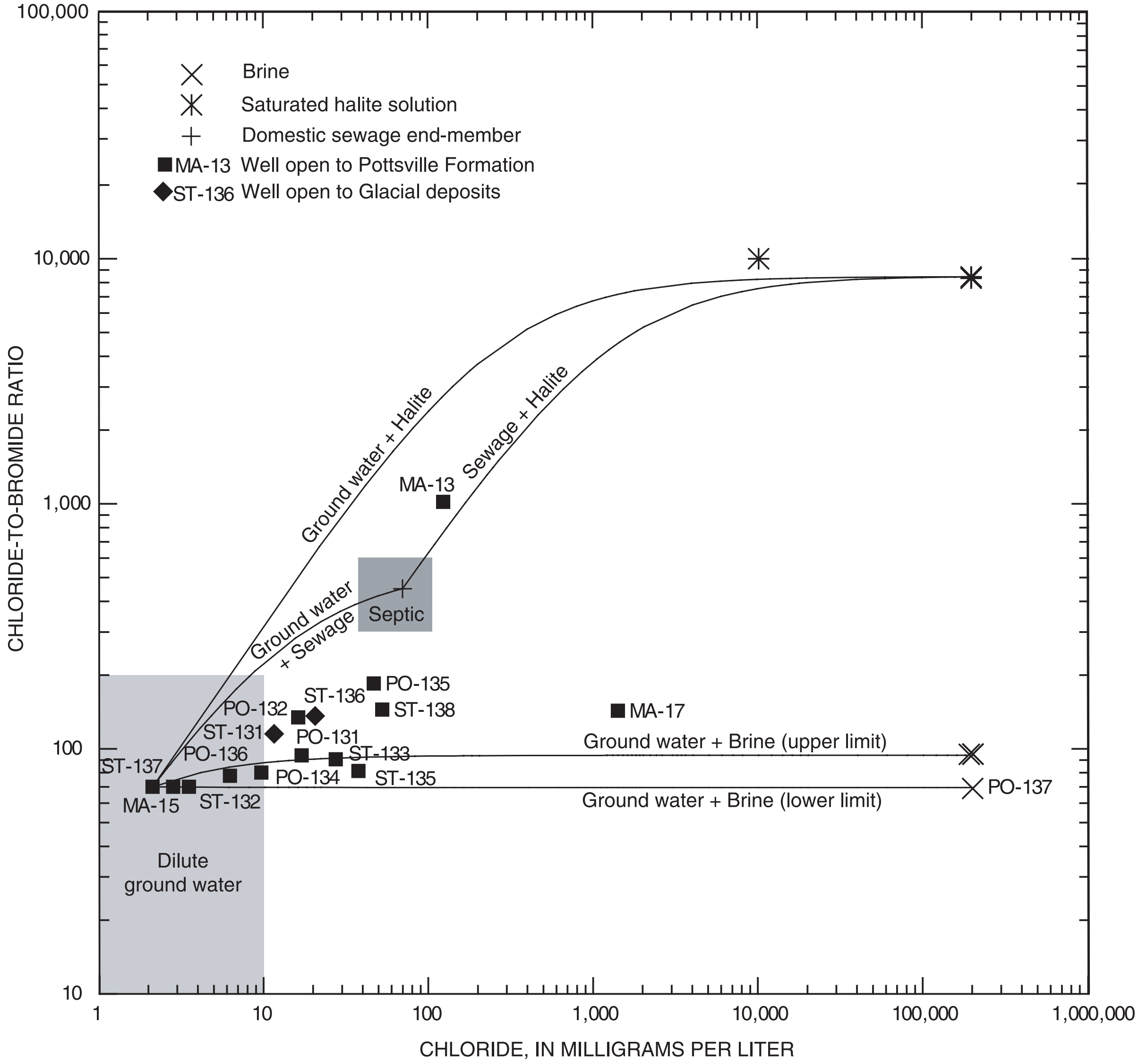
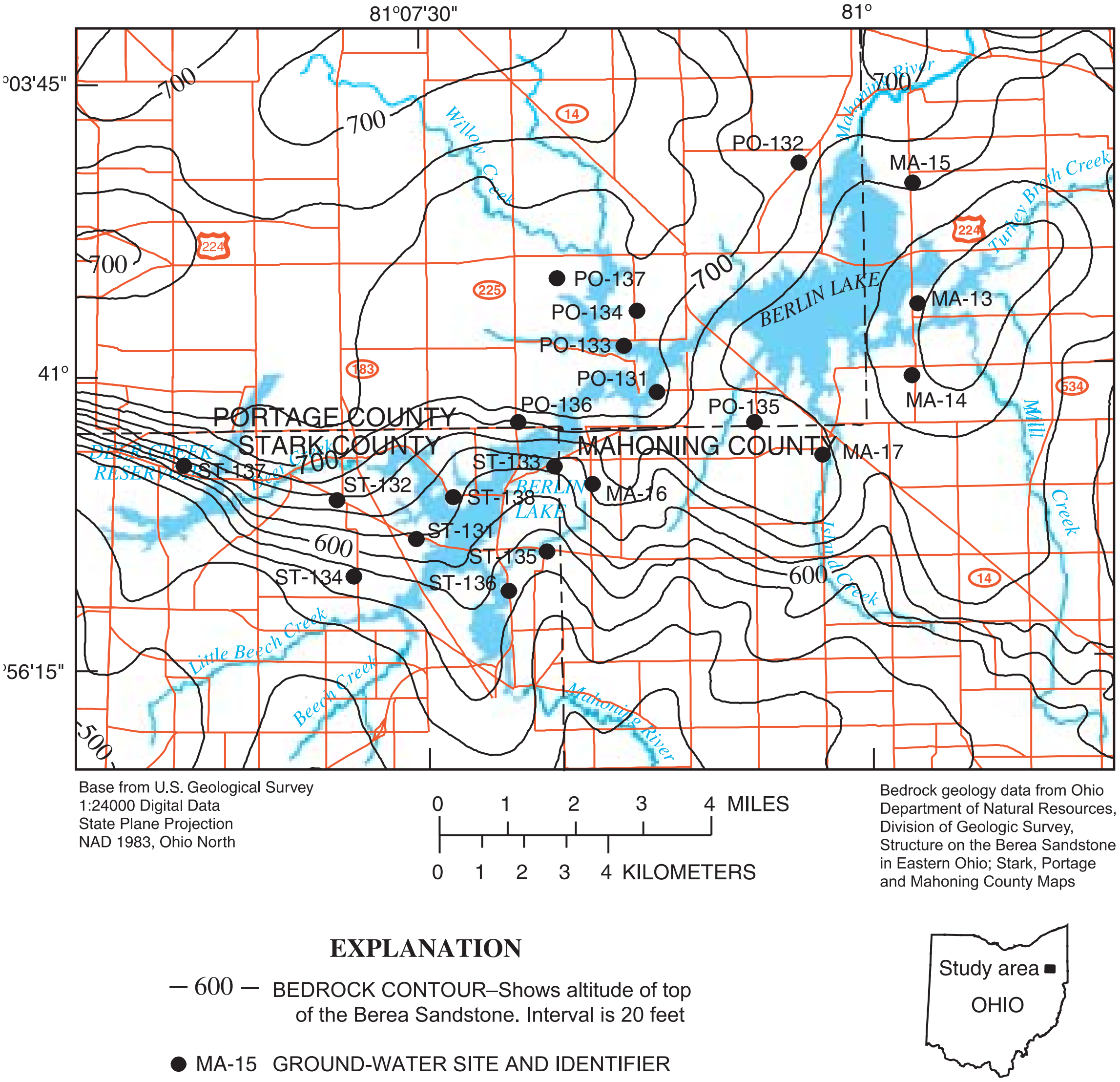


