Prepared in cooperation with the Pike County Conservation District

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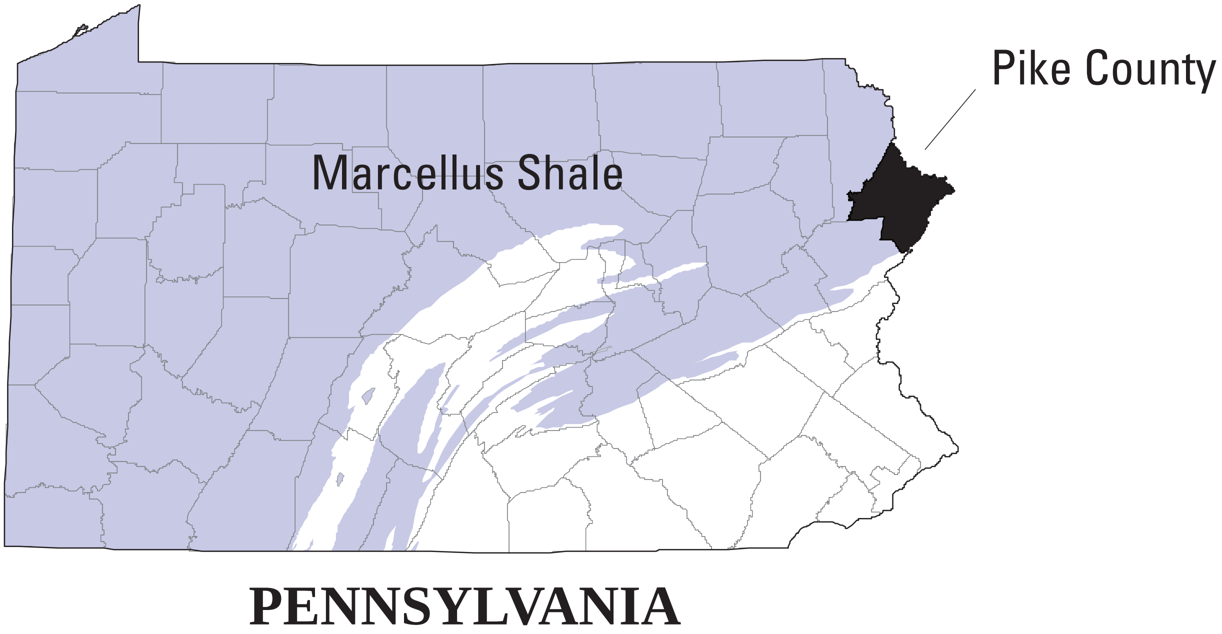

Scientific Investigations Report 2017–5110

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

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By Lisa A. Senior and Charles A. Cravotta, III

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
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)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
bar	100	kilopascal (kPa)
inch of mercury at 60ºF (in Hg)	3.377	kilopascal (kPa)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

Datum

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.

Supplemental Information

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 in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).

Results for measurements of stable isotopes of an element in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope to the number of the more abundant isotope of a sample with respect to a measurement standard.

Abbreviations

AMCL	alternate maximum contaminant levels
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
HA	Health Advisory
MCL	maximum contaminant level
PADEP	Pennsylvania Department of Environmental Protection
ROE	residue on evaporation
SC	specific conductance
SI	saturation index
SMCL	secondary maximum contaminant level
TDS	total dissolved solids
USGS	U.S. Geological Survey
VOC	volatile organic compound
µg/L	micrograms per liter
mg/L	milligrams per liter
µS/cm at 25 °C	microsiemens per centimeter at 25 degrees Celsius
pCi/L	picocuries per liter
o/oo	per mil

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Abstract

The Devonian-age Marcellus Shale and the Ordovician-age Utica Shale, which have the potential for natural gas development, underlie Pike County and neighboring counties in northeastern Pennsylvania. In 2015, the U.S. Geological Survey, in cooperation with the Pike County Conservation District, conducted a study that expanded on a previous more limited 2012 study to assess baseline shallow groundwater quality in bedrock aquifers in Pike County prior to possible extensive shale-gas development. Seventy-nine water wells ranging in depths from 80 to 610 feet were sampled during June through September 2015 to provide data on the presence of methane and other aspects of existing groundwater quality in the various bedrock geologic units throughout the county, including concentrations of inorganic constituents commonly present at low values in shallow, fresh groundwater but elevated in brines associated with fluids extracted from geologic formations during shale-gas development. All groundwater samples collected in 2015 were analyzed for bacteria, dissolved and total major ions, nutrients, selected dissolved and total inorganic trace constituents (including metals and other elements), radon-222, gross alpha- and gross beta-particle activity, dissolved gases (methane, ethane, and propane), and, if sufficient methane was present, the isotopic composition of methane. Additionally, samples from 20 wells distributed throughout the county were analyzed for selected man-made volatile organic compounds, and samples from 13 wells where waters had detectable gross alpha activity were analyzed for radium-226 on the basis of relatively elevated gross alpha-particle activity.

Results of the 2015 study show that groundwater quality generally met most drinking-water standards for constituents and properties included in analyses, but groundwater samples from some wells had one or more constituents or properties, including arsenic, iron, manganese, pH, bacteria, sodium, chloride, sulfate, total dissolved solids, and radon-222, that did not meet (commonly termed failed or exceeded) primary or secondary maximum contaminant levels (MCLs) or Health Advisories (HA) for drinking water. Except for iron, dissolved and total concentrations of major ions and most trace constituents generally were similar. Only 1 of 79 well-water samples had any constituent that exceeded a MCL, with an arsenic concentration of about 30 micrograms per liter (µg/L) that was higher than the MCL of 10 µg/L. However, total arsenic concentrations were higher than the HA of 2 µg/L in samples from another 12 of 79 wells (about 15 percent). Secondary maximum contaminant levels (SMCLs) were exceeded most frequently by pH and concentrations of iron and manganese. The pH was outside of the SMCL range of 6.5–8.5 in samples from 24 of 79 wells (30 percent), ranging from 5.5 to 9.2; more samples had pH values less than 6.5 than had pH values greater than 8.5. Total iron concentrations typically were much greater than dissolved iron concentrations, indicating substantial presence of iron in particulate phase, and exceeded the SMCL of 300 µg/L more often [35 of 79 samples (44 percent)] than dissolved iron concentrations [samples from 8 of 79 wells (10 percent)]. Total manganese concentrations exceeded the SMCL of 50 µg/L in samples from 31 of 79 wells (39 percent) and the HA of 300 µg/L in samples from 13 of 79 wells (about 16 percent). A few (1–2) samples had concentrations of sodium, chloride, sulfate, or TDS higher than the SMCLs of 60, 250, 250, and 500 mg/L, respectively. However, dissolved sodium concentrations were higher than the HA of 20 mg/L in samples from 15 of 79 wells (nearly 20 percent). Total coliform bacteria were detected in samples from 25 of 79 wells (32 percent) but *Escherichia coli* were not detected in any sample. Radon-222 activities ranged from 11 to 5,100 picocuries per liter (pCi/L), with a median of 1,440 pCi/L, and exceeded the proposed and the alternate proposed drinking-water standards of 300 and 4,000 pCi/L, respectively, in samples from 60 of 79 wells (75 percent) and in samples from 2 of 79 wells (3 percent), respectively.

Groundwater samples from all wells were analyzed for dissolved methane by one contract laboratory that determined water from 19 of the 79 wells (24 percent) had concentrations of methane greater than the reporting level of 0.010 milligrams per liter (mg/L) with a maximum methane concentration of 2.5 mg/L. Methane concentrations in 18 replicate samples submitted to a second laboratory for dissolved gas and isotopic analysis generally were higher by as much as a factor of 2.7 from those determined by the first laboratory, indicating potential bias related to combined sampling and analytical methods, and therefore, caution needs to be used when comparing methane results determined by different methods.

The isotopic composition of methane in 9 of 10 samples with sufficient dissolved methane (about 0.3 mg/L) for isotopic analysis is consistent with values reported for methane of microbial origin produced through carbon dioxide reduction; an isotopic shift in 1 or 2 samples may indicate subsequent methane oxidation. The low concentrations of ethane relative to methane in these samples further indicate that the methane may be of microbial origin. Groundwater samples with relatively elevated methane concentrations (near or greater than 0.3 mg/L) also had chemical compositions that differed in some respects from groundwater with relatively low methane concentrations (less than 0.3 mg/L) by having higher pH (greater than 8) and higher concentrations of sodium, lithium, boron, fluoride, arsenic, and bromide and chloride/bromide ratios indicative of mixing with a small amount of brine of probable natural occurrence.

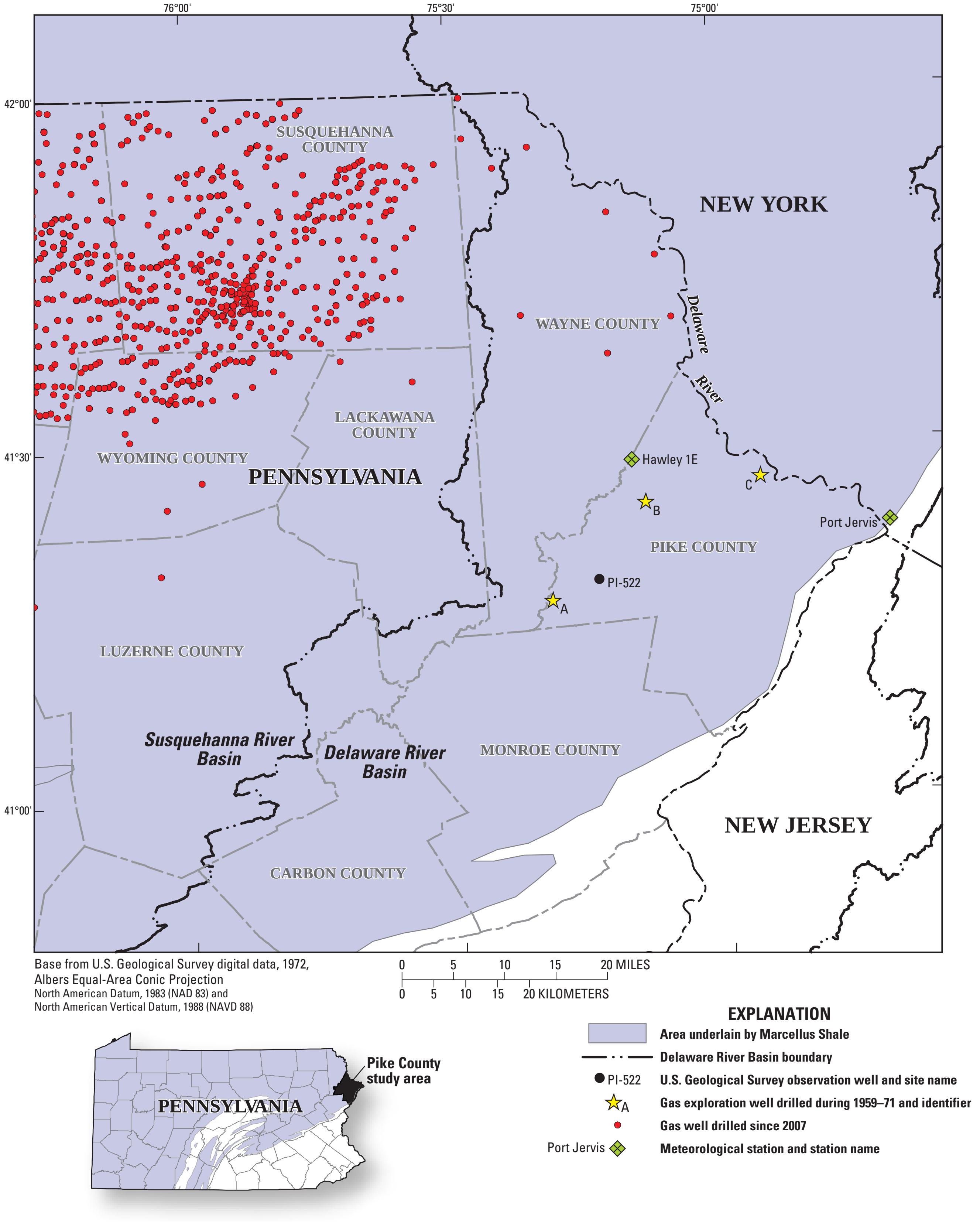
The spatial distribution of groundwater compositions differs by topographic setting and lithology and generally shows that (1) relatively dilute, slightly acidic, oxygenated, calcium-carbonate type waters tend to occur in the uplands underlain by the undivided Poplar Gap and Packerton members of the Catskill Formation in southwestern Pike County; (2) waters of near neutral pH with the highest amounts of hardness (calcium and magnesium) generally occur in areas of intermediate altitudes underlain by other members of the Catskill Formation; and (3) waters with pH values greater than 8, low oxygen concentrations, and the highest arsenic, sodium, lithium, bromide, and methane concentrations can be present in deep wells in uplands but most frequently occur in stream valleys, especially at low altitudes (less than about 1,200 feet above North American Vertical Datum of 1988) where groundwater may be discharging regionally, such as to the Delaware River in northern and eastern Pike County. Thus, the baseline assessment of groundwater quality in Pike County prior to gas-well development shows that shallow (less than about 1,000 feet deep) groundwater generally meets primary drinking-water standards for inorganic constituents but varies spatially, with methane and some constituents present in high concentrations in brine (and connate waters from gas and oil reservoirs) present at low to moderate concentrations in some parts of Pike County.

Introduction

Pike County in northeastern Pennsylvania (fig. 1) is underlain by the Marcellus Shale and, at greater depths, the Utica Shale. These formations are being developed in western and northern Pennsylvania for natural gas, using unconventional methods that involve hydraulic fracturing. The Marcellus Shale is exposed at the land surface in southeastern Pike County, cropping out along the Delaware River, and is present at increasing depths to the west. Test holes indicate depths to the formation are about 5,500 to 6,500 feet (ft) below land surface in north-central and western Pike County (Sevon and others, 1989). The Utica Shale is present thousands of feet (about 5,550 ft in western Pike County as indicated by a test hole described by Sevon and others, 1989) below the Marcellus Shale. Residents of largely rural Pike County rely on groundwater as the primary source of water supply. Drilling and hydraulic fracturing of horizontal natural gas wells used to develop the shale gas deposits have the potential to contaminate freshwater aquifers that provide drinking water and the base flow of streams (Kargbo and others, 2010; Kerr, 2010; U.S. Environmental Protection Agency, 2014, 2015, and 2016). Produced (flowback) fluids generated as a result of drilling and hydraulic-fracturing activities commonly contain concentrations elevated above background for chloride, bromide, sodium, calcium, and other constituents present in oil and gas well brines and naturally occurring Appalachian Basin brines in eastern United States (Llewellyn, 2014) (table 1).

Since 2006 when development of natural gas in shale formations using hydraulic fracturing began to increase in Pennsylvania, land was leased in northern and western Pike County for gas development (Pike County Marcellus Shale Task Force, written commun., 2011), but no permits for wells were issued. In neighboring Wayne County, permits have been issued for 33 Marcellus Shale gas wells (Pennsylvania Department of Environmental Protection, 2017). However, partly because of a drilling moratorium in the Deleware River Basin imposed by the Delaware River Basin Commission (DRBC) in 2010 (Delaware River Basin Commission, 2014), only nine vertical exploratory gas wells have been drilled in Wayne County (fig. 1) as of September 2016, and these wells were drilled during 2008–10 (Pennsylvania Department of Environmental Protection, 2016a). Three vertical exploratory natural gas test holes were drilled in Pike County between 1958 and 1971 (Sevon and others, 1989). No horizontal drilling has been conducted, and no well has been hydraulically fractured in either Pike or Wayne Counties. In contrast, in Susquehanna County on the western border of Wayne County and in the Susquehanna River Basin, where the DRBC moratorium is not applicable, a total of 1,218 gas wells (fig. 1) have been drilled from 2005 through June 2016 (Pennsylvania Department of Environmental Protection, 2016a).

Without baseline water-quality data, it is difficult to determine the effects of natural-gas production and related activities on the shallow groundwater chemistry. This study, conducted by the U.S. Geological Survey (USGS) in cooperation with Pike County Conservation District (PCCD), expands on a preliminary baseline assessment of groundwater quality done during 2012–13 by USGS in cooperation with the PCCD.



Base from U.S. Geological Survey digital data, 1972,
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Figure 1. Location of Delaware River Basin boundary and gas wells drilled in Pike County, Pennsylvania, during 1959–71 and in nearby counties in Pennsylvania during 2007 through June 2016. Gas well data for 2007–16 from Pennsylvania Department of Environmental Protection (2016b).

Table 1. Maximum concentrations reported for selected inorganic constituents in oil and gas well brines or flowback waters in western Pennsylvania and in Salt Spring in Susquehanna County, Pennsylvania.

[PA, Pennsylvania; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; TDS, total dissolved solids; pCi/L, picocuries per liter; --, no data; Cl, chloride; Br, bromide; Li, lithium; Mg, magnesium; Ba, barium; Sr, strontium]

Constituent	Concentration unit	Reported maximum concentration		
		Western PA[1]	Marcellus Shale flowback fluid[2]	Salt Spring[3]
Major ions				
Calcium	mg/L	41,600	17,900	370
Magnesium	mg/L	4,150	--	61
Potassium	mg/L	4,860	5,240	--
Sodium	mg/L	83,000	37,800	1,800
Chloride	mg/L	207,000	105,000	4,014
Sulfate	mg/L	850	420	0.65
Alkalinity	mg/L as $CaCO_3$	1,520	939	138
TDS	mg/L	354,000	197,000	6,418
Minor ions, trace elements, and metals				
Barium	mg/L	4,370	6,270	84.4
Bromide	mg/L	2,240	613	37.9
Copper	mg/L	0.13	--	--
Iodide	mg/L	56	--	--
Iron	mg/L	494	--	--
Lithium	mg/L	315	--	4.3
Lead	mg/L	0.04	--	--
Manganese	mg/L	96	29	--
Strontium	mg/L	13,100	3,570	48.5
Zinc	mg/L	1.3	--	--
Radionuclides				
Radium-226	pCi/L	5,300	5,830	18.4
Radium-228	pCi/L	--	710	9.3
Ratios[4]				
(Cl/Br)	mass ratio	92	[a]129	106
(Cl/Li)	mass ratio	657	--	933
(Sr+Ba)/Mg	mass ratio	4.2	--	2.2

[1] Brines from oil and gas wells in Devonian- and Silurian-age rocks in western Pennsylvania (Dresel and Rose, 2010).

[2] Data from Pennsylvania Department of Environmental Protection Bureau of Oil and Gas Management reported in Haluszczak and others (2013).

[3] Data from Warner and others, 2012.

[4] Mass ratios calculated from concentrations listed in column above, unless otherwise noted.

[a] Median Cl/Br mass ratio for 19 samples; data from Pennsylvania Department of Environmental Protection Bureau of Oil and Gas Management reported in Haluszczak and others (2013).

The 2015 groundwater-quality assessment is intended to provide current data on the presence, concentrations, and distribution of methane, inorganic constituents, and selected man-made organic compounds in shallow groundwater (less than about 1,000 feet deep) in bedrock aquifers prior to shale-gas production in Pike County. Groundwater samples were analyzed for constituents recommended in 2014 by the Pennsylvania Department of Environmental Protection (PADEP), which, in 2016, slightly revised the list of recommended constituents for testing of private wells in areas where gas drilling may occur in the future by adding some trace constituents and ethylene glycol (table 2) (Pennsylvania Department of Environmental Protection, 2014; 2016c). The 2015 study also included analyses for other constituents to provide a more comprehensive characterization of groundwater quality than the constituents on the basic pre-drill list. The data collected during the 2015 study described

Table 2. Pre-drill basic list of constituents recommended by the Pennsylvania Department of Environmental Protection in 2014 for analysis in private water supply wells prior to gas drilling.

[Data from Pennsylvania Department of Environmental Protection, 2014; TDS, total dissolved solids; TSS, total suspended solids]

Analyte (inorganic)	Analyte (trace metal)[1]	Analyte (organic)[2]	Analyte (microbiologic)
Alkalinity[*]	**Barium**[*]	**Ethane**[*]	Total coliform bacteria
Chloride[*]	**Calcium**[*]	**Methane**[*]	
Conductivity	**Iron**[*]	**Propane**[*]	
Hardness	Magnesium	Total petroleum hydrocarbons[***]	
Bromide	**Manganese**[*]		
pH[*]	Potassium		
Sulfate[**]	**Sodium**[*]		
TDS[*]	Strontium		
Turbidity[*]	Arsenic		
TSS	Zinc		
	Aluminum		
	Lithium		
	Selenium		

[*] As a minimum, a homeowner wishing to have their private well tested should analyze for these constituents.

[**] Consider where coal formations are present.

[***] Consider in western Pennsylvania's oil-producing regions.

[1] Pre-drill basic list revised in 2016 included all constituents in 2014 list plus copper, vanadium, boron, and chromium (Pennsylvania Department of Environmental Protection, 2016c).

[2] Pre-drill basic list revised in 2016 included all constituents in 2014 list plus ethylene glycol and for western Pennsylvania, volatile organic compounds and benzene, toluene, ethylbenzene, and xylene(BTEX compounds) (Pennsylvania Department of Environmental Protection, 2016c).

in this report and the previous 2012–13 study document groundwater quality in Pike County. In addition to serving as a baseline for future evaluations that might determine the effect of shale-gas development or other land-use changes on groundwater quality, the assessment also may be used to evaluate overall general groundwater quality in the county and identify constituents in local drinking water that may pose a health risk.

Purpose and Scope

This report presents analytical data for groundwater samples collected from 79 domestic wells in Pike County during summer 2015. The groundwater samples were analyzed for chemical and physical properties and a suite of constituents, including nutrients, major ions, trace elements and metals, radioactivity, bacteria, radon-222, and methane and other dissolved hydrocarbon gases. Samples from 20 of the 79 wells were also analyzed for selected man-made organic compounds, and samples from 13 of the 79 wells were analyzed for radium-226. The groundwater-quality data and summary statistics are presented to provide a pre-gas-well drilling baseline and for comparison to drinking-water standards to identify existing water-quality problems. The isotopic composition of methane in groundwater samples with sufficient methane to perform the analysis is compared to reported compositions of methane with thermogenic or biogenic origins.

Relations among constituents in the 2015 groundwater samples are described to provide insight into the presence of, and geochemical controls on, selected constituents, including those that pose health risks at elevated concentrations, such as arsenic, and others of concern, such as methane, which have been documented to be present in the county during previous studies (Eckhardt and Sloto, 2012; Senior, 2014). Statistical tests were used to identify groupings of constituents. Geochemical controls on the solubility of selected trace elements are shown in illustrations in relation to pH and oxidation-reduction conditions. Trilinear (Piper) diagrams are presented to show the types of groundwater in Pike County. Use of chloride/bromide (Cl/Br) ratios to identify sources of chloride is discussed. The spatial distribution of selected constituents is displayed on maps to illustrate the spatial patterns and to indicate the possible role of hydrogeologic setting on the presence of elevated concentrations of constituents of concern.

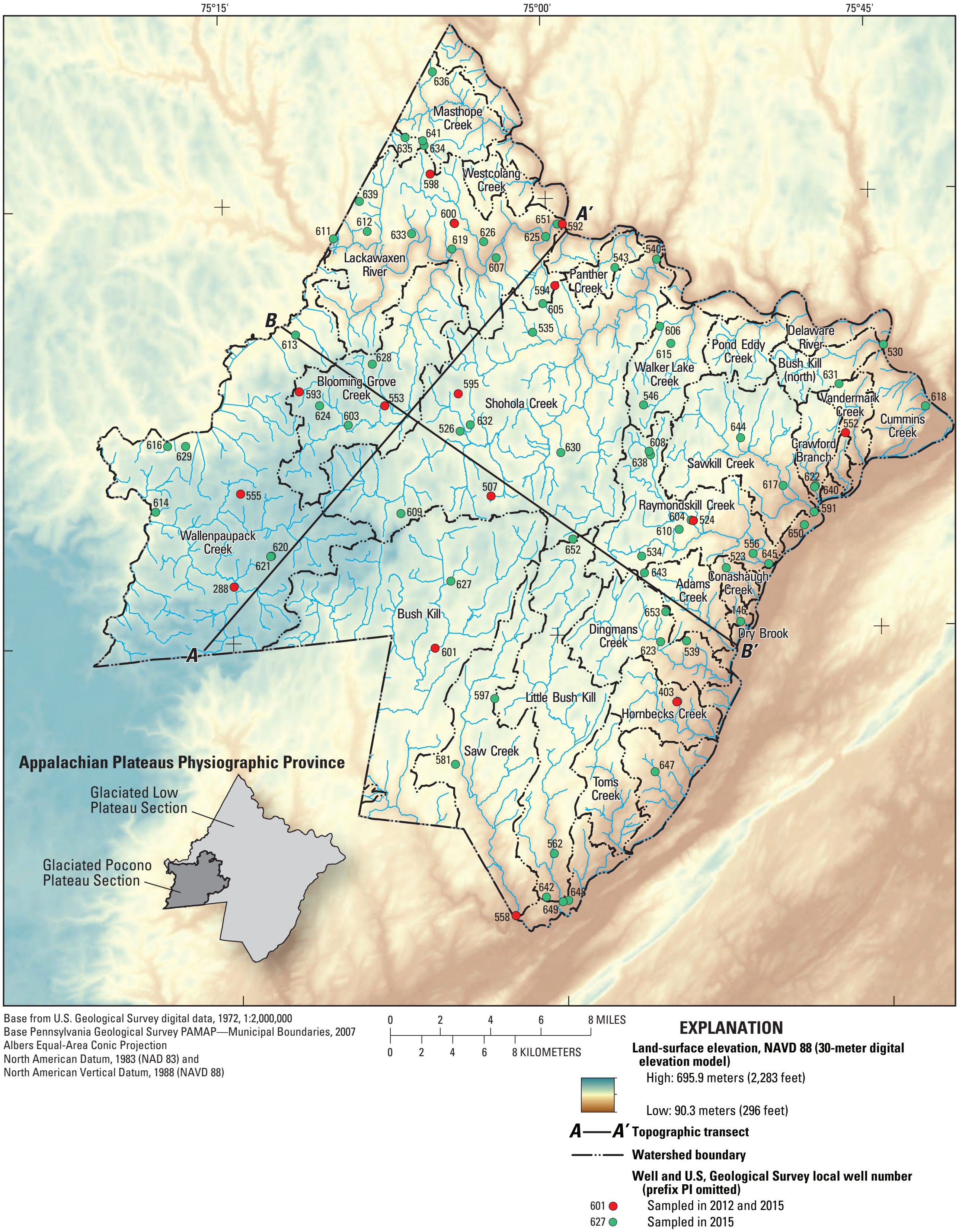
Additionally, the report includes analytical data for 1) 7 pairs of closely-spaced wells sampled in 2015 to provide data on local spatial variability in groundwater quality, and 2) 18 wells in Pike County that had been sampled by USGS at least once previously for more limited assessments in 2007, 2011, or 2012–13 (Senior, 2009; Eckhardt and Sloto, 2012; Senior, 2014) and that were resampled as part of the 2015 assessment to provide some information on variability of water quality through time. Differences and similarities in the compositions of water from the 7 pairs of closely-spaced sampled in 2015 and the 18 wells sampled in 2015 and at least once previously during 2007–13 are discussed.

Description of Study Area

Pike County covers 547 square miles (mi^2) in northeastern Pennsylvania and is flanked on the north and east by the Delaware River, which forms the boundary between Pennsylvania and the adjacent States of New York and New Jersey (fig. 1). In Pennsylvania, Pike County is bordered by Wayne County to the west and Monroe County to the south. The climate and general physical characteristics are described in more detail by Davis (1989).

Physiography and Hydrogeologic Setting

Most of Pike County is in the Glaciated Low Plateau Section of the Appalachian Plateaus Physiographic Province, but the southwestern corner of the county is in the Glaciated Pocono Plateau Section of the Appalachian Plateaus Physiographic Province (fig. 2). The Glaciated Low Plateau Section is characterized by low to moderately high rounded hills and broad to narrow valleys, all of which have been modified by glacial erosion and deposition. Swamps and peat bogs are common. The Glaciated Pocono Plateau Section is characterized by broad, undulatory upland surfaces with dissected margins (Sevon, 2000). Land-surface altitudes are highest [more than 2,000 ft above the North American Vertical Datum of 1988 (NAVD 88)] in the southwestern corner of the county (Glaciated Pocono Plateau Section) and lowest along the Delaware River (as low as about 320 ft above NAVD 88) (fig. 2).



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Base Pennsylvania Geological Survey PAMAP—Municipal Boundaries, 2007
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Figure 2. *A*, Land-surface altitude, streams and major watersheds, and location of wells sampled in 2012 and 2015, in Pike County, Pennsylvania, and *B*, transects *A*–*A*′ and *B*–*B*′. Transects *A*–*A*′ and *B*–*B*′ terminate at the Delaware River, but transect *A*–*A*′ originates near the highest altitudes in southwestern Pike County, and transect *B*–*B*′ originates at Lake Wallenpaupack at western edge of Pike County.

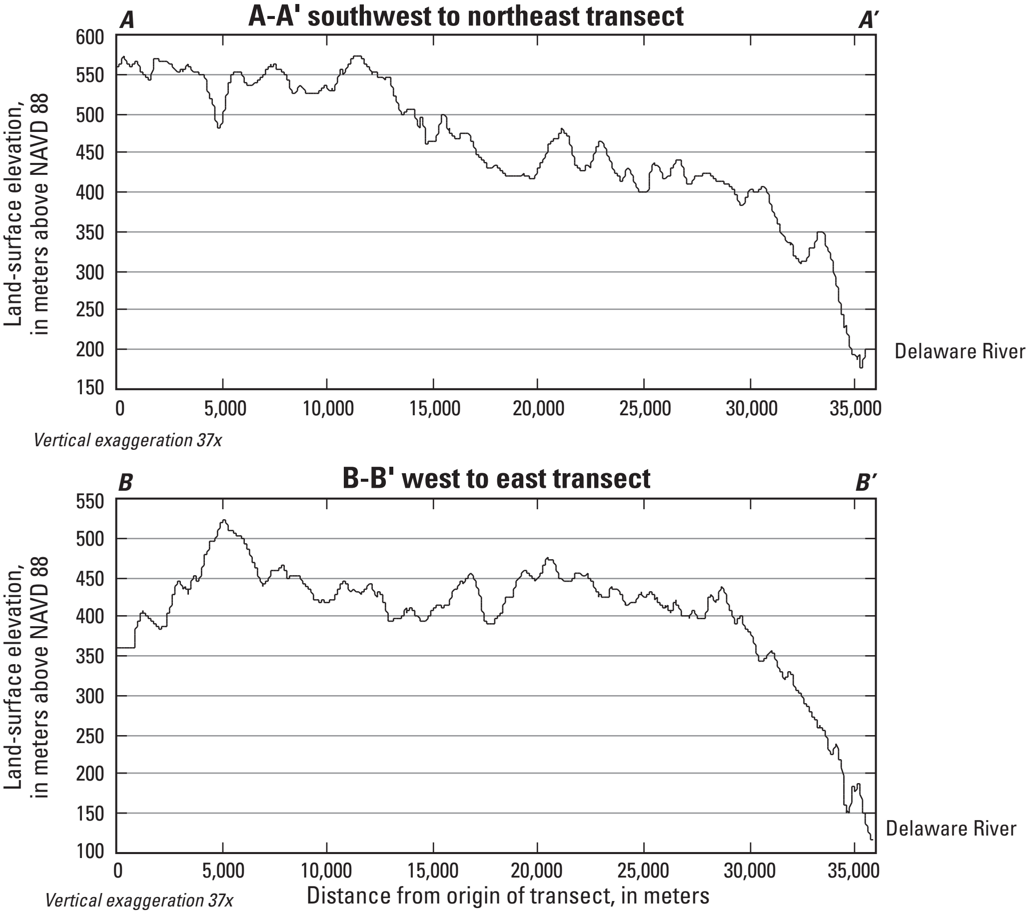
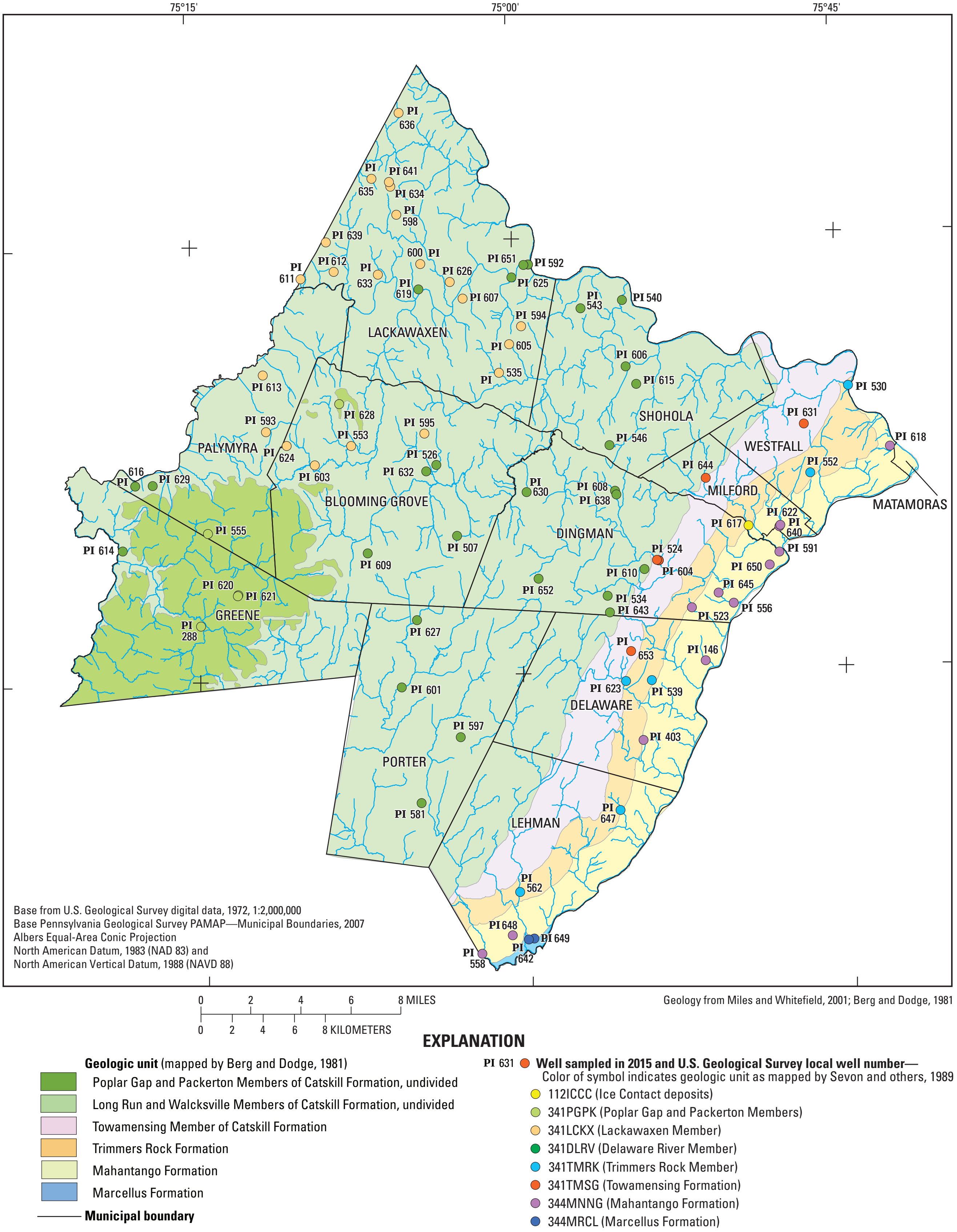


Figure 2. *A*, Land-surface altitude, streams and major watersheds, and location of wells sampled in 2012 and 2015, in Pike County, Pennsylvania, and *B*, transects *A–A′* and *B–B′*. Transects *A–A′* and *B–B′* terminate at the Delaware River, but transect *A–A′* originates near the highest altitudes in southwestern Pike County, and transect *B–B′* originates at Lake Wallenpaupack at western edge of Pike County.—Continued

The bedrock geologic units that underlie and crop out in Pike County are Devonian-age sedimentary rocks that have been mapped (fig. 3) using the Pennsylvania Geological Survey (PAGS) nomenclature (Berg and others, 1980; Berg and Dodge, 1981), in order of decreasing age from east to west, as the Marcellus Formation (Marcellus Shale in USGS nomenclature), 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. 3). In subsequent mapping (Sevon and others, 1989), the undivided Long Run and Walcksville Members of the Catskill Formation were differentiated and renamed as the Lackawaxen and Delaware River Members of the Catskill Formation; this mapping shows the Lackawaxen Member overlying the Delaware River Formation and present only in western Pike County. Mapping by Sevon and others (1989) also subdivided the siltstones and sandstones of the Trimmers Rock Formation into the Sloats Brook member (predominantly siltstone) overlain by the Millrift member (predominantly sandstone). However, the mineralogy of the two members was not differentiated (Sevon and others, 1989); therefore, these members are not differentiated for this report. The Devonian-age sedimentary rock formations in Pike County 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 (fig. 3; table 3). The bedrock units generally dip to the west at moderate to low angles, with the steepest dips (as much as 20 degrees) in the eastern part of the county and shallowest dips (0 to 5 degrees) in the western part of the county (Sevon and others, 1989).



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Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

Figure 3. Geology of the bedrock closest to land surface and location of wells sampled in Pike County, Pennsylvania, 2015.

Table 3. Lithology and mineralogy of Devonian-age bedrock geologic units in Pike County, Pennsylvania.

[Descriptions of predominant lithology (rock type) and mineralogy of geologic units from Sevon and others (1989), listed in order of decreasing age, with oldest unit at bottom; Al, aluminum; C, carbon; Ca, calcium; Cl, chloride; Cr, chromium; F, fluoride; Fe, iron; H, hydrogen; K, potassium; Li, lithium; Mg, magnesium; Mn, manganese; Na, sodium; Ni, nickel; O, oxygen; P, phosphorus; S, sulfur; Si, silicon; Th, thorium; Ti, titanium; U, uranium; V, vanadium; Zn, zinc; Zr, zirconium]

Formation name	Lithology	Mineralogy	Chemical formula for selected minerals
Catskill Formation:			
Poplar Gap and Packerton Members, undivided	Sandstone, conglomerate, siltstone, claystone, calcareous intraformational coglomerate	Quartz, muscovite, biotite, illite, chlorite, trace calcite	Biotite $K(Mg,Fe_2^{+3})(Al,Fe^{3+})Si_3O_{10}(OH,F)_2$
Lackawaxen Member[1]	Sandstone, siltstone, claystone, intraformational conglomerates with calcite cement	Quartz, muscovite, biotite, feldspar (orthoclase, plagioclase), illite, chlorite, calcite, garnet, apatite, magnetite	Orthoclase $KAlSi_3O_8$ plagioclase $(Na,Ca)AlSi_3O_8$ apatite $Ca_5(PO4)_3(F,Cl,OH)$ garnet $(Ca,Mg,Fe^{2+})_3(Al,Fe^{3+},Mn^{3+},V^{3+},Cr^{3+})(SiO_4)_3$
Delaware River Member[1]	Sandstone, interbedded siltstone and claystone, intraformational conglomerates with calcite cement	Quartz, feldspar, limonite, illite, microcrystalline silica, calcite, zircon, leucoxene	Leocoxene altered TiO_2, zircon $ZrSiO_4$ with U Th
Towamensing Member	Sandstone, interbedded siltstone and claystone, intraformational conglomerates with calcite cement	Quartz, feldspar, limonite, illite, chlorite, kaolinite, calcite, zircon, apatite, magnetite, leucoxene	Illite $(K,H_3O)\ (Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_20)]$ magnetite $Fe^{2+}(Fe^{3+})_2O_4$ with Mn,Mg,Zn,Ni,Al,Cr
Trimmers Rock Formation	Siltstone, silty shale, sandstone, and claystone	Quartz, illite, chlorite, microcrystalline silica, limonite, trace calcite and feldspar	Chlorite $(Mg,Fe,Li)_6AlSi_3O_{10}(OH)_8$
Mahantango Formation	Siltstone, silty shale, and claystone	Quartz, illite, chlorite, microcrystalline silica, limonite	Limonite $FeO(OH)nH_2O$
Marcellus Shale	Slightly siliceous clay shale and silty clay shale	Quartz, chlorite, muscovite, pyrite, siderite, marcasite, dolomite, calcite(?), feldspar (albite?)	Marcasite FeS_2 siderite $FeCO_3$ muscovite $KAl_2(Si_3Al)O_{10}(OH,F)_2$ albite $NaAlSi_3O_8$

[1] Mapped as Long Run and Walcksville Members of the Catskill Formation, undivided, by Berg and others (1980).

The Marcellus Shale (Marcellus Formation in PAGS nomenclature) underlies all of Pike County and crops out at the eastern edge of the county near the Delaware River (figs. 1 and 3). In Pike County, the thickness of the gas-producing organic-rich section of the Marcellus Shale increases from east to west and is estimated to be about 100–150 ft in western part of the county (Piotrowski and Harper, 1979). The Ordovician-age Utica Shale, another gas-producing formation, is older than, and occurs several thousand feet beneath, the Marcellus Shale and also underlies all of Pike County (Kirschbaum and others, 2012). Two of three deep wells drilled in central to western Pike County for natural gas exploration during 1958–71 penetrated the Marcellus Shale at depths of 5,500–7,500 ft below land surface, and the deepest of the three penetrated the Utica Formation at depth of about 13,000 ft below land surface (Sevon and others, 1989) (fig. 4). An exploratory 1,842-ft-deep oil and gas test hole drilled in eastern Pike County near Matamoras (fig. 3) penetrated bituminous black slate (Marcellus Shale) at a depth of about 1,040 ft, as reported by Lohman (1937).

Unconsolidated Wisconsin-age glacial deposits cover part of the bedrock units and vary in thickness and type, with the thickest deposits in valleys and thinnest deposits in upland areas, as described by Sevon and others (1989). Less than one-half of Pike County is overlain by glacial deposits, and most of these deposits are mapped as glacial till that typically is thin (less than 6 ft thick). Bedrock is exposed at the land surface in many areas not overlain by glacial deposits. The thickest glacial deposits and younger alluvium are present in a narrow band along the eastern flank of Pike County adjacent to the Delaware River and along some of the larger streams in the county, as shown by Sevon and others (1989). Other more recent types of deposits with more limited areal extent include alluvium in valleys and swamp and peat deposits that commonly occur in poorly drained glacial depressions throughout the county.

Hydrogeologic Setting

Most of the county is underlain by Devonian-age fractured-rock aquifers (shales, siltstones, and sandstones) (fig. 3) with unconsolidated Quaternary-age glacial deposits that are high yielding in groundwater in a band parallel to the Delaware River on the eastern edge of the county and in some upland stream valleys (Sevon and others, 1989). Groundwater in bedrock units and overlying glacial deposits is the main source of water supply for Pike County. These aquifers are recharged locally by precipitation and subsequently discharge to streams. Depth to water tends to be greater in upland areas than in valleys. The sedimentary rocks underlying Pike County form a layered, fractured-rock aquifer system.

In Pike County, local, intermediate, and regional groundwater flow systems with complex flow paths are thought to be present. Local and intermediate systems likely discharge to streams and larger tributaries, respectively, and the deeper regional system discharges to the Delaware River (Davis, 1989) along northern and eastern borders of the county, and possibly to other large streams, such as the Lackawaxen River (fig. 2). Topography likely affects directions of local and intermediate groundwater flow, as described in studies of Pike County and nearby counties and in other areas of the Appalachian Plateau region (Carswell and Lloyd, 1979; Davis, 1989; Reese, 2014). Shallow- to intermediate-depth fresh groundwater flows from recharge areas at higher altitudes and discharges locally and regionally into streams at lower altitudes as base flow. Only a small part of recharge is thought to enter and flow through the deeper regional flow system (Davis, 1989). Depth to saline water, which can be present in low-permeability areas of the aquifer with restricted flow, has been estimated to be greater than or equal to 1,000 ft in northeastern Pennsylvania in the vicinity of Pike County (Feth and others, 1965). For the surface-water system, streams eventually drain toward the Delaware River, radiating from near the center of Pike County (fig. 2). The aquifer properties of the various geologic units and hydrogeology of the county are described in greater detail by Davis (1989).

Most domestic wells in Pike County currently are completed in fractured bedrock aquifers rather than the overlying unconsolidated glacial deposits, except in areas along the Delaware River where thick sequences of coarse to fine glacial sediment are present and, to a lesser extent, in stream valleys and lower slopes where sufficient thickness of glacial till is present and some wells completed are in the unconsolidated deposits. The wells completed in fractured rock typically are constructed as open holes below surface casing and intercept multiple water-bearing fractures at various depths. Wells for drinking-water supply typically are completed within the local, freshwater flow system (less than 1,000 ft in depth). However, at depth in underlying rocks with restricted groundwater circulation, brines with elevated concentrations of sodium, chloride, bromide, barium, strontium, and other solutes may be present. The highly saline sodium chloride brines and overlying groundwaters of intermediate salinity generally are thought to be present at about 1,000 ft or more below the land surface in eastern Pennsylvania (Feth and others, 1965; Heisig and Scott, 2013).

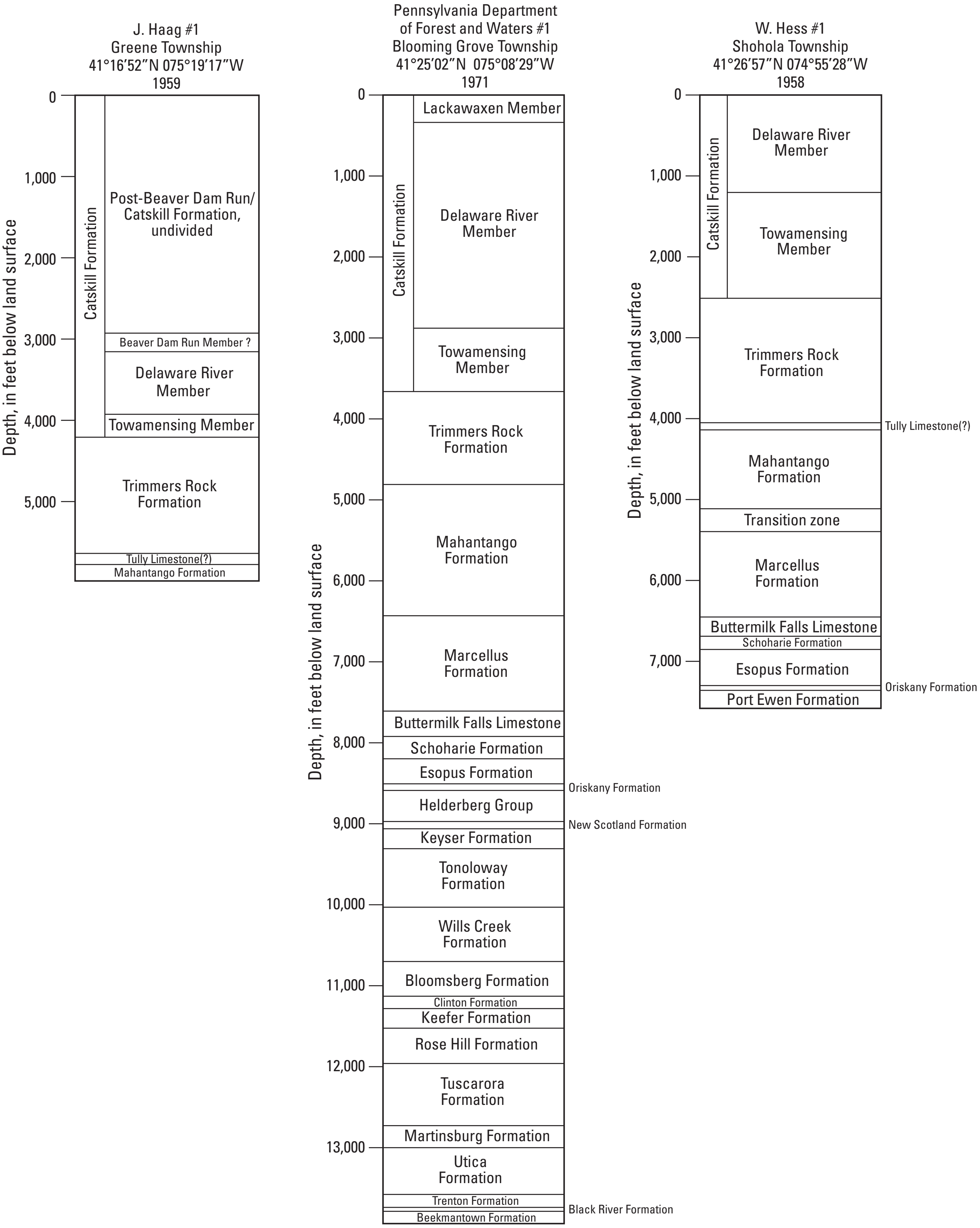


Figure 4. Stratigraphic columns showing summary of rock units penetrated by three gas exploration wells in Pike County, Pennsylvania. Well name, location, and date of drilling listed for each well are from Sevon and others, 1989, figure 2, p. 8. Location of wells shown in figure 1.

Annual precipitation that recharges the aquifers varies spatially by a few inches throughout the county, as indicated by precipitation records. The long-term [30-year normal (average), 1981–2010] total annual precipitation is about 42.9 inches (in.) at the National Oceanic and Atmospheric Administration (NOAA) Hawley 1E meteorological station on the western border between Pike and Wayne Counties, and about 46.4 in. at Port Jervis, New York, meteorological station on the eastern border of Pike County with New York State (fig. 1) (National Oceanic and Atmospheric Administration, 2015). Precipitation falls approximately evenly throughout the year, although recharge rates differ seasonally because frozen ground can inhibit recharge during winter months, and evapotranspiration reduces recharge during the warm spring and summer months of the growing season. The seasonal pattern in net recharge rates is reflected in annual fluctuations in long-term (about 15 years, 2001–16) daily median groundwater levels in the USGS observation well PI-522 in Pike County (fig. 1), a 150-ft deep well completed in the undivided Poplar Gap and Packerton Members of the Catskill Formation. Each year, generally rising water levels occur during 2 periods (March to mid-May and October to mid-November), indicating net positive recharge, and generally flat to declining water levels occur during 2 periods (mid-November to March and mid-May through September), indicating reduced to negligible recharge (fig. 5).

The groundwater-level and precipitation data from the USGS National Water Information System (NWIS) and NOAA databases indicate that the hydrologic conditions during summer 2015 were similar to, but in late June and early July were slightly wetter than, the long-term average or median conditions. During this study, daily mean groundwater levels measured in long-term observation well PI-522 were greater than the long-term median of daily mean values in late June and early July 2015 but fell to levels close to the long-term median of daily mean values by August 2015 and remained at or near the long-term median of daily mean values through the sampling period that ended in late September 2015 (fig. 5). Reported precipitation was greater than the long-term (30-year) normal for June at both the Hawley and Port Jervis meteorological stations (about 2.7 to 3.9 in., respectively); it was greater than the 30-year normal at Port Jervis (3.8 in.) but similar to the 30-year normal at Hawley in July 2015, and similar to 30-year normal at both Hawley and Port Jervis in August and September 2015 (National Oceanic and Atmospheric Administration, 2015).

Land Use

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

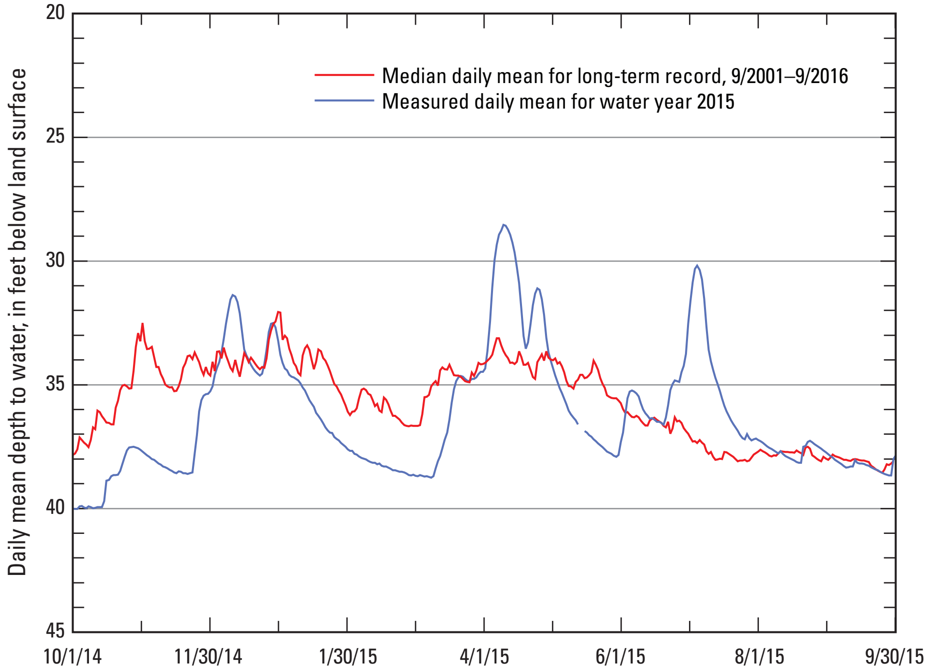


Figure 5. Hydrograph showing daily mean water levels measured during 2015 and long-term, 2001–16, median of daily mean water levels in observation well PI-522, Pike County, Pennsylvania. Data from the U.S. Geological Survey National Water Information System database.

(2 percent), and commercial (2 percent) (Pike County Planning Commission, 2006). The public lands include state forest, state park, state game, state natural area, and U.S. National Park Service (NPS) parcels, much of which are forested as are hunt club parcels. Most of the land designated as agricultural use is forested, with little in actual cultivation or other agricultural operations (28,260 acres or about 8 percent of county area is active farms according to U.S. Department of Agriculture, 2012). Much of the developed land area (residential and commercial) is in the eastern third of the county, and some areas have relatively greater development in the northern half of the county and along the western boundary with Wayne County, as shown by Senior (2014).

Population has been growing in Pike County since 1940 (Davis, 1989). The 2010 population of 57,369 (U.S. Census Bureau, 2017) represents an increase of 23.9 percent (or 11,067 people) from the population in 2000 and is more than three times the population of 18,271 in 1980. However, the recent rate of population growth has slowed in Pike County, with estimates of population relatively stable from 2010 through 2012 but decreasing slightly thereafter to about 55,652 in 2016 (U.S. Census Bureau, 2017). Because much land is public or private forested land, the population growth occurs in limited areas, as indicated by the distribution of residential land in Pike County. The largest population centers are along or near the Route 209 corridor, including Milford and Matamoras Boroughs and numerous residential developments in the eastern part of the county. In addition to the census (permanent) 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 some developments are supplied by community or public supply wells. Milford and Matamoras Boroughs 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 (Pike County Conservation District, 2014). Some developments are sewered and have sewage treatment systems that discharge treated effluent to land areas or to surface water.

Previous Investigations

Lohman (1937) presents limited water-quality data for a few wells in Pike County, including a description of one deep well with saltwater at a depth of about 1,040 ft in eastern Pike County near the Delaware River. A county-wide 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 domestic wells completed in the glacial aquifer near the Delaware River was sampled and analyzed for major ions, nutrients, trace metals, pesticides, volatile organic compounds, and radon-222 as part of the National Water-Quality Assessment (NAWQA) in the Delaware River Basin (Durlin and Schaffstall, 2002).

In 2007, the USGS, in cooperation with the PCCD, sampled 20 domestic wells throughout Pike County to provide a reconnaissance assessment of groundwater quality in the main land uses and geologic units (Senior, 2009) (17 wells were completed in bedrock aquifers, and 3 wells were completed in glacial aquifers). The laboratory analyses selected for the 2007 samples were intended to identify naturally occurring constituents in the aquifer or constituents introduced by human activities that pose a health risk or otherwise were of concern for groundwater in the county. Samples were analyzed for major ions, nutrients, selected trace metals, volatile organic compounds (VOCs), a suite of organic wastewater compounds, gross alpha- and gross beta-particle activity, and radon-222. Man-made organic compounds, including a few VOCs and wastewater compounds, were detected at low levels in groundwater from 10 of the 20 wells sampled in 2007, indicating human activities at the land surface have affected groundwater quality to some degree. Chloride and nitrite plus nitrate concentrations generally were greater in water from wells in the commercial and residential areas with on-site wastewater disposal than in undeveloped and sewered areas. Radon-222 levels ranged from 90 to 2,650 picocuries per liter (pCi/L) and were greater than or equal to the U.S. Environmental Protection Agency (EPA) proposed drinking-water standard of 300 pCi/L in water from 15 (75 percent) of the 20 wells.

In 2011, 6 National Park Service (NPS) wells in the Delaware Water Gap National Recreation Area (DEWA) and Upper Delaware Scenic and Recreational River (UPDE) national park units in northeastern Pennsylvania and 10 other wells or springs were sampled as part of a baseline groundwater-quality assessment of nine national park units in New York, Pennsylvania, and West Virginia that might be affected by shale-gas development (Eckhardt and Sloto, 2012). Two of the six DEWA and UPDE wells sampled in 2011 are in Pike County near the Delaware River, one in each of the two national park units (DEWA on eastern edge and UPDE on northern edge of Pike County). Water samples from these two wells contained methane in concentrations ranging from 2.52 to 4.77 milligrams per liter (mg/L), which were among the highest methane concentrations measured in the study.

Data were collected by USGS during 2012–13 for a reconnaissance assessment (with spatial and temporal components) of baseline groundwater quality in bedrock aquifers used for drinking-water supply in Pike County prior to potential shale-gas development (Senior, 2014). Results of the spatial component of the assessment, for which 20 wells were sampled in summer 2012 to provide baseline groundwater-quality data throughout the county but with emphasis on areas with relatively high potential for shale-gas development (mostly in the northern and western parts of the county), showed that water from 16 (80 percent) of 20 wells had detectable concentrations of methane, but concentrations were less than 0.1 mg/L in most well-water samples; only two well-water samples had concentrations greater than 1 mg/L. The groundwater with relatively elevated methane (greater than about 0.5 mg/L) also had a chemical composition that differed in some respects (pH, selected major ions, and inorganic trace constituents) from groundwater with lower methane concentrations. Results of the temporal component of the assessment, for which 4 of the 20 wells in the summer 2012 survey were sampled monthly for 1 year ending June 2013 to provide data on seasonal or other temporal variability in groundwater quality, showed that concentrations of major ions generally varied by less than 20 percent with most differences less than 4 mg/L and concentrations of methane varied by less than 1 µg/L (0.001 mg/L) in samples from three wells with low methane and by as much as 1 mg/L (1,000 µg/L) in samples from one well with relatively high methane.

Methods of Sample Collection and Analysis

To provide current data on the occurrence and spatial distribution of methane and various inorganic and man-made organic constituents in groundwater used for drinking-water supply, 79 wells throughout Pike County were sampled during summer 2015. The laboratory analyses selected were intended to determine baseline groundwater concentrations of methane and inorganic constituents, including radionuclides, that are commonly present in elevated concentrations in brines that, when disturbed, contribute to produced (flowback) fluids generated as a result of drilling and hydraulic-fracturing activities (table 1). Water samples were collected once per site from 78 wells and twice from 1 well (for a total of 79 individual wells) from late June through September 2015 and analyzed to characterize their physical properties and chemical characteristics. Samples were analyzed for all constituents on the PADEP modified pre-drill list (table 2) as of 2014 (Pennsylvania Department of Environmental Protection, 2014) and all constituents except vanadium, chrome, and ethylene glycol on the 2016 revised expanded pre-drill list (Pennsylvania Department of Environmental Protection, 2016c) (table 2). Analyses also were conducted for additional major ions, trace constituents, and dissolved gases, including methane, ethane, and radon-222. Samples from 20 wells throughout the county were also analyzed for selected man-made compounds (VOCs). Samples from 13 wells with the highest elevated gross alpha-particle activities were analyzed for radium-226. The 2015 analyses were done on unfiltered water samples using drinking-water methods for all major and several trace ions and on filtered water samples for major and trace ions using USGS methods and for additional bromide analysis by EPA method 300.1 (Appendix 1). The 2015 data enhance the 2012 data on groundwater quality in Pike County by providing greater spatial and chemical characterization of constituents, including determination of both total and dissolved concentrations of major ions, selected metals and trace elements, and additional man-made organic compounds.

Selection of Sampling Locations

Well locations were selected to provide spatially distributed data on groundwater quality in bedrock aquifers throughout Pike County. Although the goal was to have an evenly spaced sample distribution, the availability of wells constrained the selection process. Most wells considered for inclusion in the study are domestic wells used to supply individual residences or other facilities in Pike County, but a few (4) were larger supply wells that served multiple residences or were institutional. Criteria for well selection included availability of information about well construction from drillers' records submitted to the Pennsylvania Geological Survey and from well owners or other sources. Additionally, the ability to obtain a raw-water sample from a well was a requirement. The Pike County Conservation District provided support in identifying wells and obtaining permission from well owners for study participation and sampling.

Seventy-nine wells were selected for sampling in 2015 (fig. 2), 19 of which had been previously sampled at least once by USGS during 2007–12 (Senior, 2017; Appendix 5). To provide information about variability in pre-drill baseline water quality through time, the 2015 study resampled 15 of the 20 wells sampled for the 2012 reconnaissance study (Senior, 2014) and 1 other well sampled in 2011 (Eckhardt and Sloto, 2012), but 5 of the 20 wells sampled in 2012 were not resampled in 2015 because of well conditions or unavailability. Eight of the 79 wells sampled in 2015 had been sampled in 2007 (Senior, 2009), and 6 of these 8 wells were also sampled in 2012 (Senior, 2014). Nine other wells had been inventoried by USGS as part of an arsenic study for which well owners collected the samples (Low and Galeone, 2007).

Depths and other characteristics of the 79 wells sampled in 2015 are listed in table 12 (at the back of the report). Seventy-five wells were domestic wells serving individual residences, three wells served multiple residences, and one well was institutional. Wells sampled in 2015 range in depth from 80 to 610 ft with a median depth of 262 ft (as determined by available data for 74 of 79 wells). For wells with known construction, most were completed as 6-inch-diameter open holes for which steel casing was extended into competent bedrock with the remainder of the borehole left open. One well (PI-617) is reported to be completed in unconsolidated glacial deposits, an aquifer type in which wells typically are constructed with casing along the entire depth, sometimes with screens or perforations in the casing at selected depths or just open at the bottom of casing. Other wells are reported or presumed to be completed in bedrock on the basis of well construction information. The number of wells sampled in each bedrock geologic unit is approximately proportional to the areal extent of that formation in the county. Of the 79 wells, 2 wells were completed in the Marcellus Shale, 12 in the Mahantango Formation, 6 in the Trimmers Rock Formation, 5 in the Towmensing Member of the Catskill Formation, 48 in the undivided Long Run and Walcksville Members of the Catskill Formation (differentiated into two units and renamed the Lackawaxen River and Delaware River Members of the Catskill Formation in mapping by Sevon,1989), 5 in the undivided Poplar Gap and Packerton Members of the Catskill Formation, and 1 in the unconsolidated glacial (ice contact) deposits (table 12). Using the Sevon (1989) mapping, the 48 wells in the undivided Long Run and Walcksville Members of the Catskill Formation are distributed as 27 wells in the Delaware River Member and 21 wells in the Lackawaxen River Member (fig. 3).

Collection of Samples

The USGS sampled the 79 wells using standard USGS field-sampling protocols. Samples were collected at an untreated tap, typically at a pressure tank or outside tap and before any filtration, water softening, or bacteriological treatment. Water samples were analyzed in the field for unstable physical and chemical properties (such as temperature) and dissolved oxygen (DO), then shipped overnight to laboratories for analysis for major ions, nutrients, metals, trace elements, gross alpha and beta radioactivity, bacteria, man-made organic compounds, and dissolved gases. All well-water samples were collected and processed for analysis by methods described in USGS manuals for the collection of water-quality data (U.S. Geological Survey, variously dated).

Sampling was conducted at each well using the following steps. The existing submersible well pump was turned on and allowed to run. A raw-water tap was opened, and the water was allowed to flush to minimize possible effects of plumbing and ensure that the water was representative of the aquifer. While the well was pumped, the water discharging from the tap was analyzed with a multi-parameter probe meter for temperature, specific conductance (SC), pH, and DO concentration with the probe submerged in an overflowing bucket filled by the discharge line (hose). After the values of these properties and parameters stabilized, sample bottles were filled according to USGS protocols (U.S. Geological Survey, variously dated). Samples were collected through Teflon tubing attached to the raw-water tap, which avoided all water-treatment systems.

Unfiltered (whole-water) samples were collected for determination of physical properties and for analyses for radioactivity, dissolved gases, and the PADEP pre-drill constituents to obtain total concentrations (Appendix 1). Samples for analyses for concentrations of dissolved nutrients, major ions, metals, and trace elements were filtered through a field-rinsed 0.45-micrometer pore-size cellulose capsule filter. To prevent sample degradation, nitric acid was added to the major cation, metals, and trace-element samples. No preservative was added to samples for analysis of major anions and dissolved nutrients. Samples for VOC analysis were preserved with hydrochloric acid. Samples for radon analysis were obtained through an inline flexible (silicon) hose with a gas-tight syringe to avoid atmospheric contact. Samples for dissolved gases were obtained through 1) copper refrigeration grade tubing placed in sets of three 40 mL glass bottles that were filled and stoppered while submerged to avoid atmospheric contact for analysis by Seewald Laboratories, Inc., and(or) 2) direct flexible-tubing connection to an Isoflask for analysis by Isotech Laboratories, Inc.

The samples were stored on ice in coolers and shipped by overnight delivery to the following laboratories: (1) the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis for major ions, nutrients, total dissolved solids (TDS), metals, and trace elements in filtered water samples, and radon; (2) ALS Environmental, Fort Collins, Colorado, a USGS contract laboratory, for analysis of gross alpha- and gross beta-particle activity (also referred to as gross alpha and gross beta radioactivity) and, in selected samples, radium-226; and (3) Seewald Laboratories, Inc., in Williamsport, Pennsylvania, a laboratory accredited by PADEP Bureau of Laboratories, for analysis of unfiltered samples using approved drinking-water methods for (a) the 2014 PADEP pre-drill constituents (table 2), including major ions, iron, manganese, aluminum, arsenic, barium, bromide, lithium, selenium, strontium, zinc, TDS, total suspended solids (TSS), and total coliform and *Escherichia coli* (*E. coli*) bacteria; (b) dissolved methane, ethane, and propane gases; and for 20 samples (c) selected man-made organic compounds (VOCs). Filtered samples from most wells also were sent to Weck Laboratories, City of Industry, California for bromide analysis with a low reporting level (Appendix 1). Additionally, replicate samples from selected wells were sent to Isotech Laboratories, Inc., in Champaign, Illinois, for analysis of dissolved methane, other dissolved gases including hydrocarbons, and isotopes of hydrogen and carbon in methane.

Water samples from 10 wells containing a sufficient concentration of methane (as measured in replicate samples by Seewald Laboratories, Inc.), which generally is greater than about 0.3 mg/L, were submitted to Isotech Laboratories, Inc., for determination of (1) the isotopic composition of methane with analysis for the stable carbon isotopes ^{12}C and ^{13}C and the stable hydrogen isotopes ^{1}H (protium) and ^{2}H (deuterium) and (2) dissolved gases (oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, and argon) and selected hydrocarbons (methane, ethane, propane, and higher-carbon alkanes). Water samples from nine other wells with methane concentrations less than 0.3 mg/L (as measured in replicate samples by Seewald Laboratories, Inc.) were submitted to Isotech Laboratories, Inc., for analysis of dissolved gases (oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, and argon) and selected hydrocarbons (methane, ethane, propane, and higher-carbon alkanes) as part of quality assurance for dissolved gas concentrations.

Analysis of Chemical, Physical, and other Characteristics and Reporting Units

Analytical methods and reporting levels for constituents analyzed by PADEP Bureau of Laboratories accredited laboratories and other laboratories are listed in Appendix 1 (table 1–3). Descriptions of analytical methods for constituents analyzed by the USGS NWQL are available from the U.S. Geological Survey (2014a). Reporting levels for constituents analyzed by NWQL are listed in Appendix 1 (tables 1–1 and 1–2). The analytical results are available online from the USGS National Water Information System (U.S. Geological Survey, 2014b) and as a companion data release (Senior, 2017).

Methane was the only hydrocarbon with sufficient mass in the Pike County groundwater samples for isotopic carbon and hydrogen determination by Isotech Laboratories, Inc., using a method that involved initial separation of hydrocarbons followed by conversion of methane (CH_4) into carbon dioxide (for carbon isotopic analysis) and water (for hydrogen isotopic analysis) for subsequent mass-spectrometric analysis and comparison to standards (Alan R. Langenfeld, Isotech Laboratories, Inc., written commun., 2012; Senior and Cravotta, 2016). Isotopic ratios for the sample are reported relative to the isotopic ratio of a standard, where the difference (delta or δ) typically is given in parts per thousand (ppt; also denoted as ‰ or per mill) with positive values indicating enrichment of the heavier isotope and negative values indicating depletion of the heavier isotope. Thus, for R = ratio of heavier to lighter isotope, $\delta \text{ (in ‰)} = [R_{sample}/(R_{standard} - 1)] \times (1{,}000)$. The $^{13}C/^{12}C$ carbon isotopic ratio value ($\delta^{13}C$) of methane in a sample is reported in terms of the ‰ notation relative to the Vienna Pee Dee Belemnite (VPDB) standard. The $^{2}H/^{1}H$ hydrogen isotopic ratio value (δD) of methane in a sample is reported in terms of the ‰ notation relative to the Vienna Standard Mean Ocean Water (VSMOW) standard.

The other water-quality constituents have various reporting units. Specific conductance (SC) is reported in temperature-compensated units of microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C). Reporting units for dissolved and total chemical concentrations are milligrams per liter (mg/L) or micrograms per liter (µg/L); 1 mg/L is approximately equal to 1 part per million, and 1 mg/L is approximately equivalent to 1 part per billion. One mg/L equals 1,000 mg/L. Reporting units for bacteria are the most probable number of colonies per 100 milliliters of sample (MPN/100 mL). Reporting units for radioactivity are picocuries per liter (pCi/L), a commonly used unit for radioactivity in water. One picocurie (pCi) equals 10^{-12} Curie or 3.7×10^{-2} atomic disintegrations per second. Activity refers to the number of particles emitted by a radionuclide. The rate of decay is proportional to the number of atoms present and inversely proportional to half-life, which is the amount of time it takes for a radioactive element to decay to one-half its original quantity. In gas samples analyzed by Isotech Laboratories, Inc., dissolved gas values were reported in terms of mole percent in headspace for the water sample, and methane was reported as a dissolved concentration in units of mg/L.

