In cooperation with the Pike County Conservation District

Groundwater-Quality Assessment, Pike County, Pennsylvania, 2007

Scientific Investigations Report 2009–5129

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

Cover.

Typical well completed in bedrock in Pike County. Photograph by Arthur Lilienthal, U.S. Geological Survey.

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By Lisa A. Senior

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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Suggested citation:
Senior, L.A., 2009, Groundwater-quality assessment, Pike County, Pennsylvania, 2007: U.S. Geological Survey Scientific Investigations Report 2009-5129, 53 p.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Groundwater-Quality Assessment, Pike County, Pennsylvania, 2007

By Lisa A. Senior

Abstract

Pike County, a 545 square-mile area in northeastern Pennsylvania, has experienced the largest relative population growth of any county in the state from 1990 to 2000 and its population is projected to grow substantially through 2025. This growing population may result in added dependence and stresses on water resources, including the potential to reduce the quantity and degrade the quality of groundwater and associated stream base flow with changing land use. Groundwater is the main source of drinking water in the county and is derived primarily from fractured-rock aquifers (shales, siltstones, and sandstones) and some unconsolidated glacial deposits that are recharged locally from precipitation. The principal land uses in the county as of 2005 were public, residential, agricultural, hunt club/private recreational, roads, and commercial. The public lands cover a third of the county and include national park, state park, and other state lands, much of which are forested. Individual on-site wells and wastewater disposal are common in many residential areas.

In 2007, the U.S. Geological Survey, in cooperation with the Pike County Conservation District, began a study to provide current information on groundwater quality throughout the county that will be helpful for water-resource planning. The countywide reconnaissance assessment of groundwater quality documents current conditions with existing land uses and may serve as a baseline of groundwater quality for future comparison.

Twenty wells were sampled in 2007 throughout Pike County to represent groundwater quality in the principal land uses (commercial, high-density and moderate-density residential with on-site wastewater disposal, residential in a sewered area, pre-development, and undeveloped) and geologic units (five fractured-rock aquifers and one glacial unconsolidated aquifer). Analyses selected for the groundwater samples were intended to identify naturally occurring constituents from the aquifer or constituents introduced by human activities that pose a health risk or otherwise were of concern in groundwater in the county. The analyses included major ions, nutrients, selected trace metals, volatile organic compounds (VOCs), selected organic wastewater compounds, gross alpha-particle and gross beta-particle activity, uranium, and radon-222. Analyses of the 20 samples were primarily for dissolved constituents, but six samples were analyzed for both dissolved and total metals.

Results of the 2007 sampling indicated few water-quality problems, although concentrations of some constituents indicated influence of human activities on groundwater. No constituent analyzed exceeded any primary drinking-water standard or maximum contaminant level (MCL) established by the U.S. Environmental Protection Agency. Radon-222 levels were greater than, or equal to, the proposed MCL of 300 picocuries per liter (pCi/L) in water from 15 (75 percent) of the 20 wells. Radon-222 levels did not exceed the alternative MCL of 4,000 pCi/L in any groundwater sample. Radon-222 is naturally occurring, and the greatest concentrations (up to 2,650 pCi/L) were in water samples from wells in members of the Catskill Formation, a fractured-rock aquifer. The dissolved arsenic concentration of 3.9 micrograms per liter (μg/L) in one sample was greater than the health-advisory (HA) level of 2 μg/L but less than the MCL of 10 μg/L. Recommended or secondary maximum contaminant levels (SMCLs) were exceeded for pH, dissolved iron, and dissolved manganese.

In six samples analyzed for dissolved and total concentrations of selected metals, total concentrations commonly were much greater than dissolved concentrations of iron, and to a lesser degree, for arsenic, lead, copper, and manganese. Concentrations of iron above the SMCL of 300 μg/L may be more widespread in the county for particulate iron than for dissolved iron. The total arsenic concentration in one of the six samples was greater than the HA level of 2 μg/L but less than the MCL of 10 μg/L. The total manganese concentration of 361 μg/L in one sample exceeded the HA of 300 μg/L for manganese in drinking water.

Chloride concentrations were above the estimated natural background levels of 1 to 5 mg/L in about half of the wells, indicating that human activities may have influenced groundwater quality. Nitrate concentrations were less than the estimated natural background level of less than 0.8 mg/L as N in all but two groundwater samples. Boron concentrations equal to or greater than 20 mg/L are above natural background levels and were measured in wells with elevated sodium and chloride levels, indicating probable association with septic effluent and (or) road salt linked to residential development.

Anthropogenic organic compounds were detected at low or trace levels in groundwater from 10 of the 20 wells, indicating human activities at the land surface have affected groundwater quality to some degree. These compounds included VOCs in 3 groundwater samples and a few organic wastewater compounds in 10 groundwater samples. The highest VOC concentration measured was 39 μg/L of Freon-11 and indicated local groundwater contamination by improper disposal of the compound. DEET (N,N-diethyl-meta-toluamide), an insect repellent, was the most frequently detected organic wastewater compound.

Concentrations of chloride and nitrite plus nitrate as nitrogen generally were greater in water from wells in the commercial and residential areas with on-site wastewater disposal than in undeveloped and sewered areas. The anthropogenic compound DEET was detected in water from wells in most land-use areas, including undeveloped. Most other organic wastewater compounds and VOCs, except for the one well sample with Freon-11 contamination, were detected in water from wells in commercial and residential areas with on-site wastewater disposal.

Age-dating by measurement of chlorofluorocarbons (CFC-11, CFC-12, CFC-113) and sulfur hexafluoride (SF_6) in groundwater in samples from three wells yielded a range of ages from 6 to 54 years before 2007, with younger water in the glacial aquifer and older water in the bedrock aquifer. These findings indicate that groundwater in both aquifer types probably is susceptible to contamination by human activities at or near the land surface. Comparison of chloride and nitrate concentrations in the 2007 samples with samples collected previously in five wells since 1982 showed that concentrations of these constituents remained similar through time in samples from some wells but increased up to three-fold, especially for chloride, in others. The two wells with the largest increases in chloride were in a residential and commercial area along Route 209, a major transportation corridor in eastern Pike County.

Overall, based on this reconnaisance study, groundwater quality in Pike County is relatively good with no constituents exceeding any primary water-quality standards. The low levels of anthropogenic organic compounds detected and elevated concentrations of chloride and related constituents (boron and nitrate) relative to background levels indicate that human activities have influenced groundwater quality in some parts of the county.

Introduction

Pike County in northeastern Pennsylvania has experienced the largest relative population growth of any county in the state during the period 1990–2000 (U.S. Census Bureau, 2000). The 2006 Pike County Comprehensive Plan update (Pike County Commissioners, 2006) estimated as much as a 20-percent increase in population by the year 2010, and continued substantial increases are projected through 2025. This growing population may result in added dependence and stresses on groundwater, the primary source for drinking water in the county. As the demand for acceptable water quantity and quality for drinking-water supplies increases, contaminants associated with land-use changes have the potential to degrade water quality. On-site wastewater disposal is widespread. Residential growth in Pike County is associated with probable commercial development and additional infrastructure will most likely be needed to meet the needs of the increasing population.

Extensive land-use changes have the potential to reduce the quantity and affect the quality of water that recharges the groundwater system and eventually discharges to streams. At present (2009), high-quality streams that support healthy aquatic life and provide recreational fisheries are important assets of the county. This evolving landscape presents Pike County officials with current and future challenges not only in maintaining adequate groundwater quantity and quality capable of sustaining the influx of new residents but also in preserving base flow and base-flow quality in county streams.

The most recent countywide assessment of groundwater resources was done in the early 1980s (Davis, 1989) and was limited in scope. After more than 20 years of development, little is known about the current quantity and quality of groundwater in Pike County. Pike County officials, charged with managing water resources, need reliable information that characterizes those resources and provides a basis for scientifically defensible decisions to preserve and (or) mitigate potentially impaired water resources throughout the county.

Characterization of groundwater quality is an essential component in the planning process. In 2007, the U.S. Geological Survey (USGS), in cooperation with the Pike County Conservation District (PCCD), began a countywide reconnaissance assessment of groundwater quality. This report presents current (2007) groundwater-quality conditions within the context of existing land uses and may serve as a baseline of groundwater quality for future comparison. The 2007 assessment in Pike County may also be used as a basis for comparison of groundwater quality in other areas of Pennsylvania and neighboring states and to evaluate groundwater quality in relation to geology and land use.

In 2007, the USGS, in cooperation with the PCCD, also established an observation-well network to monitor groundwater levels. With continued collection of water-level data, the observation-well network (U.S. Geological Survey, 2009a) may be used for monitoring long-term trends, drought, and (or) for prediction of low streamflow conditions.

Purpose and Scope

This report describes the methods used and results for a reconnaissance groundwater-quality assessment based on samples collected from 20 wells throughout Pike County in summer-fall 2007. Samples were analyzed for major ions, nutrients, selected trace metals, volatile organic compounds (VOCs), selected organic wastewater compounds, gross alpha-particle and gross beta-particle activity, uranium, and radon-222. Analyses of the 20 samples were for dissolved constituents, but 6 samples were analyzed for both dissolved and total metals.

Measured concentrations of analyzed constituents in groundwater are compared to U.S. Environmental Protection Agency (USEPA) drinking-water standards. The relations between concentrations of dissolved and total metals for 6 of the 20 samples are presented. The relations between observed groundwater quality and the factors of geology and land use near the well are discussed. Chloride and nitrate concentrations in base flow at three Pennsylvania Department of Environmental Protection (PADEP) stream reference sites in Pike County briefly are discussed as an indicator of groundwater quality and land use. For five wells sampled at least twice from 1982 to 2007, the apparent change in groundwater quality through time is described.

Description of Study Area

Pike County covers 545 mi^2 in northeastern Pennsylvania and is flanked on the north and east by the Delaware River, which forms the boundary between the county and the adjacent states of New York and New Jersey (fig. 1). Land-surface elevations are highest [over 2,000 ft above the North American Vertical Datum of 1988 (NAVD 88), formerly referred to as sea level] in the southwestern corner of the county and lowest along the Delaware River (as low as about 320 ft above NAVD 88). Davis (1989) described the climate and general physical characteristics of the county.

Hydrogeologic Setting

Most of the county is underlain by Devonian-age fractured-rock aquifers (shales, siltstones, and sandstones) (fig. 1); high-yielding unconsolidated Quaternary-age glacial deposits are present in a band parallel to the Delaware River on the eastern edge of the county and in some upland stream valleys. These aquifers are recharged locally by precipitation and subsequently discharge to streams. In Pike County, local, intermediate, and regional groundwater-flow systems are thought to be present; local and intermediate flow systems discharge to streams and larger tributaries, respectively, and the deeper regional system discharges to the Delaware River (Davis, 1989). Only a small part of recharge is thought to enter and flow through the deeper regional flow system (Davis, 1989). For the surface-water system, streams radiate from near the center of Pike County and eventually drain toward the Delaware River.

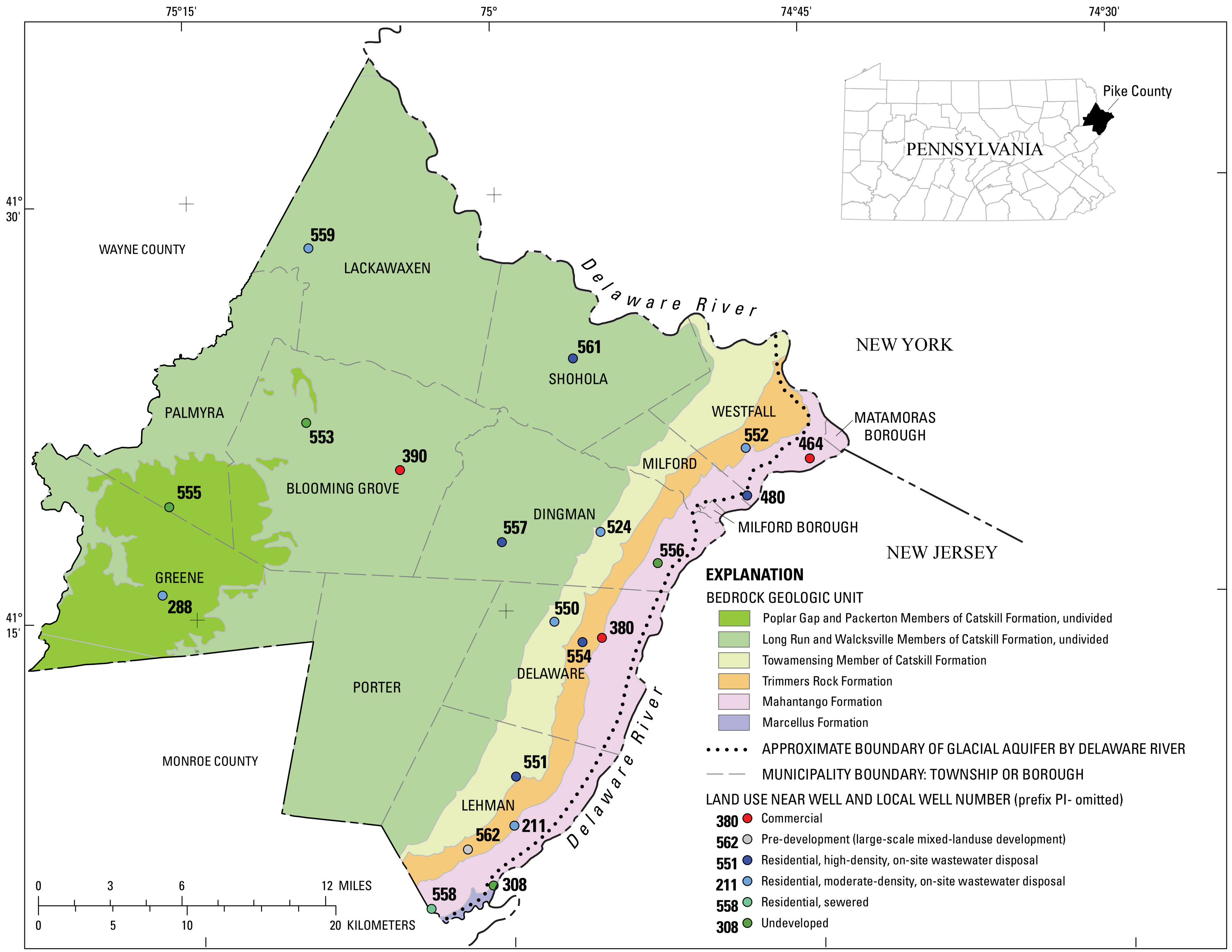
Berg and others (1980) mapped the bedrock geologic units that underlie Pike County, in order of decreasing age from east to west, as the Marcellus Formation, Mahantango Formation, Trimmers Rock Formation, Towamensing Member of the Catskill Formation, undivided Long Run and Walcksville Members of the Catskill Formation, and undivided Poplar Gap and Packerton Members of the Catskill Formation (fig. 1). These geologic units consist of sedimentary rocks that generally show a trend from finer-grained rocks (shales and siltstones) in the older units in the eastern part of the county to coarser-grained rocks (sandstones and conglomerates) in younger units in the western part of the county. Unconsolidated glacial deposits cover part of the bedrock units and vary in thickness and type. Davis (1989) describes the rock types, aquifer properties, and hydrogeology of the county in more detail. Alternate geologic mapping published by Davis (1989) shows the Delaware River and Laxawaxen Members of the Catskill Formation underlying the area mapped by Berg and others (1980) as the undivided Long Run and Walcksville Members of the Catskill Formation (fig. 1).

Land Use

As of 2005, the principal land uses in the county are public (33 percent), residential (24 percent), agricultural (23 percent), hunt club/private recreational (14 percent), roads (2 percent), and commercial (2 percent) (fig. 2) (Pike County Commissioners, 2006). The public lands include state park, state game, state natural area, and national park parcels, much of which are forested, as are hunt club parcels. Most of the land designated in agricultural use also is forested and privately owned, with little in actual cultivation or other agricultural operations. The 24 percent of land in residential use includes the classifications rural residential (4 percent), residential (10 percent), and vacant residential (10 percent).

Population has been growing in Pike County since 1940 (Davis, 1989). The increase in population of Pike County from 1990 to 2000 was ranked 36th out of 3,141 counties in the United States, with an increase of 65.6 percent (or 18,366 people) from a 1990 population of 27,966 to a 2000 population of 46,302 (U.S. Census Bureau, 2000). The period from 1970 to 1980 also was a time of relatively large population growth, increasing 54.6 percent to a population of 18,271 in 1980 (Davis, 1989). Because much land is public or private forested land, the population growth was in limited areas as can been seen by the distribution of residential land in Pike County (fig. 2). The largest population centers are the boroughs of Milford and Matamoras (fig. 1) in the eastern part of the county. In addition to the census population, use of land for recreation results in seasonal increases in population and potential stresses on the groundwater system and associated surface waters.

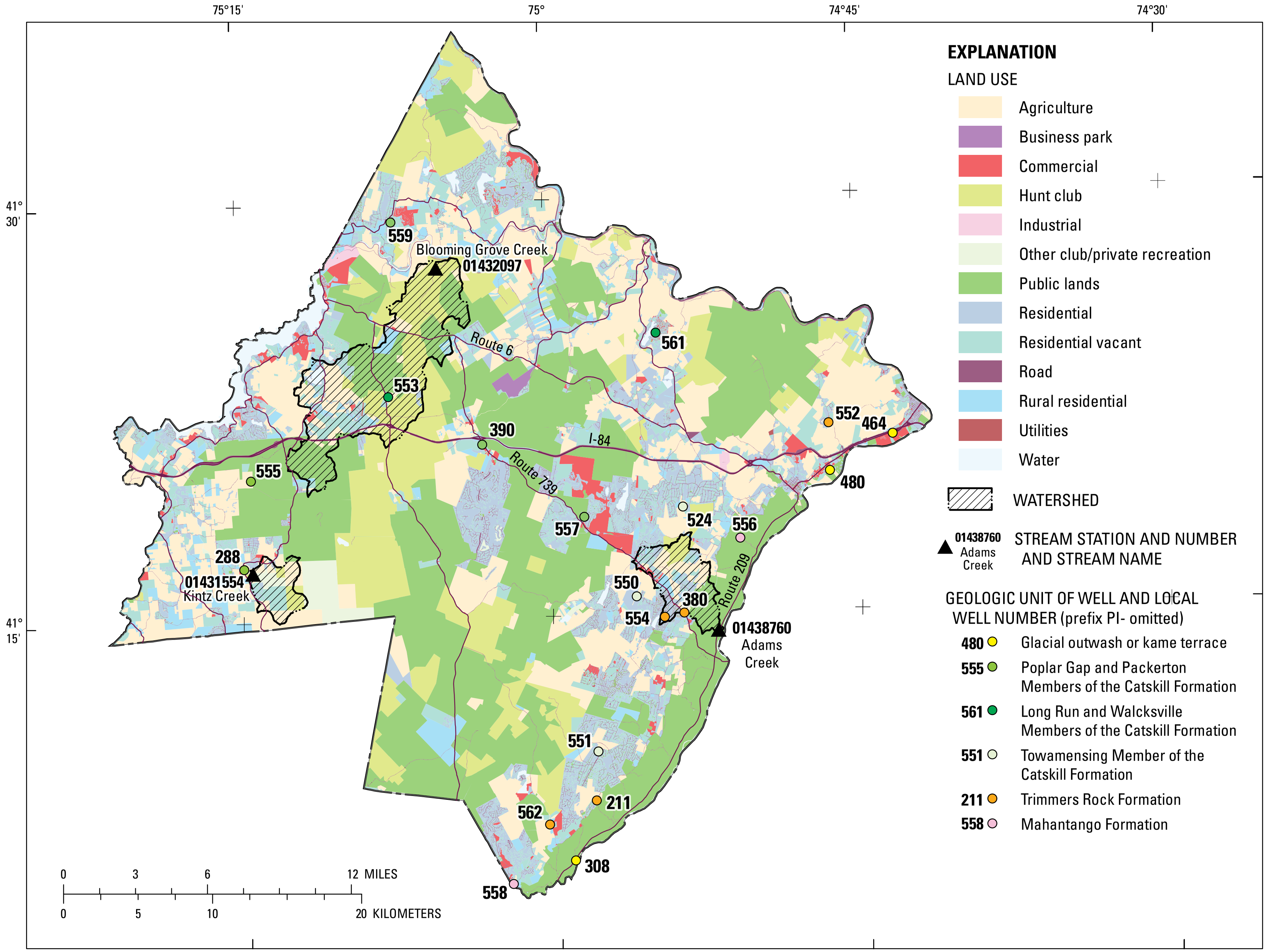
Groundwater is the main source of drinking water in the county. Individual on-site wells are common in many residential areas, although large wells supply some developments. The boroughs of Milford and Matamoras are served by public supplies whose sources are springs and wells, respectively. On-site wastewater disposal is common in residential areas; sand mounds are more commonly used than septic systems in recent developments (John Jose, Pike County Conservation



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000 Albers Equal-Area Conic Projection Standard parallels 29°30'N, central meridian 77°45'W

Geology from Miles and Whitfield, 2001

Figure 1. Geology of Pike County, Pa., showing bedrock geologic unit and extent of the glacial aquifer near the Delaware River and locations of 20 wells sampled by the U.S. Geological Survey in 2007.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000, Albers Equal-Area Conic Projection Standard parallels 29°30'N, central meridian 77°45'W

Land use from Pike County Commissioners, 2006

Figure 2. Land use in Pike County, Pa., in 2005 and locations of 20 wells sampled in 2007 and selected stream water-quality monitoring sites.

District, oral commun., 2007). Some developments are sewered and have sewage-treatment systems that discharge treated effluent to land areas or to surface water.

Previous Investigations

A countywide assessment of groundwater resources, including evaluation of general groundwater quality (major ions, nutrients, iron, and manganese) and, for some samples, selected trace metals, was done in the early 1980s (Davis, 1989). An investigation of nitrate and chloride in the glacial aquifer underlying Route 209 north of Milford in Pike County was done in 1991 (Senior, 1994). In 2001, groundwater from four wells in the glacial aquifer near the Delaware River was sampled and analyzed for major ions, nutrients, trace metals, pesticides, volatile organic compounds (VOCs), and radon-222 as part of the National Water-Quality Assessment (NAWQA) in the Delaware River Basin (Durlin and Schaffstall, 2002). Pesticides were not detected in the 2001 samples and consequently were not included in the 2007 assessment described in this report.

Study Methods

To provide a current assessment of groundwater quality in Pike County, 20 wells throughout the county were selected to represent groundwater quality in the main land uses and geologic units were sampled in 2007. Although the main geologic units and land uses were included, the assessment should be considered a reconnaissance because of the small number of samples in each geologic unit or land-use category. The laboratory analyses selected for the samples were intended to identify naturally occurring constituents from the aquifer or anthropogenic constituents that pose a health risk or otherwise were of concern in groundwater in the county. The samples were analyzed for major ions, nutrients, selected trace metals, VOCs, a suite of organic wastewater compounds, gross alpha-particle and gross beta-particle activity, and radon-222. Descriptions follow of the sample locations and collection and analytical procedures for the 2007 reconnaissance groundwater-quality assessment in Pike County.