Figure 9. Binary mixing curves for chloride-to-bromide ratios, Berlin Lake area ground-water samples, Ohio, 2001. (Halite end-member from Knuth and others, 1990; domestic sewage end-member from Davis and others, 1998, and Peavy, 1978; brine end-members from Eberts and others, 1990 and PO-137).

The sample at well MA-17 plots to the right of dilute ground water and near the brine mixing line. The water from this well contains natural gas, has a salty taste, and a specific conductance of 5,060 µS/cm. The top of well MA-17 is at an altitude of 1,074 ft, and the well is 315 ft deep (table 2); the well is near the 660-ft contour of the top of the Berea Sandstone (fig. 10), leaving about 99 ft from the bottom of the well to the top of the Berea. The bottom of well PO-131 is 168 ft from the top of the Berea, the next closest well to the top of the Berea, but the chemical characteristics of the water from PO-131 and MA-17 are different (fig. 6). As previously noted, the Berea Sandstone in this area has some potential for gas and oil production, and water from the Berea may be affecting water in this well. A more detailed study, focusing on deeper wells, would need to be done to determine the effects of withdrawing water from near the top of the Berea.

The positions of the samples from these wells (MA-13, ST-131, ST-135, PO-131, and MA-17) on the mixing diagram indicate some effect from a chloride and/or bromide source. The source could be upflow of water from the Berea Sandstone or recharge from contaminated water at land surface. Another process that could produce these results could be the dissolution and cation exchange method discussed in the major anions and cations section. A study of synoptic water-level measurements, designed to obtain a better understanding of ground-water flow, both horizontally and vertically, would benefit possible water-quality studies in the area.



Base from U.S. Geological Survey
1:24000 Digital Data
State Plane Projection
NAD 1983, Ohio North

Bedrock geology data from Ohio Department of Natural Resources, Division of Geologic Survey, Structure on the Berea Sandstone in Eastern Ohio; Stark, Portage and Mahoning County Maps

Figure 10. Top of the Berea Sandstone in the Berlin Lake area, Ohio.

Surface water. Northeastern Ohio has been drilled for oil since the mid-1800s; therefore, background, dilute surface water is difficult to define. A similar analysis as described for the ground-water samples was done for the surface water, and the dilute surface water end-member was chosen to be the lowest chloride concentration: 7.3 mg/L, with a Cl:Br of 730 (bromide concentration was less than the detection limit of 0.01 mg/L.)

According to Davis and others (1998), most streams have chloride concentrations less than 100 mg/L and Cl:Br ratios reflecting regional precipitation (about 50 for areas that are more than about 125 miles inland). For the 14 samples in which the bromide exceeded the detection limit (table 4), the median chloride concentration was 80.5 mg/L, and the median Cl:Br ratio was 1,810. The addition of brines to the surface water would tend to elevate the chloride concentration and reduce the Cl:Br ratio, which is not the case here. The high Cl:Br ratio would indicate that the elevated Cl:Br ratio from the 14 samples could be the result of sewage and road-salt-affected waters mixing with the surface water, which could overpower any effect of brine.

Historical chloride concentrations

Three of the surface-water sites sampled for this investigation were sampled previously by USGS personnel. The Mahoning River at Alliance (SW2), Mill Creek near Berlin Center (SW8), and the Mahoning River below Berlin Dam (SW6) (fig. 1) were sampled in the late 1960s and early 1970s for various constituents, including chloride. Many of the samples were targeted for events (extremely high- or low-flow condition) and may represent higher or lower than normal chloride concentrations. To make the data more comparable to current data, an instantaneous chloride discharge was computed on the basis of chloride concentration, streamflow and the conversion of time to days:

$$ICD = \frac{Cl}{1 \times 10^{6} \frac{kg}{mg}} \left(Q \times 28.32 \frac{L}{ft^{3}}\right)\left(86,400 \frac{s}{d}\right) \quad , \quad (1)$$

where ICD is the instantaneous chloride discharge, in kilograms per day, Cl is the chloride concentration, in milligrams per liter, and Q is the streamflow, in cubic feet per second.

For example, a chloride concentration of 35 mg/L and a discharge of 5.6 ft^3/s calculates as an instantaneous chloride discharge of 480 kg/d. Summary statistics for chloride concentrations and instantaneous chloride discharges for the three sites in the Berlin Lake area are presented in table 8.