Quality Control and Quality Assurance

For quality control (QC), replicate, blank, and reference samples were submitted to various laboratories. A total of seven intra-laboratory replicate pairs were collected. Two replicate pairs were collected for major ions, minor constituents, radon-222, and gross alpha and beta activity analysis. Three replicate pairs were collected for dissolved gases and isotopic composition of methane. One replicate pair was collected for VOC analysis, and one replicate pair was collected for radium-226 analysis. Replicate samples collected from two wells (PI-524 and PI-592) were submitted to the NWQL, ALS Environmental, and Seewald Laboratories, Inc., for analysis of major ions, minor constituents, radon-222, gross alpha and beta radioactivity, and bacteria. Replicate samples from three wells (PI-524, PI-592, and PI-647) for dissolved gas analysis were submitted to both the Seewald Laboratories, Inc., and Isotech Laboratories, Inc.; replicate samples for analysis of dissolved gases and isotopic composition of methane were submitted to Isotech Laboratories, Inc., only. Additionally, replicate samples from one well (PI-592) were submitted to Seewald Laboratories, Inc., for VOC analysis, and replicates from another well (PI-524) were submitted to ALS Environmental for radium-226 analysis. The QC replicate results are listed in Appendix 2 (table 2–1).

The differences in concentrations between replicate paired samples varied on the basis of analyte group, and the relative magnitude of differences tended to be greatest when concentrations were lowest. The analytes with the largest relative differences in concentrations between the sample (c1) and its replicate (c2), where the relative difference, in percent, is calculated as $100 \times (c1-c2)/[(c1+c2)/2]$, were in samples with low concentrations of these analytes near the laboratory reporting level. Typically, acceptable precision for many analyses is 5 percent. However, small absolute differences in reported concentrations between replicates can result in relative differences greater than 5 percent. For major ions, most relative differences were less than 5 percent. Only one major ion (potassium) replicate pair had a difference (6.76 percent) of more than plus or minus (±) 5 percent, which involved low (less than 0.8 mg/L) potassium concentrations. The difference between concentrations in replicate samples for metals and trace elements generally was less than 5 percent, but relative differences greater than 5 percent (10–30 percent) were apparent for one each of total iron and total zinc concentrations. The larger differences in analytical results for total metals may be related to generally greater uncertainty associated with analysis of unfiltered samples, which is a more complicated process involving chemical digestion than analysis of filtered samples. Differences among replicates for gross alpha and gross beta radioactivity were commonly 10–20 percent, which reflects some intrinsic uncertainty in the analysis, particularly for results near the reporting level of 3 pCi/L. Therefore, no corrective action to the analytical results was needed, but replicate results show that analytical uncertainty may be relatively greater for constituent concentrations near detection limits.

Results of replicate analyses for determination of bacteria show the maximum difference in the number of colonies between replicates was 19 for total coliform for one sample pair (which had results of <1 and 19 MPN/100 mL), but other results of replicate analyses were consistent—no colonies detected. *E. coli* bacteria were not detected in any sample. All replicates had relatively low (<20 MPN/ 100 mL for total coliform bacteria) to undetectable numbers of bacteria (Appendix 2, table 2–1). Differences in replicate results may be partly related to inherent variability in analyses for bacteria, especially at very low levels. Additional uncertainty in results of analyses for bacteria may have been introduced because the holding times (elapsed time from sample collection to sample preparation in the laboratory) exceeded the 6-hour limit used for compliance monitoring (although holding times were usually within the 24-hour limit used for routine monitoring).

Additionally, 18 inter-laboratory replicate samples collected from 17 wells (one well sampled twice) were submitted for dissolved gas (methane, ethane, propane) to two different laboratories, Seewald Laboratories, Inc. and Isotech Laboratories, Inc. that had different reporting levels and specified sample collection in different types of containers. Methane concentrations in replicate samples determined by the two different laboratories differed by as much as a factor of 2.7, with concentrations determined by the Seewald Laboratories, Inc. laboratory generally lower than those determined by the Isotech Laboratories, Inc., suggesting bias related to combined sampling and analytical methods and therefore indicating caution when comparing methane concentrations in well-water samples determined by different methods.

One blank (autoclaved water) was submitted to Seewald Laboratories, Inc., for bacteria analysis, and one equipment blank was submitted to NWQL for analysis of major ions, trace constituents, nutrients, and total organic carbon. No bacteria were detected in the autoclaved water sample sent to Seewald Laboratories, Inc. The equipment blanks were collected at the USGS office in Exton, Pa., by running deionized water (DI) through the flexible tubing and brass hose splitter used in the field for sample purging and collection. The equipment blanks contained no detectable concentrations of any analyzed constituent.

Three standard reference samples were submitted to Seewald Laboratories, Inc., for analysis of major ions and trace constituents. Concentrations determined by Seewald Laboratories, Inc., generally were similar or slightly higher than the reference sample concentrations for most major ions and trace constituents. The differences in concentrations determined by Seewald, Laboratories, Inc., (Cs) relative to the reference sample concentration (Cr) were less than 8 percent [calculated as 100 × (Cs-Cr/Cr)] for most analyzed constituents, less than 5 percent for many analyzed constituents, but greater than 15 percent for bromide and lithium. The relative larger percent differences for lithium and bromide indicate greater uncertainty in Seewald Laboratories, Inc., results for these constituents at concentrations near or less than that laboratory's reporting level of 0.1 mg/L for bromide and 10 µg/L for lithium.

Other QC checks on the accuracy of the data included computation of cation-anion balance, SC, and dissolved solids. These checks largely involve major ion concentrations. Differences in the sum of cation and anion milliequivalents [calculated as 100 × (C – A)/(C + A), in percent, where C is cation milliequivalents and A is anion milliequivalents] of 5 percent or less indicate accurate determination of major ion concentrations. The 2015 Pike County groundwater samples, using alkalinity determined in the laboratory, had cation-anion balances that met this criterion, with the exception of samples from three wells (PI-650, PI-610, and PI-631), which had cation-anion balances of greater than 5 but less than +/- 8 percent (-7.08, +6.68, and +5.61 percent respectively). The sample with the largest cation-anion balance of -7.08 percent was from the well (PI-650) that had the highest TDS of all samples and had relatively high concentrations of lithium, strontium, and bromide that typically are not included in, but can affect, cation-anion balance calculations. On the basis of the cation-anion balance evaluation in a previous study in a similar hydrogeologic setting in nearby Wayne County (Senior and others, 2016), the laboratory alkalinities were determined to be generally more reliable than field alkalinities, and consequently, only laboratory alkalinity values were determined and used in data analysis for the Pike County study in 2015.

The field and laboratory measured values were in good agreement for pH and SC, with a few exceptions. Furthermore, the SC, which is measured with a meter in the field or laboratory, and TDS, which is measured in the laboratory as residue on evaporation (ROE) or computed from measured ion concentrations, were linearly related with strong correlation coefficients. Differences between field SC and laboratory SC were less than 10 percent (calculated as 100*(field-lab)/[0.5 × (field+lab)] for all but three samples from wells PI-650, PI-640, and PI-615 for which differences were 17.9, 11.7, and 11.6 percent, respectively. For these three samples, the field SC was less than the laboratory value, which could result from gas bubbles accumulating on the conductivity electrode during sampling, especially as noted in the field for well PI-650 which had unstable and rising SC measured while purging. The laboratory measured SC values and most of the field SC values were equivalent to the computed SC on the basis of ionic conductivity contributions. Likewise, the measured TDS was equivalent to the computed TDS from the sum of ions (see figures in Appendix 2). These results indicate that field and laboratory measurements were consistent with one another and with the major ion analyses and therefore could be presumed to be accurate.

Reviews of data included comparison of dissolved and total concentrations determined by NWQL and Seewald Laboratories, Inc., respectively, using methods listed in Appendix 1. Except for iron, dissolved and total concentrations of major ions and most trace constituents generally were similar, indicating that these constituents mostly present in dissolved phase and that the two different laboratories provided consistent results. In about 10 percent of the analyses, total concentrations were less than the dissolved concentrations, with total concentrations ranging from 2 to 10 percent smaller than dissolved concentrations for most analyses and constituents and up to 20 to 30 percent smaller for a few cases. Total concentrations were less than dissolved concentrations most frequently for magnesium and lithium determinations. On the basis of other information, including cation-anion balances for dissolved concentrations of major ions, computed and measured sums of dissolved constituents, and reported precisions of analytical methods, the dissolved concentrations are considered more accurate than the total concentrations.

Graphical and Statistical Analyses

Various graphical and statistical techniques were used in this study to compare water-quality data among different sites, to estimate natural and man-made sources of dissolved constituents, and to identify possible factors affecting the presence, concentration, spatial distribution, or transport of solutes in the aquifers in the study area. Scatter plots were created to investigate potential relations among pH, selected constituent concentrations, and the saturation index (SI) values for minerals that may be sources or controls of the constituents. Major ion data were plotted on Piper diagrams (Appelo and Postma, 2005; Back, 1966; Hem, 1985) to illustrate the range of water composition of the samples collected for this study and to investigate possible processes, such as calcite dissolution, cation exchange, and mixing with road deicing salt or brine, that could produce the observed variations in major ions. The Piper diagrams were generated using the Geochemist's Workbench (Bethke and Yeakel, 2010).

In general, nonparametric, rank-based statistical approaches were used to accommodate non-normally distributed and censored data typical of most environmental samples (Helsel and Hirsch, 2002). Data for individual continuous variables, such as chemical concentrations, were censored to a common level, and censored values were set to a common reporting limit of 0.99 times the highest censored value before ranks were computed for use in statistical tests. Values at the highest common reporting level were assigned the minimum rank. Relations between continuous variables were evaluated with scatter plots and correlation coefficients (Spearman's rho); distributions of continuous variables were compared among different sample classifications using notched boxplots (Velleman and Hoaglin, 1981; Helsel and Hirsch, 2002). Statistically significant (p less than or equal to 0.001) Spearman's correlation coefficients are presented in Appendix 3, table 3–1.

Notched boxplots shown in Appendix 3 were constructed with P-STAT (P-STAT, Inc., 2008) to compare concentrations of major ions, trace elements, and other water-quality variables among different subsets of the 2015 data in relation to pH, specific conductance, redox variables, or aquifer geology. The pH classes considered in this report are (1) acidic, pH 5.4 to 6.4; (2) neutral, pH 6.5 to 7.4; (3) alkaline, pH 7.5 to 7.9; and (4) very alkaline, pH 8.0 to 9.4. The SC classes are (1) 40 to 130 µS/cm at 25 °C; (2) 130 to 210 µS/cm at 25 °C; (3) 210 to 400 µS/cm at 25 °C; and (4) 400 to 1,600 µS/cm at 25 °C. For the pH and SC classifications, the middle two groups represent approximately 60 and 75 percent of the data values, respectively. The redox classifications used in this report were based on concentration thresholds of McMahon and Chapelle (2008) but were simplified to consider only three major classes: (1) anoxic (DO $\leq$ 0.5 mg/L), (2) mixed (DO > 0.5 mg/L and either manganese $\geq$ 50 µg/L or iron $\geq$ 100 µg/L), and (3) oxic (DO > 0.5 mg/L, manganese < 50 µg/L, and iron < 100 µg/L). Where the median for a group is greater than the common reporting limit, it is displayed as a horizontal line within the box that is defined by the 25th and 75th percentiles for that group; otherwise, the median is displayed at the reporting limit. If the notched intervals around the medians for sample subsets in boxplots do not overlap, the medians are statistically different at the 95-percent confidence interval.

Principal components analysis (PCA), computed with SAS 9.2 (SAS Institute, Inc., 2012), was used to evaluate multivariate correlations among the dissolved concentrations of elements in the regional groundwater dataset without prior classification. The goal was to identify important hydrochemical processes or master variables that could explain element associations and distributions (Joreskog and others, 1976; Drever, 1997; Thyne and others, 2004). The Spearman-rank correlation coefficient matrix for the groundwater dataset provided the standardized input for the PCA. Because the PCA model would exclude the entire record for any sample with a missing value, those constituents that were missing or those that were censored in more than 40 percent of the samples were excluded, including dissolved fluoride and some trace constituents. The PCA model was optimized with varimax rotation to maximize the differences among the principal components; only principal components with eigenvalues greater than unity, equivalent to correlations with a probability greater than or equal to 0.999, were retained (Joreskog and others, 1976; Thyne and others, 2004). Loadings for each constituent included in the PCA model are equivalent to the Spearman-rank correlation coefficient between that constituent and the principal component. To aid in interpretations, the scores for each principal component in the PCA model were evaluated by correlation or graphical analysis with additional variables that had been excluded from the PCA, including lithology, land use, well depth, and chemical constituents. For simplification of displayed results, the loading values and Spearman-rank correlation coefficient values were multiplied by 100 and rounded. Significant correlation coefficients for the additional variables are displayed beneath the main PCA model results; only correlation coefficients with a probability greater than or equal to 0.999 are considered significant.

Geochemical Modeling

Aqueous speciation computations were conducted using the computer program PHREEQC (Appelo and Postma, 2005; Parkhurst and Appelo, 2013) with the WATEQ4F thermodynamic database (Ball and Nordstrom, 1991). The molal concentrations of aqueous species were used to estimate the ionic contributions to specific conductance (McCleskey and others, 2012). The mineral SI values for various major and trace minerals were used to indicate the potential for mineral dissolution and precipitation. If a mineral phase is undersaturated in groundwater (SI less than 0), that mineral phase (if present) has the potential to be dissolved by the groundwater. In contrast, if a mineral is supersaturated in groundwater (SI greater than 0), that mineral phase will not dissolve (if present), feasibly could precipitate, and thus limit dissolved concentrations and mobility of the component constituent.

Baseline Groundwater Quality in Pike County

The 2015 groundwater-quality assessment is intended to provide current data on the occurrence and concentrations of methane and a suite of inorganic constituents in groundwater in bedrock aquifers prior to potential shale-gas development in Pike County. Many of the inorganic constituents selected for analysis may be present in elevated concentrations in naturally occurring brines and in flowback and produced waters associated with unconventional shale-gas development (table 1) and, therefore, are part of the PADEP pre-drill list of constituents recommended for assessment (table 2). However, these same constituents commonly also are present at low to moderate concentrations in shallow, fresh (non-saline) groundwater, as has been shown for previous studies in Pike County and other areas of northeastern Pennsylvania (Senior, 2014; Sloto, 2013; Sloto, 2014; Senior and others, 2016). Additionally, some of the inorganic constituents included in groundwater analyses for this study can be introduced by human activities not directly related to shale-gas production, such as use of road salt or onsite wastewater disposal. In this report, the term “brine-related” refers to inorganic constituents present at high concentrations in brines; these constituents also may be present in low concentrations in freshwater as a result of mineral dissolution or possible mixing with small amounts of naturally-occurring brine or connate waters in the aquifer.

Sources of and Geochemical Controls on Selected Constituents in Groundwater

Dissolved constituents in groundwater may be derived from atmospheric, geologic, biologic, and man-made sources because the recharge and groundwater interact with various materials along transport pathways. Solute concentrations can range widely depending on the presence of constituents in the source(s); the extent of contact between water and the source; the aqueous solubility and interactions among the dissolved constituents and geochemical conditions, such as pH and oxidation-reduction (redox) state, that affect constituent form, mobility, and transport in the aqueous environment.

Major ions typically are derived by the dissolution of common minerals, including carbonates, silicates, oxides, sulfates, and sulfides, and their concentrations can be affected by ion exchange, redox processes, and mixing of freshwater with residual brines that remain in the aquifer matrix or that could be mobilized from deep sources. The concentrations of major ions, TDS, salinity, and SC of groundwater are directly related and generally expected to increase with progressive evaporation or mineral weathering (Hem, 1985). The concentrations of trace elements in solution may increase with TDS or SC, not only because of the release of trace constituents with the major ions dissolved from minerals, but also because of the potential for increased displacement of adsorbed or exchangeable trace ions from mineral surfaces.

Major cations (positively charged ions such as calcium, magnesium, sodium, and potassium), major anions (negatively charged ions such as sulfate, chloride, fluoride, and bicarbonate), and nonionic solutes (uncharged solutes such as silica) typically are present in natural waters at concentrations greater than 1 mg/L, whereas dissolved trace elements (such as iron, manganese, zinc, lead, copper, nickel, vanadium, molybdenum, arsenic, selenium, radium, uranium, lithium, bromide) typically are present at concentrations less than 1 mg/L (Hem, 1985). Concentrations of DO range from less than 1 mg/L in geochemical environments where oxygen has been consumed by oxidation of organic compounds or minerals to as high as 12 mg/L at 7.5 °C (saturation concentration is 11.9 mg/L at 1 atmosphere of pressure and 7.7 °C, the minimum measured groundwater temperature during 2015 sampling in Pike County) in freshly recharged or organic-poor groundwater. Concentrations of nutrients (such as nitrogen and phosphorus compounds) typically range from less than 1 mg/L in most natural settings to greater than 1 mg/L because of man-made inputs. Although biological (biochemical) processes can affect the concentrations of nutrients and trace constituents in groundwater directly or indirectly because of changes to pH and redox, such processes generally have minor effects on major ion concentrations (except sulfate).

Elevated concentrations of major and trace constituents in groundwater tend to be present locally or are associated with specific geochemical aquifer settings, particularly under (1) acidic (low pH) or basic (high pH) conditions where the solubilities and mobilities of many element species are increased (Langmuir, 1997), (2) reducing conditions where the dissolution of iron and manganese oxides can release adsorbed and coprecipitated metals (Langmuir, 1997; McMahon and Chapelle, 2008), or (3) conditions where residual brines may mix with freshwaters (Whittemore, 2007; Haluszczak and others, 2013). Although the release of both major ions and trace elements through mineral weathering is a natural process, accelerated mineral decomposition that accompanies the development of strongly acidic or reducing conditions could be a consequence of human activities, including the infiltration of organic wastes (septic systems), compounds related to industrial activities, fertilization, road salt for deicing purposes, or other land applications. Thus, to be able to determine constituent concentrations that may have been added to groundwater as a consequence of land-use or waste-disposal practices, natural background concentrations for specific geologic or environmental settings need to be established.

In order to identify geochemical environments where elevated concentrations of constituents may be present, water-quality conditions, such as pH and redox state, and major ion composition, need to be characterized. For example, some trace elements and metals may be more soluble in acidic waters (such as copper and lead), whereas others may be more soluble in basic waters (such as arsenic as arsenate, and phosphorus as phosphate). Relative solubilities and the tendency of selected trace elements and metals (as commonly occurring ions) to adsorb onto or desorb from iron oxides in relation to pH are shown in a similar report on baseline groundwater quality in nearby Wayne County (Senior and others, 2016), which can be used to explain the presence of these constituents in similar aquifer settings such as that in Pike County.

Pike County Groundwater Quality and Its Relation to Drinking-Water Standards

Because groundwater is the main source of drinking water in Pike County, assessment of groundwater quality relative to drinking-water standards is important. Naturally occurring constituents and constituents introduced by human activities may pose a risk to human health when present at certain concentrations in groundwater used for drinking-water supply. The U.S. Environmental Protections Agency (EPA) has established maximum contaminant levels (MCLs) for many constituents in drinking water to protect human health (U.S. Environmental Protection Agency, 2012). These MCLs, also known as primary drinking-water standards, may be used as a guideline for private well owners but are mandatory for public drinking-water supplies. Other EPA non-regulatory drinking-water guidelines include Health Advisory (HA) and secondary maximum contaminant levels (SMCLs). The HAs are listed by EPA for selected constituents that have no MCL or, in some cases, in addition to the MCL. SMCLs are listed for selected constituents that pose no known health risk but may have adverse aesthetic effects, such as staining or undesirable taste or odor (U.S. Environmental Protection Agency, 2012).

The concentrations of chemical constituents in the 2015 Pike County well-water samples were compared to established criteria for protection of human health, including the EPA MCLs and HAs (U.S. Environmental Protection Agency, 2012), additional health-based screening levels (HBSLs) defined by USGS (Toccalino and others, 2007; 2014), and to the non-health based SMCLs. Because water quality at a given location will vary temporally owing to natural hydrologic processes and seasonality, the assessment of water quality relative to established standards on the basis of samples collected only once from each well is limited to conditions at that time.

Overall, the quality of the groundwater sampled in Pike County in 2015 was generally within EPA drinking-water standards established for selected constituents. However, in some samples, the concentrations of certain constituents exceeded drinking-water standards (primary or secondary) and HAs (U.S. Environmental Protection Agency, 2012) indicating the water may not be suitable for drinking without treatment. Complete results for the 79 water samples are given in a USGS data release (Senior, 2017), and results for inorganic analyses are listed in table 13 at the back of the report. Summary statistics for results are discussed in the following sections from “General Characteristics” through “Man-Made Organic Compounds” and “Methane and Other Dissolved Hydrocarbon Gases”. The median and range of values for the water-quality characteristics measured in the 79 groundwater samples collected in 2015 are very similar to those determined for the 20 samples collected in 2012 (Senior, 2014). Furthermore, differences in constituent values for samples collected in 2012 and 2015 at a given site (as discussed in the section “Temporal Variability;” table 11 at back of report) were small compared to differences among sites (spatial variability), which supports the 2015 approach that considered one sample per site as representative of that site.

General Characteristics

Water quality often is characterized in terms of general chemical characteristics, such as pH, conductivity, or hardness, and physical characteristics, such as temperature. Additional characteristics that describe the water quality in relation to drinking water or other uses also may be reported. Some of these characteristics, such as pH, DO, and temperature, change after sample collection and, being unstable, typically are measured in the field at the time of sample collection. Summary statistics for chemical and physical properties measured in the field, in addition to measures of general water quality, are listed in table 4.

Table 4. Minimum, median, and maximum of well characteristics, chemical and physical properties measured in the field, and concentrations of total dissolved solids, major ions, nutrients, total organic carbon, and bacteria determined in the laboratory for groundwater samples collected from 79 wells in Pike County, Pennsylvania, J2015.

[MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum contaminant level; °C, degrees Celsius; µS/cm, microSiemens per centimeter at 25 degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L, milligrams per liter; µg/L, micrograms per liter; SiO_2, silica; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; MPN/100 mL, most probable number of colonies per 100 milliliters; --, no data or not applicable; <, less than; > greater than]

Well characteristics, sample properties and constituents	Unit	Number (percent) greater than reporting level	Minimim	Median	Maximum	Number (percent) exceeding standard	Drinking-water standard[1]		
							MCL	HA	SMCL
Well characteristics									
Well depth	feet	[*]74	80	262	610	--	--	--	--
Field properties									
Water temperature	°C	79 (100)	7.7	11	13.9	--	--	--	--
Dissolved oxygen	mg/L	78 (99)	<0.1	1.09	10.4	--	--	--	--
Specific conductance, field	µS/cm	79 (100)	47	195	1,323	--	--	--	--
pH, field	pH units	79 (100)	5.5	7.2	9.2	[a]24 (31)	6.5–8.5	--	--
Laboratory analyses[2,3]									
Specific conductance, laboratory	µS/cm	79 (100)	45	205	1,582	--	--	--	--
Total dissolved solids	mg/L	79 (100)	28	121	939	2 (3)	--	--	[b]500
Suspended solids	mg/L	27 (34)	<5	<5	161	--	--	--	--
Hardness, total	mg/L as $CaCO_3$	79 (100)	14	70.9	392	--	--	--	[c]--
Major ions (dissolved and total)									
Calcium, dissolved	mg/L	79 (100)	3.67	17.4	103.1	--	--	--	--
Calcium, total	mg/L	79 (100)	3.63	17.2	106.0				
Magnesium, dissolved	mg/L	79 (100)	0.81	5.31	32.17	--	--	--	--
Magnesium, total	mg/L	79 (100)	0.83	5.23	33.5	--	--	--	--
Sodium, dissolved	mg/L	79 (100)	1.37	9.69	283	[d]15 (19)	--	[e]20	--
Sodium, total	mg/L	78 (99)	1.3	9.5	284	[d]14 (18)	--	[e]20	--
Potassium, dissolved	mg/L	79 (100)	0.19	0.59	1.77	--	--	--	--
Potassium, total	mg/L	79 (100)	0.25	0.62	1.79	--	--	--	--
Alkalinity (dissolved)	mg/L as $CaCO_3$	79 (100)	9.79	72.2	139.7	--	--	--	--
Bromide, dissolved	µg/L	70 (89)	<10	19	2,100	--	--	--	--
Bromide, total	mg/L	5 (6)	<0.10	<0.10	1.55	--	--	--	--
Chloride, dissolved	mg/L	79 (100)	0.47	8.17	246	0 (0)	--	--	[b]250
Chloride, total	mg/L	66 (84)	<1	8.7	252	1 (1)	--	--	[b]250
Fluoride, dissolved	mg/L	79 (100)	0.023	0.09	0.964	0 (0)	4	--	2

Table 4. Minimum, median, and maximum of well characteristics, chemical and physical properties measured in the field, and concentrations of total dissolved solids, major ions, nutrients, total organic carbon, and bacteria determined in the laboratory for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.—Continued

[MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum contaminant level; °C, degrees Celsius; µS/cm, microSiemens per centimeter at 25 degrees Celsius; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate; mg/L, milligrams per liter; µg/L, micrograms per liter; SiO_2, silica; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; MPN/100 mL, most probable number of colonies per 100 milliliters; --, no data or not applicable; <, less than; > greater than]

Well characteristics, sample properties and constituents	Unit	Number (percent) greater than reporting level	Minimim	Median	Maximum	Number (percent) exceeding standard	Drinking-water standard[1]		
							MCL	HA	SMCL
Sulfate, dissolved	mg/L	79 (100)	0.39	8.43	362	1 (1)	--	500	250
Sulfate, total	mg/L	75 (95)	<1	8.7	322	1 (1)	--	500	250
Silica, dissolved	mg/L as SiO_2	79 (100)	4.00	10.25	17.2	--	--	--	--
Nutrients (dissolved)									
Ammonia, dissolved	mg/L as N	32 (41)	<0.01	<0.01	0.625	0 (0)	--	30	--
Nitrite, dissolved	mg/L as N	3 (4)	<0.001	<0.001	0.019	0 (0)	1	--	--
Nitrate + nitrite, dissolved[4]	mg/L as N	38 (48)	<0.04	<0.04	1.91	0 (0)	10	--	--
Orthophosphate, dissolved	mg/L as P	76 (96)	<0.004	0.018	0.174	--	--	--	--
Total organic carbon	mg/L	0 (0)	<0.7	<0.7	<0.7	--	--	--	--
Bacteria (total)									
Total coliform	MPN/100 mL	25 (32)	<1	<1	1,990	25 (32)	<1	--	--
Escheria coli	MPN/100 mL	0 (0)	<1	<1	<1	0 (0)	0	--	--

[1] U.S.Environmental Protection Agency (2012).

[2] Laboratory analysis for dissolved concentrations in filtered samples done by U.S. Geological Survey National Water Quality Laboratory (NWQL).

[3] Laboratory analysis for total concentrations in unfiltered samples done by contract laboratories using drinking-water methods (see Appendix 2).

[4] Because nitrite concentrations are low, nitrate is nearly equivalent to nitrate plus nitrite.

[a] pH was less than 6.5 in 16 samples (20 percent) and greater than 8.5 in 8 samples (10 percent).

[b] Same standard established by Pennsylvania Department of Environmental Protection in 2010 for flowback discharge to streams (Pennsylvania Department of Environmental Protection, 025 Pa. Code § 95.10).

[c] No drinking-watering standard but water characterized as: soft, 0-60 mg/L in 29 samples (37 percent); moderately hard, 61–120 mg/L in 43 samples (54 percent); hard, 121–180 mg/L in 4 samples (5 percent); and very hard, >180 mg/L in 3 samples (4 percent).

[d] Concentrations exceeded drinking water health-based advisory of 20 mg/L in 15 samples for dissolved sodium and in 14 samples for total sodium, and upper threshold for the drinking water advisory range of 30-60 mg/L in 2 samples for both dissolved and total sodium.

[e] EPA levels for sodium are a health-based drinking water advisory of 20 mg/L for individuals on a sodium-restricted diet and taste-based drinking water advisory of 30-60 mg/L.

[*] Data on depths available for 74 wells.

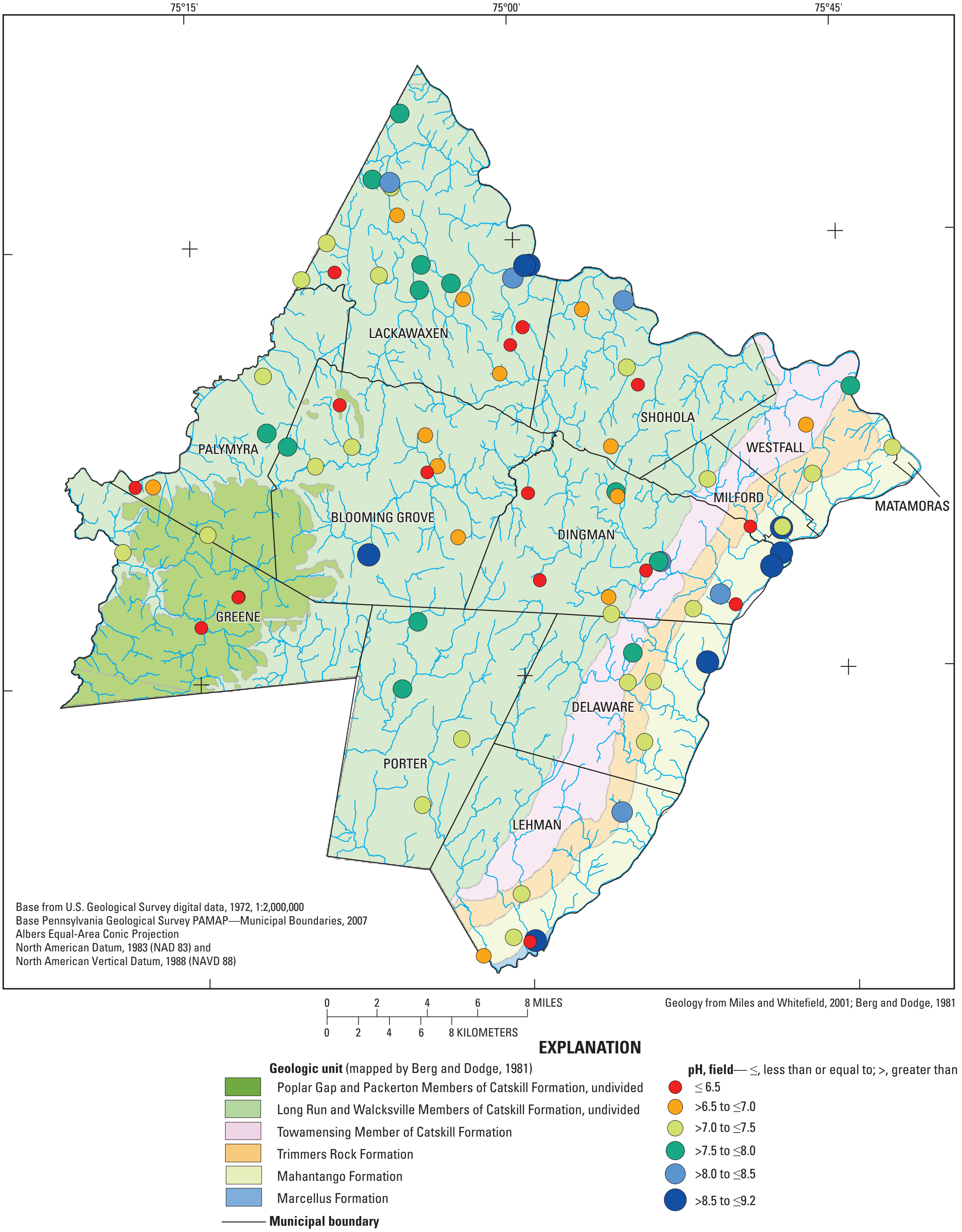
Field and laboratory measurements of pH, Alkalinity, Specific Conductance, and Dissolved Oxygen

Of the physical and chemical properties measured in the field (pH, DO, SC, temperature), drinking-water standards have been established only for pH, and results show that some samples have pH values that do not meet the SMCL range of 6.5–8.5 (table 4). pH is a measurement of the activity of hydrogen ions in water and is expressed in logarithmic units with a pH of 7 considered neutral. Water with a pH less than 7 is acidic; water with a pH greater than 7 is basic (or alkaline). The pH of groundwater samples collected from 79 wells in Pike County ranged from 5.5 to 9.2; the median pH was 7.2 (table 4). The pH of 24 of 79 samples (30 percent) was outside the EPA SMCL range of 6.5–8.5 (U.S. Environmental Protection Agency, 2012). Sixteen of 79 samples (20 percent) had a pH less than 6.5, and 8 of 79 samples (10 percent) had a pH greater than 8.5 (table 4). Water with pH less than 6.5 tends to be corrosive and has potential to leach metals, such as lead and copper, from plumbing. The spatial distribution of pH values in Pike County groundwater is shown in figure 6.

Alkalinity of a solution is a measure of the capacity for the solutes contained in the solution to react with and neutralize acid and typically consists largely of carbonate and bicarbonate ions (Hem, 1985, p. 106). Alkalinity is related to the pH of a water sample. In general, water samples with a higher pH have a higher alkalinity (fig. 7*A*). Alkalinity ranged from about 10 to 140 mg/L as calcium carbonate ($CaCO_3$); the median alkalinity was 72.2 mg/L as $CaCO_3$ (table 4).

Specific conductance is a measurement of the ability of water to conduct an electric current. Specific conductance measured in the field ranged from 47 to 1,320 µS/cm at 25 °C with a median specific conductance of 195 µS/cm at 25 °C (table 4). Evaluation of field and laboratory specific conductance indicates values generally agree within 10 percent but that the laboratory values are more accurate than field values and in better agreement with computed conductance on the basis of the ionic contributions (Appendix 1, fig. 1–1). Field notes made during sampling of the well (PI-650) with the highest field SC (1,320 µS/cm at 25 °C) indicate SC was unstable and rising during purging. The maximum laboratory specific conductance value of 1,580 µS/cm at 25 °C (table 4) was measured in the PI-650 well-water sample. Specific conductance measured in the 79 water samples is linearly related to the TDS concentration, a measure of dissolved ionic concentrations (about $r^2 = 0.99$) (fig. 8). Specific conductance (and TDS) tended to increase as pH increased in the Pike County groundwater samples (fig. 7*B*), relations that indicate that pH increases as mineral dissolution (and other weathering) increases in groundwater.

Concentrations of DO ranged from less than 0.1 to 10.4 mg/L; the median concentration was 1.09 mg/L (table 4). The DO concentration was low, less than 0.5 mg/L, in groundwater samples from 33 of 79 wells (about 42 percent) (table 13; Senior, 2017), which indicates suboxic to anoxic redox conditions in the aquifer (McMahon and Chapelle, 2008). Low DO concentrations are related to chemical or biochemical reactions that consume oxygen and may result in reducing conditions that promote the release of some metals. The chemical reactions that consume oxygen can be naturally occurring in soil or aquifer materials and are commonly associated with microbial activity or oxidation of organic carbon (from natural or man-made sources) and certain minerals such as pyrite. In the groundwater samples collected in Pike County, DO concentrations tended to decrease with increasing pH; DO concentrations generally were highest in acidic (pH less than 6.5) water and lowest (less than 0.5 mg/L) in alkaline water (pH greater than 7.8) (fig. 7*C*). These relations indicate that consumption of oxygen progresses with mineral weathering along groundwater flow paths, which are out of contact with air (source of oxygen). High DO concentrations in well-water samples most likely are associated with recently recharged groundwater, unless affected by aeration during pumping or cascading water from shallow water-bearing zones in boreholes.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Base Pennsylvania Geological Survey PAMAP—Municipal Boundaries, 2007
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

Figure 6. Geological units and spatial distribution of pH in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

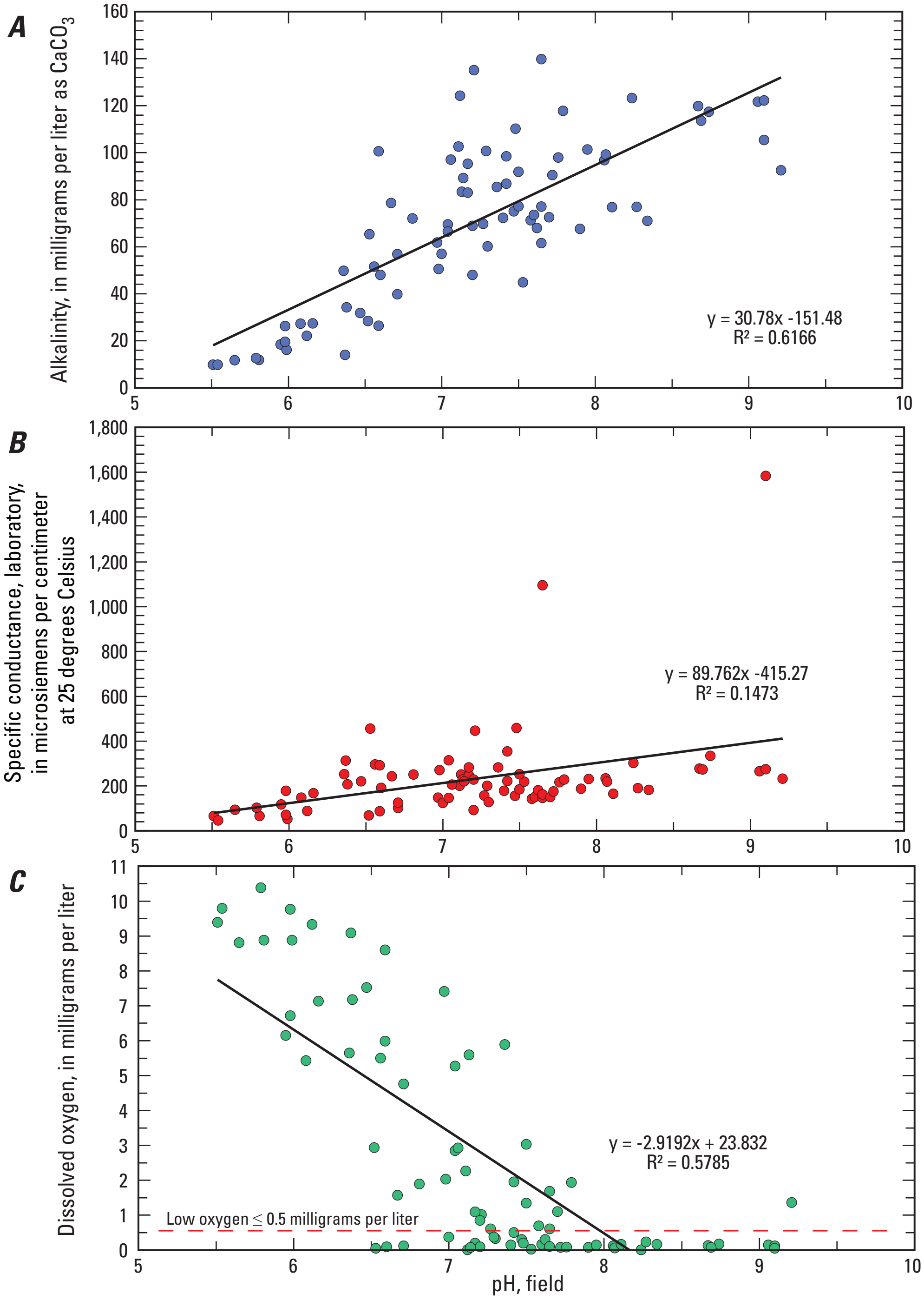


Figure 7. Relation of field measured pH to *A*, laboratory determined alkalinity, *B*, laboratory measured specific conductance, and *C*, field measured dissolved oxygen concentrations in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [$CaCO_3$, calcium carbonate]

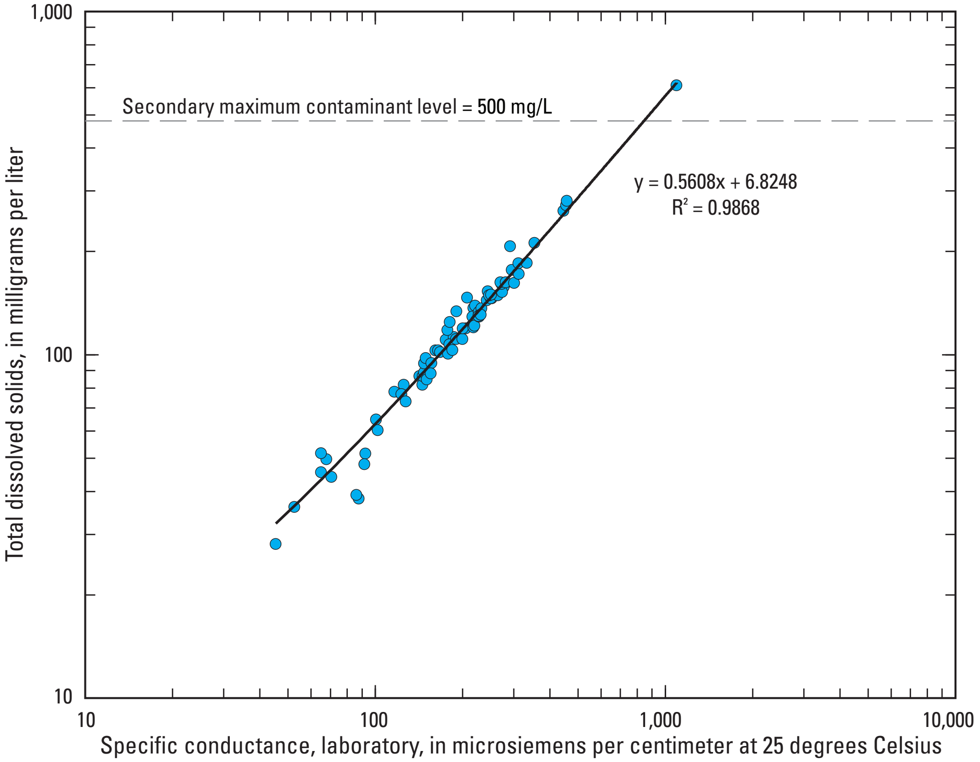


Figure 8. Relation of laboratory measured specific conductance to concentrations of total dissolved solids in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [SMCL, secondary maximum contaminant level; mg/L, milligrams per liter]

Total Dissolved Solids, Hardness, and Corrosivity

Concentrations of TDS in the groundwater samples from 79 wells ranged from 28 to 939 mg/L; 2 samples had TDS concentrations greater than the SMCL of 500 mg/L (table 4). TDS concentrations often are used as a measure of salinity. Freshwater typically is defined as having TDS concentrations less than 1,000 mg/L and saline water as having TDS concentrations greater than 1,000 mg/L. In a regional study of the presence of saline water in the United States, depth to saline water (TDS greater than 1,000 mg/L) was estimated to be greater than or equal to 1,000 ft in northeastern Pennsylvania in the vicinity of Pike County (Feth and others, 1965). On the basis of geophysical logs in similar hydrogeologic settings in Pike, Wayne, and Monroe Counties, the depth of freshwater circulation was estimated to be greater than 800 ft below land surface in Monroe County, which is south of, and adjacent to, Pike County (Carswell and Lloyd, 1979). Saltwater or brine was reported to be present at a depth of about 1,040 ft in a 1,842 ft oil and gas test hole drilled in eastern Pike County near Matamoras (Lohman, 1937). Results from the 2015 sampling of the 79 wells with depths of as much as 610 ft are consistent with these estimates of depth to saline water.

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 the potential for mineral deposits to accumulate and form scale in plumbing (pipes, sinks, showers) and on cooking utensils. Hardness of the water samples from 79 wells ranged from 14 to 392 mg/L as $CaCO_3$ with a median value of 70.9 mg/L as $CaCO_3$ (table 4) Using a common hardness classification (Dufor and Becker, 1964), the measured values (sum of dissolved calcium and magnesium concentrations) indicate that groundwater samples from 29 (37 percent) of the 79 wells were soft (less than 60 mg/L as $CaCO_3$), 43 samples (54 percent) were moderately hard (61 to 120 mg/L as $CaCO_3$), 4 samples (5 percent) were hard (121 to 180 mg/L as $CaCO_3$), and 3 samples (4 percent were very hard (greater than 180 mg/L as $CaCO_3$) (table 13; Senior, 2017). Hardness varied with pH; hardness generally was greatest at intermediate pH values (6.5 to 7.8) (fig. 9*A*). Groundwater samples with low pH (less than 6.5) or high pH (greater than 7.8) typically had hardness less than 60 mg/L as $CaCO_3$ and were soft. There are no health-related standards established specifically for hardness in drinking water.

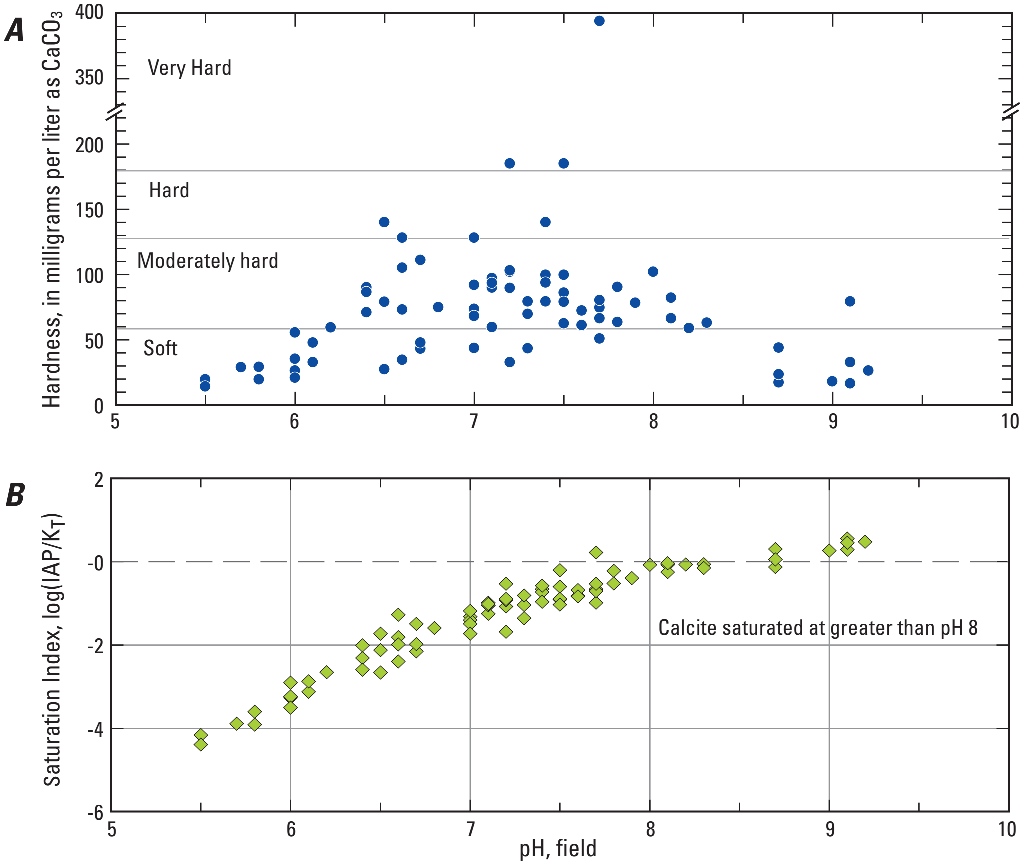


Figure 9. Relation of field measured pH to *A*, hardness, and *B*, corrosivity, as measured by calcite saturation index, in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [IAP, ion activity product; KT, solubility product (thermodynamic equilibrium constant); $CaCO_3$, calcium carbonate]

Water-resources engineers commonly identify the corrosion and encrustation potential of water on the basis of the Langelier Index (LI), which provides an indication of the potential for lead and copper to enter water supplies from pipes and plumbing (Snoeyink and Jenkins, 1981). The LI, which is the difference between the measured pH and the pH at equilibrium with calcite ($CaCO_3$), is equal in value to the calcite saturation index (SICAL), computed as the log of ion activity product divided by solubility product [log(IAP/K_T)] and discussed in more detail in section “Geochemical Modeling.” If the LI or SICAL is positive, the pH is greater than that at equilibrium with $CaCO_3$, and the water will tend to deposit a $CaCO_3$ coating or scale that can insulate pipes, boilers, and other components of a system from contact with water; however, if the LI is negative, the water is undersaturated with $CaCO_3$ and will tend to be corrosive in the distribution system, with decreasing negative values, indicating greater potential for corrosion. The optimum value for the LI or SICAL is close to zero, at which the water will be neither strongly corrosive nor scale forming. For the Pike County groundwater samples, SICAL ranged from -4.4 to 0.56, generally increasing with pH to a pH of about 8 (fig. 9*B*). Of the water samples collected from 79 wells in 2015, 40 (51 percent) had LI values that were less than -1, indicating potentially strongly corrosive characteristics with potential to leach lead, copper, and other metals from pipes and plumbing that may contain the metallic components. The most corrosive samples typically were acidic with pH less than 6.5 (and most were soft, fig. 9*A*). The remaining samples are considered neither strongly corrosive nor scale forming.

Major and Minor Ions

Sources of major and minor ions include atmospheric precipitation, mineral dissolution, and compounds introduced or associated with land-use practices, such as use of deicing salts on roads, on-site wastewater disposal (septic systems), and agricultural application of lime or fertilizers on fields. The major ions consist of positively charged cations (calcium, magnesium, sodium, and potassium) balanced by negatively charged anions (bicarbonate, chloride, sulfate). Silica is a major constituent that commonly occurs as an uncharged ion. Nitrate, discussed in the section “Nutrients,” is an anion that sometimes is present in large enough concentrations to be considered a major ion; nitrite rarely is present in concentrations greater than 1 mg/L in groundwater. Ammonia, a nitrogen compound that commonly occurs in groundwater as the cation ammonium, occasionally may be present in large enough concentrations to be considered a major ion.

Drinking-water standards have been established for only a few major ions and, except for two nitrogen compounds (nitrate and nitrite), are typically either a SMCL or HA, both of which are recommended rather than required standards. Drinking-water standards for the major ions include SMCLs for chloride and sulfate, and HAs for sodium and sulfate (table 4). Fluoride and bromide are minor anions typically present in concentrations of less than 1 mg/L in Pike County groundwater. Of these minor ions, only fluoride has an established MCL in drinking water.

The summary statistics for concentrations of major and minor ions listed in table 4 show that only sodium, chloride, and sulfate are present in concentrations greater than a HA or SMCL in a few of the 2015 Pike County groundwater samples. Dissolved sodium concentrations were greater than the HA level of 20 mg/L for individuals on a sodium-restricted diet in samples from 15 of 79 wells (19 percent) and were greater than the EPA (2012) upper drinking-water advisory limit of 60 mg/L in samples from 2 wells (PI-592, PI-650) (3 percent). These exceedances for sodium relative to the HA and SMCL were similar to those found in the 2012 study (Senior, 2014). The spatial distribution of dissolved sodium concentrations in Pike County groundwater in 2015 is shown in figure 10. In two of the wells that had sodium concentrations greater than the HA of 20 mg/L, either the chloride or the sulfate concentration also exceeded the SMCLs for those constituents. Chloride concentrations were near (246 mg/L, dissolved) or greater than (252 mg/L, total) the SMCL of 250 mg/L in the water sample from one well (PI-653). Sulfate concentrations were greater than (362 and 322 mg/L, dissolved and total, respectively) the SMCL of 250 mg/L in the water sample from well (PI-650), one of the two wells with elevated sodium concentrations. The highest chloride concentrations were in samples collected from wells in eastern Pike County (fig. 11).

Small (less than 5 percent) to no differences between dissolved and total concentrations of major and minor ions were apparent for most samples (tables 4 and 13; Senior, 2017), indicating these constituents predominantly are present in the dissolved phase in the groundwater samples. Additionally, the results of analyses for dissolved and total concentrations indicate that the quality of filtered and unfiltered water has a similar relation to drinking-water standards for these constituents.

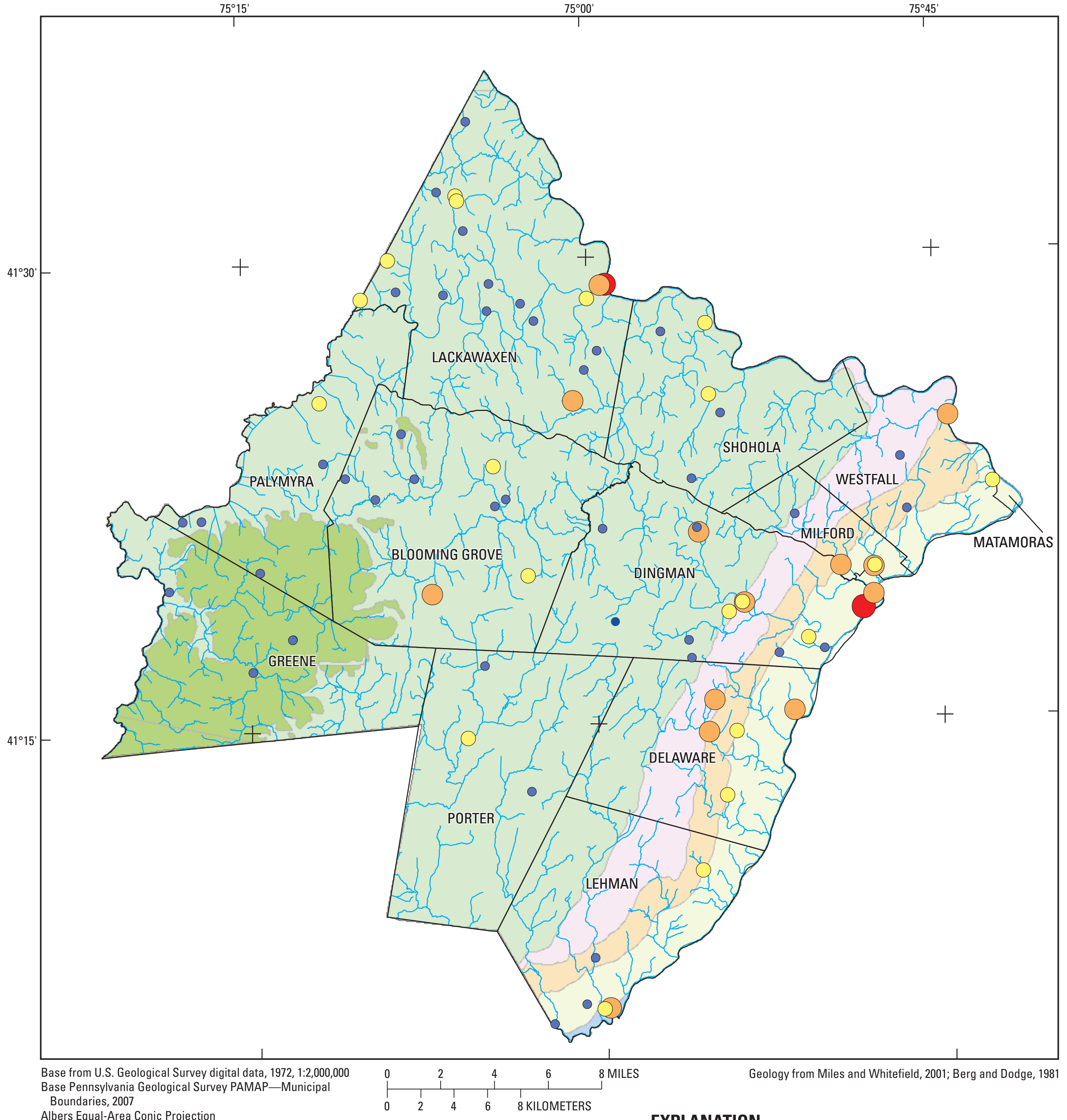
Nutrients

The nutrients nitrogen (N) and phosphorus (P) most commonly are present in groundwater in the dissolved phase. Sources of nitrogen include atmospheric precipitation, decomposing organic matter (leaves and other vegetation), fertilizers, animal wastes, and septic systems; the latter three sources potentially contribute greater amounts to groundwater than precipitation, depending on land use in recharge area. Nitrogen may be present in various forms, depending on origin and geochemical environment. Ammonia and nitrite tend to be present in reducing or suboxic environments (oxygen concentrations typically less than 0.5 mg/L), and nitrate tends to be present in oxidizing environments (oxygen concentrations typically greater than 0.5 mg/L). Sources of phosphorus include mineral dissolution, fertilizers, animal wastes, and septic systems. Orthophosphate is a common sparingly soluble form of phosphorus, which is the predominant form in water, minerals (apatite), bones, and teeth.

Ammonia and nitrite were detected in about 41 percent and 4 percent of the samples, respectively, at relatively low concentrations that met respective drinking-water standards (table 4). Nitrate was detected in 48 percent of the samples at relatively low concentrations that ranged up to about 1.9 mg/L as N and was less than the MCL of 10 mg/L as N in all samples. Orthophosphate was detected in 96 percent of the samples, with concentrations ranging up to 0.174 mg/L as P and greater than or equal to 0.02 mg/L as P in 33 samples (about 42 percent). Concentrations of orthophosphate greater than 0.01 to 0.02 mg/L in streams in glaciated northeastern Pennsylvania may represent slight enrichment relative to reference conditions (U.S. Environmental Protection Agency, 2001) but not always. Denver and others (2010) report groundwater discharged to streams (as base flow) from forested settings that were underlain by crystalline bedrock aquifers contained orthophosphate concentrations greater than 0.02 mg/L as P. Sources of elevated orthophosphate in the Pike County groundwater samples have not been identified but could include dissolution of apatite or other phosphorus-bearing minerals, such as impure feldspars (Denver and others, 2010), in addition to human-related phosphorus from wastewater disposal and fertilizers.

Bacteria

Total coliform bacteria were detected in groundwater samples from 25 of 79 (32 percent) wells (table 4) with concentrations ranging from less than 1 MPN/100 mL to 1,990 MPN/100 mL. The presence of total coliform does not necessarily indicate pathogenic bacteria, but does indicate potential pathways from the surface or near surface to groundwater. Guidelines for evaluation of health risks associated with bacteria state that analysis for bacteria of fecal origin, such as *E. coli*, should be done if total coliform bacteria are detected (U.S. Environmental Protection Agency, 2012). Of the 25 groundwater samples that had total coliform bacteria, no samples had detectable *E. coli*. Possible sources of *E. coli* include on-site wastewater disposal (septic system, sand mound) or other infiltration of surface waters containing fecal matter.



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Base Pennsylvania Geological Survey PAMAP—Municipal Boundaries, 2007
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

EXPLANATION

Geologic unit (mapped by Berg and Dodge, 1981)

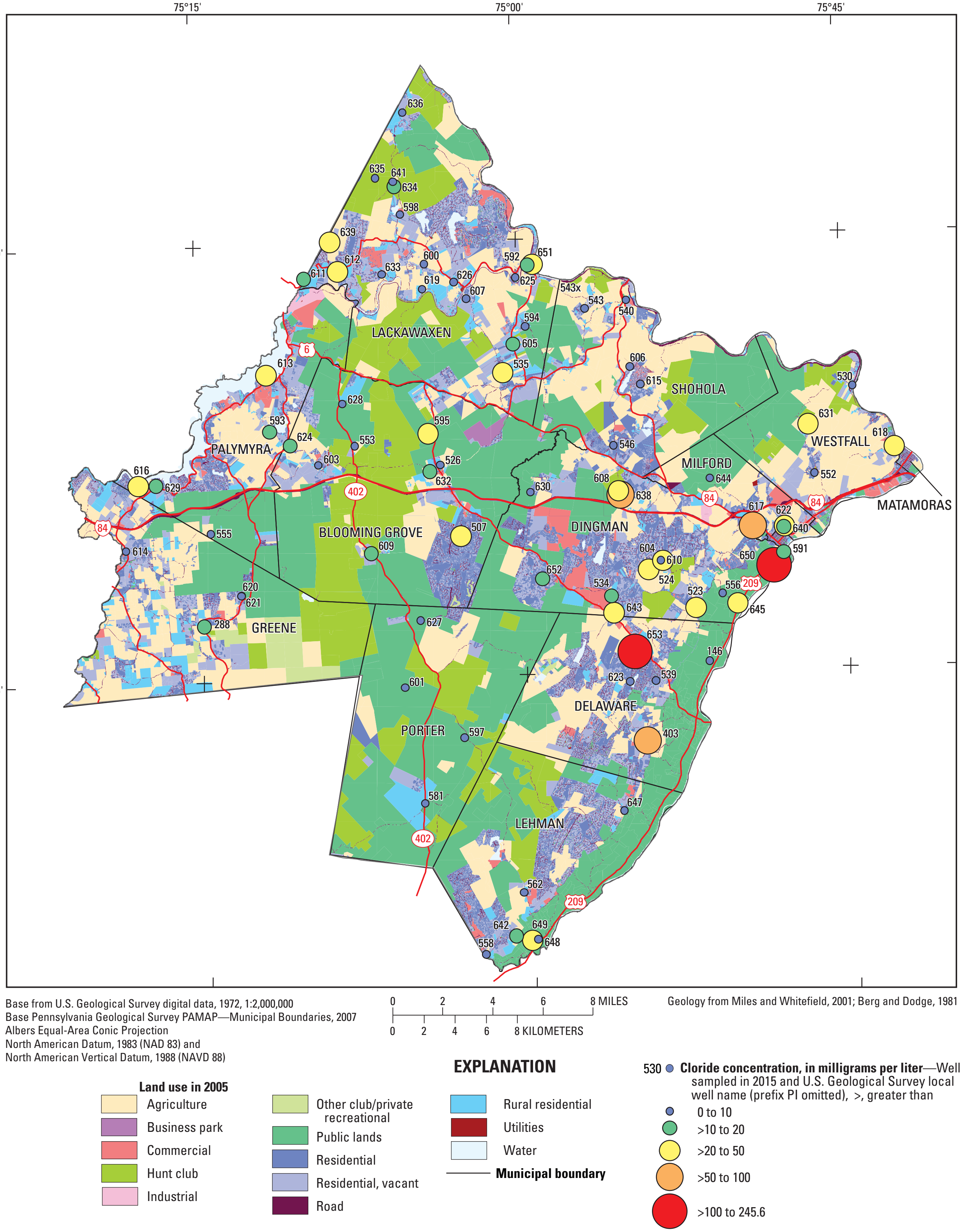
- 🟩 Poplar Gap and Packerton Members of Catskill Formation, undivided
- 🟩 Long Run and Walcksville Members of Catskill Formation, undivided
- 🟪 Towamensing Member of Catskill Formation
- 🟧 Trimmers Rock Formation
- 🟨 Mahantango Formation
- 🟦 Marcellus Formation

— **Municipal boundary**

Dissolved sodium concentration, in milligrams per liter— <, less than; >, greater than

- ● ≤ 10
- ● >10 to ≤20
- ● >20 to ≤60
- ● >60 to ≤283

Figure 10. Geologic units and spatial distribution of dissolved sodium concentrations in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.



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North American Vertical Datum, 1988 (NAVD 88)

Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

Figure 11. Map showing 2005 land use and spatial distribution of dissolved chloride concentrations in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

Trace Constituents

Most analyses for inorganic trace constituents (metals and other elements) were conducted on filtered samples (table 5) and represent dissolved concentrations. Analyses for selected constituents—aluminum, arsenic, barium, lithium, iron, manganese, selenium, strontium, and zinc—were conducted on both filtered and unfiltered samples (table 5) using USGS methods for filtered samples and drinking-water methods for unfiltered samples. Small differences (less than 10 percent) between dissolved and total concentrations may be attributed to analytical uncertainty. However, total concentrations more than 10 percent greater than dissolved concentrations generally indicate that a solid, or particulate, phase of the constituent is present. Small to no differences between dissolved and total concentrations of barium, lithium, and strontium were apparent, indicating these constituents are mostly present in the dissolved form in the groundwater samples. Likewise, differences between dissolved and total concentrations of manganese and arsenic generally were small, with dissolved concentrations representing at least 70–80 percent of total concentrations in one-half of the samples. In contrast, substantial differences in dissolved and total concentrations of iron were measured for many samples with total concentrations exceeding dissolved concentrations by more than 100 µg/L and up to about 22,970 µg/L in 41 of 79 samples (52 percent), indicating that large amounts of particulate iron are present in these samples. Differences in dissolved and total concentrations of trace constituents may occur and are sometimes caused by presence of, or adsorption of, trace metals on particulate iron or manganese oxides. Consequently, concentrations of some constituents (such as arsenic), in some cases, may exceed respective MCLs or SMCLs in unfiltered samples but not in filtered samples.

Of the 19 inorganic trace constituents (metals and other elements) included in 2015 analyses of filtered water samples, 18 were present in concentrations greater than the reporting level in at least one sample (table 5). Dissolved concentrations of the most frequently detected inorganic trace constituents (strontium, barium, lithium) generally were higher than dissolved concentrations of the less frequently detected constituents. Dissolved concentrations of barium, strontium, and lithium were measured at values greater than the reporting levels in all 79 samples. Arsenic, manganese, boron, lead, iron, and molybdenum were the next most frequently detected dissolved metals. Of the metals and trace constituents analyzed, only arsenic exceeded a primary drinking-water standard (MCL), but iron and manganese exceeded SMCLs. Arsenic and manganese exceeded HAs in some samples.

Arsenic and Chemically Similar Trace Constituents

Dissolved or total arsenic concentrations exceeded the MCL of 10 mg/L in only 1 of 79 samples (1 percent), with values of 27.8 and 30.1 µg/L, respectively (table 5), and were higher than the HA level of 2 µg/L in 8 of 79 samples (10 percent). Elevated arsenic concentrations generally occur in water with elevated pH. Arsenic concentrations in groundwater samples collected in Pike County in 2015 (fig. 12*A*) and 2012–13 (Senior, 2014) generally were greater than the MCL of 10 µg/L only when the pH was greater than 8.0 and greater than the HA of 2 µg/L when the pH was greater than 7.2. The relation between elevated pH and elevated arsenic concentrations in Pike County may be attributed to the increased mobility of arsenic under these geochemical conditions. Most arsenic is present in the dissolved phase, as shown by comparison of dissolved and total arsenic concentrations (fig. 13).

Increases in pH to levels greater than 7 may result in mobilization of some negatively charged ions (anions) that tend to be adsorbed on iron oxides or other mineral surfaces in aquifer materials at low pH, as discussed for a similar hydrogeologic setting in Wayne County in Senior and others (2016). Arsenic commonly is present in groundwater as arsenate (AsO_4^{3-}) or, in more reducing conditions, arsenite (AsO_3^{3-}); both are oxyanions (Welch and others, 2000). Under acidic to near-neutral conditions, arsenate tends to remain mostly adsorbed on aquifer materials such as iron oxides, but at pH greater than about 7, arsenate can be mobilized (desorbed) to a greater extent.

Other constituents that have some chemical characteristics similar to arsenic, forming oxyanions that are more mobile at higher pH values, include molybdenum, antimony, and selenium. Of these metals in the Pike County groundwater samples, the relation between increasing pH and dissolved concentrations was strongest for molybdenum (Appendix 3, fig. 3–1); generally higher concentrations molybdenum concentrations were measured in samples with pH greater than about 7.5 (fig. 12*B*), a value above which geochemical modeling indicates greater than 90 percent of the molybdenum ion molybdenate (MoO_4^{2-}) is likely to be dissolved rather than adsorbed (Senior and others, 2016).

Table 5. Minimum, median, and maximum concentrations of trace constituents determined in the laboratory for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

[µg/L, micrograms per liter; <, less than; --, no data or not applicable; MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum level]

Constituent	Units	Number (percent) above reporting level	Concentration range and median			Number (percent) exceeding standard	Drinking-water standard[1]		
			Minimim	Median	Maximum		MCL	HA	SMCL
Dissolved trace constituent (filtered samples)[2]									
Antimony	µg/L	43 (54)	<0.027	0.0293	0.529	0 (0)	**6**	--	--
Beryllium	µg/L	11 (14)	<0.020	<0.020	0.1104	0 (0)	**4**	--	--
Boron	µg/L	66 (84)	<5	10.87	651.4	0 (0)	--	7,000	--
Cadmium	µg/L	9 (11)	<0.030	<0.030	0.1453	0 (0)	**5**	--	--
Chromium	µg/L	0 (0)	<0.30	<0.30	<0.30	0 (0)	**100**	--	--
Cobalt	µg/L	40 (51)	<0.050	0.0509	2.757	--	--	--	--
Copper	µg/L	41 (52)	<0.80	0.901	61.8	0 (0)	**1,300**	1,000	--
Lead, dissolved	µg/L	59 (75)	<0.040	0.11	3.688	0 (0)	**15**	--	--
Molybdenum	µg/L	54 (68)	<0.05	0.0867	1.989	0 (0)	--	40	--
Nickel	µg/L	32 (41)	<0.20	<0.20	1.421	0 (0)	--	100	--
Dissolved and total trace constituents (filtered and unfiltered samples)[2,3]									
Aluminum, dissolved	µg/L	30 (38)	<3	<3	401.6	[a]5 (6)	--	--	50–200
Aluminum, total	µg/L	60 (76)	<1, <2	4.38	1,360	[a]14 (18)	--	--	50–200
Arsenic, dissolved	µg/L	68 (86)	<0.1	0.43	27.8	[b]1 (1)	**10**	2	--
Arsenic, total	µg/L	40 (51)	<0.5	0.5	30.1	[b]1 (1)	**10**	2	--
Barium, dissolved	µg/L	79 (100)	0.54	28.2	382.9	0 (0)	[c]**2,000**	--	--
Barium, total	µg/L	78 (100)	0.52, <5	32.2	398	0 (0)	[c]**2,000**	--	--
Iron, dissolved	µg/L	54 (68)	<4.0	10.5	4,010	8 (10)	--	--	300
Iron, total	µg/L	70 (89)	<10	147	23,000	35 (44)	--	--	300
Lithium, dissolved	µg/L	79 (100)	1.625	10.49	1,077	--	--	--	--
Lithium, total	µg/L	58 (100)	<10	11.5	1,140	--	--	--	--
Manganese, dissolved	µg/L	68 (86)	<0.40	11.4	962.7	[d]24 (30)	--	300	50

Table 5. Minimum, median, and maximum concentrations of trace constituents determined in the laboratory for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.—Continued

[µg/L, micrograms per liter; <, less than; --, no data or not applicable; MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum level]

Constituent	Units	Number (percent) above reporting level	Concentration range and median			Number (percent) exceeding standard	Drinking-water standard[1]		
			Minimim	Median	Maximum		MCL	HA	SMCL
Manganese, total	µg/L	73 (92)	<0.5, <10	22	1,850	[d]31 (39)	--	300	50
Selenium, dissolved	µg/L	36 (46)	<0.05	<0.05	0.972	0 (0)	**50**	--	--
Selenium, total	µg/L	4 (5)	<2.5	<2.5	33.3	0 (0)	**50**	--	--
Strontium, dissolved	µg/L	79 (100)	10.75	238.1	3,420	0 (0)	--	[c]4,000	--
Strontium, total	µg/L	79 (100)	11	245	2,700	0 (0)	--	[c]4,000	--
Zinc, dissolved	µg/L	42 (53)	<2.0	2.23	43.65	0 (0)	--	2,000	5,000
Zinc, total	µg/L	71 (90)	<0.5, <5	5.8	421	0 (0)	--	2,000	5,000

[1] U.S.Environmental Protection Agency (2012).