Selection of Sampling Locations

Wells in each of six main geologic units and six land-use categories (table 1) were selected for sampling to represent groundwater quality throughout the county (figs. 1 and 2). Of the six main geologic units, five are fractured-bedrock aquifers and one is an unconsolidated aquifer (kame terrace and outwash deposits by the Delaware River are considered as one glacial aquifer for this report). Other less-areally extensive glacial or alluvial deposits in upland areas or smaller stream valleys that may form aquifers were not sampled. The six land-use categories included commercial, high-density residential with on-site wastewater disposal, moderate-density residential with on-site wastewater disposal, residential in a sewered area, pre-development downgradient from the proposed large-scale mixed-use land development, and undeveloped. For the residential areas with on-site wastewater disposal, relative density was determined from field observation where areas with lots generally about 1 acre or less were considered high density and areas with lots 2 acres or greater were considered moderate density. Two of the four wells (PI-308 and PI-556) in the undeveloped category are within the Delaware Water Gap National Recreation Area and the other two (PI-553 and PI-555) were near state park, state natural area, state game, or privately held game lands (fig. 2).

All sampled wells were domestic-supply wells serving individual residences. Well depth and other construction data were available for all but one of the wells sampled (table 1). Additional construction information can be found in table 10 (at the back of the report).

Collection of Samples

Samples from 20 wells were collected from August 27 through October 18, 2007. Sample collection and processing were done using standard methods (Wilde and others, 1999; Wilde and others, 2004). Groundwater samples were collected from wells using existing pumps and plumbing but bypassing any treatment systems. Water levels in the wells were measured prior to pumping, and wells were pumped until field measurements (pH, temperature, specific conductance, and dissolved oxygen concentration) stabilized before collecting the sample.

Samples for analysis of dissolved constituents were filtered in the field using a 0.45-micron polyethersulfone capsule filter. Samples for analysis of dissolved major cations and trace elements were preserved using nitric acid. Samples for organic wastewater compound analysis were unfiltered and collected in baked glass bottles; these samples were subsequently filtered through a glass-fiber filter at the laboratory before analysis. Samples for VOC analysis were collected in triplicate 40-mL vials and preserved with hydrochloric acid in the field.

Samples for age-dating by use of chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6), and other dissolved gases (nitrogen, oxygen, argon, carbon dioxide, and methane) (Plummer and Friedman, 1999) were collected in glass bottles by methods described by U.S. Geological Survey (2009b). For the gas samples, bottles were filled through tubing connected to the pump and inserted into the bottle. Bottles were filled from the bottom up and allowed to overflow at least three volumes before capping. Samples for CFCs were collected through refrigeration-grade copper tubing in 125 mL glass bottles that are filled and capped underwater. Samples for SF_6 were collected in plastic safety-coated 1-L glass bottles. Samples for the other dissolved gases (such as nitrogen) were

Table 1. Geologic unit and land use for 20 wells sampled in Pike County, Pa., during the 2007 assessment.

[ft, feet; ft bls, feet below land surface; ft avd, feet above North American Vertical Datum of 1988; Geologic unit: Glacial units—112KMTC, Kame terrace; 112OTSH, Olean outwash; Bedrock units—341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; —, no data]

U.S. Geological Survey local well number	Geologic unit	Land use	Sample date	Well depth (ft)	Depth to water (ft bls)	Altitude of land surface (ft avd)
Wells listed by geologic unit						
PI-480	112KMTC	Residential, high-density, on-site wastewater	20070905	213	88.24	465
PI-464	112OTSH	Commercial	20070828	142	17.32	430
PI-308	112OTSH	Undeveloped	20070830	108	29.94	350
PI-288	341PGPK	Residential, moderate-density, on-site wastewater	20070906	151	49.25	1,650
PI-555	341PGPK	Undeveloped	20070830	380	116.92	1,789
PI-390	341DLRV[1]	Commercial	20071002	325	34.70	1,340
PI-557	341LRBW	Residential, high-density, on-site wastewater	20070904	350	49.80	1,433
PI-561	341LRBW	Residential, high-density, on-site wastewater	20071002	250	94.86	1,301
PI-559	341LRBW	Residential, moderate-density, on-site wastewater	20070912	400	—	1,259
PI-553	341LRBW	Undeveloped	20070829	610	124.35	1,510
PI-551	341TMSG	Residential, high-density, on-site wastewater	20070828	250	58.28	1,110
PI-524	341TMSG	Residential, moderate-density, on-site wastewater	20071001	380	56.82	1,139
PI-550	341TMSG	Residential, moderate-density, on-site wastewater	20070827	250	54.08	1,207
PI-380	341TMRK	Commercial	20070905	98	—	900
PI-562	341TMRK	Pre-development (large-scale mixed-use development)	20071018	200	18.06	840
PI-554	341TMRK	Residential, high-density, on-site wastewater	20070829	238	77.82	1,055
PI-211	341TMRK	Residential, moderate-density, on-site wastewater	20070827	450	71.15	712
PI-552	341TMRK[2]	Residential, moderate-density, on-site wastewater	20070828	—	65.88	975
PI-558	344MNNG	Residential, sewered	20070905	300	16.42	440
PI-556	344MNNG	Undeveloped	20070830	400	54.05	719
Wells listed by land use						
PI-380	341TMRK	Commercial	20070905	98	—	900
PI-390	341DLRV[1]	Commercial	20071002	325	34.70	1,340
PI-464	112OTSH	Commercial	20070828	142	17.32	430
PI-480	112KMTC	Residential, high-density, on-site wastewater	20070905	213	88.24	465
PI-551	341TMSG	Residential, high-density, on-site wastewater	20070828	250	58.28	1,110
PI-554	341TMRK	Residential, high-density, on-site wastewater	20070829	238	77.82	1,055
PI-557	341LRBW	Residential, high-density, on-site wastewater	20070904	350	49.80	1,433
PI-561	341LRBW	Residential, high-density, on-site wastewater	20071002	250	94.86	1,301
PI-211	341TMRK	Residential, moderate-density, on-site wastewater	20070827	450	71.15	712
PI-288	341PGPK	Residential, moderate-density, on-site wastewater	20070906	151	49.25	1,650
PI-524	341TMSG	Residential, moderate-density, on-site wastewater	20071001	380	56.82	1,139
PI-550	341TMSG	Residential, moderate-density, on-site wastewater	20070827	250	54.08	1,207
PI-552	341TMRK[2]	Residential, moderate-density, on-site wastewater	20070828	—	65.88	975
PI-559	341LRBW	Residential, moderate-density, on-site wastewater	20070912	400	—	1,259
PI-558	344MNNG	Residential, sewered	20070905	300	16.42	440
PI-562	341TMRK	Pre-development (large-scale mixed-use development)	20071018	200	18.06	840
PI-308	112OTSH	Undeveloped	20070830	108	29.94	350
PI-553	341LRBW	Undeveloped	20070829	610	124.35	1,510
PI-555	341PGPK	Undeveloped	20070830	380	116.92	1,789
PI-556	344MNNG	Undeveloped	20070830	400	54.05	719

[1] Mapped as 341LRBW by Berg and others (1980).

[2] Depth of well unknown and geologic unit for well completion based on bedrock mapping at well location, where geologic units are relatively flat lying and domestic wells are generally less than 500 feet in depth.

collected in 150 mL glass bottles that were filled and capped underwater.

Analysis of Samples

Selected physical and chemical constituents were measured while sampling each well. The pH, water temperature, acid-neutralizing capacity (ANC), specific conductance, and dissolved oxygen concentration for groundwater samples were measured in the field using standard methods (U.S. Geological Survey, variously dated).

Water samples were sent to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo., for analyses of inorganic constituents, organic compounds, and radon-222. Analyses for dissolved inorganic constituents included major ions (calcium, magnesium, sodium, potassium, silica, sulfate, chloride, and fluoride), nutrients (nitrate, nitrite, ammonium, and orthophosphate), and selected trace elements and metals (arsenic, boron, cobalt, copper, iron, manganese, mercury, molybdenum, nickel, selenium, uranium, and zinc). In addition, unfiltered samples from 6 of the 20 wells were analyzed for selected total metals (arsenic, copper, iron, lead, and manganese). Analyses for organic compounds included a suite of about 65 compounds commonly present in domestic or industrial wastewater (such as detergent metabolites, food additives, fragrances, antioxidants, flame retardants, plasticizers, industrial solvents, disinfectants, fecal sterols, polycyclic aromatic hydrocarbons, and high-use domestic pesticides) (Zaugg and others, 2002; Zaugg and Leiker, 2006). Many of these wastewater compounds are potential endocrine-disrupters (compounds that disturb normal biological processes) or are toxic. Samples for gross alpha-particle and gross beta-particle activity at 72-hours and 30-day counting times were analyzed at a private laboratory under contract to the NWQL. Water samples for age-dating by CFCs and SF_6 were analyzed by the USGS Chlorofluorocarbon Laboratory in Reston, Va., using methods described by U.S. Geological Survey (2009b) and by Busenberg and others (2006). Results of all analyses are presented in tables 11–15 at the back of the report.

For quality assurance, a field blank sample was collected at well PI-557 and analyzed for dissolved inorganic constituents, nutrients, trace metals, VOCs, and organic wastewater compounds. Results showed that none of the constituents or compounds analyzed for in the blank were detected, indicating that field equipment or sampling methodology did not contaminate the sample. No additional quality-assurance samples were collected; however, quality-assurance samples such as replicates and blanks collected for other studies using the same equipment, personnel, and procedures within 2 years of this study resulted in few to no apparent quality-assurance problems for these constituents (Senior and Cinotto, 2007). For the analysis of organic wastewater compounds, the NWQL adds compounds (surrogates) to the environmental sample that are similar chemically to some compounds analyzed to determine the relative sensitivity of the analysis to measure these types of compounds. The percent recovery reported by the NWQL for surrogates added to the samples undergoing analysis for wastewater compounds (see table 13 at the back of the report) were within the range commonly reported by NWQL (Zaugg and Leiker, 2006) for all but surrogate bisphenol-A-d3, for which the recoveries were very low. The very low surrogate recoveries indicate that the laboratory results for the compound bisphenol-A are questionable. For other surrogates, the recoveries indicate acceptable analytical results but are of limited use for assessing method compound recoveries because the surrogates are not necessarily chemically representative of every method compound (Zaugg and others, 2002).

The concentrations of major ions typically are reported in milligrams per liter, which are approximately equivalent to parts per million. Nitrogen compounds, such as nitrate and ammonia, are reported in milligrams per liter as nitrogen (as N), and phosphorus compounds, such as orthophosphate, are reported in milligrams per liter as phosphorus (as P). The concentrations of trace elements and organic compounds typically are reported in micrograms per liter, which are approximately equivalent to parts per billion.

Groundwater-Quality Assessment

The groundwater-quality assessment was intended to provide data on the occurrence in Pike County groundwater of naturally occurring constituents and constituents introduced by human activities. The 2007 assessment may be used to evaluate overall groundwater quality in the county, identify constituents that may pose a health risk, identify areas where land use may have impacted groundwater quality, and serve as a baseline for future evaluations to determine the effect of land-use changes on groundwater quality.

Both naturally occurring constituents and constituents introduced by human activities may pose a risk to human health when present at elevated concentrations in groundwater used for drinking-water supply. The USEPA has established maximum contaminant levels (MCLs) for some constituents in drinking water to protect human health. These MCLs may be used as a guideline for private well owners but must be followed for public drinking-water supplies. Other non-regulatory drinking-water standards include health advisory (HA) levels, listed by USEPA for selected constituents that have no MCL or, in some cases, in addition to the MCL, and secondary maximum contaminant levels (SMCLs) for selected constituents that pose no health risk but at a certain concentration may have adverse effects, such as taste or staining, on the use of water.

A discussion of the analyzed constituents in water from 20 wells sampled in 2007 in Pike County follows. Complete results for laboratory analyses of groundwater samples collected in 2007 are listed in tables 11–15 at the back of the report.

Inorganic Constituents

The amount and relative proportion of inorganic constituents in groundwater reflect dissolution of minerals in the soils and aquifer materials and other chemical processes in the subsurface. In addition, some constituents are present in precipitation that recharges the aquifer but also may be introduced into the aquifer by recharge from areas affected by human activities. For example, sodium and chloride are present in low concentrations in precipitation in Pike County (table 2) and also may be introduced to groundwater in areas that receive salt from highway deicing or through discharge of septic-system effluent.

Although precipitation is relatively dilute, as a result of evaporation, conservative constituents in precipitation can become more concentrated in recharge. The concentration of conservative constituents in recharge derived from precipitation may be estimated to be about twice of that in precipitation, on the basis of rates of recharge relative to precipitation from Davis (1989). Thus, the concentration of chloride from precipitation in recharge would be about 0.5 mg/L or twice that for average precipitation at Milford, Pa., in 2006 (table 2). The concentrations of most analyzed constituents have remained relatively stable since precipitation monitoring began in 1982, with the exception of sulfate, nitrate, and pH (Lynch and others, 2007a). The concentrations of sulfate and nitrate and the level of acidity declined at Milford over that 24-year period.

General Water Quality

Groundwater samples from about half of the 20 wells were slightly acidic. The median pH was 6.8, just below the neutral value of 7.0 pH units, and the pH was equal to or less than the SMCL lower limit of 6.5 in 9 (45 percent) of the 20 samples (table 3). Precipitation that falls on Pike County is acidic, had an average pH of about 4.5 in 2006 (table 2), and is neutralized by reactions with soils and aquifer minerals. The ANC and specific conductance are properties that may be related to mineral dissolution. ANC consists largely of bicarbonate alkalinity. The specific conductance is proportional to the amount and type of dissolved charged ions in solution. In the groundwater samples from Pike County, ANC and specific conductance generally tended to increase with pH (fig. 3), suggesting that mineral dissolution results in reducing acidity.

Table 2. Annual average concentrations of selected constituents in precipitation at Milford, Pa., 2006.

[Source of data is Lynch and others (2007a) and Lynch and others (2007b); Concentration is weighted by volume; mg/L, milligrams per liter; mg/L as N, milligrams per liter as nitrogen; ng/L, nanograms per liter]

Chemical constituent	Concentration	Units
pH	4.510	pH units
Calcium	.077	mg/L
Sodium	.133	mg/L
Magnesium	.022	mg/L
Potassium	.030	mg/L
Chloride	.255	mg/L
Sulfate	1.418	mg/L
Nitrate as N	.228	mg/L as N
Ammonia as N	.163	mg/L as N
Mercury	7.500	ng/L

Hardness of the water samples ranged from 23 to 140 mg/L as calcium carbonate ($CaCO_3$), which indicates the water is very soft (less than 75 mg/L as $CaCO_3$) to soft (less than 140 mg/L as $CaCO_3$). Hardness reflects the concentrations of calcium and magnesium ions, which are released into groundwater from the dissolution of calcium- and magnesium-bearing minerals. Hard water decreases lathering of soap and increases accumulation of mineral deposits in plumbing and cooking utensils. No health-related standards are established specifically for hardness in drinking water.

Dissolved oxygen concentrations were low (less than 1 mg/L) in 9 (45 percent) of the 20 well samples. Low concentrations of dissolved oxygen are related to chemical or biochemical reactions that consume oxygen and may be associated with reducing conditions that promote the release of some metals. The chemical reactions that consume oxygen can be naturally occurring in soils or aquifer materials.

Major Ions

Major ions generally comprise most of the dissolved constituents in groundwater. The major ions consist of positively charged cations (calcium, magnesium, sodium, and potassium) balanced by negatively charged anions (bicarbonate, chloride, sulfate, and fluoride). Silica is a major constituent that commonly occurs as an uncharged ion. Nitrate, discussed in the section on nutrients, is an anion that sometimes may be present in large enough concentrations to be considered a major ion.

The range and median concentrations of major ions in water from 20 wells sampled in Pike County in 2007 are listed in table 3. In the 20 groundwater samples, the only drinking-water standard exceeded for major ions was the sodium concentration in one sample (from well PI-524). The highest sodium concentration of 39.9 mg/L exceeded the HA level of 20 mg/L for individuals on sodium-restricted diets and the taste threshold SMCL value of 30 mg/L.

The concentrations of many major ions may be related to the concentrations of other major or minor constituents or to water-quality characteristics, such as pH. These relations provide information about the sources of the ions and chemical controls on these constituents in groundwater. The highest sodium concentration is associated with the highest boron concentration. Sodium concentrations are generally related to both chloride and boron concentrations (fig. 4), indicating salt

Table 3. Minimum, median, and maximum values for well characteristics, field measurements, and concentrations of dissolved major ions and nutrients in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

[MCL, maximum contaminant level; HA, health advisory; SMCL, secondary maximum contaminant level; ft bls, feet below land surface; ft, feet; gal/min, gallons per minute; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; -, no standard or not applicable; <, less than; E, estimated value]

Constituent	Units	Number of samples	Minimum	Median	Maximum	Drinking-water standard[1]		
						MCL	HA	SMCL
Well characteristics and sampling data								
Depth of well	ft bls	19	98	250	610	-	-	-
Depth to water level	ft bls	18	16.4	55.5	124	-	-	-
Altitude of land surface	ft	20	350	1,083	1,790	-	-	-
Flow rate, instantaneous,	gal/min	20	2.5	5	15	-	-	-
Pump or flow period prior to sampling	minutes	20	53	90	190	-	-	-
Temperature, air	°C	20	15	25	29	-	-	-
Field measurements of water quality								
Dissolved oxygen	mg/L	20	.1	3.3	10.8	-	-	-
Dissolved oxygen	percent of saturation	20	0	30	94	-	-	-
pH	standard units	20	5.7	6.8	8.3	-	-	6.5–8.5
Specific conductance	µS/cm	20	70	185	351	-	-	-
Temperature, water	°C	20	9.2	11.1	12.6	-	-	-
Acid neutralizing capacity	mg/L as $CaCO_3$	20	12	53.5	114	-	-	-
Dissolved inorganic constituents								
Calcium	mg/L	20	5.5	15.9	46.9	-	-	-
Magnesium	mg/L	20	1.12	5.9	11.3	-	-	-
Potassium	mg/L	20	.20	.54	.80	-	-	-
Sodium	mg/L	20	1.4	6.9	39.9	-	20	30-60
Chloride	mg/L	20	.53	7.6	39.9	-	-	250
Fluoride	mg/L	20	.05E	.09E	.21	4	-	2
Silica as SiO_2	mg/L	20	4.8	9.9	16.9	-	-	-
Sulfate	mg/L	20	.4	11.7	29.6	-	500	250
Hardness	mg/L as $CaCO_3$	20	23	64.5	140	-	-	-
Dissolved nutrients								
Ammonia	mg/L as N	20	<.010	<.020	.063	-	30	taste threshold
Nitrite plus nitrate[2]	mg/L as N	20	<.04	.205	2.00	10	-	-
Nitrite	mg/L as N	20	[3]<.002	<.002	.47	1	-	-
Orthophosphate	mg/L as P	20	[4]<.006	.012	.055	-	-	-

[1] From U.S. Environmental Protection Agency, 2006.

[2] Because nitrite concentrations were low except for one sample, nitrate is nearly equivalent to nitrite plus nitrate.

[3] Estimated values less than the reporting level were reported for eight samples at concentrations of E0.001 mg/L as N.

[4] Estimated values less than the reporting level were reported for two samples at concentrations of E0.004 and E0.005 mg/L as N.

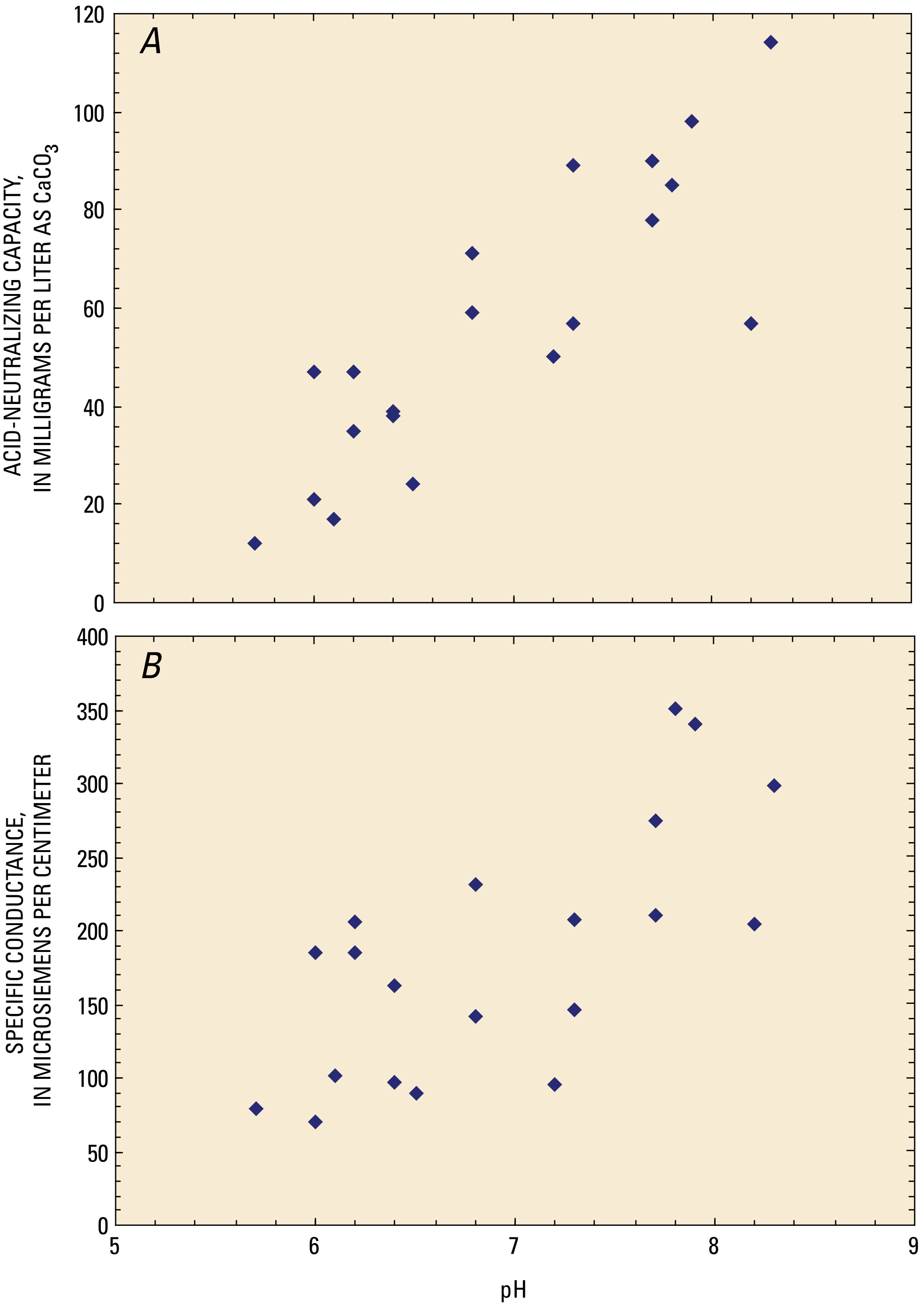


Figure 3. (*A*) Acid-neutralizing capacity and (*B*) specific conductance in relation to pH in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

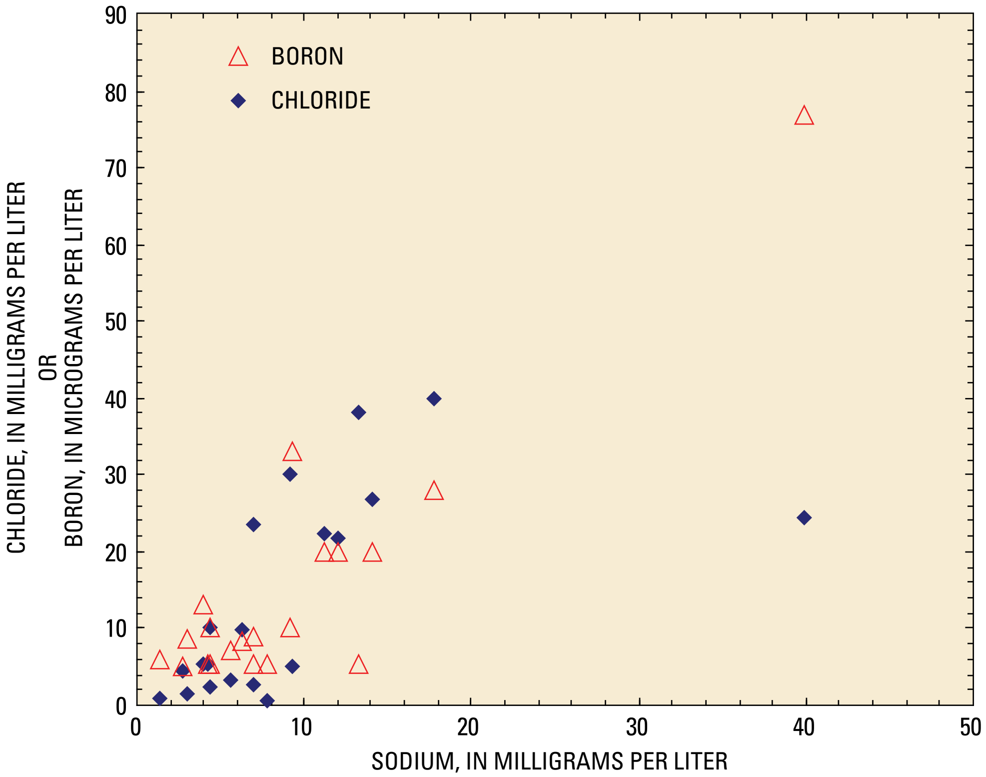


Figure 4. Chloride and boron concentrations in relation to sodium concentrations in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

and possibly borax (a sodium borate compound) as sources of these ions in groundwater.