A seasonal analysis of the historical data indicates that, for the Mahoning River above the dam (site SW2) and below the dam (site SW6), chloride discharges in the early spring were higher than other seasons of the year (fig. 11); most likely because of road salt in surface runoff. The data from 2001 at these three sites do not indicate chloride discharges outside the historical range for the months of July and November (table 8). With only two samples at each site, no conclusions about the overall chloride discharges are justifiable. More sampling, focusing on different streamflows and seasonal changes, would need to be done to indicate any overall change (or lack of change) from the 1960s–70s to the present.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are a large group of environmentally important compounds that result from the incomplete combustion of organic carbon, such as that in wood and fossil fuels. PAHs are considered to be the most acutely toxic component of petroleum products, and they also are associated with chronic and carcinogenic effects (Irwin and others, 1998). Acute toxicity because of exposure to a single PAH is rare, so PAHs are more frequently associated with long-term chronic toxicity (Irwin and others, 1997). PAHs have a low solubility in water and a high affinity for sorbing to sediment-associated organic matter; therefore, bed sediments tend to act as reservoirs for PAHs (Smith and others, 1988). These samples provide a baseline for comparison to future work and a method for comparison with other regional studies.

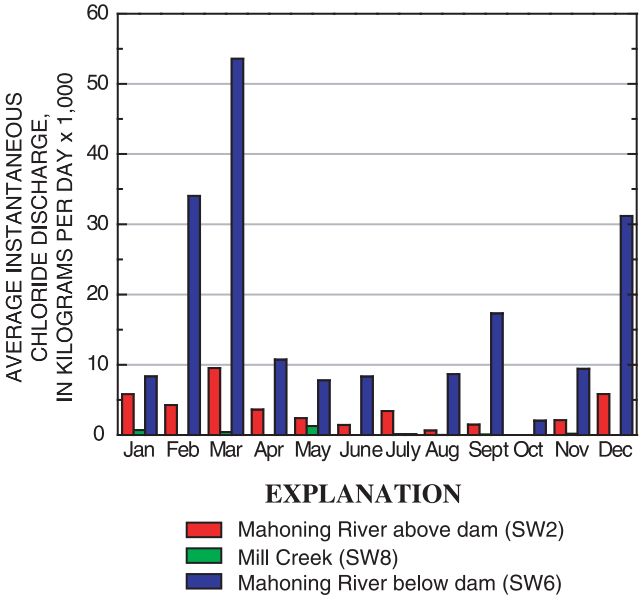


Figure 11. Average instantaneous chloride discharge for three surface-water sites near Berlin Lake, Ohio.

The data set of five bed-sediment samples analyzed for PAHs is too small for statistical analysis; therefore, the following discussion (modeled after a discussion in Rheaume and others, 2000) gives a brief description of selected constituents (those found to exceed the labs detection limit), detection frequency, maximum concentration, and a comparison with the detection frequency among sites in the Lake Erie-Lake Saint Clair Drainages. The data for all

Table 8. Historical chloride concentrations and instantaneous chloride discharge at three sites near Berlin Lake, Ohio

[NA, not applicable.]

Map Identifier	Time period	Number of samples	Chloride concentration (in milligrams per liter)			Instantaneous chloride discharge (in kilograms per day)		
			Minimum	Median	Maximum	Minimum	Median	Maximum
SW8	1965-73	20	13	20	90	0.4	122	2,690
	2001	2	57.0	NA	74.8	11	NA	933
SW2	1965-77	38	18	28	59	191	2,520	30,200
	2001	2	48.8	NA	60.8	1,060	NA	10,900
SW6	1965-77	38	18	26	43	1,040	9,800	105,000
	2001	2	58.7	NA	64.9	36	NA	168

PAHs analyzed for are presented by site in table 6.

Anthracene. Anthracene is a low-molecular-weight, three-ring PAH. Wastewaters from synthetic fuel industries are most likely to contain anthracene (Irwin and others, 1998). The sampling at Berlin Lake found detectable levels of anthracene in three of the five samples with a maximum concentration of 310 µg/kg at the Mahoning River at Rockhill Road site. Rheaume and others (2000) found anthracene in 76 of 392 bed-sediment samples collected in the Lake Erie-Lake Saint Clair Drainages.

Benz[*a*]anthracene. Benz[*a*]anthracene is a high-molecular-weight, four-ring PAH. Benz[*a*]anthracene is formed when gasoline, garbage, or any animal or plant material burns, and it usually is found in smoke and soot. It also is found in creosote. In 1990, benz[*a*]anthracene was found in 62 of the 1,177 sites on the NPL of hazardous waste sites in the United States (Irwin and others, 1998). The sampling at Berlin Lake found detectable levels of benz[*a*]anthracene in all of the five samples, with a maximum concentration of 830 µg/kg at the Mahoning River at Rockhill Road. Rheaume and others (2000) found benz[*a*]anthracene in 158 of 393 bed-sediment samples collected in the Lake Erie-Lake Saint Clair Drainages.

Benzo[*a*]pyrene. Benzo[*a*]pyrene is a high-molecular-weight, five-ring PAH. Benzo[*a*]pyrene is widespread in the environment because it is a product of incomplete combustion. Natural sources include volcanoes and forest fires, but it also is produced from gasoline, motor oil, diesel oil, asphalt, and coal tar pitch (Irwin and others, 1998). The sampling at Berlin Lake found detectable levels of benzo[*a*]pyrene in all of the five samples, with a maximum concentration of 940 µg/kg at the Mahoning River at Rockhill Road. Rheaume and others (2000) found benz[*a*]pyrene in 147 of 388 bed-sediment samples collected in the Lake Erie-Lake Saint Clair Drainages.

Chrysene. Chrysene is a component in coal tar and is present in exhaust from gasoline engines. The sampling at Berlin Lake found detectable levels of chrysene in three of the five samples, with a maximum concentration of 760 µg/kg at the Mahoning River at Rockhill Road. Rheaume and others (2000) found chrysene in 189 of 396 bed-sediment samples collected in the Lake Erie-Lake Saint Clair Drainages.

Phenanthrene. Phenanthrene is present naturally in coal and petroleum and is used in the synthesis of dyes and drugs (Parker, 1984). It also is a high-temperature combustion product of coal and petroleum. The sampling at Berlin Lake found detectable levels of phenanthrene in four of the five samples, with a maximum concentration of 2,100 µg/kg at the Mahoning River at Rockhill Road. Rheaume and others (2000) found phenanthrene in 187 of 298 bed-sediment samples collected in the Lake Erie-Lake Saint Clair Drainages.