[2] Laboratory analysis for dissolved concentrations in filtered samples done by U.S. Geological Survey National Water Quality Laboratory (NWQL).

[3] Laboratory analysis for total concentrations in unfiltered samples done by contract laboratories using drinking-water methods (see Appendix 2).

[a] Dissolved aluminum concentrations exceeded the lower SMCL threshold of 50 µg/L in 5 samples (6 percent) and the upper SMCL threshold of 200 µg/L in 1 sample (1 percent); total aluminum concentrations exceeded the lower SMCL threshold of 50 µg/L in 14 samples (18 percent) and the upper SMCL threshold of 200 µg/L in 17 samples (22 percent).

[b] Dissolved and total arsenic concentrations exceeded the MCL of 10 µg/L in 1 sample (1 percent); dissolved and total arsenic concentrations exceeded the HA of 2 µg/L and 8 samples (10 percent) and 14 samples (18 percent), respectively.

[c] Pennsylvania Department of Environmental Protection established standards in 2010 of 10 mg/L (10,000 µg/L) for barium and 10 mg/L (10,000 µg/L) for strontium in flowback discharge to streams (Pennsylvania Department of Environmental Protection, 025 Pa. Code § 95.10).

[d] Dissolved manganese concentrations exceeded the SMCL level of 50 ug/L in 24 of 79 samples (30 percent) and the HA of 300 µg/L in 10 of 79 samples (13 percent). Total manganese concentrations exceed the SMCL level of 50 µg/L in 31 of 79 samples (39 percent) and the HA of 300 µg/L in 13 of 79 samples (16.5 percent).

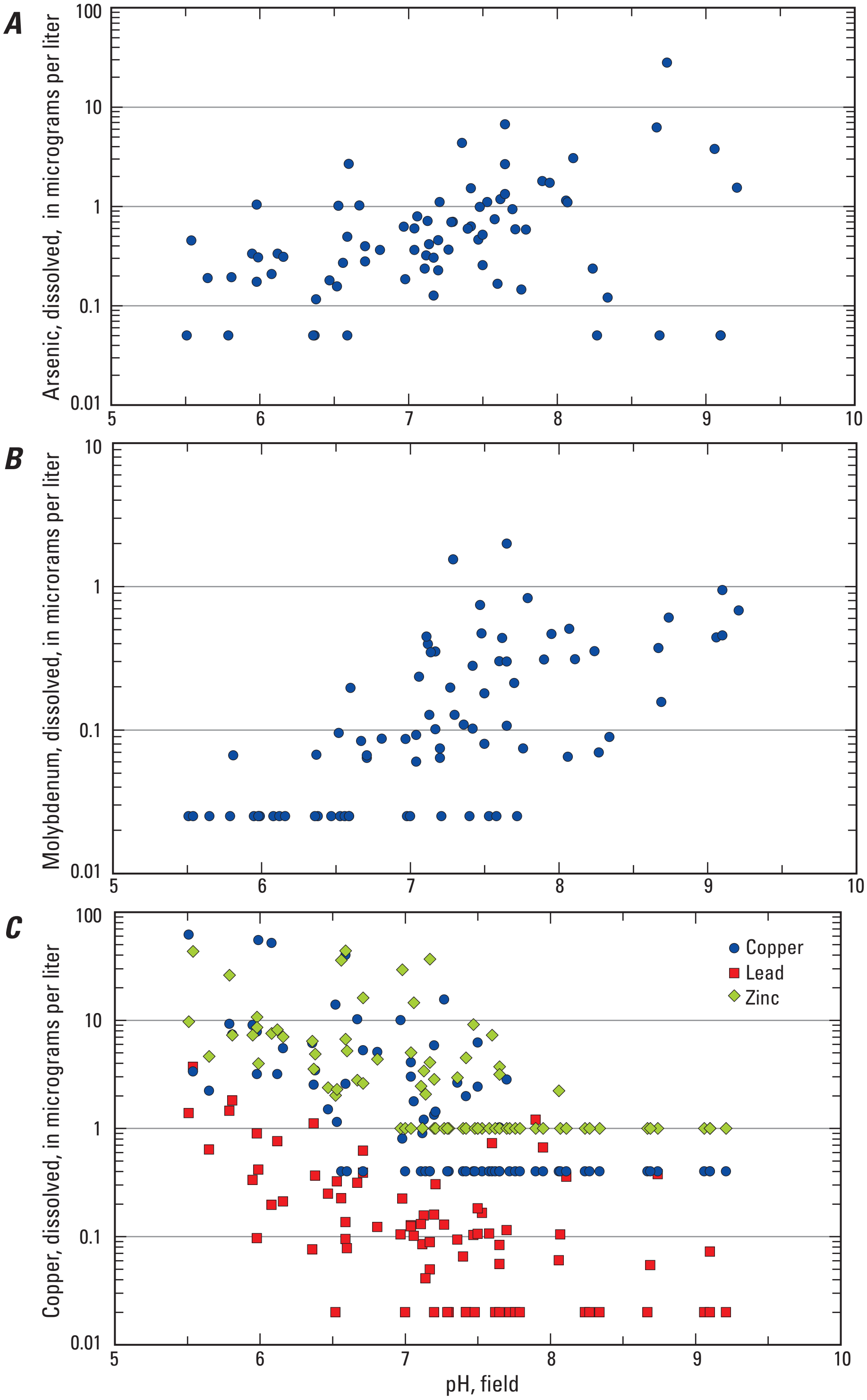


Figure 12. Relation of field measured pH to dissolved concentrations of *A*, arsenic, *B*, molybdenum, and *C*, copper, lead, and zinc in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

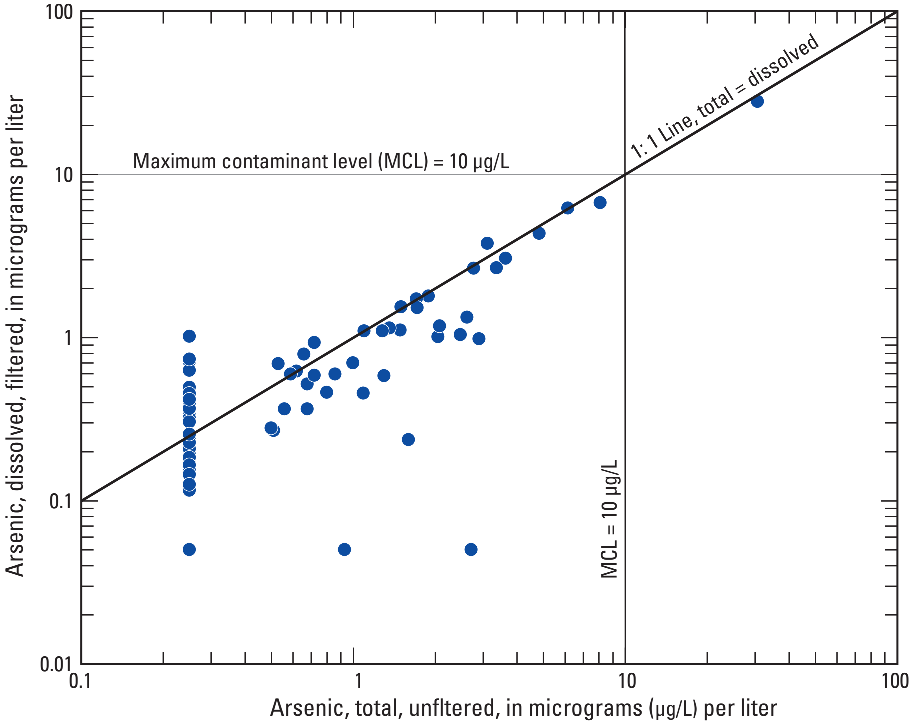


Figure 13. Relation of dissolved to total arsenic concentrations in filtered and unfiltered groundwater samples, respectively, collected from 79 wells in Pike County, Pennsylvania, 2015. [MCL, maximum contaminant level; µg/L, micrograms per liter]

Iron and Manganese

Total iron concentrations were greater than the SMCL of 300 µg/L in 35 of 79 samples (44 percent). Fewer dissolved iron concentrations (8 of 79 samples or 10 percent) exceeded this standard, indicating that the particulate phase of iron (as indicated by total concentrations greater than dissolved concentrations) is a more frequent water-quality concern (fig. 14*A*).

Concentrations of dissolved or total manganese exceeded the SMCL of 50 µg/L in 24 of 79 samples (30 percent) and in 31 of 79 samples (39 percent), respectively, indicating both dissolved and, to a lesser extent, particulate phases of manganese can be a water-quality concern (fig. 14B). Concentrations of dissolved and total manganese were nearly equal for about 20 percent of the samples and dissolved concentrations represented at least 70 percent of total manganese concentrations in one-half of the samples, showing that the dissolved phase of manganese is predominant for about 70 percent of the samples. Concentrations of dissolved or total manganese concentrations exceeded the HA of 300 µg/L in 10 of 79 samples (13 percent) and 13 of 79 samples (16 percent), respectively. The spatial distribution of total iron and manganese concentration in 2015 in Pike County groundwater samples is shown in figure 15.

Dissolved iron and manganese concentrations greater than the SMCLs of 300 and 50 µg/L, respectively, such as those in numerous groundwater samples in Pike County (fig. 14, table 4), generally are present in water that has low DO associated with reducing conditions favorable for iron and manganese mobilization. DO and nitrate concentrations were very low (less than 0.5 mg/L) for most of the samples with elevated dissolved iron and manganese concentrations (fig. 16), indicating reducing (but not extremely reducing) conditions are present that can result in the reductive dissolution of iron and manganese oxides in aquifer materials.

Iron occurs in particulate form to a greater extent than does manganese in the Pike County groundwater samples, where the particulate concentration is the concentration of total minus dissolved metal. Total and particulate iron concentrations showed no clear relation to pH, DO, nitrate, or sulfate concentrations, indicating that controls on the formation of particulate iron are complex and may involve additional factors (such as pH) in combination with the redox conditions. Like iron, particulate manganese concentrations showed no strong relation to pH or DO concentration, but most of the highest total manganese concentrations were nearly equal to dissolved manganese concentrations and were associated with the lowest DO (and nitrate) concentrations, reflecting the predominant presence of manganese in the dissolved phase.

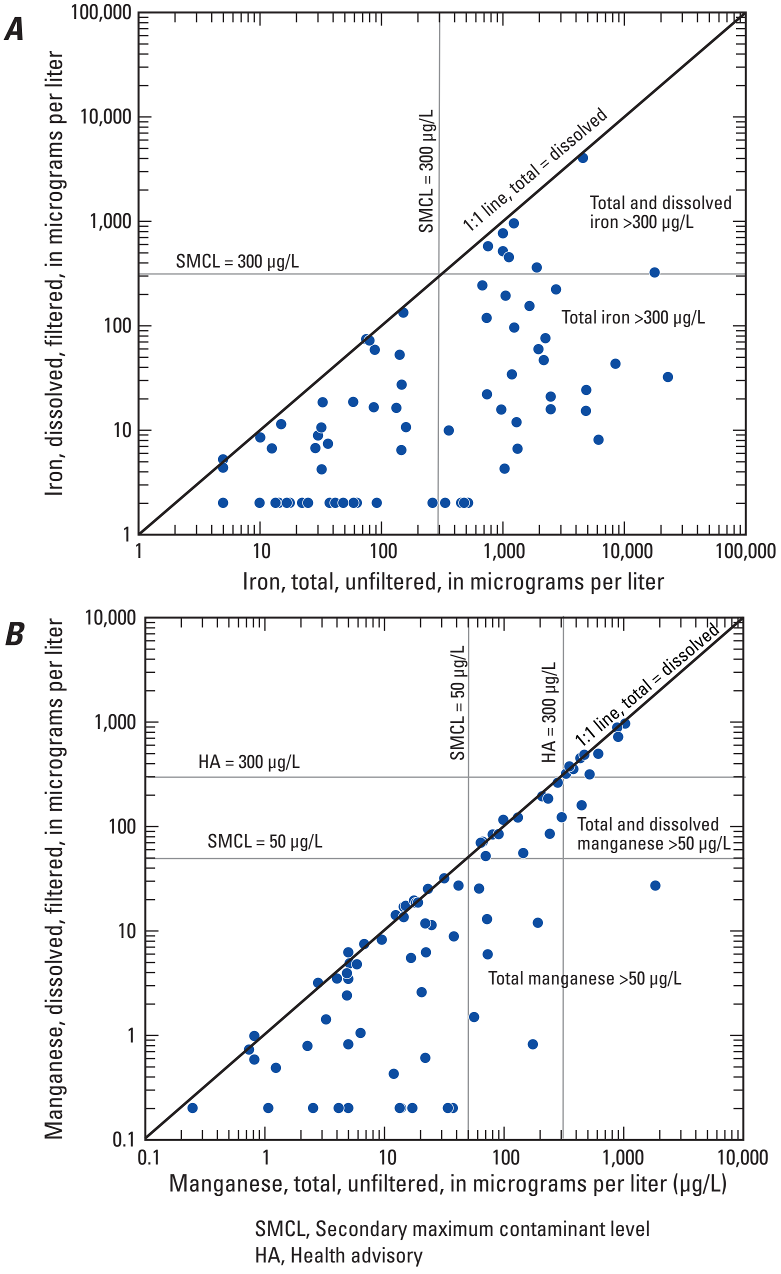
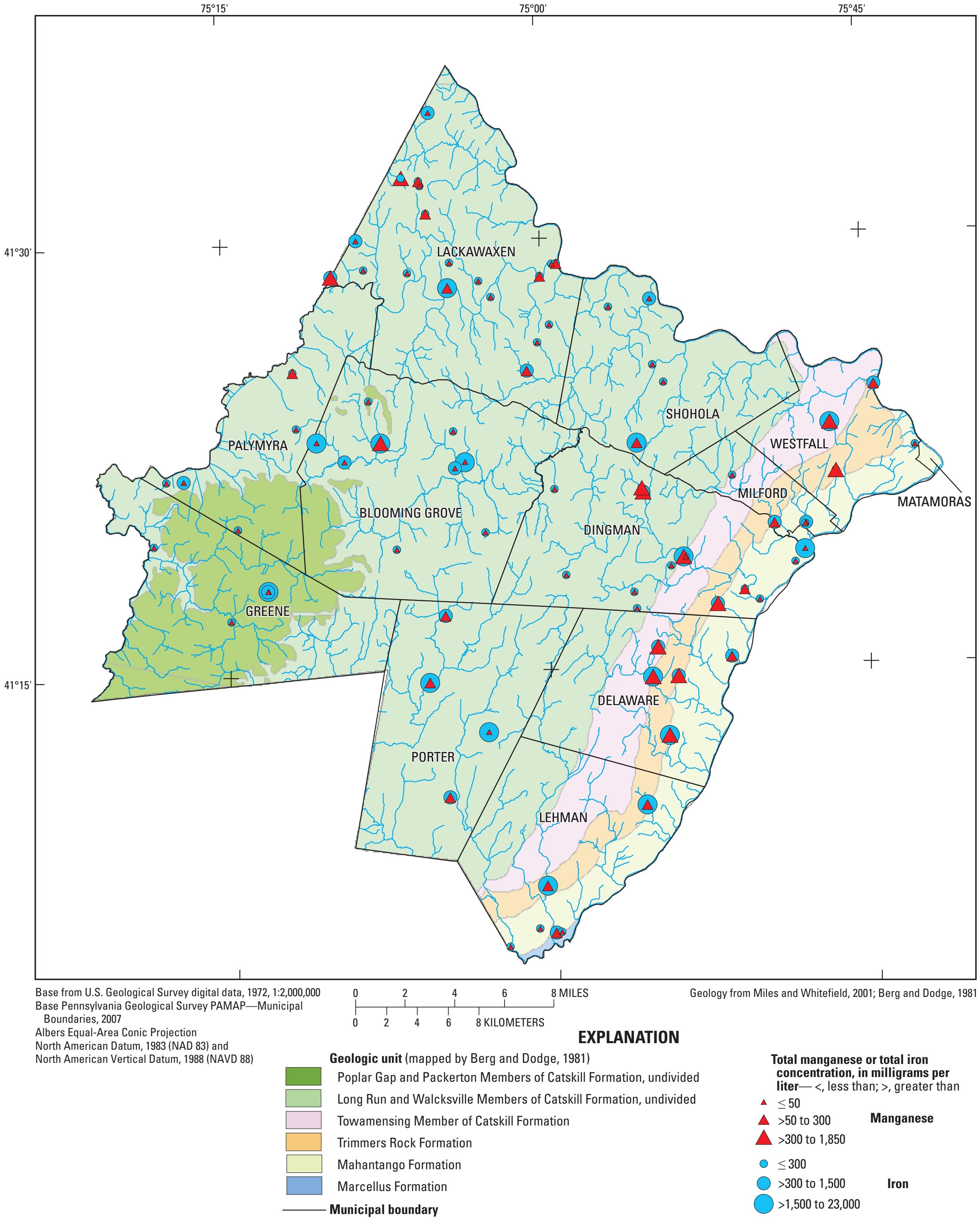


Figure 14. Relation between concentrations of *A*, dissolved and total iron, and *B*, dissolved and total manganese in filtered and unfiltered groundwater samples, respectively, collected from 79 wells in Pike County, Pennsylvania, 2015. [SMCL, secondary maximum contaminant level; HA, health advisory; µg/L, micrograms per liter]



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Base Pennsylvania Geological Survey PAMAP—Municipal Boundaries, 2007
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

Figure 15. Geologic units and spatial distribution of total iron and total manganese concentrations in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

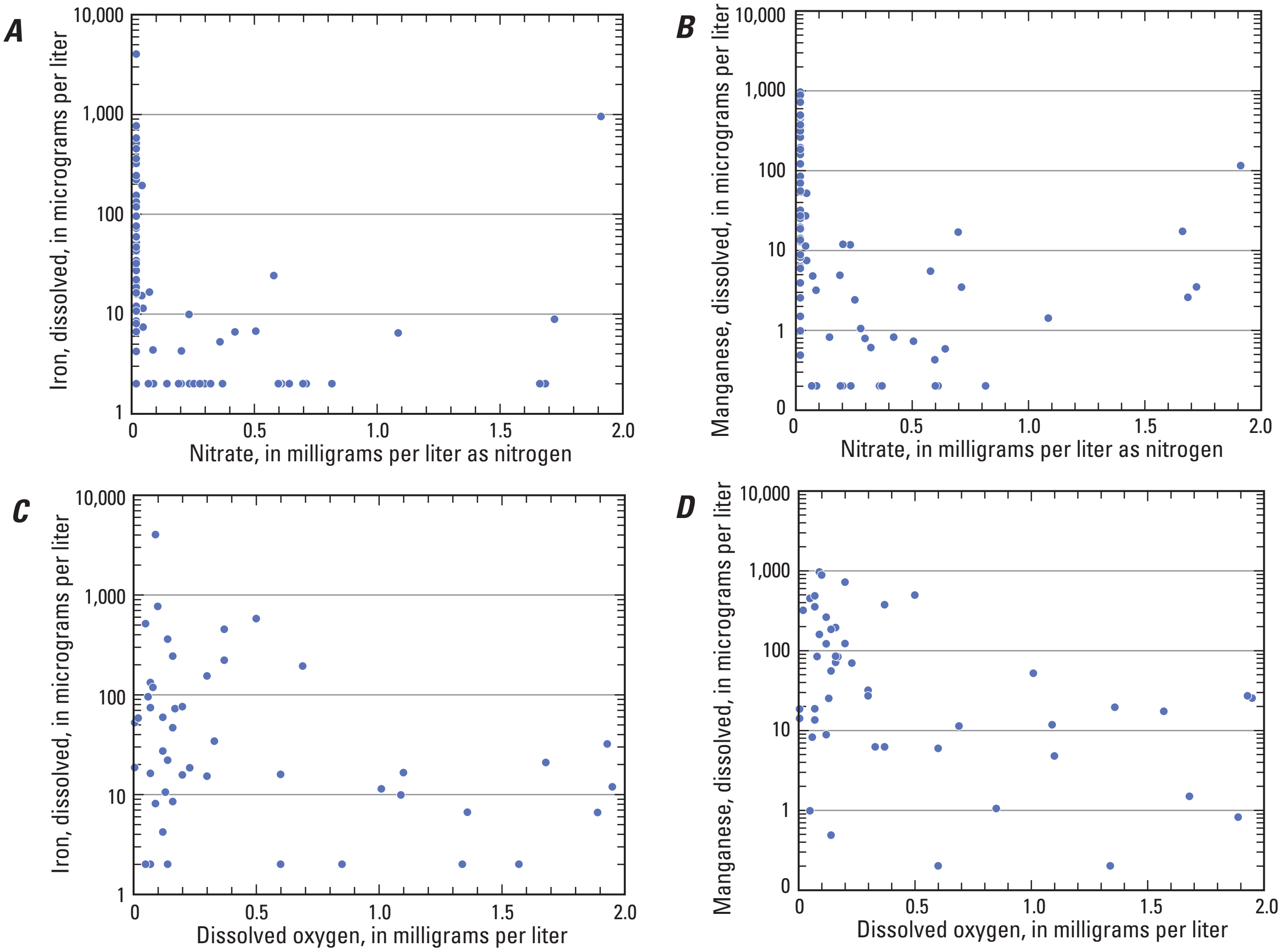


Figure 16. Relation of concentrations of nitrate to concentrations of *A*, dissolved iron and *B*, dissolved manganese and concentrations of dissolved oxygen to concentrations of *C*, dissolved iron and *D*, dissolved manganese in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [SMCL, secondary maximum contaminant level; µg/L, micrograms per liter]

Radionuclides

Radionuclides naturally present in rocks and soils may enter or leach into groundwater through mineral dissolution, desorption from mineral surfaces, or in the case of radon (gas), diffusion. Elevated concentrations of some radionuclides, especially radium, are present in brines associated with Marcellus Shale and other formations with natural gas and oil (Rowan and others, 2011). Naturally occurring radioactivity in groundwater is produced primarily by the radioactive decay of uranium-238 and thorium-232. These isotopes of uranium and thorium disintegrate in steps emitting either alpha or beta particles and forming a series of radioactive nuclide “daughter” products, mostly short-lived, until a stable lead isotope is produced. Radioactivity is the release of energy and energetic particles (alpha or beta) by changes in the structure of certain unstable elements as they break down to form more stable arrangements, for which (1) alpha radiation consists of positively charged helium nuclei, (2) beta radiation consists of electrons or positrons, and (3) gamma radiation consists of electromagnetic waves. The uranium-238 decay series commonly produces the greatest amount of radioactivity in natural groundwater (Hem, 1985, p. 147), and includes the alpha-particle-emitting radionuclides radium-226 and its daughter product, radon-222. Radionuclides from the thorium-232 decay chain also can be present in groundwater in some geologic settings, including radium-228, a beta-particle-emitting daughter product in the thorium-232 decay chain.

Analyses for radioactivity and radionuclides in the groundwater samples collected from 79 wells in Pike County in 2015 included gross alpha radioactivity, gross beta radioactivity, and dissolved radon-222 (radon gas). Uranium, a radioactive element (composed of uranium-238, uranium-235, and uranium-234 isotopes), also was analyzed in the dissolved form. Summary statistics for radioactive constituents are given in table 6, and analytical results are provided in Senior (2017) and table 13 (in back of report). Selected water samples with among the highest measured gross alpha radioactivity were analyzed for dissolved radium-226, a radionuclide that may be elevated (to a greater extent than radium-228) in brines associated with the Marcellus Shale (Rowan and others, 2011). The EPA drinking-water MCL is 5 pCi/L for combined radium-226 plus radium-228 activities. Previous limited results for radium in groundwater in Pike County show radium-226 values were less than 1 pCi/L (Senior, 2014).

Gross Alpha and Gross Beta Radioactivity

Various radioactive isotopes present in groundwater may contribute to the total or gross radioactivity measured in a sample, as measured in analyses for gross alpha and gross beta radioactivity. Differences between gross alpha and gross beta radioactivity measured soon after sample collection (within 72 hours) and after 30 days indicate whether short-lived radionuclides (such as radium-224, half-life of 3.6 days) are present in the sample. Because well owners typically are consuming water soon after it is pumped from a well, it is prudent to assess radioactivity measured as soon as possible (such as within 72 hours) relative to the established drinking-water standards. If gross alpha- or gross beta-particle activities are elevated, it is likely that a radionuclide (such as radium-226 for gross alpha-particle activities and potassium-40 for gross beta particle activities) that contributes to those radioactivities is also elevated. Thus, gross alpha- and gross beta-particle activities commonly are used to screen for possible presence of radionuclides in concentrations of concern.

The gross alpha-particle activity (72-hour count) in water from the 78 sampled wells (1 of 79 wells is missing gross alpha and beta analysis) ranged from non-detect (less than the detection limit) to 13.9 pCi/L, and the median activity was 0.715 pCi/L (table 6). All water samples had gross alpha-particle activity less than the EPA MCL of 15 pCi/L, although the maximum measured value of 13.9 pCi/L is near the MCL (table 6). Values considered “non-detects” are listed with an “R” preceding the value (Senior, 2017; table 13 at back of report). Most gross alpha radioactivity values were less than the method reporting level (MRL) of 3 pCi/L and, when reported without an “R” qualifier, are considered to be estimated values that have larger uncertainty than those quantified at greater than the MRL. Seventeen of 78 samples (about 20 percent) had gross alpha radioactivity (72-hour count) greater than or equal to 3 pCi/L. Gross alpha-particle activity in the 30-day count was similar to or slightly less than the activity in the 72-hour count (fig. 17*A*).

The gross beta-particle activity (72-hour count) ranged from non-detect (less than the detection limit) to 14 pCi/L, and the median activity was 1.6 pCi/L (table 6). As with gross alpha-particle activity, uncertainty is relatively greater for values less than the MRL of 3 pCi/L. Sixteen of 78 samples (20 percent) had gross beta-particle activity (72-hour count) greater than or equal to 3 pCi/L. Gross beta-particle activity in the 30-day count was similar to, or either slightly higher or slightly lower than, the activity in the 72-hour count in most of the samples (fig. 17*A*). Gross alpha- and gross beta-particle activities generally were directly related but were more strongly related at 72 hours than at 30 days (fig. 17*B*). Relative changes in gross beta-particle activities differed from relative changes in gross alpha-particle activities when counts at 72 hours were compared to counts at 30 days, indicating that the relative abundance and composition of gross beta- and gross alpha-emitting radionuclides differ among the samples.

Radium-226

Radium-226 has a half-life of 1,620 years and emits alpha particles during radioactive decay. Samples from 12 wells with the highest gross alpha-particle activities were analyzed for radium-226.. The radium-226 activities ranged from 0.09 to 1.84 pCi/L, with a median of 0.24 pCi/L, less than the EPA MCL of 5 pCi/L on the basis of radium-226 alone in any sample. Radium-228 may also be present but was not included in the 2015 analyses. Radium-226 activities were related to gross alpha-particle activity at 30 days (fig. 18*A*) but not to gross alpha-particle activity at 72 hours, indicating that gross alpha-particle activity at 30 days appears to be a stronger indicator of radium-226 activity than gross alpha-particle activity at 72 hours in Pike County groundwater. Radium-226 likely contributes relatively more to the gross alpha-particle activity at 30 days than at 72 hours if other radionuclides with shorter half-lives are present. Radium-226 activities were related to specific conductance, with higher activities in samples with higher specific conductance (fig. 18*B*).

Table 6. Minimum, median, and maximum concentrations of selected radioactive constituents determined in the laboratory for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

[pCi/L, picocuries per liter; mrem/yr, millirem per year; µg/L, micrograms per liter; <, less than; --, no data or not applicable; MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum level; nd, non-detect]

Radioactive constituent[1]	Units	Number of samples	Number (percent) above reporting level	Concentration range and median			Number (percent) exceeding standard	Drinking-water standard[2]		
				Minimim	Median	Maximum		MCL	HA	SMCL
Total (unfiltered sample)										
Gross alpha radioactivity, 30-day recount	pCi/L	78	33 (42)	nd	nd	10.4	0 (0)	**15**	--	--
Gross alpha radioactivity, 72-hour count	pCi/L	78	39 (50)	nd	0.715	13.9	0 (0)	**15**	--	--
Gross beta radioactivity, 30-day recount	pCi/L	78	59 (76)	nd	1.7	7.5	0 (0)	[a]**4 mrem/yr**	--	--
Gross beta radioactivity, 72-hour count	pCi/L	78	47 (60)	nd	1.6	14.0	0 (0)	[a]**4 mrem/yr**	--	--
Radon-222	pCi/L	79	79 (100)	11.5	1,425	5,110	61 (77)/2 (3)	[b]**300/4,000**	--	--
Radium-226	pCi/L	13	13 (100)	0.09	0.25	1.84	0 (0)	[c]**5**	--	--
Dissolved (filtered sample)										
Uranium (natural)	µg/L	79	72 (91)	<0.014	0.13	1.81	0 (0)	**30**	20	--

[1] Gross alpha-particle activity measured using thorium-230 curve; gross beta-particle activity measured using cesium-137-curve.

[2] U.S.Environmental Protection Agency (2012).

[a] MCL expressed as a dose.

[b] Radon-222 activity exceeded proposed MCL of 300 pCi/L in 61 samples (77 percent) and proposed alternative MCL of 4,000 pCi/L in 2 samples (3 percent).

[c] MCL is for combined activities of radium-226 plus radium-226; radium-226 alone did not exceed 5 pCi/L in any of the 2015 Pike County samples.

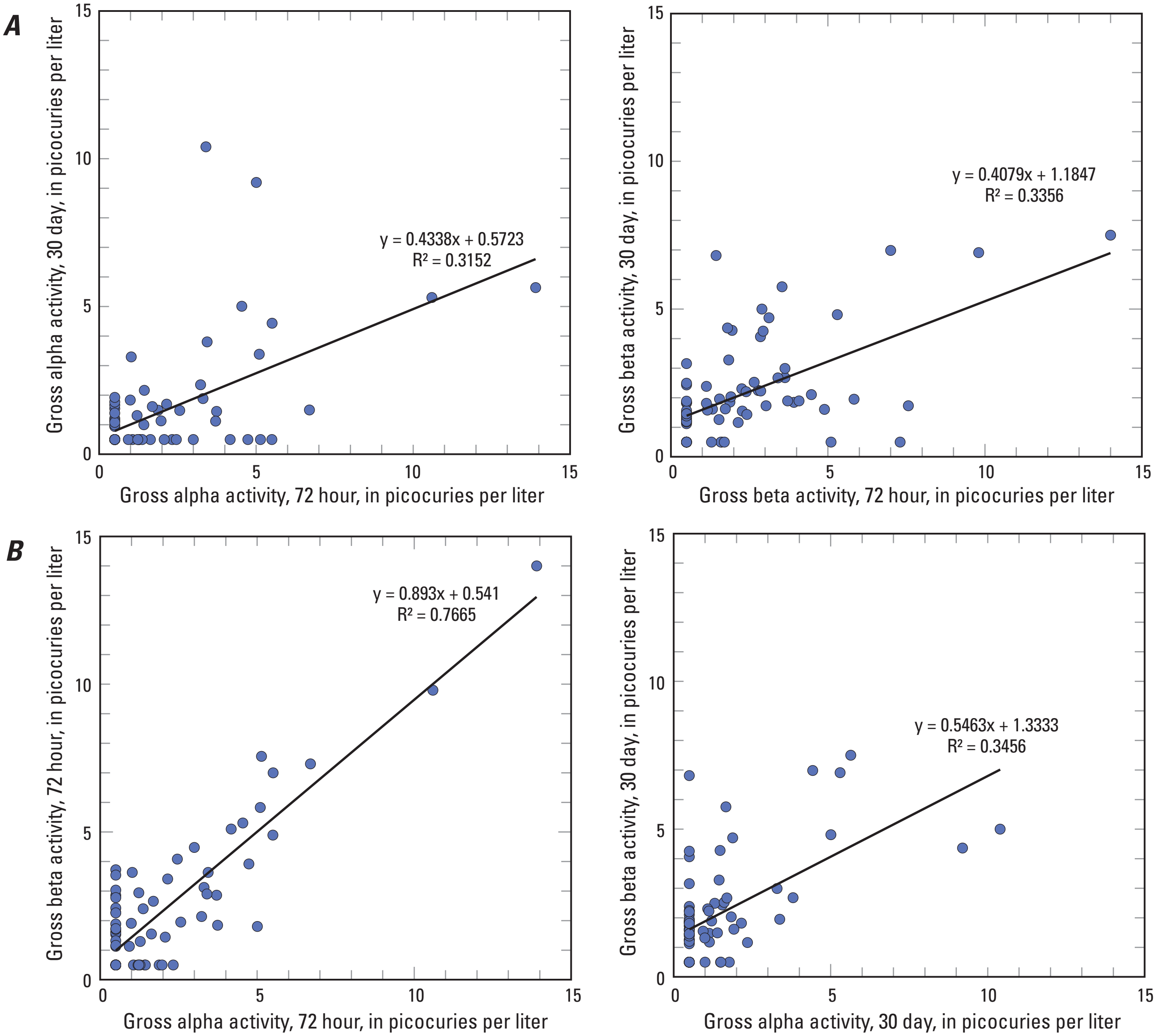


Figure 17. Relation between *A*, 72-hour and 30-day gross alpha- and gross beta-particle activities, and *B*, gross alpha-particle activity and gross beta-particle activity at 72 hours and 30 days in groundwater samples collected from 78 wells in Pike County, Pennsylvania, 2015.

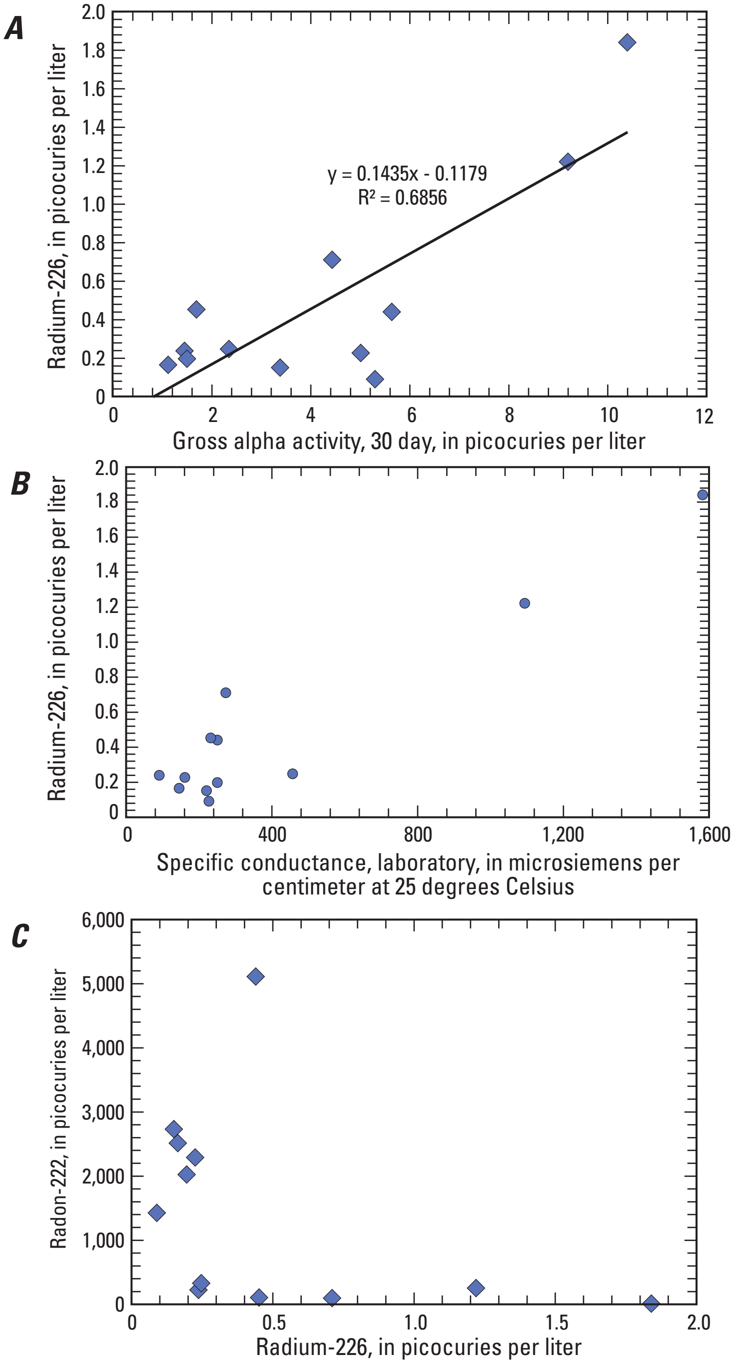


Figure 18. Relation of radium-226 activity to *A*, gross alpha-particle activity at 30 days, *B*, laboratory specific conductance, and *C*, radon-222 activity in groundwater samples collected from 12 wells in Pike County, Pennsylvania, 2015.

Radon-222

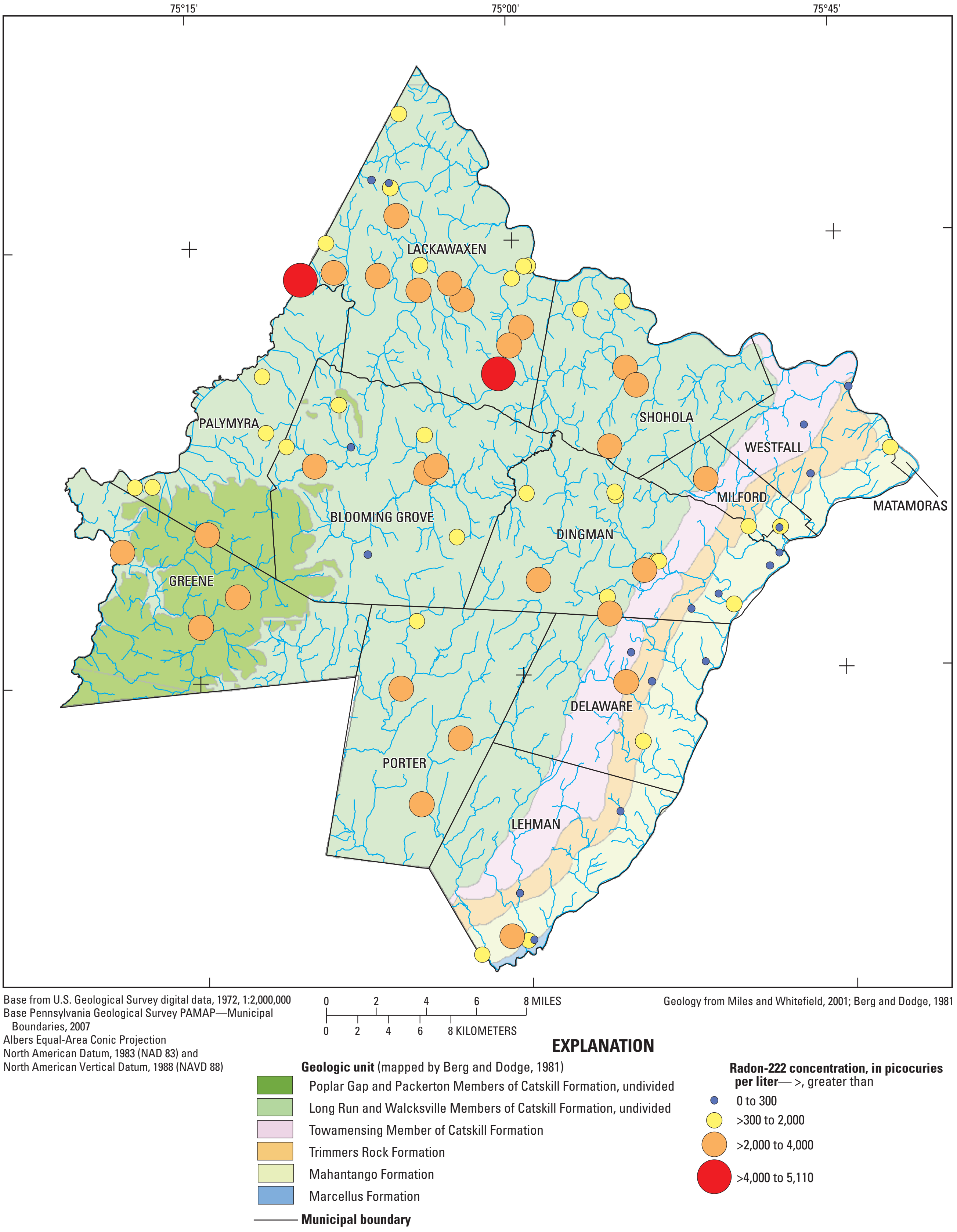
Radon-222, a short-lived (half-life of 3.8 days) daughter product of radium-226 decay, is a colorless, odorless, chemically inert, alpha-particle-emitting gas that is soluble in water. The EPA has set a health-based standard for radon-222 in air (4 pCi/L) but currently does not regulate radon-222 in drinking water. However, under the framework specified by the 1999 Notice for the Proposed Radon in Drinking Water Rule (Federal Register, 1999), the EPA proposed an alternative maximum contaminant level (AMCL) of 4,000 pCi/L for radon-222 for community water systems that use groundwater for all or some of the supply in states with an enhanced indoor radon program. For states without an enhanced indoor air program, EPA proposed an MCL of 300 pCi/L for radon-222.

Activities of radon-222 in water samples from the 79 wells ranged from 11.5 to 5,110 pCi/L, with a median activity of 1,425 pCi/L (table 6). Water samples from 61 of the 79 wells (77 percent) exceeded the proposed EPA MCL of 300 pCi/L, and samples from 2 of the 79 wells (3 percent) exceeded the proposed EPA AMCL of 4,000 pCi/L for radon-222. Radon-222 activities in water samples from the 79 wells did not appear to be directly related to other measured sources of radioactivity (gross alpha- or gross beta-particle radioactivity, uranium, or radium-226). The limited available data (samples from 13 wells) indicate an inverse relation between radon-222 and its parent radium-226; relatively higher radon-222 activities were associated with relatively lower radium-226 activities (fig. 18*C*). The spatial distribution of radon-222 activities (concentrations) in Pike County groundwater is shown in figure 19.

Uranium

The concentration of uranium ranged from less than 0.014 to 1.81 µg/L with a median concentration of 0.13 µg/L (table 6). No water samples exceeded the EPA MCL of 30 µg/L or the HA of 20 µg/L for uranium. Uranium concentrations were only weakly related to gross alpha- and gross beta-particle activity measured at either 30 days or 72 hours, with a slightly stronger relation was observed for 30-day gross alpha-particle activity (r^2=0.19) than for 30-day gross beta-particle activity (r^2=0.11). Thus, gross alpha-particle activity may be limited in strength, but more useful than gross beta-particle activity, to serve as a screen for potentially elevated concentrations of uranium in Pike County groundwater.

Although measured uranium concentrations in groundwater samples did not exceed drinking-water standards in Pike County, at least one sample had a concentration (16.4 µg/L) near the HA level of 20 µg/L in neighboring Wayne County, where uranium concentrations in groundwater generally are greater than in Pike County (Senior and others, 2016). Uranium has been reported to be present at enriched levels at some localities in the Catskill Formation in Pennsylvania (McCauley, 1961; Pirc and Rose, 1981), including central Wayne County (Kleimic, 1962). Where uranium is not present in enriched concentrations in aquifer materials, elevated concentrations in groundwater are less likely. Uranium ion solubility is affected by pH, alkalinity, and redox conditions; uranium ions in +6 oxidation state (UO_2^{+2} under oxidizing conditions) can form soluble complexes with bicarbonate and carbonate, which commonly are abundant and can thus contribute to increased uranium mobility at neutral to alkaline pH. The concentrations of uranium in groundwater in Pike County tended to be highest at or near neutral pH (fig. 20), which is similar to findings in neighboring Wayne County (Senior and others, 2016).



Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Base Pennsylvania Geological Survey PAMAP—Municipal Boundaries, 2007
Albers Equal-Area Conic Projection
North American Datum, 1983 (NAD 83) and
North American Vertical Datum, 1988 (NAVD 88)

Geology from Miles and Whitefield, 2001; Berg and Dodge, 1981

Figure 19. Geologic units and spatial distribution of radon-222 concentrations in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

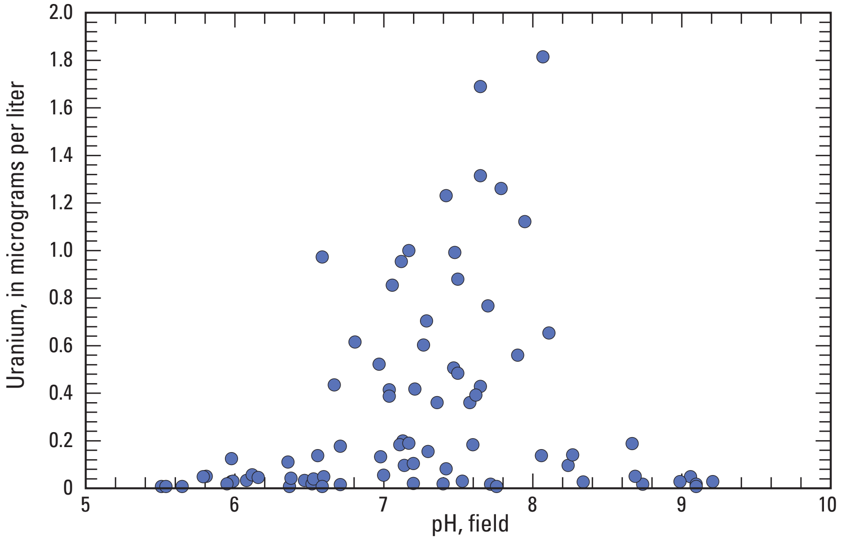


Figure 20. Relation of concentrations of dissolved uranium to field measured pH in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

Total Organic Carbon and Man-Made Organic Compounds

Samples from all 79 wells were analyzed for total organic carbon to determine carbon concentrations in groundwater from both natural and man-made sources, if present. Natural organic carbon may be comprised of organic acids and other products formed by microbial decay of organic matter. No groundwater sample had detectable concentrations of total organic carbon greater than the reporting level of 0.7 mg/L (table 4).

Samples from 20 of 79 wells were analyzed for 68 man-made (synthetic) organic compounds (table 7). Three VOCs were detected in low concentrations in water samples from only two wells (PI-556, PI-617). The sources of, and explanation for, the presence of these VOCs in well-water samples in Pike County are unknown, although disposal of VOCs in septic or other on-lot systems may be a potential pathway for these compounds to enter groundwater. No detected VOC was present in concentrations that exceeded drinking-water MCLs. Toluene was measured at a concentration of 1.98 µg/L in the water sample from well PI-617. Toluene commonly is used as a solvent, such as in paint thinner. Trichlorofluoromethane, a chlorofluorocarbon (CFC), and styrene were measured at concentrations of 4.98 µg/L and 0.54 µg/L, respectively, in the water sample from well PI-556, which when sampled previously in 2007 was also found to contain trichlorofluoromethane at 39 µg/L but no detectable styrene. Trichlorofluoromethane, also known as Freon-11 or CFC-11, was used as a refrigerant, degreaser, and solvent and as a component in aerosol products, fire extinguishing foam, and other applications from the 1950s until 1996 when CFC manufacture was banned in the United States because of CFC contribution to depletion of ozone in the atmosphere. Styrene can occur naturally at trace to low levels in some plants and foods (American sweetgum, cinnamon, beef, coffee beans, and strawberries, for example) but is also a man-made compound used in manufacture of polystyrene and other plastics.

The laboratory reporting level for VOCs was 0.5 µg/L, which is lower than drinking-water MCLs established for most VOCs included in the analysis (table 7). However, drinking-water MCLs for two compounds—1,2-dibromo-3-chloropropane (DBCP) and 1,2-dibromoethane (EDB)—are less than the method reporting level, as performed by the laboratory, so for these compounds, a more sensitive method is needed to determine whether they are present in concentrations greater than the MCLs (although below the reporting level of 0.5 µg/L). Therefore, with the exception of these two compounds, if VOCs are present in groundwater at concentrations less than the reporting level of 0.5 µg/L, those concentrations would not exceed an established drinking-water standard.

Table 7. Reporting levels and drinking-water standards for man-made organic compounds analyzed in groundwater samples collected from 20 wells in Pike County, Pennsylvania, 2015.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; % Rec., percent recovery; MCL, maximum contaminant level; HA, health advisory; HBSL, health-based screening level; --, no data or not available]

Analyte name	USGS Parameter code	Units	Reporting Limit	Number (percent) above reporting level	Detected VOC concentration	Drinking-water standard[1]		
						MCL	HA	HBSL
Volatile organic compounds (method EPA 524.2)								
% 1,2-Dichlorobenzene-d4 (surrogate)	90475	% Rec.	None	20 (100)	69–94	--	--	--
% 4-Bromofluorobenzene (surrogate)	99834	% Rec.	None	20 (100)	69–93	--	--	--
1,1,1,2-Tetrachloroethane	77562	µg/L	0.5	0 (0)	--	--	70	0.1–100
1,1,1-Trichloroethane	34506	µg/L	0.5	0 (0)	--	200	--	--
1,1,2,2-Tetrachloroethane	34516	µg/L	0.5	0 (0)	--	--	40	0.2–20
1,1,2-Trichloroethane	34511	µg/L	0.5	0 (0)	--	5	--	--
1,1-Dichloroethane	34496	µg/L	0.5	0 (0)	--	--	--	--
1,1-Dichloroethene (1,1-Dichloroethylene)	34501	µg/L	0.5	0 (0)	--	7	--	--
1,1-Dichloropropene	77168	µg/L	0.5	0 (0)	--	--	--	--
1,2,3-Trichlorobenzene	77613	µg/L	0.5	0 (0)	--	--	--	--
1,2,3-Trichloropropane (1,2,3-TCP)	77443	µg/L	0.5	0 (0)	--	--	100	--
1,2,4-Trichlorobenzene	34551	µg/L	0.5	0 (0)	--	70	--	--
1,2,4-Trimethylbenzene	77222	µg/L	0.5	0 (0)	--	--	--	--
1,2-Dibromo-3-Chloropropane (DBCP, Dibromochloropropane)	82625	µg/L	0.5	0 (0)	--	0.2	--	--
1,2-Dibromoethane (EDB, Ethylene dibromide)	77651	µg/L	0.5	0 (0)	--	0.05	--	--
1,2-Dichlorobenzene (o-Dichlorobenzene)	34536	µg/L	0.5	0 (0)	--	600	--	--
1,2-Dichloroethane	32103	µg/L	0.5	0 (0)	--	5	--	--
1,2-Dichloropropane	34541	µg/L	0.5	0 (0)	--	5	--	--
1,3,5-Trimethylbenzene	77226	µg/L	0.5	0 (0)	--	--	--	--
1,3-Dichlorobenzene (m-Dichlorobenzene)	34566	µg/L	0.5	0 (0)	--	--	600	--
1,3-Dichloropropane	77173	µg/L	0.5	0 (0)	--	--	--	--
1,4-Dichlorobenzene (p-Dichlorobenzene)	34571	µg/L	0.5	0 (0)	--	75	--	--
2,2-Dichloropropane	77170	µg/L	0.5	0 (0)	--	--	--	--
2-Chlorotoluene	77275	µg/L	0.5	0 (0)	--	--	100?	--
4-Chlorotoluene	77277	µg/L	0.5	0 (0)	--	--	100?	--
Benzene	34030	µg/L	0.5	0 (0)	--	5	--	--
Bromobenzene	81555	µg/L	0.5	0 (0)	--	--	60	--
Bromochloromethane	77297	µg/L	0.5	0 (0)	--	--	90	--
Bromodichloromethane	32101	µg/L	0.5	0 (0)	--	[a]80	--	--
Bromoform	32104	µg/L	0.5	0 (0)	--	[a]80	--	--
Bromomethane (Methyl bromide)	34413	µg/L	0.5	0 (0)	--	--	10	--

Table 7. Reporting levels and drinking-water standards for man-made organic compounds analyzed in groundwater samples collected from 20 wells in Pike County, Pennsylvania, 2015.—Continued

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; % Rec., percent recovery; MCL, maximum contaminant level; HA, health advisory; HBSL, health-based screening level; --, no data or not available]

Analyte name	USGS Parameter code	Units	Reporting Limit	Number (percent) above reporting level	Detected VOC concentration	Drinking-water standard[1]		
						MCL	HA	HBSL
Carbon Tetrachloride	32102	µg/L	0.5	0 (0)	--	5	--	--
Chlorobenzene	34301	µg/L	0.5	0 (0)	--	--	--	--
Chloroethane	34311	µg/L	0.5	0 (0)	--	--	--	--
Chloroform	32106	µg/L	0.5	0 (0)	--	[a]80	--	--
cis-1,2-Dichloroethene	77093	µg/L	0.5	0 (0)	--	70	--	--
cis-1,3-Dichloropropene	34704	µg/L	0.5	0 (0)	--	--	40	0.3–30
Dibromochloromethane	32105	µg/L	0.5	0 (0)	--	[a]80	--	--
Dibromomethane	30217	µg/L	0.5	0 (0)	--	--	--	--
Dichlorodifluoromethane (Freon 12)	34668	µg/L	0.5	0 (0)	--	--	1,000	--
Ethylbenzene	34371	µg/L	0.5	0 (0)	--	700	--	--
Hexachlorobutadiene (1,3-Hexachlorobutadiene)	39702	µg/L	0.5	0 (0)	--	--	10	2
Isopropylbenzene (Cumene)	77223	µg/L	0.5	0 (0)	--	--	4	700
m+p-Xylene	85795	µg/L	1	0 (0)	--	10,000	--	--
Methyl Chloride (Chloromethane)	34418	µg/L	0.5	0 (0)	--	--	400	--
Methylene Chloride (Dichloromethane, DCM)	34423	µg/L	0.5	0 (0)	--	5	--	--
Naphthalene	34696	µg/L	0.5	0 (0)	--	--	100	--
n-Butylbenzene	77342	µg/L	0.5	0 (0)	--	--	--	--
n-Propylbenzene	77224	µg/L	0.5	0 (0)	--	--	--	--
o-Xylene	77135	µg/L	0.5	0 (0)	--	10,000	--	--
p-Isopropyltoluene (4-Isopropyltoluene)	77356	µg/L	0.5	0 (0)	--	--	--	--
sec-Butylbenzene	77350	µg/L	0.5	0 (0)	--	--	--	--
Styrene	77128	µg/L	0.5	1 (1)	0.54	100	--	--
tert-Butylbenzene	77353	µg/L	0.5	0 (0)	--	--	--	--
Tetrachloroethene (Perchloroethylene, PCE)	34475	µg/L	0.5	0 (0)	--	5	--	--
Toluene	34010	µg/L	0.5	1 (1)	1.98	1,000	--	--
trans-1,2-Dichloroethene	34546	µg/L	0.5	0 (0)	--	100	--	--
trans-1,3-Dichloropropene	34699	µg/L	0.5	0 (0)	--	--	40	0.3–30
Trichloroethene (TCE, Trichloroethylene)	39180	µg/L	0.5	0 (0)	--	5	--	--
Trichlorofluoromethane (Freon 11)	34488	µg/L	0.5	1 (1)	4.98	--	2,000	--
Vinyl Chloride (Chloroethene)	39175	µg/L	0.5	0 (0)	--	2	--	--
1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)	77652	µg/L	0.5	0 (0)	--	--	--	200,000

[1] U.S.Environmental Protection Agency (2012) for MCL and HA values and Toccalino (2007) for HBSLs that differ from MCL and HA values.

[a] MCL for total trihalomethane concentrations is 80 µg/L; trihalomethanes include bromodichloromethane, bromoform, dibromochloromethane, and chloroform.

Methane and Other Dissolved Hydrocarbon Gases

Methane is a colorless, odorless, combustible gas that may occur naturally in groundwater. Methane may be derived from several sources, including but not limited to surficial sediments, organic-rich layers within rocks, and microbial activity involved in the breakdown of organic matter. Methane can be broadly classified as thermogenic or microbial (biogenic) in origin (Schoell, 1980). Thermogenic methane is formed from breakdown of organic material in sediments under high-temperature conditions caused by deep burial. In contrast, microbial methane is formed in shallow subsurface or near surface environments by microbial (bacterial) reduction of carbon dioxide or fermentation of organic debris (Breen and others, 2007). The methane present in the Marcellus Shale and Utica Shale being developed for natural gas in Pennsylvania is of thermogenic origin (Baldassare and others, 2014; Kirschbaum and others, 2012). Sources of methane may be inferred from the isotopic composition of the methane itself and from the presence of other gases on the basis of numerous studies described in Breen and others (2007).

Although the presence of methane in well water is not known to pose a health risk through ingestion, methane at sufficient concentrations in well water may increase the hazard of explosion when vented into a confined space (Eltschlager and others, 2001). Recommended action levels for methane concentrations in well water listed in table 8 are guidelines, but site-specific conditions need to be considered when evaluating potential risks (Eltschlager and others, 2001).

Water samples from 79 wells were analyzed for the hydrocarbon gases methane, ethane, and propane by a contract laboratory (Seewald Laboratories, Inc.) which used method PA-DEP 3686 for samples from 74 wells and subcontracted analyses for samples from 5 wells to a second laboratory that used a method (RSK-175) with lower reporting limits for these gases. In these analyses of water from 79 wells, only methane was detected. Methane was measured in concentrations greater than the laboratory reporting level of 0.010 mg/L for Seewald Laboratories, Inc. using method PA-DEP 3686 in samples from 19 of 79 wells (24 percent), ranging from less than 0.01 to 2.5 mg/L, including results from the second laboratory (table 8). Methane was measured in concentrations greater than the second laboratory reporting level of 0.002 mg/L (2 µg/L) using method RSK-175 in 3 of 5 samples, ranging from 0.002 to 0.380 mg/L (2 to 380 µg/L) with only 1 value greater than 0.010 mg/L (table 13; Senior, 2017). No sample had dissolved methane concentrations greater than the Pennsylvania action level of 7 mg/L set to minimize hazards related to explosion (Commonwealth of Pennsylvania, 2014). Ethane and propane, with laboratory reporting levels of 0.01 and 0.02 mg/L, respectively, were not detected by the contract laboratory (Seewald Laboratories, Inc.) in any of the samples from the 79 wells.

The spatial distribution of relatively elevated methane concentrations (greater than 0.5 mg/L as determined by Seewald Laboratories, Inc.) in the 2015 Pike County groundwater samples is shown in figure 21, which also shows that relatively elevated methane tends to occur in samples with relatively elevated lithium concentrations. Methane

Table 8. Minimum, median, and maximum concentrations of methane, ethane, and propane determined in the laboratory using method PA-DEP 3686 for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015, and recommended action levels for methane in well water.

[mg/L, milligrams per liter; <, less than; >, greater than; --, no data or not applicable; PA-DEP, Pennsylvania Department of Environmental Protection]

	Units	Number (percent) above reporting level	Concentration range and median			Number (percent) exceeding standard	Well-water action level[1] (mg/L)		
			Minimim	Median	Maximum		Immediate	Warning - investigate	No immediate action - periodic monitoring
Dissolved gas by PA-DEP 3686 method (74 samples) and by alternate RSK-175 method (5 samples)[2]									
Methane	mg/L	[a]19 (24)	<0.01, <0.0015	<0.01	2.5	0 (0)	>28	>10 but <28	<7
Ethane	mg/L	0 (0)	<0.01, <0.0033	<0.01	<0.01	0 (0)	--	--	--
Propane	mg/L	0 (0)	<0.02, <0.0032	<0.02	<0.02	0 (0)	--	--	--

[1] Recommended action level to minimize the hazard of explosion, with lowest action level of 10 mg/L (Eltschlager and others, 2001); alternate lowest action level for methane in well water is 7 mg/L (Commonwealth of Pennsylvania, 2014).

[2] Alternate RSK-175 method has lower reporting levels than PA-DEP 3686 method as listed in column for minimum concentrations.

[a] Methane was detected in concentrations greater than 0.01 mg/L in 18 of 74 samples analyzed by PA-DEP 3686 method and in 1 of 5 samples analyzed using RSK-175 method, in addition to being measured in a concentration of 0.003 mg/L in another of the 5 water samples analyzed by RSK-175 method.

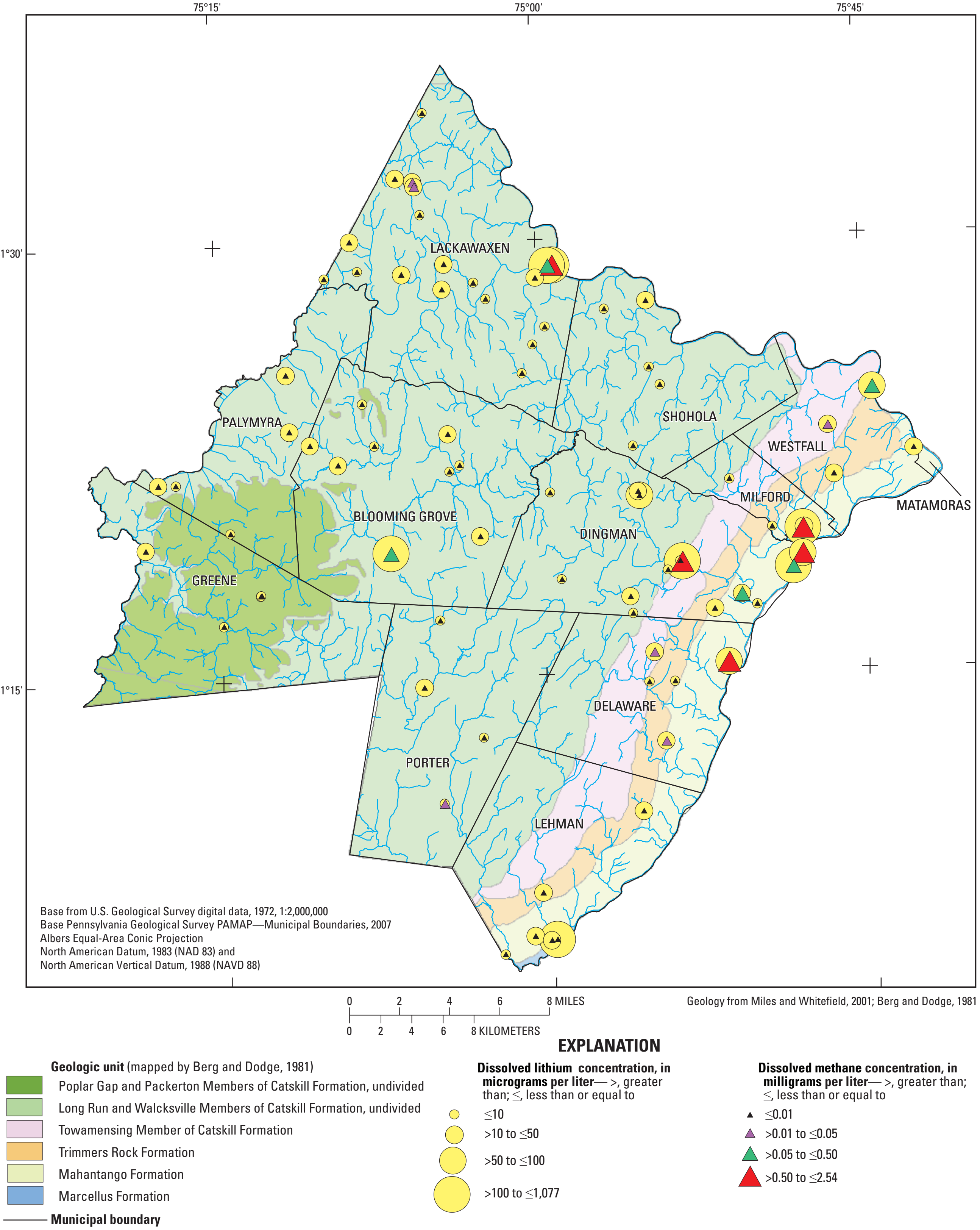


Figure 21. Map showing geologic units and spatial distribution of methane and lithium concentrations in water samples collected from 79 wells in Pike County, Pennsylvania, 2015. Methane concentrations shown were determined by Seewald Laboratories, Inc., for all 79 samples. [Methane concentrations determined by Seewald Laboratories, Inc., commonly were lower than (by as much as one-half) methane concentrations determined by Isotech Laboratories, Inc., in 18 replicates samples as shown in table 9.]

concentrations (as determined by Seewald Laboratories, Inc.) generally were greater than 0.1 mg/L in groundwater samples that had lithium concentrations greater than 100 µg/L (fig. 22). Only one sample with a lithium concentration greater than 100 µg/L had a methane concentration less than 0.1 mg/L; this sample (from well PI-648) had a dissolved lithium concentration of 115 µg/L and a dissolved methane concentration of less than 0.01 mg/L (0.002 mg/L as determined by Isotech Laboratories, Inc.). However, the methane gas concentration in the sample from this particular well (PI-648) could have been affected (lowered) by aeration during sampling because dissolved oxygen concentrations increased and bubbles were reported in purge water while the well was being pumped prior to sampling.

Eighteen inter-laboratory replicate samples from 17 wells (well PI-524 sampled twice) sampled in 2015 also were sent to Isotech Laboratories, Inc., for isotopic characterization of methane; for dissolved gas analysis that included methane, ethane, ethylene, propane, propylene, iso-butane, and N-butane; and for analysis for the hydrocarbon liquids iso-pentane, N-pentane, and hexane (table 14 at back of report; Senior, 2017). Replicate samples from 5 of 17 wells sent to Isotech Laboratories, Inc., for dissolved gas analysis had methane concentrations near or greater than 1 mg/L, higher than but consistent with, the relatively elevated concentrations (>0.5 mg/L) determined by the other contract laboratory (Seewald Laboratories, Inc.) using method PA-DEP 3686. However, methane concentrations determined by Isotech Laboratories, Inc., generally were greater (commonly about 2 times greater and as much as 2.7 times greater) than those determined by Seewald Laboratories, Inc., using method PA-DEP 3686 (fig. 23, table 9). Differences in results between laboratories may be related to analytical techniques, calibrations, sample-collection methods, or sample containers.

Of the hydrocarbon gases analyzed by Isotech Laboratories, Inc., only methane and ethane were detected (table 14, at back of report). Methane concentrations were measured at greater than the reporting level of 0.0003 mg/L in all samples from the 17 wells; those concentrations ranged from 0.00036 to 5.9 mg/L, with the highest level near the PADEP action level of 7 mg/L (table 9). Ethane was measured at greater than the reporting level of 0.0002 mg/L in samples from 6 of 17 wells; concentrations ranged from 0.00041 to 0.0019 mg/L.

Methane Isotopic Composition and Origin of Methane Gas

The isotopic composition of methane was determined for groundwater samples from 10 wells that had methane concentrations ranging from 0.11 to 5.9 mg/L, as determined by Isotech Laboratories, Inc., (or 0.084 to 4.12 mg/L as determined by Seewald Laboratories, Inc.) (table 9). The isotopic compositions of methane in Pike County groundwater samples when compared to methane of known origins plotted mostly in the range of compositions for methane gas of microbial origin (formed by carbon dioxide reduction processes). The sample from one well (see PI-622) plotted in the range of methane gas of thermogenic origin, and the

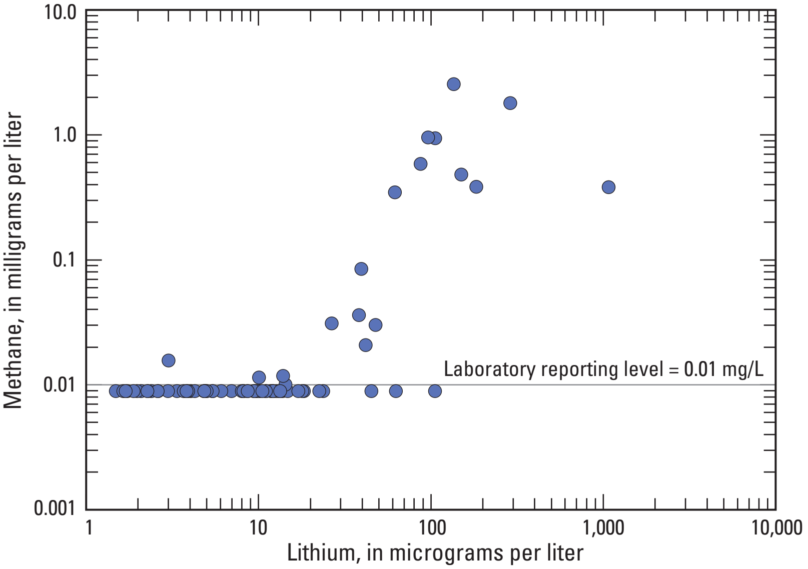


Figure 22. Methane concentrations in relation to lithium concentrations in water samples collected from 79 wells in Pike County, Pennsylvania, 2015. Methane concentrations shown were determined by Seewald Laboratories, Inc., for all 79 samples. [Methane concentrations determined by Seewald Laboratories, Inc., commonly were lower than (by as much as one-half of) methane concentrations determined by Isotech Laboratories, Inc., in 18 replicates samples as shown in table 9.] (mg/L, milligrams per liter)

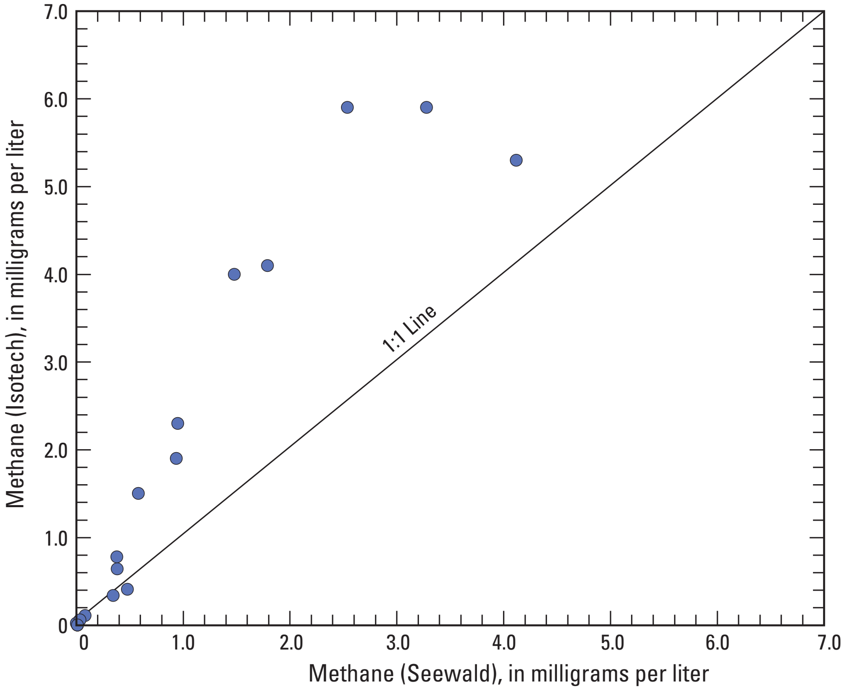


Figure 23. Relation of methane concentrations determined by Isotech Laboratories, Inc., to those determined by Seewald Laboratories, Inc., in groundwater samples collected from 78 wells in Pike County, Pennsylvania, 2015. Methane concentrations determined by Seewald Laboratories, Inc. (Seewald), typically were lower than (by as much as one-half) methane concentrations determined by Isotech Laboratories, Inc., (Isotech) in 18 replicates samples as shown in table 9.

samples from two wells (PI-530 and PI-651) plotted in an undefined field (fig. 24*A*). Microbial methane formed by carbon dioxide reduction is commonly associated with "drift gas" in glacial deposits. Microbial methane generated in near-surface environments such as swamps and marshes is formed by a different chemical process (fermentation) involving acetate and has an isotopic composition that has lighter (more negative) δD_{CH4} and heavier (less negative) in $\delta^{13}C_{CH4}$ values than the "drift-gas" methane (Coleman, 1995). The isotopic composition of methane from the PI-622 well water sample is in the range reported for methane gas derived from the geologic formations that underlie the study area (although gas samples are from elsewhere in Pennsylvania) (fig. 24*A*).