Chloride concentrations greater than a few milligrams per liter probably represent influence of human activities on groundwater quality. The amount of chloride from precipitation (table 2) probably contributes on average less than 1 mg/L of choride to recharge concentrations. Natural background concentrations of chloride in groundwater are estimated to range from 1 to 5 mg/L. Chloride concentrations were greater than 6 mg/L in water from 10 of 20 wells sampled in 2007, indicating that groundwater quality at and near the 10 wells may be affected by human activities such as use of de-icing salts on roads and(or) septic systems.

Nitrate and Other Nutrients

Nitrogen and phosphorus compounds occur naturally and are essential nutrients for plant growth. Nitrogen and phosphorus compounds also are present in elevated concentrations in domestic and municipal wastewater. Elevated concentrations of nutrients may result in impairment of surface waters (where impairment is related to algal growth) and may pose a health risk when consumed in drinking water. The principal soluble nitrogen compounds of nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_4^+) were included in analyses of groundwater samples collected in 2007. Orthophosphate (PO_4^-), a soluble form of phosphorus, was also analyzed in the samples. The laboratory analyses determine nitrite plus nitrate so nitrite concentrations must be subtracted to obtain nitrate concentrations.

Ammonia is a reduced form of nitrogen, it is the predominant nitrogen compound in septic-tank effluent, and it oxidizes to nitrate in the presence of oxygen. Nitrite (NO_2^-) is a less-oxidized form of nitrogen than nitrate (NO_3^-) and may be formed during an intermediate step in nitrification, a process in which ammonia is oxidized. Nitrite also may accumulate in groundwater during denitrification (Smith and others, 2004), a process in which nitrate is reduced to nitrogen gas usually in the absence of oxygen. Nitrification and denitrification reactions generally are biologically mediated. In low-oxygen environments, ammonia and nitrite will be more stable than nitrate. Conversely, where oxygen is present in higher quantities, nitrate is the more stable form.

Low concentrations of ammonia, nitrite, nitrate and orthophosphate were measured in most of the 20 groundwater samples, and no drinking-water standards for these compounds were exceeded (table 3). Ammonia concentrations were less than the reporting level of 0.02 mg/L as N in all but 6 groundwater samples that had concentrations ranging from 0.025 to 0.063 mg/L as N. Nitrite concentrations were less than or equal to the reporting level of 0.002 mg/L as N in all but two groundwater samples that had concentrations of 0.005

and 0.47 mg/L as N, respectively. The highest concentrations of nitrite and ammonia were measured in samples that had low dissolved oxygen concentrations (0.2 or less mg/L)

Nitrate concentrations (calculated by subtracting nitrite concentration from the reported sum of nitrite plus nitrate concentration) were less than 0.8 mg/L as N in all but one groundwater sample that had about 2 mg/L as N, suggesting that most nitrate concentrations are within the range of estimated natural background levels. An estimated concentration of nitrate derived from precipitation (table 2) in recharge is up to about 0.8 mg/L as N, assuming no nitrogen loss and that all ammonia was converted to nitrate. Nitrate can be reduced, however, in low-oxygen environments such as were observed in 9 (45 percent) of the 20 well samples that had dissolved oxygen concentrations less than 1 mg/L. Many of the low nitrate concentrations might be attributed to nitrate reduction in soils and in the groundwater system.

Orthophosphate concentrations were less than 0.02 mg/L as P in all but five groundwater samples that had concentrations ranging from 0.02 to 0.055 mg/L as P. Concentrations of orthophosphate greater than 0.02 mg/L in eastern Pennsylvania commonly represent slight enrichment from human-related sources (Andrew Reif, U.S. Geological Survey, oral commun. 2008).

Trace Elements and Metals

The dissolved trace elements and metals selected for analyses included boron (an indicator of domestic wastewater), and iron and manganese (known water-quality problem constituents). Analyses also included a suite of the following constituents that may pose health risks and that have established drinking-water MCLs or HA levels: arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc (table 4). Complete results are listed in table 11 at the back of the report.

Boron occurs naturally but may be elevated above background levels in areas that receive recharge affected by

Table 4. Minimum, median, and maximum values for concentrations of dissolved metals in groundwater samples collected from 20 wells and concentrations of dissolved and total metals in groundwater from 6 of the 20 wells in Pike County, Pa., in 2007.

[MCL, maximum contaminant level; HA, health advisory; SMCL, secondary maximum contaminant level; µg/L, micrograms per liter; <, less than; -, no standard]

Constituent	Minimum	Median	Maximum	MCL	HA	SMCL
Dissolved metals in 20 groundwater samples (µg/L)						
Aluminum	<1.6	<1.6	7.9	-	-	-
Arsenic	<.12	.29	3.5	10	2	-
Boron	5	8.8	77	-	1,000	-
Cadmium	.04	.04	.08	5	-	-
Chromium	.06	.12	.14	100	-	-
Copper	.4	9.75	72.2	1,300	-	1,000
Iron	4	17.5	675	-	-	300
Lead	.08	.16	2.2	15	-	-
Manganese	.2	15.8	292	-	300	50
Mercury	<.01	<.01	<.01	2	-	-
Molybdenum	.01	.01	1.5	-	40	-
Nickel	.09	.3	2.7	-	100	-
Selenium	.04	.08	1.3	50	-	-
Zinc	4	6	73	-	2,000	5000
Dissolved and total metals in a subset consisting of 6 of 20 groundwater samples (µg/L)						
Arsenic, total	.1	1.3	3.9	10	2	-
Arsenic, dissolved	.09	.34	.69	10	2	-
Copper, total	7.1	18.45	92.2	1,300	-	1,000
Copper, dissolved	.97	10	32.4	1,300	-	1,000
Iron, total	237	4,230	8,760	-	-	300
Iron, dissolved	14	89	675	-	-	300
Lead, total	.34	1.09	11.8	15	-	-
Lead, dissolved	<.12	<.12	.3	15	-	-
Manganese, total	12.4	200	361	-	300	50
Manganese, dissolved	2.2	169	248	-	300	50

wastewater, such as septic-tank effluent. Boron minerals, such as borax (sodium borate), commonly are used as laundry additives. Based on relations between sodium, chloride, and boron (fig. 4), boron concentrations less than 20 µg/L probably represent natural background levels in Pike County. Boron concentrations of 20 µg/L or greater are associated with elevated chloride concentrations (greater than 20 mg/L) and probably represent some contributions from anthropogenic sources and were measured in 6 of 20 groundwater samples in 2007; the maximum concentration was 77 µg/L (table 4 and table 11 at the back of the report).

Concentrations of dissolved iron and manganese previously were reported to be elevated above SMCLs of 300 µg/L and 50 µg/L, respectively, in groundwater samples collected in a countywide assessment in 1982 (Davis, 1989). In the 1982 study, iron concentrations were greater than the SMCL of 300 µg/L in 4 (7 percent) of 59 samples, and manganese concentrations were greater than the SMCL of 50 µg/L in 23 (40 percent) of 58 samples. The 2007 assessment also shows concentrations of dissolved iron and manganese in groundwater samples elevated above the SMCLs; the maximum concentrations were 675 and 292 µg/L, respectively (table 4). In the 2007 study, concentrations of dissolved iron were greater than 300 µg/L in 3 (15 percent) of 20 samples, and concentrations of dissolved manganese were greater than 50 µg/L in 7 (35 percent) of 20 samples. Two samples in 2007 had dissolved manganese concentrations (267 and 292 µg/L) close to the HA of 300 µg/L. In 2007, most concentrations of dissolved iron and manganese above the SMCLs of 300 and 50 µg/L, respectively, were in groundwater samples with low dissolved oxygen concentrations (0.2 mg/L or less) (fig. 5), which indicates geochemical control on concentrations of these metals.

Of the other dissolved metals analyzed in the 2007 assessment, none were present in concentrations that exceeded established MCLs (table 4). The concentration of 3.5 µg/L for dissolved arsenic in one groundwater sample (from well PI-464), however, was greater than the HA level of 2 µg/L. This sample also had the highest concentration (0.055 mg/L as P) of orthophosphate, an ion that can interfere with sorption of arsenic ions on aquifer materials, suggesting that this relatively high arsenic may occur partly as a result of the elevated orthophosphate concentration. Dissolved arsenic concentrations in the other 19 groundwater samples ranged from less than 0.12 to 0.83 µg/L.

The concentrations of some metals may be above natural background levels. Concentrations of dissolved copper and zinc greater than 20 µg/L are associated with acidic water (pH less than 6.5) (fig. 6), suggesting that copper and zinc might be leached from household plumbing. Copper and zinc are common components in the manufacture of metal pipes and plumbing fixtures and are susceptible to dissolution in acidic water. The highest concentration of dissolved copper (72 µg/L) was in the same sample that had the highest concentration of dissolved zinc (73 µg/L).

Mercury was selected for analysis because of the mercury-related fish advisories issued by the PADEP for lakes in Pike County (Pennsylvania Department of Environmental Protection, 2009). Dissolved mercury was not detected in any of the groundwater samples collected in 2007. The laboratory reporting level for mercury in water is 0.01 µg/L. Mercury is present in precipitation in Pike County at an average concentration of about 7.5 nanograms per liter (ng/L) (table 2), which is equivalent to 0.0075 µg/L. If all the mercury in precipitation entered the aquifers through recharge, the mercury concentration in recharge would be no greater than about 0.015 µg/L, or just above the laboratory reporting level for water analysis. Based on results from the 2007 assessment, dissolved mercury was not elevated above the detection level and does not appear to be a problem in groundwater in Pike County.

Relation Between Dissolved and Total Major Ions and Metals

Most groundwater samples collected and analyzed by USGS in Pike County and elsewhere have been analyzed for dissolved constituents. Major ions are predominantly in the dissolved phase in groundwater, as can be seen by comparing filtered and unfiltered samples from a well (PI-308) in Pike County. Major ion concentrations in the sample collected and analyzed for dissolved ions in this study were about the same as in the sample collected a week later for a different study and analyzed for total constituents (table 5). The difference between total and dissolved concentrations represents the concentration of particulate phase in the sample, which typically is negligible for major ions.

However, the particulate phase may be important for some trace metals. Treatment of water to reduce unwanted levels of constituents partly depends on how that constituent occurs. For example, a sediment filter may remove most of the constituent in the particulate phase but little to none of the constituents in the dissolved phase. To investigate the relation between dissolved and total concentrations of a few metals, 6 of the 20 groundwater samples collected in 2007 were selected for additional analyses of total metals—arsenic, copper, lead, iron, and manganese. Iron and manganese oxides can form particulates that are present in groundwater and may act to adsorb other metals. The samples selected for additional analyses represent a range of chemical characteristics (pH, specific conductance, and dissolved oxygen concentration) as well as different geologic units and land uses (see wells PI-390, PI-550, PI-553, PI-554, PI-556, and PI-562 in table 11 at the back of the report). However, because only six samples were analyzed for dissolved and total concentrations, results may not be representative of the county as a whole.

Results show that total concentrations of some metals can be much higher than concentrations of dissolved metals in groundwater in Pike County, indicating that these metals occur in higher concentrations in the particulate phase than in the dissolved phase. Because the number of samples analyzed for dissolved and total metal concentrations was relatively small (6), results should be considered indicative rather than definitive for the countywide assessment.

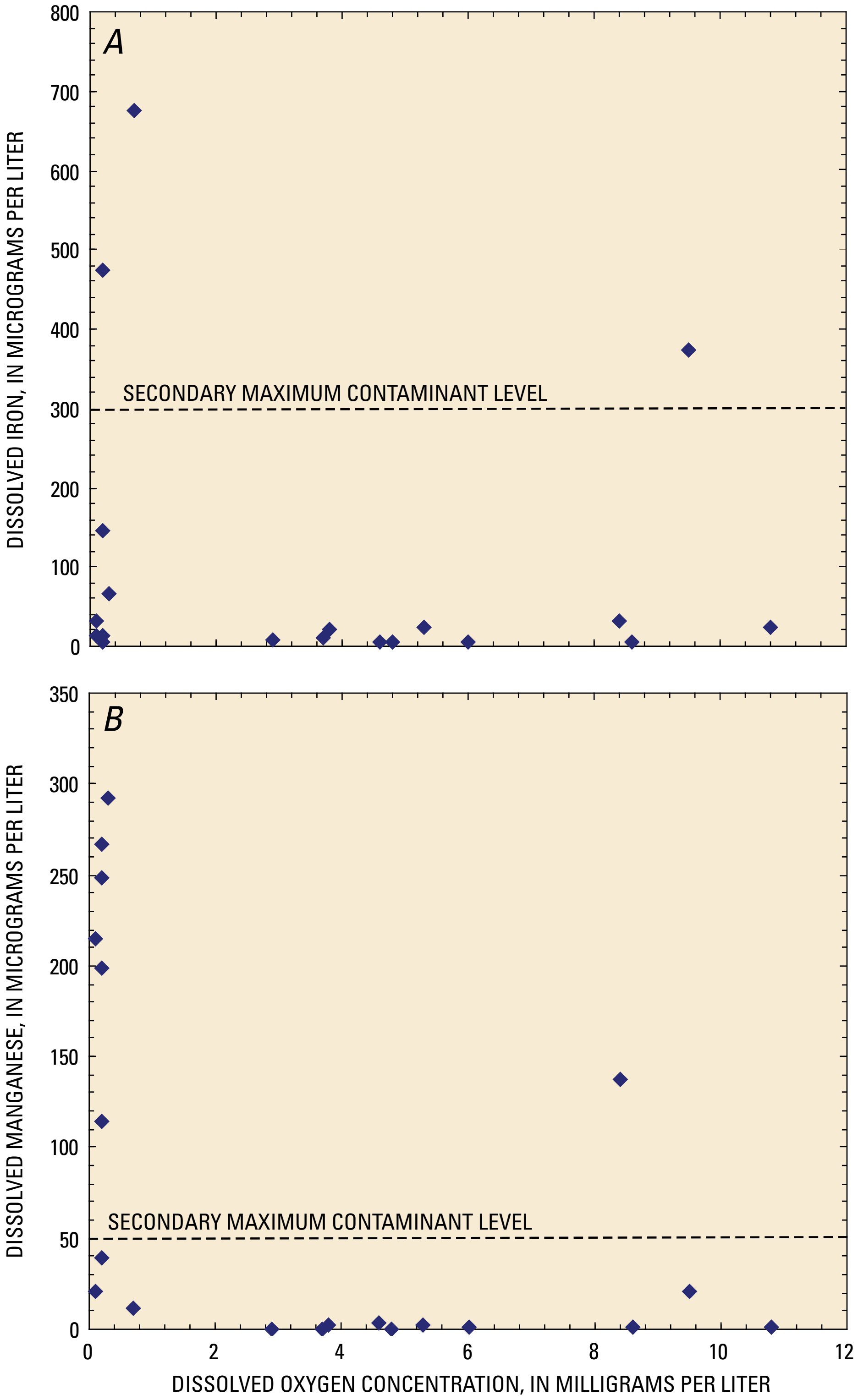


Figure 5. Concentrations of (A) dissolved iron and (B) dissolved manganese in relation to dissolved oxygen concentrations in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

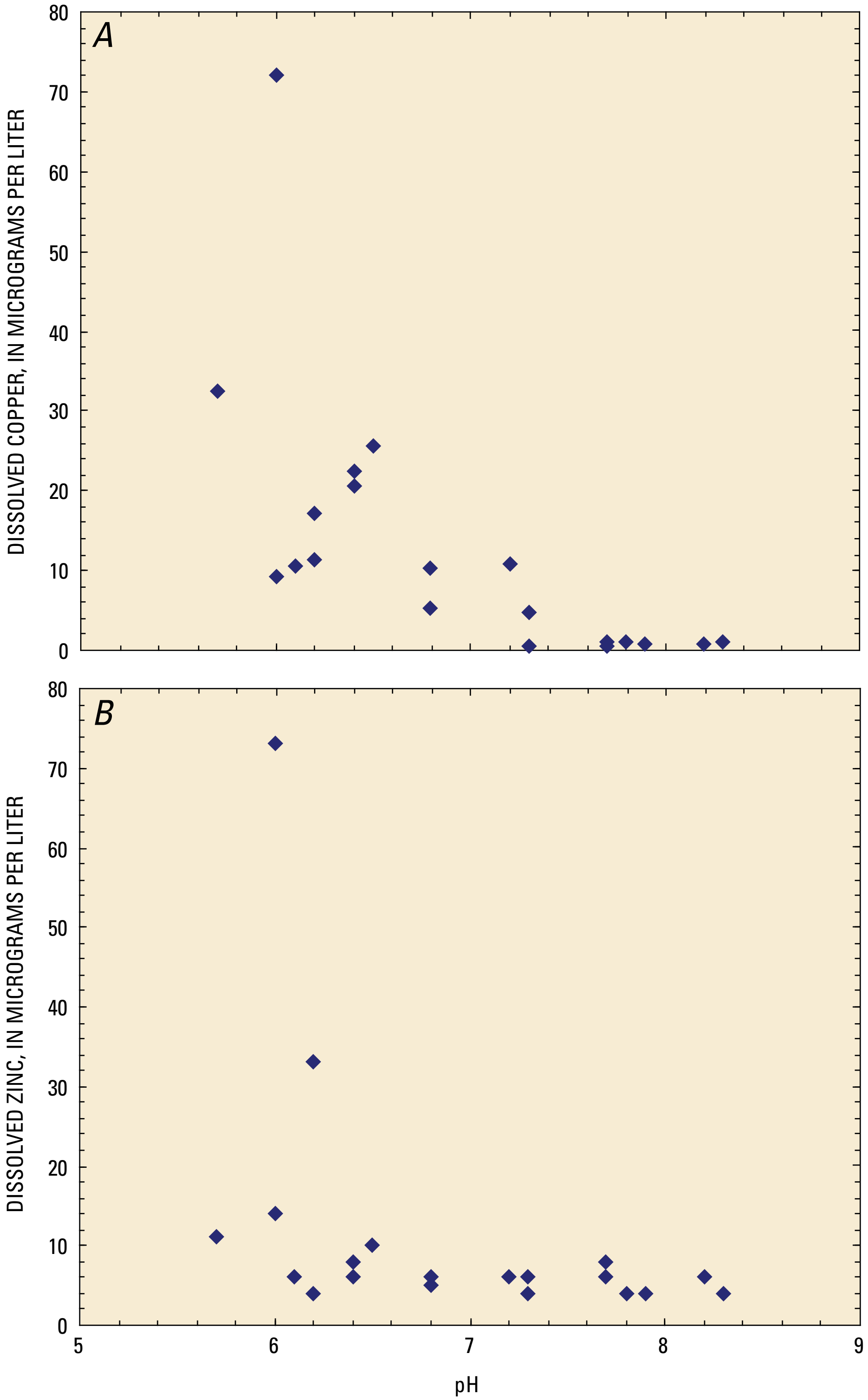


Figure 6. Concentrations of (*A*) dissolved copper and (*B*) dissolved zinc in relation to pH in groundwater samples collected from 20 wells in Pike County, Pa., in 2007

Table 5. Concentrations of major ions, iron, and manganese in filtered and unfiltered samples from well PI-308 collected August 30 and September 9, 2007, respectively, in Pike County, Pa.

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; —, could not calculate for less-than values]

	Filtered[1] (collected 8/30/2007)	Unfiltered[2] (collected 9/6/2007)	Absolute difference[3]	Percent difference[4]
Calcium (mg/L)	8.93	9.38	0.45	5.0
Magnesium (mg/L)	1.83	1.84	.01	.5
Potassium (mg/L)	.73	.78	.05	6.8
Sodium (mg/L)	6.24	6.40	.16	2.6
Fluoride (mg/L)	<.10	<.18	—	—
Silica (mg/L)	9.00	8.95	-.05	-.6
Iron (µg/L)	373	3,350	2,977	798.1
Manganese (µg/L)	20.4	33.6	13.2	64.7

[1] Filtered samples yield results for dissolved constituents.

[2] Unfiltered samples yield results for total constituents (dissolved plus particulate).

[3] Absolute difference = unfiltered concentration - filtered concentration.

[4] Percent difference = 100 × (absolute difference/filtered concentration)

The largest differences between dissolved and total concentrations were for iron. Concentrations of total iron were from about 90 to 8,300 µg/L greater than concentrations of dissolved iron, and in samples from two wells (PI-390 and PI-550), were more than 100 times greater than dissolved iron concentrations (fig. 7, table 11 at the back of the report). The difference between total and dissolved iron concentrations is the concentration of particulate iron, which represented from about 38 to more than 99 percent of iron measured in the samples. The SMCL of 300 µg/L was exceeded in two of the six groundwater samples analyzed for dissolved iron and in five of the six groundwater samples analyzed for total iron, suggesting that particulate iron may be a water-quality problem more frequently in Pike County than dissolved iron. The cause of high concentrations of particulate iron is unknown, although high concentrations of particulate iron in some cases may be related to use of existing plumbing for collecting well samples despite pumping wells for 40 minutes or longer to flush plumbing before collecting samples, because particulate iron may accumulate in pressure tanks.