Summary and conclusions

Berlin Lake is a U.S. Army Corps of Engineers water-control project on the Mahoning River in northeastern Ohio. The area, encompassing parts of Stark, Mahoning, and Portage Counties, has been heavily developed for oil and gas production. This development could lead to potential contamination of water resources with hydrocarbons and (or) brine from oil and gas production. In cooperation with the U.S. Department of the Interior, Bureau of Land Management, the U.S. Geological Survey collected and analyzed ground-water, surface-water, and bed-sediment samples to determine the current (2001) water and sediment quality.

When compared to results from other studies in the region, the pH of ground- and surface-water samples did not indicate any anomalies. An analyses of specific conductance and dissolved solids indicate that 78 percent (14 of 18) of the ground-water samples exceeded the USEPA (2002) Secondary Maximum Contaminant Level for dissolved solids in public water supplies (500 mg/L). This result compares to 6 percent found in two nearby studies.

A graphical analysis of major ions indicates a wide range of waters in the region, and no specific aquifer or area produces a single type of water. Water with a hardness concentration of greater than 180 mg/L is considered very hard water, and the median hardness concentration for ground-water samples in this study is 400 mg/L. The analysis also indicates that three ground-water samples were softened. The sample from another well plots near a brine sample, indicating a possible effect of brine.

An analysis of the cations showed some signs that are seen in other studies in the region: a pattern of losing calcium and magnesium cations to sodium ions. A common natural process that supports this pattern is dissolution of carbonate minerals combined with cation exchange. Cation exchange is a process in which calcium and magnesium ions are removed from solution and replaced by sodium ions on exchangeable sites in clay minerals. As the reaction proceeds, the ratio of calcium ions to sodium ions remaining in solution decreases.

Chloride-to-bromide ratios were used to determine effects of road salt, domestic sewage (septic-system leachate), and oil and gas brine on dilute water. Ground-water-sample results from one well indicate an effect from oil and gas brine, either from upwelling from deeper ground waters or recharge from contaminated surface water, or the dissolution of carbonate minerals combined with cation exchange. Four other samples plot outside the dilute-ground-water area and between the brine and sewage mixing lines. These wells may be affected by a combination of brine and infiltration from malfunctioning septic systems. The two wells completed in the glacial deposits are included in this group. The other two samples, from wells completed in the Pottsville Formation, plot along the mixing curve between dilute ground water and brine.

For the 14 surface-water samples in which the bromide exceeded the detection limit, the median chloride concentration was 80.5 mg/L and the median Cl:Br ratio was 1,810. The addition of brines to the surface water would tend to elevate the chloride concentration and draw down the Cl:Br ratio. The elevated Cl:Br ratio from the 14 samples could be the result of sewage and road-salt-affected waters mixing with the surface water, which would overpower any effect of the brine.

Three of the surface-water sites sampled for this investigation were previously sampled by USGS personnel in the late 1960s and early 1970s for many constituents, including chloride. A seasonal analysis of the data indicated elevated instantaneous chloride discharges in the early spring for the Mahoning River above and below the dam, most likely because of road salt in surface-water runoff. The limited data from the 2001 sampling, compared to the historical data for these three sites, do not indicate an increase in chloride concentration or discharges for the months of July and November. Examining the seasonal change in chloride concentrations would require more to indicate an overall change in concentrations.

Polycyclic aromatic hydrocarbons (PAHs) are a large group of environmentally important compounds that result from the incomplete combustion of organic carbon such as wood and fossil fuels. PAHs are considered to be the most acutely toxic component of petroleum products, and they also are associated with chronic and carcinogenic effects. PAHs have a low solubility in water and a high affinity for sorbing to sediment-associated organic matter; therefore, bed sediments tend to act as reservoirs for PAHs. With only five samples collected during the study, a statistical analyses would be nearly insignificant in any finding; therefore, a comparison to other regional studies was done. An analyses comparing the concentration of selected polycyclic aromatic hydrocarbons in streambed sediments does not indicate that the sites near Berlin Lake are different than other regional sites.

Further research in the vicinity of Berlin Lake would benefit from synoptic water-level measurements designed to obtain a general understanding of the ground-water-flow direction. A more detailed water-quality study, focusing on water wells open to waters near the top of the Berea, may give insight into the effects of the deeper waters on drinking water. Continued water-quality sampling at the three surface-water sites with historical data may help define a trend in chloride discharges for surface water in the vicinity of Berlin Lake.

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Table 4. Physical and chemical characteristics of ground-water samples collected in the vicinity of Berlin Lake, Ohio, July and August 2001

[µS/cm, microsiemens per centimeter at 25 degrees Celcius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than.]

Map Identifier	Date	Water level, depth below land surface (feet)	Depth of well, total (feet)	Specific conductance (µS/cm)	pH, water whole, field (standard units)	Temperature, water (degrees Celsius)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as CaCO$_3$)
ST-131	07-24-2001	--	56	1,100	7.1	12.8	0.4	569
ST-132	07-25-2001	25.73	202	630	6.9	12.4	5.1	341
ST-133	07-25-2001	31.59	134	1,760	7.4	11.8	<.1	329
ST-134[a]	07-25-2001	38.90	111	712	8.7	12.9	2.7	3.07
ST-135	07-25-2001	35.77	115	1,400	7.6	12.1	<.1	191
ST-136	07-25-2001	--	89	1,590	6.8	14.7	2.7	949
ST-137	08-08-2001	7.09	100	721	6.9	14.3	.1	390
ST-138	08-08-2001	7.09	186	1,150	7.2	12.2	<.1	480
PO-131	07-24-2001	30.85	175	2,430	7.2	14.3	.4	869
PO-132	07-25-2001	--	124	1,630	7.0	12.0	1.7	470
PO-133[a]	07-25-2001	22.49	114	1,200	7.1	12.3	<.1	68.4
PO-134	07-26-2001	9.59	100	1,690	7.1	11.1	.9	321
PO-135	07-26-2001	14.28	67	930	7.2	12.0	5.8	499
PO-136	08-08-2001	30.81	105	950	7.2	12.3	.1	400
PO-137[b]	08-09-2001	--	5,450	212,000	3.2	--	--	146,000
MA-13	07-20-2001	36.35	151	1,020	7.5	11.7	1.4	435
MA-14[a]	07-20-2001	66.70	203	1,180	8.9	13.3	.5	19
MA-15	07-25-2001	67.31	175	764	7.6	12.1	.4	317
MA-17	08-09-2001	114.80	315	5,060	7.4	12.9	<.1	175