The isotopic composition of the methane in the water samples may not be conclusive, without other information, to identify sources of methane in these samples because the measured isotopic composition can result from more than one pathway or process, including gas maturation, oxidation, and (or) mixing of groundwater within the well or aquifer from different water-bearing zones. As gas matures or originates from greater depths, the isotopic composition of methane apparently becomes heavier (less negative), as shown by the composition of Marcellus gas samples in figure 24*A* (Baldassare and others, 2014). However, shifts in isotopic composition related to gas maturation and oxidation are similar. Oxidation of methane may result in a shift toward heavier composition (toward the upper right corner of figure 24*A*). Oxidation of microbial ("drift-gas" type) methane may account for the observed isotopic composition of samples (PI-530 and PI-651) that plot in the undefined field. Oxidation of microbial ("marsh" type) methane may result in an isotopic composition that is similar to that of thermogenic methane and could explain the isotopic composition of methane in water from well PI-622. Oxidation of the methane may not be occurring at locations in the aquifer where elevated methane concentrations were measured in the groundwater; all samples with methane concentrations greater than 0.5 mg/L had very low oxygen concentrations ($\leq$0.5 mg/L). A previous study (Breen and others, 2007) indicates that the values for isotopic composition of dissolved inorganic carbon, $\delta^{13}C_{DIC}$, would be near -25 ‰ if oxidation of methane were an active process in the groundwater. Limited data for $\delta^{13}C_{DIC}$ (values ranged from -16 to -10 ‰ in samples from three wells) from the 2012 Pike County groundwater study (Senior, 2014) do not provide sufficient evidence to definitively identify reactions involving methane. These $\delta^{13}C_{DIC}$ values of -16 to -10 ‰ likely reflect a mixture of isotopic compositions of DIC from various sources (dissolution of carbonate minerals, silicate mineral weathering reactions involving carbonic acid produced by dissolution of biogenic carbon dioxide entrained in recharge through soil zone, or possible oxidation of methane) and could indicate that oxidation of methane is not an active process where methane in groundwater was measured but could have occurred elsewhere in the aquifer.

Table 9. Concentrations of methane and ethane determined by two laboratories for groundwater samples collected from 17 wells and isotopic composition of methane in 10 of the 17 wells in Pike County, Pennsylvania, 2015.

[Gas concentrations determined by Isotech Laboratories, Inc. (Isotech) and Seewald Labortories, Inc. (Seewald); USGS, U.S. Geological Survey; <, less than; nd, not detected; --, no data or not applicable; C1, methane (one carbon compound); C2, ethane (two carbon compound); C1/C2 ratio, ratio of methane (C1) to ethane (C2) concentration; shaded cells indicate replicate samples; values in italics determined by Seewald Laboratories, Inc.]

USGS local well number	Geologic unit	Sample date	Sample time	Dissolved carbon-based gases			Methane		Concentrations (milligrams per liter)				Ratio of Isotech to Seewald methane concentration
							Isotopic composition		Isotech[1]		Seewald[2]		
				C1 (mole percent)	C2 (mole percent)	C1/C2 ratio	$\delta^{13}C_1$ (per mil)	δDC_1 (per mil)	Methane	Ethane	Methane	Ethane	
Water samples analyzed for dissolved gas and methane isotopic composition													
PI 556	344MNNG	8/6/2015	10:30	0.614	nd	--	-48.04	--	0.11	<0.0002	*0.084*	*<0.01*	1.31
PI 530	341TMRK	8/5/2015	13:30	1.78	nd	--	-62.58	-151.2	0.34	<0.0002	*0.346*	*<0.01*	0.98
PI 609	341LRBW	7/8/2015	13:00	2.19	nd	--	-59.11	-162.4	0.41	<0.0002	*0.479*	*<0.01*	0.86
PI 650	344MNNG	9/23/2015	11:00	2.99	0.0023	1,300	-57.74	-193.9	0.78	0.0012	*0.38*	*<0.01*	2.05
PI 651	341LRBW	9/22/2015	11:00	3.23	nd	--	-54.41	-121.7	0.64	<0.0002	*0.382*	*<0.01*	1.68
PI 146	344MNNG	8/6/2015	14:00	7.17	nd	--	-58.89	-175.3	1.5	<0.0002	*0.582*	*<0.01*	2.58
PI 622	344MNNG	7/14/2015	16:00	7.38	0.0013	5,677	-40.99	-175.0	1.9	0.00067	*0.936*	*<0.01*	2.03
PI 591	344MNNG	8/5/2015	16:00	8.39	0.0007	11,986	-58.97	-203.2	2.3	0.00041	*0.95*	*<0.01*	2.42
PI 592	341LRBW	6/24/2015	11:00	16.17	0.0012	13,475	-63.25	-198.0	4.1	0.00059	*1.79*	*<0.01*	2.29
PI 592	341LRBW	6/24/2015	11:01	16.46	0.0014	11,757	-63.32	-199.7	4.0	0.00069	*1.48*	*<0.05*	2.70
PI 524	341TMSG	6/25/2015	15:00	20.18	0.0021	9,610	-63.44	-219.4	5.9	0.0013	*2.54*	*<0.1*	2.32
PI 524	341TMSG	9/22/2015	13:30	20.21	0.0029	6,969	-63.28	-221.2	5.3	0.0016	*4.12*	*<0.01*	1.29
PI 524	341TMSG	9/22/2015	13:31	21.89	0.0035	6,254	-63.12	-221.6	5.9	0.0019	*3.28*	*<0.01*	1.80
Water samples analyzed for dissolved gas concentrations only													
PI 642	344MNNG	9/22/2015	14:00	0.0020	nd	--	--	--	0.00036	<0.0002	*<0.01*	*<0.01*	--
PI 604	341TMSG	9/21/2015	15:00	0.0052	nd	--	--	--	0.00095	<0.0002	*<0.01*	*<0.01*	--
PI 625	341LRBW	7/15/2015	10:00	0.0075	nd	--	--	--	0.0013	<0.0002	*<0.01*	*<0.01*	--
PI 648	344MRCL	9/24/2015	13:00	0.0102	nd	--	--	--	0.0022	<0.0002	*<0.01*	*<0.01*	--
PI 647	341TMRK	9/23/2015	15:00	0.125	nd	--	--	--	0.023	<0.0002	*0.002*	*<0.01*	11.50
PI 647	341TMRK	9/23/2015	15:01	0.133	nd	--	--	--	0.023	<0.0002	--	--	--
PI 641	341LRBW	9/22/2015	10:30	0.287	nd	--	--	--	0.055	<0.0002	*0.03*	*<0.01*	1.83
PI 653	341TMSG	9/24/2015	11:30	0.317	nd	--	--	--	0.058	<0.0002	*0.036*	*<0.01*	1.61

[1] Isotech gas analytical results differentiated from Seewald results by 5 minute offset in time in USGS NWIS database.

[2] Gas concentrations determined using method PA-DEP 3686.

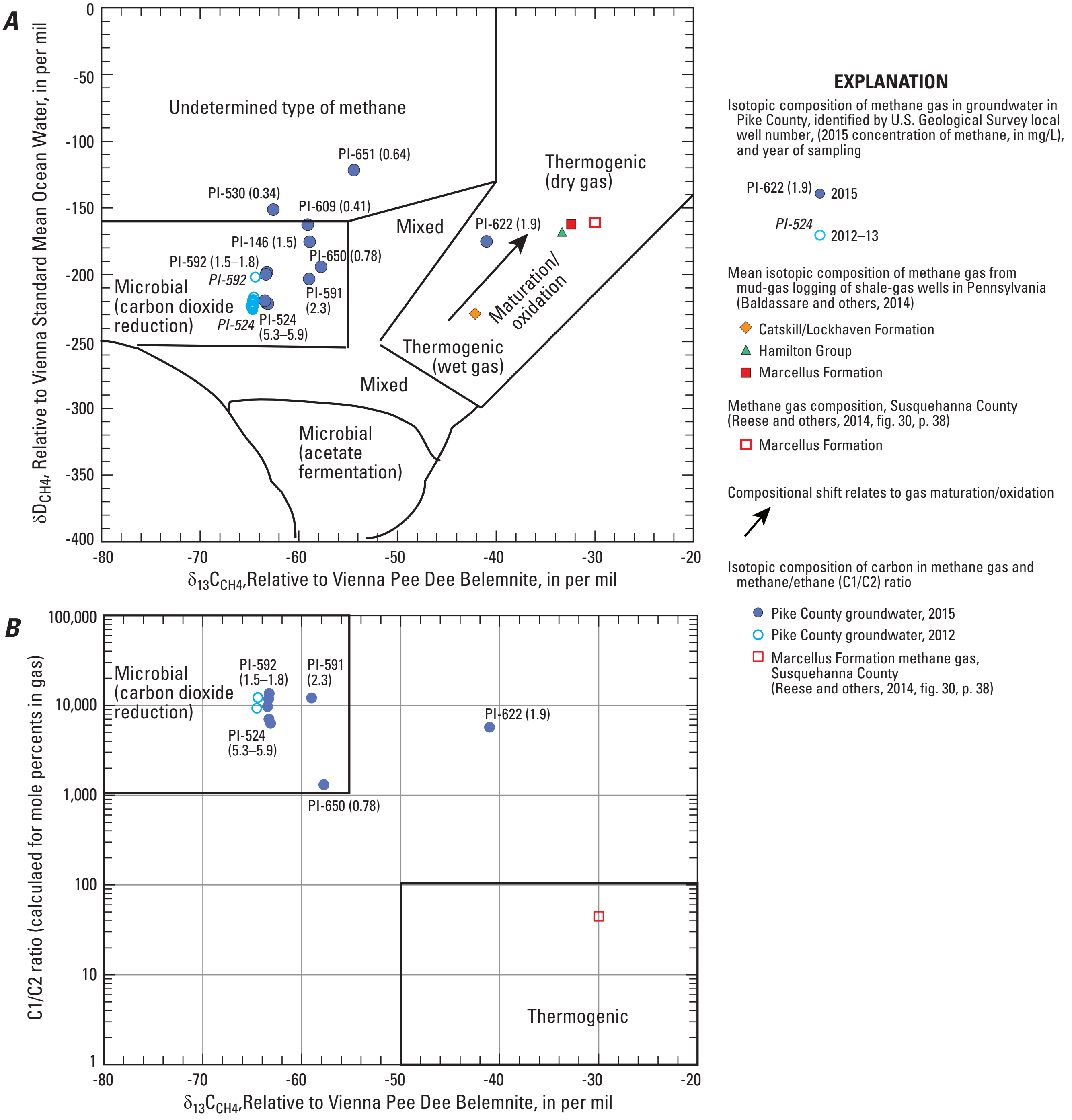


Figure 24. *A*, Isotopic composition of methane in groundwater samples collected from 9 wells in Pike County, Pennsylvania, 2012–15, and in mud-gas logging samples collected from various geologic formations during drilling of gas wells in Marcellus Shale in Pennsylvania, and *B*, C1/C2 ratios in relation to carbon-isotopic composition for methane in the same samples. Boundaries of gas types from Reese and others (fig. 30, p. 38, 2014) and mud-gas logging data from Baldassare and others (2014). ($\partial^{13}C_{CH4}$, isotopic composition of carbon in methane; ∂D_{CH4}, isotopic composition of hydrogen in methane; C1/C2 ratio of methane to ethane)

The isotopic composition of methane in the 2015 Pike County groundwater samples appeared to differ in relation to methane concentration (fig. 24*A*). Samples with relatively higher methane concentrations tended to have a lighter (more negative) isotopic composition for both δD and $\delta^{13}C$ than samples with comparatively lower concentrations (figs. 24*A*; 25*A*, *B*). These relations indicate that processes, such as oxidation, may reduce the concentrations of methane and result in methane that has an isotopic composition relatively more enriched in heavier (less negative) isotopes in some water samples.

Microbial methane may be differentiated from thermogenic methane by evaluating the ratio of methane (C1) to ethane (C2) and higher chain carbon compounds. The ratio of methane to higher chain carbon compounds (commonly denoted as C1/C2 for ratio of methane to ethane or C1/C2+ for ratio of methane to sum of all higher chain carbon compounds) has been used to identify the origins of methane; the ratio also is a measure of gas "wetness," with larger amounts of C2+ compounds in wetter gas. Methane accompanied by low concentrations of ethane and higher chain carbon compounds commonly is called "dry gas." C1/C2+ ratios (calculated for gases reported in units of volume or molar percent) greater than 1,000 have been reported to indicate microbial origins and ratios less than 1,000 to indicate thermogenic origins (Taylor and others, 2000). The relatively small amounts of accompanying ethane and C1/C2 ratios (computed from reported mole percent of gases) greater than 1,000 in the Pike County groundwater samples (fig. 24*B*) may be interpreted to support a microbial origin for the methane (Bernard and others, 1978; Schoell, 1980; Révész and others, 2012). The sample from well PI-622 could also have been derived from thermogenic natural gas that is depleted in ethane for other reasons, such as relative depletion of ethane as part of gas maturation or migration (Coleman and others, 1995).

The isotopic composition and C1/C2 ratios for gas dissolved in the Pike County groundwater samples do not definitively characterize the source of the methane gas. The available evidence indicates that the methane in groundwater appears to be predominantly of microbial origin and may have undergone various amounts of oxidation. Alternatively, methane in at least one of the samples (from well PI-622, fig. 24) may be thermogenic but from a source relatively depleted in ethane, such as been reported for a well in Bradford County, Pennsylvania (Risser and others, 2013). Organic material within the Catskill Formation and other Devonian-age deposits in northern Pennsylvania may be a source of "dry-gas" methane (Wilson, 2014). Use of both the isotopic composition of methane and C1/C2 ratios may be helpful in distinguishing existing baseline gas in groundwater from gas that might be introduced through shale-gas development. Additional data, such as analyses for carbon-14 (for age dating) of methane and for $\delta^{13}C_{DIC}$, discussed previously, might be useful to further characterize the origin and fate of methane in groundwater in Pike County and elsewhere.

Relation of Water Quality to Geochemical and Hydrogeologic Setting

Results from previous assessments of baseline groundwater quality in Pike County (Senior, 2014) and other counties in northeastern Pennsylvania with similar hydrogeology and little to no unconventional drilling for natural gas (Sloto, 2013; Senior and others, 2016) indicate some common associations among constituents and various types of groundwater that are associated with the presence or absence of detectable methane. Groundwater with relatively elevated methane concentrations (greater than about 0.3–0.5 mg/L) differs in composition from that of groundwater with lower methane concentrations by having relatively higher pH (greater than 8) and higher concentrations of sodium, lithium, boron, fluoride, and bromide, as shown in figure 26. Relatively elevated concentrations of some other constituents, such as barium, strontium, and chloride, commonly are present in, but not limited to, well-water samples with elevated methane concentrations in Pike County.

Identification of associations among constituents leads to improved understanding of processes controlling the existing water quality that may be useful in predicting where existing water-quality problems are likely to occur and in determining possible effects related to possible future shale-gas development or other changes in land use. Some associations among constituents likely are due to evolution of groundwater composition along flow paths in the aquifers that may differ in composition (mineralogy), but other associations likely are related to effects of current land-use activities that can contribute specific constituents (such as salts and nutrients from deicing roads and septic systems) to groundwater.

A general conceptual model to describe how groundwater quality evolves in the hydrogeologic setting in northeastern Pennsylvania, including Pike County, is useful to assist in understanding the main patterns of groundwater quality in Pike County. The 2015 water-quality data for Pike County are further analyzed in the following sections to characterize groundwater by use of (1) major ion composition or type through Piper diagrams, (2) geochemical modeling of mineral saturation indices to identify minerals that can affect groundwater composition through dissolution or precipitation, (3) ratios of chloride to bromide and sodium to provide insight on origins of chloride, (4) correlations among constituents to identify patterns in constituent associations and to infer geochemical processes that might affect groundwater composition, and (5) geologic units to identify differences in water quality related to aquifer lithology and mineralogy, and hydrogeologic setting. These additional analyses provide evidence to support the conceptual model of groundwater quality. Additionally, the spatial distribution of groundwater quality throughout Pike County is discussed.

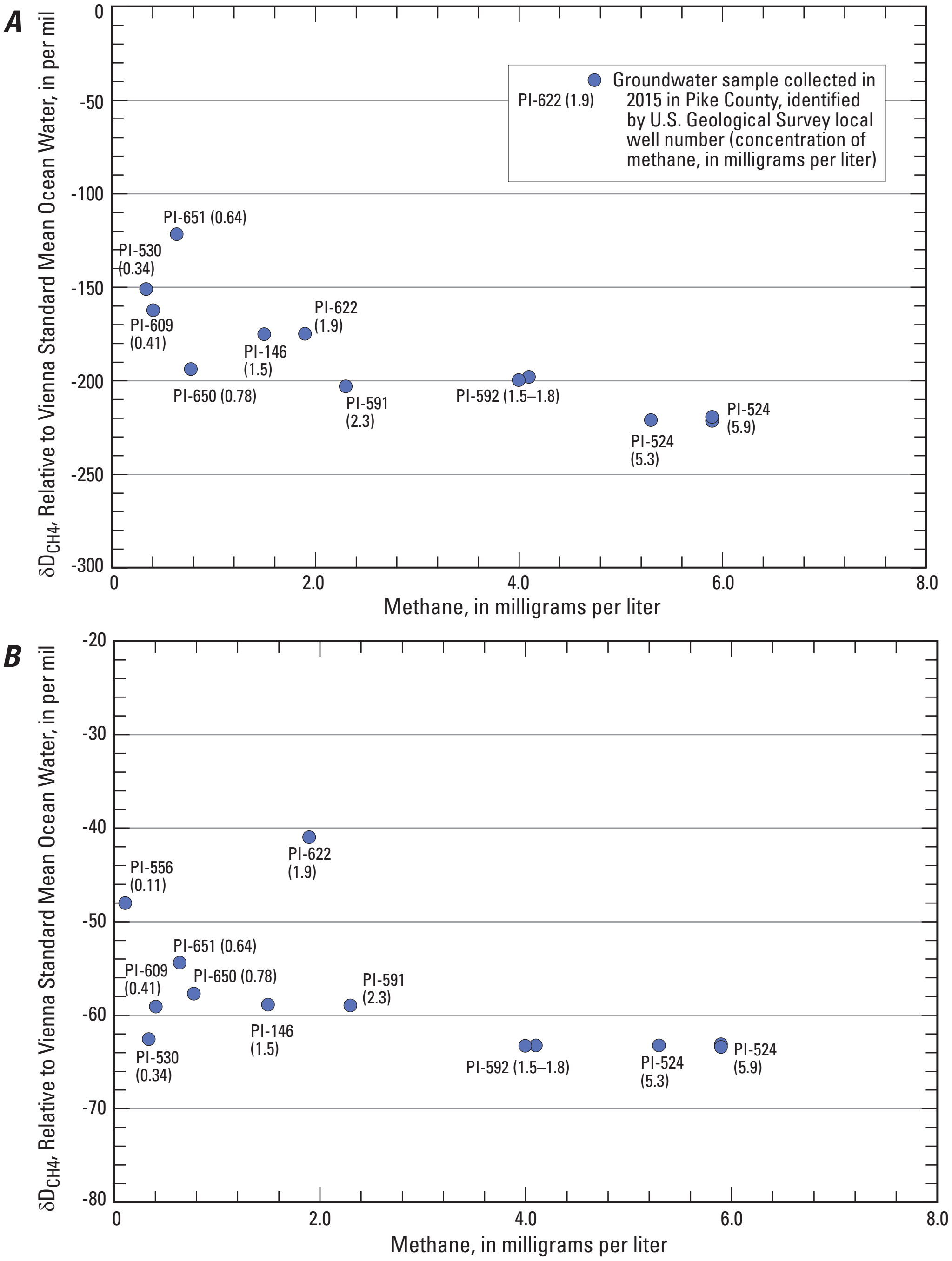


Figure 25. Relation of methane concentrations to isotopic composition of methane (CH_4) as *A*, hydrogen/deuterium component (δD) and *B*, carbon-12/carbon-13 component ($\delta^{13}C$) in groundwater samples collected from 10 wells in Pike County, Pennsylvania, 2015. The methane concentration was too low in the sample from one well (PI-556) to determine δD_{CH4}.

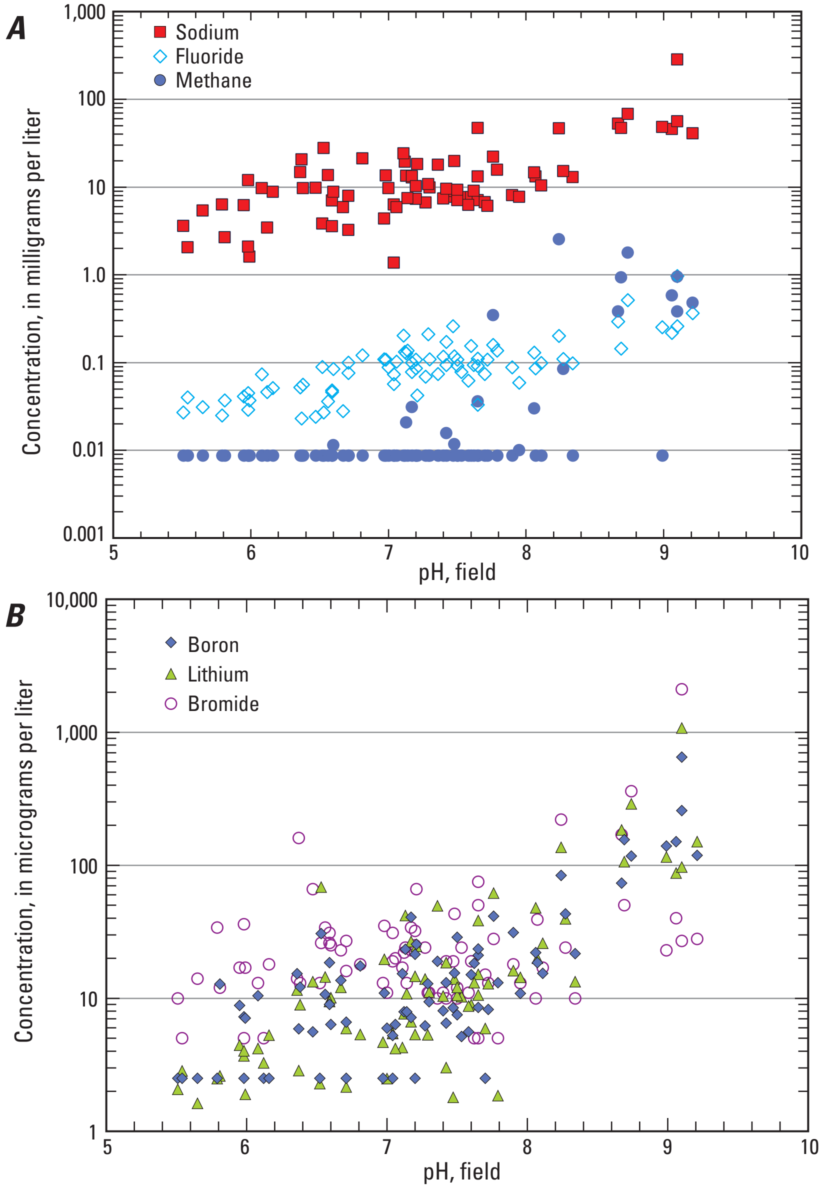


Figure 26. Relation of pH to concentrations of *A*, sodium, fluoride, and methane and *B*, lithium, boron, and bromide in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

Evolution of Chemical Composition and Conceptual Hydrogeochemical Model

The conceptual model for geochemical evolution of groundwater in hydrogeologic settings in northeastern Pennsylvania involves chemical reactions starting in the recharge areas and continuing along the groundwater flow paths. A schematic diagram illustrating the conceptual model of how water quality is thought to evolve along local and regional groundwater flow paths, based on the data analysis presented in this report and previous studies (for example, Senior and others, 2016), is shown in figure 27. The schematic diagram shows the general distribution of groundwater chemistry types but does not depict the complexity of groundwater flow paths in the hydrogeologic setting. The geologic units underlying Pike County form a layered (sedimentary) fractured-rock aquifer system, which has been described as having local, intermediate, and regional flow.

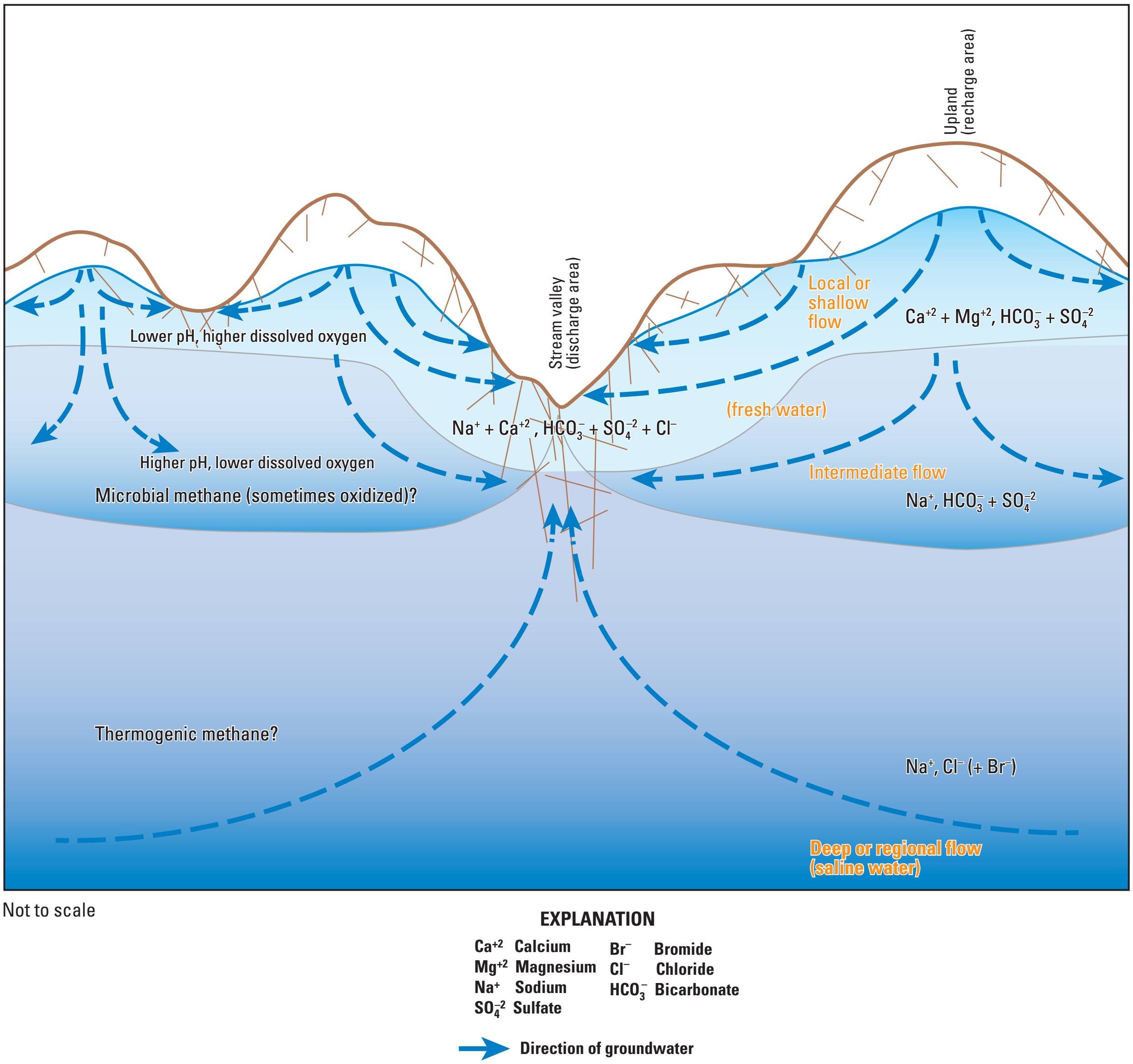


Figure 27. Schematic diagram of generalized conceptual hydrogeochemical model for distribution of fresh and saline groundwater in fractured bedrock aquifer setting showing 1) evolution of groundwater composition from calcium-magnesium-bicarbonate-sulfate type with relatively low pH and high dissolved oxygen concentrations (DO) in recharge areas and local flow zones to predominantly sodium-bicarbonate-sulfate with higher pH and lower DO along intermediate flow paths and 2) presence of deeper or regional water that is relatively saline and possibly mixing with intermediate-flow waters, especially in discharge areas, such as stream valleys, where methane from microbial and (or) thermogenic sources appears to be present most frequently and at highest concentrations in northeastern Pennsylvania. (Groundwater-flow directions shown in blue with local, intermediate, and regional flow paths indicated.)

Groundwater in the uplands tends to be relatively dilute, acidic, oxygenated, and young, reflecting the quality of recharge water and degree of chemical weathering. This recently (less than a few years) recharged shallow groundwater in uplands likely has limited interaction with aquifer and soil materials and, consequently, has relatively low pH, low TDS concentrations, and high DO concentrations. The precipitation that recharges aquifers in northeastern Pennsylvania is dilute and acidic, although currently (2015) less acidic than it was 30 years ago. The pH of precipitation has increased from about 4.2 in 1985 to about 5.0 in 2013 (National Atmospheric Deposition Program, 2016). In addition, rocks that underlie uplands tend to be more resistant to erosion and mineral weathering than rocks underlying lower elevations, and thus, groundwater in the uplands may also have smaller amounts of dissolved constituents than groundwater at lower elevations because of differences in mineralogy.

After recharge occurs in the shallow part of the aquifer, groundwater continues to interact with aquifer materials, and relatively soluble minerals, such as calcite, begin to dissolve. As calcite dissolves, pH rises to near neutral, and calcium, magnesium, and bicarbonate (alkalinity) concentrations increase. Hardness (a measure of calcium and magnesium) reaches a maximum near a pH of 7.5. Along the groundwater flow paths, oxygen is consumed by various biochemical reactions involving oxidation of organic material in soils or aquifer or by oxidation of some minerals, such as pyrite. Exchange of alkali metals (such as sodium and lithium) for alkaline earth metals (calcium, magnesium, and to a lesser extent barium and strontium) on mineral surfaces (such as illite, a mineral reported to be present in aquifer materials) is thought to occur on the basis of apparent relations between various constituents. Through ion exchange, concentrations of calcium and magnesium decrease, whereas sodium and other alkali metals, alkalinity, and pH continue to increase. This shift from calcium to sodium as the predominant cation generally is accompanied by increases in pH, alkalinity, and TDS. The increases in pH, alkalinity, and TDS result from the progressive dissolution of calcite (to maintain equilibrium) as calcium and magnesium are removed from solution by exchange processes. Formation of sodium-bicarbonate waters with elevated pH as a result of ion-exchange (sodium for calcium) has been reported for shallow shale aquifers elsewhere (Kresse and others, 2012). At pH values greater than 8, oxyanions, such as arsenate, are mobilized, resulting in increases in dissolved concentrations of arsenic and other trace elements with similar chemical properties.

Mixing of groundwater with naturally occurring Appalachian Basin brines or other saline waters from deep parts of the aquifer (fig. 27) or areas of restricted flow (low permeability) where flushing of the aquifer by freshwater may be limited and residual brines may be present contributes certain constituents, such as bromide and chloride. Wells that penetrate deep parts of the aquifer or are near areas of regional groundwater discharge appear to be the most likely to intercept groundwater with a saline component. Geochemical modeling indicates that the measured (observed) concentrations of chloride and bromide in nearby Wayne County groundwater samples with the highest concentrations of bromide could result from a mixture of freshwater and brine, with brine representing less than 0.02 percent of the solution (Senior and others, 2016). Other sources of chloride include road salt and septic effluent. Similar processes likely occur in Pike County.

Brines with elevated concentrations of sodium, chloride, bromide, barium, strontium, and other solutes occupy pore spaces in deep sedimentary rocks throughout Pennsylvania. The highly saline sodium/chloride brines and overlying groundwaters of intermediate salinity generally are present 1,000 feet or more below the surface (Feth and others, 1965; Heisig and Scott, 2013). Such brine-affected waters typically discharge from gas or oil wells (Dresel and Rose, 2010) and may be present locally at springs and some shallow water wells in northeastern Pennsylvania (Llewellyn, 2014), although shallow (less than 1,000 ft) brines have not been reported in Pike County.

The shallowest flow systems tend to be present in highly fractured aquifers where actively circulating freshwater over time has depleted sodium, chloride, and other vestiges of residual or connate brines (fluids trapped in rocks during and after formation). In the shallow groundwater zone (fig. 27), water types of predominantly calcium-magnesium/bicarbonate and calcium-magnesium/bicarbonate-sulfate compositions are produced by the active weathering of moderately soluble carbonate minerals and, to a lesser extent sulfate, sulfide, and silicate minerals. In the intermediate zone, groundwater of sodium/bicarbonate type and moderate salinity typically is present between the shallow, actively circulating freshwater and the deeper, slower moving sodium/chloride type water. Poth (1963) explains the freshening process in the intermediate zone as follows: "[t]he chloride is readily removed by circulating groundwater, but the sodium is more difficult to remove because much of it is adsorbed on the clay in the rocks." The sodium that occupies exchange sites on clay minerals, tends to be displaced by calcium and magnesium though cation exchange. Such processes lead to the formation of sodium/bicarbonate type waters, which are transitional between the sodium/chloride waters at great depth and the calcium-magnesium/bicarbonate waters in the overlying freshwater zone.

Most wells constructed for domestic use are completed within the local, freshwater flow system. Wells with known construction sampled for this study in Pike County were completed at depths ranging from 80 to 680 ft below land surface; one-half of these were drilled to depths of about 180 to 360 ft. The observed water types and relations among selected constituents and pH in Pike County, nearby Wayne County (Senior, 2014; Sloto, 2014; Senior and others, 2016), and other areas in northeastern Pennsylvania (Sloto, 2013; Gross and Cravotta, 2017) indicate that dilute recharge waters likely interact with minerals in the near surface, gradually becoming less acidic and less oxygenated, while increasing in concentrations of dissolved constituents.

Groundwater with lower pH (<6.4) tended to be the most dilute (TDS < 100 mg/L) and have higher DO concentrations (>3 mg/L), whereas groundwater with higher pH (>7.8) tended to have higher concentrations of TDS (>150 mg/L) and lower concentrations of DO (<1 mg/L). Geochemical modeling showed that mineral dissolution, cation exchange (sodium for calcium), and mixing with small amounts of brine are processes that might explain the observed quality of groundwater associated with various ranges of methane concentrations in northeastern Pennsylvania, and Wayne and Lycoming Counties (Senior and others, 2016; Gross and Cravotta, 2017), and could be processes that help to explain the quality of groundwater with various methane concentrations in Pike County.

Types of Groundwater as Characterized by Major Ions

The relative proportions of major ions in water samples may be used to distinguish different types of water, as shown on Piper diagrams (fig. 28*A*, *B*). The types of water reflect natural processes of the interaction of recharge with minerals in the aquifer, geochemical reactions in the groundwater flow system, and (or) inputs from human activities, such as introduction of sodium chloride by road-salt applications. Major cations are calcium, magnesium, and sodium (and potassium which usually is less than, but plotted with, the sodium component). Major anions are bicarbonate (HCO_3^-), sulfate, and chloride (and nitrate and fluoride, both of which are plotted with, but usually are less than, the chloride component). The types of waters are characterized by the predominant cation(s) and anion(s), calculated as a percentage of total cation or anion milliequivalents. For example, a calcium-bicarbonate type water has more than 50 percent calcium and bicarbonate as cations and anions, respectively, and in a mixed calcium-magnesium-bicarbonate water, the sum of calcium and magnesium ions is more than 50 percent of cations.

The major ion composition of water samples collected from 79 wells during 2015 in Pike County as plotted on Piper diagrams using different symbols to distinguish ranges of pH and SC (fig. 27*A*, *B*) shows differences in relation to those characteristics that may be helpful in distinguishing the origins of the groundwaters. Comparison of diagrams displaying water composition for ranges of pH and SC (fig. 28*A*, *B*) indicates the following general patterns: (1) the most acidic waters are of mixed ion composition with a wide range of SC values; (2) intermediate pH waters are predominantly calcium-bicarbonate type with intermediate SC; and (3) the highest pH waters are predominantly sodium-bicarbonate type with relatively higher SC. The SC is directly and linearly related to TDS in the Pike County groundwater samples (fig. 8), such that a SC of 130 µS/cm at 25 °C is approximately equivalent to 80 mg/L TDS, and a SC of 435 µS/cm at 25 °C is approximately equivalent to the SMCL of 250 mg/L for TDS. SC and TDS values in groundwater generally indicate the amount of dissolved constituents contributed by mineral weathering, although high SC and TDS values also may be related to road-salt or other salt contamination. The shift in groundwater composition from calcium (Ca) and magnesium (Mg) as the predominant cations to sodium (Na) as the predominant cation in Pike County groundwater accompanied by increases in pH and SC (and TDS), as shown on the Piper diagrams, likely reflects the processes of calcite dissolution followed by cation exchange, as described in the section “Evolution of Chemical Composition and Conceptual Hydrogeochemical Model.”

The major ion composition of about two-thirds of the Pike County groundwater samples is predominantly calcium-bicarbonate (about 38 percent of samples) or mixed calcium-magnesium-bicarbonate (about 25 percent of samples). The pH of these predominantly calcium-bicarbonate type and mixed calcium-magnesium-bicarbonate type water samples was near neutral, ranging from 6.5 to 8.5 (fig. 28*A*). The SC of most of these samples ranged from relatively low (less than 130 µS/cm at 25 °C) to intermediate (up to 280 µS/cm at 25 °C); a few transitional (toward more chloride-type water) samples had higher SC of as much as 500 µS/cm at 25 °C (fig. 28*B*). The calcium-bicarbonate type water samples with near neutral pH and a range of low to intermediate SC (and TDS concentrations) could have been produced by the dissolution of calcite with differing amounts of mineral dissolution (as indicated by TDS concentrations).

A few water samples (8 of 79 or about 10 percent) plot as much higher in sodium than the other samples, have bicarbonate as the predominant anion, and thus can be categorized as sodium-bicarbonate type water (more than 50 percent sodium and bicarbonate as cations and anions, respectively). In contrast to the calcium-carbonate type water samples, the pH of these predominantly sodium-bicarbonate type water samples is mostly alkaline (greater than 8.5) (fig. 28*A*) with somewhat higher SC, ranging from greater than 210 to 400 µS/cm (fig. 28*B*). Most water samples that are classified as sodium-bicarbonate types have intermediate to high SC, TDS, and pH values, indicating relatively greater amounts of mineral dissolution and sodium-for-calcium cation exchange.

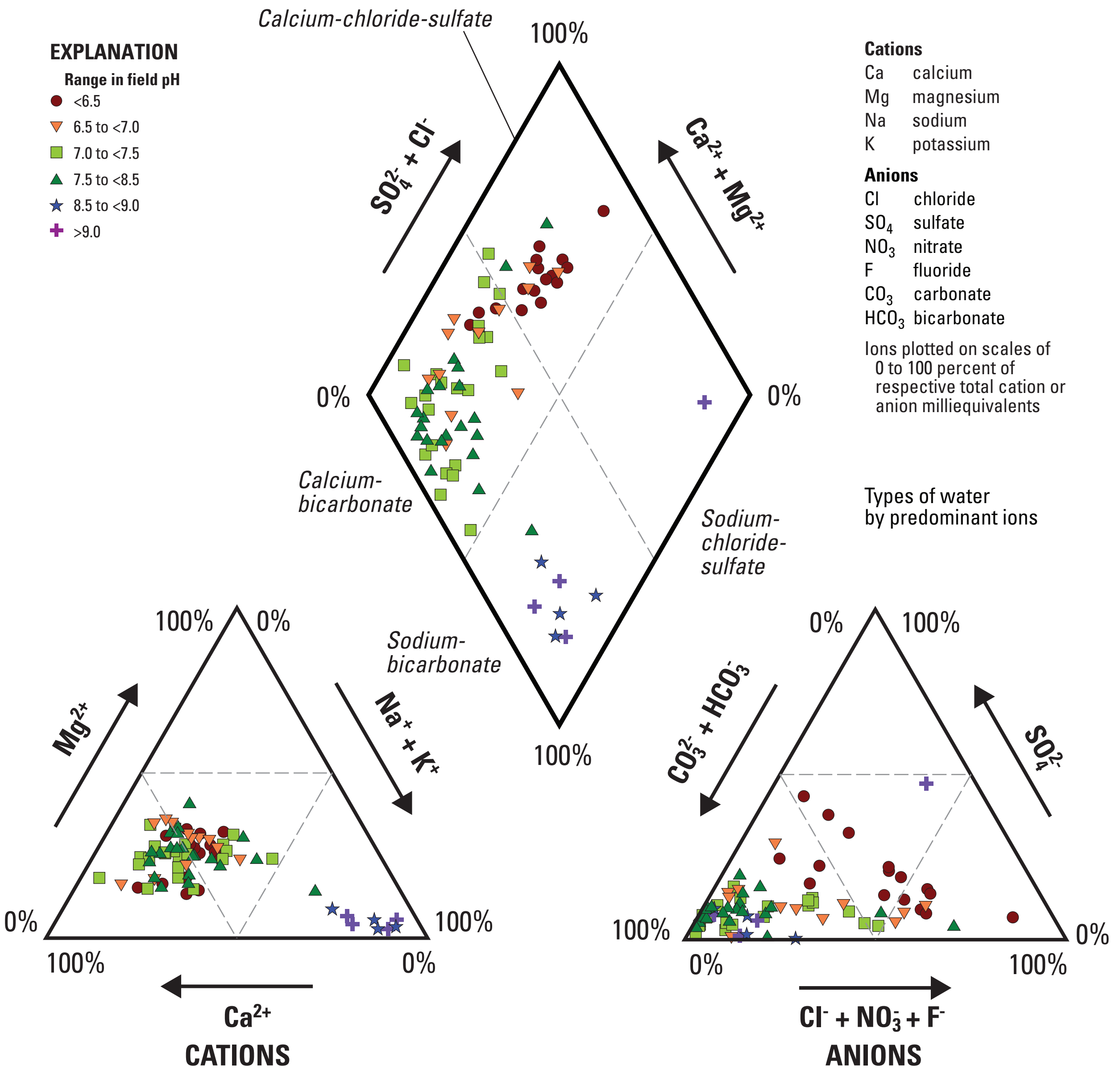


Figure 28. Piper diagrams showing major ion composition for water samples collected from 79 wells in Pike County, Pennsylvania, 2015, for ranges of *A*, field pH and *B*, laboratory specific conductance.

Another sample (from well PI-650) with sodium as the predominant cation plotted as a sodium-sulfate-chloride type water with slightly greater percentages of sulfate than chloride, which exceeds bicarbonate, as anions (fig. 28*A*, *B*). This sample from well PI-650 had high pH (greater than 9) and the highest SC (1,580 µS/cm) (fig. 28*A*, *B*) of the 79 well-water samples. Although the water sample from well PI-650 plotted in the area of the Piper diagram near the plotted location for Pennsylvania oil and gas-well brines and Marcellus flowback (sodium/chloride type) (Senior and others, 2016; fig. 25*B*, p. 46), it had a greater concentration of sulfate (362 mg/L) and much lower concentrations of chloride (223 mg/L) and sodium (283 mg/L) than typical brines (table 1). Geochemical modeling done in a study of similar groundwater in nearby Wayne County indicates that sodium-chloride type water with elevated pH can be formed by calcite dissolution followed by sodium-for-calcium cation exchange and mixing with residual brines in the aquifer (Senior and others, 2016). Likewise, a sodium-sulfate-bicarbonate type water could result where pyrite oxidation has occurred in addition to calcite dissolution and cation exchange. The geochemical modeling also describes an evolution pathway for mixing of groundwater plus road deicing salt that produces sodium/chloride water type (on the right corner of the Piper diagram). Sodium-chloride type waters resulting from contamination by road salt

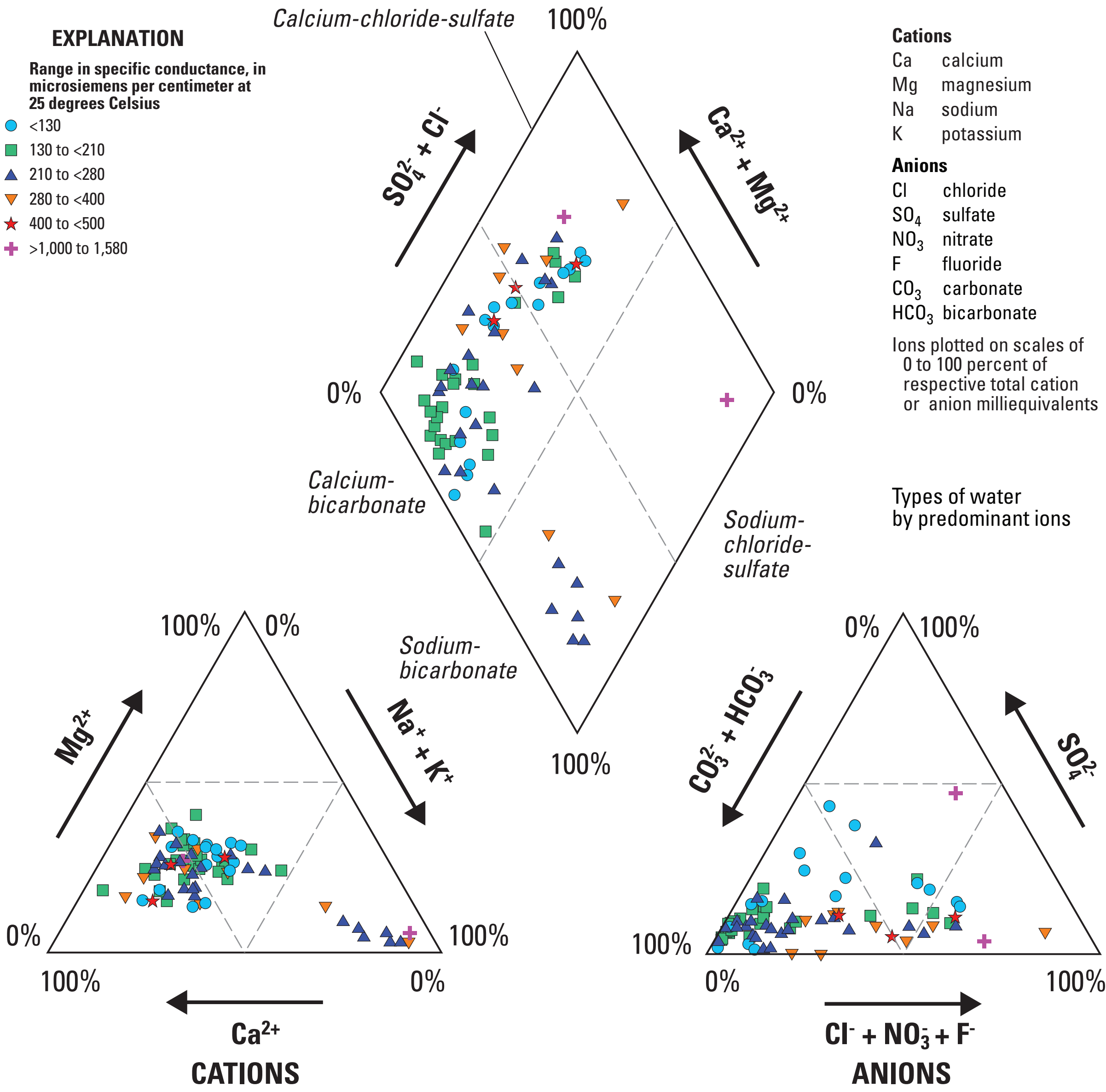


Figure 28. Piper diagrams showing major ion composition for water samples collected from 79 wells in Pike County, Pennsylvania, 2015, for ranges of *A*, field pH and *B*, laboratory specific conductance.—Continued

have been described elsewhere in northeastern Pennsylvania (Reilly and others, 2015).

The remaining water samples can be characterized as mixed calcium-chloride-sulfate or mixed calcium-bicarbonate-chloride-sulfate type waters with a wide range in pH (< 6.5–8.5) and SC (less than 130 to greater than 1,000 µS/cm at 25 °C) (fig. 28*A*, *B*). All of the most acidic of the 79 well-water samples (lowest pH, less than 6.5) plotted as these mixed-type waters. These most acidic samples also tended to be the most dilute (SC less than 130 µS/cm at 25 °C). The characteristics of the dilute, acidic samples could have been formed by evaporation of rainwater (recharge) with minor additions of sulfate (from pyrite, gypsum, or other sources) and chloride (from road salt or other sources) and limited dissolution of calcite. Samples with pH in the range of 6.5–7.5 tended to have intermediate to relatively high SC (210–500 µS/cm at 25 °C) with generally more bicarbonate than the dilute samples, indicating greater amounts of mineral dissolution and the addition of chloride. One (well PI-653) of the two samples with pH in the range of 7.5–8.5 had very high SC (>1,094 µS/cm at 25 °C) and elevated calcium, magnesium, sodium, and chloride concentrations, possibly indicating the presence of calcium, magnesium, and sodium deicing salts.

Geochemical Modeling of Mineral Saturation Indices

The potential for various minerals to be dissolved or precipitated can affect the composition of groundwater and can be evaluated by calculating the mineral SI, which takes into account such factors as pH and concentrations of all ions in solution. A negative value for SI indicates that the mineral is undersaturated, unstable, and can dissolve. A zero value for SI indicates that the mineral is at saturation (equilibrium between dissolution and precipitation), and a positive value for SI indicates that the mineral is oversaturated and can precipitate out of solution.

The bedrock units underlying Pike County consist of marine (Marcellus, Mahantango, and Trimmers Rock Formations) and non-marine (Catskill Formation) clastic sedimentary rocks, including shale, siltstones, and sandstones, that are mainly composed of silicate and aluminosilicate minerals, such as quartz, chlorite, muscovite, and illite (table 3), plus minor carbonate, sulfate, sulfide, and oxide minerals that occur as clasts, fracture filling, and cements. Feldspar is present in several members of the Catskill Formation but is not reported for the Poplar Gap and Packerton members of the Catskill Formation and is limited to trace amounts or no presence in the marine sedimentary rocks (Marcellus, Mahantango, and Trimmers Rock Formations; table 3) (Sevon and others, 1989). Although mineralogy is expected to vary locally, the carbonate (such as calcite, $CaCO_3$), sulfate, and sulfide (such as pyrite, FeS_2) minerals in particular are prone to weathering in near-surface environments where they may be important sources of hardness (Ca and Mg), acid neutralizing capacity (ANC) or alkalinity, sulfate (SO_4), and other solutes. Weathering of aluminosilicates, such as feldspars, can lead to release of cations, silica, and aluminum, and to formation of clays, which may undergo further dissolution. Additionally, various clay minerals, which are hydrated aluminosilicates having layered crystal structures that readily accommodate ionic substitutions, are widely recognized to be involved in cation-exchange and sorption processes (Hem, 1985; Appelo and Postma, 2005). In Pike County, for example, reactions involving common clay minerals in soils, shales, and siltstones, such as chlorite, muscovite, illite, and kaolinite, could affect solute concentrations in groundwater in the study area through both mineral dissolution/precipitation and ion-exchange processes.

To evaluate the potential for various minerals to be dissolved or precipitated by the groundwater, the SI values computed using PHREEQC (Parkhurst and Appelo, 2013) and WATEQ4F database (Ball and Nordstrom, 1991) are displayed as a function of pH for the 2015 Pike County well-water samples in figure 29. The SI for most carbonate minerals is negative at low pH (acidic water), indicating potential for dissolution, but increases with increasing pH. Calcite ($CaCO_3$) is a carbonate mineral reported to be present in Pike County rocks and may be an important source of Ca, alkalinity (HCO_3^-, CO_3^{2-}), and acid neutralizing capacity (ANC). The samples that had pH less than or equal to 8 were undersaturated (SI less than 0) with respect to calcite and dolomite [$CaMg(CO_3)_2$], indicating the groundwater could feasibly dissolve these carbonate minerals, if present. The SI for calcite increased linearly from pH of 5.5 (SI -4.2) to pH of 8 (SI -0.1), above which the SI value approximately equal to 0 was maintained. Despite the indicated equilibrium, dissolution of calcite could be anticipated to continue at pH values greater than 8 because of the removal of calcium in the exchange of sodium. As the concentrations of calcium are depleted, the groundwater could dissolve more calcite with progressive increases in concentrations of ANC and pH to values as high as 9.2 (fig. 29).

The major Ca and Mg carbonate minerals commonly contain traces of other cations, including iron (Fe), manganese (Mn), strontium (Sr), and barium (Ba) (Hanshaw and Back, 1979). These trace cations also could be present locally as pure carbonate phases. Understanding sources of, and geochemical controls on, barium and strontium in groundwater is important in baseline assessments because flowback and produced waters from gas-well development contain elevated concentrations of these constituents. Dissolution of calcite, dolomite, or other carbonates could release various trace cations to solution. Over the range of pH, the SI values for siderite ($FeCO_3$) and witherite ($BaCO_3$) were negative (fig. 28), indicating these carbonate minerals, if present, could feasibly be dissolved by the groundwater. However, the SI values for other carbonate minerals—rhodochrosite ($MnCO_3$) and strontianite ($SrCO_3$)—change from predominantly negative at low pH to mixed negative and positive with increasing pH, indicating decreasing potential for dissolution at higher pH values and potential solubility controls on concentrations. The concentrations of trace elements may be further limited by the formation of other solid phases. For example, the accumulation of SO_4 from rainfall, sulfide mineral oxidation, or gypsum ($CaSO_4 \cdot 2H_2O$) dissolution could promote the supersaturation and precipitation of barite ($BaSO_4$) and thus limit the concentrations of dissolved barium. The SI for barite in 2015 Pike County groundwater samples ranged from negative values at pH less than 6.5, indicating undersaturation, to mixed negative, near zero, and positive values at pH greater than 6.5 (fig. 29), indicating some potential for barite precipitation and limits to barium concentrations at pH greater than 6.5. In contrast, celestine ($Sr\ SO_4$) was indicated to be undersaturated, and therefore an unlikely mineral to limit strontium concentrations, in all samples. However, strontium concentrations could possibly be limited by coprecipitation with barium in barite (Hanor, 1968), as well as by precipitation of strontianite ($SrCO_3$) at high pH (near pH of 9). Furthermore, strontium, barium, and other trace cations could participate in exchange reactions with clay minerals or adsorption processes, which may affect concentrations of those constituents in groundwater.

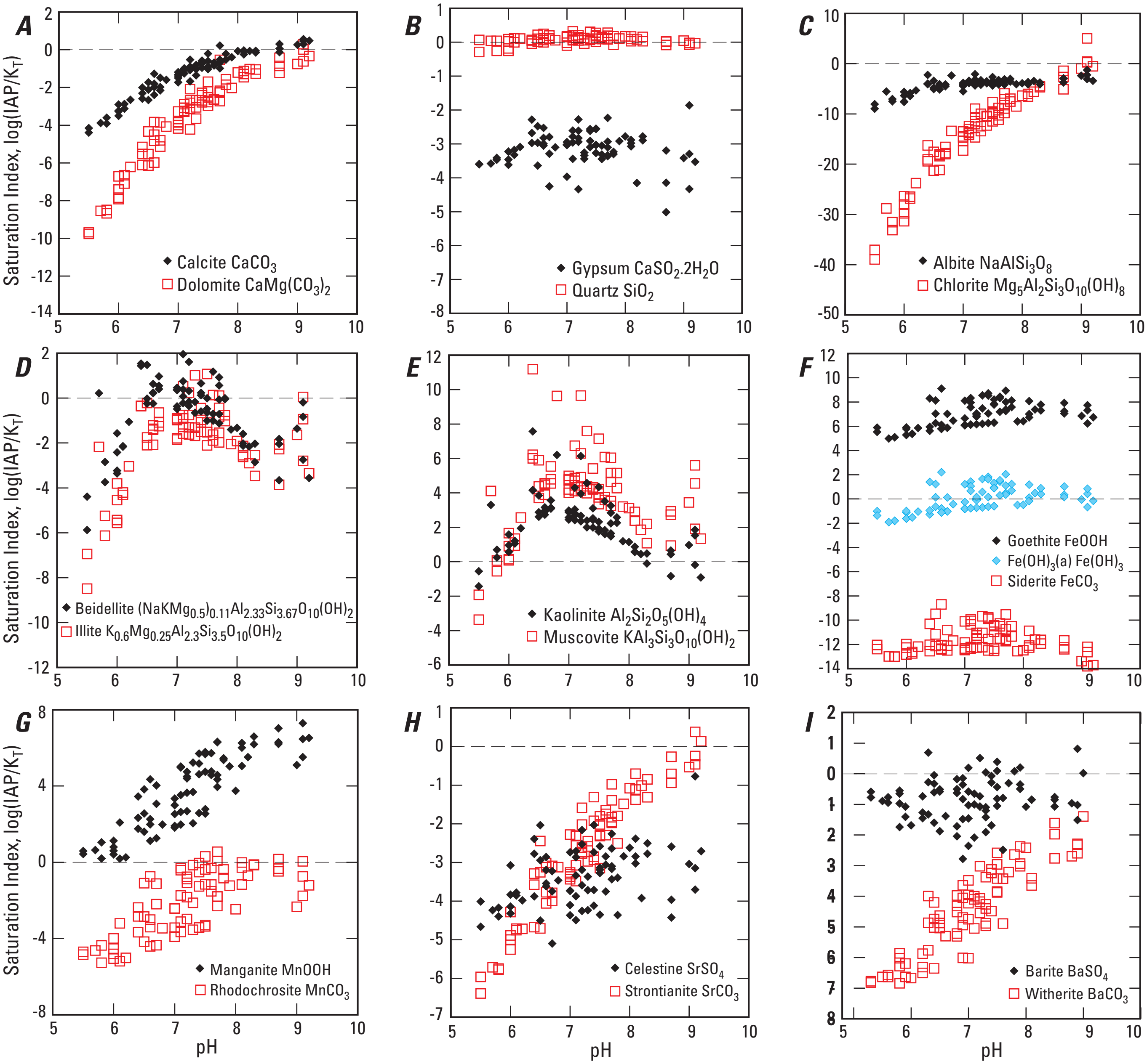


Figure 29. Relation of saturation indices for minerals and other solids to pH for groundwater samples from 79 wells in Pike County, Pennsylvania, 2015, computed using PHREEQC (Parkhurst and Appelo, 2013) with WATEQ4F database (Ball and Nordstrom, 1991). [IAP, ion activity product; KT, solubility product (thermodynamic equilibrium constant)]

Over the range of pH for the samples in this study, the unstable aluminosilicates, such as feldspar, generally would be anticipated to dissolve incongruently, releasing cations to solution while silicon (Si) and aluminum (Al) are retained in secondary solid phases, such as quartz and kaolinite. On the basis of negative SI values, feldspar minerals represented by albite ($NaAlSi_3O_8$) were undersaturated (fig. 29) and could feasibly dissolve in groundwater, albeit slowly. In addition to being sources of base cations [sodium, potassium (K), calcium], aluminum, and silica, the feldspars commonly contain traces of phosphate (PO_4) and, thus, could be a potential natural source of phosphate in the sampled groundwaters (Denver and others, 2010). The “clay” (phyllosilicate) mineral chlorite $[Mg_5Al_2Si_3O_{10}(OH)_8)]$ was undersaturated at most pH values to about 9.1; at greater than 9.1, the SI value was positive or approximately equal to zero, indicating that chlorite would not continue to dissolve as a source of magnesium. In contrast, quartz (SiO_2) and kaolinite $[Al_2Si_2O_5(OH)_4]$ were saturated or supersaturated and thus are stable. Other clay minerals, including illite $[K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2)]$, muscovite $[KAl_3Si_3O_{10}(OH)_2]$, and beidellite $[(NaKMg_{0.5})_{0.11}Al_{2.33}Si_{3.67}O_{10}(OH)_2)]$, had SI values that ranged from negative to positive (fig. 29), indicating these or similar phases could potentially dissolve where undersaturated, or such phases could participate in surface complexation or exchange reactions where saturated or supersaturated.

Hydrous oxides of iron [FeOOH, $Fe(OH)_3(a)$] and manganese (MnOOH) are common in soils and weathered bedrock. The groundwaters sampled for the study generally were indicated to be saturated or supersaturated with respect to some iron and manganese oxides, which indicates such phases could precipitate as stable secondary phases (although the redox state is uncertain) upon dissolution of carbonates or oxidation of sulfides containing iron and manganese. At low pH, the iron oxide [$Fe(OH)_3(a)$] was slightly undersaturated (fig. 29), indicating possible dissolution of that iron-bearing mineral under acidic conditions (pH less than 6.5). The common occurrence of total iron concentrations that exceed dissolved iron concentrations in the 2015 Pike County groundwater samples indicates particulate iron is present, which is consistent with positive SI vales for hydrous iron oxides. The hydrous iron and manganese oxides are widely recognized as potential sorbents of trace anions such as arsenic, selenium, molybdenum, and boron (As, Se, Mo, B) at acidic pH and cations such as copper, lead, and zinc (Cu, Pb, Zn) at neutral to alkaline pH (Appelo and Postma, 2005; Dzombak and Morel, 1990; Hem 1985). Adsorption, or surface complexation, can maintain trace-element concentrations at low levels compared to the solubilities of corresponding trace-element minerals; however, as the pH or redox conditions change, the trace ions could be released into solution by the oxides (Chapman and others, 2013; Cravotta and Brady, 2015). In the Pike County groundwater samples, the pattern of higher concentrations of copper, lead, and zinc in acidic samples and higher concentrations of arsenic, selenium, molybdenum, and boron in alkaline samples may reflect differing adsorption characteristics of these ions on hydrous iron and manganese oxides.

Ratios of Chloride, Bromide, Sodium, and Lithium in Groundwater

Chloride/bromide ratios can be useful in distinguishing different sources of chloride (Davis and others, 1998; Mullaney and others, 2009; Whittemore, 2007). Bromide, like chloride, is a soluble anion that exhibits conservative transport properties and can be used as a tracer. Some sources of chloride introduced into the environment by human activities, such as salt (sodium chloride, NaCl) used for road deicing or present in septic effluent, typically have relatively low amounts of bromide and, consequently, relatively high chloride/bromide mass ratios (Davis and others, 1998).

In Pike County, chloride concentrations greater than a few milligrams per liter in shallow groundwater likely represent the effects of local and distributed land-use activities or potential contributions from naturally occurring deeper, more saline groundwater of regional extent. The concentrations of chloride (0.47–246 mg/L) ranged widely for the groundwater samples collected in 2015 from 79 wells, as did concentrations of two constituents commonly associated with chloride—sodium (1.37–283 mg/L) and bromide (<0.01–2.1 mg/L) (table 4). In some samples, the elevated chloride concentrations are associated with elevated concentrations of sodium (fig. 30*A*) and, in a few cases with relatively elevated nitrate, which indicates effects from human or animal waste. In other samples, elevated chloride concentrations are associated with relatively elevated bromide concentrations (fig. 30*B*), which could indicate effects from residual brine of geologic origin. Recent studies of groundwater quality in nearby Susquehanna County in northeastern Pennsylvania (Warner and others, 2012; Llewellyn, 2014) describe groundwater that has relatively elevated concentrations of chloride and chloride/bromide ratios indicative of possible mixing of freshwater within the shallow aquifer with higher salinity or brine-type waters.

Plots of the mass ratio of chloride to bromide (Cl/Br) and the concentration of bromide or sodium compared to the concentration of chloride in groundwater samples show potentially different sources of salinity, including road-deicing salts and Appalachian Basin brines. Bromide concentrations determined by the laboratory (Weck Laboratories, Inc.) with the lowest reporting level of 0.010 mg/L (10 µg/L) for bromide in summer 2015 were used to calculate chloride/bromide mass ratios. The chloride/bromide mass ratios for the 2015 water samples from 79 wells in Pike County are shown in relation to chloride concentrations in figure 30*C*, which also shows curves (mixing lines) representing compositions resulting from mixing of different proportions of dilute groundwater with (1) low-bromide salt (such as sodium chloride used for road salt or in septic effluent) or (2) Appalachian Basin brine, including those of Marcellus Shale type oil and gas brines.