The ratio of total iron to dissolved iron concentrations appears generally related to dissolved oxygen concentrations in the six groundwater samples—total iron is higher relative to dissolved iron in water with more oxygen. In the two samples with oxygen concentrations greater than 1 mg/L, the concentrations of total iron were more than 100 times greater than concentrations of dissolved iron, whereas in most (3 of 4) samples with dissolved oxygen concentrations less than 1 mg/L, the concentrations of total iron were less than 20 times greater than concentrations of dissolved iron. This apparent result is consistent with higher concentrations of dissolved iron in water with less oxygen (fig. 5). Thus, in oxygenated groundwater, the potential for high concentrations of particulate iron is greater than for high concentrations of dissolved iron. About half (11 of 20) the wells in the 2007 assessment had dissolved oxygen concentrations greater than 1 mg/L.

For metals other than iron, relative differences between total and dissolved concentrations (measured as a ratio of total to dissolved concentrations) generally were least for manganese and copper and somewhat higher for arsenic and lead. The ratio of total to dissolved concentrations was less than 1.3 for manganese in five of six samples and less than 1.6 for copper in five of six samples. These results indicate manganese and copper mostly are present in the dissolved phase. Manganese concentrations exceeded the SMCL in four of the six groundwater samples for both dissolved and total manganese. The total manganese concentration of 361 µg/L in one groundwater sample (from well PI-562) exceeded the HA of 300 µg/L. No concentrations of dissolved or total copper exceeded the drinking-water standards.

The ratio of total to dissolved concentrations ranged from 7.1 to 18.9 for arsenic in 3 of 6 samples and was greater than 3.8 for lead in all 6 samples, indicating the particulate phase of arsenic and lead can be higher in concentration than the dissolved phase of these metals. The HA level of 2 µg/L was exceeded by total arsenic in one groundwater sample. No drinking-water standard was exceeded by concentrations of dissolved or total lead, although the maximum lead concentration measured in the study (11.8 µg/L) was for total lead (table 4).

Higher concentrations of total iron appear to be associated with higher concentrations of total arsenic and total lead in general (fig. 8) but not with higher concentrations of copper or manganese, suggesting perhaps that arsenic and (or) lead

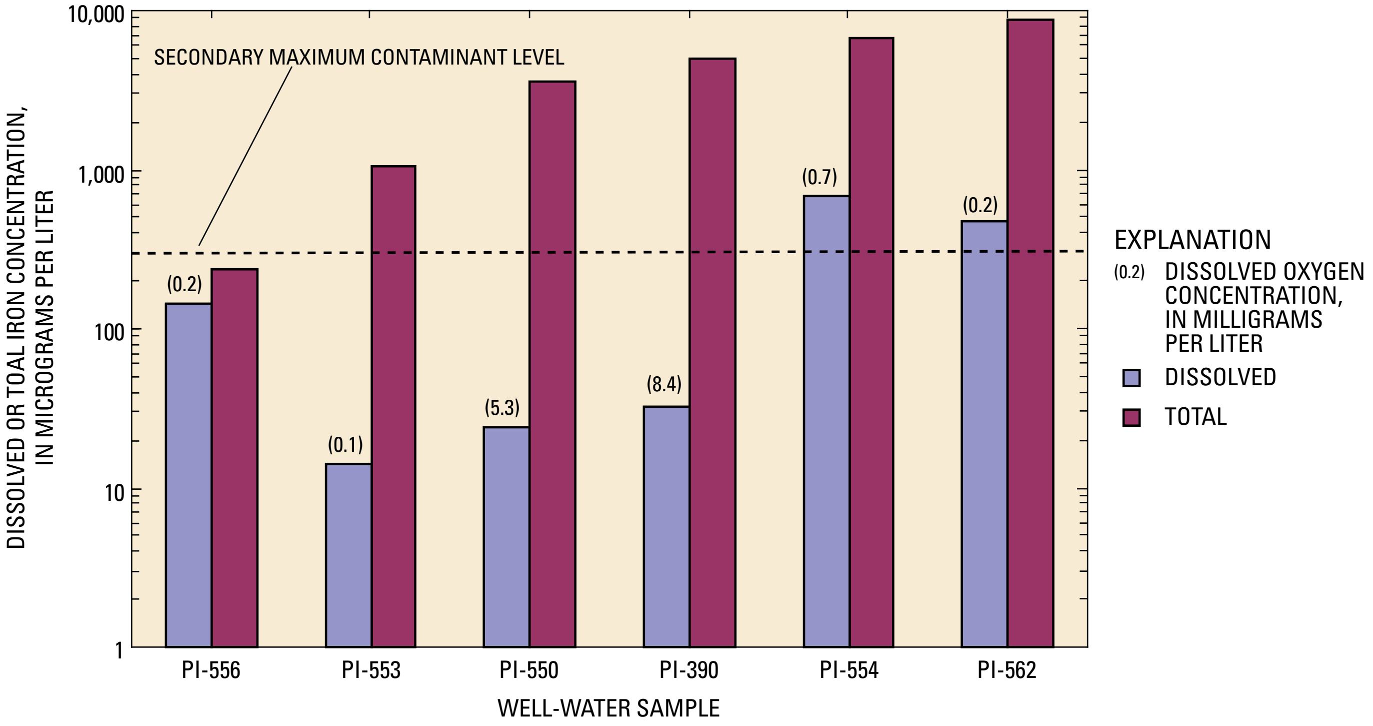


Figure 7. Dissolved and total concentrations of iron, in order of increasing total iron concentrations, in groundwater samples collected from six wells in Pike County, Pa., in 2007.

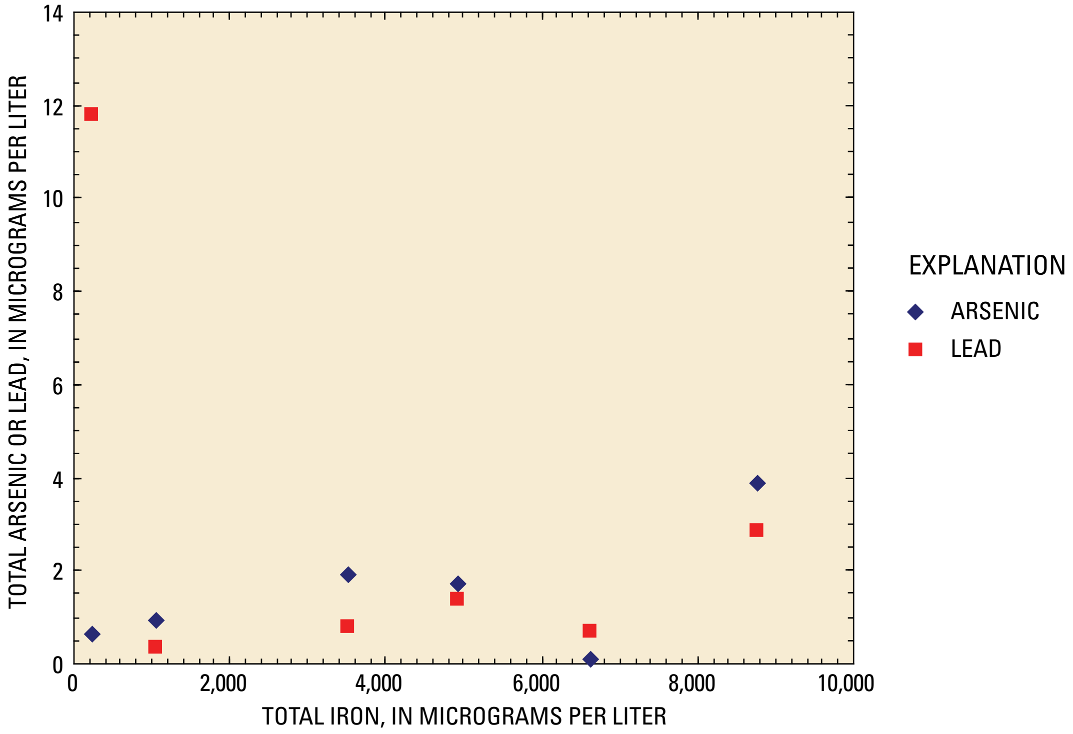


Figure 8. Total arsenic and lead concentrations in relation to total iron concentrations in groundwater samples collected from six wells in Pike County, Pa., in 2007.

may adsorb on iron oxide particles. Additional investigation would be needed to determine geochemical relations and processes controlling the distribution of metals between dissolved and particulate phases.

Organic Compounds

The organic compounds analyzed in samples for the 2007 groundwater-quality assessment included human-made VOCs and organic wastewater compounds. Detection of these compounds in groundwater indicates infiltration of recharge affected by human activities.

Volatile Organic Compounds

VOCs largely consist of human-made organic compounds, many of which commonly are used as solvents, such as trichloroethylene (TCE). VOCs may be associated with industrial activities and may be present in septic-tank effluent. Of the 29 regulated VOC compounds analyzed in the 20 groundwater samples, only 3 were detected at or above the reporting level: 1,1,1-trichloroethane (TCA) at 0.2 µg/L, trichlorofluoromethane (Freon-11) at 39 µg/L, and trichloromethane (TCM, also known as chloroform) at 0.8 µg/L (table 6). Samples from three wells (PI-554, PI-556, and PI-559) each had only one of these VOC compounds (chloroform, Freon-11, and TCA, respectively) (table 12 at the back of the report). Thus, 3 (15 percent) of 20 groundwater samples had at least 1 VOC, but the detection frequency of each VOC was 1 (5 percent) of 20 groundwater samples. The concentrations of TCA, Freon-11, and chloroform in the samples did not exceed any established USEPA drinking-water standards (table 6). Although the measured VOC concentrations do not pose an established health risk, the detection of these human-made compounds in groundwater indicates a low level of groundwater contamination by human activities.

TCA has been used as an industrial solvent, but its use is being phased out since 1996 as part of an international treaty to reduce gases that have a role in depleting the ozone layer of the earth (United Nations Environment Programme, 2006). Freon-11 was widely used as a refrigerant until 1996, when its use and uses of some other gases were banned because of their role in depleting the ozone layer. Chloroform is used as a solvent and reagent in synthesis of organic chemicals and can be produced as a by-product when chlorine bleach reacts with some other organic compounds in domestic wastewater.

Wastewater Compounds

Selected organic compounds present in industrial and domestic wastewater have been identified as having potential for endocrine disruption in living organisms. Methods to detect and measure these compounds at low concentrations in water (Zaugg and others, 2002) may provide sensitive indication of groundwater and surface-water contamination by wastewater. At present, drinking-water standards have been established for only a few of these organic wastewater compounds.

Of the 60 organic wastewater compounds analyzed, 5 were detected at low levels in groundwater samples collected in Pike County in 2007 (table 6). Concentrations of these compounds in most samples were detected below the laboratory reporting level but could not be quantified (reported by the laboratory as “M,” meaning measured) and are considered trace levels. DEET (N,N-diethyl-meta-toluamide, an insect repellent) was the most frequently detected compound, being

Table 6. Detected dissolved organic compounds in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

[MCL, maximum contaminant level; HA, health advisory; MRL, method reporting level; µg/L, micrograms per liter; M, measured but not quantified below MRL; —, minumum equals maximum because only one detection; -, no standard; E, estimated value below MRL; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran]

Organic compound	Number of samples with detections	Percent of samples with detection	MRL	Detected concentration		MCL (µg/L)	HA (µg/L)
				Minimum (µg/L)	Maximum (µg/L)		
Volatile organic compounds							
1,1,1-trichloroethane	1	5	<0.1	—	0.2	200	-
trichlorofluromethane	1	5	<.2	—	39	-	2,000
chloroform	1	5	<.1	—	.8	[1]80	70
Organic wastewater compounds							
DEET	9	45	<0.1 - <0.2	M	.2	-	-
HHCB	3	15	<.5	M	E.1	-	-
tributyl phosphate	1	5	<.2	—	M	-	-
triphenyl phosphate	1	5	<0.1 - <0.2	—	E.1	-	-
tris(2-butoxyethyl) phosphate	1	5	<0.4 - <0.5	—	E.1	-	-

[1] Includes all trihalomethanes.

present in 9 (45 percent) of the 20 groundwater samples at concentrations below the reporting level. HHCB (hexahydrohexamethyl cyclopentabenzopyran, a fragrance) was detected in 3 (15 percent) of the 20 groundwater samples. Tributyl phosphate (a flame retardant), triphenyl phosphate (plasticizer, finish, flame retardant), and tris(2-butoxyethyl)phosphate (a flame retardant) were each detected in 1 (5 percent) of the 20 groundwater samples. In a national reconnaissance study of the occurrence of wastewater compounds in groundwater, DEET was the most frequently detected compound, measured in 35 percent of samples, and triphenyl phosphate was measured in about 4 percent of the samples (Barnes and others, 2008). All five of the organic wastewater compounds detected in groundwater in Pike County samples commonly have been found in surface waters affected by wastewater discharges (Kolpin and others, 2002; Focazio and others, 2008; Tertuliani and others, 2008). In a study of the persistence of organic wastewater contaminants through a drinking-water treatment plant, DEET, HHCB, tributyl phosphate, and tris(2-butoxyethyl) phosphate were present in raw and finished water (Stackelberg and others, 2004). Results from the drinking-water-treatment study suggest that these and other compounds may also persist in the natural environment.

At least one organic wastewater compound was detected in 10 of the 20 groundwater samples. Multiple organic wastewater compounds were detected in three groundwater samples. The sample from well PI-552 had the most (four) organic wastewater compounds detected (table 13 at the back of the report). Two organic wastewater compounds were detected in samples from wells PI-554 and PI-555, and only one wastewater compound was detected in the remaining seven groundwater samples with detections (PI-211, PI-308, PI-464, PI-480, PI-551, PI-556, and PI-557). Samples from two wells with detections of organic wastewater compounds (PI-554 and PI-556) also had one VOC detection.

Radionuclides

Radioactive elements or radionuclides occur naturally in geologic materials and may be present in soils, unconsolidated deposits, and bedrock. The principal parent radioactive elements are uranium, thorium, and potassium. The decay of radioactive parent elements through nuclear disintegration emits associated alpha particles, beta particles, and (or) gamma radiation and produces daughter products that may also be radioactive. The half-life of a radionuclide is the amount of time required for one-half of the original parent radionuclide to undergo radioactive decay. The activity is a measure of the rate of decay and, in water, commonly is expressed in units of picocuries per liter. One picocurie is equivalent to 2.2 nuclear disintegrations per minute. The USEPA (2006) has established or proposed drinking-water standards for only some radionuclides, including two radium isotopes (radium-226 and radium-228), gross alpha-particle and gross beta-particle activity, radon-222, and uranium.

Radon-222

Radon-222 is produced from the decay of radium-226, itself a daughter product in the uranium-238 decay chain. Radon-222 is a gas that is soluble in water. Radon-222 has a half-life of about 3.8 days and decays by alpha-particle emission to polonium-218 and a series of relatively short-lived radionuclides that are non-gaseous. Radon-222 has the longest half-life of the 34 isotopes of radon. Radon-222 may pose a health risk, especially when in air, and may be released into household air from well water when that water is used and agitated (as in showering or washing clothes).

The USEPA has proposed two standards for radon-222 in drinking water, a MCL of 300 pCi/L or the alternative MCL of 4,000 pCi/L (U.S. Environmental Protection Agency, 2007). The standard of 4,000 pCi/L would be for public drinking-water systems in states that implement management of multimedia mitigation programs (programs to address the health risks of radon-222 in indoor air) and the lower standard of 300 pCi/L would befor public drinking-water systems in states that do not implement multimedia mitigation programs.

Radon-222 activities were greater than or equal to the proposed MCL of 300 pCi/L in water from 15 (75 percent) of the 20 wells sampled in Pike County in 2007. Radon-222 activities did not exceed the alternative MCL of 4,000 pCi/L in any groundwater samples. The highest radon-222 activity measured was 2,650 pCi/L and was present at that level in water samples from two wells (PI-288 and PI-551) completed in members of the Catskill Formation (table 7 and table 14 at the back of the report).

Gross Alpha-Particle and Gross Beta-Particle Activity

During radioactive decay, alpha particles or beta particles are emitted depending on the radioactive isotope undergoing decay. For example, during decay, radium-226 releases alpha particles and radium-228 releases beta particles. The analyses for gross alpha-particle and gross beta-particle radioactivity measure the sum of each type of particle release rate and will include particles from all radionuclides present. Gross alpha-particle and gross beta-particle analyses in water do not identify which radionuclides are present but can be used to screen for elevated radionuclides.

The USEPA has established drinking-water standards for gross alpha-particle and gross beta-particle activities. The MCLs for gross alpha-particle and gross beta-particle activities are expressed in different units. The MCL of 15 pCi/L for gross alpha-particle activity uses the units as directly reported by the laboratory. The MCL for gross beta-particle activity is 4 millirem per year, which is a dose and requires calculation on the basis of estimates of exposure and biological efficiency of specific radionuclides. The units of picocuries per liter cannot be directly converted to millirem without additional information. However, elevated levels of gross beta activity may be

Table 7. Minimum, median, and maximum values for activities of dissolved radionuclides and uranium concentrations in groundwater samples collected from 20 wells in Pike County, Pa. in 2007.

[MCL, maximum contaminant level; HA, health advisory; SMCL, secondary maximum contaminant level; AMCL, alternative maximum contaminant level; R, radchem no detect; Th-230, thorium-230; Cs-137, cesium-137; pCi/L, picocuries per liter; -, no standard; µg/L, micrograms per liter; mrem/yr, millirem per year]

Constituent	Units	Number of samples with detections	Minimum	Median	Maximum	MCL	HA	Remarks
Radon-222	pCi/L	20	90	610	2,650	300	150	AMCL of 4,000 pCi/L
Gross alpha-particle radioactivity[1]								
72-hour count	pCi/L	3	R-1.2	R0.1	2	15	-	
30-day count	pCi/L	0	R-2.4	R-0.2	R0.6	15	-	
Gross beta-particle radioactivity[2]								
72-hour count	pCi/L	5	R-1.9	R0.4	1.4	4 mrem/yr	-	MCL expressed in terms of dose
30-day count	pCi/L	7	R-0.4	R0.6	2.4	4 mrem/yr	-	MCL expressed in terms of dose
Uranium (natural)	µg/L	17	[3].03	.08	1.15	30	20	

[1] Gross alpha-particle activity, based on Th-230 curve.

[2] Gross beta-particle activity, based on Cs-137 curve.

[3] Value less than the reporting level of less than 0.04 µg/L was reported for one sample.

used to screen for presence of beta-emitting radionuclides that warrant further investigation.

Gross alpha-particle and gross beta-particle activities in samples collected from the 20 wells in 2007 were counted by the laboratory at two different times after collection, 72 hours and 30 days (table 14 at the back of the report), to provide information on the presence of radionuclides with half-lives of different lengths. Short-lived radionuclides decay quickly and, if present, will be associated with a decrease in radioactivity from 72 hours to 30 days. Increases in radioactivity over that time period indicate in-growth of longer-lived radionuclides in the water sample.

None of the groundwater samples had elevated gross alpha-particle activities that exceeded drinking-water MCLs at either 72 hours or 30 days (table 7). The low level of gross beta-particle activities measured in the 20 groundwater samples (less than 3 pCi/L) probably do not correspond to an exceedence of the standard of 4 millirem per year. Many of the reported laboratory results were less than zero, indicating that background radiation in the laboratory analyses was greater than the radiation in these samples. Gross alpha-particle activities tended to be slightly higher in the 72-hour counts than in the 30-day counts, indicating the presence of short-lived alpha-particle emitters. Gross beta-particle activities tended to be slightly lower in the 72-hour counts than in the 30-day counts, indicating ingrowth of beta-particle-emitting radionuclides in the sample. Overall, the results indicate low potential for the presence of elevated activities of radionuclides other than radon-222 in the groundwater samples from Pike County in 2007.

Uranium

Uranium is a naturally occurring element with three natural isotopes—uranium-238, uranium-235, and uranium-234—that are all radioactive. The long-lived uranium-238 is the most abundant uranium isotope in nature. Uranium measured by chemical methods, as was done for the 2007 assessment, typically includes all uranium isotopes present in the sample and is reported as natural uranium. The USEPA has established a MCL of 30 μg/L for uranium in drinking water on the basis of health risks posed by uranium metal toxicity, although some risk is caused by uranium radioactivity. The USEPA also lists a HA level of 20 μg/L for uranium.

None of the groundwater samples collected in Pike County in 2007 had uranium concentrations that exceeded either the HA of 20 μg/L or the MCL of 30 μg/L in drinking water (table 7 and table 14 at the back of the report). The highest uranium concentration in water from the 20 wells sampled was 1.15 μg/L. Thus, although the observed radon-222 concentrations indicate that uranium probably is present in aquifer materials in Pike County, the uranium does not appear to dissolve in groundwater in concentrations large enough to exceed an established drinking-water standard.

Relation Between Groundwater Quality and Setting

Groundwater acquires solutes through natural and anthropogenic loading of constituents in the recharge area, including from precipitation, weathering reactions of minerals in the soil and aquifer materials, and constituents applied by human activities at or near the surface. Additional solutes may be acquired as groundwater flows through the aquifer. On the basis of the hydrogeology described by Davis (1989), groundwater that supplies most domestic wells completed in upland areas of Pike County in the fractured bedrock aquifer is derived principally from local recharge and will be influenced by land use and geology near the well. In wells completed in the glacial deposits along the Delaware River, some component of water in that aquifer may have originated in the upland bedrock areas but most water supplying a well is assumed to be derived locally.

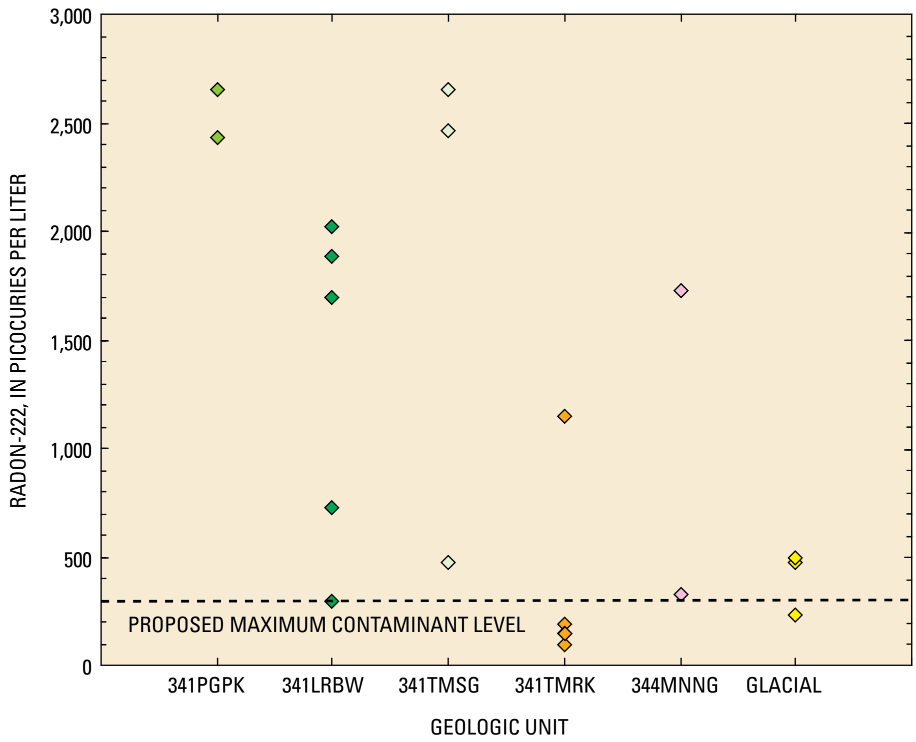
Although the number of wells sampled in the 2007 groundwater-quality assessment is too small to permit a rigorous statistical comparison of differences in groundwater quality among different land uses and geologic units, results are presented to infer some relations between groundwater quality and these factors.