Map Identifier	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, water, field (mg/L as HCO$_3$)	Alkalinity, water, ield (mg/L as CaCO$_3$)	Sulfate, dissolved (mg/L as SO$_4$)	Chloride, dissolved (mg/L as Cl)
ST-131	139	53.7	39.4	3.9	498	409	235	11.5
ST-132	91	27.7	10.8	1.68	296	243	104	3.5
ST-133	84.5	28.5	312	5.6	604	498	465	27.2
ST-134[a]	.73	.301	177	1.43	407	344	41.2	2.3
ST-135	49.1	16.5	259	4.68	657	542	177	37.3
ST-136	262	71.7	12.9	5.21	282	232	723	20.4
ST-137	111	28.5	7.5	2.28	444	365	90.6	2.1
ST-138	117	45.3	75.9	3.81	512	421	184	52.3
PO-131	195	92.7	231	8.42	789	648	778	16.9
PO-132	122	41	221	9.39	771	633	295	16.1
PO-133[a]	14.8	7.6	281	5.07	834	685	1.6	15.1
PO-134	75.8	31.9	291	8.3	839	690	310	9.6
PO-135	135	39.6	19	2.95	364	299	184	46.2
PO-136	99	37	63.3	5.26	389	320	230	6.2
PO-137[b]	49,800	5,290	56,600	3,960	--	--	214	199,000
MA-13	132	25.6	34.7	2.6	317		65.9	122
MA-14[a]	5.39	1.35	282	2.22	617	529	.6	58.6
MA-15	84.5	25.8	48.9	4.26	323	266	148	2.8
MA-17	49.7	12.4	996	6.37	454	375	.9[c]	1,450

Table 4. Physical and chemical characteristics of ground-water samples collected in the vicinity of Berlin Lake, Ohio, July and August 2001—Continued

[µS/cm, microsiemens per centimeter at 25 degrees Celcius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than.]

Map Identifier	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 degrees Celsius, dissolved (mg/L)	Fluoride, dissolved (mg/L as F)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
ST-131	0.1	18.3	747	0.1[c]	510	335
ST-132	.05	14.9	400	.3	260	394
ST-133	.3	11.4	1230	.8	180	112
ST-134[a]	.08	7.4	432	1.5	7.6[c]	2.0[c]
ST-135	.46	8.2	877	1.6	80	45.1
ST-136	.15	14.7	1250	.1[c]	3510	1710
ST-137	.03	15.4	477	.2	1130	78.9
ST-138	.36	19	752	.1[c]	1700	26.4
PO-131	.18	10.5	1720	.4	80	69.7
PO-132	.12	8.8	1090	.5	30	135
PO-133[a]	.2	6.6	743	.6	280	18.3
PO-134	.12	7.2	1150	.5	340	110
PO-135	.25	13.2	619	.2	770	67.8
PO-136	.08	12	645	.2	590	41.5
PO-137[b]	2,900	14	--	8	146	49.8
MA-13	.12	14.6	553	.2	<10	<3.0
MA-14[a]	.57	6.9	663	1.7	30	5
MA-15	.04	14.6	489	.2	570	77.7
MA-17	.81	7.3	--	.4	450	25.3

[a] Although efforts were made to collect untreated water that would be representative of the aquifer, the high sodium concentration and unusually low concentrations of hardness, calcium, magnesium, iron, manganese, and strontium suggest that this water sample was softened by ion-exchange methods.

[b] The sample collected from PO-137 is a brine sample from waters in the Albion Group.

[c] Estimated value.

Table 5. Physical and chemical characteristics of surface-water samples collected in the vicinity of Berlin Lake, Ohio, July and August 2001

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celcius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than.]

Map identifier	Site identifier	Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH, water, whole, field (standard units)	Temperature, water (degrees Celsius)	Oxygen, dissolved (mg/L)	Hardness, total (mg/L as $CaCO_3$)
SW1	410037080572800	07-18-2001	0.02	565	8.0	17.3	7.8	286
		11-27-2001	.21	670	7.2	9.5	9.4	246
SW2	03086500	07-18-2001	7.07[a]	823	8.1	25.9	8.6	307
		11-28-2001	91[a]	590	7.6	9.8	9.8	237
SW3	405744081053300	07-18-2001	.001	1,410	7.4	22.3	5.1	672
		11-28-2001	.05	1,560	7.1	7.6	7.4	821
SW4	410121081020400	07-17-2001	.007	1,410	7.9	22.8	8.9	--
		11-27-2001	.34	990	6.9	10.2	8.9	281
SW5	405643081091500	07-19-2001	.21	720	7.7	21	4.9	305
		11-28-2001	3.1	824	7.8	7.8	11.6	301
SW6	03090500	07-19-2001	168[b]	560	7.4	17.8	7.2	186
		11-29-2001	36[b]	580	7.9	9.6	11.3	192
SW7	405551081083400	07-19-2001	.03	910	8.0	20.8	7.5	275
		11-28-2001	.34	1,200	8.0	8.8	9.8	304
SW8	03089500	07-18-2001	.08	782	7.8	20.5	4.7	314
		11-27-2001	5.1	740	7.6	9.6	9.8	278
SW9	405536081091400	07-19-2001	.22	795	7.8	22	5.9	293
		11-28-2001	9.4	610	8.2	8.1	12.3	221
SW10	410025081055600	07-25-2001	.18	1,080	7.9	19.8	7.8	590
		11-28-2001	.25	900	7.7	7.6	11.1	422
SW11	405847081085300	07-24-2001	13.3	489	7.8	28.4	5.8	162
		11-28-2001	3.9	570	7.7	8.2	9.9	209
SW12	410157081055500	07-24-2001	.01[c]	1,280	7.8	25.5	7.4	660
		11-28-2001	3.8	550	7.4	7.8	10.8	152
SW13	410238081043900	07-24-2001	.02	2,060	8.1	25.7	9.4	520
		11-28-2001	3.1	630	7.4	8.3	10.3	170
SW14	410105081052100	07-26-2001	3	1,800	7.8	--	--	913
		11-29-2001	0.07	1,410	7.4	7.4	8.8	675
SW15	405823081004700	11-28-2001	1.5	990	7.7	8.2	9.7	300
SW16	405944081021000	11-29-2001	.04	590	7.2	8.1	7.5	190

Table 5. Physical and chemical characteristics of surface-water samples collected in the vicinity of Berlin Lake, Ohio, July and August 2001—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celcius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than.]