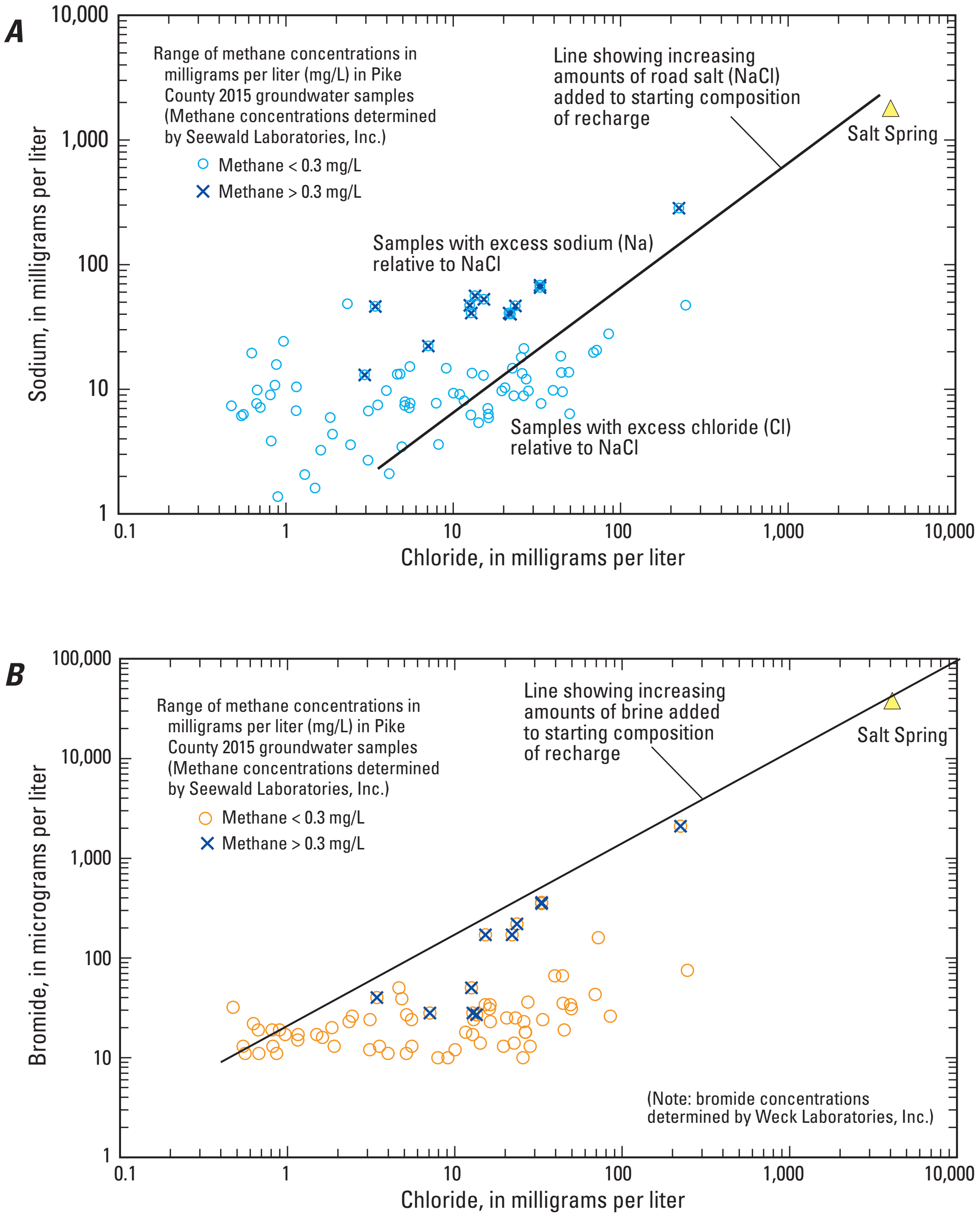
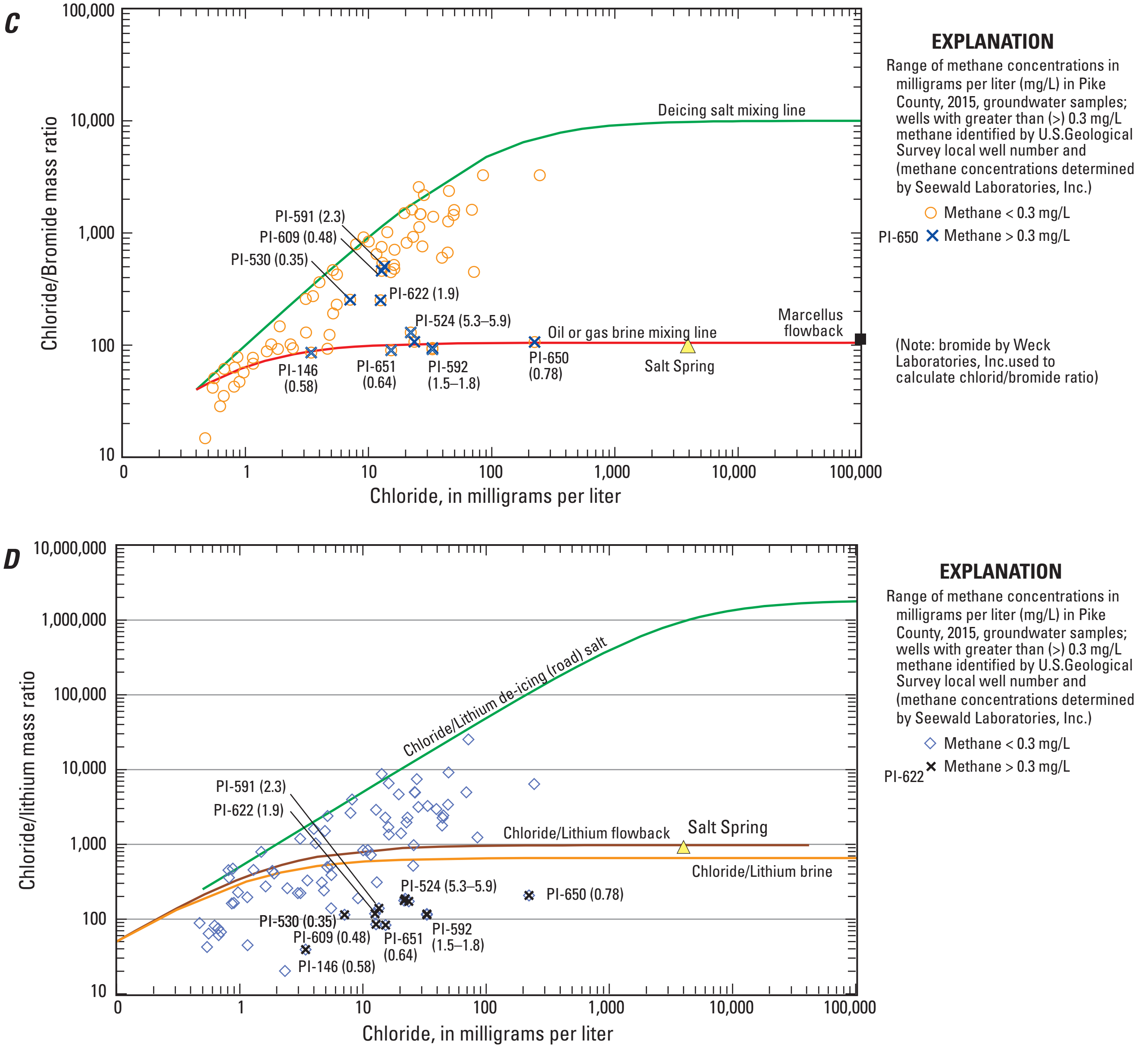


Figure 30. Relation of chloride concentrations to *A*, sodium concentrations, *B*, bromide concentrations, *C*, chloride/bromide mass ratios, and *D*, lithium/chloride mass ratios in groundwater samples with and without methane concentrations greater than 0.3 milligrams per liter collected from 79 wells in Pike County, Pennsylvania, 2015, plus median values for Salt Spring, flowback waters from Marcellus Shale gas wells, and oil- and gas-field brines from western Pennsylvania. Mixing lines were computed for initial freshwater with chloride concentration of 0.4 mg/L and bromide concentration of 0.01 mg/L mixed with road deicing salt having composition $NaCl_{0.99996}Br_{0.00004}$ or with median composition of oil- and gas-field brine. Salt Spring values from Llewellyn (2014) and Warner and others (2012). Flowback water values from Marcellus Shale gas wells from Hayes (2009). Oil- and gas-field brine values from Dresel and Rose (2010). Road salt composition from Llewellyn (2014). [Cl/Li, chloride/lithium mass ratio]



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The chloride/bromide mass ratio for saline water (Salt Spring) in Susquehanna County, Pa., is approximately 100 and is similar to the range of ratios reported for Salt Spring, which is a naturally occurring saline spring in Susquehanna County, and associated Appalachian Basin brine, as well as Marcellus Shale produced (flowback) waters and oil- and gas-field brines from Pennsylvania (table 1; fig. 30; Reilly and others, 2015).

Most of the Pike County well-water samples plot on or near the mixing-line curve representing chloride/bromide mass ratios that would result from addition of a low-bromide source of chloride, such as sodium chloride in deicing salt (road salt) or septic systems, to the groundwater (fig. 30*C*). However, several Pike County well-water samples (with bromide concentrations greater than 0.030 mg/L) plot near or on the mixing-line curve for brines (including Salt Spring, a naturally occurring saline spring in Susquehanna County, and oil and gas field brines) (figs. 30*A* and *C*), indicating a possible small contribution of chloride and bromide from a brine-like source. As chloride concentrations increase, the chloride/bromide mass ratios in these groundwater samples appear to stabilize on the brine mixing line at values of about 100 to 120 (fig. 30*C*). Pike County samples plotting on the brine mixing line with chloride concentrations as low as 3 mg/L have chloride/bromide mass ratios that are similar to those of the brines, indicating a source of chloride that is similarly enriched in bromide.

Six of the 10 water samples with methane concentrations greater than 0.3 mg/L (as determined by Seewald Laboratories, Inc.) are among those samples plotting on the brine mixing line (fig. 30*C*). The other four samples with relatively elevated methane plot between the road-deicing and brine mixing lines, which indicates that chloride from the two different sources is present in these samples. Also plotting on the brine mixing line is Salt Spring (fig. 30*C*). These methane and chloride/bromide relations are similar to those for 20 groundwater samples collected in 2012 in Sullivan County (Sloto, 2013) and 117 groundwater samples collected during 2013–14 in Wayne County (Sloto, 2014; Senior and others, 2016), where relatively elevated methane concentrations (greater than 1 mg/L) also were present in well-water samples that plot on the brine mixing line. The association of relatively elevated methane with chloride/bromide ratios on the brine mixing line confirms previous results for 20 groundwater samples collected in 2012 in Pike County (Senior, 2014). These findings indicate that groundwater with relatively elevated bromide and methane concentrations is present locally in northeastern Pennsylvania.

Although most of the Pike County well-water samples have chloride/bromide mass ratios that plot along the mixing curve for low-bromide salt (NaCl) (fig. 30*C*), the concentrations of chloride are not balanced by equivalent amounts of sodium (fig. 30*A*). Many samples, including the 10 samples with relatively elevated methane (>0.3 mg/L), contain excess sodium relative to chloride, indicating sources for sodium other than salt. The most likely sources of this excess sodium, as explained previously in section "Evolution of Chemical Composition and Conceptual Hydrogeochemical Model," are residual sodium on cation exchange sites on clay minerals in the aquifer and, to a lesser extent, dissolution of sodium-bearing silicate minerals. Other samples have excess chloride relative to sodium, which may indicate the presence of calcium or magnesium chloride, compounds also used for deicing roads. Salt Spring, a naturally occurring saline water with brine characteristics, has only a slight excess of chloride relative to sodium compared to pure NaCl salt.

Lithium concentrations may be relatively elevated in brines (table 1) and are positively correlated with methane concentrations in groundwater samples in Pike County and nearby Wayne County (Senior and others, 2016). Like Cl/Br mass ratios, the plot of chloride/lithium (Cl/Li) mass ratio in relation to chloride concentration (fig. 30*D*) shows that samples with relatively elevated methane have Cl/Li mass ratios equal to about 100. However, unlike the Cl/Br mass ratios for these samples which are similar to those for brines (fig. 30*C*), the Cl/Li mass ratios in the groundwater samples with relatively elevated methane are much lower than those for brines (table 1; fig. 30*D*; Macpherson, 2015), indicating that much of the lithium in these samples probably is from a source other than brines. Lithium, like sodium, may become enriched in groundwater through cation exchange. Shale and clay minerals may be a source of lithium (Macpherson, 2015). The association between lithium and methane may indicate that methane is present in relatively older water that has undergone extensive chemical reactions as indicated by elevated pH and concentrations of sodium and lithium.

Correlations Among Major and Trace Constituents in Groundwater

Correlations between individual constituents, as determined by the Spearman-rho rank correlation coefficient, assist in identifying chemical controls on and associations between constituents. Values of the Spearman-rho rank correlation coefficient greater than 0.42 (positive correlation) or less than -0.42 (negative correlation) generally indicate statistically significant correlations on the basis of corresponding p-values less than or equal to 0.0001 for the 79 groundwater samples (Appendix 3, table 3–1). Certain variables, such as pH, DO, and TDS, correlated with numerous other constituents, whereas others, such as barium, beryllium, cobalt, and gross alpha activity correlated with few other constituents. The relations between pH and DO and other constituents reflect geochemical controls of these variables. Constituents with few values greater than the reporting level, such as beryllium and other trace elements and gross alpha radioactivity, tend to be poorly or not correlated with other constituents. The sparsity of correlations between barium and other variables indicate processes other than, or in addition to, chemical controls affect barium distribution in groundwater. Boxplots included in Appendix 3 show the relations among selected individual constituents with pH, SC, and redox class intervals.

Principal component analysis (PCA) is a statistical technique used to indicate intercorrelations among multiple chemical constituents and environmental variables that may provide further insight into hydrochemical processes affecting groundwater chemistry in the study area. Five principal components (PCs) explain about 81.3 percent of the variance in the groundwater dataset and consist of loadings (correlations of individual variables to PCs) for 22 commonly detected constituents (table 10). Associations of 15 additional chemical and physical variables excluded from the statistical (PCA) model because of few detections, redundancy, or other reasons are indicated by the Spearman-rho rank coefficient of correlation of these variables with the principal component scores, which are listed below the PCA model constituents with loading values in table 10. Positive correlations or loadings indicate that as the values of one constituent increases, the value of the correlated constituent also increases; negative correlations and loadings indicate that as the value of one constituent increases, the value of the correlated constituent decreases.

The first principal component, PC1, accounts for most of the variance of the data (35.2 percent) and is labeled “pH” (table 10) because many of the correlated constituents are interpreted to represent weathering and cation exchange processes as groundwater composition evolves, increasing in pH and becoming more reducing. PC1 has statistically significant positive loadings of pH, fluoride, alkalinity, boron, sodium, lithium, and SC and negative loadings of DO and nitrate (table 10). Some of these relations can be seen in plots of constituents in relation to pH (fig. 26; Appendix 3). The negative associations of PC1 with DO and nitrate and positive associations with pH and alkalinity are consistent with the conceptual model of older, more evolved groundwater. As recharge passes through the soil zone into the underlying fractured rock aquifer, oxygen and nitrate are reduced by oxidation of organic matter, and pH and alkalinity increase as groundwater interacts with soil and aquifer materials. Groundwater becomes more mineralized, alkaline, and “softened” through cation exchange (lower in calcium and magnesium and higher in sodium) along flow paths from recharge areas in uplands to discharge areas in valleys. With the addition of sodium and the removal of calcium and magnesium from solution, the groundwater can become undersaturated with respect to calcite and dolomite, thus promoting additional dissolution of the carbonate minerals and progressive increases in pH and alkalinity. The resultant sodium-bicarbonate waters have alkaline (basic) pH values and high positive scores on PC1. Scores on PC1 are positively correlated with molybdenum, methane, and TDS and negatively correlated with zinc, copper, lead, and nickel (table 10). The positive scores for molybdenum and negative scores for zinc, copper, lead, and nickel reflect differences in mobilities of these metals under various pH conditions. Molybdenum tends to be mobile as an oxyanion in water with alkaline pH (values >7) and the other metals tend to be mobile as cations in water with acidic pH (values <6) but immobile owing to their adsorption by mineral surfaces at alkaline pH or by cation exchange. The higher concentrations of methane tend to be present in the higher pH, apparently older groundwater. Of the constituents with loadings for PC1, methane correlates most strongly with lithium (Appendix 3, table 3–1). Lithium, a monovalent cation like sodium, may become progressively elevated in groundwater through cation exchange processes along the flow path. Boxplots in Appendix 3 indicate that PC1 scores increase progressively with pH class (fig. 3–1) and are highest for samples with SC greater than 400 µS/cm at 25 °C but less than 1,600 µS/cm at 25 °C and classified as anoxic (fig. 3–3).

PC2 is labeled “Redox” (table 10) because positive loadings and positively correlated constituents are interpreted to indicate reducing conditions, and negative loadings and negatively correlated constituents indicate oxidizing conditions. PC2, which explains 15.6 percent of the variance in the data, has positive loadings for dissolved iron and manganese and negative loadings for DO, nitrate, and radon-222 (table 10). Scores on PC2 are positively correlated with ammonia and negatively correlated with copper and selenium, which likely reflect that reducing conditions favor ammonia as reduced form of nitrogen and that copper and selenium are more soluble in oxic (and, for copper, the associated acidic) waters. Most samples that had positive scores for PC2 were classified as anoxic (DO less than or equal to 0.5 mg/L) (Appendix 3, fig. 3–3). High positive scores on PC2 are interpreted to indicate isolation from the atmosphere and the development of reducing conditions through reactions that deplete oxygen and nitrate and increase dissolved iron and manganese concentrations in groundwater. The reductive dissolution of iron and manganese oxides typically is coupled with the oxidation of organic compounds after supplies of DO, nitrate (NO_3^-), and nitrite (NO_2^-) have been depleted but before the development of sulfate-reducing conditions that can result in precipitation of sulfide minerals (Ehrlich, 1990; Stumm and Morgan, 1996; Drever, 1997; McMahon and Chapelle, 2008). Possible explanations for the negative loading of radon-222 on PC2 could include (1) the lack of potential iron or manganese oxide sorption sites for radium-226, parent (and source) of radon-222, under reducing conditions or (2) the possible tendency of concentrations of radon-222, a short-lived radionuclide, to be higher in groundwater that is younger and less isolated from the atmosphere than groundwater with high scores on PC2.

PC3 is labeled “Hardness” (table 10) because positive loadings and correlations are interpreted to indicate processes that increase hardness in groundwater. PC3, which explains 10.0 percent of the variance in the data, has positive loadings for magnesium, calcium, silica, sulfate, and specific conductance (table 10). Scores on PC3 are positively correlated with hardness, uranium, and dissolved solids [TDS and residue on evaporation (ROE)]. High positive scores on PC3 can be attributed to the dissolution of calcite, dolomite, gypsum, and possibly, calcium- and (or) magnesium-bearing aluminosilicates such as chlorite, and pyrite or other sulfide

Table 10. Principal components analysis model of major factors controlling the chemistry of groundwater and statistically significant Spearman rank correlations of other variables with those factors determined from chemical properties of and dissolved concentrations of constituents in groundwater samples from 79 wells, Pike County, Pennsylvania, 2015.

[Varimax rotation factor pattern for rank-transformed data (SAS Institute, 2012); minimum eigenvalue >1; loading values multiplied by 100 and rounded; shading indicates significant loadings (p <0.0001); Sr-Li, strontium-lithium; Cl-Br, chloride-bromide; Ba-K, barium-potassium; PC, principal component; .., indicates Spearman correlation not significant at P<0.001]

Constituent loadings:	**pH**	**Redox**	**Hardness**	**Sr-Li**	**Cl-Br**	**Ba-K**	**Commu-nality**
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	
Fluoride (F)	87	25	-10	-2	-1	-9	0.835
pH (pH)	84	22	0	32	1	16	0.884
Alkalinity (ALK)	83	13	28	12	20	9	0.856
Manganese (Mn)	13	90	12	11	11	2	0.865
Iron (Fe)	16	89	4	-8	9	-8	0.841
Dissolved oxygen (DOX)	-53	-60	-19	-22	-7	-20	0.771
Nitrate (NO3N)	-59	-66	2	-17	15	-10	0.851
Magnesium (Mg)	5	10	89	-9	23	2	0.857
Calcium (Ca)	5	-4	87	6	17	19	0.827
Silica (SIO2)	7	29	72	23	-19	6	0.705
Strontium (Sr)	32	4	25	70	24	39	0.856
Lithium (Li)	50	2	9	69	35	25	0.913
Sulfate (SO4)	-17	-24	55	63	9	-17	0.819
Boron (B)	59	1	1	60	36	-6	0.846
Radon 222 (Rn222)	-20	-39	5	-75	-17	6	0.781
Chloride (Cl)	-25	-11	30	21	78	8	0.823
Bromide (Br)	10	15	-5	11	77	5	0.645
Specific conductance (SCL)	39	2	47	24	69	9	0.92
Sodium (Na)	55	20	3	22	68	-1	0.859
Barium (Ba)	5	13	-6	35	12	83	0.848
Potassium (K)	-9	-21	7	-20	21	70	0.638
Arsenic (As)	24	13	29	1	-22	66	0.641
Eigenvalue:	7.735	3.428	2.21	1.794	1.432	1.281	17.881
Percent variance explained	35.2	15.6	10.0	8.2	6.5	5.8	
Cumulative percent variance explained:	35.2	50.7	60.8	68.9	75.5	81.3	
Significant Spearman Correlations (p < 0.001):							
pH, Lab (pHL)	85	..	..	..	..	..	..
Molybdenum (Mo)	78	..	..	..	..	..	..
Methane (Methane)	49	..	..	..	..	..	..
Total dissolved solids (TDS)	43	..	48	..	66	..	..
Nickel (Ni)	-48	..	..	..	..	..	..
Copper (Cu)	-53	-58	..	..	..	..	..
Lead (Pb)	-54	..	..	..	..	..	..
Zinc (Zn)	-58	..	..	..	..	..	..
Ammonia (NH3N)	..	52	..	..	..	..	..
Selenium (Se)	..	-63	..	..	..	..	..
Hardness (Hard)	..	..	91	..	..	..	..
Uranium (U)	..	..	53	..	..	..	..
Residue on Evaporation 180C (ROE180)	..	..	51	..	68	..	..
Specific conductance, field (SCF)	..	..	49	..	69	..	..
Land surface elevation (LSELEV)	..	..	..	..	..	46	..

minerals without the cation-exchange softening effects (alkaline pH) indicated by high scores on PC1. Boxplots in Appendix 3 indicate that PC3 scores are highest for samples with pH greater than 7.4 but less than 7.9 (Appendix 3, fig. 3–1); PC3 scores increase progressively with SC (fig. 3–2) but are distributed among the redox classes (fig. 3–3). The positive correlation with uranium is consistent with its mobilization as the uranyl-carbonate complex, whereas positive association of sulfate implies intermediate redox conditions. Uranium mineralization at some locations in the Catskill Formation in northeastern Pennsylvania is associated with copper and iron sulfides (Klemic, 1962), potentially providing sources of sulfate where uranium is present.

PC4 is labeled “Sr-Li” for strontium-lithium (table 10) because positive loadings are for constituents strongly correlated with strontium and lithium. PC4, which explains 8.2 percent of the variance in the data, has negative loadings for radon-222, which is the most strongly associated constituent, and positive loadings for strontium, lithium, sulfate, and boron (table 10). Boxplots in Appendix 3 indicate that samples with the highest PC4 scores have pH greater than 7.4 (Appendix 3, fig. 3–1) and SC greater than 400 µS/cm at 25 °C, and are classified as anoxic (fig. 3–3). Additional boxplots for bedrock geology (fig. 3–4) indicate PC4 scores are generally higher for the water samples from wells completed in the Mahantango Formation (344MNNG) and Marcellus Shale (344MRCL) compared to those completed in other less shaley, sandstone-dominated units higher in the section (fig. 3–4; table 3). The younger sandstone-dominated units are exposed in the western, higher elevation areas of the county, whereas the shaley units are exposed in the eastern, lower elevations, corresponding to recharge and discharge areas, respectively, for regional groundwater (west to east flow paths). Thus, high scores on PC4 could be interpreted to indicate geochemically evolved water near the discharge area that contains strontium, lithium, and sulfate. Dissolution and ion exchange may enrich Sr and Li concentrations, resulting in progressively higher PC4 scores along the groundwater flow path. Low radon-222 activities may be related to sparsity (or limited surface availability) of radium-226 in aquifer materials. Such conditions may be associated with moderately reducing environments where sulfate remains stable but where iron (FeIII) and manganese (MnIII-IV) oxides are not available to sorb radium and where any previously released radon has disintegrated to low values.

PC5, which explains 6.5 percent of the variance in the data, is labeled “Cl-Br” for chloride-bromide (table 10) because it has positive loadings, in order of magnitude, for chloride, bromide, SC, and sodium. Scores on PC5 are positively correlated with TDS (and ROE) and tend to be greatest for the water samples collected from wells completed in the Mahantango Formation (344MNNG) and Marcellus Shale (344MRCL) (Appendix 3, fig. 3–4; table 3). Loadings and correlations for PC5 provide information about various possible sources of chloride and bromide. The strong positive association between chloride and bromide indicates a possible contribution of Appalachian Basin brine to the groundwater of associated well-water samples. However, few samples have elevated chloride and bromide, which produces statistically weak associations with the geology. Furthermore, the additional correlations with sodium indicate possible man-made sources of contamination, such as septic-system effluent or road-deicing salt, which could affect samples throughout the county, and the possible effect of cation exchange on the samples that have high scores on PC5. The relations between chloride and other constituents associated with PC5 indicate that chloride (and sodium) appears to be from multiple sources (high-bromide brine source and low-bromide man-made sources), as discussed in section “Ratios of Chloride, Bromide, Sodium, and Lithium in Groundwater” and shown on the sodium, bromide, chloride, and chloride/bromide ratio plots (fig. 30*A*–*C*).

PC6, which explains 5.8 percent of the variance in the data, is labeled “Ba-K” for barium-potassium (table 10) because it has positive loadings, in order of magnitude, by barium, potassium, arsenic, and strontium (table 10). Scores on PC6 are positively correlated with land-surface altitude and are highest for Catskill Formation bedrock geologic units that predominate in the western, higher elevation parts of the county [Appendix 3, fig. 3–4, Poplar Gap and Packerton Members (341PGPK); Lackawaxen Member (341LCKX); and Delaware River Member (341DLRV) of Catskill Formation]. The positive associations of these cations and land-surface altitude could indicate a common origin (source minerals within the aquifer in high-elevation parts of the county) or geochemical control. For example, barium, potassium, and strontium commonly substitute for calcium in carbonate (aragonite) minerals and one another in sulfate (barite-celestine) minerals, which could be possible sources or sinks of the cations (Hanor, 1968; Hanshaw and Back, 1979). Additionally, these cations generally will be more strongly retained than sodium and lithium, but less strongly than calcium and magnesium, by clay minerals involved in cation-exchange (Appelo and Postma, 2005) and, thus, may be released as the exchange sites become depleted in sodium and lithium and enriched in calcium and magnesium.

Barium and strontium also are present in high concentrations in brines (table 1), but the association of these constituents with PC6 rather than with PC5, the chloride-bromide factor indicative of brines, indicates only a limited link between barium and strontium and brines in Pike County groundwater. The mass ratio of barium and strontium in relation to magnesium [(Ba+Sr)/Mg mass ratio] has been used to identify sources of regional brine and road salt in northern Susquehanna County and vicinity, with (Ba+Sr)/Mg mass ratio values greater than about 0.2, indicating contributions of brine to groundwater and streams (Johnson and others, 2015). In the Pike County groundwater samples, the (Ba+Sr)/Mg mass ratio generally increased with pH from values near 0.01–0.1 at acidic pH (less than 6.5) to values near 0.1–1.2 at pH of 8 and greater (fig. 31), with some exceptions that may be related to local aquifer mineralogy, indicating possible

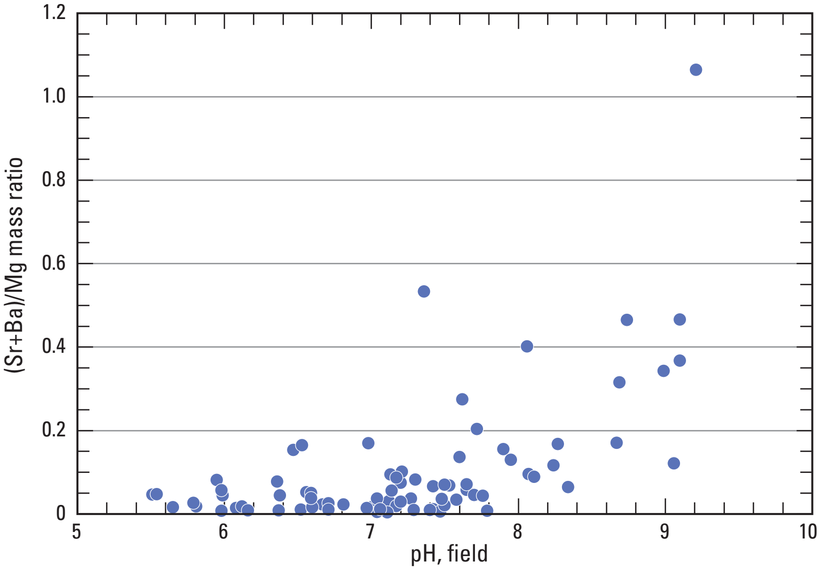

Figure 31. Relation of pH to mass ratios of (Strontium + Barium)/Magnesium in groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [Sr, strontium; Ba,barium; Mg, magnesium]

small contributions of barium and strontium in samples with pH 8 or greater. However, some of the increase in barium and strontium with pH may be related to dissolution of barium- and strontium-bearing minerals or cation exchange. Thus, barium and strontium may not be conservative tracers for the presence of brines in groundwater because these constituents may be removed from or added to solution through processes of ion exchange (like other alkaline earth metals such as calcium) or mineral dissolution and precipitation.

Spatial Distribution of Groundwater Quality and Relation to Hydrogeologic Setting

The observed distributions of water types, pH, methane, and trace elements, such as lithium, vary spatially throughout Pike County and, in some cases, exhibit apparent relations to hydrogeologic setting. In the highlands along the southwestern areas of Pike County, groundwater tends to be relatively more dilute, with lower pH, and higher DO concentrations than in other areas; the highlands areas correspond to the uplands recharge area on the generalized conceptual schematic diagram of groundwater flow (fig. 27). Sandstone is the predominant bedrock lithology at the land surface in the highlands, whereas shale is the predominant bedrock lithology at the land surface in the lowlands. At lower elevations in Pike County, groundwater has higher pH, dissolved solids, alkalinity, and hardness; these areas correspond to the intermediate flow zone on the generalized conceptual schematic diagram (fig. 27). This schematic diagram is similar to that presented by Siegel and others (2015) for a generalized Appalachian Plateau hydrogeologic setting, which would pertain to Pike County.

In selected stream valleys (Lackawaxen Creek) and (or) near the Delaware River in Pike County, some groundwater samples had high pH (greater than 8) and elevated concentrations of sodium, lithium, boron, bromide, fluoride, and methane; these areas correspond to the valley settings on the generalized conceptual schematic diagram in figure 27, where groundwaters from shallow local, intermediate, and deep regional flow zones mix. Similar occurrences of relatively elevated methane in groundwater associated with valley hydrogeologic settings have been reported for nearby areas in New York with similar geology. In a study of methane in groundwater in Upper Devonian shale bedrock in south-central New York, methane concentrations were found to differ by hydrogeologic setting with the highest concentrations measured in water from wells in confined valley settings and the lowest concentrations in water from wells in upland unconfined settings (Heisig and Scott, 2013).

Statistically significant correlations indicated an inverse relation between the altitude of the well bottom (calculated by subtracting well depth from land-surface altitude) and pH, SC, TDS, sodium, lithium, boron, and water temperature (Appendix 3, table 3–1). These correlations support the conceptual model (fig. 27) by showing that the more chemically evolved waters, characterized by alkaline pH, elevated SC, and reducing conditions, tend to be present at lower elevations that correspond to intermediate and regional groundwater discharge areas at the end of groundwater flow paths in the aquifer. The inverse relation between water temperature and well-bottom altitude may indicate the presence of deeper, warmer (geothermally affected), and likely older water at lower elevations than at higher elevations; differences in recharge temperature may also contribute to this inverse relation, with colder water being recharged at higher elevations than at lower elevations.

In Pike County, the topographic setting is related to underlying geologic unit lithology and structure and affects groundwater flow paths. Additionally, the chemical composition of water differs among the geologic units because of differences in lithology and position along groundwater flow paths. Differences in chemical composition among the geologic units are shown in boxplots (see Appendix 3, fig. 3–4); boxplots of selected constituents are shown in figure 32 in relation to geologic units. Data in boxplots are displayed in stratigraphic order, from youngest to oldest geologic units, which corresponds to the spatial distribution of youngest bedrock units in the west to oldest bedrock units in the east. The single sample from a well completed in youngest geologic formation (glacial deposits rather than bedrock) is plotted on the far right of the boxplots; this well was completed in glacial deposits overlying the Mahantango Formation in eastern Pike County. Concentrations of some constituents and properties appear to show trends by order of formation. From left to right on boxplots, corresponding to the sequence of youngest to oldest bedrock units (or west to east) and uplands to lowlands, values of pH, SC, and water temperature, and concentrations of TDS, sodium, fluoride, sulfate, boron, and lithium generally increase, but land-surface and well-bottom altitudes and concentrations of dissolved oxygen, potassium, and radon-222 generally decrease (fig. 32; fig. A3–4 in Appendix 3).

The spatial distribution of pH values for samples collected from 79 wells in 2015 shows the lowest pH values (<6.5, acidic water) in the highlands underlain by the Packerton and Poplar Gap Members, undivided, of the Catskill Formation in southwestern Pike County. The pH of groundwater in other geologic units generally is near neutral and tends to increase from west to east, and to a more limited extent, and from south to north coincident with decreasing altitude (figs. 2*A* and 6). Groundwater with highest pH (>8.0, alkaline water) tends to be present in stream valleys and (or) near the Delaware River. This observed distribution of pH is consistent (fig. 6) with a conceptual model that shows groundwater in upland areas is young, dilute, and acidic, whereas groundwater in lowland areas (at lower elevations) has higher pH and TDS acquired through mineral dissolution along flow paths. Groundwater samples with the highest pH (>8) appear to represent waters that have undergone cation exchange, have mixed with a small amount of brine, and may be mixed with shallow groundwater of more recent origin. Differences in pH in relation to altitude are indicated by boxplots showing the distribution in altitudes of well bottoms and land surfaces for four groups of pH ranges (Appendix 3, fig. 3–1); the most acidic (pH <6.5) groundwater is associated with wells in uplands with the highest land-surface and well-bottom altitudes (where well-bottom altitude is calculated by subtracting well depth from land-surface altitude), and the most alkaline groundwater (pH ≥8) is associated with wells in lowlands with the lowest land-surface and well-bottom altitudes. Little to no relation between pH and well depth is indicated by the data (Appendix 3, table 3–1).

Additionally, the spatial distribution of pH may reflect aquifer mineralogy. For example, the area of low pH (<6.5) in the uplands along the southwestern border of Pike County (fig. 6) is underlain by geologic units that are more resistant to erosion and, consequently, may contain a smaller amount of relatively soluble minerals (such as calcite in the humid climate of northeastern Pennsylvania) than those geologic units that underlie lowlands.

Other constituents also show upward trends in concentration from west to east, which is similar to the spatial trends in pH. The samples with highest pH also generally have among the highest alkalinity and concentrations of dissolved methane, sodium, lithium, boron, bromide, and fluoride (fig. 26). Most of these constituents, as identified through statistical analysis, correlate with each other and generally group together (factor PC1). Of these constituents, methane concentrations are most strongly correlated with lithium concentrations (Appendix 3, table 3–1). Elevated lithium concentrations show a strong relation to elevated methane concentrations and are present in samples with the highest pH, mostly in stream valley settings (figs. 6 and 21). Similar relations among constituents were apparent in studies of groundwater quality in nearby Wayne and Sullivan Counties (Senior and others, 2016; Sloto, 2013). The elevated sodium and lithium concentrations may be present as a result of cation exchange along flow paths. The presence of moderately elevated bromide may indicate a small amount of brine mixing with fresh groundwater, which has evolved in chemical composition along groundwater flow paths and discharges to stream valleys.

The spatial trends in radon-222 likely are partly related to differences in lithology and mineralogy (aquifer composition). In general, high concentrations of radon-222 are in western Pike County, and even higher concentrations are in the westward direction in Wayne County, where aquifer materials may be relatively enriched in uranium and daughter products. The presence of uranium associated with an old copper prospect in Waymart Township, west-central Wayne County, was described by Klemic (1962).

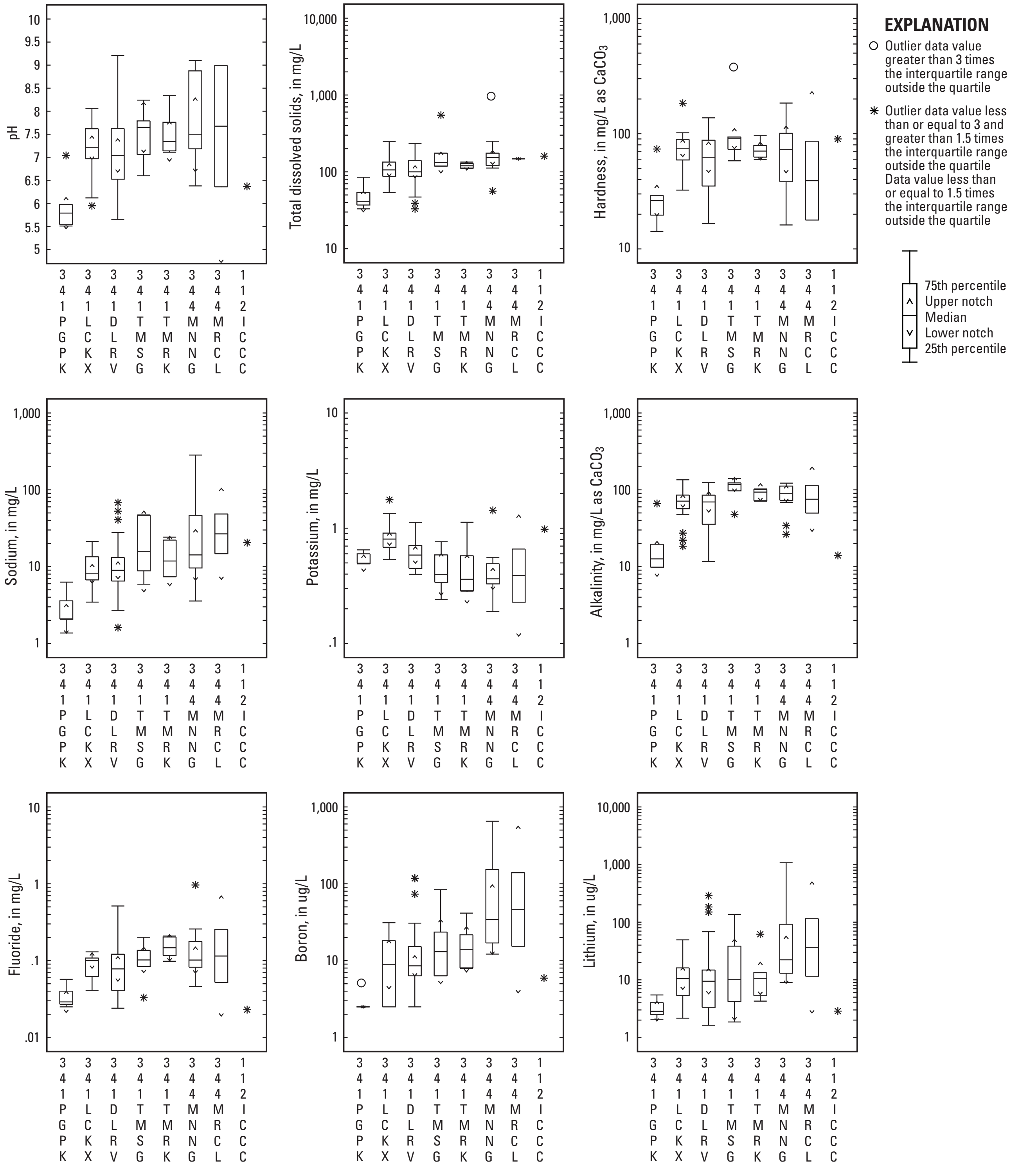

Figure 32. Boxplots showing distribution by geologic formation of *A*, pH and dissolved concentrations of total dissolved solids, hardness, sodium, potassium, alkalinity, fluoride, boron, and lithium and *B*, dissolved concentrations of iron, manganese, dissolved oxygen, uranium, arsenic, methane, and radon-222, and land-surface altitude and temperature in water samples collected from 79 wells in Pike County, Pennsylvania, 2015. [Altitudes are in feet above North American Vertical Datum 1988. mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; $CaCO_3$, calcium carbonate; Geologic units: 122ICC, Ice contact deposits; 341DLRV, Delaware River Member of the Catskill Formation; 341LCKX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MRCL, Marcellus Shale]

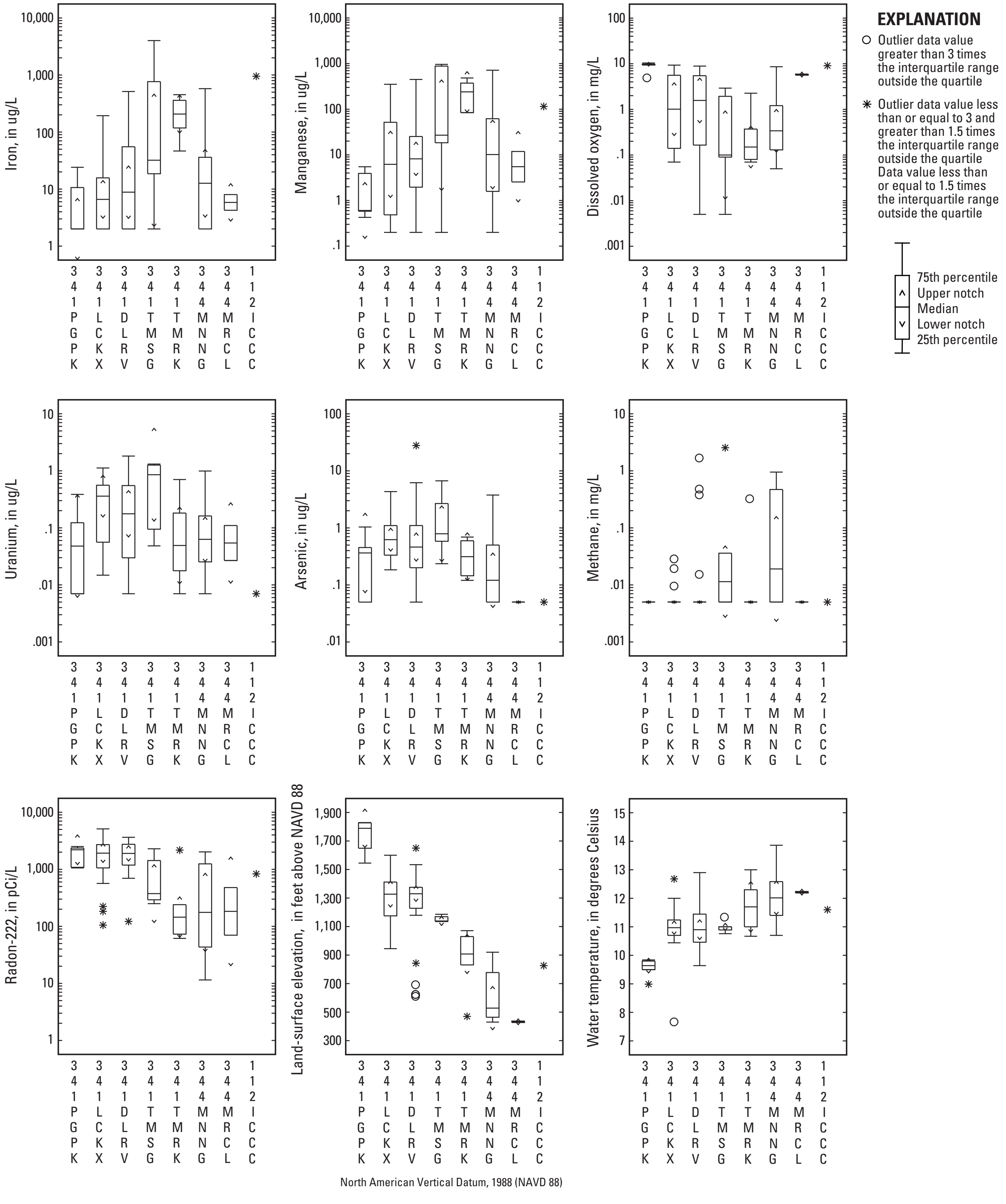

Figure 32. Boxplots showing distribution by geologic formation of *A*, pH and dissolved concentrations of total dissolved solids, hardness, sodium, potassium, alkalinity, fluoride, boron, and lithium and *B*, dissolved concentrations of iron, manganese, dissolved oxygen, uranium, arsenic, methane, and radon-222, and land-surface altitude and temperature in water samples collected from 79 wells in Pike County, Pennsylvania, June–September 2015. [Altitudes are in feet above North American Vertical Datum 1988. mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; $CaCO_3$, calcium carbonate; Geologic units: 122ICC, Ice contact deposits; 341DLRV, Delaware River Member of the Catskill Formation; 341LCKX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MRCL, Marcellus Shale]—Continued

Other differences in groundwater composition among the various geologic units also may be at least partly related to aquifer composition. Potassium concentrations are highest in groundwater in the Lackawaxen member of the Catskill Formation (fig. 32*A*), the only geologic unit in Pike County reported to contain orthoclase, a potassium-bearing feldspar mineral. Groundwater in the western non-marine geologic units of the Catskill Formation tends to have higher concentrations of barium than groundwater in the eastern marine geologic units (Trimmers Rock, Mahantango, and Marcellus Formations), but the eastern units have higher sulfate concentrations (Appendix 3, fig. 3–4). The spatial trends in barium and sulfate probably are at least partly affected by differences in mineralogy among the geologic units. Barium was associated with potassium in the principal component analysis (PC6), indicating the possible presence of feldspars with barium substitution for potassium. Sulfate concentrations tend to be highest in the Marcellus Shale, a geologic unit reported to contain pyrite, an iron sulfide mineral that releases sulfate when oxidized.

Some differences in groundwater composition among the geologic units may be related to difference in chemical controls in addition to differences in aquifer mineralogy. Dissolved iron and manganese tend to be highest in the groundwater in the Trimmers Rock Formation (fig. 32*B*), which also has low dissolved oxygen concentrations that favors mobility of these metals. Concentrations of arsenic, molybdenum, uranium, and alkalinity tend to be highest in groundwater in the Towamensing Member of the Catskill Formation (fig. 32*B*; Appendix 3, table 3–4), which is reflective of similar chemical characteristics (arsenic and molybdenum) or favorable co-occurrence (uranium carbonate ion is most soluble at pH of about 7–8).

Local Spatial and Temporal Variability in Groundwater Quality

Local Spatial Variability

Samples were collected from seven pairs of closely spaced wells located throughout Pike County to provide data on local variability (Appendix 4, table 4–1). Comparison of water quality between the paired samples shows general similarity for many properties and constituent concentrations, but substantial differences were apparent for some properties and constituents in samples from some pairs. The general relative chemical composition depicted on Piper diagrams is similar for 5 of the 7 paired well samples, although with differences in concentrations, as indicated by differences in SC ranging from 6 to 238 μS/cm at 25 °C (fig. 33). The largest apparent differences in general chemical composition were for samples from the well pairs PI-648 near PI-649 and PI-622 near PI-640 (fig. 33). Other differences were observed between the paired samples; for example, differences in pH ranged from 0 to 2.6, in barium from 1.6 to 208 μg/L, in strontium from 13 to 1,496 μg/L, in chloride from 4 to 51.4 mg/L, in methane from <0.01 to 3 mg/L, and in radon-222 from 100 to 1,600 pCi/L.

Some local variability may be related to differences in groundwater flow paths for specific fractures that contribute water to the wells. Factors that affect water quality of these fractures include local land use, aquifer mineralogy, and chemical reactions in the aquifer upgradient from the well. In fractured-rock settings, depths and water quality of water-bearing zones may differ in closely spaced wells, even wells of similar construction.

Temporal Variability

Samples were collected only once from 78 wells and twice from 1 well (for a total of 79 wells) in Pike County from June through September 2015, and the groundwater-quality data from those samples are assumed to be representative for the purpose of evaluating spatial distributions in water quality for this study. The proportion of well-water samples with various water-quality characteristics, including exceedances of drinking-water standards and detection of methane, would be expected to remain relatively constant for similarly distributed samples collected under relatively constant hydrologic conditions. For example, in an evaluation of groundwater quality in adjacent Wayne County, the overall distribution of groundwater quality for samples collected in the same season (summer) but 1 year apart and from different wells was similar (Senior and others, 2016).

However, groundwater quality may vary locally or regionally through time as a result of seasonal or annual differences in recharge, land use, or other factors. Some changes in water quality in a single well may be relatively rapid if there is good hydraulic connection to the land surface or near surface where contaminants, such as road salt, have been applied, but groundwater quality generally varied more spatially from well to well than temporally at a single well, as indicated during the 2-year study of 35 wells in Susquehanna County (Rhodes and Horton, 2015). In a 1-year study of temporal variability in groundwater quality with monthly sampling of four wells in Pike County during 2012–13, large increases in salt concentrations related to road-salt application near the well head were measured in samples from one well during winter months, and smaller differences in water quality were measured in samples from all wells during the study period (Senior, 2014).

To provide some assessment of possible differences in water quality in individual wells through time, 18 wells previously sampled by USGS during 2007–12 in Pike County were resampled in 2015; all wells were sampled in the same season (summer) of each year (Appendix 5). The resampled wells in 2015 included the following 16 wells from previous “pre-drill” baseline assessments in 2011 and 2012 (Eckhardt and Sloto, 2012; Senior, 2014): 1 well sampled in 2011 (PI-591); 1 well sampled in both 2011 and 2012 (PI-592); and 14 wells sampled in 2012. Six wells previously sampled in

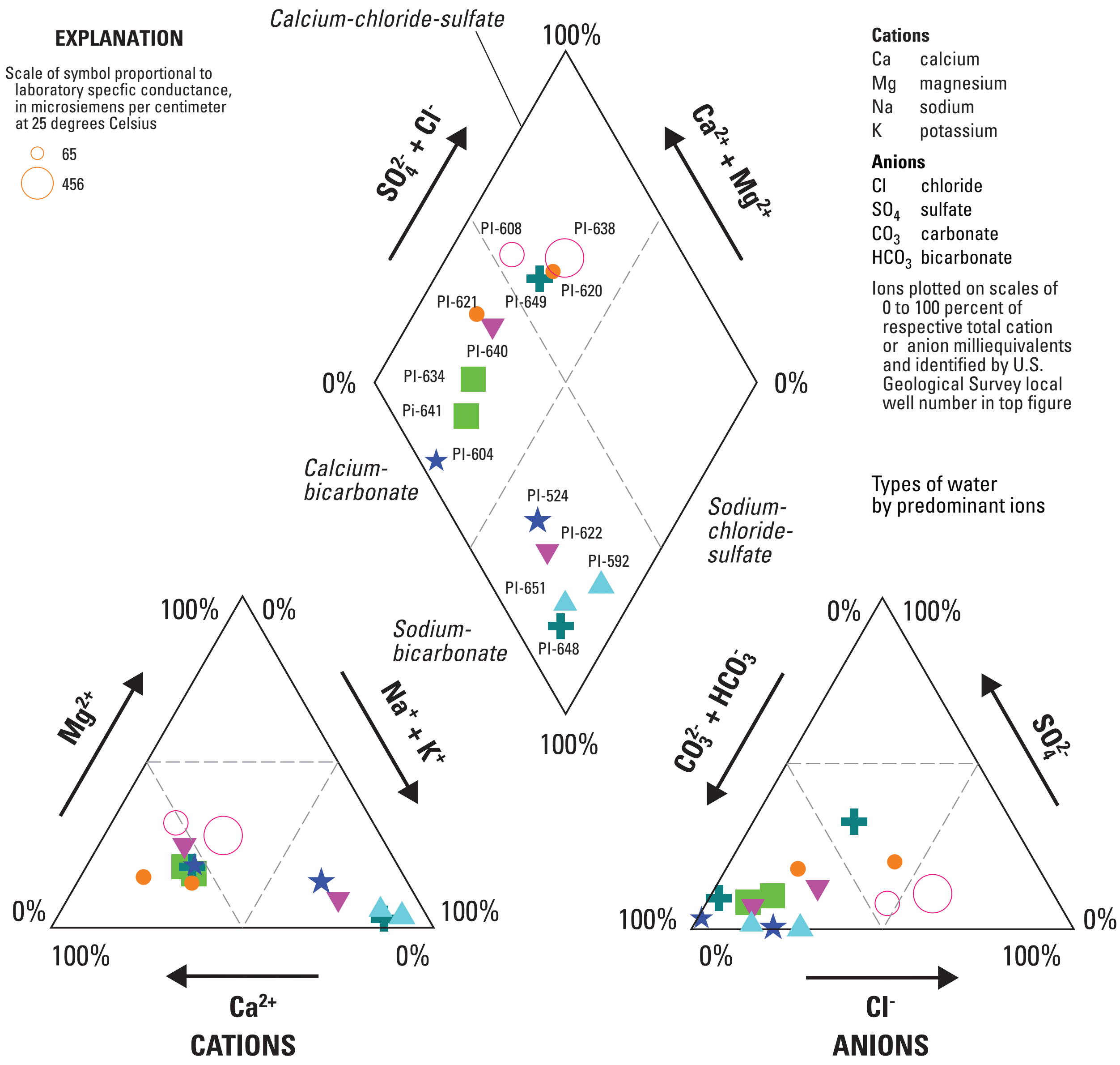

Figure 33. Piper diagrams showing composition of water for seven pairs of closely spaced wells sampled in Pike County, Pennsylvania, 2015. Each pair shown with the same symbol scaled to the specific conductance of the individual sample.

summer 2012 also had been sampled in summer 2007 (Senior, 2009), and 2 other wells sampled in 2007, but not in 2012, were resampled in 2015. Additionally, 4 of the wells sampled in 2012 and resampled in 2015 had been sampled monthly from summer 2012 to summer 2013 (Senior, 2014). Results of the analyses for 16 wells sampled during 2011–12 and 2015 (table 11; Appendix 5) were compared; comparisons were limited to the constituents analyzed in the 2011–12 samples, which included dissolved major ions, nutrients, selected trace metals, gross alpha and gross beta radioactivity, radon-222, and methane. Available data also were compared for the two other wells sampled in 2007 and 2015 but not in 2012; comparisons were limited to the constituents analyzed in the 2007 samples, which included dissolved major ions, nutrients, selected trace metals, gross alpha and gross beta radioactivity, and radon-222. Minor differences may be expected owing to analytical uncertainty; however, differences greater than 20 percent for constituents occurring in concentrations substantially higher than the reporting level may represent real differences in water quality between samples collected at different times. At low concentrations, relatively small differences in concentrations can result in large percent differences in concentrations.

Differences in dissolved concentrations of major ions between most 2015 Pike County well-water samples and 2012 samples ranged from about -20 percent (2015 lower than 2012) to about +20 percent (2015 higher than 2012). For a few samples, differences between 2015 and 2012 concentrations were greater than +/- 20 percent for some major ions and as large as about 36 percent for calcium (2 samples), 39 percent for magnesium (2 samples), 79 percent for sodium (2 samples), -25 to 199 percent for chloride (8 samples), and 220 percent for sulfate (2 samples) (table 11). These relatively large percent differences likely represent real, but sometimes relatively small, changes in concentrations of these ions. Samples collected from well PI-288 had the largest percent differences between 2015 and 2012 concentrations for calcium, magnesium, sodium, and chloride, although the differences between actual concentrations were not as large as those for other samples owing to the relatively dilute nature of water from well PI-288. Sulfate concentrations differed by only 0.26 mg/L in the samples with the largest percent difference of 220 between 2015 and 2012.

Changes in concentration greater than 20 percent were more common for chloride than for other major ions. Plots of chloride concentrations in samples collected during 2007–15 show that concentrations appear relatively constant in samples from one-half of the wells (such as PI-553, PI-555) but appeared to increase between 2012 and 2015 in samples from 7 of 16 wells (such as PI-288) (fig. 34*A*). Fluctuations in the same season from year to year may be smaller than fluctuations from month to month, as indicated by the chloride concentrations in samples collected monthly from four wells during 2012–13. Generally, the chloride/bromide ratios in water samples from wells collected during 2012–13 and again in 2015 were relatively similar, especially for samples that plot on the brine-mixing line (fig. 34*B*). Differences in chloride/bromide ratios for some wells may be related to increases in chloride concentrations related to road salt, as indicated by ratios that plot along or parallel to the road salt mixing line (fig. 34*B*); such differences were described for samples from well PI-592, which had transient increases related to road salt contamination in winter 2012–13 (Senior, 2014).

The percent differences in dissolved concentrations of minor ions and trace metals in most 2015 Pike County well-water samples compared to 2012 samples generally were higher than percent differences in the major ions (table 11). Minor ions and trace metals commonly are present in relatively low concentrations, sometimes near or less than the laboratory reporting level, in Pike County groundwater, and small differences in actual concentrations can result in large percent differences for these constituents. Percent and actual differences in concentrations can be calculated precisely only for values greater than the reporting level. For most constituents that were reported as having concentrations less than the reporting level, such as nitrite and some trace metals (table 11; Appendix 5; Senior, 2017), the 2015 and 2012 results for samples collected from a given well were consistent. Concentrations of only a few trace constituents—barium, strontium, and lithium—and radon-222 were measured at greater than the reporting level in all 2012 and 2015 samples, including barium, strontium, and lithium; for these constituents, differences in dissolved concentrations between 2015 and 2012 ranged from about -82 percent (2015 lower than 2012) to about 121 percent (2015 higher than 2012) (table 11). Decreases in concentrations of barium, lithium, and strontium in 2015 compared to 2012 in the samples from one well (PI-555) account for the relatively large negative percent differences for these constituents. Although the 2007 analyses did not include barium, lithium, and strontium, comparison of boron concentrations in 2007, 2012, and 2015 samples from well PI-555 show that 2007 and 2015 concentrations were similar and less than one-half of 2012 concentrations. The magnitudes of fluctuations of some trace constituent concentrations in samples from well PI-555 from 2007 to 2015 were larger than in samples from many other wells.

Evaluation of these limited results for 16 wells sampled twice about 3 years apart indicate that temporal variability in water quality may be a factor to consider when establishing baseline water quality. Additional monitoring through time beyond the one-time sampling conducted for this assessment would be needed to determine seasonal or other types of variability in water quality.

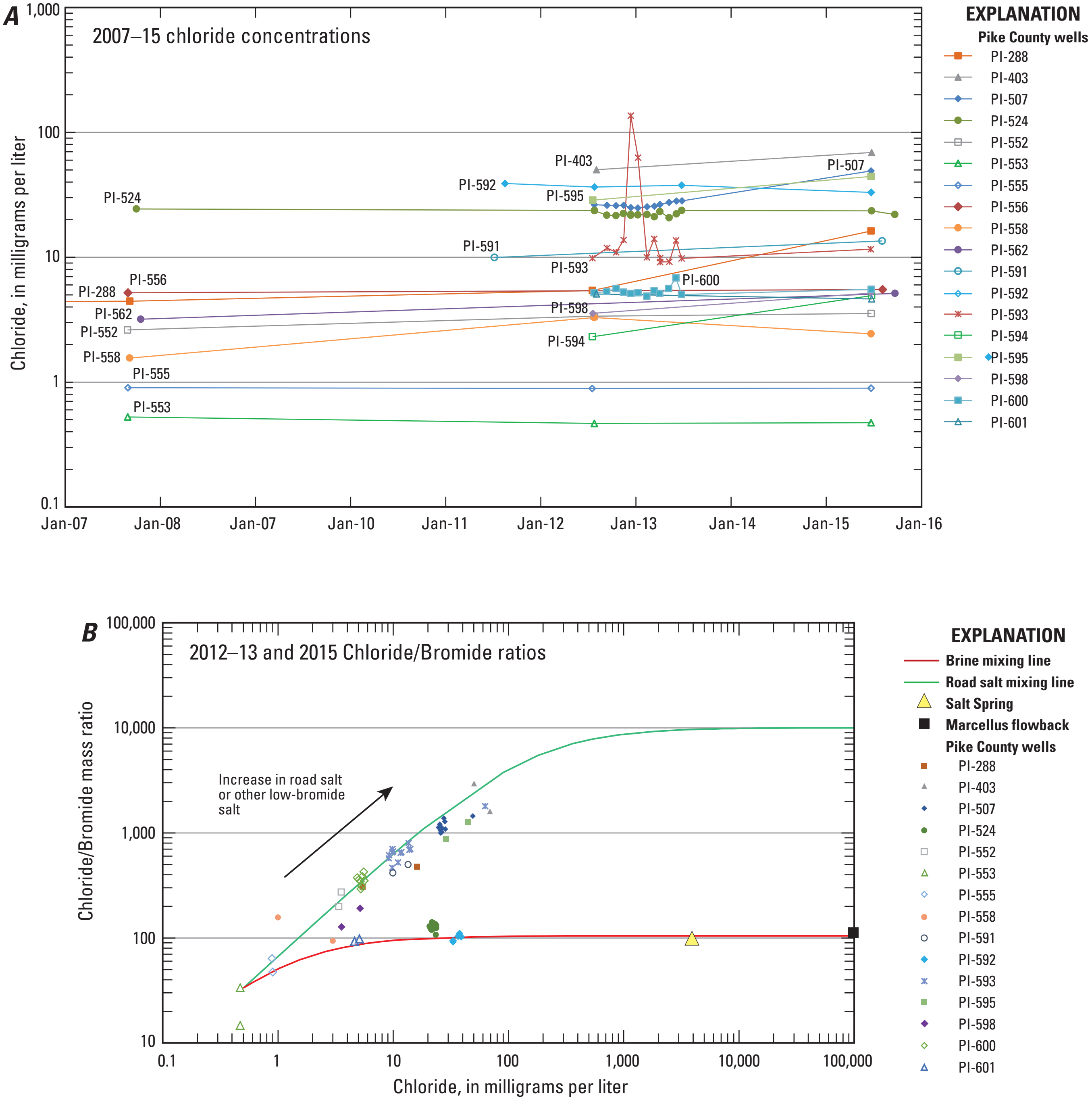

Figure 34. *A*, Chloride concentrations in water samples collected from wells at least twice during 2007–15 and *B*, chloride/bromide ratios in relation to chloride concentrations in water samples collected from wells during 2012–13 and 2015 in Pike County, Pennsylvania. (Wells identified by U.S. Geological Survey local well number)

Summary and Conclusions

In 2015, the U.S. Geological Survey (USGS), in cooperation with the Pike Conservation District, conducted a study to assess baseline shallow groundwater quality in bedrock aquifers prior to possible shale-gas development in Pike County. Pike County in northeastern Pennsylvania is underlain by Devonian-age and older sedimentary rocks, including the Devonian-age Marcellus Shale and Ordovician-age Utica Shale, formations that have potential for natural gas development and are being developed elsewhere in Pennsylvania as near as Susquehanna County, about 20 miles west of Pike County. The Marcellus Shale crops out at the eastern edge of Pike County, dips west, and is present at depths of about 7,500 feet (ft) below land surface in western Pike County. The Utica Shale is present thousands of feet below the Marcellus Shale. Bedrock units nearest the land surface in Pike County form fractured bedrock aquifers, which are recharged by precipitation and discharge locally to streams and regionally to rivers. Glacial deposits that partly cover the bedrock units are minor sources of groundwater. In rural Pike County, groundwater is the primary source of supply; most wells are completed in bedrock aquifers.

The 2015 study expanded on a previous study done in 2012, for which 20 wells were sampled in Pike County. Seventy-nine wells were sampled in summer 2015 to provide data on the presence of methane and other aspects of existing groundwater quality throughout the county, including concentrations of inorganic constituents typically present at low concentrations in shallow, fresh groundwater but elevated in brines present at depth in the region and also associated with fluids extracted from geologic formations during shale-gas development. Reported depths of sampled wells ranged from 80 to 610 feet (ft), with a median of 262 ft. All groundwater samples collected in Pike County in 2015 were analyzed for bacteria, major ions, nutrients, selected inorganic trace constituents (including metals and other elements), total organic carbon, radon-222, gross alpha- and gross beta-particle activity, dissolved hydrocarbon gases (methane, ethane, and propane), and if possible, the isotopic composition of methane. Analyses for total concentrations of major ions and selected trace constituents were done on unfiltered samples using U.S. Environmental Protection Agency drinking-water methods; analyses for dissolved concentrations were done on filtered samples using USGS National Water Quality Laboratory methods. Additionally, samples from 20 wells were analyzed for selected volatile organic compounds, and samples from 16 wells with relatively elevated gross alpha-particle activity were analyzed for radium-226.

Results of the 2015 sampling show that groundwater quality generally met most drinking-water standards, but some samples had one or more constituents or properties, including arsenic, pH, iron, manganese, bacteria, sodium, total dissolved solids, sulfate, and radon-222, that exceeded primary or secondary maximum contaminant levels (MCLs) or a Health Advisory (HA). Arsenic concentrations were greater than the maximum contaminant level (MCL) of 10 µg/L in 1 of the 79 well-water samples (1 percent), as high as about 30 µg/L. Arsenic concentrations were greater than the HA level of 2 µg/L in samples from 8 of 79 wells (10 percent). Only three VOCs were present in samples from two wells at low levels below MCLs.

Dissolved and total concentrations were similar in most samples for most constituents analyzed, indicating that these constituents predominantly are present in the dissolved phase. However, total concentrations commonly were higher than dissolved concentrations of iron, indicating particulate iron contributed substantially to the total iron concentrations. Total iron concentrations exceeded the secondary maximum contaminant level (SMCL) of 300 micrograms per liter (µg/L) in water samples from 35 of the 79 wells (44 percent), and dissolved iron concentrations exceeded the SMCL of 300 µg/L in only 8 of 79 well-water samples (10 percent). Dissolved and total manganese concentrations typically were similar; total manganese concentrations exceeded the SMCL of 50 µg/L in samples from 31 of 79 wells (39 percent).

The pH ranged from 5.5 to 9.2 and did not meet the SMCL range of 6.5–8.5 in groundwater samples from 24 of 79 wells (30 percent). Sixteen samples (20 percent) had pH less than 6.5, and 8 samples (10 percent) had pH greater than 8.5. Total coliform bacteria were detected in samples from 25 of 79 wells (32 percent) but *Escherichia coli* (*E. coli)* was not detected in any sample. Radon-222 activities ranged from 11 to 5,110 picocuries per liter (pCi/L), with a median of 1,425 pCi/L, and exceeded the proposed drinking-water standard of 300 pCi/L in samples from 61 of 79 wells (77 percent); radon-222 activities were higher than the alternative proposed standard of 4,000 pCi/L in samples from 2 of 79 wells (3 percent). A few (1–2) samples had concentrations of sodium, chloride, sulfate, or TDS that exceeded the SMCLs of 60, 250, 250, and 500 mg/L, respectively. However, dissolved sodium concentrations exceeded the HA of 20 mg/L in samples from 15 of 79 wells (19 percent).

Water from 19 (24 percent) of 79 wells sampled in 2015 had concentrations of methane greater than the reporting level of 0.01 milligrams per liter (mg/L) with the maximum of 2.5–5.9 mg/L, depending on laboratory. Concentrations of methane in replicate samples from 16 wells analyzed by a second laboratory were correlated but were as much as about 2.7 times higher than the first laboratory. Low levels of ethane (as much as 0.0019 mg/L) were measured by the second laboratory in the samples from five wells that had among the highest methane concentrations. Groundwater samples from nine wells had sufficient methane for isotopic analysis of both carbon and hydrogen components of methane, which yielded $\delta^{13}C_{CH4}$ values ranging from -63.44 parts per thousand (‰) to -40.99 ‰ and δD_{CH4} values ranging from -221.6 ‰ to -121.7 ‰. These results are consistent with isotopic compositions for a microbial methane (carbon dioxide reduction) source for most Pike County groundwater samples, a possibly oxidized microbial methane source for 2 samples, and a possible thermogenic methane source for 1 sample. However, the ratios of methane to ethane indicate that the methane in all samples is consistent with microbial origin. The sample that has methane with an isotopic composition within ranges reported for thermogenic methane may be a mixture of methane from a thermogenic source depleted in ethane and microbial source that underwent oxidation.

The groundwater with elevated methane concentrations had a chemical composition that differed in some respects (pH, selected major ions, and inorganic trace constituents) from groundwater with low methane concentrations. The seven well-water samples with the highest methane concentrations (greater than 0.3 mg/L) also had among the highest pH values (8.1–9.3, respectively) and highest concentrations of sodium, lithium, boron, fluoride, arsenic, ammonia, and bromide. Elevated concentrations of some other constituents, such as barium, strontium, and chloride, also were present but typically were not limited to well-water samples with elevated methane. Results of geochemical modeling of similar data from nearby Wayne County show that water in samples with elevated pH, sodium, lithium, bromide, and alkalinity could have been formed by dissolution of calcite (calcium carbonate), followed by ion exchange, and mixing with a small amount (less than 0.02 percent) of brine. Brine contributions may originate from deep parts (greater than 1,000 ft below land surface) of the aquifer system.

Characterization of water by major ion composition shows that most groundwaters are of a calcium-magnesium-bicarbonate-sulfate type; a few samples were mostly a sodium-bicarbonate type. The sodium-bicarbonate type waters generally have low dissolved oxygen and high pH values, and some of the highest concentrations of methane and arsenic. Elevated pH is an important geochemical control on arsenic concentrations because arsenic tends to be more soluble at pH values greater than 7.5. Relations among chemical constituents were investigated through statistical (principal component analysis; PCA) and graphical (Piper diagrams, scatter plots, and boxplots) methods, which aid in understanding how groundwaters develop different chemical compositions, especially those waters that have elevated concentrations of constituents of concern, such as arsenic and methane. The statistical grouping of constituents through PCA identified six main factors that reflect geochemical processes (including pH, redox, ion exchange, mineral dissolution, mixing with brine) and man-made contributions (such as road salt).

Groundwater samples with elevated methane concentrations (near or greater than 0.3 mg/L as determined by one laboratory) have chloride/bromide ratios that indicate mixing with a small amount of Appalachian Basin brine similar in composition to that reported for shale-gas brines in Pennsylvania. Most other samples with low methane concentrations (less than about 0.3 mg/L) have chloride/bromide ratios that indicate predominantly man-made sources of chloride, such as road salt or septic systems.

The observed water types and relations among selected constituents and pH indicate that dilute recharge waters interact with minerals in the near surface, gradually becoming less acidic and less oxygenated while increasing in concentrations of dissolved constituents. The predominant processes that likely account for the observed chemical composition of groundwaters in Pike County are the progressive dissolution of calcite (calcium carbonate) to equilibrium, combined in some cases with cation exchange and mixing with saline or brine-like waters. In general, calcite is undersaturated (can dissolve) in waters with pH less than about 7.5 to 8 but nears saturation in waters with pH greater than about 8. As calcite dissolves and other minerals undergo weathering, it is thought that the groundwater evolves from dilute acidic mixed-ion water that tends be soft (low hardness) to intermediate total dissolved solids, neutral pH calcium-bicarbonate water that tends to have moderate to high hardness. Further dissolution of calcite and sodium-for-calcium ion exchange results in higher TDS sodium bicarbonate water with pH greater than 8 and low hardness. Mixing of these waters with road salt and (or) residual brine adds chloride and (or) bromide. These different types of waters were observed in Pike County.

Relatively elevated methane (greater than 0.3 mg/L as determined by Seewald Laboratories, Inc.) was measured most frequently in sodium-bicarbonate type groundwater samples with elevated pH (greater than 8), and chloride/bromide ratios indicative of brine contribution. These findings and chemical models indicate that the waters with the relatively elevated methane concentrations in Pike County and other areas in northeastern Pennsylvania appear to have been formed by a series of chemical reactions, including mineral dissolution, ion exchange, and some mixing with brine that could be residual, related to connate waters, or discharging from greater depths in the aquifer. Sodium-bicarbonate type water appears to be distinct from other groundwater types in Pike County, although data suggest this type of water may have formed gradually through a series of chemical reactions in the aquifer.

The composition of groundwater varies spatially in Pike County and differs by geologic unit, partly because of differences in aquifer mineralogy and different positions along groundwater flow paths. The spatial distribution of groundwater composition generally shows that relatively dilute, slightly acidic, oxygenated, calcium-carbonate type waters with relatively high radon-222 (>1,000 pCi/L) tend to be present in the uplands along the western border of Pike County; waters with near neutral pH and with the highest amounts of hardness (calcium and magnesium) generally were present in areas of intermediate elevations. Waters with pH values greater than 8, low oxygen concentrations (<1 mg/L), and the highest arsenic, sodium, lithium, fluoride, boron, bromide, and methane concentrations but lowest radon-222 concentrations most frequently were present in lowland areas along stream valleys, especially at relatively lower elevations near areas of regional groundwater discharge, such as the Delaware River.

Thus, the baseline assessment of groundwater quality in Pike County prior to gas-well development shows that shallow (less than about 1,000 feet deep) groundwater is generally meets primary drinking-water standards for inorganic constituents but varies spatially. Methane and some constituents (sodium, lithium, bromide, boron, and others) that are present in high concentrations in residual or other naturally-occurring brines (and potentially associated with future shale-gas development in Pike County) and are present at low to moderate concentrations, and in some areas at relatively elevated concentrations, in groundwater in Pike County.

The flow and transport processes responsible for the presence of methane and the relatively elevated sodium and associated trace constituent concentrations in groundwater in Pike County are not known. Although isotopic characterization of methane may be used to help identify the naturally occurring methane in shallow bedrock aquifers as part of the baseline assessment, additional investigations may be needed to definitively determine the origin of this methane and explain its association with the high pH, sodium-bicarbonate, bromide-enriched groundwater.

Results for 16 wells sampled twice about 3 years apart (15 wells in 2012 and 2015 and 1 well in 2011 and 2015) indicate that temporal variability in water quality may be a factor to consider when establishing baseline water quality. Although some differences may be related to analytical uncertainty, differences greater than 20 percent for constituents occurring in concentrations substantially higher than the reporting level may represent real differences in water quality between samples collected at different times. Additional monitoring through time beyond the one-time sampling conducted for this assessment would be needed to determine seasonal or other types of variability in water quality.