Groundwater Quality and Geology

Naturally occurring constituents might be expected to differ among geologic units because of differences in mineralogy, recharge rates, traveltimes, and other aquifer characteristics. These constituents include most major ions, selected trace elements, and radionuclides.

Differences in concentrations of some constituents in groundwater from the six geologic units sampled were indicated by the limited data. These constituents included potassium, silica, sulfate, nitrite plus nitrate as nitrogen, selenium, and radon-222. Concentrations of potassium and nitrite plus nitrate as nitrogen tended to be higher in water from the glacial deposits and the Long Run and Walcksville Members of the Catskill Formation, undivided, than in water from the other geologic units. The higher permeability of the glacial deposits compared to soils on bedrock aquifers may explain the higher concentrations of nitrite plus nitrate as nitrogen. Sulfate and selenium concentrations also tended to be higher in water from the glacial deposits than from the other geologic units. Silica concentrations were highest in water from the Trimmers Rock Formation.

Radon-222 activities were highest in water from the bedrock aquifers and lowest in the water from the glacial deposits (fig. 9), perhaps reflecting in part the occurrence of uranium-bearing minerals in the aquifers. Radon-222 activities in groundwater ranged from 90 to 2,650 pCi/L (median of 1,150 pCi/L) for bedrock aquifers and ranged from 230 to 490 pCi/L (median of 470 pCi/L) for the glacial deposits. Among the bedrock units, radon-222 activities appeared high-



EXPLANATION

341PGPK	Poplar Gap and Packerton Members of Catskill Formation, undivided
341LRBW	Long Run and Walcksville Members of Catskill Formation, undivided
341TMSG	Towamensing Member of Catskill Formation
341TMRK	Trimmers Rock Formation
344MNNG	Mahantango Formation
GLACIAL	Outwash (112OTSH) and Kame terrace (112KMTC)

Figure 9. Radon-222 activities in groundwater samples from 20 wells in different geologic units, Pike County, Pa., 2007. (Geologic units are shown on fig. 2.)

est in water from the Poplar Gap and Packerton Members of the Catskill Formation, undivided (median of 2,540 pCi/L), followed by water from the Towamensing Member (median of 2,460 pCi/L) and Long Run and Walcksville Members, undivided (median of 1,700 pCi/L), of the Catskill Formation; and lowest in water from the Trimmers Rock Formation (median of 150 pCi/L) (fig. 9). Montgomery (1969) noted that uranium minerals, a likely source of radon-222, occur in Catskill Formation rocks elsewhere in Pennsylvania.

Groundwater Quality and Land Use

Human activities at the land surface can contribute constituents or contaminants to groundwater. The predominant land uses associated with human activities that have the potential to affect groundwater quality in Pike County are residential and commercial. In Pike County, residential on-site wastewater disposal is common and has the potential to contribute salts (chloride compounds), nutrients (nitrogen and phosphorus compounds), boron (a laundry additive), VOCs, and organic wastewater compounds to groundwater. Bacteria and other compounds present in wastewater were not analyzed in this study but also have potential to affect groundwater quality. Large areas of paved surfaces (parking lots) near commercial zones and roads throughout the county have seasonal application of de-icing salts that may infiltrate into groundwater. Other compounds such as pesticides and herbicides, not included in this study, also may be applied near roadways, on lawns, or in agricultural areas.

Of the constituents included in analyses of the 20 groundwater samples collected in 2007 in Pike County, only a few differences in individual constituent concentrations among the different land uses were indicated by the limited data. Water from one (PI-556) of the four wells in the undeveloped area had a number of constituents that indicated unexpected contamination (such as Freon-11) that likely indicates nearby improper disposal of the chemical and is not related to the land use. Constituents with probable differences in concentrations among different land uses included chloride, nitrite plus nitrate as nitrogen, and manganese.

Chloride concentrations tended to be highest in groundwater from wells in the high- and moderate-density residential areas with on-site wastewater disposal and lowest in some of the undeveloped and sewered areas (fig. 10A, table 8). A water sample from a well in a commercial area also had an elevated (40 µg/L) chloride concentration. The highest boron and ammonia concentrations were in samples that also had elevated chloride concentrations from wells in commercial and residential areas with on-site wastewater disposal. The combination of elevated chloride, boron, and ammonia concentrations suggests septic effluent as a source. Road salt may be a main source of chloride in samples with elevated chloride concentrations but not elevated concentrations of boron or nitrogen compounds. Chloride concentrations were less than the estimated low-range natural background of 1 mg/L from precipitation in two of the wells in undeveloped areas.

Concentrations of nitrite plus nitrate as nitrogen tended to be higher in wells in high- and moderate-density residential areas with on-site septic and commercial areas (fig. 10B). Water samples from the two wells in the sewered residential and pre-development areas had among the lowest concentrations of chloride and nitrite plus nitrate as nitrogen as did two of the four wells in the undeveloped areas, suggesting human activities had less impact on water quality in those land-use areas.

Manganese concentrations tended to be lowest in water from wells in the high-density residential areas with on-site wastewater disposal and the sewered residential area compared to water from wells in other land-use areas. It is unknown why low manganese concentrations occurred in water from these areas.

The detection of VOCs in groundwater samples appears somewhat related to land use. VOCs were detected in water from only three wells, two (PI-554 and PI-559) in residential areas with on-site wastewater disposal and one (PI-556) in an undeveloped area with probable local contamination (table 8). The VOCs detected in water from wells in residential areas, TCA and chloroform, are likely associated with the on-site wastewater disposal. The well (PI-556) in the undeveloped area had 39 µg/L of freon-11, a compound used as a refrigerant and solvent whose presence and concentration indicate groundwater contamination by improper chemical disposal such as dumping. No VOCs or wastewater compounds were detected in the two wells in the sewered residential and pre-development areas.

Of the five organic wastewater compounds detected in groundwater in Pike County, no strong relation between land use and detection in groundwater was apparent for DEET or HHCB. DEET was detected most often and was measured at very low levels in samples from about half of the 20 wells and in most categories of land use, including commercial, residential with on-site septic (high and moderate density), and undeveloped. The frequent detection of DEET at low levels in Pike County probably is related to the high mobility and persistence of DEET in the environment, as noted in other studies throughout the United States (Barnes and others, 2008). As described previously, all samples in Pike County were from residential wells and, thus, in areas where DEET may be used. HHCB was detected in water from three wells, two wells in residential areas with on-site wastewater disposal, and one well in an undeveloped area. HHCB, like DEET, commonly is detected in surface waters affected by wastewater discharges (Barnes and others, 2008; Focazio and others, 2008). However, the other three organic wastewater compounds, triphenyl phosphate, tributyl phosphate, and tris(2-butoxylethyl) phosphate, were each detected only once and were present in water samples from two wells (PI-211 and PI-552) in moderate-density residential areas with on-site disposal.

Four groundwater samples had more than one organic wastewater compound or VOC detected and were from an area with residential on-site wastewater disposal land use and from an area with undeveloped land use. The sample with the most

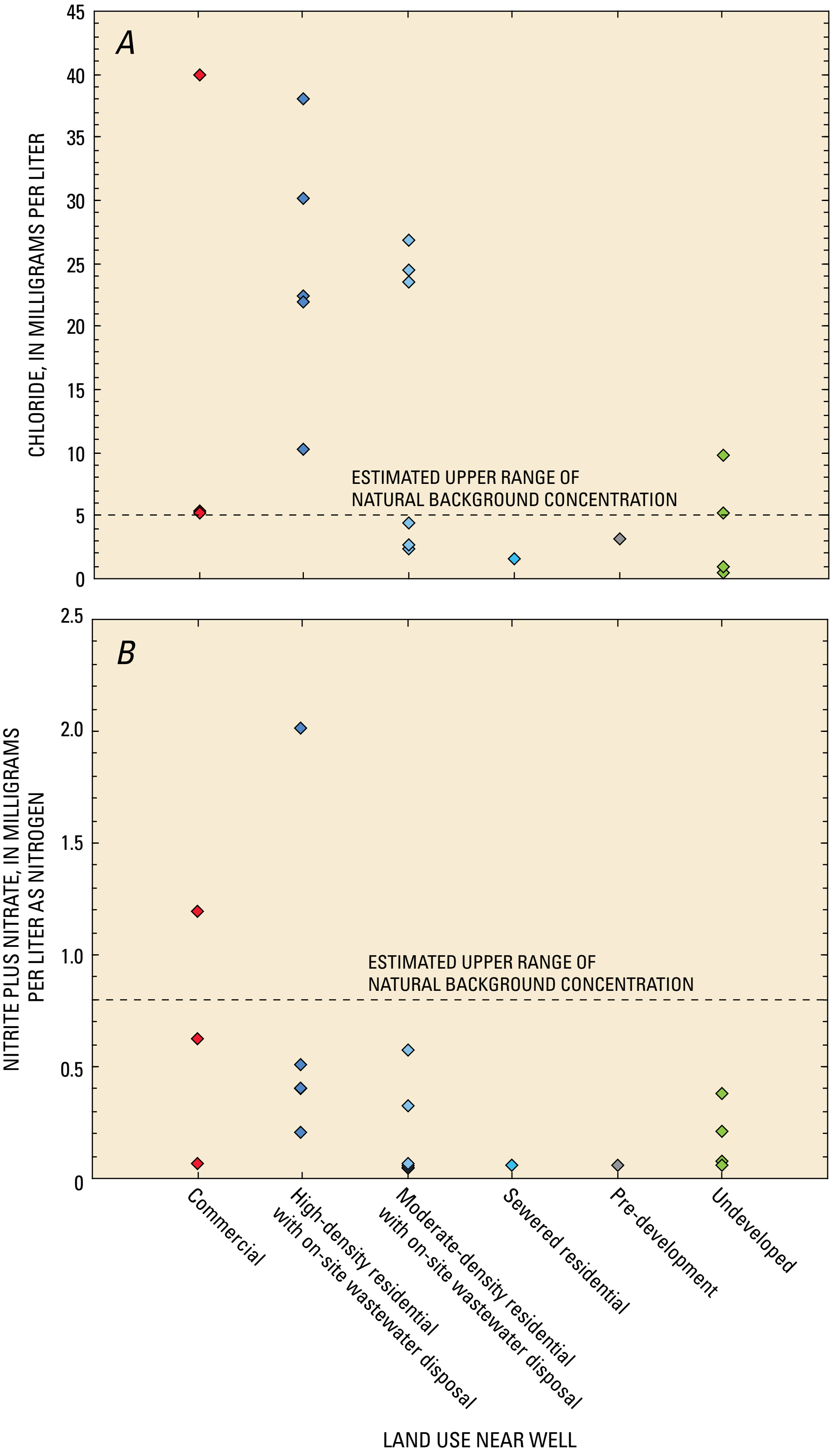


Figure 10. Concentrations of (*A*) chloride and (*B*) nitrite plus nitrate as nitrogen in groundwater samples from 20 wells in different land-use areas, Pike County, Pa., 2007.

Table 8. Detected organic wastewater and volatile organic compounds and concentrations of inorganic and nutrient wastewater indicators in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.

[Shaded values indicate concentrations above estimated natural background. µg/L, micrograms per liter; mg/L, milligrams per liter; VOCs, volatile organic compounds; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; tb-phos, tributyl phosphate; tp-phos, triphenyl phosphate; t2b-phos, tris(2-butoxyethylphosphate); TCA, 1,1,1-trichloroethane; TCM, trichloromethane or chloroform; B, boron; Na, sodium, Cl, chloride; NH_4 as N, ammonia as nitrogen; NO_2+NO_3 as N, nitrite plus nitrate as nitrogen; PO_4 as P, orthophosphate as phosphorus; <, less than; E, estimated; M, measured but not quantified below method reporting level; Geologic unit: Glacial units—12KMTC, Kame terrace; 112OTSH, Olean outwash; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; Bedrock units—341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

Well number	Geologic unit	Organic wastewater compounds (µg/L)					VOCs (µg/L)		
		DEET	HHCB	tb-phos	tp-phos	t2b-phos	TCA	freon-11	TCM
		Commercial							
PI-380	341TMRK								
PI-390	341DLRV[1]								
PI-464	112OTSH	M							
		Residential, high-density, on-site wastewater							
PI-480	112KMTC	M							
PI-551	341TMSG	M							
PI-554	341TMRK	M	M						0.8
PI-557	341LRBW	M							
PI-561	341LRBW								
		Residential, moderate-density, on-site wastewater							
PI-211	341TMRK				E0.1				
PI-288	341PGPK								
PI-524	341TMSG								
PI-550	341TMSG								
PI-552	341TMRK	M	E0.1	M		E.1			
PI-559	341LRBW						0.2		
		Residential, sewered							
PI-558	344MNNG								
		Pre-development (large-scale mixed-use land development)							
PI-562	341TMRK								
		Undeveloped							
PI-308	112OTSH	M							
PI-553	341LRBW								
PI-555	341PGPK	0.2	M						
PI-556	344MNNG	M						39.0	

[1] Mapped as 341LRBW by Berg and others (1980).

Table 8. Detected organic wastewater and volatile organic compounds and concentrations of inorganic and nutrient wastewater indicators in groundwater samples collected from 20 wells in Pike County, Pa., in 2007.—Continued

[Shaded values indicate concentrations above estimated natural background. µg/L, micrograms per liter; mg/L, milligrams per liter; VOCs, volatile organic compounds; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; tb-phos, tributyl phosphate; tp-phos, triphenyl phosphate; t2b-phos, tris(2-butoxyethylphosphate); TCA, 1,1,1-trichloroethane; TCM, trichloromethane or chloroform; B, boron; Na, sodium, Cl, chloride; NH_4 as N, ammonia as nitrogen; NO_2+NO_3 as N, nitrite plus nitrate as nitrogen; PO_4 as P, orthophosphate as phosphorus; <, less than; E, estimated; M, measured but not quantified below method reporting level; Geologic unit: Glacial units—112KMTC, Kame terrace; 112OTSH, Olean outwash; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; Bedrock units—341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

Well number	Inorganic and nutrient wastewaster indicators (mg/L)					
	B	Na	Cl	NH_4 as N	NO_2+NO_3 as N	PO_4 as P
			Commercial			
PI-380	28.0	17.8	39.9	0.059	<0.06	0.011
PI-390	13.0	3.9	5.4	.027	.63	.007
PI-464	5.4	4.3	5.3	<.020	1.19	.055
			Residential, high-density, on-site wastewater			
PI-480	5.3	13.2	38.1	<.020	.52	E.005
PI-551	10.0	9.2	30.1	<.020	.41	.009
PI-554	20.0	11.2	22.4	E.012	.22	<.006
PI-557	20.0	12.0	21.9	<.020	2.00	.029
PI-561	10.0	4.4	10.2	<.020	.41	.015
			Residential, moderate-density, on-site wastewater			
PI-211	20.0	14.1	26.8	.059	<.06	.011
PI-288	5.0	2.7	4.4	E.010	.56	.016
PI-524	77.0	39.9	24.4	.059	<.04	.020
PI-550	5.3	4.4	2.4	E.016	E.05	.011
PI-552	8.9	6.9	2.6	E.016	<.06	.011
PI-559	5.3	7.0	23.6	<.020	.32	.012
			Residential, sewered			
PI-558	8.7	3.1	1.6	<.020	E.04	.018
			Pre-development (large-scale mixed-use land development)			
PI-562	7.3	5.6	3.2	.025	<.04	E.004
			Undeveloped			
PI-308	8.2	6.2	9.8	<.020	.19	<.006
PI-553	5.3	7.8	.5	<.020	<.06	.020
PI-555	6.0	1.4	.9	<.020	.36	.021
PI-556	33.0	9.3	5.2	.063	E.04	.016

(four) organic wastewater compounds detected was from a well (PI-554) in a moderate-density residential area with on-site wastewater disposal. Two organic wastewater compounds and a VOC were detected in water from a well (PI-552) in a high-density residential area with on-site wastewater disposal. DEET and HHCB were detected in water from a residential well (PI-555) in an undeveloped area. DEET and Freon-11 were detected in water from a well (PI-556) in an undeveloped area thought to be affected by contamination.

Relation Between Groundwater Quality and Surface-Water Quality

Groundwater discharge to streams is the source of stream base flow (groundwater component as opposed to runoff). Some constituents dissolved in groundwater, especially relatively soluble constituents that are not adsorbed onto soils or aquifer materials or readily degraded in the groundwater system, may be transported in groundwater and discharge to streams in the drainage area. In headwater areas and small streams, groundwater discharge originates locally. Multiple levels of groundwater flow systems may be present from shallow local flow to deeper regional flow. In Pike County, groundwater may also discharge to swampy areas and to lakes and ponds, whether naturally occurring or where created artificially by placement of dams on streams.

Data on stream water quality collected by USGS for PADEP are available for six stream sites in Pike County. These sites are sampled as part of the PADEP statewide water-quality network (WQN). Some sites in the WQN are identified by PADEP as reference sites to represent water quality in watersheds with low levels of human influence in different regions of the state and typically receive no direct discharges from human activities, such as wastewater treatment plants (WWTPs), and are sampled monthly for 5 years. Base-flow quality at these reference stream sites will reflect quality of the groundwater discharge to the streams. Three of the six WQN stream sites in Pike County are reference sites.

Chloride is a relatively conservative (remains in solution, unaffected by degradation, sorption, or other chemical processes) constituent in groundwater and surface-water systems and can be used, for example, to investigate the relation between groundwater and surface-water quality. In Pike County, stream water-quality data are available for one former WQN reference site (014738760 Adams Creek at Dingmans Ferry, WQN 192) and two current WQN reference sites (01432097 Blooming Grove Creek at Glen Eyre, WQN site 197 and 01431554 Kintz Creek at Romersville, WQN site 199) (fig. 2). Chloride concentrations in the lowest flows (less than 2 $(ft^3/s)/mi^2$, estimated to represent base flow) at these sites ranged from 8.5 to 15.1 mg/L in Adams Creek (2002–2004), from 8.5 to 15.5 mg/L in Blooming Grove Creek (2005–2008), and from 3.9 to 5.5 mg/L in Kintz Creek (2005–2008); the medians were 11.8, 10.8, and 4.5 mg/L, respectively. Although overall chloride concentrations are relatively low, the higher chloride concentrations in stream base flow at Adams Creek and Blooming Grove Creek compared to Kintz Creek indicate higher levels of human influence in the Adams Creek and Blooming Grove Creek watersheds. The upper areas of Adams Creek and Blooming Grove Creek watersheds are in residential land-use areas with major roads (routes 739 and I-84, 6, respectively) whereas most of Kintz Creek is vacant residential land (fig. 2). On the basis of the results of the 2007 groundwater-quality assessment, areas in residential land use generally have higher chloride concentrations in groundwater than undeveloped areas in Pike County.

Nitrate is a less conservative constituent in the environment than chloride but may be relatively elevated in stream base flow in watersheds with elevated nitrate concentrations in groundwater. Nitrate concentrations in the lowest flows at the three WQN reference sites in Pike County ranged from less than 0.04 to 0.27 mg/L as N in Adams Creek (2002–2004), from less than 0.04 to 0.08 mg/L as N in Blooming Grove Creek (2005–2008), and from less than 0.04 to 0.12 mg/L as N in Kintz Creek (2005–2008); the medians were 0.10, less than 0.04, and 0.07 mg/L as N, respectively. All the nitrate concentrations were low and within the range of estimated natural background levels. Of the three sites, Adams Creek had the highest chloride and nitrate concentrations, which probably reflects a higher degree of impact by human activities in that watershed compared to the other two.

Temporal Aspects of Groundwater Quality

Groundwater quality can change through time because of (1) changes in land use and sources at the land surface, (2) changes in recharge and direction of groundwater flow, or (3) transport and chemical reactions in the aquifer. Changes in groundwater quality may result in increased risks to human health if water-quality standards are exceeded or in other undesirable effects, such as elevated concentrations of iron and manganese, on non-consumptive water use. Some variability in groundwater quality may be seasonal if related to the natural hydrological cycle; other variability may show a trend reflecting long-term changes in land use.

Age of Groundwater

The age of groundwater may be used to evaluate potential for contamination by human activities in the recharge area. For example, young groundwater recharged within the last 5 years will be more affected by recent land use than old groundwater recharged more than 500 years ago. Techniques to date relatively young groundwater (less than 50 years old) have been developed using the concentration of anthropogenic gases (such as chlorofluorocarbons) released into the atmosphere that equilibrate with recharge (Busenberg and Plummer, 2000; Plummer, 2005; International Atomic Energy Agency, 2006). The technique actually dates the introduction of these gases to recharge rather than the age of the water itself. A statewide study in Virginia used this approach to determine that all groundwater in fractured-rock terrains and most of the shallow groundwater in the unconsolidated Coastal Plain aquifers were susceptible to near-surface contamination (Nelms and others, 2003). In general, younger water is most susceptible to near-surface contamination but would be expected to flush out of the aquifer more quickly than older water.

Water from 4 of the 20 wells sampled in 2007 was selected for age-dating by analysis of the gases CFC-11 (trichlorofluoromethane or $CFCl_3$), CFC-12 (dichlorodifluoromethane or CF_2Cl_2), CFC-113 (trichlorotrifluoroethane or $C_2F_3Cl_3$), and SF_6 (sulfur hexafluoride). The four wells (PI-308, PI-553, PI-555, and PI-556) were in relatively undeveloped areas of Pike County (fig. 2). Three of the wells were completed in bedrock and one well (PI-308) was completed in the glacial outwash or kame terrace aquifer near the Delaware River. Duplicate samples from each well were collected for analysis. Dissolved gas samples were also collected to allow calculation of recharge temperature and excess air (table 15 at the back of the report) for better estimation of age-dating by CFC and SF_6 methods (Busenberg and Plummer, 1992; U.S. Geological Survey, 2009b).

Apparent ages ranged from 17 to 34 years and 39 to 54 years for samples from two bedrock wells (PI-555 and PI-553, respectively) and from 6 to 19 years for the well in the glacial aquifer (PI-308) (table 9). The chlorofluorocarbons may be affected by chemical processes, such as sorption and degradation, to a greater extent than SF_6 (Han and others, 2006), and if CFC concentrations have been reduced by chemical processes, ages estimated from CFCs may be somewhat older than those estimated from SF_6. Estimated ages from SF_6 (table 9) are slightly younger than those estimated from CFCs. The water sample from well PI-556 could not be used for age-dating because the sample had elevated levels of CFC-11 (also known as Freon-11), possibly from improper waste disposal in the area that resulted in groundwater contamination.