Map identifier	Site identifier	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, water, field (mg/L as HCO_3)	Alkalinity, water, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
SW1	410037080572800	75.5	23.7	9.4	2.24	244	202	57.5
		69.6	17.5	40.3	3.76	185	152	72.7
SW2	03086500	82.2	24.7	45.1	7.14	182	152	140
		65.0	18.3	27.5	5.95	163	134	103
SW3	405744081053300	150	72.4	50.2	7.83	149	123	569
		191	83.5	42.7	7.47	70	58	834
SW4	410121081020400	--	--	--	--	437	367	--
		75.2	22.6	87.3	8.47	162	133	139
SW5	405643081091500	82.3	24.1	27.2	3.05	292	242	72
		80.3	24.4	53.4	5.54	207	171	116
SW6	03090500	50.7	14.4	33.3	5.05	129	106	70.6
		50.5	16	37.9	6.1	101	122	93.9
SW7	405551081083400	78.4	19.1	73.8	3.61	259	215	58.9
		89.2	19.7	124	4.22	248	205	95.1
SW8	03089500	81	27.2	36.1	5.99	231	191	78.8
		73.7	22.8	37.9	10.2	179	148	121
SW9	405536081091400	81.3	21.8	47.3	4.7	288	238	72.5
		62.9	15.6	36.9	5.96	166	138	75.7
SW10	410025081055600	150	52	17.7	7.5	240	199	384
		104	39.6	21.0	6.07	156	130	272
SW11	405847081085300	43.7	12.8	30.1	4.45	136	113	38.8
		55.2	17.2	35.0	3.90	168	138	61.6
SW12	410157081055500	153	67.5	35.9	5.12	278	233	445
		37.6	14.2	40.8	5.62	45	37	100
SW13	410238081043900	122	52.5	226	18.4	336	280	335
		41.0	16.0	55.0	5.10	86	71	110
SW14	410105081052100	249	70.5	56.3	11.7	154	127	762
		182	53.4	39.3	9.17	150	124	566
SW15	405823081004700	75.5	27.0	79.1	8.40	147	121	158
SW16	405944081021000	47.0	17.0	22.0	33.0	102	84	120

Table 5. Physical and chemical characteristics of surface-water samples collected in the vicinity of Berlin Lake, Ohio, July and August 2001—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celcius; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed; <, less than.]

Map identifier	Site identifier	Chloride, dissolved (mg/L as Cl)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 degrees Celsius, dissolved (mg/L)	Fluoride, dissolved (mg/L as F)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
SW1	410037080572800	7.3	<0.01	15.5	313	0.4	10	135
		81.3	<.06	12.9	389	.2	40	92.2
SW2	03086500	60.8	.02	7.1	459	.4	9.3[c]	140
		48.8	.02[c]	7.2	356	.2	60	176
SW3	405744081053300	48.8	<.01	4.3	981	.4	50	4,750
		49.2	<.03	6.4	1,250	.2	40	279
SW4	410121081020400	28.6	.02	--	--	--	--	--
		135	.05	10.2	558	.3	100	35
SW5	405643081091500	47.6	<.01	8.6	408	.2	20	508
		89.2	.02[c]	7.5	478	.2	50	64.7
SW6	03090500	58.7	<.01	2.8	299	.2	7.3[c]	672
		64.9	<.03	1.5	321	.3	20	43.5
SW7	405551081083400	117	.06	10.3	488	.3	20	117
		208	.16	10.2	673	.3	30	102
SW8	03089500	57	<.01	8.0	409	.3	<10	295
		74.8	.03[c]	8.0	437	.2	60	58.5
SW9	405536081091400	71.8	<.01	5.4	441	.3	10	250
		63.9	<.03	7.1	350	.2	100	53.2
SW10	410025081055600	20.6	.03	8.3	758	.3	<10	174
		29.0	<.03	7.6	556	.2	10	140
SW11	405847081085300	53.9	<.01	1.5	253	.2	<10	142
		64.0	<.03	2.8	323	.2	20	163
SW12	410157081055500	33.5	.02	3.9	882	.3	<10	346
		79.5	<.03	8.6	309	.1[c]	220	76.6
SW13	410238081043900	256	.19	7.5	1,180	.2	<30	17.9
		83.0	<.06	6.1	355	.1	97	46
SW14	410105081052100	86.2	.14	8.2	1,320	1.4	<10	619
		64.4	.09	7.5	998	.9	10	590
SW15	405823081004700	135	.02[c]	5.2	561	.3	70	56.3
SW16	405944081021000	54.0	<.15	4.4	345	.2	99	63

[a] Discharge from U.S. Geological Survey rating curve.

[b] Discharge from rating curve provided by U.S. Army Corps of Engineers.

[c] Estimated value.

Table 6. Summary of polycyclic aromatic hydrocarbon compounds found in bed sediment in the vicinity of Berlin Lake, Ohio, September 2001

[ws, wet sieve; mm, millimeters; dw, dry weight; rec, recoverable; µg/kg, micrograms per kilogram; <, less than; E, estimated; M, detected at concentrations so low that quantities are not reported.]