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Table 11. Minimum, median, and maximum of actual and percent differences in chemical and physical properties measured in the field, and concentrations of total dissolved solids, major ions, nutrients, selected minor ions and trace metals, radon-222, and methane determined in the laboratory for water samples collected from 16 wells sampled during 2011–12 and 2015 in Pike County, Pennsylvania.

[Of 16 wells sampled twice, 1 well was sampled in 2011 and 2015 and 15 wells were sampled in 2012 and 2015. Actual difference = 2015 result - 2012 result; percent difference = 100*(2015 result - 2012 result)/2015 result; µS/cm, microSiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; °C, degrees Celsius; SiO_2, silica; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; --, no data or not applicable; <, less than]

Sample properties and constituents	Units	Reporting level	Number above reporting level	Actual difference in concentration			Percent difference in concentration			Range and median of concentrations above reporting level		
				Minimim	Median	Maximum	Minimim	Median	Maximum	Minimim	Median	Maximum
Field properties												
Water temperature	°C	0.1	16	-0.8	-0.1	1	-7.2	-1.1	8.1	8.99	10.75	13
Dissolved oxygen	mg/L	<0.1	16	-2.65	0.1	2.7	-93.0	39.0	1,110.0	0.1	0.2	10.38
Specific conductance, field	µS/cm	<10	16	-26	5	75	-23.0	2.5	59.0	64	186	458
pH, field	pH units	0.1	16	-0.21	-0.03	1	-2.8	-0.4	12.3	5.75	7.2	9.1
Laboratory analyses [2,3]												
Specific conductance, laboratory	µS/cm	<5	16	-22	7	77	-20.4	3.6	48.1	69	214	458
Total dissolved solids	mg/L	<20	16	-28	-3.5	50	-41.0	-2.2	50.7	38	121.0	280.0
Major ions (dissolved)												
Calcium, dissolved	mg/L	<0.22	16	-2.59	0.6	8.8	-19.5	3.9	35.8	4.2	13.25	60.17
Magnesium, dissolved	mg/L	<0.011	16	-0.46	0.01	2.554	-19.4	-0.1	39.3	0.9	4.197	10.08
Sodium, dissolved	mg/L	<0.06	16	-1.31	0.34	4	-21.5	2.8	79.1	1.361	8.125	69.42
Potassium, dissolved	mg/L	<0.03	16	-0.05	0.34	0.118	-11.7	5.3	17.6	0.239	0.608	1.228
Alkalinity (dissolved)	mg/L as $CaCO_3$	<4.6	16	-5.2	-0.5	123.1	-21.4	-0.8	3.5	12.6	65	126.8
Bromide, dissolved	µg/L	<10	16	-4.400	4	40	-27.0	10.0	154.0	13	27	360
Chloride, dissolved	mg/L	<0.02	16	-3.50	0.98	23	-25.9	12.6	199.0	0.467	5.543	69
Fluoride, dissolved	mg/L	<0.04	15	-0.025	-0.01	0.016	-23.3	-6.9	18.0	0.025	0.1	0.5
Sulfate, dissolved	mg/L	<0.02	16	-2.30	-0.32	0	-7.9	5.5	11.1	0.376	7.405	17.4
Silica, dissolved	mg/L as SiO_2	<0.018	16	-0.72	0.63	1.0	-7.9	5.5	11.1	4.31	9.28	17.24
Nutrients (dissolved)												
Ammonia, dissolved	mg/L as N	<0.01	6	-0.002	0.0018	0.038	-2.4	3.8	13.2	0.038	0.1	0.3
Nitrite, dissolved	mg/L as N	<0.001	0	<0.001	<0.001	<0.001	--	--	--	--	--	--
Nitrate + nitrite, dissolved	mg/L as N	<0.04	5	-0.1	-0.00958	0.10966	-24.5	0.0	21.8	0.02	0.0	0.9
Orthophosphate, dissolved	mg/L as P	<0.004	15	-0.0089	0.0011	0.00735	-35.2	8.9	46.5	<0.004	0.02	0.178

Table 11. Minimum, median, and maximum of actual and percent differences in chemical and physical properties measured in the field, and concentrations of total dissolved solids, major ions, nutrients, selected minor ions and trace metals, radon-222, and methane determined in the laboratory for water samples collected from 16 wells sampled during 2011–12 and 2015 in Pike County, Pennsylvania.—Continued

[Of 16 wells sampled twice, 1 well was sampled in 2011 and 2015 and 15 wells were sampled in 2012 and 2015. Actual difference = 2015 result - 2012 result; percent difference = 100*(2015 result - 2012 result)/2015 result; µS/cm, microSiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; °C, degrees Celsius; SiO_2, silica; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorus; --, no data or not applicable; <, less than]

Sample properties and constituents	Units	Reporting level	Number above reporting level	Actual difference in concentration			Percent difference in concentration			Range and median of concentrations above reporting level		
				Minimim	Median	Maximum	Minimim	Median	Maximum	Minimim	Median	Maximum
Selected dissolved and total trace constituents (filtered and unfiltered samples)[2,3]												
Arsenic, dissolved	µg/L	<0.1	13	-2.28	-0.024	0.1775	-33.9	-6.0	95.4	0.03	0.33	30.1
Barium, dissolved	µg/L	<0.25	16	-22	0.033	51.1	-31.7	1.0	55.3	2.63	46.88	318.1
Boron	µg/L	<5	12	-11.9	-1	0.7	-69.5	-3.3	6.9	<3	11.6	264
Iron, total	µg/L	<4.6	11	-190	4.5	4,864	-84.7	83.2	427.0	<4.5	74.4	6,170
Iron, dissolved	µg/L	<4	10	-76.5	-0.8	80	-91.2	0.0	174.0	<3.2	9.9	132
Lithium, dissolved	µg/L	<0.13	16	-2	1.1	41.75	-26.9	9.4	121.1	0.975	12.86	289.4
Manganese, total	µg/L	<0.5	15	-30.3	0.327	255	-89.4	11.2	195.0	0.2	20.4	901
Manganese, dissolved	µg/L	<0.4	14	-34.5	-0.38	100.5	-82.2	-0.9	95.4	0.2	8.8	715
Molybdenum	µg/L	<0.014,<0.05	11	-3.39	-0.0119	0.1152	-98.3	-3.1	32.8	0.14	0.322	3.45
Strontium, dissolved	µg/L	<0.8	16	-351	3.4	130	-81.8	2.5	39.5	13.87	331.3	986.7
Uranium (natural)	µg/L	<0.014	14	-0.619	-0.0019	0.079	-44.3	-4.8	65.6	<0.004	0.095	1.21
Radon-222	pCi/L		16	-1,500	-120	366	-39.7	-9.0	41.7	73	1243	4,130
Methane[1]	mg/L	<0.01	3	-0.003	-1.01	-1.56	-23.0	-36.0	-38.0	0.012	2.8	4.1

[1] Methane determined by TestAmerica Laboratories, Inc., in 2012 and Seewald Laboratories, Inc., in 2015.

[2] Laboratory analysis for dissolved concentrations in filtered samples done by U.S. Geological Survey National Water Quality Laboratory (NWQL).

[3] Laboratory analysis for total concentrations in unfiltered samples done by contract laboratories using drinking-water methods (see Appendix 2).

Table 12. Land-surface altitude, well depth, and geologic unit (aquifer) code for 79 wells sampled in 2015 in Pike County, Pennsylvania.

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; --, no data or not applicable; Geologic units: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation;344MRCL, Marcellus Shale]

USGS local well number	USGS station number	Municipality (township)	Land-surface altitude (feet above NAVD 88)	Depth of well (feet)	USGS geologic code[1]
PI 146	411518074513201	Delaware	459	238	344MNNG
PI 288	411700075145801	Greene	1,649	151	341PGPK
PI 403	411237074543301	Delaware	849	192	344MNNG
PI 507	411951075025501	Blooming Grove	1,354	305	341DLRV
PI 523	411709074520701	Dingman	919	400	344MNNG
PI 524	411849074533901	Dingman	1,138	380	341TMSG
PI 526	412218075034501	Blooming Grove	1,340	275	341DLRV
PI 530	412439074443201	Westfall	469	220	341TMRK
PI 534	411738074560101	Dingman	1,279	180	341DLRV
PI 535	412526075004601	Lackawaxen	1,219	125	341LCKX
PI 539	411452074534701	Delaware	1,030	214	341TMRK
PI 540	412749074545601	Shohola	699	250	341DLRV
PI 543	412734074565701	Shohola	1,256	200	341DLRV
PI 546	412240074553701	Shohola	1,419	150	341DLRV
PI 552	412141074462301	Westfall	974	--	341TMRK
PI 553	412303075074301	Blooming Grove	1,509	610	341LCKX
PI 555	412009075142901	Palmyra	1,788	380	341PGPK
PI 556	411738074505001	Delaware	718	400	344MNNG
PI 558	410525075021701	Lehman	439	300	344MNNG
PI 562	410731075002701	Lehman	839	200	341TMRK
PI 581	411041075045401	Porter	1,178	270	341DLRV
PI 591	411859074475901	Dingman	430	300	344MNNG
PI 592	412908074591401	Lackawaxen	618	200	341DLRV
PI 593	412337075114001	Palmyra	1,569	255	341LCKX
PI 594	412701074593901	Lackawaxen	1,378	320	341LCKX
PI 595	412324075041701	Blooming Grove	1,468	443	341LCKX
PI 597	411254075025901	Porter	1,366	340	341DLRV
PI 598	413058075051901	Lackawaxen	1,338	190	341LCKX
PI 600	412915075041401	Lackawaxen	1,259	300	341LCKX
PI 601	411441075054101	Porter	1,295	200	341DLRV
PI 603	412225075092601	Blooming Grove	1,502	225	341LCKX
PI 604	411850074533901	Dingman	1,135	--	341TMSG
PI 605	412624075001401	Lackawaxen	1,310	424	341LCKX
PI 606	412531074545001	Shohola	1,241	220	341DLRV
PI 607	412802075022001	Lackawaxen	945	440	341LCKX
PI 608	412115074553001	Dingman	1,369	360	341DLRV
PI 609	411920075070501	Blooming Grove	1534	400	341DLRV
PI 610	411831074541401	Dingman	1,281	330	341DLRV
PI 611	412851075095201	Lackawaxen	979	127	341LCKX
PI 612	412904075081801	Lackawaxen	1,175	180	341LCKX

Table 12. Land-surface altitude, well depth, and geologic unit (aquifer) code for 79 wells sampled in 2015 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; NAVD 88, North American Vertical Datum of 1988; --, no data or not applicable; Geologic units: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation;344MRCL, Marcellus Shale]

USGS local well number	USGS station number	Municipality (township)	Land-surface altitude (feet above NAVD 88)	Depth of well (feet)	USGS geologic code[1]
PI 613	412534075114501	Palmyra	1,320	380	341LCKX
PI 614	411937075182801	Greene	1,311	180	341DLRV
PI 615	412455074542201	Shohola	1,355	175	341DLRV
PI 616	412152075174901	Palmyra	1,215	175	341DLRV
PI 617	411956074492101	Dingman	826	160	112ICCC
PI 618	412230074423901	Westfall	527	115	344MNNG
PI 619	412823075042301	Lackawaxen	843	175	341DLRV
PI 620	411800075130901	Greene	1,829	136	341PGPK
PI 621	411759075131001	Greene	1,827	180	341PGPK
PI 622	411951074475401	Milford	529	460	344MNNG
PI 623	411441074551501	Delaware	1,071	80	341TMRK
PI 624	412307075104301	Blooming Grove	1,600	300	341LCKX
PI 625	412843075000201	Lackawaxen	633	180	341DLRV
PI 626	412836075025401	Lackawaxen	946	--	341LCKX
PI 627	411659075045201	Porter	1,375	300	341DLRV
PI 628	412430075081301	Blooming Grove	1,545	160	341PGPK
PI 629	412151075170001	Palmyra	1,381	390	341DLRV
PI 630	412117074593601	Dingman	1,384	340	341DLRV
PI 631	412322074463701	Westfall	1,186	140	341TMSG
PI 632	412206075041501	Blooming Grove	1341	120	341DLRV
PI 633	412856075061501	Lackawaxen	1021	360	341LCKX
PI 634	413158075053301	Lackawaxen	1,388	291	341LCKX
PI 635	413215075062501	Lackawaxen	1,327	525	341LCKX
PI 636	413429075050401	Lackawaxen	1,163	600	341LCKX
PI 638	412107074552701	Dingman	1,384	350	341DLRV
PI 639	413006075083701	Lackawaxen	1,369	500	341LCKX
PI 640	411954074475101	Milford	540	115	344MNNG
PI 641	413207075053601	Lackawaxen	1,412	500	341LCKX
PI 642	410602075005101	Lehman	836	350	344MNNG
PI 643	411704074555401	Dingman	1,330	240	341DLRV
PI 644	412136074511501	Milford	1,169	200	341TMSG
PI 645	411716074500801	Dingman	468	300	344MNNG
PI 647	411014074554001	Lehman	831	190	341TMRK
PI 648	410554074595101	Lehman	427	300	344MRCL
PI 649	410552075000601	Lehman	437	300	344MRCL
PI 650	411833074482501	Dingman	481	300	344MNNG
PI 651	412907074592801	Lackawaxen	634	240	341DLRV
PI 652	411818074591001	Dingman	1,400	300	341DLRV
PI 653	411543074545801	Delaware	1,137	440	341TMSG

[1] Geologic units mapped as 341DLRV and 341LCXX by Sevon and others (1989) are mapped as LongRun, Beaverdam Run, Walckville Members of Catskill Formation, Undivided (341LRBW) by Berg and others (1981).

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; CaCO$_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Station number	Date	Sample start time	Dissolved oxygen, water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	pH, water, unfiltered, laboratory (standard units)	Specific conductance, water, unfiltered, laboratory (µS/cm at 25 °C)	Specific conductance, water, unfiltered (µS/cm at 25 °C)
				00300	00400	00403	90095	00095
PI 146	411518074513201	8/6/2015	1400	0.1	9.1	8.9	265	251
PI 288	411700075145801	6/23/2015	930	10.4	5.8	6.5	102	102
PI 403	411237074543301	6/25/2015	1400	0.2	7.5	7.9	458	458
PI 507	411951075025501	6/23/2015	1100	5.5	6.6	7	296	276
PI 523	411709074520701	9/21/2015	1200	0.5	7.4	7.8	354	326
PI 524	411849074533901	6/25/2015	1500	<0.01	8.2	8.4	302	287
PI 524	411849074533901	9/22/2015	1330	0.1	8.4	8.4	297	275
PI 524	411849074533901	9/22/2015	1331	--	--	8.3	293	--
PI 526	412218075034501	8/3/2015	1130	0.4	7	7.5	123	119
PI 530	412439074443201	8/5/2015	1330	0.1	7.8	8.2	217	209
PI 534	411738074560101	8/4/2015	1500	1.6	6.7	7.3	243	239
PI 535	412526075004601	8/4/2015	1230	1.9	6.8	7.5	251	253
PI 539	411452074534701	8/5/2015	1100	0.4	7.3	8	200	194
PI 540	412749074545601	8/5/2015	1030	0.1	8.1	8.2	218	207
PI 543	412734074565701	8/3/2015	1500	4.8	6.7	7.2	101	99
PI 546	412240074553701	8/4/2015	1000	2.9	6.5	E7.0	E68	68
PI 552	412141074462301	6/24/2015	1445	0.1	7.1	7.8	220	212
PI 553	412303075074301	6/23/2015	1400	0.1	7.2	E7.7	E92	91
PI 555	412009075142901	6/23/2015	1100	5.3	7	7.7	146	145
PI 556	411738074505001	8/6/2015	1030	0.2	8.3	8.2	190	187
PI 558	410525075021701	6/23/2015	1500	8.6	6.6	E7.1	E86	85
PI 562	410731075002701	9/23/2015	900	0.1	7.4	7.8	178	172
PI 581	411041075045401	8/3/2015	1430	1.9	7.4	7.8	221	212
PI 591	411859074475901	8/5/2015	1600	0.1	9.1	8.9	274	267
PI 592	412908074591401	6/24/2015	1100	0.2	8.7	8.5	333	324
PI 592	412908074591401	6/24/2015	1101	--	--	8.6	329	--
PI 593	412337075114001	6/22/2015	1300	0.1	7.9	8.1	187	172
PI 594	412701074593901	6/25/2015	1130	9.3	6.1	E6.9	E88	84
PI 595	412324075041701	6/23/2015	930	2	7	7.5	270	268
PI 597	411254075025901	7/8/2015	1000	0.3	7.5	7.9	156	156
PI 598	413058075051901	6/22/2015	1600	0.1	6.7	7.4	126	114
PI 600	412915075041401	6/24/2015	1400	0.1	8	8.1	230	226
PI 601	411441075054101	6/25/2015	1000	0.6	7.7	8	146	141
PI 603	412225075092601	7/6/2015	1230	0.3	7.3	7.7	128	122
PI 604	411850074533901	9/21/2015	1500	1.9	7.8	8.1	228	215
PI 605	412624075001401	7/8/2015	1100	6.2	6	6.5	116	118
PI 606	412531074545001	6/24/2015	1100	<0.01	7.1	7.8	250	244
PI 607	412802075022001	7/7/2015	1530	7.4	7	7.5	147	146
PI 608	412115074553001	7/15/2015	930	M	7.5	7.8	218	208
PI 609	411920075070501	7/8/2015	1300	1.4	9.2	9	231	228
PI 610	411831074541401	7/14/2015	1300	6.7	6	6.4	178	172
PI 611	412851075095201	7/7/2015	1230	0.2	7.2	7.7	247	248
PI 612	412904075081801	7/7/2015	1230	7.1	6.2	6.6	168	165

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm; microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Station number	Date	Sample start time	Dissolved oxygen, water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	pH, water, unfiltered, laboratory (standard units)	Specific conductance, water, unfiltered, laboratory (µS/cm at 25 °C)	Specific conductance, water, unfiltered (µS/cm at 25 °C)
				00300	00400	00403	90095	00095
PI 613	412534075114501	7/6/2015	1500	1	7.2	7.7	447	427
PI 614	411937075182801	7/9/2015	1000	0.6	7.3	7.9	156	156
PI 615	412455074542201	7/8/2015	1530	8.9	5.8	E6.3	E65	58
PI 616	412152075174901	6/22/2015	1530	7.5	6.5	7	220	207
PI 617	411956074492101	7/9/2015	1230	9.1	6.4	7	312	315
PI 618	412230074423901	7/9/2015	1000	0.8	7.2	8	227	226
PI 619	412823075042301	7/7/2015	1000	1.7	7.7	7.9	162	160
PI 620	411800075130901	7/16/2015	1000	9.4	5.5	E6.6	E65	71
PI 621	411759075131001	7/9/2015	1300	9.8	6	E6.8	E71	70
PI 622	411951074475401	7/14/2015	1600	0.1	8.7	8.4	273	267
PI 623	411441074551501	7/15/2015	1400	2.3	7.1	7.6	201	199
PI 624	412307075104301	7/14/2015	1230	0.3	7.6	7.9	180	179
PI 625	412843075000201	7/15/2015	1000	0.2	8.1	8.2	165	164
PI 626	412836075025401	7/7/2015	1530	1.1	7.7	7.9	149	149
PI 627	411659075045201	7/8/2015	1300	0.2	7.6	7.9	151	152
PI 628	412430075081301	7/8/2015	1430	9.8	5.5	E6.3	E45	47
PI 629	412151075170001	7/14/2015	1430	6	6.6	7.2	292	290
PI 630	412117074593601	7/15/2015	1500	8.9	6	E6.5	E53	52
PI 631	412322074463701	7/15/2015	1230	0.1	6.6	7	191	191
PI 632	412206075041501	8/3/2015	1230	8.8	5.7	E6.2	E93	89
PI 633	412856075061501	8/6/2015	1000	3	7.5	8	185	179
PI 634	413158075053301	8/4/2015	930	5.6	7.1	7.5	228	215
PI 635	413215075062501	8/4/2015	1030	0.1	7.7	8.1	175	169
PI 636	413429075050401	8/4/2015	1400	0.7	7.6	7.9	142	135
PI 638	412107074552701	8/5/2015	1600	0.1	6.5	7.3	456	440
PI 639	413006075083701	8/6/2015	1230	5.9	7.4	8	282	272
PI 640	411954074475101	9/21/2015	1400	1.1	7.2	7.7	282	251
PI 641	413207075053601	9/22/2015	1030	0.1	8.1	8.1	233	217
PI 642	410602075005101	9/22/2015	1400	1.3	7.5	7.9	251	242
PI 643	411704074555401	9/24/2015	900	2.9	7	7.7	313	299
PI 644	412136074511501	9/21/2015	1130	2.9	7.1	7.5	205	195
PI 645	411716074500801	9/23/2015	1000	7.2	6.4	7.2	207	190
PI 647	411014074554001	9/23/2015	1500	0.2	8.3	8.3	181	173
PI 647	411014074554001	9/23/2015	1501	--	--	--	--	--
PI 648	410554074595101	9/24/2015	1300	5.9	9	8.9	245	229
PI 649	410552075000601	9/24/2015	1030	5.6	6.4	7.2	252	235
PI 650	411833074482501	9/23/2015	1100	0.1	9.1	8.7	1,580	1,320
PI 651	412907074592801	9/22/2015	1100	0.1	8.7	8.6	277	267
PI 652	411818074591001	9/23/2015	1330	5.4	6.1	6.7	148	146
PI 653	411543074545801	9/24/2015	1130	0.1	7.7	8	1,090	1,060

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Local identifier	Date	Sample start time	Temperature, water (°C)	Dissolved solids dried at 180 °C, water, filtered (mg/L)	Dissolved solids, water, filtered, sum of constituents (mg/L)	Hardness, water (mg/L as $CaCO_3$)	Suspended solids, dried at 105 °C, water (mg/L)	Calcium, water, filtered (mg/L)	Calcium, water, unfiltered, recoverable (mg/L)
			00010	70300	70301	00900	70293	00915	00916
PI 146	8/6/2015	1400	10.7	149	154	32.8	6	9.41	11.7
PI 288	6/23/2015	930	9.8	60	54	29.2	<5	9.18	8.6
PI 403	6/25/2015	1400	13	280	250	185	100	60.2	56.7
PI 507	6/23/2015	1100	10.4	176	154	105	<5	25.3	24.8
PI 523	9/21/2015	1200	11.4	211	189	140	6	41.3	44
PI 524	6/25/2015	1500	11.4	162	176	58.9	<5	14.4	14.3
PI 524	9/22/2015	1330	11.4	177	166	55.6	<5	13.7	14.3
PI 524	9/22/2015	1331	--	176	166	57.1	<5	14	14.2
PI 526	8/3/2015	1130	12.2	77	E73	43.6	<5	9.23	8.94
PI 530	8/5/2015	1330	12.2	129	129	63.5	5	14.8	15.6
PI 534	8/4/2015	1500	10.9	144	E137	111	<5	26.8	26.7
PI 535	8/4/2015	1230	10.7	149	E136	75	29	18.1	17.8
PI 539	8/5/2015	1100	13	111	117	79.2	9	22.8	23.6
PI 540	8/5/2015	1030	11.3	120	125	82.5	<5	21.8	22.7
PI 543	8/3/2015	1500	11.4	65	E66	43.1	<5	10	9.36
PI 546	8/4/2015	1000	12.2	50	47	27.3	12	6.46	6.26
PI 552	6/24/2015	1445	11.2	121	134	97.2	<5	26.1	24.6
PI 553	6/23/2015	1400	11.2	48	59	32.7	13	7.77	6.99
PI 555	6/23/2015	1100	9	87	85	73.7	5	23.8	22.5
PI 556	8/6/2015	1030	13.9	111	113	63.2	<5	16.7	17.5
PI 558	6/23/2015	1500	12.2	39	56	34.5	<5	10.7	9.52
PI 562	9/23/2015	900	11	118	111	79.2	9	19	17.8
PI 581	8/3/2015	1430	10.9	139	127	99.8	<5	28.6	28.2
PI 591	8/5/2015	1600	11	152	160	16.6	74	4.98	5.6
PI 592	6/24/2015	1100	11.1	185	188	17.2	<5	4.41	4.13
PI 592	6/24/2015	1101	--	185	185	16.5	<5	4.23	4.16
PI 593	6/22/2015	1300	10.6	112	109	78.2	<5	24.1	22.4
PI 594	6/25/2015	1130	11	38	54	32.7	<5	7.66	7.54
PI 595	6/23/2015	930	10.8	162	141	92	<5	25.4	25.6
PI 597	7/8/2015	1000	10.9	88	91	62.4	5	16.6	15.9
PI 598	6/22/2015	1600	10.4	82	76	47.7	<5	11.1	9.98
PI 600	6/24/2015	1400	10.4	130	134	102	<5	28.3	26.5
PI 601	6/25/2015	1000	9.9	82	91	50.8	10	10.6	8.86
PI 603	7/6/2015	1230	10.6	73	79	43.4	<5	11	11.5
PI 604	9/21/2015	1500	11	129	132	90.5	161	26.8	26.8
PI 605	7/8/2015	1100	10.9	78	67	35.3	<5	8.46	8.49
PI 606	6/24/2015	1100	9.9	146	145	90.4	<5	21	20.6
PI 607	7/7/2015	1530	11	89	90	68.1	<5	15.8	14.4
PI 608	7/15/2015	930	10.5	137	E121	86.1	<5	21.3	20.4
PI 609	7/8/2015	1300	11	131	136	26.4	<5	8.14	7.73
PI 610	7/14/2015	1300	11.5	100	99	55.5	<5	14	13.3
PI 611	7/7/2015	1230	12.7	149	142	102	<5	25.9	24.2
PI 612	7/7/2015	1230	11.9	102	94	59.3	<5	15.1	13.8

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Temperature, water (°C)	Dissolved solids dried at 180 °C, water, filtered (mg/L)	Dissolved solids, water, filtered, sum of constituents (mg/L)	Hardness, water (mg/L as $CaCO_3$)	Suspended solids, dried at 105 °C, water (mg/L)	Calcium, water, filtered (mg/L)	Calcium, water, unfiltered, recoverable (mg/L)
			00010	70300	70301	00900	70293	00915	00916
PI 613	7/6/2015	1500	11	262	248	185	<5	50.4	53.4
PI 614	7/9/2015	1000	12.9	95	92	69.8	<5	19	17.3
PI 615	7/8/2015	1530	10.4	45	40	19.6	<5	4.55	4.45
PI 616	6/22/2015	1530	9.6	127	116	79.1	<5	24.8	23.2
PI 617	7/9/2015	1230	11.6	185	159	90.2	<5	23.1	21.8
PI 618	7/9/2015	1000	11.9	129	128	89.5	<5	23.9	23
PI 619	7/7/2015	1000	11.1	103	98	74.6	22	17.7	15.5
PI 620	7/16/2015	1000	9.5	52	E37	19.7	19	6.36	6.1
PI 621	7/9/2015	1300	9.8	44	41	26.3	7	8.6	8.38
PI 622	7/14/2015	1600	12.2	161	164	43.8	36	12	11.4
PI 623	7/15/2015	1400	12.3	119	E122	59.6	42	13	13.2
PI 624	7/14/2015	1230	12	107	106	72.2	5	23	22.5
PI 625	7/15/2015	1000	12.4	103	101	66.3	<5	17.6	17.6
PI 626	7/7/2015	1530	11.9	98	91	66.4	<5	16.2	15.2
PI 627	7/8/2015	1300	10.4	85	90	60.7	<5	15.7	15.5
PI 628	7/8/2015	1430	9.6	28	33	14.2	9	3.67	3.63
PI 629	7/14/2015	1430	12.9	207	165	128	<5	41.4	40
PI 630	7/15/2015	1500	11	36	33	21	<5	5.28	5.17
PI 631	7/15/2015	1230	10.8	134	115	73.2	<5	17.4	17.2
PI 632	8/3/2015	1230	10.8	52	55	28.8	<5	6.2	6.06
PI 633	8/6/2015	1000	10.8	103	107	79	<5	16.1	16.7
PI 634	8/4/2015	930	11.1	133	E135	89.8	<5	26.9	25.8
PI 635	8/4/2015	1030	7.7	111	E114	80.3	<5	23.2	22.9
PI 636	8/4/2015	1400	11	87	87	61.1	<5	16.2	16
PI 638	8/5/2015	1600	10.2	272	237	140	<5	32.9	34.2
PI 639	8/6/2015	1230	11.5	162	159	93.7	<5	28.6	29.9
PI 640	9/21/2015	1400	13	161	155	103	5	27.9	28.8
PI 641	9/22/2015	1030	11	136	136	82.1	<5	24.7	25.9
PI 642	9/22/2015	1400	12.1	149	143	99.8	16	27.6	30.4
PI 643	9/24/2015	900	10.6	172	162	128	<5	31.6	32.4
PI 644	9/21/2015	1130	10.9	119	119	93.6	44	27	27.7
PI 645	9/23/2015	1000	11.4	147	115	70.9	<5	17.7	18.4
PI 647	9/23/2015	1500	10.7	124	110	63	7	16.4	16.8
PI 647	9/23/2015	1501	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	12.2	153	149	18.1	5	5.79	5.85
PI 649	9/24/2015	1030	12.2	146	148	86.4	<5	25.7	24.8
PI 650	9/23/2015	1100	11.5	940	975	79.4	<5	14.5	12.5
PI 651	9/22/2015	1100	12.4	157	161	23.4	5	6.26	6.56
PI 652	9/23/2015	1330	10.5	94	85	47.8	<5	11.9	11.2
PI 653	9/24/2015	1130	11	608	547	392	<5	103	106

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Local identifier	Date	Sample start time	Magnesium, water, filtered (mg/L)	Magnesium, water, unfiltered, recoverable (mg/L)	Potassium, water, filtered (mg/L)	Potassium, water, unfiltered, recoverable (mg/L)	Sodium fraction of cations, water, (percent in equivalents of major cations)	Sodium, water, filtered, (mg/L)	Sodium, water, unfiltered, recoverable (mg/L)
			00925	00927	00935	00937	00932	00930	00929
PI 146	8/6/2015	1400	2.18	2.45	0.3	<0.50	75	46	43.9
PI 288	6/23/2015	930	1.52	1.39	0.49	<0.50	31	6.29	5.88
PI 403	6/25/2015	1400	8.28	7.81	0.56	0.67	19	19.7	19.6
PI 507	6/23/2015	1100	10.1	9.24	0.83	0.82	22	13.7	13.5
PI 523	9/21/2015	1200	8.68	9.42	0.36	<0.50	13	9.52	10.4
PI 524	6/25/2015	1500	5.39	4.91	0.24	<0.50	63	46.6	45.2
PI 524	9/22/2015	1330	5.04	5.31	0.26	<0.50	61	40	43.1
PI 524	9/22/2015	1331	5.19	5.31	0.26	<0.50	61	40.8	45.2
PI 526	8/3/2015	1130	4.96	4.6	0.51	0.51	32	9.72	9.31
PI 530	8/5/2015	1330	6.37	6.49	0.29	<0.50	43	22.2	22.2
PI 534	8/4/2015	1500	10.6	9.53	0.43	<0.50	10	5.87	5.73
PI 535	8/4/2015	1230	7.18	7.1	0.85	1.36	38	21.2	22.1
PI 539	8/5/2015	1100	5.41	5.68	1.13	1.19	23	10.8	10.8
PI 540	8/5/2015	1030	6.67	6.98	0.69	0.66	26	13.2	13.3
PI 543	8/3/2015	1500	4.37	4.24	0.59	0.6	14	3.24	3.39
PI 546	8/4/2015	1000	2.72	2.45	0.45	<0.50	23	3.83	3.71
PI 552	6/24/2015	1445	7.63	7.16	0.28	<0.50	14	7.46	6.91
PI 553	6/23/2015	1400	3.16	2.94	0.61	0.67	32	7.33	7.09
PI 555	6/23/2015	1100	3.42	3.13	0.6	0.62	4	1.37	1.28
PI 556	8/6/2015	1030	4.99	4.95	0.19	<0.50	35	15.2	15.6
PI 558	6/23/2015	1500	1.9	1.72	0.37	<0.50	18	3.57	3.38
PI 562	9/23/2015	900	7.71	7.51	0.35	<0.50	17	7.38	7.16
PI 581	8/3/2015	1430	6.86	6.67	0.59	0.6	14	7.71	7.45
PI 591	8/5/2015	1600	0.904	1.33	0.36	<0.50	88	55.9	57.2
PI 592	6/24/2015	1100	1.36	1.24	0.77	0.71	89	68.1	63.3
PI 592	6/24/2015	1101	1.3	1.25	0.72	0.71	89	65.4	63.2
PI 593	6/22/2015	1300	4.2	3.76	0.86	0.8	18	8.08	7.7
PI 594	6/25/2015	1130	3.28	2.74	0.65	0.74	18	3.45	3.26
PI 595	6/23/2015	930	6.68	6.46	1.23	1.18	24	13.6	13.7
PI 597	7/8/2015	1000	5.1	4.67	0.4	<0.50	24	8.96	8.59
PI 598	6/22/2015	1600	4.84	4.43	0.79	0.77	26	7.9	7.72
PI 600	6/24/2015	1400	7.45	7.03	0.65	0.69	14	7.71	7.22
PI 601	6/25/2015	1000	5.83	5.4	0.4	0.5	36	13.2	12.2
PI 603	7/6/2015	1230	3.82	3.87	0.81	0.85	33	9.84	9.9
PI 604	9/21/2015	1500	5.74	5.62	0.76	0.82	27	15.8	16.5
PI 605	7/8/2015	1100	3.38	3.36	0.72	0.74	27	6.19	6.15
PI 606	6/24/2015	1100	9.15	8.7	0.55	0.57	32	19.4	18.7
PI 607	7/7/2015	1530	6.93	6.67	0.72	0.76	12	4.35	4.18
PI 608	7/15/2015	930	7.89	7.84	0.45	0.5	16	7.67	<7.19
PI 609	7/8/2015	1300	1.16	1.11	0.82	0.83	77	40.8	40.1
PI 610	7/14/2015	1300	5.01	4.37	0.47	<0.50	32	12	11.4
PI 611	7/7/2015	1230	9.05	8.92	0.9	0.97	21	12.9	12.6
PI 612	7/7/2015	1230	5.25	4.96	0.68	0.71	24	8.84	8.1

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Magnesium, water, filtered (mg/L)	Magnesium, water, unfiltered, recoverable (mg/L)	Potassium, water, filtered (mg/L)	Potassium, water, unfiltered, recoverable (mg/L)	Sodium fraction of cations, water, (percent in equivalents of major cations)	Sodium, water, filtered, (mg/L)	Sodium, water, unfiltered, recoverable (mg/L)
			00925	00927	00935	00937	00932	00930	00929
PI 613	7/6/2015	1500	14.1	14.1	1.34	1.42	18	18.3	18.5
PI 614	7/9/2015	1000	5.35	4.91	0.64	0.66	17	6.66	6.1
PI 615	7/8/2015	1530	1.99	1.94	0.42	<0.50	23	2.68	2.64
PI 616	6/22/2015	1530	4.03	3.6	0.98	0.92	21	9.79	9.04
PI 617	7/9/2015	1230	7.9	7.36	0.98	0.99	33	20.6	18.8
PI 618	7/9/2015	1000	7.16	6.87	0.43	<0.50	20	10.2	9.66
PI 619	7/7/2015	1000	7.29	6.87	0.7	1.12	17	7.1	6.18
PI 620	7/16/2015	1000	0.914	0.91	0.5	0.5	28	3.59	3.49
PI 621	7/9/2015	1300	1.16	1.18	0.5	0.78	14	2.09	1.9
PI 622	7/14/2015	1600	3.08	2.42	0.44	<0.50	70	47	44.6
PI 623	7/15/2015	1400	6.61	6.25	0.58	0.51	47	24.2	23.8
PI 624	7/14/2015	1230	3.37	3.23	0.91	0.88	21	9.08	8.5
PI 625	7/15/2015	1000	5.31	5.29	0.62	0.62	25	10.4	9.66
PI 626	7/7/2015	1530	6.21	6.04	0.53	0.59	18	6.72	6.41
PI 627	7/8/2015	1300	5.06	5.04	0.42	<0.50	22	7.65	7.57
PI 628	7/8/2015	1430	1.22	1.19	0.65	0.7	23	2.06	2.03
PI 629	7/14/2015	1430	5.83	5.94	0.88	0.94	11	7	7.05
PI 630	7/15/2015	1500	1.88	1.86	0.4	<0.50	14	1.61	1.51
PI 631	7/15/2015	1230	7.22	7.26	0.34	<0.50	21	8.82	8.3
PI 632	8/3/2015	1230	3.23	2.51	0.72	0.7	28	5.38	5.13
PI 633	8/6/2015	1000	9.36	9.38	0.92	0.91	16	7.09	7.25
PI 634	8/4/2015	930	5.33	5.06	0.9	0.95	24	13.5	13.4
PI 635	8/4/2015	1030	5.19	5.23	1.13	1.08	14	6.11	5.98
PI 636	8/4/2015	1400	4.94	4.94	0.64	0.67	18	6.27	6.38
PI 638	8/5/2015	1600	13.4	14.6	1.12	1.17	30	27.8	28
PI 639	8/6/2015	1230	4.74	4.66	1.77	1.79	30	17.9	18.3
PI 640	9/21/2015	1400	7.97	8.43	0.34	<0.50	22	13.3	14.7
PI 641	9/22/2015	1030	4.47	4.52	0.79	0.86	28	14.7	16.3
PI 642	9/22/2015	1400	7.38	7.65	0.32	<0.50	17	9.29	9.76
PI 643	9/24/2015	900	11.8	12	0.48	0.53	10	6.34	6.64
PI 644	9/21/2015	1130	6.35	6.33	0.4	<0.50	12	5.91	6.07
PI 645	9/23/2015	1000	6.38	6.45	0.56	0.58	23	9.7	10.6
PI 647	9/23/2015	1500	5.25	5.24	0.38	<0.50	31	13	14.2
PI 647	9/23/2015	1501	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	0.81	0.83	0.23	<0.50	85	48.4	51.8
PI 649	9/24/2015	1030	5.28	5.25	0.66	0.86	27	14.7	15.2
PI 650	9/23/2015	1100	9.5	8.54	1.43	1.38	89	283	284
PI 651	9/22/2015	1100	1.82	1.83	0.59	0.63	83	52.7	53.9
PI 652	9/23/2015	1330	4.4	4.26	0.45	<0.50	30	9.69	9.43
PI 653	9/24/2015	1130	32.2	33.5	0.59	0.61	21	47.1	47.3

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, laboratory, (mg/L as $CaCO_3$)	Bromide, water, filtered (µg/L)	Bromide, water, filtered (mg/L)	Bromide, water, unfiltered (mg/L)	Chloride, water, filtered (mg/L)	Chloride, water, unfiltered (mg/L)	Fluoride, water, filtered, (mg/L)	Silica, water, filtered, (mg/L as SiO_2)
			29801	91000	71870	63689	00940	99220	00950	00955
PI 146	8/6/2015	1400	122	40	0.032	<0.10	3.42	3.8	0.22	8.62
PI 288	6/23/2015	930	12.6	34	--	<0.10	16.2	16	0.03	4.34
PI 403	6/25/2015	1400	110	43	--	<0.10	69	69	0.12	14.3
PI 507	6/23/2015	1100	51.5	34	--	<0.10	49.1	49	0.04	9.28
PI 523	9/21/2015	1200	86.8	19	0.016	<0.10	45	56	0.09	16.2
PI 524	6/25/2015	1500	123	220	--	<0.10	23.5	24	0.2	10.1
PI 524	9/22/2015	1330	121	170	0.166	<0.10	22	23	0.21	9.66
PI 524	9/22/2015	1331	120	--	0.16	<0.10	21.6	24	0.2	9.61
PI 526	8/3/2015	1130	56.9	11	E0.010	<0.10	4	4.4	0.09	8.33
PI 530	8/5/2015	1330	97.8	28	0.023	<0.10	7.08	7.6	0.16	13.1
PI 534	8/4/2015	1500	78.6	23	E0.020	<0.10	16.3	17	0.03	10.6
PI 535	8/4/2015	1230	72	18	E0.016	<0.10	26.4	28	0.12	9.28
PI 539	8/5/2015	1100	101	11	<0.010	<0.10	0.86	<1.0	0.21	10
PI 540	8/5/2015	1030	99.2	39	0.02	<0.10	4.82	5.2	0.09	8.98
PI 543	8/3/2015	1500	39.8	16	E0.012	<0.10	1.62	1.8	0.08	13
PI 546	8/4/2015	1000	28.4	13	<0.010	<0.10	0.82	<1.0	0.09	10.9
PI 552	6/24/2015	1445	89.1	13	--	<0.10	3.55	3.8	0.14	17.2
PI 553	6/23/2015	1400	47.9	32	--	<0.10	0.47	<1.0	0.11	9.29
PI 555	6/23/2015	1100	66.4	19	--	<0.10	0.9	<1.0	0.06	6.07
PI 556	8/6/2015	1030	76.9	24	0.021	<0.10	5.51	5.7	0.11	9.93
PI 558	6/23/2015	1500	26.3	26	--	<0.10	2.44	2.5	0.05	8.45
PI 562	9/23/2015	900	72.2	11	0.016	<0.10	5.13	5.5	0.12	16.7
PI 581	8/3/2015	1430	98.4	10	<0.010	<0.10	7.92	8.7	0.17	10.3
PI 591	8/5/2015	1600	122	27	0.025	<0.10	13.5	14	0.26	7.62
PI 592	6/24/2015	1100	117	360	--	0.16	33	33	0.51	7.14
PI 592	6/24/2015	1101	117	350	--	0.16	33	33	0.51	7.08
PI 593	6/22/2015	1300	67.6	18	--	<0.10	11.6	12	0.09	10.3
PI 594	6/25/2015	1130	22.1	<10	--	<0.10	4.93	5.1	0.05	8.09
PI 595	6/23/2015	930	50.5	35	--	<0.10	44.4	48	0.11	11.5
PI 597	7/8/2015	1000	75	19	--	<0.10	0.81	<1.0	0.26	8.47
PI 598	6/22/2015	1600	56.8	27	--	<0.10	5.16	5.2	0.1	10.1
PI 600	6/24/2015	1400	101	13	--	<0.10	5.54	5.7	0.06	12.1
PI 601	6/25/2015	1000	61.5	50	--	<0.10	4.63	3.9	0.11	12.3
PI 603	7/6/2015	1230	60.2	11	--	<0.10	0.68	<1.0	0.11	10.8
PI 604	9/21/2015	1500	118	<10	<0.010	<0.10	0.88	<1.0	0.14	6.92
PI 605	7/8/2015	1100	18.4	17	--	<0.10	12.8	13	0.04	8.59
PI 606	6/24/2015	1100	124	22	--	<0.10	0.63	<1.0	0.13	9.51
PI 607	7/7/2015	1530	61.8	13	--	<0.10	1.91	1.9	0.11	11.9
PI 608	7/15/2015	930	44.8	24	E0.019	<0.10	33.5	34	0.08	15.2
PI 609	7/8/2015	1300	92.4	28	--	<0.10	12.8	13	0.37	8.68
PI 610	7/14/2015	1300	26.2	36	--	<0.10	27.3	13	0.05	10.2
PI 611	7/7/2015	1230	95.2	34	--	<0.10	15.2	14	0.1	11.8

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, laboratory, (mg/L as CaCO$_3$)	Bromide, water, filtered (µg/L)	Bromide, water, filtered (mg/L)	Bromide, water, unfiltered (mg/L)	Chloride, water, filtered (mg/L)	Chloride, water, unfiltered (mg/L)	Fluoride, water, filtered, (mg/L)	Silica, water, filtered, (mg/L as SiO$_2$)
			29801	91000	71870	63689	00940	99220	00950	00955
PI 612	7/7/2015	1230	27.3	18	--	<0.10	26.4	26	0.05	10.8
PI 613	7/6/2015	1500	135	66	--	<0.10	44	44	0.04	13.3
PI 614	7/9/2015	1000	69.7	24	--	<0.10	3.11	3.1	0.07	8.01
PI 615	7/8/2015	1530	11.9	12	--	<0.10	3.1	3.2	0.04	8.8
PI 616	6/22/2015	1530	31.8	66	--	0.35	39.5	40	0.02	8
PI 617	7/9/2015	1230	14	160	--	<0.10	71.9	73	0.02	7.61
PI 618	7/9/2015	1000	68.8	25	--	<0.10	20.4	20	0.09	11.9
PI 619	7/7/2015	1000	77	<10	--	<0.10	0.71	<1.0	0.09	10
PI 620	7/16/2015	1000	9.8	<10	E0.011	<0.10	8.17	8.2	0.03	4
PI 621	7/9/2015	1300	19.5	<10	--	<0.10	4.15	4.2	0.03	4.37
PI 622	7/14/2015	1600	114	50	0.042	<0.10	12.5	16	0.14	9.24
PI 623	7/15/2015	1400	103	17	E0.016	<0.10	0.97	<1.0	0.2	9.86
PI 624	7/14/2015	1230	67.9	<10	--	<0.10	10.9	11	0.09	10.5
PI 625	7/15/2015	1000	76.8	17	--	<0.10	1.16	1.2	0.1	10.8
PI 626	7/7/2015	1530	72.4	15	--	<0.10	1.16	1.1	0.07	11.1
PI 627	7/8/2015	1300	73.5	19	--	<0.10	0.67	<1.0	0.15	10.2
PI 628	7/8/2015	1430	9.8	<10	--	<0.10	1.3	1.3	0.04	9.06
PI 629	7/14/2015	1430	101	31	0.02	<0.10	16.1	28	0.05	11.5
PI 630	7/15/2015	1500	16.1	17	0.017	<0.10	1.49	1.5	0.04	5.4
PI 631	7/15/2015	1230	47.9	25	--	<0.10	23	23	0.08	14.3
PI 632	8/3/2015	1230	11.7	14	<0.010	<0.10	14.2	8.7	0.03	8.88
PI 633	8/6/2015	1000	77.2	<10	0.012	<0.10	5.47	6	0.11	10.2
PI 634	8/4/2015	930	83.4	24	E0.017	<0.10	13	14	0.13	13
PI 635	8/4/2015	1030	90.5	13	E0.011	<0.10	0.54	<1.0	0.11	13.8
PI 636	8/4/2015	1400	71.2	11	<0.010	<0.10	0.56	<1.0	0.06	11.6
PI 638	8/5/2015	1600	65.3	26	0.023	<0.10	84.9	91	0.03	13.1
PI 639	8/6/2015	1230	85.4	10	0.015	<0.10	25.6	27	0.07	9.78
PI 640	9/21/2015	1400	83	23	0.017	<0.10	25.9	28	0.08	11.1
PI 641	9/22/2015	1030	96.8	10	0.013	<0.10	9.11	10	0.13	12.1
PI 642	9/22/2015	1400	91.8	12	0.013	<0.10	10	11	0.09	12.9
PI 643	9/24/2015	900	69.5	31	0.03	<0.10	49.7	51	0.07	12.2
PI 644	9/21/2015	1130	97	20	0.011	<0.10	1.84	2.1	0.1	11.1
PI 645	9/23/2015	1000	34.2	13	0.012	<0.10	28.2	29	0.06	9.71
PI 647	9/23/2015	1500	70.9	<10	0.011	<0.10	2.96	3.1	0.1	11.8
PI 647	9/23/2015	1501	--	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	114	23	0.02	<0.10	2.33	2.5	0.25	10.4
PI 649	9/24/2015	1030	49.8	14	0.013	<0.10	22.6	24	0.05	9.21
PI 650	9/23/2015	1100	105	2,100	1.97	1.6	223	200	0.96	8.79
PI 651	9/22/2015	1100	120	170	0.15	0.65	15.3	17	0.29	9.67
PI 652	9/23/2015	1330	27.2	13	0.012	<0.10	19.6	21	0.07	10.6
PI 653	9/24/2015	1130	140	75	0.054	0.56	246	250	0.03	12.6

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[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Sulfate, water, filtered (mg/L)	Sulfate, water, unfiltered (mg/L)	Ammonia, water, filtered (mg/L as nitrogen)	Nitrate plus nitrite, water, filtered (mg/L as nitrogen)	Nitrate, water, filtered (mg/L as nitrogen)	Nitrite, water, filtered (mg/L as nitrogen)	Ortho-phosphate, water, filtered (mg/L as phosphorus)	Escherichia *coli*, water, most probable number per 100 milliliters
			00945	**00946**	**00608**	**00631**	**00618**	**00613**	**00671**	**31689**
PI 146	8/6/2015	1400	9.91	9.1	0.17	<0.040	<0.040	<0.001	0.042	<1
PI 288	6/23/2015	930	5.86	6	<0.01	0.643	0.643	<0.001	0.02	<1
PI 403	6/25/2015	1400	10.5	11.3	0.05	<0.040	<0.040	<0.001	0.028	<1
PI 507	6/23/2015	1100	11.1	11.3	<0.01	0.612	0.612	<0.001	0.013	<1
PI 523	9/21/2015	1200	13.5	13.6	0.07	<0.040	<0.040	<0.001	0.024	<1
PI 524	6/25/2015	1500	0.89	<1.0	0.07	<0.040	<0.040	<0.001	0.029	<1
PI 524	9/22/2015	1330	1.11	<1.0	0.06	<0.040	<0.040	<0.001	0.027	<1
PI 524	9/22/2015	1331	1.15	<1.0	0.06	<0.040	<0.040	<0.001	0.027	<1
PI 526	8/3/2015	1130	1.78	1.8	<0.01	<0.040	<0.040	<0.001	<0.004	<1
PI 530	8/5/2015	1330	5.8	6.4	0.05	<0.040	<0.040	<0.001	0.056	<1
PI 534	8/4/2015	1500	11.2	11.8	<0.01	1.66	1.66	0.006	0.008	<1
PI 535	8/4/2015	1230	7.64	8.1	<0.01	0.422	0.422	<0.001	0.031	<1
PI 539	8/5/2015	1100	4.28	4.7	0.03	<0.040	<0.040	<0.001	0.043	<1
PI 540	8/5/2015	1030	8.61	9.6	<0.01	<0.040	<0.040	<0.001	0.007	<1
PI 543	8/3/2015	1500	7.59	8.1	<0.01	0.206	0.206	<0.001	0.044	<1
PI 546	8/4/2015	1000	4.92	5.4	<0.01	<0.040	<0.040	<0.001	0.032	<1
PI 552	6/24/2015	1445	17.4	18.6	0.04	<0.040	<0.040	<0.001	0.011	<1
PI 553	6/23/2015	1400	0.85	<1.0	<0.01	<0.040	<0.040	<0.001	0.018	<1
PI 555	6/23/2015	1100	7.75	8	<0.01	0.323	0.323	<0.001	0.016	<1
PI 556	8/6/2015	1030	13.1	13.6	0.09	<0.040	<0.040	<0.001	0.019	<1
PI 558	6/23/2015	1500	12.1	12	<0.01	0.088	0.088	<0.001	0.014	<1
PI 562	9/23/2015	900	11.1	12	0.02	<0.040	<0.040	<0.001	0.014	<1
PI 581	8/3/2015	1430	5.06	5.6	<0.01	<0.040	<0.040	<0.001	0.056	<1
PI 591	8/5/2015	1600	1.7	1.3	0.32	<0.040	<0.040	<0.001	0.037	<1
PI 592	6/24/2015	1100	0.39	<1.0	0.06	<0.040	<0.040	<0.001	0.174	<1
PI 592	6/24/2015	1101	0.39	<1.0	0.06	<0.040	<0.040	<0.001	0.178	<1
PI 593	6/22/2015	1300	8.54	8.8	<0.01	<0.040	<0.040	<0.001	0.007	<1
PI 594	6/25/2015	1130	8.84	9.3	<0.01	0.816	0.816	<0.001	0.022	<1
PI 595	6/23/2015	930	6.64	6.9	<0.01	0.048	0.048	<0.001	0.005	<1
PI 597	7/8/2015	1000	5.31	<5.8	<0.01	<0.040	<0.040	<0.001	0.05	<1
PI 598	6/22/2015	1600	0.77	<1.0	0.09	<0.040	<0.040	<0.001	0.083	<1
PI 600	6/24/2015	1400	10.9	11.1	<0.01	<0.040	<0.040	<0.001	0.006	<1
PI 601	6/25/2015	1000	6.44	7.6	<0.01	<0.040	<0.040	<0.001	0.029	<1
PI 603	7/6/2015	1230	5.05	5.6	<0.01	<0.040	<0.040	<0.001	0.024	<1
PI 604	9/21/2015	1500	3.93	4.3	0.04	<0.040	<0.040	<0.001	0.023	<1
PI 605	7/8/2015	1100	10.2	10.4	<0.01	1.09	1.09	<0.001	0.031	<1
PI 606	6/24/2015	1100	9.69	10.2	<0.01	<0.040	<0.040	<0.001	0.027	<1
PI 607	7/7/2015	1530	9.53	9.5	<0.01	0.237	0.237	<0.001	0.025	<1
PI 608	7/15/2015	930	7.5	8.2	0.01	<0.040	<0.040	<0.001	0.007	<1
PI 609	7/8/2015	1300	6.42	6.1	0.07	<0.040	<0.040	<0.001	0.017	<1
PI 610	7/14/2015	1300	6.79	10	<0.01	1.72	1.72	<0.001	0.019	<1
PI 611	7/7/2015	1230	8.34	8.1	<0.01	<0.040	<0.040	<0.001	0.02	<1
PI 612	7/7/2015	1230	8.71	8.7	<0.01	0.36	0.36	<0.001	0.027	<1

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Sulfate, water, filtered (mg/L)	Sulfate, water, unfiltered (mg/L)	Ammonia, water, filtered (mg/L as nitrogen)	Nitrate plus nitrite, water, filtered (mg/L as nitrogen)	Nitrate, water, filtered (mg/L as nitrogen)	Nitrite, water, filtered (mg/L as nitrogen)	Ortho-phosphate, water, filtered (mg/L as phosphorus)	Escherichia *coli*, water, most probable number per 100 milliliters
			00945	00946	00608	00631	00618	00613	00671	31689
PI 613	7/6/2015	1500	24.1	24.6	0.02	0.048	0.048	<0.001	0.007	<1
PI 614	7/9/2015	1000	3.96	3.9	<0.01	0.6	0.6	<0.001	0.017	<1
PI 615	7/8/2015	1530	9.89	9.9	<0.01	0.191	0.191	<0.001	0.021	<1
PI 616	6/22/2015	1530	7.37	7.6	<0.01	0.507	0.507	<0.001	<0.004	<1
PI 617	7/9/2015	1230	8.44	8.5	0.05	1.91	1.89	0.019	<0.004	<1
PI 618	7/9/2015	1000	11	11.2	<0.01	0.279	0.279	<0.001	0.013	<1
PI 619	7/7/2015	1000	7.57	8	<0.01	<0.040	<0.040	<0.001	0.016	<1
PI 620	7/16/2015	1000	5.22	5.3	<0.01	0.58	0.577	0.002	0.018	<1
PI 621	7/9/2015	1300	5.43	5.5	<0.01	0.598	0.598	<0.001	0.023	<1
PI 622	7/14/2015	1600	9.63	14.3	0.23	<0.040	<0.040	<0.001	0.017	<1
PI 623	7/15/2015	1400	4.78	5.4	0.01	<0.040	<0.040	<0.001	0.01	<1
PI 624	7/14/2015	1230	6.55	7.1	0.01	0.043	0.043	<0.001	0.004	<1
PI 625	7/15/2015	1000	8.06	8.7	0.01	<0.040	<0.040	<0.001	0.01	<1
PI 626	7/7/2015	1530	4.69	4.6	<0.01	0.074	0.074	<0.001	0.015	<1
PI 627	7/8/2015	1300	5	5.5	0.01	<0.040	<0.040	<0.001	0.009	<1
PI 628	7/8/2015	1430	8.7	9.1	<0.01	<0.040	<0.040	<0.001	0.054	<1
PI 629	7/14/2015	1430	14.2	6.9	<0.01	1.69	1.69	<0.001	0.015	<1
PI 630	7/15/2015	1500	6.04	6.3	<0.01	0.299	0.299	<0.001	0.014	<1
PI 631	7/15/2015	1230	9.84	10.5	0.04	<0.040	<0.040	<0.001	0.03	<1
PI 632	8/3/2015	1230	5.96	5.5	<0.01	0.713	0.713	<0.001	0.024	<1
PI 633	8/6/2015	1000	9.9	12	<0.01	0.203	0.203	<0.001	0.011	<1
PI 634	8/4/2015	930	11	11.7	<0.01	0.145	0.145	<0.001	0.019	<1
PI 635	8/4/2015	1030	8.55	9.5	0.02	<0.040	<0.040	<0.001	0.006	<1
PI 636	8/4/2015	1400	3.55	3.8	<0.01	0.044	0.044	<0.001	0.012	<1
PI 638	8/5/2015	1600	21.3	23.2	0.02	<0.040	<0.040	<0.001	0.004	<1
PI 639	8/6/2015	1230	15.8	16.5	<0.01	0.09	0.09	<0.001	0.007	<1
PI 640	9/21/2015	1400	16.7	17.6	0.01	0.235	0.235	<0.001	0.015	<1
PI 641	9/22/2015	1030	9.43	10.4	0.03	<0.040	<0.040	<0.001	0.007	<1
PI 642	9/22/2015	1400	19.1	20.3	<0.01	0.192	0.192	<0.001	0.026	<1
PI 643	9/24/2015	900	5.86	6.2	<0.01	0.371	0.371	<0.001	0.028	<1
PI 644	9/21/2015	1130	7.32	7.7	<0.01	0.069	0.069	<0.001	0.016	<1
PI 645	9/23/2015	1000	20.2	21.2	<0.01	0.255	0.255	<0.001	0.019	<1
PI 647	9/23/2015	1500	17.2	18.5	0.05	<0.040	<0.040	<0.001	0.022	<1
PI 647	9/23/2015	1501	--	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	11.7	12.7	0.12	<0.040	<0.040	<0.001	0.017	--
PI 649	9/24/2015	1030	37.8	38	<0.01	0.204	0.204	<0.001	0.026	--
PI 650	9/23/2015	1100	362	322	0.63	<0.040	<0.040	<0.001	0.009	<1
PI 651	9/22/2015	1100	1.99	2.1	0.01	<0.040	<0.040	<0.001	0.037	<1
PI 652	9/23/2015	1330	8.61	9.3	<0.01	0.699	0.699	<0.001	0.021	<1
PI 653	9/24/2015	1130	18	20.5	0.04	<0.040	<0.040	<0.001	0.009	--

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[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Total coliforms, water (most probable number per 100 milliliters)	Aluminum, water, filtered (µg/L)	Aluminum, water, unfiltered, recoverable (µg/L)	Barium, water, filtered (µg/L)	Barium, water, unfiltered, recovera)ble (µg/L	Beryllium, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)	Chromium, water, filtered (µg/L)
			31686	01106	01105	01005	01007	01010	01025	01030
PI 146	8/6/2015	1400	6	6.6	M	13.3	16.7	<0.020	<0.030	<0.30
PI 288	6/23/2015	930	18	3.3	M	20.7	19.8	0.021	0.145	<0.30
PI 403	6/25/2015	1400	<1	<3.0	100	11.9	16.8	<0.020	<0.030	<0.30
PI 507	6/23/2015	1100	5	<3.0	M	62.6	62.4	<0.020	<0.030	<0.30
PI 523	9/21/2015	1200	<1	<3.0	<1	22.6	25.2	<0.020	<0.030	<0.30
PI 524	6/25/2015	1500	<1	<3.0	M	137	130	<0.020	<0.030	<0.30
PI 524	9/22/2015	1330	<1	<3.0	M	130	125	<0.020	<0.030	<0.30
PI 524	9/22/2015	1331	<1	<3.0	M	132	126	<0.020	<0.030	<0.30
PI 526	8/3/2015	1130	<1	<3.0	<20	6.53	<10.0	<0.020	<0.030	<0.30
PI 530	8/5/2015	1330	18	4.2	100	40.4	41.3	<0.020	<0.030	<0.30
PI 534	8/4/2015	1500	<1	<3.0	<1	41.6	40.9	<0.020	<0.030	<0.30
PI 535	8/4/2015	1230	1	71.4	1,400	7.54	19.2	<0.020	<0.030	<0.30
PI 539	8/5/2015	1100	<1	<3.0	M	2.85	3.8	<0.020	<0.030	<0.30
PI 540	8/5/2015	1030	<1	<3.0	M	53.2	53.9	<0.020	<0.030	<0.30
PI 543	8/3/2015	1500	<1	<3.0	<20	41.8	42.6	<0.020	<0.030	<0.30
PI 546	8/4/2015	1000	<1	<3.0	<20	11.2	15.5	<0.020	<0.030	<0.30
PI 552	6/24/2015	1445	<1	<3.0	M	12.8	12.3	<0.020	<0.030	<0.30
PI 553	6/23/2015	1400	<1	<3.0	M	46.9	66.1	<0.020	<0.030	<0.30
PI 555	6/23/2015	1100	2	<3.0	M	48.4	45.6	<0.020	<0.030	<0.30
PI 556	8/6/2015	1030	<1	<3.0	M	17	17.8	<0.020	<0.030	<0.30
PI 558	6/23/2015	1500	1,990	<3.0	M	2.63	2.7	<0.020	<0.030	<0.30
PI 562	9/23/2015	900	<1	<3.0	M	10.6	12.1	<0.020	<0.030	<0.30
PI 581	8/3/2015	1430	10	4.7	M	23.9	26.9	<0.020	<0.030	<0.30
PI 591	8/5/2015	1600	<1	56.3	900	24.1	56.9	0.036	<0.030	<0.30
PI 592	6/24/2015	1100	19	<3.0	M	298	292	<0.020	<0.030	<0.30
PI 592	6/24/2015	1101	<1	3.5	M	294	291	<0.020	<0.030	<0.30
PI 593	6/22/2015	1300	<1	<3.0	<1	77.7	77.3	<0.020	<0.030	<0.30
PI 594	6/25/2015	1130	<1	<3.0	M	5.09	5.1	<0.020	0.053	<0.30
PI 595	6/23/2015	930	<1	<3.0	<1	143	146	<0.020	<0.030	<0.30
PI 597	7/8/2015	1000	<1	<3.0	M	3.04	4.5	<0.020	<0.030	<0.30
PI 598	6/22/2015	1600	<1	3.1	M	20.2	20.7	<0.020	0.031	<0.30
PI 600	6/24/2015	1400	<1	<3.0	M	160	156	<0.020	<0.030	<0.30
PI 601	6/25/2015	1000	<1	4.8	M	28.2	39.9	<0.020	<0.030	<0.30
PI 603	7/6/2015	1230	<1	<3.0	M	53	61.1	<0.020	<0.030	<0.30
PI 604	9/21/2015	1500	<1	9.5	200	1.23	18.8	<0.020	<0.030	<0.30
PI 605	7/8/2015	1100	7	<3.0	M	32.3	32.2	0.024	<0.030	<0.30
PI 606	6/24/2015	1100	<1	<3.0	M	103	104	<0.020	<0.030	<0.30
PI 607	7/7/2015	1530	<1	<3.0	M	32.5	32.3	<0.020	<0.030	<0.30
PI 608	7/15/2015	930	<1	<3.0	M	200	190	<0.020	<0.030	<0.30
PI 609	7/8/2015	1300	<1	3.8	M	216	207	<0.020	<0.030	<0.30
PI 610	7/14/2015	1300	2	3.1	M	3.48	3.5	<0.020	<0.030	<0.30
PI 611	7/7/2015	1230	<1	<3.0	M	50.5	55.7	<0.020	<0.030	<0.30
PI 612	7/7/2015	1230	<1	<3.0	<20	3.24	3.2	<0.020	<0.030	<0.30

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Local identifier	Date	Sample start time	Total coliforms, water (most probable number per 100 milliliters)	Aluminum, water, filtered (µg/L)	Aluminum, water, unfiltered, recoverable (µg/L)	Barium, water, filtered (µg/L)	Barium, water, unfiltered, recovera)ble (µg/L	Beryllium, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)	Chromium, water, filtered (µg/L)
			31686	01106	01105	01005	01007	01010	01025	01030
PI 613	7/6/2015	1500	<1	<3.0	<1	122	135	<0.020	<0.030	<0.30
PI 614	7/9/2015	1000	32	35.4	M	36.2	36	<0.020	<0.030	<0.30
PI 615	7/8/2015	1530	96	3.6	M	18.1	18	0.074	0.054	<0.30
PI 616	6/22/2015	1530	<1	<3.0	M	91.8	91.2	<0.020	<0.030	<0.30
PI 617	7/9/2015	1230	>1	9.2	M	9.57	9.7	<0.020	<0.030	<0.30
PI 618	7/9/2015	1000	>1	102	M	0.56	0.5	<0.020	0.054	<0.30
PI 619	7/7/2015	1000	10	11.5	1,300	65.8	87.5	<0.020	<0.030	<0.30
PI 620	7/16/2015	1000	<1	3.6	M	31.6	37	0.025	<0.030	<0.30
PI 621	7/9/2015	1300	28	<3.0	600	42.1	48.6	<0.020	<0.030	<0.30
PI 622	7/14/2015	1600	3	7.6	M	22.2	22.5	<0.020	<0.030	<0.30
PI 623	7/15/2015	1400	<1	<3.0	M	0.54	1.1	0.11	0.109	<0.30
PI 624	7/14/2015	1230	756	<3.0	M	182	184	<0.020	<0.030	<0.30
PI 625	7/15/2015	1000	<1	<3.0	<1	79.3	79.1	<0.020	<0.030	<0.30
PI 626	7/7/2015	1530	<1	<3.0	<1	25.6	25.6	<0.020	<0.030	<0.30
PI 627	7/8/2015	1300	<1	10.8	M	128	129	<0.020	<0.030	<0.30
PI 628	7/8/2015	1430	<1	5.9	M	28.7	29.1	0.021	<0.030	<0.30
PI 629	7/14/2015	1430	23	<3.0	300	111	112	<0.020	0.034	<0.30
PI 630	7/15/2015	1500	<1	<3.0	M	18.7	18.8	0.021	<0.030	<0.30
PI 631	7/15/2015	1230	25	<3.0	M	33.9	33.4	0.031	<0.030	<0.30
PI 632	8/3/2015	1230	<1	41.5	<20	23.8	24.9	0.022	<0.030	<0.30
PI 633	8/6/2015	1000	41	<3.0	M	11.1	13.1	<0.020	<0.030	<0.30
PI 634	8/4/2015	930	<1	<3.0	<20	58.2	62.1	<0.020	<0.030	<0.30
PI 635	8/4/2015	1030	<1	<3.0	<20	169	171	<0.020	<0.030	<0.30
PI 636	8/4/2015	1400	<1	<3.0	M	7.45	<10.0	<0.020	<0.030	<0.30
PI 638	8/5/2015	1600	9	3.2	M	383	398	<0.020	<0.030	<0.30
PI 639	8/6/2015	1230	<1	<3.0	<1	318	311	<0.020	<0.030	<0.30
PI 640	9/21/2015	1400	43	10.5	100	9.45	11.9	<0.020	<0.030	<0.30
PI 641	9/22/2015	1030	>1	<3.0	M	243	237	<0.020	<0.030	<0.30
PI 642	9/22/2015	1400	<1	23.5	M	3.18	3.7	<0.020	<0.030	<0.30
PI 643	9/24/2015	900	<1	<3.0	M	4.96	5.5	<0.020	<0.030	<0.30
PI 644	9/21/2015	1130	<1	9.4	100	6.35	8.7	<0.020	<0.030	<0.30
PI 645	9/23/2015	1000	<1	10.3	M	2.45	2.5	<0.020	<0.030	<0.30
PI 647	9/23/2015	1500	<1	<3.0	M	11.2	15.8	<0.020	<0.030	<0.30
PI 647	9/23/2015	1501	--	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	9	20.3	M	13.4	15	<0.020	<0.030	<0.30
PI 649	9/24/2015	1030	10	402	300	8.08	13.4	<0.020	0.139	<0.30
PI 650	9/23/2015	1100	<1	82.5	M	71.6	69.7	0.04	0.032	<0.30
PI 651	9/22/2015	1100	<1	5.8	M	124	116	<0.020	<0.030	<0.30
PI 652	9/23/2015	1330	<1	<3.0	<1	11.9	12	<0.020	<0.030	<0.30
PI 653	9/24/2015	1130	816	<3.0	M	350	341	<0.020	<0.030	<0.30