Change in Groundwater Quality through Time

Five of the 20 wells sampled in 2007 were sampled by USGS at least once before; the time elapsed between sampling ranged from 6 to 25 years. Two wells were in residential areas (PI-288 and PI-480), two wells were in commercial areas (PI-380 and PI-464), and one well was in an undeveloped area (PI-308) (fig. 2). All but one well (PI-288) are in the eastern, more-developed part of Pike County. Four of the five wells were sampled twice and one well (PI-480) was sampled three times. Samples collected at the different times were analyzed for major ions, nutrients, iron, and manganese, allowing for a comparison of a limited set of constituents. Because elevated concentrations of chloride and nitrite plus nitrate as nitrogen commonly were associated in the 2007 groundwater samples with the predominant types of development in Pike County, residential and commercial, comparison of these constituents are discussed.

Chloride concentrations showed little change in some well samples and large changes in others, suggesting changes related to development intensity vary spatially throughout the county. The chloride concentrations were relatively similar in samples collected in three of the wells (PI-288, PI-308, and PI-464) in different land uses (residential, undeveloped, and commercial, respectively) over time spans ranging from 6 to 25 years, indicating relatively stable inputs. However, chloride concentrations in samples from two other wells increased substantially over time spans that ranged from 16 to 25 years (fig. 11A). Chloride concentrations tripled in water from well PI-380 in a commercial area and more than doubled in water from well PI-480 in a residential area to concentrations near 40 mg/L (table 11 at the back of the report). These large

Table 9. Estimated apparent ages in years before 2007 for groundwater samples from four wells in Pike County, Pa., in 2007. Ages based on piston-flow model for gas in recharge. (Replicate samples analyzed for each well.)

[SF_6, sulfur hexafluoride; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluorothane; —, no data because sample bottle broken; contam., contaminated, sample could not be analyzed; NP, not possible ratio]

Well	Replicate	Age in years, based on single gas					Age in years, based on ratio of gases		
		SF_6	SF_6 local[1]	CFC-11	CFC-12	CFC-113	CFC-11/ CFC-12	CFC-113/ CFC-12	CFC-113/ CFC-11
PI-308	1	5.7	9.2	contam.	contam.	19.2	NP	NP	NP
	2	—	—	—	—	19.2	NP	NP	NP
PI-553	1	38.7	40.7	49.7	53.2	50.2	36.2	30.2	28.7
	2	39.2	40.7	50.7	53.7	51.7	40.2	32.7	29.2
PI-555	1	16.7	18.7	33.7	30.7	25.2	NP	22.2	16.7
	2	16.7	18.7	34.2	30.2	25.7	NP	22.7	16.7
PI-556	1	contam.	contam.	contam.	contam.	contam.	contam.	contam.	contam.
	2	contam.	contam.	contam.	contam.	contam.	contam.	contam.	contam.

[1] Enrichment factor of 1.2 used for SF_6 due to local use of gas estimated to be up to about 20 percent greater than Northern Hemisphere clean air levels for area 75-100 miles west of New York City based on data from Santella and others (2008).

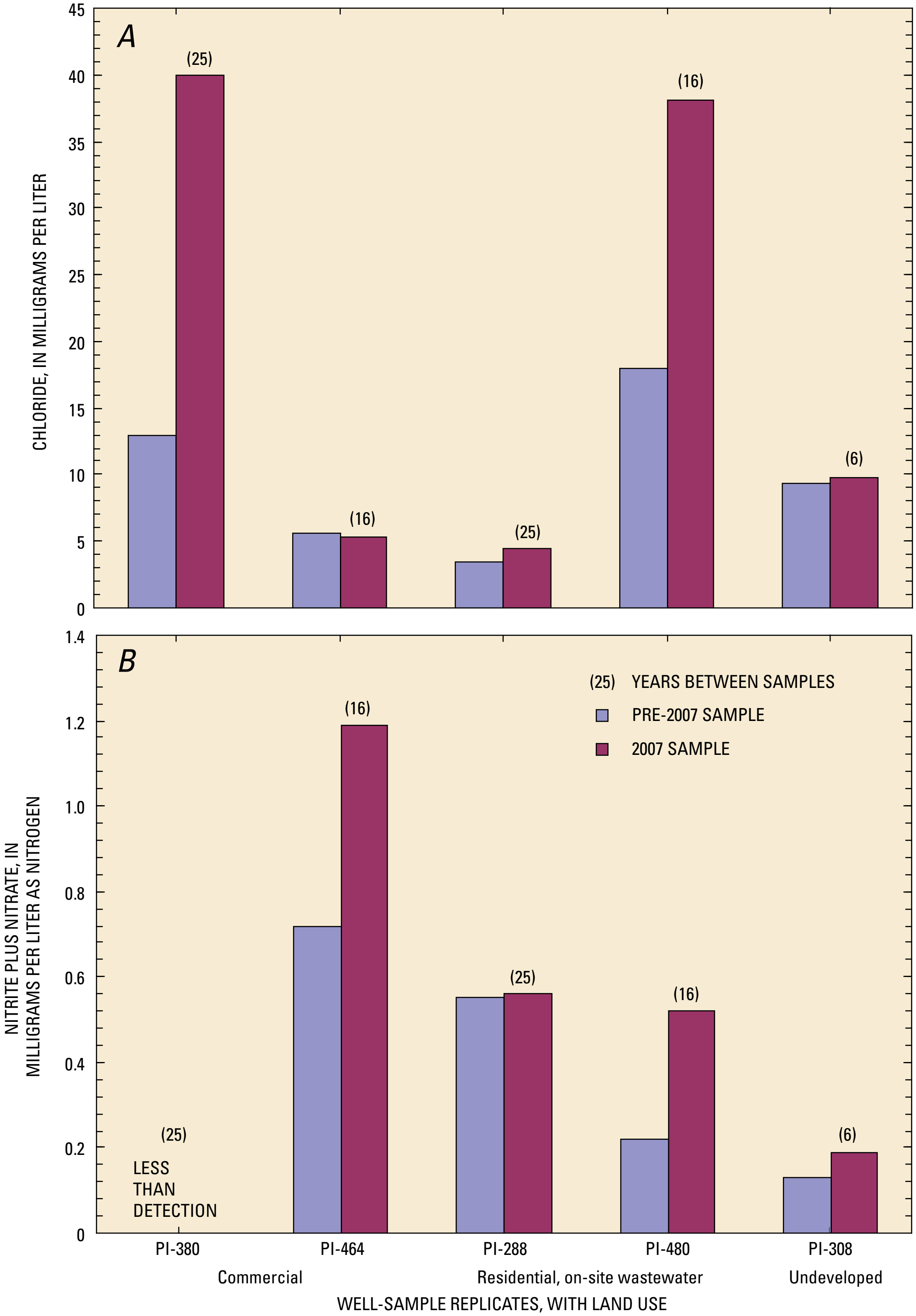


Figure 11. Concentrations of (*A*) chloride and (*B*) nitrite plus nitrate as nitrogen in groundwater from five wells sampled at time intervals ranging from 6 to 25 years in the period from 1982 to 2007, Pike County, Pa.

increases in chloride concentrations were in water samples from wells along the Route 209 corridor.

Similar to chloride, concentrations of nitrite plus nitrate as nitrogen showed little change in some well samples and larger changes in others. Nitrogen compounds are not necessarily as conservative as chloride, however, and can change through time related to chemical reactions rather than to changes in the groundwater of the wells (PI-288, PI-308, and PI-380) in different land uses (residential, undeveloped, and commercial, respectively) over time spans ranging from 6 to 25 years (fig. 11B). Concentrations of nitrite plus nitrate as nitrogen in samples from two other wells (PI-480 and PI-464) increased by 0.30 to 0.47 mg/L as N over 16-year time spans. The groundwater samples from well PI-480 in a residential area also showed a relatively large increase in chloride concentration, reflecting loads from potential septic and road-salt sources.

Summary and Conclusions

Pike County in northeastern Pennsylvania has experienced the largest relative population growth of any county in the state during the period 1990–2000, and its population is projected to increase substantially through 2025. This growing population may result in added dependence and stresses on water resources, including the potential to degrade the quality of groundwater and associated stream base flow with changing land use. The most recent county-wide assessment of groundwater resources done in the early 1980s was limited in scope and, after more than 20 years of development, little was known about the current quantity and quality of groundwater in Pike County.

In 2007, the U.S. Geological Survey, in cooperation with the Pike County Conservation District, began a study to provide current information on groundwater quality throughout the county that will be helpful for water-resource planning. The countywide reconnaissance assessment of groundwater quality documents current conditions with existing land uses and may serve as a baseline of groundwater quality for future comparison in Pike County. The 2007 assessment may also be used as a basis for comparison of groundwater quality in other areas of Pennsylvania and to evaluate groundwater quality in relation to geology and land use.

Pike County covers 545 square miles and is underlain by Devonian-age fractured-rock aquifers (shales, siltstones, and sandstones); high-yielding unconsolidated Quaternary-age glacial deposits are present in a band parallel to the Delaware River on the eastern edge of the county and in some upland stream valleys. These aquifers are recharged locally by precipitation and discharge to streams. The bedrock geologic units that underlie Pike County are, in order of decreasing age, Marcellus Formation, Mahantango Formation, Trimmers Rock Formation, Towamensing Member of the Catskill Formation, undivided Long Run and Walcksville Members of the Catskill Formation, and undivided Poplar Gap and Packerton Members of the Catskill Formation. Glacial deposits cover part of the bedrock units and vary in thickness and type.

As of 2005, the principal land uses in the county were public (33 percent), residential (24 percent), agricultural (23 percent), hunt club/private recreational (14 percent), roads (2 percent), and commercial (2 percent). The public lands include state park, state game, state natural area, and national park parcels, much of which are forested, as are hunt club parcels. Use of land for seasonal recreation results in seasonal increases in population.

Groundwater is the main source of drinking water in the county. Individual on-site wells are common in many residential areas, although large wells supply some developments. On-site wastewater disposal is common in residential areas; sand mounds are more commonly used than septic systems in the more recent developments, although some developments are sewered and have sewage-treatment systems that discharge treated effluent to land areas or to surface water.

For this reconnaissance assessment of groundwater quality in Pike County, 20 wells were sampled in 2007 throughout the county to represent groundwater quality in the principal land uses and geologic units. The laboratory analyses selected for the samples were intended to identify naturally occurring constituents from the aquifer or constituents introduced by human activities that pose a health risk or otherwise were of concern in groundwater in the county. The samples were analyzed for major ions, nutrients, selected trace metals, volatile organic compounds (VOCs), selected organic wastewater compounds, gross alpha-particle and gross beta-particle activity, uranium, and radon-222. Wells in each of six main geologic units (five fractured-rock aquifers and one glacial unconsolidated aquifer) and six land-use categories (commercial, high-density residential with on-site wastewater disposal, moderate-density residential with on-site wastewater disposal, residential in a sewered area, pre-development downgradient from a proposed large-scale mixed-use land development, and undeveloped) were selected for sampling.

Results of the sampling were compared to established USEPA drinking-water standards. No established primary drinking-water standard or maximum contaminant level (MCL) was exceeded by any constituent analyzed. However, radon-222 activities were greater than or equal to the proposed MCL of 300 pCi/L in water from 15 (75 percent) of the 20 wells sampled in Pike County in 2007. Radon-222 did not exceed the alternative MCL of 4,000 pCi/L in any groundwater sample. The gross alpha-particle and gross beta-particle activities were low and did not indicate potential for elevated radioactivity other than radon-222. The dissolved arsenic concentration of 3.9 μg/L in one sample was greater than the health advisory level of 2 μg/L but less than the MCL of 10 μg/L.

Concentrations of dissolved iron and dissolved manganese and pH exceeded the recommended or secondary maximum contaminant levels (SMCLs). Groundwater samples from about half of the 20 wells tended to be slightly acidic (median pH was 6.8), and the pH was equal to or less than the SMCL lower limit of 6.5 in 9 (45 percent) of the 20 samples. Concentrations of dissolved iron were greater than the SMCL of 300 µg/L in 3 (15 percent) of 20 samples, and concentrations of dissolved manganese were greater than the SMCL of 50 µg/L in 7 (35 percent) of 20 samples. Most concentrations of dissolved iron and manganese above the SMCLs of 300 and 50 µg/L, respectively, were in groundwater samples with low dissolved oxygen concentrations (0.2 mg/L or less), which indicates geochemical control on these metals. Although not elevated above drinking-water standards, higher concentrations of copper and zinc were related to lower pH, suggesting dissolution of plumbing or naturally occurring metals in acidic well water.

Six samples were analyzed for both dissolved and total concentrations of selected metals. Total concentrations commonly were much greater than dissolved concentrations of iron, in particular, and to a lesser degree for arsenic, lead, and copper. Concentrations of dissolved and total manganese were relatively similar. Concentrations above the SMCL of 300 µg/L may be more widespread in the county for particulate iron than for dissolved iron. Higher concentrations of total arsenic and total lead appeared to be associated with higher concentrations of total iron, suggesting that arsenic and lead may sorb onto iron particulates in groundwater. The total arsenic concentration in one of the six samples was greater than the health advisory level of 2 µg/L but less than the MCL of 10 µg/L. The total manganese concentration of 361 µg/L in one sample was greater than the health advisory level of 300 µg/L for manganese.

About half of the groundwater samples had chloride concentrations above the estimated natural background levels of about 1 to 5 mg/L, indicating that human activities may have influenced groundwater quality. Nitrate concentrations were less than the estimated natural background level of less than 0.8 mg/L as N in all but two groundwater samples. Boron concentrations equal to or greater 20 mg/L were above natural background levels and were measured in groundwater from six wells with elevated sodium and chloride levels, indicating probable association with septic effluent and (or) road salt linked to residential development.

Anthropogenic organic compounds were detected at low levels in water from 10 of the 20 wells, indicating human activities at the land surface have affected groundwater quality to some degree. These compounds included VOCs in three groundwater samples and a few organic wastewater compounds in nine groundwater samples. The highest measured VOC concentration was 39 µg/L of Freon-11 and indicated local groundwater contamination by improper disposal of the compound. DEET, an insect repellent, was the most frequently detected organic wastewater compound at trace levels.

The relations between groundwater quality and geology and land-use factors were investigated. Because of the small sample size, comparisons between geologic and land-use factors could not be evaluated with rigorous statistics. The non-statistical, preliminary review indicated some water-quality differences were apparent for different geologic units. Higher radon-222 activities generally were measured in water samples from wells in the Catskill Formation; the highest activities (greater than 2,600 pCi/L) were measured in water from the Poplar Gap and Packerton Members, undivided. Radon-222 activities were lower in water from the Trimmers Rock Formation and the glacial units.

Concentrations of chloride and nitrite plus nitrate as nitrogen tended to be greater in water from wells in the commercial and residential areas with on-site wastewater disposal than in undeveloped and sewered areas. DEET was detected in water from wells in most land-use areas, including undeveloped. Except for the one well sample with the Freon-11 contamination, VOCs and most other organic wastewater compounds detected were in water from wells in commercial and residential areas with on-site wastewater disposal. These results indicate greater impacts on groundwater quality where land use is more intensive.

Stream-monitoring data in watersheds with no point discharges were reviewed to assess the relation between groundwater quality and surface-water quality. Chloride and nitrate concentrations were highest in stream base flow in the watershed with the most development (roads and residential land use) indicating groundwater quality in that watershed has been affected by human activities.

Age-dating of groundwater in samples from three wells yielded a range of ages from 6 to 54 years before 2007; the younger water was in the glacial aquifer and the older water was in the bedrock aquifer. Age-dating can be used to estimate susceptibility of groundwater to contamination by human activities at or near the land surface—younger water is generally more susceptible to contamination than older water is.

Five of the wells sampled in 2007 were sampled previously at least once since 1982. Comparison of chloride and nitrate concentrations in the 2007 samples with previous samples showed that concentrations of these constituents remained similar through time in some wells but increased up to three-fold, especially for chloride, in others. The two wells with the largest increases in chloride were in a residential and commercial area along the Route 209 corridor.

Overall, based on this reconnaissance study, groundwater quality in Pike County is relatively good with no constituents exceeding any established primary water-quality standards. The low levels of human-made organic compounds detected and relatively elevated concentrations of chloride and related constituents (boron and nitrate) indicate that human activities have influenced groundwater quality in some parts of the county.

Acknowledgments

The cooperation of the Pike County Conservation District (PCCD) and the property owners who permitted the collection of groundwater samples from their wells is gratefully acknowledged. Personnel from PCCD were instrumental in developing the scope and providing information about potential sampling locations. The assistance of Lindsay Hale and Leif Olson of the U.S. Geological Survey in sample collection also is greatly appreciated.

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Table 10. Construction characteristics and location of 20 wells sampled in 2007 in Pike County, Pa.

[NAD 83, North American Datum of 1983; DDMMSS, degrees, minutes, seconds; NAVD 88, North American Vertical Datum of 1988; —, no data; Twp., township; Geologic unit: 112KMTC, Kame terrace; 112OTSH, Olean outwash; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

U.S. Geological Survey local well number	Site identification number	Latitude (NAD 83), DDMMSS	Longitude (NAD 83), DDMMSS	Land-surface altitude, feet above NAVD 88	Well depth, feet	Casing length, feet	Year drilled	Township	Geologic Unit
PI-211	410812074581501	410820	745812	711	450	43	1975	Lehman	341TMRK
PI-288	411700075145801	411658	751457	1,649	151	23	1980	Greene	341PGPK
PI-308	410612074591501	410611	745916	349	108	103	1961	Lehman	112OTSH
PI-380	411500074534001	411500	745340	899	98	20	1979	Delaware	341TMRK
PI-390	412115075031401	412115	750314	1,339	325	42	1980	Blooming Grove	341DLRV
PI-464	412114074431801	412114	744318	429	142	142	1984	Westfall	112OTSH
PI-480	411957074462601	411957	744625	464	213	213	1981	Westfall	112KMTC
PI-524	411849074533901	411848	745335	1,138	380	182	2004	Dingman	341TMSG
PI-550	411538074555601	411538	745557	1,206	250	160	1991	Delaware	341TMSG
PI-551	411006074580101	411005	745803	1,109	250	42	1985	Lehman	341TMSG
PI-552	412141074462301	412140	744625	974	—	—	—	Westfall	341TMRK
PI-553	412303075074301	412303	750744	1,509	610	195	1997	Blooming Grove	341LRBW
PI-554	411452074543601	411451	745437	1,054	238	—	—	Delaware	341TMRK
PI-555	412009075142901	412009	751431	1,788	380	40	1999	Palmyra	341PGPK
PI-556	411738074505001	411737	745051	718	400	51	1999	Delaware	344MNNG
PI-557	411833074582201	411833	745824	1,432	350	66	1977	Dingman	341LRBW
PI-558	410525075021701	410525	750219	439	300	21	1985	Lehman	344MNNG
PI-559	412920075072201	412920	750723	1,258	400	42	1990	Lackawaxen	341LRBW
PI-561	412506074543901	412506	745441	1,300	250	42	1984	Shohola	341LRBW
PI-562	410731075002701	410730	750028	839	200	40	1977	Lehman	341TMRK

Table 11. Field measurements and results of laboratory analyses for concentrations of major ions, nutrients, and selected metals and trace elements in groundwater samples from 20 wells in Pike County, Pa., 1982–2007.

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; LSD, land surface datum; gal/min, gallons per minute; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value; Geologic unit: Glacial units—112KMTC, Kame terrace; 112OTSH, Olean outwash; Bedrock units—341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

U.S. Geological Survey local well number	Geologic unit	Sample date	Time	Depth to water level (feet below LSD) (72019)	Pump flow rate, instantaneous (gal/min) (00059)	Pump or flow period prior to sampling (minutes) (72004)	Barometric pressure (mm Hg) (00025)	Dissolved oxygen (mg/L) (00300)	Dissolved oxygen (percent of saturation) (00301)	pH, water, unfiltered field (standard units) (00400)	pH, water, unfiltered lab (standard units) (00403)
PI-211	341TMRK	8/27/2007	1400	71.15	5	120	755	0.2	2	7.7	7.8
PI-288	341PGPK	6/2/1982	1615	—	—	—	—	—	—	5.7	6.2
PI-288	341PGPK	9/6/2007	1200	49.25	15	60	747	10.8	94	6.0	7.8
PI-308	112OTSH	7/16/2001	1200	30.11	2	120	752	7.3	66	6.2	6.5
PI-308	112OTSH	8/30/2007	1600	29.94	5	80	750	9.5	87	6.1	6.5
PI-380	341CSKL	7/27/1982	1515	—	—	—	—	—	—	7.7	7.7
PI-380	341TMRK	9/5/2007	1400	—	2.5	90	760	.2	2	7.9	7.7
PI-390	341DLRV	10/2/2007	1000	34.70	5	100	740	8.4	76	5.7	6.4
PI-464	112OTSH	10/29/1991	1445	—	—	—	—	.2	—	7.3	7.9
PI-464	112OTSH	8/28/2007	1330	17.32	6.4	53	746	.2	2	8.2	8.3
PI-480	112KMTC	10/25/1991	1053	—	—	—	—	1.2	—	6.9	8.0
PI-480	112KMTC	7/11/2001	1200	86.99	5.9	40	740	3.1	30	7.7	7.7
PI-480	112KMTC	9/5/2007	1800	88.24	5	90	761	3.8	34	7.8	7.7
PI-524	341TMSG	4/17/2006	1200	—	—	—	—	—	—	—	—
PI-524	341TMSG	10/1/2007	1400	56.82	6.5	80	750	.1	0	8.3	8.3
PI-550	341TMSG	8/27/2007	1730	54.08	5	140	755	5.3	48	6.4	7.1
PI-551	341TMSG	8/28/2007	1000	58.28	5	105	746	3.7	34	6.2	6.8
PI-552	341TMRK	8/28/2007	1600	65.88	5	85	746	.3	2	7.3	7.6
PI-553	341LRBW	8/29/2007	1000	124.35	6.2	140	735	.1	1	7.2	7.6
PI-554	341TMRK	8/29/2007	1430	77.82	5	90	746	.7	6	6.0	6.5
PI-555	341PGPK	8/30/2007	1000	116.92	8.6	90	724	4.6	40	6.8	7.1
PI-556	344MNNG	8/30/2007	1230	54.05	5	190	750	.2	2	7.7	7.8
PI-557	341LRBW	9/4/2007	1700	49.80	5	95	730	6.0	55	6.2	6.2
PI-558	344MNNG	9/5/2007	1100	16.42	5	120	761	8.6	79	6.5	6.9
PI-559	341LRBW	9/12/2007	1100	—	5	130	730	4.8	43	6.8	7.3
PI-561	341LRBW	10/2/2007	1500	94.86	5	65	740	2.9	26	6.4	6.6
PI-562	341TMRK	10/18/2007	1100	18.06	5	60	760	.2	2	7.3	7.9

Table 11. Field measurements and results of laboratory analyses for concentrations of major ions, nutrients, and selected metals and trace elements in groundwater samples from
20 wells in Pike County, Pa., 1982–2007.—Continued