Map identifier	Site identifier	Acenaphthylene, ws, <2mm dw, rec (µg/kg)	Acenaphthene, ws, <2mm dw, rec (µg/kg)	Acridine, ws <2mm dw, rec (µg/kg)	C8-Alkyl phenol, ws <2mm dw, rec (µg/kg)	Anthracene, ws <2mm dw, rec (µg/kg)	9,10 Anthraquinone, ws <2mm dw, rec (µg/kg)	Azobenzene, ws <2mm dw, rec (µg/kg)	Benz[*a*]anthracene, ws <2mm dw, rec (µg/kg)
SD1	410021080592000	<50	<50	<50	<50	<50	<50	<50	E20
SD2	410014081035900	<50	<50	<50	<50	<50	<50	<50	E20
SD3	405739081064000	E30	140	50	E20	310	340	<50	830
SD4	405807081064000	E5	<50	<50	<50	E10	40	<50	50
SD5	405924081004900	E8	E7	<50	E20	E40	E50	<50	100

Map identifier	Site identifier	Benzocinnoline, ws <2mm dw, rec (µg/kg)	Benzo[*b*] fluoranthene, ws <2mm dw, rec (µg/kg)	Benzo[*k*] fluoranthene, ws <2mm dw, rec (µg/kg)	Benzo [*g,h,i*] perylene, ws <2mm dw, rec (µg/kg)	Benzo[*a*] pyrene, ws <2mm dw, rec (µg/kg)	2, 2'-Biquinoline, ws <2mm dw, rec (µg/kg)	4-Bromophenylphenylether, ws <2mm dw, rec (µg/kg)	Butylbenzylphthalate, ws <2mm dw, rec (µg/kg)
SD1	410021080592000	<50	E20	M	E40	E20	<50	<50	E40
SD2	410014081035900	<50	E20	<50	E10	E20	<50	<50	50
SD3	405739081064000	<50	820	700	440	760	<50	<50	<50
SD4	405807081064000	<50	80	60	60	60	<50	<50	50
SD5	405924081004900	<50	120	100	190	120	<50	<50	50

Map identifier	Site identifier	Carbazole, ws <2mm dw, rec (µg/kg)	Bis (2-chloroethoxy) methane, ws <2mm dw, rec (µg/kg)	4-Chloro-3-methylphenol, ws <2mm dw, rec (µg/kg)	2-Chloronaphthalene, ws <2mm dw, rec (µg/kg)	2-Chlorophenol, ws <2mm dw rec (µg/kg)	4-Chlorophenylphenyl ether, ws <2mm dw, rec (µg/kg)	Chrysene, ws <2mm dw, rec (µg/kg)	*p*-Cresol, ws <2mm dw, rec (µg/kg)
SD1	410021080592000	<50	<50	<50	<50	<50	<50	M	<50
SD2	410014081035900	<50	<50	<50	<50	<50	<50	<50	<50
SD3	405739081064000	250	<50	<50	<50	<50	<50	940	110
SD4	405807081064000	M	<50	<50	<50	<50	<50	60	E50
SD5	405924081004900	M	<50	<50	<50	<50	<50	120	E30

Map identifier	Site identifier	Dibenz [a,h] anthracene, ws <2mm dw, rec (µg/kg)	Dibenzothiophene, ws <2mm dw, rec (µg/kg)	Di-*n* butylphthalate, ws <2mm dw, rec (µg/kg)	1,2-Dichlorobenzene, ws <2mm dw, rec (µg/kg)	1,3-Dichlorobenzene, ws <2mm dw, rec (µg/kg)	1,4-Dichlorobenzene, ws <2mm dw, rec (µg/kg)	Diethylphthalate, ws <2mm dw, rec (µg/kg)	1,2-Dimethylnaphthalene, ws <2mm dw, rec (µg/kg)
SD1	410021080592000	<50	<50	M	<50	<50	<50	<50	<50
SD2	410014081035900	<50	<50	E10	<50	<50	<50	<50	<50
SD3	405739081064000	160	100	<50	<50	<50	<50	<50	E40
SD4	405807081064000	60	<50	E10	<50	<50	<50	<50	<50
SD5	405924081004900	E30	E10	E20	<50	<50	<50	M	E40

Table 6. Summary of polycyclic aromatic hydrocarbon compounds found in bed sediment in the vicinity of Berlin Lake, Ohio, September 2001—Continued

[ws, wet sieve; mm, millimeters; dw, dry weight; rec, recoverable; μg/kg, micrograms per kilogram; <, less than; E, estimated; M, detected at concentrations so low that quantities are not reported.]

Map identifier	Site identifier	1,6-Dimethylnaphthalene, ws <2mm dw, rec (μg/kg)	2,6-Dimethylnaphthalene, ws <2mm dw, rec (μg/kg)	3,5-Dimethylphenol, ws <2mm dw, rec (μg/kg)	Dimethyl phthalate, ws <2mm dw, rec (μg/kg)	2,4-Dinitrotoluene, ws <2mm dw, rec (μg/kg)	2,6-Dinitrotoluene, ws <2mm dw, rec (μg/kg)	Di-*n*-octylphthalate, ws <2mm dw, rec (μg/kg)	Bis(2-ethylhexyl) phthalate, ws <2mm dw, rec (μg/kg)
SD1	410021080592000	E10	E10	<50	<50	<50	<50	<50	70
SD2	410014081035900	<50	M	<50	<50	<50	<50	<50	120
SD3	405739081064000	110	150	<50	<50	<50	<50	<50	400
SD4	405807081064000	E10	E40	<50	<50	<50	<50	<50	130
SD5	405924081004900	110	130	<50	<50	<50	<50	<50	E50

Map identifier	Site identifier	Fluoranthene, ws <2mm dw, rec (μg/kg)	Fluorene, ws <2mm dw, rec (μg/kg)	Hexachlorobenzene, ws <2mm dw, rec (μg/kg)	Indeno [1,2,3- *cd*] pyrene, ws <2mm dw, rec (μg/kg)	Isophorone, ws <2mm dw, rec (μg/kg)	Isoquinoline, ws <2mm dw, rec (μg/kg)	2-Methylanthracene, ws <2mm dw, rec (μg/kg)	4,5-Methylenephenanthrene, ws <2mm dw, rec (μg/kg)
SD1	410021080592000	20	<50	<50	E30	<50	<50	<50	<50
SD2	410014081035900	E20	<50	<50	E30	<50	<50	<50	<50
SD3	405739081064000	2,400	190	<50	580	<50	<50	80	<50
SD4	405807081064000	110	<50	<50	80	<50	<50	E20	M
SD5	405924081004900	200	30	<50	100	<50	<50	E20	E10