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Iron, water, unfiltered, recoverable (µg/L)	Lead, water, filtered, (µg/L)	Lithium, water, filtered (µg/L)	Lithium, water, unfiltered, recoverable (µg/L)	Manganese, water, filtered, (µg/L)
			01035	01040	01046	01045	01049	01130	01132	01056
PI 146	8/6/2015	1400	<0.050	<0.80	22	744	<0.040	87.4	90	55.2
PI 288	6/23/2015	930	<0.050	9.2	<4.0	10	1.45	2.48	<10	0.58
PI 403	6/25/2015	1400	0.253	<0.80	75.9	2,250	<0.040	13.9	10	715
PI 507	6/23/2015	1100	0.146	<0.80	<4.0	<10	0.225	14.5	10	<0.40
PI 523	9/21/2015	1200	<0.050	<0.80	576	761	<0.040	18.6	20	493
PI 524	6/25/2015	1500	<0.050	<0.80	18.6	59	<0.040	136	140	18.4
PI 524	9/22/2015	1330	0.09	<0.80	22.4	51	<0.040	118	130	20.3
PI 524	9/22/2015	1331	<0.050	<0.80	20.9	37	<0.040	122	140	19.9
PI 526	8/3/2015	1130	<0.050	<0.80	222	2,760	<0.040	2.49	<10	6.22
PI 530	8/5/2015	1330	<0.050	<0.80	118	739	<0.040	61.8	70	84
PI 534	8/4/2015	1500	0.711	10.2	<4.0	<10	0.313	12.1	10	17.2
PI 535	8/4/2015	1230	0.175	5.1	6.6	1,330	0.122	5.35	<10	0.82
PI 539	8/5/2015	1100	<0.050	<0.80	452	1,130	<0.040	5.31	<10	373
PI 540	8/5/2015	1030	<0.050	<0.80	95.4	1,250	0.104	20	20	8.18
PI 543	8/3/2015	1500	<0.050	5.3	<4.0	<10	0.388	5.91	<10	<0.40
PI 546	8/4/2015	1000	<0.050	13.9	42.9	8,500	<0.040	2.28	<10	12.9
PI 552	6/24/2015	1445	0.051	<0.80	132	152	0.041	10.8	10	484
PI 553	6/23/2015	1400	0.064	1.3	8.1	6,170	<0.040	5.34	<10	158
PI 555	6/23/2015	1100	0.066	3	<4.0	42	0.124	5.46	<10	0.6
PI 556	8/6/2015	1030	0.059	<0.80	18.5	33	<0.040	39.5	40	69.5
PI 558	6/23/2015	1500	0.068	40	4.3	<10	0.135	9.46	<10	3.17
PI 562	9/23/2015	900	0.065	<0.80	360	1,910	0.065	10.4	10	184
PI 581	8/3/2015	1430	0.052	2	11.9	1,300	<0.040	3.02	<10	25.2
PI 591	8/5/2015	1600	0.63	<0.80	59.3	1,970	0.073	96.8	120	8.81
PI 592	6/24/2015	1100	<0.050	<0.80	72.1	80	0.377	289	270	83.7
PI 592	6/24/2015	1101	<0.050	<0.80	69.7	81	0.35	282	270	83
PI 593	6/22/2015	1300	<0.050	<0.80	<4.0	<10	1.2	16.1	20	13.5
PI 594	6/25/2015	1130	<0.050	3.2	<4.0	14	0.761	3.26	<10	<0.40
PI 595	6/23/2015	930	0.174	0.8	7.4	37	0.224	19.7	20	7.47
PI 597	7/8/2015	1000	<0.050	<0.80	154	1,670	0.103	1.8	<10	31.8
PI 598	6/22/2015	1600	0.117	<0.80	27.2	148	0.619	2.16	<10	262
PI 600	6/24/2015	1400	<0.050	<0.80	<4.0	<10	0.662	14.3	10	0.48
PI 601	6/25/2015	1000	<0.050	<0.80	15.8	2,500	0.083	15.1	20	5.93
PI 603	7/6/2015	1230	<0.050	<0.80	34.1	1,190	<0.040	11.1	10	6.19
PI 604	9/21/2015	1500	0.174	<0.80	32.1	23,000	<0.040	1.85	<10	27
PI 605	7/8/2015	1100	0.124	9	6.4	147	0.333	4.43	<10	1.41
PI 606	6/24/2015	1100	0.065	0.9	52.3	142	0.085	7.62	<10	14.1
PI 607	7/7/2015	1530	<0.050	10	<4.0	38	0.105	4.67	<10	<0.40
PI 608	7/15/2015	930	0.1	<0.80	58.3	88	0.165	10.3	10	318
PI 609	7/8/2015	1300	0.338	<0.80	6.6	13	<0.040	150	150	19.4
PI 610	7/14/2015	1300	0.078	7.8	8.8	30	0.894	3.68	<10	3.49
PI 611	7/7/2015	1230	<0.050	<0.80	15.7	976	0.05	6.66	<10	122
PI 612	7/7/2015	1230	<0.050	5.5	5.2	<10	0.21	5.27	<10	<0.40

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Iron, water, unfiltered, recoverable (µg/L)	Lead, water, filtered, (µg/L)	Lithium, water, filtered (µg/L)	Lithium, water, unfiltered, recoverable (µg/L)	Manganese, water, filtered, (µg/L)
			01035	01040	01046	01045	01049	01130	01132	01056
PI 613	7/6/2015	1500	0.091	1.4	11.4	15	0.305	24.6	30	51.7
PI 614	7/9/2015	1000	0.054	15.5	<4.0	63	0.128	14	20	<0.40
PI 615	7/8/2015	1530	0.359	7.3	<4.0	14	1.81	2.61	<10	4.88
PI 616	6/22/2015	1530	0.117	1.5	6.7	29	0.248	13.3	10	0.72
PI 617	7/9/2015	1230	0.147	2.5	951	1,240	1.11	2.86	<10	115
PI 618	7/9/2015	1000	<0.050	5.8	<4.0	25	0.159	14.6	20	1.05
PI 619	7/7/2015	1000	<0.050	1	20.9	2,500	<0.040	10.5	20	1.49
PI 620	7/16/2015	1000	0.107	61.8	24.1	4,890	1.38	2.06	<10	5.48
PI 621	7/9/2015	1300	<0.050	3.2	<4.0	481	0.096	4.02	<10	0.43
PI 622	7/14/2015	1600	0.101	<0.80	16.2	134	0.054	106	110	18.6
PI 623	7/15/2015	1400	0.388	<0.80	322	17,900	0.13	4.27	<10	314
PI 624	7/14/2015	1230	<0.050	<0.80	15.2	4,870	<0.040	13.1	20	27
PI 625	7/15/2015	1000	<0.050	<0.80	8.5	10	0.355	25.9	30	71.1
PI 626	7/7/2015	1530	<0.050	2.8	16.5	87	0.115	5.91	<10	4.77
PI 627	7/8/2015	1300	0.176	<0.80	243	682	0.729	8.95	10	193
PI 628	7/8/2015	1430	<0.050	3.4	10.6	160	3.69	2.84	<10	3.92
PI 629	7/14/2015	1430	0.061	2.6	<4.0	519	0.095	9.44	10	2.58
PI 630	7/15/2015	1500	<0.050	54.7	<4.0	<10	0.416	1.89	<10	0.79
PI 631	7/15/2015	1230	2.76	<0.80	4,010	4,600	0.078	10.1	<10	963
PI 632	8/3/2015	1230	<0.050	2.2	<4.0	457	0.634	1.62	<10	3.45
PI 633	8/6/2015	1000	<0.050	2.4	<4.0	17	0.106	10.5	10	<0.40
PI 634	8/4/2015	930	<0.050	1.2	<4.0	<10	0.156	42	50	0.82
PI 635	8/4/2015	1030	<0.050	<0.80	74.2	75	<0.040	12.8	10	352
PI 636	8/4/2015	1400	<0.050	<0.80	194	1,060	0.106	8.75	10	11.3
PI 638	8/5/2015	1600	0.265	1.1	514	1,010	0.322	68.5	80	450
PI 639	8/6/2015	1230	<0.050	2.6	<4.0	336	0.093	49.4	50	<0.40
PI 640	9/21/2015	1400	0.078	<0.80	9.9	361	0.088	26.6	30	11.7
PI 641	9/22/2015	1030	0.087	<0.80	4.2	32	0.06	47.9	50	122
PI 642	9/22/2015	1400	<0.050	6.2	<4.0	92	0.182	12.1	20	<0.40
PI 643	9/24/2015	900	0.107	4.1	<4.0	18	0.127	5.44	<10	<0.40
PI 644	9/21/2015	1130	0.062	1.8	<4.0	265	0.101	4.19	<10	<0.40
PI 645	9/23/2015	1000	<0.050	3.4	<4.0	59	0.364	8.96	10	2.39
PI 647	9/23/2015	1500	<0.050	<0.80	46.5	2,180	<0.040	13.3	10	84.5
PI 647	9/23/2015	1501	--	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	0.276	1.5	8	114	0.117	115	120	2.55
PI 649	9/24/2015	1030	0.15	6.1	4.3	1,040	0.076	11.5	10	11.9
PI 650	9/23/2015	1100	0.116	<0.80	<4.0	49	<0.040	1,080	1,140	0.98
PI 651	9/22/2015	1100	<0.050	<0.80	10.6	32	<0.040	184	210	25.2
PI 652	9/23/2015	1330	<0.050	51.6	<4.0	22	0.196	4.19	<10	16.9
PI 653	9/24/2015	1130	0.13	<0.80	765	1,010	0.056	38.4	50	881

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Local identifier	Date	Sample start time	Manganese, water, unfiltered, recoverable (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Strontium, water, unfiltered, recoverable (µg/L)	Zinc, water, filtered (µg/L)	Zinc, water, unfiltered, recoverable (µg/L)	Antimony, water, filtered (µg/L)
			01055	01060	01065	01080	01082	01090	01092	01095
PI 146	8/6/2015	1400	145	0.441	<0.20	250	261	<2.0	40	<0.027
PI 288	6/23/2015	930	0.8	<0.050	0.61	19.1	19	26.1	20	<0.027
PI 403	6/25/2015	1400	901	0.469	0.5	281	284	<2.0	M	0.028
PI 507	6/23/2015	1100	<0.5	<0.050	0.31	460	462	35.8	30	0.038
PI 523	9/21/2015	1200	617	0.102	<0.20	550	612	<2.0	M	<0.027
PI 524	6/25/2015	1500	18.4	0.353	<0.20	488	490	<2.0	<0.5	<0.027
PI 524	9/22/2015	1330	18.9	0.367	<0.20	472	485	<2.0	<0.5	<0.027
PI 524	9/22/2015	1331	18.2	0.371	<0.20	475	500	<2.0	<0.5	<0.027
PI 526	8/3/2015	1130	<10.0	<0.050	<0.20	73.8	76	<2.0	<5	<0.027
PI 530	8/5/2015	1330	90.5	0.074	<0.20	238	245	<2.0	M	<0.027
PI 534	8/4/2015	1500	15.1	0.084	0.51	198	201	2.8	M	0.098
PI 535	8/4/2015	1230	175	0.087	0.34	157	161	4.4	20	0.044
PI 539	8/5/2015	1100	354	1.54	<0.20	47.7	50	<2.0	M	0.054
PI 540	8/5/2015	1030	9.6	0.507	<0.20	586	612	<2.0	M	0.09
PI 543	8/3/2015	1500	<10.0	0.064	<0.20	70	72	2.6	<5	<0.027
PI 546	8/4/2015	1000	72.3	0.095	0.2	17.6	18	2	<5	<0.027
PI 552	6/24/2015	1445	471	0.347	<0.20	410	379	2.1	M	<0.027
PI 553	6/23/2015	1400	446	0.064	<0.20	188	178	<2.0	M	0.041
PI 555	6/23/2015	1100	22	0.06	<0.20	77.8	76	<2.0	M	0.067
PI 556	8/6/2015	1030	64.3	0.07	<0.20	820	873	<2.0	M	0.029
PI 558	6/23/2015	1500	2.8	<0.050	0.52	69	68	6.7	M	<0.027
PI 562	9/23/2015	900	235	<0.050	<0.20	60	61	<2.0	M	<0.027
PI 581	8/3/2015	1430	62.1	0.28	<0.20	54.5	56	4.5	M	<0.027
PI 591	8/5/2015	1600	38.3	0.454	0.23	397	429	<2.0	M	0.128
PI 592	6/24/2015	1100	80.9	0.606	<0.20	331	325	<2.0	20	<0.027
PI 592	6/24/2015	1101	80.4	0.623	<0.20	331	327	<2.0	20	<0.027
PI 593	6/22/2015	1300	14.6	0.31	<0.20	574	583	<2.0	M	0.067
PI 594	6/25/2015	1130	1.1	<0.050	<0.20	53	54	8.2	M	<0.027
PI 595	6/23/2015	930	6.8	<0.050	0.24	987	1,000	29.3	30	0.065
PI 597	7/8/2015	1000	31.8	0.741	<0.20	27.2	28	9.1	20	<0.027
PI 598	6/22/2015	1600	282	0.066	<0.20	31.3	31	16.1	20	<0.027
PI 600	6/24/2015	1400	1.2	0.466	<0.20	803	810	<2.0	M	0.069
PI 601	6/25/2015	1000	73.3	1.99	<0.20	332	338	3.7	M	0.036
PI 603	7/6/2015	1230	22.4	0.127	<0.20	259	279	<2.0	M	0.033
PI 604	9/21/2015	1500	1,850	0.827	0.4	40.2	46	<2.0	M	0.087
PI 605	7/8/2015	1100	3.3	<0.050	0.38	241	246	7.3	M	<0.027
PI 606	6/24/2015	1100	12.5	0.397	<0.20	173	172	<2.0	M	<0.027
PI 607	7/7/2015	1530	13.8	0.086	0.33	62.9	63	<2.0	M	<0.027
PI 608	7/15/2015	930	331	<0.050	<0.20	334	339	<2.0	M	0.053
PI 609	7/8/2015	1300	17.7	0.68	<0.20	1,020	977	<2.0	50	0.088
PI 610	7/14/2015	1300	4	<0.050	0.57	33.8	33	10.7	10	0.036
PI 611	7/7/2015	1230	304	0.352	0.31	115	121	4.1	10	<0.027
PI 612	7/7/2015	1230	<10.0	<0.050	<0.20	38.8	39	7	M	<0.027

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			01055	01060	01065	01080	01082	01090	01092	01095
PI 613	7/6/2015	1500	70.6	<0.050	0.29	1,300	1,470	<2.0	M	0.064
PI 614	7/9/2015	1000	2.5	0.197	<0.20	162	163	<2.0	M	0.029
PI 615	7/8/2015	1530	5.1	0.066	1.4	18.1	15	7.3	M	0.107
PI 616	6/22/2015	1530	0.7	<0.050	0.23	525	524	2.4	M	0.044
PI 617	7/9/2015	1230	99.3	0.067	0.46	57.2	58	3.5	M	<0.027
PI 618	7/9/2015	1000	6.3	0.074	0.31	209	222	2.8	M	<0.027
PI 619	7/7/2015	1000	56.5	0.299	<0.20	352	352	<2.0	M	0.037
PI 620	7/16/2015	1000	16.8	<0.050	0.78	10.8	11	9.7	10	0.038
PI 621	7/9/2015	1300	12	<0.050	<0.20	23.8	25	8.6	10	<0.027
PI 622	7/14/2015	1600	19.2	0.156	<0.20	947	958	<2.0	M	0.033
PI 623	7/15/2015	1400	520	0.448	0.99	22.9	22	2.5	M	0.081
PI 624	7/14/2015	1230	41.8	0.436	<0.20	742	755	<2.0	10	0.056
PI 625	7/15/2015	1000	66.5	0.31	<0.20	391	403	<2.0	M	0.067
PI 626	7/7/2015	1530	5.9	0.212	0.5	257	270	<2.0	M	0.038
PI 627	7/8/2015	1300	209	0.301	<0.20	562	578	7.3	M	0.072
PI 628	7/8/2015	1430	4.9	<0.050	0.58	28.5	29	43.2	40	0.035
PI 629	7/14/2015	1430	20.5	<0.050	0.64	179	175	43.6	50	0.071
PI 630	7/15/2015	1500	2.3	<0.050	<0.20	64	65	4	M	<0.027
PI 631	7/15/2015	1230	1,030	0.196	0.83	82.9	86	5.2	M	0.037
PI 632	8/3/2015	1230	<10.0	<0.050	0.86	27.4	28	4.6	M	<0.027
PI 633	8/6/2015	1000	13.5	0.08	<0.20	184	192	<2.0	M	<0.027
PI 634	8/4/2015	930	<10.0	0.127	<0.20	448	459	3.4	<5	0.057
PI 635	8/4/2015	1030	381	<0.050	<0.20	887	929	<2.0	<5	<0.027
PI 636	8/4/2015	1400	24.9	<0.050	<0.20	160	164	<2.0	<5	0.035
PI 638	8/5/2015	1600	436	<0.050	0.23	1,830	1,900	2.3	M	0.04
PI 639	8/6/2015	1230	17.2	0.108	<0.20	2,210	2,310	2.9	M	0.529
PI 640	9/21/2015	1400	22	0.101	<0.20	682	706	36.7	70	<0.027
PI 641	9/22/2015	1030	131	0.065	<0.20	1,550	1,590	2.2	420	0.028
PI 642	9/22/2015	1400	34.1	0.18	<0.20	513	532	<2.0	M	<0.027
PI 643	9/24/2015	900	4.2	0.092	<0.20	51.7	51	5	M	0.041
PI 644	9/21/2015	1130	37.5	0.235	<0.20	65	63	14.5	20	0.073
PI 645	9/23/2015	1000	4.9	<0.050	0.33	282	289	4.9	M	<0.027
PI 647	9/23/2015	1500	242	0.089	<0.20	326	335	<2.0	M	<0.027
PI 647	9/23/2015	1501	--	--	--	--	--	--	--	--
PI 648	9/24/2015	1300	3.2	0.081	0.23	264	260	<2.0	<0.5	0.05
PI 649	9/24/2015	1030	193	<0.050	1.4	402	369	6.4	20	<0.027
PI 650	9/23/2015	1100	0.8	0.942	<0.20	3,420	2,700	<2.0	M	<0.027
PI 651	9/22/2015	1100	23.2	0.371	<0.20	185	194	<2.0	M	<0.027
PI 652	9/23/2015	1330	14.6	<0.050	0.48	49.9	50	7.5	M	<0.027
PI 653	9/24/2015	1130	887	0.107	0.35	1,930	1,900	3.1	M	0.054

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Arsenic, water, filtered (µg/L)	Arsenic, water, unfiltered (µg/L)	Boron, water, filtered (µg/L)	Selenium, water, filtered (µg/L)	Selenium, water, unfiltered (µg/L)	Ethane, water, dissolved, recoverable (mg/L)	Ethane, water, unfiltered, recoverable (µg/L)
			01000	01002	01020	01145	01147	68832	
PI 146	8/6/2015	1400	3.8	3	151	<0.05	<2	<0.010	--
PI 288	6/23/2015	930	<0.10	<0.5	<5	0.07	<2	<0.010	--
PI 403	6/25/2015	1400	0.98	3	16	<0.05	<2	<0.010	--
PI 507	6/23/2015	1100	0.27	M	11	0.14	<2	<0.010	--
PI 523	9/21/2015	1200	1.5	2	13	<0.05	<2	<0.010	--
PI 524	6/25/2015	1500	0.24	<0.5	84	<0.05	<2	<0.100	--
PI 524	9/22/2015	1330	0.23	<0.5	79	<0.05	<2	<0.010	--
PI 524	9/22/2015	1331	0.23	<0.5	79	<0.05	<2	<0.010	--
PI 526	8/3/2015	1130	<0.10	<0.5	6	0.07	<2	<0.010	--
PI 530	8/5/2015	1330	0.14	<0.5	42	<0.05	<2	<0.010	--
PI 534	8/4/2015	1500	1	<0.5	14	0.97	<2	<0.010	--
PI 535	8/4/2015	1230	0.36	M	17	0.05	<2	<0.010	--
PI 539	8/5/2015	1100	0.69	M	13	<0.05	<2	<0.010	--
PI 540	8/5/2015	1030	1.1	1	19	0.06	<2	<0.010	--
PI 543	8/3/2015	1500	0.4	<0.5	7	0.07	<2	<0.010	--
PI 546	8/4/2015	1000	0.16	<0.5	<5	<0.05	<2	<0.010	--
PI 552	6/24/2015	1445	0.42	<0.5	8	<0.05	<2	<0.010	--
PI 553	6/23/2015	1400	0.45	1	<5	<0.05	<2	<0.010	--
PI 555	6/23/2015	1100	0.36	M	5	0.23	<2	<0.010	--
PI 556	8/6/2015	1030	<0.10	<0.5	43	<0.05	<2	<0.010	--
PI 558	6/23/2015	1500	<0.10	<0.5	19	<0.05	<2	<0.010	--
PI 562	9/23/2015	900	0.6	M	8	<0.05	<2	--	<3.3
PI 581	8/3/2015	1430	0.63	<0.5	6	0.06	<2	<0.010	--
PI 591	8/5/2015	1600	<0.10	<0.5	257	<0.05	<2	<0.010	--
PI 592	6/24/2015	1100	27.8	31	117	<0.05	<2	<0.100	--
PI 592	6/24/2015	1101	27.8	32	118	<0.05	<2	<0.050	--
PI 593	6/22/2015	1300	1.8	2	31	<0.05	<2	<0.010	--
PI 594	6/25/2015	1130	0.33	<0.5	<5	0.05	<2	<0.010	--
PI 595	6/23/2015	930	0.18	<0.5	11	0.08	<2	<0.010	--
PI 597	7/8/2015	1000	0.46	M	8	<0.05	<2	<0.010	--
PI 598	6/22/2015	1600	0.28	M	<5	<0.05	<2	<0.010	--
PI 600	6/24/2015	1400	1.7	2	11	0.08	<2	<0.010	--
PI 601	6/25/2015	1000	2.6	3	21	0.1	<2	<0.010	--
PI 603	7/6/2015	1230	0.7	1	9	0.07	<2	<0.010	--
PI 604	9/21/2015	1500	0.58	1	13	<0.05	<2	<0.010	--
PI 605	7/8/2015	1100	0.33	<0.5	9	<0.05	<2	<0.010	--
PI 606	6/24/2015	1100	0.32	<0.5	8	<0.05	<2	<0.010	--
PI 607	7/7/2015	1530	0.62	M	<5	0.15	<2	<0.010	--
PI 608	7/15/2015	930	1.1	1	5	<0.05	<2	<0.010	--
PI 609	7/8/2015	1300	1.5	2	118	<0.05	5	<0.010	--
PI 610	7/14/2015	1300	0.17	<0.5	7	<0.05	<2	<0.010	--
PI 611	7/7/2015	1230	0.3	<0.5	7	<0.05	<2	<0.010	--
PI 612	7/7/2015	1230	0.31	<0.5	<5	0.06	<2	<0.010	--

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

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Local identifier	Date	Sample start time	Arsenic, water, filtered (µg/L)	Arsenic, water, unfiltered (µg/L)	Boron, water, filtered (µg/L)	Selenium, water, filtered (µg/L)	Selenium, water, unfiltered (µg/L)	Ethane, water, dissolved, recoverable (mg/L)	Ethane, water, unfiltered, recoverable (µg/L)
			01000	01002	01020	01145	01147	68832	
PI 613	7/6/2015	1500	1.1	1	25	<0.05	<2	<0.010	--
PI 614	7/9/2015	1000	0.37	<0.5	6	0.19	<2	<0.010	--
PI 615	7/8/2015	1530	0.19	<0.5	13	0.23	<2	<0.010	--
PI 616	6/22/2015	1530	0.18	<0.5	6	0.09	<2	<0.010	--
PI 617	7/9/2015	1230	<0.10	<0.5	6	0.07	<2	<0.010	--
PI 618	7/9/2015	1000	0.23	<0.5	21	0.17	<2	<0.010	--
PI 619	7/7/2015	1000	1.3	3	9	0.1	<2	<0.010	--
PI 620	7/16/2015	1000	<0.10	3	<5	<0.05	<2	<0.010	--
PI 621	7/9/2015	1300	1	2	<5	<0.05	<2	<0.010	--
PI 622	7/14/2015	1600	<0.10	<0.5	156	<0.05	4	<0.010	--
PI 623	7/15/2015	1400	0.24	2	15	0.08	<2	<0.010	--
PI 624	7/14/2015	1230	1.2	2	18	<0.05	<2	<0.010	--
PI 625	7/15/2015	1000	3	4	15	<0.05	<2	<0.010	--
PI 626	7/7/2015	1530	0.93	M	<5	0.11	<2	<0.010	--
PI 627	7/8/2015	1300	0.17	<0.5	15	<0.05	<2	<0.010	--
PI 628	7/8/2015	1430	0.45	<0.5	<5	<0.05	<2	<0.010	--
PI 629	7/14/2015	1430	0.49	<0.5	9	0.2	<2	<0.010	--
PI 630	7/15/2015	1500	0.31	<0.5	7	<0.05	<2	<0.010	--
PI 631	7/15/2015	1230	2.7	3	6	<0.05	2	<0.010	--
PI 632	8/3/2015	1230	0.19	<0.5	<5	0.09	<2	<0.010	--
PI 633	8/6/2015	1000	0.52	M	8	0.17	<2	<0.010	--
PI 634	8/4/2015	930	0.71	<0.5	23	0.1	<2	<0.010	--
PI 635	8/4/2015	1030	0.58	M	8	<0.05	<2	<0.010	--
PI 636	8/4/2015	1400	0.74	<0.5	6	0.23	<2	<0.010	--
PI 638	8/5/2015	1600	1	2	31	<0.05	<2	<0.010	--
PI 639	8/6/2015	1230	4.3	5	19	0.67	<2	<0.010	--
PI 640	9/21/2015	1400	0.13	<0.5	41	<0.05	<2	<0.010	--
PI 641	9/22/2015	1030	1.1	1	22	<0.05	<2	<0.010	--
PI 642	9/22/2015	1400	0.26	<0.5	29	0.15	<2	<0.010	--
PI 643	9/24/2015	900	0.6	M	<5	0.09	<2	<0.010	--
PI 644	9/21/2015	1130	0.79	M	6	0.08	<2	<0.010	--
PI 645	9/23/2015	1000	0.12	<0.5	12	0.08	<2	--	<3.3
PI 647	9/23/2015	1500	0.12	<0.5	22	<0.05	<2	--	<3.3
PI 647	9/23/2015	1501	--	--	--	--	--	--	<3.3
PI 648	9/24/2015	1300	<0.10	<0.5	139	<0.05	<2	<0.010	--
PI 649	9/24/2015	1030	<0.10	M	15	0.1	<2	<0.010	--
PI 650	9/23/2015	1100	<0.10	<0.5	651	0.18	33	--	<3.3
PI 651	9/22/2015	1100	6.2	6	73	<0.05	<2	<0.010	--
PI 652	9/23/2015	1330	0.21	<0.5	10	<0.05	<2	--	<3.3
PI 653	9/24/2015	1130	6.7	8	24	<0.05	<2	<0.010	--

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Local identifier	Date	Sample start time	Methane, water, dissolved, recoverable (mg/L)	Organic carbon, water, unfiltered (mg/L)	Propane, water, dissolved, recoverable (mg/L)	Propane, water, unfiltered, recoverable (µg/L)	Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve (pCi/L)	Gross alpha radioactivity, 72 hour count, water, unfiltered, Th-230 curve, (pCi/L)
			68831	00680	68834	82358	63016	63014
PI 146	8/6/2015	1400	0.582	<0.7	<0.020	--	R0.5	0.9
PI 288	6/23/2015	930	<0.010	<0.7	<0.020	--	R-0.3	R1.3
PI 403	6/25/2015	1400	0.012	<0.7	<0.020	--	2.4	3.2
PI 507	6/23/2015	1100	<0.010	<0.7	<0.020	--	R-1.8	R-0.6
PI 523	9/21/2015	1200	<0.010	<0.7	<0.020	--	R-0.1	R0.2
PI 524	6/25/2015	1500	2.54	<0.7	<0.200	--	1.4	R1.0
PI 524	9/22/2015	1330	4.12	<0.7	<0.020	--	3.4	4.7
PI 524	9/22/2015	1331	3.28	<0.7	<0.020	--	1.9	1.3
PI 526	8/3/2015	1130	<0.010	<0.7	<0.020	--	R0.8	5.1
PI 530	8/5/2015	1330	0.346	<0.7	<0.020	--	R0.2	R0.6
PI 534	8/4/2015	1500	<0.010	<0.7	<0.020	--	R0.5	3
PI 535	8/4/2015	1230	<0.010	<0.7	<0.020	--	5.6	13.9
PI 539	8/5/2015	1100	<0.010	<0.7	<0.020	--	R0.0	R-0.4
PI 540	8/5/2015	1030	<0.010	<0.7	<0.020	--	1.3	1.2
PI 543	8/3/2015	1500	<0.010	<0.7	<0.020	--	R0.9	R-0.7
PI 546	8/4/2015	1000	<0.010	<0.7	<0.020	--	R-0.1	4.7
PI 552	6/24/2015	1445	<0.010	<0.7	<0.020	--	R0.2	R1.2
PI 553	6/23/2015	1400	<0.010	<0.7	<0.020	--	1.4	3.7
PI 555	6/23/2015	1100	<0.010	<0.7	<0.020	--	1.1	3.7
PI 556	8/6/2015	1030	0.084	<0.7	<0.020	--	R0.3	R0.5
PI 558	6/23/2015	1500	<0.010	<0.7	<0.020	--	R0.4	R0.3
PI 562	9/23/2015	900	--	<0.7	--	<3.2	R0.1	1.3
PI 581	8/3/2015	1430	0.016	<0.7	<0.020	--	3.4	5.1
PI 591	8/5/2015	1600	0.95	<0.7	<0.020	--	4.4	5.5
PI 592	6/24/2015	1100	1.79	<0.7	<0.100	--	0.9	R0.9
PI 592	6/24/2015	1101	1.48	<0.7	<0.100	--	R0.4	1.4
PI 593	6/22/2015	1300	<0.010	<0.7	<0.020	--	R0.3	R0.3
PI 594	6/25/2015	1130	<0.010	<0.7	<0.020	--	R0.3	R0.1
PI 595	6/23/2015	930	<0.010	<0.7	<0.020	--	1.1	R0.7
PI 597	7/8/2015	1000	<0.010	<0.7	<0.020	--	1.7	R-0.1
PI 598	6/22/2015	1600	<0.010	<0.7	<0.020	--	1	1.4
PI 600	6/24/2015	1400	0.01	<0.7	<0.020	--	1	R0.9
PI 601	6/25/2015	1000	<0.010	<0.7	<0.020	--	R0.0	2.3
PI 603	7/6/2015	1230	<0.010	<0.7	<0.020	--	R0.3	R0.2
PI 604	9/21/2015	1500	<0.010	<0.7	<0.020	--	5.3	10.6
PI 605	7/8/2015	1100	<0.010	<0.7	<0.020	--	R0.9	R0.2
PI 606	6/24/2015	1100	<0.010	<0.7	<0.020	--	1.6	R0.8
PI 607	7/7/2015	1530	<0.010	<0.7	<0.020	--	1.5	2.6
PI 608	7/15/2015	930	<0.010	<0.7	<0.020	--	R0.9	R1.1
PI 609	7/8/2015	1300	0.479	<0.7	<0.020	--	1.8	1
PI 610	7/14/2015	1300	<0.010	<0.7	<0.020	--	R0.7	R0.2
PI 611	7/7/2015	1230	<0.010	<0.7	<0.020	--	2.2	1.4
PI 612	7/7/2015	1230	<0.010	<0.7	<0.020	--	R0.6	R0.4

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Local identifier	Date	Sample start time	Methane, water, dissolved, recoverable (mg/L)	Organic carbon, water, unfiltered (mg/L)	Propane, water, dissolved, recoverable (mg/L)	Propane, water, unfiltered, recoverable (µg/L)	Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve (pCi/L)	Gross alpha radioactivity, 72 hour count, water, unfiltered, Th-230 curve, (pCi/L)
			68831	00680	68834	82358	63016	63014
PI 613	7/6/2015	1500	<0.010	<0.7	<0.020	--	R0.7	R0.2
PI 614	7/9/2015	1000	<0.010	<0.7	<0.020	--	R0.6	R0.8
PI 615	7/8/2015	1530	<0.010	<0.7	<0.020	--	R0.8	1.1
PI 616	6/22/2015	1530	<0.010	<0.7	<0.020	--	R1.0	R0.5
PI 617	7/9/2015	1230	<0.010	<0.7	<0.020	--	R-0.1	R-0.5
PI 618	7/9/2015	1000	<0.010	<0.7	<0.020	--	R0.6	R0.9
PI 619	7/7/2015	1000	<0.010	<0.7	<0.020	--	5	4.5
PI 620	7/16/2015	1000	<0.010	<0.7	<0.020	--	R0.4	1.2
PI 621	7/9/2015	1300	<0.010	<0.7	<0.020	--	1.1	R0.8
PI 622	7/14/2015	1600	0.936	<0.7	<0.020	--	R0.8	R0.4
PI 623	7/15/2015	1400	<0.010	<0.7	<0.020	--	R0.9	R-0.1
PI 624	7/14/2015	1230	<0.010	<0.7	<0.020	--	R0.3	1.6
PI 625	7/15/2015	1000	<0.010	<0.7	<0.020	--	R1.0	2.1
PI 626	7/7/2015	1530	<0.010	<0.7	<0.020	--	1.8	R0.0
PI 627	7/8/2015	1300	<0.010	<0.7	<0.020	--	1.1	2
PI 628	7/8/2015	1430	<0.010	<0.7	<0.020	--	1.9	R-1.4
PI 629	7/14/2015	1430	<0.010	<0.7	<0.020	--	3.8	3.4
PI 630	7/15/2015	1500	<0.010	<0.7	<0.020	--	R0.1	R0.4
PI 631	7/15/2015	1230	0.011	<0.7	<0.020	--	R1.0	R0.8
PI 632	8/3/2015	1230	<0.010	<0.7	<0.020	--	R-0.2	R0.8
PI 633	8/6/2015	1000	<0.010	<0.7	<0.020	--	1.6	1.7
PI 634	8/4/2015	930	0.021	<0.7	<0.020	--	R-0.3	5.5
PI 635	8/4/2015	1030	<0.010	<0.7	<0.020	--	--	--
PI 636	8/4/2015	1400	<0.010	<0.7	<0.020	--	R0.3	4.2
PI 638	8/5/2015	1600	<0.010	<0.7	<0.020	--	1.2	R0.5
PI 639	8/6/2015	1230	<0.010	<0.7	<0.020	--	1.9	3.3
PI 640	9/21/2015	1400	0.031	<0.7	<0.020	--	R0.3	1.3
PI 641	9/22/2015	1030	0.03	<0.7	<0.020	--	1.7	2.1
PI 642	9/22/2015	1400	<0.010	<0.7	<0.020	--	1.5	6.7
PI 643	9/24/2015	900	<0.010	<0.7	<0.020	--	1.5	1.9
PI 644	9/21/2015	1130	<0.010	<0.7	<0.020	--	3.3	1
PI 645	9/23/2015	1000	--	<0.7	--	<3.2	R0.8	R0.6
PI 647	9/23/2015	1500	--	<0.7	--	<3.2	R0.6	R-0.6
PI 647	9/23/2015	1501	--	--	--	<3.2	--	--
PI 648	9/24/2015	1300	<0.010	<0.7	<0.020	--	R-0.5	1.2
PI 649	9/24/2015	1030	<0.010	<0.7	<0.020	--	R0.5	1.4
PI 650	9/23/2015	1100	--	<0.7	--	<3.2	10.4	3.4
PI 651	9/22/2015	1100	0.382	<0.7	<0.020	--	R-0.1	2.5
PI 652	9/23/2015	1330	--	<0.7	--	<3.2	R0.7	R0.4
PI 653	9/24/2015	1130	0.036	<0.7	<0.020	--	9.2	5

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; $CaCO_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Gross beta radioactivity, 30 day recount, water, unfiltered, Cs-137 curve (pCi/L)	Gross beta radioactivity, 72 hour count, water, unfiltered, Cs-137 curve (pCi/L)	Radium-226, water, unfiltered (pCi/L)	Radon-222, water, unfiltered (pCi/L)	Uranium (natural), water, filtered (µg/L)
			63017	63015	09501	82303	22703
PI 146	8/6/2015	1400	1.8	1.1	--	62	0.048
PI 288	6/23/2015	930	R0.6	R-0.2	--	2,200	0.048
PI 403	6/25/2015	1400	1.2	2.1	0.25	330	0.991
PI 507	6/23/2015	1100	R0.7	R1.1	--	1,590	0.136
PI 523	9/21/2015	1200	R0.7	R-0.1	--	21	0.08
PI 524	6/25/2015	1500	1.5	R1.2	--	380	0.095
PI 524	9/22/2015	1330	R1.5	2.7	0.3	450	0.157
PI 524	9/22/2015	1331	R1.6	R1.3	0.3	470	0.147
PI 526	8/3/2015	1130	1.7	7.6	--	2,870	0.054
PI 530	8/5/2015	1330	1.6	1.2	--	62	<0.014
PI 534	8/4/2015	1500	2.1	4.5	--	1,440	0.433
PI 535	8/4/2015	1230	7.5	14	0.44	5,100	0.614
PI 539	8/5/2015	1100	1.6	1.7	--	152	0.703
PI 540	8/5/2015	1030	2.5	R1.4	--	1,120	1.81
PI 543	8/3/2015	1500	R0.7	R1.4	--	1,440	0.176
PI 546	8/4/2015	1000	1.8	3.9	--	2,550	0.017
PI 552	6/24/2015	1445	R1.1	R0.3	--	73	0.095
PI 553	6/23/2015	1400	3.3	1.8	0.24	223	0.019
PI 555	6/23/2015	1100	2.2	2.9	0.16	2,510	0.386
PI 556	8/6/2015	1030	R-0.2	R1.2	--	56	0.139
PI 558	6/23/2015	1500	1.6	R-0.2	--	1,190	<0.014
PI 562	9/23/2015	900	R0.5	1.3	--	138	0.018
PI 581	8/3/2015	1430	1.9	5.8	0.15	2,730	1.23
PI 591	8/5/2015	1600	7	7	0.71	94	0.015
PI 592	6/24/2015	1100	1.6	2.3	--	1,210	0.015
PI 592	6/24/2015	1101	3.1	R0.7	--	1,240	<0.014
PI 593	6/22/2015	1300	1.8	R0.3	--	1,100	0.558
PI 594	6/25/2015	1130	R0.7	R-0.4	--	2,630	0.056
PI 595	6/23/2015	930	1.2	R0.3	--	1,060	0.131
PI 597	7/8/2015	1000	5.8	3.5	--	3,600	0.504
PI 598	6/22/2015	1600	R0.6	R1.2	--	2,710	0.015
PI 600	6/24/2015	1400	1.3	R0.5	--	1,240	1.12
PI 601	6/25/2015	1000	1.2	R0.5	--	2,060	0.427
PI 603	7/6/2015	1230	R0.8	1.7	--	2,560	0.154
PI 604	9/21/2015	1500	6.9	9.8	0.09	1,420	1.26
PI 605	7/8/2015	1100	1.7	3	--	2,020	0.017
PI 606	6/24/2015	1100	2.4	R1.2	--	2,850	0.952
PI 607	7/7/2015	1530	4.3	1.9	--	3,900	0.521
PI 608	7/15/2015	930	4.1	2.9	--	1,060	0.029
PI 609	7/8/2015	1300	2	1.9	--	122	0.027
PI 610	7/14/2015	1300	R0.8	1.6	--	2,550	0.027
PI 611	7/7/2015	1230	1.8	R1.1	--	4,200	0.998
PI 612	7/7/2015	1230	1.4	2.4	--	3,270	0.045

Table 13. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for water samples collected from 79 wells in 2015 in Pike County, Pennsylvania. Constituents listed with associated 5-digit U.S. Geological Survey parameter code. Sample times offset by 1 minute indicate environmental relicate.—Continued

[mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter µS/cm;, microsiemens per centimeter; CaCO$_3$, µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected]

Local identifier	Date	Sample start time	Gross beta radioactivity, 30 day recount, water, unfiltered, Cs-137 curve (pCi/L)	Gross beta radioactivity, 72 hour count, water, unfiltered, Cs-137 curve (pCi/L)	Radium-226, water, unfiltered (pCi/L)	Radon-222, water, unfiltered (pCi/L)	Uranium (natural), water, filtered (µg/L)
			63017	63015	09501	82303	22703
PI 613	7/6/2015	1500	2.2	2.8	--	840	0.417
PI 614	7/9/2015	1000	3.1	R0.7	--	2,760	0.601
PI 615	7/8/2015	1530	1.1	R0.4	--	2,430	0.049
PI 616	6/22/2015	1530	1.9	1.9	--	1,900	0.032
PI 617	7/9/2015	1230	1.3	1.5	--	830	<0.014
PI 618	7/9/2015	1000	1.5	R0.7	--	1,880	0.104
PI 619	7/7/2015	1000	4.8	5.3	0.23	2,290	1.69
PI 620	7/16/2015	1000	4.2	2.9	--	1,060	<0.014
PI 621	7/9/2015	1300	2.3	2.3	--	2,360	0.123
PI 622	7/14/2015	1600	1.9	R0.7	--	34	0.049
PI 623	7/15/2015	1400	R0.7	R0.8	--	2,170	0.182
PI 624	7/14/2015	1230	2	1.6	--	1,880	0.39
PI 625	7/15/2015	1000	6.8	1.4	--	700	0.652
PI 626	7/7/2015	1530	R0.7	R0.6	--	2,890	0.766
PI 627	7/8/2015	1300	1.5	R-0.5	--	950	0.182
PI 628	7/8/2015	1430	1.6	1.3	--	1,080	<0.014
PI 629	7/14/2015	1430	2.7	3.6	--	1,630	0.972
PI 630	7/15/2015	1500	2.4	1.1	--	1,700	0.029
PI 631	7/15/2015	1230	1.4	R1.0	--	290	0.048
PI 632	8/3/2015	1230	R1.0	1.6	--	3,410	<0.014
PI 633	8/6/2015	1000	2.5	2.6	--	2,490	0.879
PI 634	8/4/2015	930	1.6	4.9	--	1,730	0.198
PI 635	8/4/2015	1030	--	--	--	180	0.016
PI 636	8/4/2015	1400	R1.5	5.1	--	1,920	0.36
PI 638	8/5/2015	1600	1.9	3.7	--	1,160	0.038
PI 639	8/6/2015	1230	4.7	3.1	--	560	0.359
PI 640	9/21/2015	1400	1.5	R0.4	--	1,310	0.188
PI 641	9/22/2015	1030	2.7	3.4	0.45	105	0.136
PI 642	9/22/2015	1400	R1.4	7.3	0.2	2,020	0.483
PI 643	9/24/2015	900	R0.6	R1.1	--	3,600	0.413
PI 644	9/21/2015	1130	3	3.6	--	2,290	0.853
PI 645	9/23/2015	1000	R1.1	R0.5	--	520	0.042
PI 647	9/23/2015	1500	1.2	R1.0	--	240	0.025
PI 647	9/23/2015	1501	--	--	--	--	--
PI 648	9/24/2015	1300	R0.1	R0.3	--	70	0.027
PI 649	9/24/2015	1030	2.2	2.4	--	480	0.11
PI 650	9/23/2015	1100	5	2.9	1.8	12	<0.014
PI 651	9/22/2015	1100	1.9	4.1	--	1,030	0.187
PI 652	9/23/2015	1330	1.8	R1.0	--	2,970	0.031
PI 653	9/24/2015	1130	4.4	1.8	1.2	250	1.31

Table 14. Results of dissolved gas analysis and isotopic characterization of methane by Isotech Laboratories, Inc. for water samples collected from 17 wells in Pike County, 2015. Results listed by geologic unit. One well (PI-524) was sampled twice. Replicates (shaded in gray) collected from three wells (PI-592, PI-524, PI-647) are listed with time offset of 1 minute.

[USGS, U.S. Geological Survey; na, not analyzed; nd, not detected; --, no data; %, mole percent; ‰, per mil or parts per trillion; cc/L, cubic centimeters per liter; mg/L, milligrams per liter; Geologic units: DLRV, Deleware River Member of Catskill Formation; LCSS, Lackawaxen Member of Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MRCL, Marcellus Shale. He, helium; H_2, hydrogen; Ar, argon; O_2, oxygen; CO_2, carbon dioxide; N_2, nitrogen; CO, carbon monoxide; C_1, methane; C_2, ethane; C_2H_4, ethene; C_3, propane; iC_4, nC_4, iC_5, nC_5, C_6+, hydrocarbons with 4, 5, and 6 carbon atome per molecule, respectively; $\delta^{13}C_1$, carbon-13 and carbon-12 isotopic composition of methane; δDC_1, deuterium and hydrogen isotopic composition of methane; CH_4, methane; C_2H_6, ethane; C_3H_8, propane. Isotopic composition of carbon is relative to Vienna Pee Dee Belemnite (VPDB). Isotopic composition of hydrogen is relative to Vienna Standard Mean Ocean Water (VSMOW)]

USGS local name	Geologic unit	Sample date	Sample time	GC date	He (%)	H_2 (%)	Ar (%)	O_2 (%)	CO_2 (%)	C1 (%)	C2 (%)	C_2H_4 (%)	C_3 (%)	C_3H_6 (%)	iC_4 (%)	nC_4 (%)	iC_5 (%)	nC_5 (%)	C_6+ (%)
PI 592	341DLRV	6/24/2015	11:05	9/24/2015	na	nd	1.44	4.37	0.19	16.17	0.0012	nd	nd	nd	nd	nd	nd	nd	nd
PI 592	341DLRV	6/24/2015	11:06	9/24/2015	na	nd	1.44	3.72	0.14	16.46	0.0014	nd	nd	nd	nd	nd	nd	nd	nd
PI 609	341DLRV	7/8/2015	13:05	9/24/2015	na	nd	1.76	5.05	0.046	2.19	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 625	341DLRV	7/15/2015	10:05	9/25/2015	na	nd	1.87	4.49	0.52	0.0075	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 641	341DLRV	9/22/2015	10:35	11/19/2015	na	nd	1.81	3.02	0.72	0.287	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 651	341DLRV	9/22/2015	11:05	11/19/2015	na	nd	1.73	3.61	0.25	3.23	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 524	341TMSG	6/25/2015	15:05	9/24/2015	na	nd	1.31	5.37	0.29	20.18	0.0021	nd	nd	nd	nd	nd	nd	nd	nd
PI 524	341TMSG	9/22/2015	13:35	11/19/2015	na	nd	1.41	1.57	0.30	20.21	0.0029	nd	nd	nd	nd	nd	nd	nd	nd
PI 524	341TMSG	9/22/2015	13:36	11/19/2015	na	nd	1.39	1.71	0.33	21.89	0.0035	nd	nd	nd	nd	nd	nd	nd	nd
PI 604	341TMSG	9/21/2015	15:05	11/19/2015	na	nd	1.82	5.68	1.25	0.0052	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 653	341TMSG	9/24/2015	11:35	11/19/2015	na	nd	1.68	3.65	2.05	0.317	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 530	341TMRK	8/5/2015	13:305	9/25/2015	na	nd	1.73	4.11	0.54	1.78	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 647	341TMRK	9/23/2015	15:05	11/19/2015	na	nd	1.80	4.17	0.36	0.125	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 647	341TMRK	9/23/2015	15:06	11/19/2015	na	nd	1.84	3.84	0.37	0.133	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 146	344MNNG	8/6/2015	14:05	9/24/2015	na	nd	1.63	3.79	0.10	7.17	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 556	344MNNG	8/6/2015	10:35	9/25/2015	na	nd	1.86	4.52	0.54	0.614	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 591	344MNNG	8/5/2015	16:05	9/24/2015	na	nd	1.52	3.01	0.074	8.39	0.0007	nd	nd	nd	nd	nd	nd	nd	nd
PI 622	344MNNG	7/14/2015	16:05	9/24/2015	na	nd	1.54	2.28	0.16	7.38	0.0013	nd	nd	nd	nd	nd	nd	nd	nd
PI 642	344MNNG	9/22/2015	14:05	11/19/2015	na	nd	1.78	7.93	1.98	0.0020	nd	nd	nd	nd	nd	nd	nd	nd	nd
PI 650	344MNNG	9/23/2015	11:05	11/19/2015	na	nd	1.57	0.079	0.064	2.99	0.0023	nd	nd	nd	nd	nd	nd	nd	nd
PI 648	344MRCL	9/24/2015	13:05	11/19/2015	na	nd	1.84	13.93	0.098	0.0102	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 14. Results of dissolved gas analysis and isotopic characterization of methane by Isotech Laboratories, Inc. for water samples collected from 17 wells in Pike County, 2015. Results listed by geologic unit. One well (PI-524) was sampled twice. Replicates (shaded in gray) collected from three wells (PI-592, PI-524, PI-647) are listed with time offset of 1 minute.—Continued

[USGS, U.S. Geological Survey; na, not analyzed; nd, not detected; --, no data; %, mole percent; ‰, per mil or parts per trillion; cc/L, cubic centimeters per liter; mg/L, milligrams per liter; Geologic units: DLRV, Deleware River Member of Catskill Formation; LCSS, Lackawaxen Member of Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MRCL, Marcellus Shale. He, helium; H_2, hydrogen; Ar, argon; O_2, oxygen; CO_2, carbon dioxide; N_2, nitrogen; CO, carbon monoxide; C_1, methane; C_2, ethane; C_2H_4, ethene; C_3, propane; iC_4, nC_4, iC_5, nC_5, C_6+, hydrocarbons with 4, 5, and 6 carbon atome per molecule, respectively; $\delta^{13}C_1$, carbon-13 and carbon-12 isotopic composition of methane; δDC_1, deuterium and hydrogen isotopic composition of methane; CH_4, methane; C_2H_6, ethane; C_3H_8, propane. Isotopic composition of carbon is relative to Vienna Pee Dee Belemnite (VPDB). Isotopic composition of hydrogen is relative to Vienna Standard Mean Ocean Water (VSMOW)]

USGS local name	Geologic unit	Sample date	Sample time	MS date	$d^{13}C_1$ (‰)	dDC_1 (‰)	Specific gravity	BTU	Dissolved CH_4		Dissolved C_2H_6		Dissolved C_3H_8		Helium dilution factor *
									cc/L	mg/L	cc/L	mg/L	cc/L	mg/L	
PI 592	341DLRV	6/24/2015	11:05	9/30/2015	-63.25	-198.0	0.913	164	6.1	4.1	0.00047	0.00059	<0.0001	<0.0003	0.74
PI 592	341DLRV	6/24/2015	11:06	9/30/2015	-63.32	-199.7	0.911	167	6.0	4.0	0.00055	0.00069	<0.0001	<0.0002	0.71
PI 609	341DLRV	7/8/2015	13:05	10/1/2015	-59.11	-162.4	0.973	22	0.61	0.41	<0.0001	<0.0002	<0.0001	<0.0002	0.75
PI 625	341DLRV	7/15/2015	10:05	--	--	--	0.984	0	0.0020	0.0013	<0.0001	<0.0002	<0.0001	<0.0002	0.79
PI 641	341DLRV	9/22/2015	10:35	--	--	--	0.982	3	0.083	0.055	<0.0002	<0.0002	<0.0001	<0.0003	0.80
PI 651	341DLRV	9/22/2015	11:05	12/9/2015	-54.41	-121.7	0.967	33	0.95	0.64	<0.0002	<0.0002	<0.0002	<0.0003	0.80
PI 524	341TMSG	6/25/2015	15:05	9/30/2015	-63.44	-219.4	0.898	204	8.9	5.9	0.0010	0.0013	<0.0001	<0.0002	0.67
PI 524	341TMSG	9/22/2015	13:35	12/9/2015	-63.28	-221.2	0.893	205	7.9	5.3	0.0012	0.0016	<0.0001	<0.0002	0.69
PI 524	341TMSG	9/22/2015	13:36	12/8/2015	-63.12	-221.6	0.887	222	8.8	5.9	0.0015	0.0019	<0.0001	<0.0003	0.71
PI 604	341TMSG	9/21/2015	15:05	--	--	--	0.989	0	0.0014	0.00095	<0.0002	<0.0002	<0.0001	<0.0003	0.81
PI 653	341TMSG	9/24/2015	11:35	--	--	--	0.989	3	0.086	0.058	<0.0002	<0.0002	<0.0001	<0.0003	0.80
PI 530	341TMRK	8/5/2015	13:305	10/1/2015	-62.58	-151.2	0.976	18	0.51	0.34	<0.0001	<0.0002	<0.0001	<0.0002	0.78
PI 647	341TMRK	9/23/2015	15:05	--	--	--	0.982	1	0.034	0.023	<0.0001	<0.0002	<0.0001	<0.0002	0.79
PI 647	341TMRK	9/23/2015	15:06	--	--	--	0.982	1	0.035	0.023	<0.0001	<0.0002	<0.0001	<0.0003	0.81
PI 146	344MNNG	8/6/2015	14:05	9/30/2015	-58.89	-175.3	0.950	73	2.3	1.5	<0.0001	<0.0002	<0.0001	<0.0002	0.76
PI 556	344MNNG	8/6/2015	10:35	10/1/2015	-48.04	--	0.982	6	0.16	0.11	<0.0002	<0.0002	<0.0001	<0.0003	0.82
PI 591	344MNNG	8/5/2015	16:05	9/30/2015	-58.97	-203.2	0.943	85	3.5	2.3	0.00033	0.00041	<0.0002	<0.0003	0.73
PI 622	344MNNG	7/14/2015	16:05	9/30/2015	-40.99	-175.0	0.947	75	2.8	1.9	0.00054	0.00067	<0.0001	<0.0002	0.69
PI 642	344MNNG	9/22/2015	14:05	--	--	--	0.996	0	0.00055	0.00036	<0.0001	<0.0002	<0.0001	<0.0003	0.80
PI 650	344MNNG	9/23/2015	11:05	12/9/2015	-57.74	-193.9	0.962	30	1.2	0.78	0.00096	0.0012	<0.0002	<0.0003	0.74
PI 648	344MRCL	9/24/2015	13:05	--	--	--	0.994	0	0.0033	0.0022	<0.0002	<0.0002	<0.0001	<0.0003	0.77

[*] Analysis is of gas extracted from water by headspace equilibration. Analysis has been corrected for helium added to create headspace.

[*] Addition of helium negates the ability to detect native helium and may negate the ability to detect hydrogen.

Samples without He dilution factor had sufficient headspace to be extracted directly.

Appendixes 1–5

Appendix 1. Analytical methods and reporting levels for constituents analyzed, by laboratory.

Appendix 2. Quality assurance and quality control data.

Appendix 3. Spearman rho correlations and boxplots showing sample compositions by groups (ranges of pH, specific conductance, and redox values, principal components, and geologic units) for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015.

Appendix 4. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of closely spaced wells in Pike County, Pennsylvania, 2015.

Appendix 5. Field measurements and results of laboratory analyses for major and minor ions, nutrients, trace metals, radioactivity, radon-222 in groundwater samples collected from 18 wells in Pike County, Pennsylvania, 2007–15.

Table A1–1. Methods used for determination of dissolved major ions, trace constituents, nutrients, alkalinity, and total organic carbon by the U.S. Geological Survey National Water Quality Laboratory and Weck Laboratories, Inc. in filtered groundwater samples collected from wells in Pike County, Pennsylvania, 2015.

[RL, reporting level; USGS, U.S. Geological Survey; NWQL, NationaL Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter, µS/cm, microSiemens per centimeter; ICP-MS, Inductively coupled plasma mass spectrometry]

Analyte	USGS parameter code	RL	Unit
USGS NWQL Schedule 2364 - Description: Major and trace elements in filtered water by ICP-MS and ICP			
Aluminum	01784	3	µg/L
Antimony	01785	0.027	µg/L
Arsenic	03122	0.1	µg/L
Barium	01786	0.25	µg/L
Beryllium	01787	0.02	µg/L
Boron	02504	5	µg/L
Bromide	03166	0.03	mg/L
Cadmium	01788	0.03	µg/L
Calcium	00659	0.022	mg/L
Chloride	01571	0.02	mg/L
Chromium	03126	0.3	µg/L
Cobalt	03124	0.05	µg/L
Copper	03128	0.8	µg/L
Fluoride	00651	0.01	mg/L
Iron	00645	4	µg/L
Lead	01792	0.04	µg/L
Lithium	00664	0.13	µg/L
Magnesium	00663	0.011	mg/L
Manganese	01793	0.4	µg/L
Molybdenum	01794	0.05	µg/L
Nickel	03130	0.2	µg/L
pH, laboratory	00068	0.1	pH
Potassium	02773	0.03	mg/L
Residue, 180 degrees Celsius (TDS)	00027	20	mg/L
Selenium	03132	0.05	µg/L
Silica	00667	0.018	mg/L
Silver	01796	0.02	µg/L
Sodium	00675	0.06	mg/L
Specific conductance, laboratory	00069	5	µS/cm
Strontium	02507	0.8	µg/L
Sulfate	01572	0.02	mg/L
Uranium, natural	01797	0.014	µg/L
Zinc	03138	2	µg/L
USGS NWQL Schedule 101 - Description: Ground water, nutrients (USGS methods), filtered water			
Nitrogen, ammonia	00608	0.01	mg/L
nitrogen, nitrite	00613	0.001	mg/L
nitrogen, nitrite + nitrate	00631	0.04	mg/L
phosphorus, phosphate, ortho	00671	0.004	mg/L
USGS NWQL Lab Code 2109 - Description: Titration, alkalinity as CaCO3, lab value, filtered water			
Alkalinity, laboratory	29801	4.6	mg/L
USGS NWQL Lab Code 3211 - Description: Total nonpurgeable organic carbon, unfiltered water			
Total organic carbon	77135	0.7	mg/L
Weck Laboratories, Inc. - Description: Bromide by EPA method 300.1			
Bromide	91000	10	µg/L

Table A1–2. Methods and reporting levels used for determination of gross alpha and beta radioactivity, radon-222, and radium-226 by the U.S. Geological Survey National Water Quality Laboratory in unfiltered groundwater samples collected from wells in Pike County, Pennsylvania, 2015.

[RL, reporting level; USGS, U.S. Geological Survey; NWQL, National Water Quality Laboratory; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137]

Analyte	USGS parameter code	RL	Unit
USGS NWQL Lab Code 2806 - Gross-Alpha (Th-230 curve)/ Beta (Cs-137 curve), 72 hr and 30 day, water, unfiltered[1]			
Gross-alpha radioactivity, 72 hour count	63014	3	pCi/L
Gross-alpha radioactivity, 30 day count	63016	3	pCi/L
Gross-beta radioactivity, 72 hour count	63015	4	pCi/L
Gross-beta radioactivity, 30 day count	63017	4	pCi/L
USGS NWQL Lab Code 1369 - Description: Radon-222, water, unfiltered, by liquid scintillation			
Radon-222	82303	20	pCi/L
USGS NWQL Lab Code 2622 - Description: Radium-226, water, unfiltered[1]			
Radium-226	09501	0.1	pCi/L

[1] Gross alpha and gross beta radioactivity and radium-226 activity determined by ALS Environmental, Fort Collins, Colorado under contract to NWQL.

Table A1–3. Methods used for determination of total concentrations of major ions, trace constituents, and constituents determined by Seewald Laboratories, Inc., in unfiltered groundwater samples collected from wells in Pike County, Pennsylvania, 2015.

[USGS, U.S.Geological Survey; MRL, laboratory minumum reporting level; mg/L, milligrams per liter; µg/L, micrograms per liter; MPN/100 mL, most probable number per 100 milliliters; PADEP, Pennsylvania Department of Environmental Protection; SM, standard method; EPA, U.S. Environmental Protection Agency; VOC, volatile organic compound]

Analyte	USGS parameter code	MRL	Unit	Method
Seewald Laboratories, Inc. - dissolved gases by method PADEP 3686				
Ethane	68832	0.01	mg/L	PADEP 3686
Methane	68831	0.01	mg/L	PADEP 3686
Propane	68834	0.02	mg/L	PADEP 3686
Seewald Laboratories, Inc. - various inorganic analytes by various drinking-water methods				
Total dissolved solids (residue, filterable)	70300	5	mg/L	SM 2540C
Total suspended solids	70293	5	mg/L	SM 2540D
Calcium	00916	0.3	mg/L	EPA 200.7
Iron	01045	0.01	mg/L	EPA 200.7
Lithium	01132	0.01	mg/L	EPA 200.7
Magnesium	00927	0.01	mg/L	EPA 200.7
Potassium	00937	0.05	mg/L	EPA 200.7
Sodium	00932	0.05	mg/L	EPA 200.7
Strontium	01082	0.01	mg/L	EPA 200.7
Aluminum	01105	0.001	mg/L	EPA 200.8
Arsenic	01002	0.0005	mg/L	EPA 200.8
Barium	01007	0.0005	mg/L	EPA 200.8
Manganese	01055	0.0005	mg/L	EPA 200.8
Selenium	01147	0.0025	mg/L	EPA 200.8
Zinc	01092	0.0005	mg/L	EPA 200.8
Bromide	63689	0.1	mg/L	EPA 300.0
Chloride	99220	1	mg/L	EPA 300.0
Sulfate	00946	1	mg/L	EPA 300.0
Seewald Laboratories, Inc. - VOCs by EPA method 542.2				
- see table 6 for listing of analytes and reporting levels				EPA 524.2
Seewald Laboratories, Inc. - Bacteria enumeration				
Total coliform bacteria	31686	1	MPN/100 mL	SM 9223 Colilert total
E. Coli	31689	1	MPN/100 mL	SM 9223 Colilert total

Table A2–1. Results of laboratory analysis in replicate groundwater samples collected from 3 wells (identified by U.S. Geological Survey well name and station number) in Pike County, Pennsylvania, 2015.

[Analyses for major and minor ions, volatile organic compounds, and dissolved gases (methane, ethane, propane) on unfiltered samples done by Seewald Laboratories, Inc. and other analyses done by U.S. Geological Survey (USGS) National Water Quality Laboratory (NWQL); percent difference = 100x(c1-c2)/[c1+c2)/2],where c1 and c2 are concentrations in first and second sample of replicates; std. units, standard units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; as N, as nitrogen; as P, as phosphorus; MPN/100 mL, most probable number per 100 milliliters; pCi/L, picocuries per liter; %, percent; -, no data; <, less than; R, non-detect for radiological analysis]

USGS well number and station number			PI 524 411849074533901					PI 592 412908074591401			PI 647 411014074554001		
Constituent	Reporting unit	USGS parameter code	Sample date (time) 6/25/2015 (1500)	Sample date (time) 9/22/2015 (1300)	Sample date (time) 9/22/2015 (1331)	Percent difference, replicate samples	Percent difference, June and September samples	Sample date (time) 6/24/2015 (1100)	Sample date (time) 6/24/2015 (1101)	Percent difference between replicate samples	Sample date (time) 9/23/2015 (1500)	Sample date (time) 9/23/2015 (1501)	Percent difference between replicate samples
Dissolved oxygen, water, unfiltered	mg/L	00300	<0.01	0.13	--	--	--	0.17	--	--	0.16	--	--
pH, water, unfiltered, field	std. units	00400	8.24	8.39	--	--	-1.80	8.74	--	--	8.34	--	--
pH, water, unfiltered, laboratory	std. units	00403	8.39	8.37	8.33	0.48	0.24	8.53	8.59	-0.70	8.27	--	--
Calcium, water, filtered	mg/L	00915	14.43	13.71	14.03	-2.31	5.12	4.412	4.228	4.26	16.41	--	--
Magnesium, water, unfiltered, recoverable	mg/L	00927	4.91	5.31	5.31	0.00	-7.83	1.24	1.25	-0.80	5.24	--	--
Potassium, water, unfiltered, recoverable	mg/L	00937	<0.5	<0.5	<0.5	--	--	0.712	0.709	0.42	<0.5	--	--
Sodium, water, filtered	mg/L	00930	46.57	39.99	40.83	-2.08	15.20	68.11	65.39	4.07	13.01	--	--
Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, laboratory	mg/L as $CaCO_3$	29801	123.1	121.1	120.5	0.50	1.64	117.4	117.4	0.00	70.92	--	--
Bromide, water, filtered	µg/L	91000	220	170	--	--	25.64	360	350	2.82	<10	--	--
Bromide, water, unfiltered	mg/L	63689	<0.1	<0.1	<0.1	--	--	0.159	0.158	0.63	<0.1	--	--
Chloride, water, filtered	mg/L	00940	23.529	22.028	21.587	2.02	6.59	33.035	33.016	0.06	2.962	--	--
Chloride, water, unfiltered	mg/L	99220	23.7	23	23.5	-2.15	3.00	33.2	33.1	0.30	3.12	--	--
Fluoride, water, filtered	mg/L	00950	0.201	0.208	0.2	3.92	-3.42	0.514	0.507	1.37	0.098	--	--
Silica, water, filtered, as SiO_2	mg/L	00955	10.07	9.657	9.614	0.45	4.19	7.139	7.085	0.76	11.78	--	--

Table A2–1. Results of laboratory analysis in replicate groundwater samples collected from 3 wells (identified by U.S. Geological Survey well name and station number) in Pike County, Pennsylvania, 2015.—Continued

[Analyses for major and minor ions, volatile organic compounds, and dissolved gases (methane, ethane, propane) on unfiltered samples done by Seewald Laboratories, Inc. and other analyses done by U.S. Geological Survey (USGS) National Water Quality Laboratory (NWQL); percent difference = 100x(c1-c2)/[c1+c2)/2],where c1 and c2 are concentrations in first and second sample of replicates; std. units, standard units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; as N, as nitrogen; as P, as phosphorus; MPN/100 mL, most probable number per 100 milliliters; pCi/L, picocuries per liter; %, percent; -, no data; <, less than; R, non-detect for radiological analysis]

USGS well number and station number			PI 524 411849074533901					PI 592 412908074591401			PI 647 411014074554001		
Constituent	Reporting unit	USGS parameter code	Sample date (time) 6/25/2015 (1500)	Sample date (time) 9/22/2015 (1300)	Sample date (time) 9/22/2015 (1331)	Percent difference, replicate samples	Percent difference, June and September samples	Sample date (time) 6/24/2015 (1100)	Sample date (time) 6/24/2015 (1101)	Percent difference between replicate samples	Sample date (time) 9/23/2015 (1500)	Sample date (time) 9/23/2015 (1501)	Percent difference between replicate samples
Sulfate, water, filtered	mg/L	00945	0.887	1.112	1.154	-3.71	-22.51	0.391	0.39	0.26	17.236	--	--
Sulfate, water, unfiltered	mg/L	00946	<1	<1	<1	--	--	<1	<1	--	18.5	--	--
Ammonia, water, filtered, as nitrogen	mg/L as N	00608	0.06591	0.06301	0.0608	3.57	4.50	0.05913	0.05963	-0.84	0.04529	--	--
Nitrate plus nitrite, water, filtered	mg/L as N	00631	<0.04	<0.04	<0.04	--	--	<0.04	<0.04	--	<0.04	--	--
Nitrite, water, filtered	mg/L as N	00613	<0.0010	<0.001	<0.001	--	--	<0.0010	<0.0010	--	<0.001	--	--
Orthophosphate, water, filtered	mg/L as P	00671	0.02866	0.02661	0.02744	-3.07	7.42	0.1744	0.178	-2.04	0.02216	--	--
Escherichia coli, water	MPN/100 mL	31689	<1	<1	<1	--	--	<1	<1	--	<1	--	--
Total coliforms, water	MPN/100 mL	31686	<1	<1	<1	--	--	19	<1	--	<1	--	--
Aluminum, water, filtered	µg/L	01106	<3.0	<3	<3	--	--	<3.0	3.469	--	<3	--	--
Aluminum, water, unfiltered, recoverable	µg/L	01105	2.62	2.56	1.89	30.11	2.32	1.04	1.19	-13.45	2.52	--	--
Barium, water, filtered	µg/L	01005	136.8	130.4	132.3	-1.45	4.79	298.5	294.5	1.35	11.24	--	--
Barium, water, unfiltered, recoverable	µg/L	01007	130	125	126	-0.80	3.92	292	291	0.34	15.8	--	--
Beryllium, water, filtered	µg/L	01010	<0.02	<0.02	<0.02	--	--	<0.02	<0.02	--	<0.02	--	--
Cadmium, water, filtered	µg/L	01025	<0.03	<0.03	<0.03	--	--	<0.03	<0.03	--	<0.03	--	--
Chromium, water, filtered	µg/L	01030	<0.3	<0.3	<0.3	--	--	<0.3	<0.3	--	<0.3	--	--
Cobalt, water, filtered	µg/L	01035	<0.05	0.0903	<0.05	--	--	<0.05	<0.05	--	<0.05	--	--

Table A2–1. Results of laboratory analysis in replicate groundwater samples collected from 3 wells (identified by U.S. Geological Survey well name and station number) in Pike County, Pennsylvania, 2015.—Continued

[Analyses for major and minor ions, volatile organic compounds, and dissolved gases (methane, ethane, propane) on unfiltered samples done by Seewald Laboratories, Inc. and other analyses done by U.S. Geological Survey (USGS) National Water Quality Laboratory (NWQL); percent difference = 100x(c1-c2)/[c1+c2)/2],where c1 and c2 are concentrations in first and second sample of replicates; std. units, standard units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; as N, as nitrogen; as P, as phosphorus; MPN/100 mL, most probable number per 100 milliliters; pCi/L, picocuries per liter; %, percent; -, no data; <, less than; R, non-detect for radiological analysis]

USGS well number and station number			PI 524 411849074533901					PI 592 412908074591401			PI 647 411014074554001		
Constituent	Reporting unit	USGS parameter code	Sample date (time) 6/25/2015 (1500)	Sample date (time) 9/22/2015 (1300)	Sample date (time) 9/22/2015 (1331)	Percent difference, replicate samples	Percent difference, June and September samples	Sample date (time) 6/24/2015 (1100)	Sample date (time) 6/24/2015 (1101)	Percent difference between replicate samples	Sample date (time) 9/23/2015 (1500)	Sample date (time) 9/23/2015 (1501)	Percent difference between replicate samples
Copper, water, filtered	µg/L	01040	<0.8	<0.8	<0.8	--	--	<0.8	<0.8	--	<0.8	--	--
Iron, water, filtered	µg/L	01046	18.57	22.41	20.92	6.88	-18.74	72.08	69.65	3.43	46.51	--	--
Iron, water, unfiltered, recoverable	µg/L	01045	58.8	50.8	37.2	30.91	14.60	80.3	80.9	-0.74	2,180	--	--
Lead, water, filtered	µg/L	01049	<0.04	<0.04	<0.04	--	--	0.3772	0.3499	7.51	<0.04	--	--
Lithium, water, filtered	µg/L	01130	136.4	117.7	122.4	-3.92	14.72	289.4	281.9	2.63	13.3	--	--
Lithium, water, unfiltered, recoverable	µg/L	01132	138	133	140	-5.13	3.69	268	270	-0.74	14.4	--	--
Manganese, water, filtered	µg/L	01056	18.42	20.31	19.92	1.94	-9.76	83.72	82.98	0.89	84.52	--	--
Manganese, water, unfiltered, recoverable	µg/L	01055	18.4	18.9	18.2	3.77	-2.68	80.9	80.4	0.62	242	--	--
Molybdenum, water, filtered	µg/L	01060	0.3528	0.3673	0.3711	-1.03	-4.03	0.606	0.6225	-2.69	0.0893	--	--
Nickel, water, filtered	µg/L	01065	<0.20	<0.2	<0.2	--	--	<0.20	<0.20	--	<0.2	--	--
Strontium, water, filtered	µg/L	01080	487.5	472.3	475.2	-0.61	3.17	331.3	330.7	0.18	326.1	--	--
Strontium, water, unfiltered, recoverable	µg/L	01082	490	485	500	-3.05	1.03	325	327	-0.61	335	--	--
Zinc, water, filtered	µg/L	01090	<2.0	<2	<2	--	--	<2.0	<2.0	--	<2	--	--
Zinc, water, unfiltered, recoverable	µg/L	01092	<0.5	<0.5	<0.5	--	--	16.3	18.1	-10.47	1.64	--	--
Antimony, water, filtered	µg/L	01095	<0.027	<0.027	<0.027	--	--	<0.027	<0.027	--	<0.027	--	--
Arsenic, water, filtered	µg/L	01000	0.2355	0.2321	0.2341	-0.86	1.45	27.83	27.76	0.25	0.1203	--	--

Table A2–1. Results of laboratory analysis in replicate groundwater samples collected from 3 wells (identified by U.S. Geological Survey well name and station number) in Pike County, Pennsylvania, 2015.—Continued

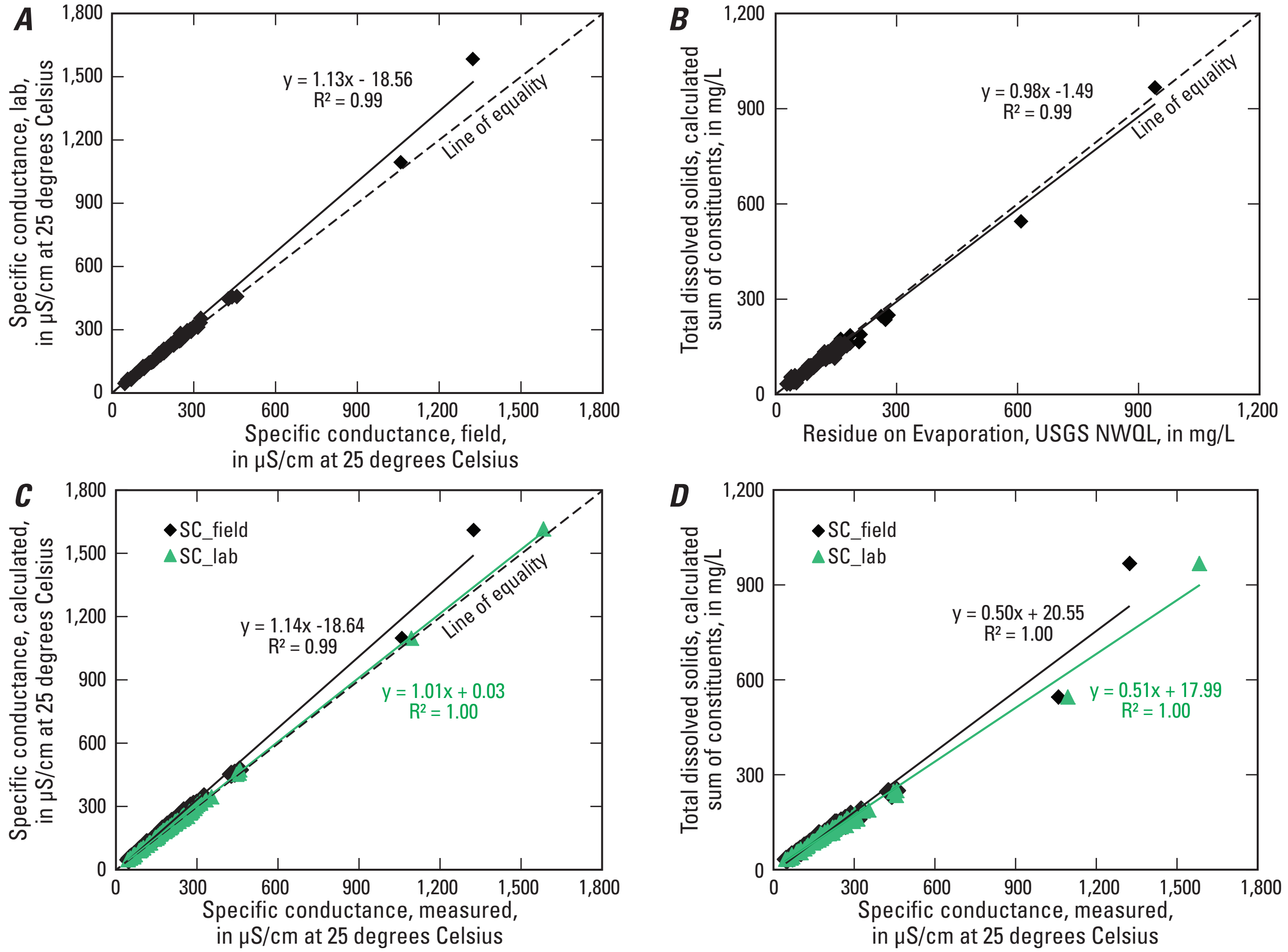
[Analyses for major and minor ions, volatile organic compounds, and dissolved gases (methane, ethane, propane) on unfiltered samples done by Seewald Laboratories, Inc. and other analyses done by U.S. Geological Survey (USGS) National Water Quality Laboratory (NWQL); percent difference = 100x(c1-c2)/[c1+c2)/2],where c1 and c2 are concentrations in first and second sample of replicates; std. units, standard units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; as N, as nitrogen; as P, as phosphorus; MPN/100 mL, most probable number per 100 milliliters; pCi/L, picocuries per liter; %, percent; -, no data; <, less than; R, non-detect for radiological analysis]

USGS well number and station number			PI 524 411849074533901					PI 592 412908074591401			PI 647 411014074554001		
Constituent	Reporting unit	USGS parameter code	Sample date (time) 6/25/2015 (1500)	Sample date (time) 9/22/2015 (1300)	Sample date (time) 9/22/2015 (1331)	Percent difference, replicate samples	Percent difference, June and September samples	Sample date (time) 6/24/2015 (1100)	Sample date (time) 6/24/2015 (1101)	Percent difference between replicate samples	Sample date (time) 9/23/2015 (1500)	Sample date (time) 9/23/2015 (1501)	Percent difference between replicate samples
Arsenic, water, unfiltered	µg/L	01002	<0.5	<0.5	<0.5	--	--	30.7	31.8	-3.52	<0.5	--	--
Boron, water, filtered	µg/L	01020	83.94	79.47	79.11	0.45	5.47	117.3	118.3	-0.85	21.68	--	--
Selenium, water, filtered	µg/L	01145	<0.05	<0.05	<0.05	--	--	<0.05	<0.05	--	<0.05	--	--
Selenium, water, unfiltered	µg/L	01147	<2.5	<2.5	<2.5	--	--	<2.5	<2.5	--	<2.5	--	--
Ethane, water, dissolved, recoverable	mg/L	68832	<0.1	<0.01	<0.01	--	--	<0.1	<0.05	--	--	--	--
Ethane, water, unfiltered, recoverable	ug/L	82045	--	--	--	--	--	--	--	--	<3.3	<3.3	--
Methane, water, dissolved, recoverable	mg/L	68831	2.54	4.12	3.28	22.70	-47.45	1.79	1.48	18.96	--	--	--
Methane, water, unfiltered, recoverable	mg/L	76994	--	--	--	--	--	--	--	--	2.2	2.9	-27.45
Propane, water, dissolved, recoverable	mg/L	68834	<0.2	<0.02	<0.02	--	--	<0.1	<0.1	--	--	--	--
Propane, water, unfiltered, recoverable	µg/L	82358	--	--	--	--	--	--	--	--	<3.2	<3.2	--
Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve	pCi/L	63016	1.39	3.4	1.87	58.06	-83.92	0.94	R0.35	--	R0.61	--	--
Gross alpha radioactivity, 72 hour count, water, unfiltered, Th-230 curve	pCi/L	63014	R0.98	4.73	1.27	115.33	--	R0.93	1.44	--	R-0.58	--	--

Table A2–1. Results of laboratory analysis in replicate groundwater samples collected from 3 wells (identified by U.S. Geological Survey well name and station number) in Pike County, Pennsylvania, 2015.—Continued

[Analyses for major and minor ions, volatile organic compounds, and dissolved gases (methane, ethane, propane) on unfiltered samples done by Seewald Laboratories, Inc. and other analyses done by U.S. Geological Survey (USGS) National Water Quality Laboratory (NWQL); percent difference = 100x(c1-c2)/[c1+c2)/2],where c1 and c2 are concentrations in first and second sample of replicates; std. units, standard units; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; as N, as nitrogen; as P, as phosphorus; MPN/100 mL, most probable number per 100 milliliters; pCi/L, picocuries per liter; %, percent; -, no data; <, less than; R, non-detect for radiological analysis]

USGS well number and station number			**PI 524 411849074533901**					**PI 592 412908074591401**			**PI 647 411014074554001**		
Constituent	**Reporting unit**	**USGS parameter code**	**Sample date (time) 6/25/2015 (1500)**	**Sample date (time) 9/22/2015 (1300)**	**Sample date (time) 9/22/2015 (1331)**	**Percent difference, replicate samples**	**Percent difference, June and September samples**	**Sample date (time) 6/24/2015 (1100)**	**Sample date (time) 6/24/2015 (1101)**	**Percent difference between replicate samples**	**Sample date (time) 9/23/2015 (1500)**	**Sample date (time) 9/23/2015 (1501)**	**Percent difference between replicate samples**
Gross beta radioactivity, 30 day recount, water, unfiltered, Cs-137 curve	pCi/L	63017	1.49	R1.53	R1.60	--	--	1.55	3.05	-65.22	1.2	--	--
Gross beta radioactivity, 72 hour count, water, unfiltered, Cs-137 curve	pCi/L	63015	R1.22	2.74	R1.30	--	--	2.27	R0.66	--	R0.95	--	--
Radium-226, water, unfiltered	pCi/L	09501	--	0.303	0.304	-0.33	--	--	--	--	--	--	--
Radon-222, water, unfiltered	pCi/L	82303	375	452	472	-4.33	-18.62	1,212	1,242	-2.44	240	--	--
Uranium (natural), water, filtered	ug/L	22703	0.0947	0.157	0.1469	6.65	-49.50	0.0152	<0.014	--	0.0253	--	--
Organic carbon, water, unfiltered	mg/L	00680	<0.7	<0.7	<0.7	--	--	<0.7	<0.7	--	<0.7	--	
VOCs - see table 7; VOC surrogates, unfiltered water	µg/L			--	--	--	--	<0.5	<0.5	--		--	--
1-Bromo-4-fluorobenzene, surrogate	% recovery	99834		--	--	--	--	90	90	0.00	--	--	--
1,2-Dichlorobenzene-d4, gasoline-range organic surrogate	% recovery	90475		--	--	--	--	94	88	6.59	--	--	--



NWQL, National Water Quality Laboratory

Figure 2–1. Relations between *A*, Field and laboratory measured specific conductance, *B*, Measured residue on evaporation and calculated sum of total dissolved solids, *C*, Measured (field and laboratory) and calculated (from dissolved ions) specific conductance, and *D*, Measured (field and laboratory) specific conductance and calculated sum of total dissolved solids for groundwater samples collected from 79 wells in Pike County, Pennsylvania, 2015. [μS/cm, microsiemens per centimeter]

Table A2–2. Results of laboratory analysis by Seewald Laboratories, Inc. of U.S. Geological Survey reference water samples and defined reference water-sample concentrations, 2015.