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U.S. Geological Survey local well number	Sample date	Specific conductance, wat unf lab (µS/cm at 25 °C) (90095)	Specific conductance, wat unf (µS/cm at 25 °C) (00095)	Temperature, air (°C) (00020)	Temperature, water (°C) (00010)	Hardness, water (mg/L as $CaCO_3$) (00900)	Calcium water, filtered (mg/L) (00915)	Magnesium, water, filtered (mg/L) (00925)	Potassium, water, filtered (mg/L) (00935)	Sodium fraction of cations (percent) (00932)	Sodium, water, filtered (mg/L) (00930)
PI-211	8/27/2007	282	275	28	12.6	100	27	8.73	0.69	23	14.1
PI-288	6/2/1982	66	72	—	10.0	22	6.8	1.1	.50	14	1.6
PI-288	9/6/2007	72	70	25.5	9.2	23	7.38	1.13	.41	20	2.71
PI-308	7/16/2001	105	100	—	10.4	32	9.55	1.93	.72	26	5.24
PI-308	8/30/2007	102	101	25	11.1	30	8.93	1.83	.73	31	6.24
PI-380	7/27/1982	297	305	—	13.0	130	32	11	<.10	—	12
PI-380	9/5/2007	353	340	22	11.7	130	33.3	11.3	.20	23	17.8
PI-390	10/2/2007	81	79	15	10.9	25	5.47	2.67	.80	25	3.92
PI-464	10/29/1991	189	185	—	11.5	84	27	4.1	.50	9	4
PI-464	8/28/2007	215	205	29	12.2	90	28.2	4.68	.53	9	4.28
PI-480	10/25/1991	311	300	—	10.5	140	47	6.2	.50	8	5.7
PI-480	7/11/2001	336	329	—	11.8	140	45.7	6.17	.47	12	9.04
PI-480	9/5/2007	363	351	24	10.0	140	46.9	6.31	.55	17	13.2
PI-524	4/17/2006	—	—	—	—	—	—	—	—	—	—
PI-524	10/1/2007	303	299	15	11.1	62	15.5	5.69	.24	58	39.9
PI-550	8/27/2007	100	97	25	10.5	41	10.4	3.73	.28	19	4.42
PI-551	8/28/2007	216	206	24	11.1	74	18.1	7.02	.46	21	9.21
PI-552	8/28/2007	215	207	25	11.0	89	23.7	7.21	.25	14	6.92
PI-553	8/29/2007	98	95	25	11.4	33	8.03	3.1	.63	34	7.8
PI-554	8/29/2007	190	185	29	11.2	59	14.5	5.6	.58	29	11.2
PI-555	8/30/2007	149	142	25	9.2	70	22.4	3.3	.59	4	1.42
PI-556	8/30/2007	216	211	25	11.5	87	24.7	6.18	.21	19	9.32
PI-557	9/4/2007	195	185	25	10.9	62	14.2	6.36	.66	29	12
PI-558	9/5/2007	93	90	20.5	11.6	36	11	1.98	.39	16	3.07
PI-559	9/12/2007	237	231	20	10.6	93	25.3	7.29	.78	14	6.95
PI-561	10/2/2007	163	162	20	10.5	67	16.2	6.51	.58	12	4.42
PI-562	10/18/2007	149	147	18	11.7	61	14.4	6.08	.30	17	5.59

Table 11. Field measurements and results of laboratory analyses for concentrations of major ions, nutrients, and selected metals and trace elements in groundwater samples from 20 wells in Pike County, Pa., 1982–2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; LSD, land surface datum; gal/min, gallons per minute; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value; Geologic unit: Glacial units—112KMTC, Kame terrace; 112OTSH, Olean outwash; Bedrock units—341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

U.S. Geological Survey local well number	Sample date	ANC, wat unf fixed end point, field (mg/L as $CaCO_3$) (00410)	ANC, wat unf infl pt titr., field (mg/L as $CaCO_3$) (00419)	Chloride, water, filtered (mg/L) (00940)	Silica, water, filtered (mg/L as SiO_2) (00955)	Sulfate water, filtered (mg/L) (00945)	Residue water, filtered, sum of constituents (mg/L) (70301)	Ammonia water, filtered (mg/L as N) (00608)	Nitrite + nitrate water filtered (mg/L as N) (00631)	Nitrite water, filtered (mg/L as N) (00613)	Orthophosphate, water, filtered, (mg/L as P) (00671)
PI-211	8/27/2007	—	78	26.8	14.2	20	E159	0.059	<.06	0.002	0.011
PI-288	6/2/1982	[1]12	—	3.5	4	9	34	<.010	.55	<.010	.01
PI-288	9/6/2007	—	21	4.44	4.8	6.74	E43	E.010	.56	E.001	.016
PI-308	7/16/2001	—	[2]14	9.3	8.79	12.7	E57	E.02	.13	E.003	<.02
PI-308	8/30/2007	—	17	9.81	9	13.1	E61	<.020	.19	<.002	<.006
PI-380	7/27/1982	[1]114	—	13	16	16	169	.07	<.100	<.010	.01
PI-380	9/5/2007	—	98	39.9	13.9	10.8	E186	.059	<.06	E.001	.011
PI-390	10/2/2007	—	12	5.42	7	10.8	E46	.027	.63	E.001	.007
PI-464	10/29/1991	64	—	5.6	8.2	29	120	<.010	.72	.47	.04
PI-464	8/28/2007	—	57	5.28	9.1	29.6	E122	<.020	1.19	.47	.055
PI-480	10/25/1991	92	—	18	8	42	184	<.010	.22	<.010	<.01
PI-480	7/11/2001	—	b78	34.4	8.53	26.1	E180	<.04	.54	<.006	<.02
PI-480	9/5/2007	—	85	38.1	8.8	26.6	E194	<.020	.52	E.001	E.005
PI-524	4/17/2006	—	—	—	—	—	—	—	—	—	—
PI-524	10/1/2007	—	114	24.4	10.1	.36	E165	.059	<.04	E.001	.02
PI-550	8/27/2007	—	38	2.42	9.2	4.88	E59	E.016	E.05	.002	.011
PI-551	8/28/2007	—	47	30.1	7.3	11.7	E114	<.020	.41	<.002	.009
PI-552	8/28/2007	—	89	2.62	16.9	15.7	E127	E.016	<.06	<.002	.011
PI-553	8/29/2007	—	50	.53	9.1	1.07	E61	<.020	<.06	<.002	.02
PI-554	8/29/2007	—	47	22.4	14.1	11.3	E110	E.012	.22	<.002	<.006
PI-555	8/30/2007	—	71	.9	6.5	7.61	E87	<.020	.36	<.002	.021
PI-556	8/30/2007	—	90	5.2	11.2	14	E126	.063	E.04	.005	.016
PI-557	9/4/2007	—	35	21.9	10.3	10.6	E106	<.020	2	<.002	.029
PI-558	9/5/2007	—	24	1.56	9.6	14.9	E57	<.020	E.04	E.001	.018
PI-559	9/12/2007	—	59	23.6	10.1	11.7	E123	<.020	.32	E.001	.012
PI-561	10/2/2007	—	39	10.2	11.7	15.8	E91	<.020	.41	E.001	.015
PI-562	10/18/2007	—	57	3.19	16.4	11.7	E93	.025	<.04	<.002	E.004

[1] ANC determined in laboratory.

[2] ANC deterined on filtered sample.

Table 11. Field measurements and results of laboratory analyses for concentrations of major ions, nutrients, and selected metals and trace elements in groundwater samples from 20 wells in Pike County, Pa., 1982–2007.—Continued

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U.S. Geological Survey local well number	Sample date	Aluminum, water, filtered (µg/L) (01106)	Arsenic water, filtered (µg/L) (01000)	Arsenic water, unfiltered (µg/L) (01002)	Boron, water, filtered (µg/L) (01020)	Cadmium water, filtered (µg/L) (01025)	Chromium, water, filtered (µg/L) (01030)	Copper, water, filtered (µg/L) (01040)	Copper, water, unfiltered recoverable (µg/L) (01042)	Iron, water, filtered (µg/L) (01046)	Iron, water, unfiltered recoverable (ug/L) (01045)
PI-211	8/27/2007	7.9	0.17	—	20	<0.04	<0.12	<0.40	—	<6	—
PI-288	6/2/1982	—	—	—	—	—	—	—	—	M	—
PI-288	9/6/2007	E1.4	E.11	—	5	.08	.14	72.2	—	23	—
PI-308	7/16/2001	<1.0	<.2	—	10	<.04	<.8	17.3	—	74	—
PI-308	8/30/2007	3.8	<.12	—	8.2	<.04	E.06	10.5	—	373	—
PI-380	7/27/1982	—	—	—	—	—	—	—	—	60	—
PI-380	9/5/2007	E1.1	.75	—	28	<.04	<.12	.67	—	13	—
PI-390	10/2/2007	7.7	.09	1.7	13	.04	E.07	32.4	23.9	32	4,930
PI-464	10/29/1991	—	—	—	—	—	—	—	—	10	—
PI-464	8/28/2007	1.6	3.5	—	5.4	<.04	<.12	.75	—	14	—
PI-480	10/25/1991	—	—	—	—	—	—	—	—	16	—
PI-480	7/11/2001	<1.0	E.1	—	E5	<.04	<.8	1.5	—	14	—
PI-480	9/5/2007	E1.2	.12	—	5.3	<.04	E.08	1	—	21	—
PI-524	4/17/2006	—	—	<4.0	—	—	—	—	—	—	—
PI-524	10/1/2007	E1.2	.29	—	77	<.04	<.12	<1.0	—	32	—
PI-550	8/27/2007	<1.6	.12	1.9	5.3	<.04	<.12	22.4	30.1	24	3,530
PI-551	8/28/2007	<1.6	E.10	—	10	<.04	<.12	11.4	—	11	—
PI-552	8/28/2007	<1.6	.34	—	8.9	<.04	<.12	<.40	—	67	—
PI-553	8/29/2007	<1.6	.69	.92	5.3	<.04	<.12	10.8	8.9	14	1,060
PI-554	8/29/2007	1.8	<.12	E.10	20	<.04	<.12	9.2	13	675	6,630
PI-555	8/30/2007	<1.6	.31	—	6	<.04	<.12	5.3	—	<6	—
PI-556	8/30/2007	2.8	.55	.65	33	<.04	<.12	.97	92.2	146	237
PI-557	9/4/2007	E1.1	.83	—	20	<.04	<.12	17.1	—	<6	—
PI-558	9/5/2007	<1.6	<.12	—	8.7	<.04	E.07	25.7	—	E4	—
PI-559	9/12/2007	<1.6	.65	—	5.3	<.04	<.12	10.3	—	<6	—
PI-561	10/2/2007	<1.6	.29	—	10	<.04	<.12	20.6	—	<8	—
PI-562	10/18/2007	<1.6	.55	3.9	7.3	<.04	E.11	4.7	7.1	474	8,760

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U.S. Geological Survey local well number	Sample date	Lead, water, filtered (µg/L) (01049)	Lead, water, unfiltered recoverable (µg/L) (01051)	Manganese, water, filtered (µg/L) (01056)	Manganese, water, unfiltered recoverable (µg/L) (01055)	Mercury water, filtered (µg/L) (71890)	Molybdenum, water, filtered (µg/L) (01060)	Nickel, water, filtered (µg/L) (01065)	Selenium, water, filtered (µg/L) (01145)	Zinc, water, filtered (µg/L) (01090)	Hardness (mg/L as $CaCO_3$) (00900)
PI-211	8/27/2007	<0.12	—	38.8	—	<0.010	E0.1	0.11	<0.08	<6	100
PI-288	6/2/1982	—	—	M	—	—	—	—	—	—	22
PI-288	9/6/2007	1.6	—	.6	—	<.010	<.1	.71	.12	73	23
PI-308	7/16/2001	.43	—	5	—	—	<.2	.71	<.3	2.8	32
PI-308	8/30/2007	.16	—	20.4	—	<.010	<.1	.8	.17	<6	30
PI-380	7/27/1982	—	—	180	—	—	—	—	—	—	130
PI-380	9/5/2007	.23	—	114	—	<.010	.3	.2	<.08	E4	130
PI-390	10/2/2007	.3	1.4	138	170	<.010	<.2	2	.06	11	25
PI-464	10/29/1991	<1	—	290	—	—	—	—	—	—	84
PI-464	8/28/2007	<.12	—	267	—	<.010	1	.11	1.3	<6	90
PI-480	10/25/1991	<1	—	13	—	—	—	—	—	—	140
PI-480	7/11/2001	.46	—	1.6	—	—	.3	<.06	.5	1.4	140
PI-480	9/5/2007	.42	—	1.8	—	<.010	.4	.34	.3	E4	140
PI-524	4/17/2006	—	—	—	—	—	—	—	—	—	—
PI-524	10/1/2007	<.08	—	20.5	—	<.010	.3	<.20	<.04	<4	62
PI-550	8/27/2007	<.12	.78	2.2	12.4	<.010	E.1	.63	E.07	<6	41
PI-551	8/28/2007	.34	—	.3	—	<.010	<.1	.25	E.06	E4	74
PI-552	8/28/2007	E.09	—	292	—	<.010	.4	.09	<.08	<6	89
PI-553	8/29/2007	E.09	.34	215	234	<.010	E.1	.13	<.08	<6	33
PI-554	8/29/2007	E.09	.68	11.2	13.2	<.010	<.1	.65	<.08	14	59
PI-555	8/30/2007	<.12	—	4	—	<.010	<.1	.15	.14	<6	70
PI-556	8/30/2007	<.12	11.8	248	230	<.010	E.1	2.2	<.08	8	87
PI-557	9/4/2007	2.23	—	.9	—	<.010	.2	2.7	E.06	33	62
PI-558	9/5/2007	.89	—	1.7	—	<.010	<.1	.72	E.06	10	36
PI-559	9/12/2007	.22	—	<.2	—	<.010	.1	.4	.1	E5	93
PI-561	10/2/2007	.92	—	E.3	—	<.010	<.2	E.19	.28	8	67
PI-562	10/18/2007	.15	2.86	199	361	<.010	1.5	<.20	<.04	<4	61

Table 12. Results of laboratory analysis for volatile organic compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; surrog, surrogate; Sch, laboratory schedule, %, percent]

U.S. Geological Survey local well number	Sample date	Tetrachloroethene, water, filtered (µg/L) (34476)	1,1,1-Trichloroethane, water, unfiltered (µg/L) (34506)	CFC-113 water, unfiltered (µg/L) (77652)	1,1-Dichloroethane, water, unfiltered (µg/L) (34496)	1,1-Dichloroethene, water, unfiltered (µg/L) (34501)	1,2-Dichlorobenzene water, unfiltered (µg/L) (34536)	1,2-Dichloroethane, water, unfiltered (µg/L) (32103)	1,2-Dichloroethane-d4, sur Sch2090 wat unf % recvy (99832)	1,2-Dichloropropane water, unfiltered (µg/L) (34541)	1,3-Dichlorobenzene water, unfiltered (µg/L) (34566)
PI-211	8/27/2007	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	109	<0.1	<0.1
PI-288	9/6/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	141	<.1	<.1
PI-308	7/16/2001	—	<.03	<.06	<.04	<.04	<.03	<.1	77.6	<.03	<.03
PI-308	8/30/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	112	<.1	<.1
PI-380	9/5/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	134	<.1	<.1
PI-390	10/2/2007	<.1	<.1	<.1	<.1	<.1	<.1	<.2	134	<.1	<.1
PI-464	8/28/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	109	<.1	<.1
PI-480	7/11/2001	—	<.03	<.06	<.04	<.04	<.03	<.1	109	<.03	<.03
PI-480	9/5/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	141	<.1	<.1
PI-524	10/1/2007	<.1	<.1	<.1	<.1	<.1	<.1	<.2	127	<.1	<.1
PI-550	8/27/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	127	<.1	<.1
PI-551	8/28/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	109	<.1	<.1
PI-552	8/28/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	111	<.1	<.1
PI-553	8/29/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	110	<.1	<.1
PI-554	8/29/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	110	<.1	<.1
PI-555	8/30/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	111	<.1	<.1
PI-556	8/30/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	110	<.1	<.1
PI-557	9/4/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	108	<.1	<.1
PI-558	9/5/2007	<.2	<.1	<.1	<.1	<.1	<.1	<.2	132	<.1	<.1
PI-559	9/12/2007	<.2	.2	<.1	<.1	<.1	<.1	<.2	118	<.1	<.1
PI-561	10/2/2007	<.1	<.1	<.1	<.1	<.1	<.1	<.2	135	<.1	<.1
PI-562	10/18/2007	<.1	<.1	<.1	<.1	<.1	<.1	<.2	110	<.1	<.1

Table 12. Results of laboratory analysis for volatile organic compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; surrog, surrogate; Sch, laboratory schedule, %, percent]

U.S. Geological Survey local well number	Sample date	1,4-Dichlorobenzene water, unfiltered (µg/L) (34571)	14Bromo fluorobenzene surrog, VOC Sch water, unfiltered % recovery (99834)	Benzene water, unfiltered (µg/L) (34030)	Bromodichloromethane water, unfiltered (µg/L) (32101)	Tribromomethane water, unfiltered (µg/L) (32104)	Chlorobenzene water, unfiltered (µg/L) (34301)	cis-1,2-Dichloroethene, water, unfiltered (µg/L) (77093)	Dibromochloromethane water, unfiltered (µg/L) (32105)	Dichlorodifluoromethane water, unfiltered (µg/L) (34668)	Dichloromethane water, unfiltered (µg/L) (34423)
PI-211	8/27/2007	<0.1	93.4	<0.1	<0.1	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2
PI-288	9/6/2007	<.1	100	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-308	7/16/2001	<.05	93.9	<.04	<.05	<.06	<.03	<.04	<.2	<.27	<.2
PI-308	8/30/2007	<.1	91.3	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-380	9/5/2007	<.1	101	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-390	10/2/2007	<.1	71.5	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-464	8/28/2007	<.1	92.1	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-480	7/11/2001	<.05	80.7	<.04	<.05	<.06	<.03	<.04	<.2	<.27	<.2
PI-480	9/5/2007	<.1	98.6	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-524	10/1/2007	<.1	71.3	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-550	8/27/2007	<.1	75.6	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-551	8/28/2007	<.1	91.8	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-552	8/28/2007	<.1	91.8	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-553	8/29/2007	<.1	91.2	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-554	8/29/2007	<.1	91.3	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-555	8/30/2007	<.1	91.2	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-556	8/30/2007	<.1	91.1	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-557	9/4/2007	<.1	89.8	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-558	9/5/2007	<.1	99.5	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-559	9/12/2007	<.1	74.7	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-561	10/2/2007	<.1	72	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2
PI-562	10/18/2007	<.1	84.2	<.1	<.1	<.2	<.1	<.1	<.2	<.2	<.2

Table 12. Results of laboratory analysis for volatile organic compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; surrog, surrogate; Sch, laboratory schedule, %, percent]

U.S. Geological Survey local well number	Sample date	Diethyl ether, water, unfiltered (µg/L) (81576)	Diisopropyl ether, water, unfiltered (µg/L) (81577)	Ethylbenzene water, unfiltered (µg/L) (34371)	Methyl tert-pentyl ether, water, unfiltered (µg/L) (50005)	meta- + para-Xylene, water, unfiltered (µg/L) (85795)	o-Xylene, water, unfiltered (µg/L) (71135)	Styrene water, unfiltered (µg/L) (71128)	t-Butyl ethyl ether, water, unfiltered (µg/L) (50004)	Methyl t-butyl ether, water, unfiltered (µg/L) (78032)	Tetrachloroethene, water, unfiltered (µg/L) (34475)
PI-211	8/27/2007	<0.2	<0.2	<0.1	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	<0.1
PI-288	9/6/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-308	7/16/2001	<.2	<.10	<.03	<.11	<.06	<.04	<.04	<.05	<.2	<.10
PI-308	8/30/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-380	9/5/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	.2	<.1
PI-390	10/2/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-464	8/28/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-480	7/11/2001	<.2	<.10	<.03	<.11	<.06	<.04	<.04	<.05	<.2	<.10
PI-480	9/5/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-524	10/1/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-550	8/27/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-551	8/28/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-552	8/28/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-553	8/29/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-554	8/29/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-555	8/30/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-556	8/30/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-557	9/4/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-558	9/5/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-559	9/12/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-561	10/2/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1
PI-562	10/18/2007	<.2	<.2	<.1	<.2	<.2	<.1	<.1	<.1	<.2	<.1

Table 12. Results of laboratory analysis for volatile organic compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; surrog, surrogate; Sch, laboratory schedule, %, percent]

U.S. Geological Survey local well number	Sample date	Tetrachloromethane water, unfiltered (µg/L) (32102)	Toluene water, unfiltered (µg/L) (34010)	Toluene -d8, surrog, Sch2090 water, unfiltered % recovery (99833)	trans-1,2-Dichloroethene, water, unfiltered (µg/L) (34546)	Trichloroethene, water, unfiltered (µg/L) (39180)	Trichlorofluoromethane water, unfiltered (µg/L) (34488)	Trichloromethane water, unfiltered (µg/L) (32106)	Vinyl chloride, water, unfiltered (µg/L) (39175)
PI-211	8/27/2007	<0.2	<0.1	98.3	<0.1	<0.1	<0.2	<0.1	<0.2
PI-288	9/6/2007	<.2	<.1	104	<.1	<.1	<.2	<.1	<.2
PI-308	7/16/2001	<.06	<.05	99.2	<.03	<.04	<.09	<.02	<.1
PI-308	8/30/2007	<.2	<.1	99	<.1	<.1	<.2	<.1	<.2
PI-380	9/5/2007	<.2	<.1	101	<.1	<.1	<.2	<.1	<.2
PI-390	10/2/2007	<.2	<.1	96	<.1	<.1	<.2	<.1	<.2
PI-464	8/28/2007	<.2	<.1	98.2	<.1	<.1	<.2	<.1	<.2
PI-480	7/11/2001	<.06	<.05	94.9	<.03	<.04	<.09	<.02	<.1
PI-480	9/5/2007	<.2	<.1	98.9	<.1	<.1	<.2	<.1	<.2
PI-524	10/1/2007	<.2	<.1	94.1	<.1	<.1	<.2	<.1	<.2
PI-550	8/27/2007	<.2	<.1	89.9	<.1	<.1	<.2	<.1	<.2
PI-551	8/28/2007	<.2	<.1	99	<.1	<.1	<.2	<.1	<.2
PI-552	8/28/2007	<.2	<.1	98.4	<.1	<.1	<.2	<.1	<.2
PI-553	8/29/2007	<.2	<.1	98.4	<.1	<.1	<.2	<.1	<.2
PI-554	8/29/2007	<.2	<.1	99	<.1	<.1	<.2	.8	<.2
PI-555	8/30/2007	<.2	<.1	99.2	<.1	<.1	<.2	<.1	<.2
PI-556	8/30/2007	<.2	<.1	99	<.1	<.1	39	<.1	<.2
PI-557	9/4/2007	<.2	<.1	98	<.1	<.1	<.2	<.1	<.2
PI-558	9/5/2007	<.2	<.1	102	<.1	<.1	<.2	<.1	<.2
PI-559	9/12/2007	<.2	<.1	94.5	<.1	<.1	<.2	<.1	<.2
PI-561	10/2/2007	<.2	<.1	93.8	<.1	<.1	<.2	<.1	<.2
PI-562	10/18/2007	<.2	<.1	99	<.1	<.1	<.2	<.1	<.2