Map identifier	Site identifier	1-Methyl-9h-fluorene, ws <2mm dw, rec (μg/kg)	1-Methylphenanthrene, ws <2mm dw, rec (μg/kg)	1-Methylpyrene, ws <2mm dw, rec (μg/kg)	Naphthalene, ws <2mm dw, rec (μg/kg)	Nitrobenzene, ws <2mm dw, rec (μg/kg)	N-Nitrosodiphenylamine, ws <2mm dw, rec (μg/kg)	N-Nitrosodi-*n*-propylamine, ws <2mm dw, rec (μg/kg)	Pentachloroanisole, ws <2mm dw, rec (μg/kg)
SD1	410021080592000	<50	M	M	E20	<50	<50	<50	<50
SD2	410014081035900	<50	<50	<50	<50	<50	<50	<50	<50
SD3	405739081064000	E50	140	100	230	<50	<50	<50	<50
SD4	405807081064000	<50	M	E10	E20	<50	<50	<50	<50
SD5	405924081004900	E30	60	E50	160	<50	<50	<50	<50

Map identifier	Site identifier	Pentachloronitrobenzene, ws <2mm dw, rec (μg/kg)	Phenanthrene, ws <2mm dw, rec (μg/kg)	Phenanthridine, ws <2mm dw, rec (μg/kg)	Phenol, ws <2mm dw, rec (μg/kg)	Pyrene, ws <2mm dw, rec (μg/kg)	Quinoline, ws <2mm dw, rec (μg/kg)	1,2,4-Trichloro benzene, ws <2mm dw, rec (μg/kg)	2,3,6 Trimethylnaphthalene, ws <2mm dw, rec (μg/kg)
SD1	410021080592000	<50	E40	<50	E20	E20	<50	<50	<50
SD2	410014081035900	<50	<50	<50	E30	E10	<50	<50	<50
SD3	405739081064000	<50	2,100	50	E40	1,900	E10	<50	60
SD4	405807081064000	<50	E40	<50	E30	90	<50	<50	M
SD5	405924081004900	<50	250	<50	E30	190	<50	<50	E40

Table 7. Concentration limits defined by primary and secondary public drinking-water regulations for selected properties and chemical constituents in water samples collected in the vicinity of Berlin Lake, Ohio, June and November 2001.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; USEPA, U.S. Environmental Protection Agency; OEPA, Ohio Environmental Protection Agency; SMCL, Secondary maximum contaminant level; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; >, greater than. SMCLs based on standards set by the Ohio Environmental Protection Agency (1994). Secondary Maximum Contaminant Level (SMCL) is a nonenforceable, esthetically based standard set by the U.S. Environment al Protection Agency for public drinking water. SMCLs are established for constituents that can adversely affect the odor or appearance of water (U.S. Environmental Protection Agency, 2000b).]

Constituent or property	Concentration limits and water-use implications
Specific conductance, µS/cm	Regulatory standards not established with respect to drinking water.
pH, standard units	The SMCL requires values between 7.0 and 10.5. Values outside this range may be corrosive to metal well casings and pipes, creating costly replacement problems. A pH below 6.5 can generate health-related problems by dissolving small quantities of trace metals such as lead, especially in a house built before lead solder was banned in 1987.
Temperature, degrees Celsius	Regulatory standards not established with respect to drinking water.
Dissolved oxygen, mg/L	Regulatory standards not established with respect to drinking water.
Hardness, mg/L as $CaCO_3$	Upon heating and evaporation, hard water precipitates carbonate mineral deposits, scale, and crusts on pipes, hot water heaters, boilers, and cooking utensils. Also causes increased soap consumption. Dufor and Becker (1964) give the following hardness classification: Hardness Range — Description 0 - 60 — Soft 61 -120 — Moderately hard 121 -180 — Hard More than 180 — Very hard
Calcium, dissolved, mg/L	Regulatory standards not established with respect to drinking water. Major contributor to hardness and scale formation.
Magnesium, dissolved, mg/L	Regulatory standards not established with respect to drinking water. Contributes to hardness and scale formation. At high concentrations (>125 mg/L) may cause laxative effects, especially to transient users.
Sodium, dissolved, mg/L	Regulatory standards not established with respect to drinking water, but sodium is listed on the U.S. EPA Drinking Water Contaminant Candidate List (CCL) as a Research Priority.
Potassium, dissolved, mg/L	Regulatory standards not established with respect to drinking water.
Alkalinity, mg/L as $CaCO_3$	Regulatory standards not established with respect to drinking water. Alkalinity is a measure of the capacity of water to neutralize acid.
Fluoride, dissolved, mg/L	The SMCL is 2.0 mg/L.
Sulfate, dissolved, mg/L as SO_4	The SMCL is 250 mg/L. Combines with calcium to form scale in water heaters and boilers. At concentrations exceeding 500-600 mg/L, imparts a bitter taste and may cause laxative effects in some individuals.
Chloride, dissolved, mg/L	The SMCL is 250 mg/L. At concentrations greater than 250 to 400 mg/L, imparts a salty taste to water depending on individual tolerance. High concentrations are corrosive to most metals.
Bromide, dissolved, mg/L	Regulatory standards not established with respect to drinking water.
Silica, dissolved, mg/L	Regulatory standards not established with respect to drinking water
Dissolved solids, residue at 180^{o}C	The SMCL is 500 mg/L. Concentrations greater than 1,000 mg/L may cause objectionable tastes and laxative effects. May also cause foaming or may corrode some metals.
Iron, dissolved, µg/L	The SMCL is 300 ìg/L. At concentrations exceeding the SMCL, iron contributes to staining of fixtures, utensils, and laundry. Higher concentrations form reddish-brown sediment and water-line deposits. At concentration greater than 1,800 ìg/L, the water has a metallic taste (Fetter,1980 ,p. 355).
Manganese, dissolved, µg/L	The SMCL is 50 µg/L. At concentrations exceeding the SMCL, manganese may cause dark-brown or black staining of fixtures, utensils, and laundry.

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