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	1,4-Dichlorobenzene water, filtered (µg/L) (34572)	-1 Methylnaphthalene, water, filtered (µg/L) (62054)	2,6-Dimethylnaphthalene, water, filtered (µg/L) (62055)	-2 Methylnaphthalene, water, filtered (µg/L) (62056)	3-beta-Coprostanol, water, filtered (µg/L) (62057)	-3 Methyl-1H-indole, water, filtered (µg/L) (62058)	3-tert-Butyl-4-hydroxyanisole water, filtered (µg/L) (62059)	-4 Cumylphenol, water, filtered (µg/L) (62060)	4-n-Octylphenol, water, filtered (µg/L) (62061)	-4 Nonylphenol, all isomers, water, filtered (µg/L) (62085)
PI-211	8/27/2007	<0.1	<0.1	<0.2	<0.1	<2	<0.08	<0.6	<0.14	<2	<5
PI-288	9/6/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-308	7/16/2001	—	—	—	—	—	—	—	—	—	—
PI-308	8/30/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-380	9/5/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-390	10/2/2007	<.1	<.1	<.1	<.1	<1	<.08	<.6	<.1	<1	<5
PI-464	8/28/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-480	7/11/2001	—	—	—	—	—	—	—	—	—	—
PI-480	9/5/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-524	10/1/2007	<.1	<.1	<.1	<.1	<1	<.08	<.6	<.1	<1	<5
PI-550	8/27/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-551	8/28/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-552	8/28/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-553	8/29/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-554	8/29/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-555	8/30/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-556	8/30/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-557	9/4/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-558	9/5/2007	<.1	<.1	<.2	<.1	<2	<.08	<.6	<.14	<2	<5
PI-559	9/12/2007	<.1	<.1	<.2	<.1	<2	<.08	—	<.14	<2	<5
PI-561	10/2/2007	<.1	<.1	<.1	<.1	<1	<.08	<.6	<.1	<1	<5
PI-562	10/18/2007	<.1	<.1	<.1	<.1	<1	<.08	<.6	<.1	<1	<5

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	4-Nonyl phenol di-ethoxylate, water, filtered (µg/L) (62083)	4t-Octyl-phenol di-ethoxylate, water, filtered (µg/L) (61705)	4t-Octyl-phenol mono-ethoxylate, water, filtered (µg/L) (61706)	4-tert-Octyl-phenol, water, filtered (µg/L) (62062)	5-Methyl-1H-benzo-triazole, water, filtered (µg/L) (62063)	9,10-Anthra-quinone water, filtered (µg/L) (62066)	Aceto-phenone, water, filtered (µg/L) (62064)	AHTN, water, filtered (µg/L) (62065)	Anthra-cene, water, filtered (µg/L) (34221)	Benzo-[a]-pyrene, water, filtered (µg/L) (34248)
PI-211	8/27/2007	<1	<1	<1	<0.10	<2	<0.2	<0.1	<0.5	<0.1	<0.1
PI-288	9/6/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-308	7/16/2001	—	—	—	—	—	—	—	—	—	—
PI-308	8/30/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-380	9/5/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-390	10/2/2007	<1	<1	<1	<1	<.08	<.2	<.1	<.5	<.1	<.1
PI-464	8/28/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-480	7/11/2001	—	—	—	—	—	—	—	—	—	—
PI-480	9/5/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-524	10/1/2007	<1	<1	<1	<1	<.08	<.2	<.1	<.5	<.1	<.1
PI-550	8/27/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-551	8/28/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-552	8/28/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-553	8/29/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-554	8/29/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-555	8/30/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-556	8/30/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-557	9/4/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-558	9/5/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-559	9/12/2007	<1	<1	<1	<.10	<2	<.2	<.1	<.5	<.1	<.1
PI-561	10/2/2007	<1	<1	<1	<1	<.08	<.2	<.1	<.5	<.1	<.1
PI-562	10/18/2007	<1	<1	<1	<1	<.08	<.2	<.1	<.5	<.1	<.1

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	Benzophenone water, filtered (µg/L) (62067)	beta-Sitosterol, water, filtered (µg/L) (62068)	beta-Stigmastanol, water, filtered (µg/L) (62086)	Bisphenol A, water, filtered (µg/L) (62069)	Bisphenol A-d3 surrog, Sch 2033 & 8033, water, filtered % recovery (99583)	Bromacil, water, filtered (µg/L) (04029)	Caffeine, water, filtered (µg/L) (50305)	Caffeine-13C, surrog, wat flt percent recovry (99959)	Caffeine-13C sur Sch 2033 & 8033, wat flt % recvy (99584)	Camphor water, filtered (µg/L) (62070)
PI-211	8/27/2007	<0.2	<2	<2	—	5.4	<0.4	<0.2	—	92.3	<0.1
PI-288	9/6/2007	<.2	<2	<2	—	0	<.4	<.2	—	88.2	<.1
PI-308	7/16/2001	—	—	—	—	—	<.03	<.010	108	—	—
PI-308	8/30/2007	<.2	<2	<2	M	7.9	<.4	<.2	—	84.8	<.1
PI-380	9/5/2007	<.2	<2	<2	—	4.1	<.4	<.2	—	80.4	<.1
PI-390	10/2/2007	<.1	<2	<1	—	0	<.4	<.1	—	89.7	<.1
PI-464	8/28/2007	<.2	<2	<2	—	3.9	<.4	<.2	—	87.2	<.1
PI-480	7/11/2001	—	—	—	—	—	<.03	<.010	100	—	—
PI-480	9/5/2007	<.2	<2	<2	—	0	<.4	<.2	—	81.3	<.1
PI-524	10/1/2007	<.1	<2	<1	—	0	<.4	<.1	—	95	<.1
PI-550	8/27/2007	<.2	<2	<2	—	0	<.4	<.2	—	91.3	<.1
PI-551	8/28/2007	<.2	<2	<2	—	4.3	<.4	<.2	—	85	<.1
PI-552	8/28/2007	<.2	<2	<2	—	13.6	<.4	<.2	—	84.9	<.1
PI-553	8/29/2007	<.2	<2	<2	—	0	<.4	<.2	—	82.5	<.1
PI-554	8/29/2007	<.2	<2	<2	—	E4.8	<.4	<.2	—	83.5	<.1
PI-555	8/30/2007	<.2	<2	<2	—	0	<.4	<.2	—	44.9	<.1
PI-556	8/30/2007	<.2	<2	<2	—	0	<.4	<.2	—	88.9	<.1
PI-557	9/4/2007	<.2	<2	<2	—	0	<.4	<.2	—	74	<.1
PI-558	9/5/2007	<.2	<2	<2	—	0	<.4	<.2	—	83	<.1
PI-559	9/12/2007	<.2	<2	<2	—	0	<.4	<.2	—	83.4	<.1
PI-561	10/2/2007	<.1	<2	<1	—	0	<.4	<.1	—	88.3	<.1
PI-562	10/18/2007	<.1	<2	<1	—	2.9	<.4	<.1	—	84.2	<.1

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	Carbaryl, water, fltrd 0.7u GF (µg/L) (82680)	Carbazole, water, filtered (µg/L) (62071)	Chlorpyrifos water, filtered (µg/L) (38933)	Cholesterol, water, filtered (µg/L) (62072)	Cotinine, water, filtered (µg/L) (62005)	DecaF-biphenl surrog, Sch 2033 & 8033, water, filtered % recovery (99585)	DEET, water, filtered (µg/L) (62082)	Diazinon, water, filtered (µg/L) (39572)	D-Limonene, water, filtered (µg/L) (62073)	Fluoranthene, water, filtered (µg/L) (34377)
PI-211	8/27/2007	<1	<0.1	<0.2	<1	<0.400	63.7	<0.2	<0.2	<0.1	<0.1
PI-288	9/6/2007	<1	<.1	<.2	<1	<.400	59.7	<.2	<.2	<.1	<.1
PI-308	7/16/2001	<.041	—	<.005	—	—	—	—	<.005	—	—
PI-308	8/30/2007	<1	<.1	<.2	<1	<.400	61.9	M	<.2	<.1	<.1
PI-380	9/5/2007	<1	<.1	<.2	<1	<.400	55	<.2	<.2	<.1	<.1
PI-390	10/2/2007	<1	<.1	<.1	<1	<.400	53.7	<.1	<.1	<.04	<.1
PI-464	8/28/2007	<1	<.1	<.2	<1	<.400	54.8	M	<.2	<.1	<.1
PI-480	7/11/2001	<.041	—	<.005	—	—	—	—	<.005	—	—
PI-480	9/5/2007	<1	<.1	<.2	<1	<.400	54.5	M	<.2	<.1	<.1
PI-524	10/1/2007	<1	<.1	<.1	<1	<.400	44.9	<.1	<.1	<.04	<.1
PI-550	8/27/2007	<1	<.1	<.2	<1	<.400	67.2	<.2	<.2	<.1	<.1
PI-551	8/28/2007	<1	<.1	<.2	<1	<.400	49.4	M	<.2	<.1	<.1
PI-552	8/28/2007	<1	<.1	<.2	<1	<.400	53.9	M	<.2	<.1	<.1
PI-553	8/29/2007	<1	<.1	<.2	<1	<.400	61.4	<.2	<.2	<.1	<.1
PI-554	8/29/2007	<1	<.1	<.2	<1	<.400	64.4	M	<.2	<.1	<.1
PI-555	8/30/2007	<1	<.1	<.2	<1	<.400	49.8	.2	<.2	<.1	<.1
PI-556	8/30/2007	<1	<.1	<.2	<1	<.400	63.4	M	<.2	<.1	<.1
PI-557	9/4/2007	<1	<.1	<.2	<1	<.400	50.9	M	<.2	<.1	<.1
PI-558	9/5/2007	<1	<.1	<.2	<1	<.400	55	<.2	<.2	<.1	<.1
PI-559	9/12/2007	<1	<.1	<.2	<1	<.400	56.2	<.2	<.2	<.1	<.1
PI-561	10/2/2007	<1	<.1	<.1	<1	<.400	50.2	<.1	<.1	<.04	<.1
PI-562	10/18/2007	<1	<.1	<.1	<1	<.400	53.8	<.1	<.1	<.04	<.1

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	Fluorathene -d10, surrog, Sch 20/8033 water, filtered % recovery (99586)	HHCB, water, filtered (µg/L) (62075)	Indole, water, filtered (µg/L) (62076)	Isoborneol, water, filtered (µg/L) (62077)	Isophorone water, filtered (µg/L) (34409)	Isopropylbenzene water, filtered (µg/L) (62078)	Isoquinoline, water, filtered (µg/L) (62079)	Menthol water, filtered (µg/L) (62080)	Metalaxyl, water, filtered (µg/L) (50359)	Methyl salicylate, water, filtered (µg/L) (62081)
PI-211	8/27/2007	88.2	<0.5	<0.1	<0.1	<0.1	<0.1	<0.4	<0.2	<0.2	<0.2
PI-288	9/6/2007	81.4	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-308	7/16/2001	—	—	—	—	—	—	—	—	<.02	—
PI-308	8/30/2007	84.9	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-380	9/5/2007	77.3	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-390	10/2/2007	90	<.5	<.1	<.1	<.1	<.1	<.2	<.2	<.1	<.1
PI-464	8/28/2007	85	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-480	7/11/2001	—	—	—	—	—	—	—	—	<.02	—
PI-480	9/5/2007	76.8	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-524	10/1/2007	93.5	<.5	<.1	<.1	<.1	<.1	<.2	<.2	<.1	<.1
PI-550	8/27/2007	88.9	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-551	8/28/2007	81	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-552	8/28/2007	80.2	E.1	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-553	8/29/2007	83.8	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-554	8/29/2007	79.7	M	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-555	8/30/2007	87.9	M	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-556	8/30/2007	89.2	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-557	9/4/2007	70	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-558	9/5/2007	77.6	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-559	9/12/2007	90.5	<.5	<.1	<.1	<.1	<.1	<.4	<.2	<.2	<.2
PI-561	10/2/2007	91.9	<.5	<.1	<.1	<.1	<.1	<.2	<.2	<.1	<.1
PI-562	10/18/2007	85	<.5	<.1	<.1	<.1	<.1	<.2	<.2	<.1	<.1

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	Metolachlor, water, filtered (µg/L) (39415)	Naphthalene, water, filtered (µg/L) (34443)	p-Cresol, water, filtered (µg/L) (62084)	Phenanthrene, water, filtered (µg/L) (34462)	Phenol, water, filtered (µg/L) (34466)	Prometon, water, filtered (µg/L) (04037)	Pyrene, water, filtered (µg/L) (34470)	Tri-bromomethane water, filtered (µg/L) (34288)	Tri-butyl phosphate, water, filtered (µg/L) (62089)	Triclosan, water, filtered (µg/L) (62090)
PI-211	8/27/2007	<0.2	<0.1	<0.18	<0.1	<0.4	<0.4	<0.1	<0.1	<0.2	<0.2
PI-288	9/6/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-308	7/16/2001	<.013	—	—	—	—	<.01	—	—	—	—
PI-308	8/30/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-380	9/5/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-390	10/2/2007	<.1	<.1	<.18	<.1	<.2	<.2	<.1	<.1	<.2	<.2
PI-464	8/28/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-480	7/11/2001	<.013	—	—	—	—	<.01	—	—	—	—
PI-480	9/5/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-524	10/1/2007	<.1	<.1	<.18	<.1	<.2	<.2	<.1	<.1	<.2	<.2
PI-550	8/27/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-551	8/28/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-552	8/28/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	M	<.2
PI-553	8/29/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-554	8/29/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-555	8/30/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-556	8/30/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-557	9/4/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-558	9/5/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-559	9/12/2007	<.2	<.1	<.18	<.1	<.4	<.4	<.1	<.1	<.2	<.2
PI-561	10/2/2007	<.1	<.1	<.18	<.1	<.2	<.2	<.1	<.1	<.2	<.2
PI-562	10/18/2007	<.1	<.1	<.18	<.1	<.2	<.2	<.1	<.1	<.2	<.2

Table 13. Results of laboratory analysis for organic wastewater compounds in groundwater samples from 20 wells in Pike County, Pa., 2001 and 2007.—Continued

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value below method reporting level; M, measured but not quantified below method reporting level; DEET, N,N-diethyl-meta-toluamide; HHCB, hexahydrohexamethyl cyclopentabenzopyran; AHTN, acetyl hexamethyl tetrahydro napthalene; surrog, surrogate; Sch, laboratory schedule; %, percent]

U.S. Geological Survey local well number	Sample date	Tri-ethyl citrate water, filtered (µg/L) (62091)	Tri-phenyl phosphate, water, filtered (µg/L) (62092)	Tris(2-butoxy-ethyl) phosphate, water, filtered (µg/L) (62093)	Tris(2-chloro-ethyl) phosphate, water, filtered (µg/L) (62087)	Tris(dichloro-i-Pr) phosphate, water, filtered (µg/L) (62088)
PI-211	8/27/2007	<0.4	E0.1	<0.5	<0.2	<0.2
PI-288	9/6/2007	<.4	<.2	<.5	<.2	<.2
PI-308	7/16/2001	—	—	—	—	—
PI-308	8/30/2007	<.4	<.2	<.5	<.2	<.2
PI-380	9/5/2007	<.4	<.2	<.5	<.2	<.2
PI-390	10/2/2007	<.2	<.1	<.4	<.1	<.1
PI-464	8/28/2007	<.4	<.2	<.5	<.2	<.2
PI-480	7/11/2001	—	—	—	—	—
PI-480	9/5/2007	<.4	<.2	<.5	<.2	<.2
PI-524	10/1/2007	<.2	<.1	<.4	<.1	<.1
PI-550	8/27/2007	<.4	<.2	<.5	<.2	<.2
PI-551	8/28/2007	<.4	<.2	<.5	<.2	<.2
PI-552	8/28/2007	<.4	<.2	E.1	<.2	<.2
PI-553	8/29/2007	<.4	<.2	<.5	<.2	<.2
PI-554	8/29/2007	<.4	<.2	<.5	<.2	<.2
PI-555	8/30/2007	<.4	<.2	<.5	<.2	<.2
PI-556	8/30/2007	<.4	<.2	<.5	<.2	<.2
PI-557	9/4/2007	<.4	<.2	<.5	<.2	<.2
PI-558	9/5/2007	<.4	<.2	<.5	<.2	<.2
PI-559	9/12/2007	<.4	<.2	<.5	<.2	<.2
PI-561	10/2/2007	<.2	<.1	<.4	<.1	<.1
PI-562	10/18/2007	<.2	<.1	<.4	<.1	<.1

Table 14. Results of laboratory analysis for radionuclide activities in water from 20 wells in Pike County, Pa., 2001 and 2007.

[Value in parentheses is the parameter code–a 5-digit number used in the U.S. Geological Survey computerized data system to uniquely identify a specific constituent; pCi/L, picocuries per liter; µg/L, micrograms per liter; —, no data; <, less than; E, estimated value; R, radchem no detect; 2-sigma, uncertainty at two standard deviations; Th-230, thorium-230; Cs-137, cesium-137; Rn-222, radon-222; alpha, alpha-particle; beta, beta-particle; Geologic unit: 112KMTC, Kame terrace; 112OTSH, Olean outwash; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of Catskill Formation; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation]

U.S. Geological Survey local well number	Geologic unit	Sample date	Alpha radioactivity 30 day, water filtered Th-230, (pCi/L) (62639)	Alpha radioactivity 72 day, water filtered Th-230, (pCi/L) (62636)	Beta radioactivity 30 day, water filtered Cs-137, (pCi/L) (62645)	Beta radioactivity 30 day, water filtered Cs-137, (pCi/L) (62642)	Rn-222 2-sigma water, unfiltered (pCi/L) (76002)	Rn-222, water, unfiltered (pCi/L) (82303)	Uranium natural water, filtered (µg/L) (22703)
PI-211	341TMRK	8/27/2007	R-.2	R.0	R-.1	R.5	17	90	0.04
PI-288	341PGPK	9/6/2007	R.1	R-.4	R.6	R.4	46	2,650	.05
PI-308	112OTSH	7/16/2001	—	—	—	—	28	820	<.02
PI-308	112OTSH	8/30/2007	R-.7	R-.6	R.2	1.1	20	490	<.04
PI-380	341TMRK	9/5/2007	R-2.4	R-1.2	R-.4	R.3	17	190	.1
PI-390	341DLRV	10/2/2007	R-.8	R.4	2.2	R-.1	27	730	.03
PI-464	112OTSH	8/28/2007	R.3	R.2	1.2	1.4	19	230	.59
PI-480	112KMTC	7/11/2001	—	—	—	—	24	500	.15
PI-480	112KMTC	9/5/2007	R-1.6	R-.3	.6	R.5	21	470	.17
PI-524	341TMSG	10/1/2007	R-.1	R-1.0	R.9	.9	23	470	.22
PI-550	341TMSG	8/27/2007	R.1	R.4	R.4	R-1.9	46	2,460	.05
PI-551	341TMSG	8/28/2007	R-.3	R.1	R.1	R-.4	46	2,650	<.04
PI-552	341TMRK	8/28/2007	R-.2	1.0	R.4	R.5	17	150	.21
PI-553	341LRBW	8/29/2007	R-2.0	R.2	2.4	R.2	21	300	E.04
PI-554	341TMRK	8/29/2007	R.6	R-.7	R.1	R.1	34	1,150	<.04
PI-555	341PGPK	8/30/2007	R.5	1.3	1.4	.9	45	2,430	.33
PI-556	344MNNG	8/30/2007	R.1	2.0	R-.4	R.1	21	330	.13
PI-557	341LRBW	9/4/2007	R-.8	R-.5	.9	.9	37	1,700	.25
PI-558	344MNNG	9/5/2007	R-.3	R-.3	R.6	R-.5	37	1,730	<.04
PI-559	341LRBW	9/12/2007	R.5	R.6	R.8	R.4	43	1,880	1.15
PI-561	341LRBW	10/2/2007	R-.9	R.0	R.1	R.2	42	2,020	.05
PI-562	341TMRK	10/18/2007	R-.2	R.5	1.0	R.6	17	150	.28

Table 15. Dissolved gas data used to calculate excess air and recharge temperature for CFC and SF_6 age-dating and measured concentrations of CFC and SF_6 gases in groundwater samples collected from four wells in Pike County, Pa., in 2007.

[N_2, nitrogen; Ar, argon; O_2, oxygen; CO_2, carbon dioxide; CH_4, methane, SF_6, sulfur hexafluoride; trichlorotrifluorothane; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluorothane; —, no data; °C, degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters mercury, BP, barometric pressure; cc, cubic centimeters; STP, standard temperature and pressure; pmol/kg, picomol per kilogram; fmol/kg, fentomol per kilogram; pptv, parts per trillion by volume; contam., contaminated, sample could not be analyzed]

Sample name	Date	Time	Field temperature (°C)	Salinity	Recharge elevation (feet)	N_2 (mg/L)	Ar (mg/L)	O_2 (mg/L)	CO_2 (mg/L)	CH_4 (mg/L)
PI-308	8/30/2007	1600	11.13	0.00	350	23.469	0.812	8.44	19.87	0.000
PI-308	8/30/2007	1600	11.13	.00	350	22.894	.803	8.22	20.10	.000
PI-553	8/29/2007	1000	11.45	.00	1,510	22.866	.793	.28	5.13	.000
PI-553	8/29/2007	1000	11.45	.00	1,510	22.701	.790	.31	5.16	.000
PI-555	8/30/2007	1000	9.21	.00	1,790	19.911	.727	4.43	14.77	.001
PI-555	8/30/2007	1000	9.21	.00	1,790	20.055	.730	4.64	14.60	.001
PI-556	8/30/2007	1230	11.51	.00	660	22.419	.781	.61	3.41	.003
PI-556	8/30/2007	1230	11.51	.00	660	—	—	—	—	—

Sample name	Date	Time	mm Hg BP	cc from N_2	cc from Ar	Delta cc	Recharge T °C	Excess Air cc STP/L
PI-308	8/30/2007	1600	750.3	3.918	3.918	0.000	6.1	3.9
PI-308	8/30/2007	1600	750.3	3.309	3.309	.000	6.0	3.3
PI-553	8/29/2007	1000	719.0	3.751	3.751	.000	5.2	3.8
PI-553	8/29/2007	1000	719.0	3.593	3.593	.000	5.2	3.6
PI-555	8/30/2007	1000	711.6	1.514	1.514	.000	6.4	1.5
PI-555	8/30/2007	1000	711.6	1.630	1.630	.000	6.3	1.6
PI-556	8/30/2007	1230	741.8	3.443	3.443	.000	6.9	3.4
PI-556	8/30/2007	1230	741.8	—	—	—	—	—

Sample name	Date	Time	Corrected CFC concentrations		
			CFC-12 (pmol/kg)	CFC-11 (pmol/kg)	CFC-113 (pmol/kg)
PI-308	08/30/07	1600	4.191	9.059	0.548
PI-308	08/30/07	1600	4.146	9.319	.547
PI-553	08/29/07	1000	.109	.201	.008
PI-553	08/29/07	1000	.104	.171	.007
PI-555	08/30/07	1000	1.638	2.497	.234
PI-555	08/30/07	1000	1.697	2.439	.228
PI-556	08/30/07	1230	16.812	contam.	contam.

Sample name	Date	Time	SF_6 (fmol/kg)	Calculated SF_6 (pptv) partial pressure
PI-308	08/30/07	1600	3.173	5.130
PI-308		second bottle broken		
PI-553	08/29/07	1000	.134	.213
PI-553	08/29/07	1000	.128	.208
PI-555	08/30/07	1000	1.288	2.601
PI-555	08/30/07	1000	1.316	2.624
PI-556	08/30/07	1230	[1]6.683	[1]11.354
PI-556	08/30/07	1230	[1]6.964	[1]11.831

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[1] Laboratory indicated possible contamination for well PI-556.

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