[USGS, U.S. Geological Survey; Seewald, Seewald Laboratories, Inc.; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; <, less than; percent difference calculated as 100*(Seewald result - reference value)/reference value]

Laboratory or code for USGS reference sample	Date	Sample start time	Dissolved solids dried at 180 degrees Celsius, filtered	Concentrations of constituents in unfiltered water samples, as recoverable by laboratory or as defined for reference sample						
				Calcium	Magnesium	Potassium	Sodium	Bromide	Chloride	Sulfate
Units			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Seewald	8/5/2015	1205	204	17.4	3.84	1.89	17.6	<0.10	30.8	83.6
Reference T221, M214		--	217	16.7	3.77	1.9	17.4	0.134	28.8	77.6
Seewald	8/5/2015	1305	88	26	5.29	0.975	9.85	<0.10	15.7	10.5
Reference T211, M198		--	85	24.6	5.21	0.979	9.78	0.1	14.6	10
Seewald	9/23/2015	1705	259	31.6	7.4	2.57	21.3	0.342	66.9	35.6
Reference T217, M208		--	253	30.9	7.5	2.49	19.7	0.14	64	33.4
Percent difference between Seewald and reference sample concentrations										
	8/5/2015	1205	-6.0	4.2	1.9	-0.5	1.1	--	6.9	7.7
	8/5/2015	1305	3.4	5.4	1.5	-0.4	0.7	--	7.0	4.8
	9/23/2015	1705	2.4	2.3	-1.3	3.2	8.1	144.3	4.5	6.6
Average for all three samples			-0.1	3.9	0.7	0.8	3.3	--	6.2	6.4
Difference between Seewald and reference sample concentrations										
	8/5/2015	1205	-13	0.7	0.07	-0.01	0.2	--	2	6
	8/5/2015	1305	3	1.4	0.08	-0.004	0.07	--	1.1	0.5
	9/23/2015	1705	6	0.7	-0.1	0.08	1.6	0.202	2.9	2.2
Average for all three samples			*-1.3*	*0.9*	*0.02*	*0.02*	*0.6*	--	*2.0*	*2.9*

Laboratory or code for USGS reference sample	Date	Sample start time	Concentrations of constituents in unfiltered water samples, as recoverable by laboratory or as defined for reference sample								
			Aluminum	Barium	Iron	Lithium	Manganese	Strontium	Zinc	Arsenic	Selenium
Units			µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Seewald	8/5/2015	1205	381	29.5	344	<10	31	103	24.2	17.3	3.63
Reference T221, M214		--	374	29	328	2.54	33.6	97.8	25.2	17.7	3.8
Seewald	8/5/2015	1305	14.1	55.2	56.2	<10	45.3	141	411	5.07	<2.5
Reference T211, M198		--	14.5	55	54.4	1.32	45.5	134	404	4.95	0.292
Seewald	9/23/2015	1705	49.1	41.6	56.8	13.5	212	195	190	5.54	3.84
Reference T217, M208		--	48.3	40.1	54.1	11.6	201	186	191	5.99	3.8
Percent difference between Seewald and reference sample concentrations											
	8/5/2015	1205	1.9	1.7	4.9	--	-7.7	5.3	-4.0	-2.3	-4.5
	8/5/2015	1305	-2.8	0.4	3.2	--	-0.4	5.0	1.7	2.4	--
	9/23/2015	1705	1.7	3.7	5.0	16.4	5.5	4.8	-0.5	-7.5	1.1
Average for all three samples			0.2	1.9	4.4	--	-0.9	5.0	-0.9	-2.5	--
Difference between Seewald and reference sample concentrations											
	8/5/2015	1205	7	0.5	16	--	-2.6	5.2	-1	-0.4	-0.17
	8/5/2015	1305	-0.4	0.2	1.8	--	-0.2	7	7	0.12	--
	9/23/2015	1705	0.8	1.5	2.7	1.9	11	9	-1	-0.45	0.04
Average for all three samples			*2.5*	*0.7*	*6.8*	--	*2.7*	*7.1*	*1.7*	*-0.2*	--

Table A3–1. Spearman rank correlation coefficient (r) matrix for properties and concentrations of constituents in groundwater samples collected from 79 wells in , Pike County, Pennsylvania, 2015.

[Analysis included dissolved concentrations of all inorganic constituents except gross alpha and beta activities which were determined in unfiltered samples; Spearman rank correlation coefficient r-values multiplied by 100 and rounded; only values significant at a = 0.001 shown; --, not significant; parameters in red-italics use a lower common detection limit than corresponding parameter]

Matrix position	Variable label	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
		PC1	PC2	PC3	PC4	PC5	TEMPC	DOX	LSELEV	WELLZALT	WELLZ	pH	pHL	SCL	SCF	ROE180	TDS	Hard	Ca	Mg	K	Na	ALK	Br	Cl	F	SIO2	SO4	NH3N	NO3N
1	PC1	100						-56				84	85								52	81			85				-61	
2	PC2		100																								68			
3	PC3			100										48	49	50	47	93	88	89						73	50			
4	PC4				100			-56																				53	-66	
5	PC5					100								70	70	68	66				66		81	78						
6	TEMPC						100		-55	-54																				
7	DOX	-56			-56			100				-70	-67				-43				-46	-59			-55			-54	75	
8	LSELEV						-55		100	90			-45				-45				-45	-45								
9	WELLZALT						-54		90	100		-48	-51	-45	-44	-45	-49				-48	-48								
10	WELLZ										100																			
11	pH	84						-70		-48		100	97				46				55	76			72			59	-69	
12	pHL	85						-67	-45	-51		97	100	45	45		49				59	78			72			57	-64	
13	SCL			48		70				-45			45	100	100	99	99	62	60	54	75	68	52	65				47		
14	SCF			49		70				-44			45	100	100	98	99	62	59	55	75	68	52	65				47		
15	ROE180			50		68				-45				99	98	100	98	62	59	55	73	64	50	67				47		
16	TDS			47		66		-43	-45	-49		46	49	99	99	98	100	60	57	53	76	72	52	60				52		
17	Hard			93										62	62	62	60	100	97	86						54	48			
18	Ca			88										60	59	59	57	97	100	75						51	46			
19	Mg			89										54	55	55	53	86	75	100						56				
20	K																													
21	Na	52				66		-46	-45	-48		55	59	75	75	73	76				100	62	51	43	51			61		
22	ALK	81						-59	-45	-48		76	78	68	68	64	72				62	100			66			53	-55	
23	Br					81								52	52	50	52				51		100	51						
24	Cl					78								65	65	67	60				43		51	100						
25	F	85						-55				72	72								51	66			100			51	-68	
26	SIO2			73														54	51	56						100				
27	SO4		68	50														48	46								100			
28	NH3N				53			-54				59	57	47	47	47	52				61	53			51			100	-56	

Table A3–1. Spearman rank correlation coefficient (r) matrix for properties and concentrations of constituents in groundwater samples collected from 79 wells in , Pike County, Pennsylvania, 2015.—Continued

[Analysis included dissolved concentrations of all inorganic constituents except gross alpha and beta activities which were determined in unfiltered samples; Spearman rank correlation coefficient r-values multiplied by 100 and rounded; only values significant at a = 0.001 shown; --, not significant; parameters in red-italics use a lower common detection limit than corresponding parameter]

Matrix position	Variable label	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
		PO4P	Tcoli	Al	Ba	Be	Cd	Co	Cu	Fe	Pb	Li	Mn	Mo	Ni	Sr	Zn	Sb	As	B	Se	Alpha30	Alpha72	Beta30	Beta72	Rn222	U	CH4
1	PC1								-55		-53	48		77	-53		-60			54								48
2	PC2											70				74				66						-76		
3	PC3																										55	
4	PC4								-56	90			90								-64							
5	PC5																											
6	TEMPC																											
7	DOX								74	-52	48	-53	-62	-50	47	-52	57			-44								
8	LSELEV																			-44								
9	WELLZALT											-49								-51						50		
10	WELLZ															47												
11	pH								-70		-55	69		67	-54	59	-73			65						-49		55
12	pHL								-64		-54	70		67	-52	55	-71			67						-49		54
13	SCL											65				58				60								47
14	SCF											65				57				60								46
15	ROE180											64				57				58								45
16	TDS											68				59				63						-44		49
17	Hard																										56	
18	Ca					-45										43											58	
19	Mg																										46	
20	K																											
21	Na								-54			66		44		52				75						-44		56
22	ALK								-57		-53	60		66		47	-53			63							45	54
23	Br											45																
24	Cl																											
25	F								-58		-59			68	-45		-47			48								48
26	SIO2																											
27	SO4															43												
28	NH3N								-63	54		51	65							56	-54					-72		58

Table A3–1. Spearman rank correlation coefficient (r) matrix for properties and concentrations of constituents in groundwater samples collected from 79 wells in , Pike County, Pennsylvania, 2015.—Continued

[Analysis included dissolved concentrations of all inorganic constituents except gross alpha and beta activities which were determined in unfiltered samples; Spearman rank correlation coefficient r-values multiplied by 100 and rounded; only values significant at a = 0.001 shown; --, not significant; parameters in red-italics use a lower common detection limit than corresponding parameter]

Matrix position	Variable label	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
		PC1	PC2	PC3	PC4	PC5	TEMPC	DOX	LSELEV	WELLZALT	WELLZ	pH	pHL	SCL	SCF	ROE180	TDS	Hard	Ca	Mg	K	Na	ALK	Br	Cl	F	SIO2	SO4	NH3N	NO3N
29	NO3N	-61			-66			75				-69	-64									-55			-68			-56	100	
30	PO4P																													
31	Tcoli																													
32	Al																													
33	Ba																													
34	Be																		-45											
35	Cd																													
36	Co																													
37	Cu	-55			-56			74				-70	-64								-54	-57			-58			-63	76	
38	Fe				90			-52																				54	-63	
39	Pb	-53						48				-55	-54									-53			-59				55	
40	Li	48	70					-53		-49		69	70	65	65	64	68				66	60	45					51		
41	Mn				90			-62																				65	-64	
42	Mo	77						-50				67	67								44	66			68				-56	
43	Ni	-53						47				-54	-52												-45					
44	Sr		74					-52			47	59	55	58	57	57	59		43		52	47					43			
45	Zn	-60						57				-73	-71									-53			-47				53	
46	Sb																													
47	As																													
48	B	54	66					-44	-44	-51		65	67	60	60	58	63				75	63			48			56		
49	Se				-64																							-54	49	
50	Alpha30																													
51	Alpha72																													
52	Beta30																													
53	Beta72																													
54	Rn222		-76							50		-49	-49				-44				-44							-72	45	
55	U			55														56	58	46		45								
56	CH4	48										55	54	47	46	45	49				56	54			48			58		

Table A3–1. Spearman rank correlation coefficient (r) matrix for properties and concentrations of constituents in groundwater samples collected from 79 wells in , Pike County, Pennsylvania, 2015.—Continued

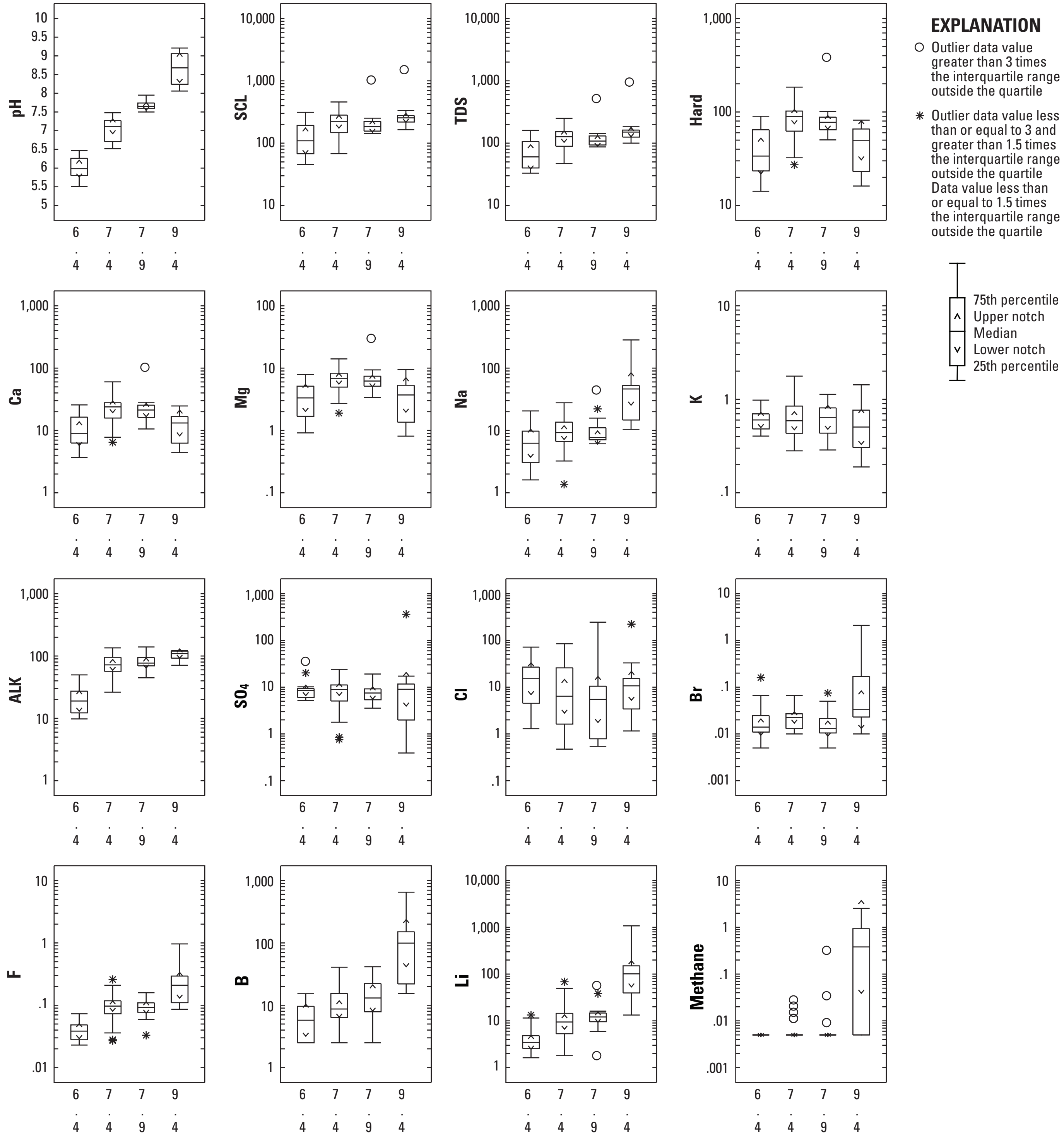
[Analysis included dissolved concentrations of all inorganic constituents except gross alpha and beta activities which were determined in unfiltered samples; Spearman rank correlation coefficient r-values multiplied by 100 and rounded; only values significant at a = 0.001 shown; --, not significant; parameters in red-italics use a lower common detection limit than corresponding parameter]

Matrix position	Variable label	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
		PO4P	Tcoli	Al	Ba	Be	Cd	Co	Cu	Fe	Pb	Li	Mn	Mo	Ni	Sr	Zn	Sb	As	B	Se	Alpha30	Alpha72	Beta30	Beta72	Rn222	U	CH4
29	NO3N								76	-63	55		-64	-56			53				49					45		
30	PO4P	100														-47												
31	Tcoli		100																									
32	Al			100																								
33	Ba				100							50				58			45									
34	Be					100									44													
35	Cd						100																					
36	Co							100							43			43										
37	Cu								100	-59	49	-48	-62	-52	43	-46	43			-44						46		-45
38	Fe								-59	100			79								-52							
39	Pb								49		100			-43			50											
40	Li				50				-48			100				83	-47			80						-62		60
41	Mn								-62	79			100								-63					-49		
42	Mo								-52		-43			100			-43			44							45	
43	Ni					44		43	43						100		44											
44	Sr	-47			58				-46			83				100				66						-56		
45	Zn								43		50	-47		-43	44		100											
46	Sb							43										100										
47	As				45														100								47	
48	B								-44			80		44		66				100						-58		58
49	Se									-52			-63								100							
50	Alpha30																					100	47	47				
51	Alpha72																					47	100		60			
52	Beta30																					47		100	55			
53	Beta72																						60	55	100			
54	Rn222								46			-62	-49			-56				-58						100		-47
55	U													45					47								100	
56	CH4								-45			60								58						-47		100

Table A3–1. Spearman rank correlation coefficient (r) matrix for properties and concentrations of constituents in groundwater samples collected from 79 wells in , Pike County, Pennsylvania, 2015.—Continued

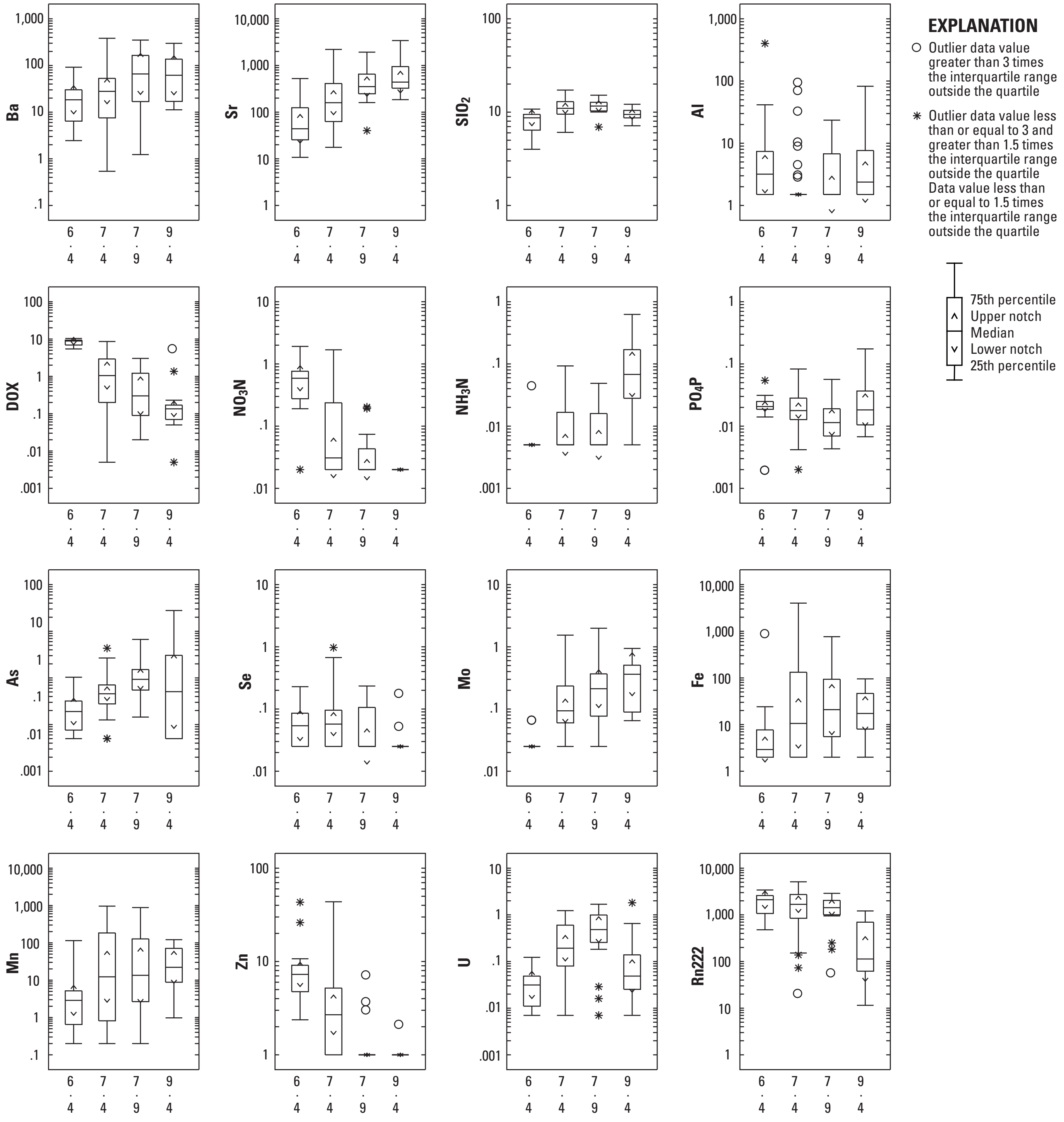
[Analysis included dissolved concentrations of all inorganic constituents except gross alpha and beta activities which were determined in unfiltered samples; Spearman rank correlation coefficient r-values multiplied by 100 and rounded; only values significant at a = 0.001 shown; --, not significant; parameters in red-italics use a lower common detection limit than corresponding parameter]

Variable label	Explanation of variable label abbreviation	Variable label	Explanation of variable label abbreviation
PC1	principal component	Al	aluminum
TEMPC	water temperature in degrees Celsius	Ba	barium
DOX	dissolved oxygen	Be	berrylium
LSELEV	land surfacde elevation	Cd	cadmium
WELLZALT	altitude of bootom of well	Co	cobalt
WELLZ	well depth	Cu	copper
pHL	laboratory pH	Fe	iron
SCL	laboratory specific conductance	Pb	lead
SCF	field specific conductance	Li	lithium
ROE180	residue on evaporation at 180 degrees Celsius	Mn	manganese
TDS	total dissolved solids	Mo	molybdenum
Hard	hardness	Ni	nickel
Ca	calcium	Sr	strontium
Mg	magnesium	Zn	zinc
K	potassium	Sb	antimony
Na	sodium	As	arsenic
ALK	alkalinity	B	boron
Br	bromide	Se	selenium
Cl	chloride	Alpha30	gross alpha activity 30-day count
F	fluoride	Alpha72	gross alpha activity 72-hour count
SIO2	silica	Beta30	gross beta activity 30-day count
SO4	sulfate	Beta72	gross beta activity 72-hour count
NH3N	ammonia as nitrogen	Rn-222	radon-222
NO3N	nitrate as nitrogen	U	uranium
PO4P	orthophosphate as phospohorous	CH4	methane
Tcoli	total coliform bacteria		



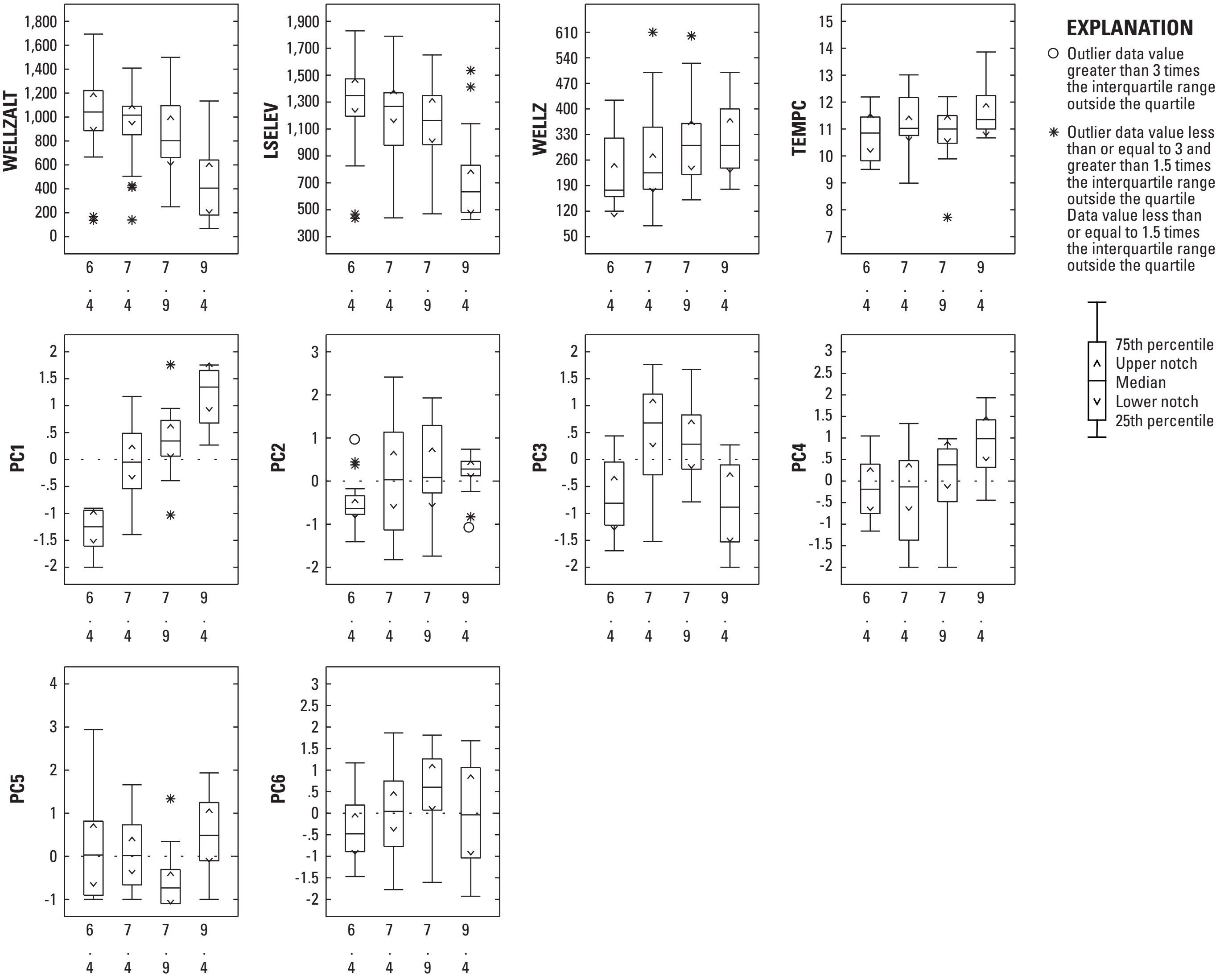
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; $CaCO_3$, calcium carbonate; SCL, laboratory specific conductance in microsiemens per centimeter at 25 degrees Celsius; TDS, Total dissolved solids in mg/L; Hard, hardness in mg/L as $CaCO_3$; Ca, calcium in mg/L; Mg, magnesium in mg/L; Na, sodium in mg/L; K, potassium in mg/L; ALK, alkalinity in mg/L as $CaCO_3$; SO_4, sulfate in mg/L; Cl, chloride in mg/L; Br, bromide in mg/L; F, fluoride in mg/L; B, boron in µg/L; Li, lithium in ug/L; Methane in mg/L.

Figure 3–1



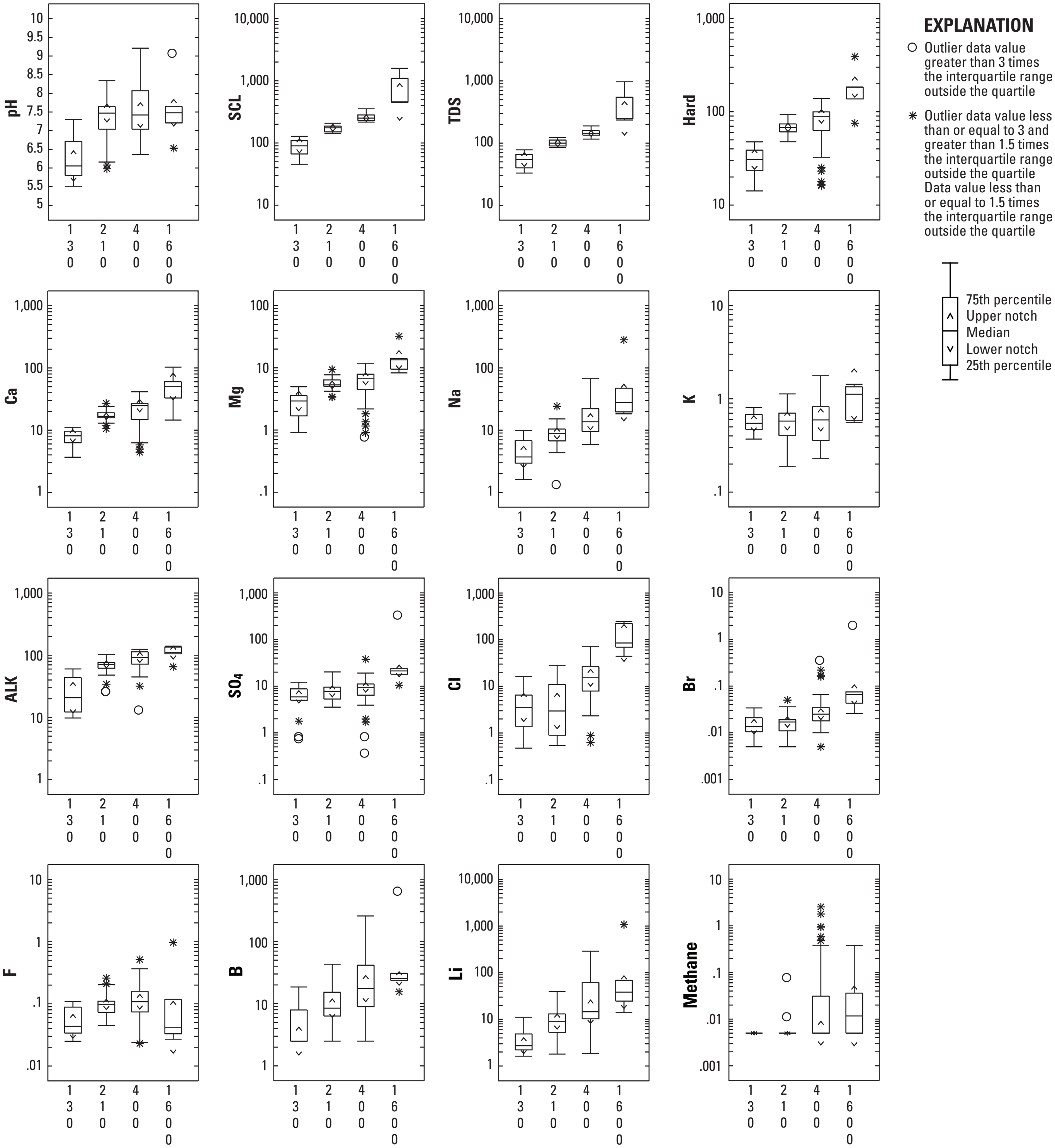
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; Ba, barium in ug/L; Sr, strontium in ug/L; SIO2, silica in mg/L; Al, aluminum in ug/L; DOX, dissolved oxygen in mg/L; NO3N, nitrate in mg/L as nitrogen; NH3N, ammonia in mg/L as nitrogen; PO4P, orthophosphate in mg/L as phosphorus; As, arsenic in ug/L; Se, selenium in ug/L; Mo, molybdenum in µg/L; Fe, iron in ug/L; Mn, manganese in ug/L; Zn, zinc in ug/L; U, uranium in ug/L; Rn222, radon-222 in pCi/L.

Figure 3–1—Continued



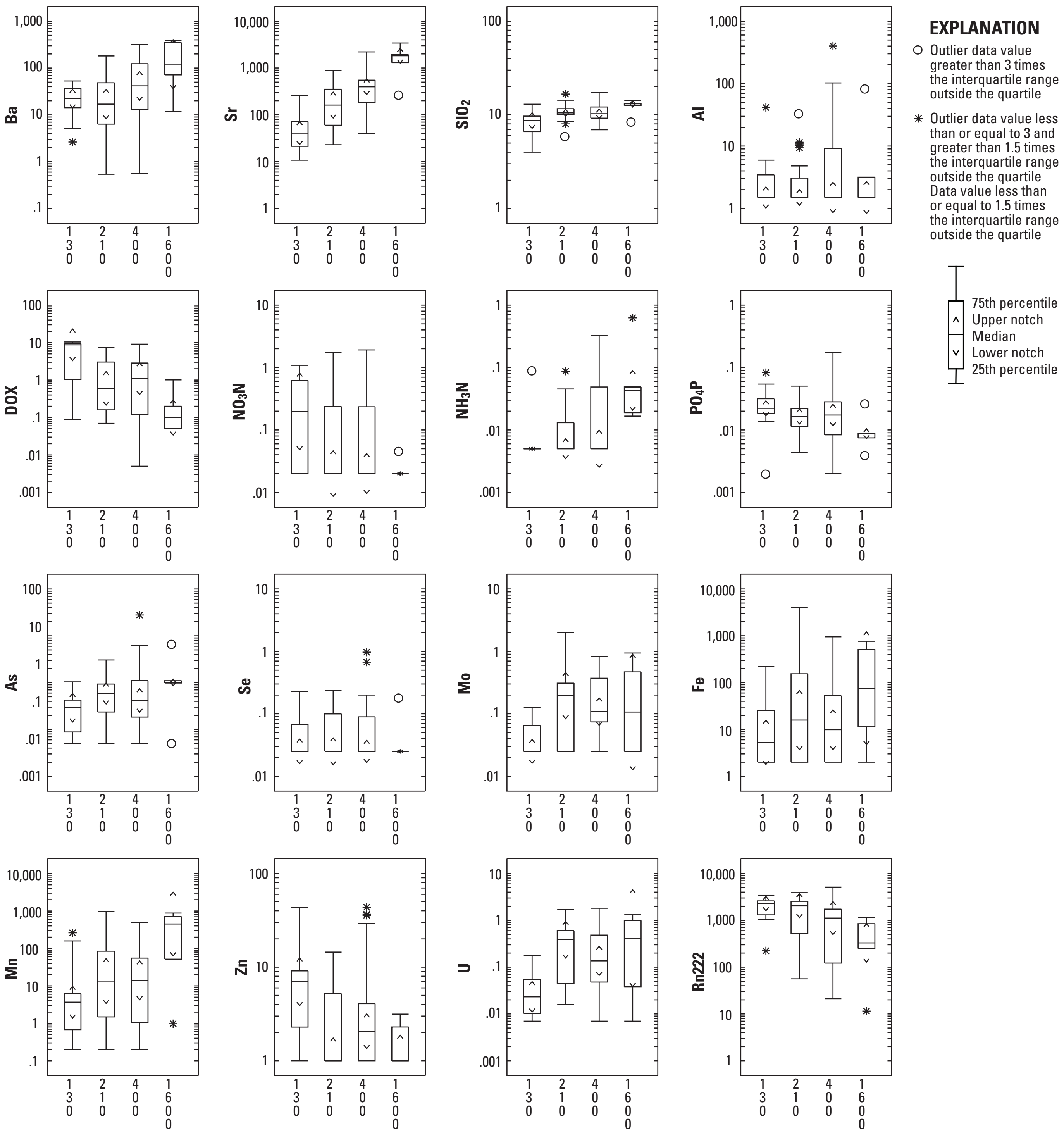
Abbreviations: ft, feet; WELLZALT, altitude of well bottom in ft above NAVD 88; LSELEV, land-surface elevation in ft above NAVD 88; WELLZ, depth of well in ft below land surface; TEMPC, water temperature in degrees Celsius; PC, principal component.

Figure 3–1—Continued



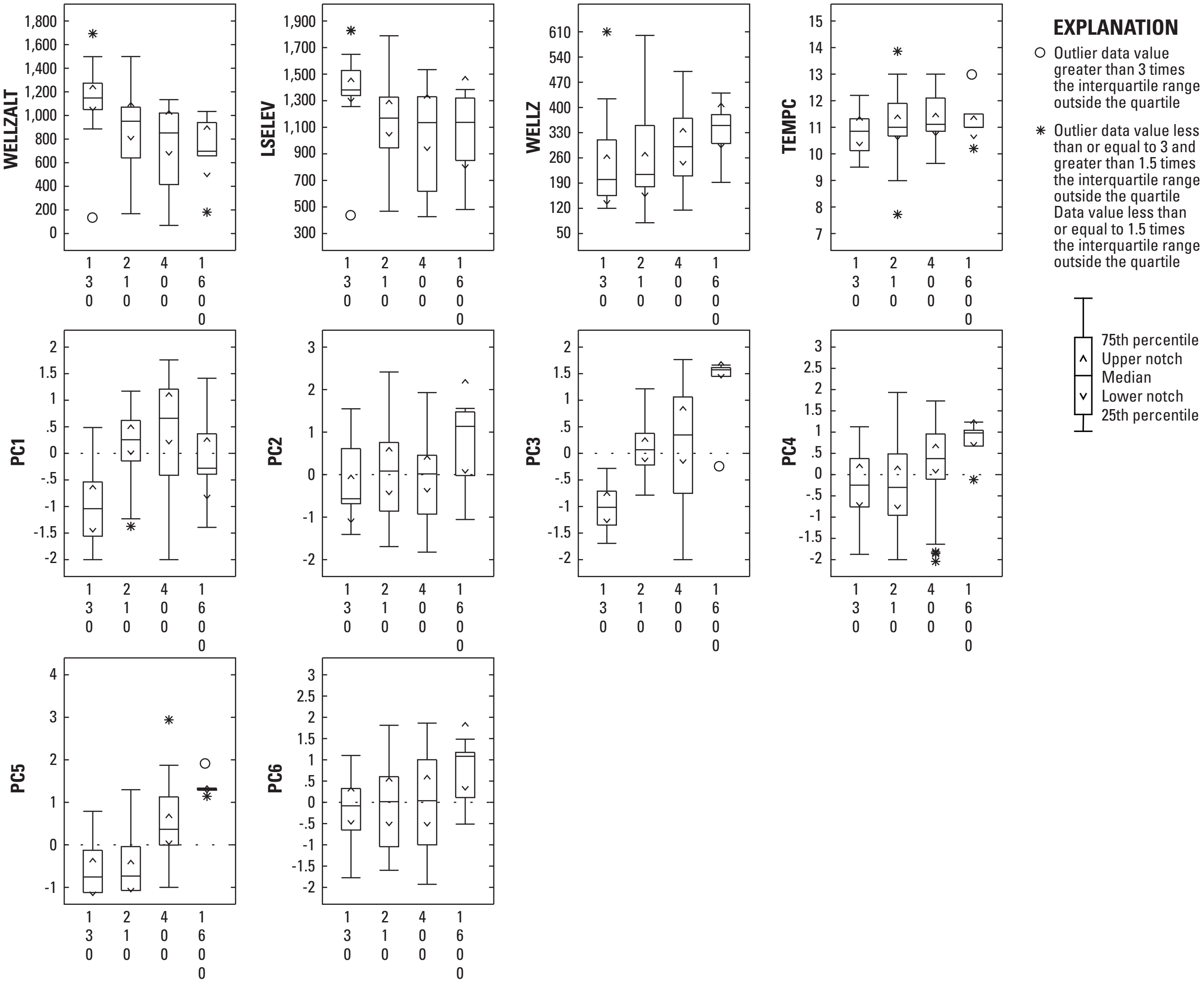
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; $CaCO_3$, calcium carbonate; SCL, laboratory specific conductance in microsiemens per centimeter at 25 degrees Celsius; TDS, Total dissolved solids in mg/L; Hard, hardness in mg/L as $CaCO_3$; Ca, calcium in mg/L; Mg, magnesium in mg/L; Na, sodium in mg/L; K, potassium in mg/L; ALK, alkalinity in mg/L as $CaCO_3$; SO_4, sulfate in mg/L; Cl, chloride in mg/L; Br, bromide in mg/L; F, fluoride in mg/L; B, boron in µg/L; Li, lithium in ug/L; Methane in mg/L.

Figure 3–2



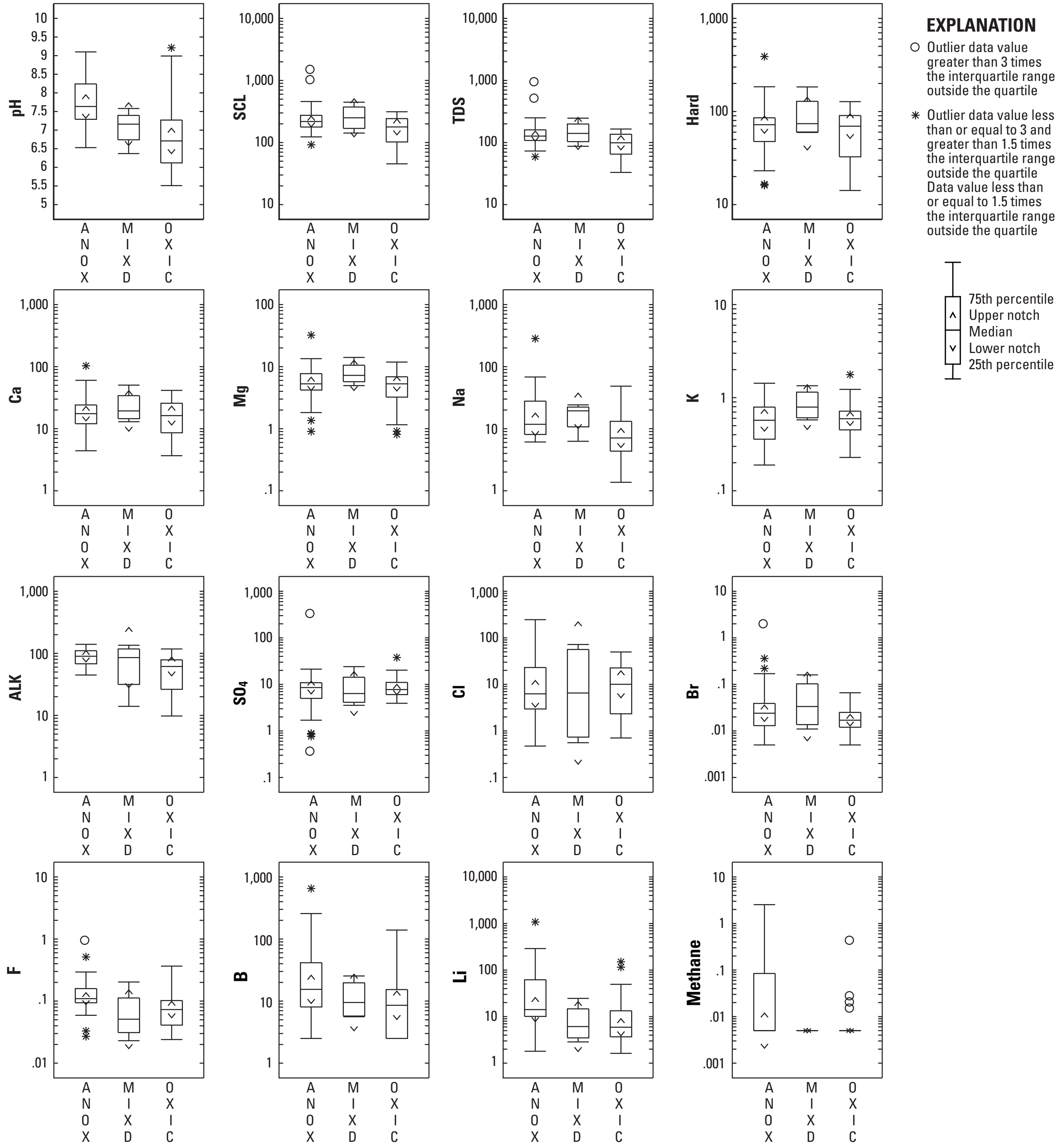
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; Ba, barium in ug/L; Sr, strontium in ug/L; SIO$_2$, silica in mg/L; Al, aluminum in ug/L; DOX, dissolved oxygen in mg/L; NO$_3$N, nitrate in mg/L as nitrogen; NH$_3$N, ammonia in mg/L as nitrogen; PO$_4$P, orthophosphate in mg/L as phosphorus; As, arsenic in ug/L; Se, selenium in ug/L; Mo, molybdenum in μg/L; Fe, iron in ug/L; Mn, manganese in ug/L; Zn, zinc in ug/L; U, uranium in ug/L; Rn222, radon-222 in pCi/L.

Figure 3–2—Continued



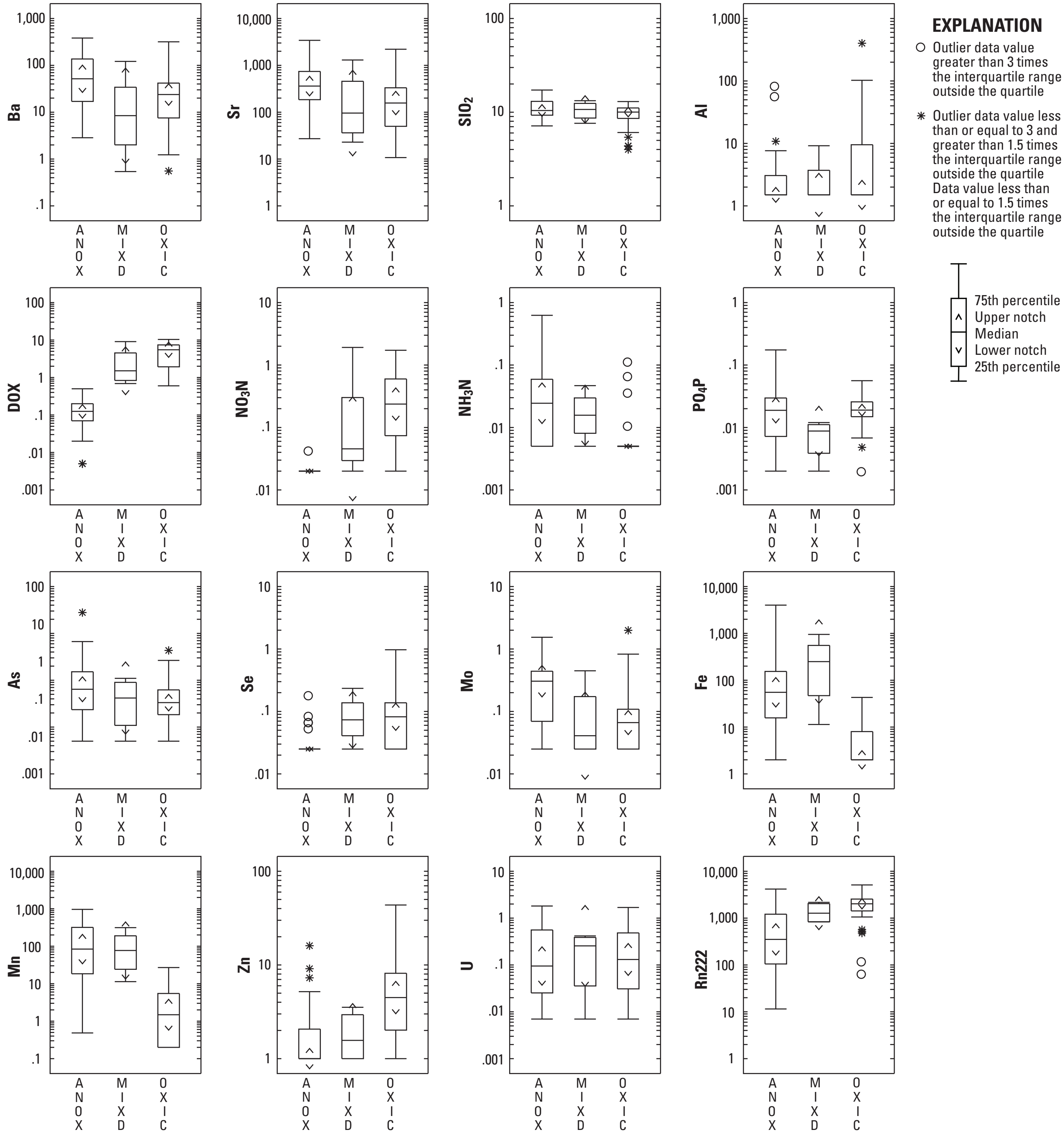
Abbreviations: ft, feet; SiO_2, silica in mg/L; WELLZALT, altitude of well bottom in ft above North American Vertical Datum, 1988 (NAVD 88); LSELEV, land-surface elevation in ft above NAVD 88; WELLZ, depth of well in ft below land surface; TEMPC, water temperature in degrees Celsius; PC, principal component.

Figure 3–2—Continued



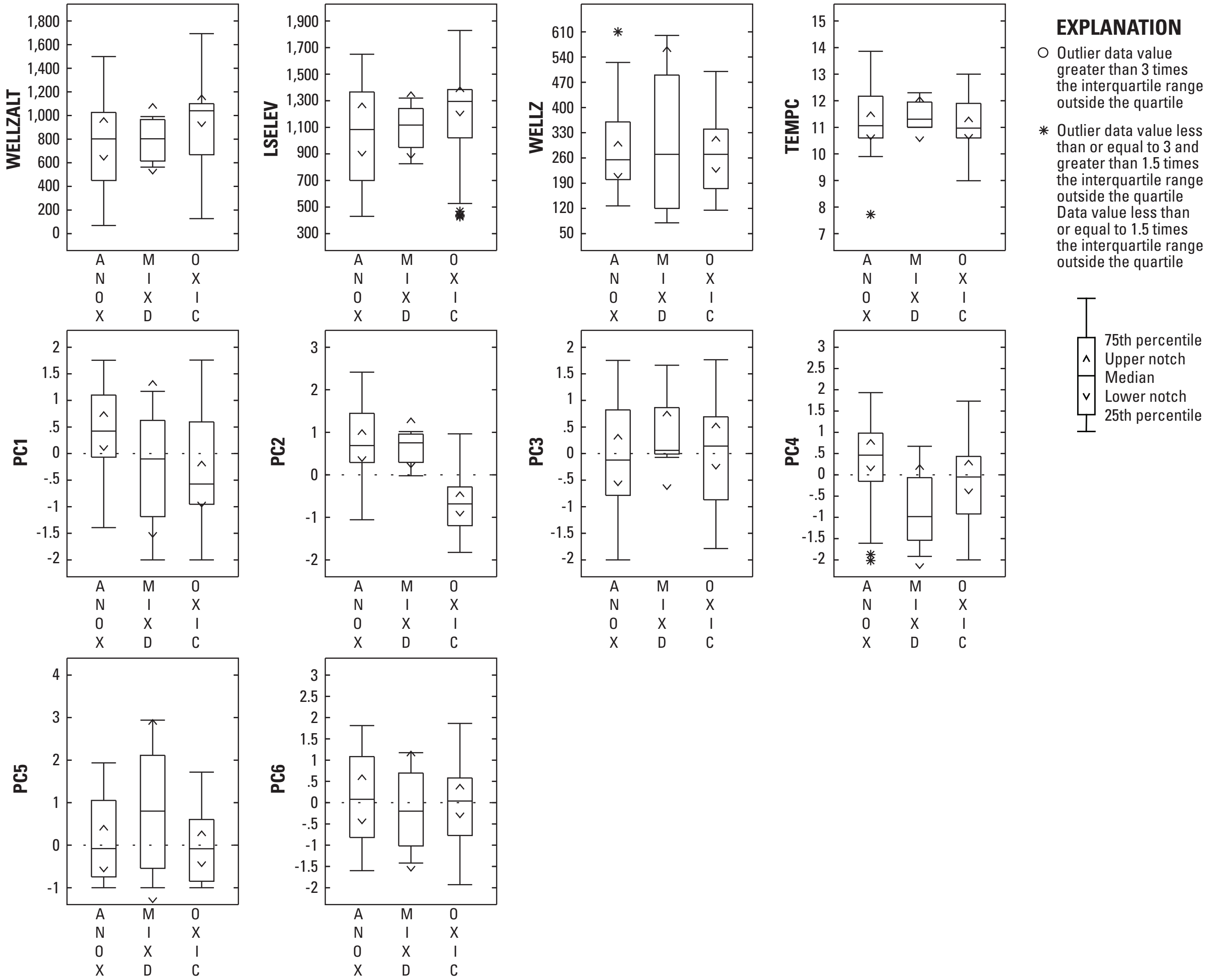
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; $CaCO_3$, calcium carbonate; SCL, laboratory specific conductance in microsiemens per centimeter at 25 degrees Celsius; TDS, Total dissolved solids in mg/L; Hard, hardness in mg/L as $CaCO_3$; Ca, calcium in mg/L; Mg, magnesium in mg/L; Na, sodium in mg/L; K, potassium in mg/L; ALK, alkalinity in mg/L as $CaCO_3$; SO_4, sulfate in mg/L; Cl, chloride in mg/L; Br, bromide in mg/L; F, fluoride in mg/L; B, boron in µg/L; Li, lithium in ug/L; Methane in mg/L.

Figure 3–3



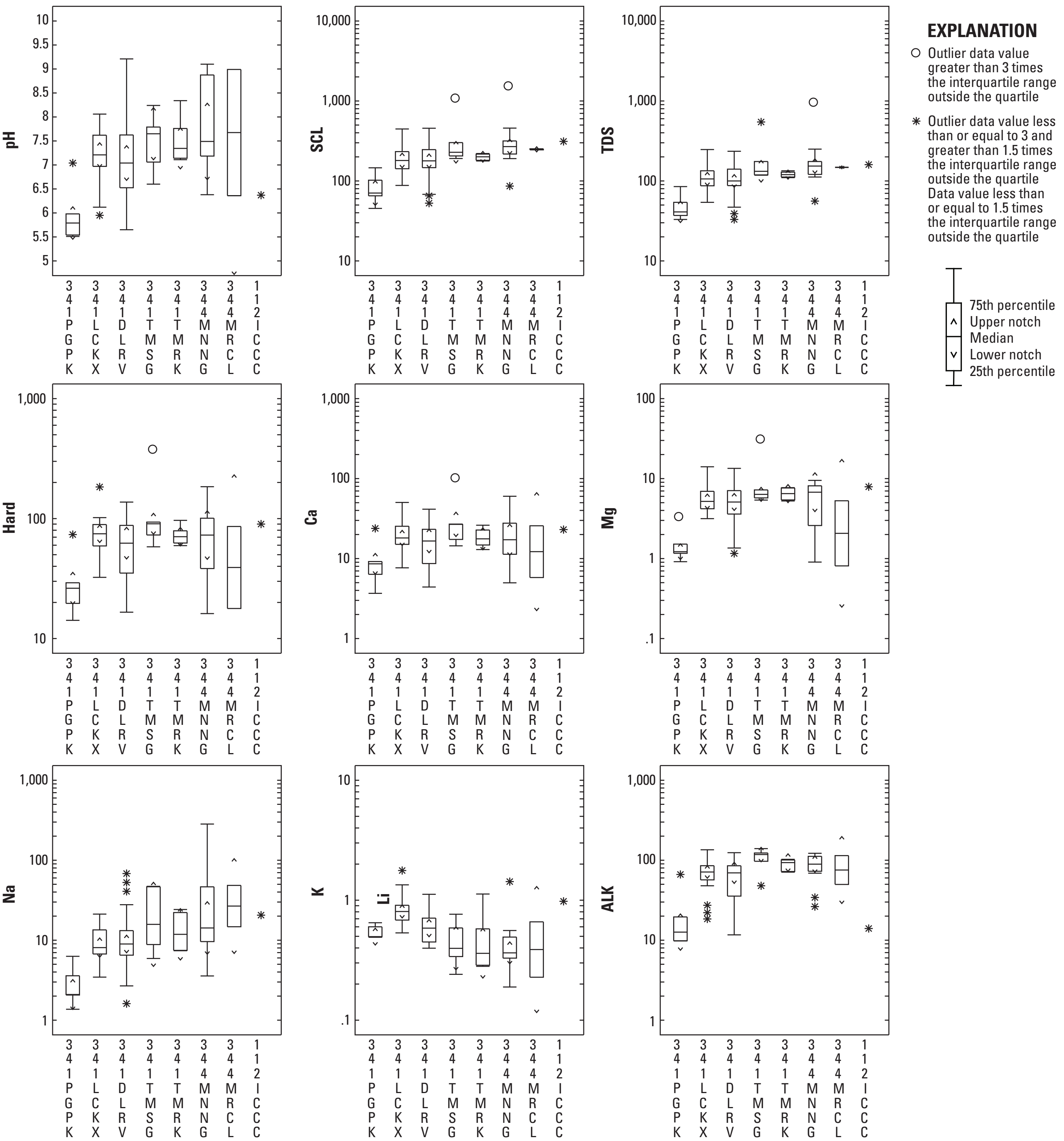
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; Ba, barium in ug/L; Sr, strontium in ug/L; SIO_2, silica in mg/L; Al, aluminum in ug/L; DOX, dissolved oxygen in mg/L; NO_3N, nitrate in mg/L as nitrogen; NH_3N, ammonia in mg/L as nitrogen; PO_4P, orthophosphate in mg/L as phosphorus; As, arsenic in ug/L; Se, selenium in ug/L; Mo, molybdenum in µg/L; Fe, iron in ug/L; Mn, manganese in ug/L; Zn, zinc in ug/L; U, uranium in ug/L; Rn222, radon-222 in pCi/L.

Figure 3–3—Continued



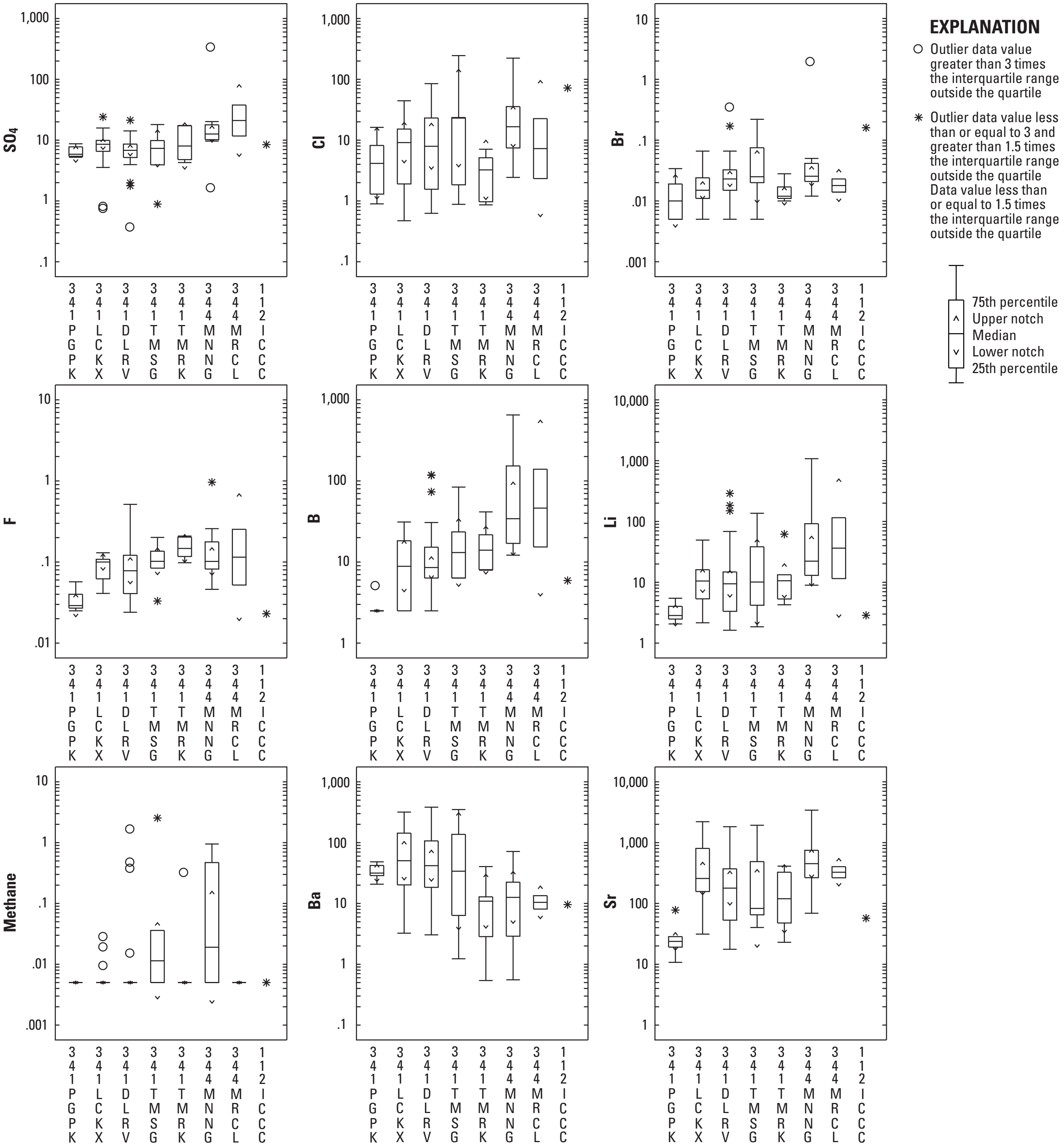
Abbreviations: ft, feet; WELLZALT, altitude of well bottom in ft above North American Vertical Datum, 1988 (NAVD 88); LSELEV, land-surface elevation in ft above NAVD 88; WELLZ, depth of well in ft below land surface; TEMPC, water temperature in degrees Celsius; PC, principal component.

Figure 3–3—Continued



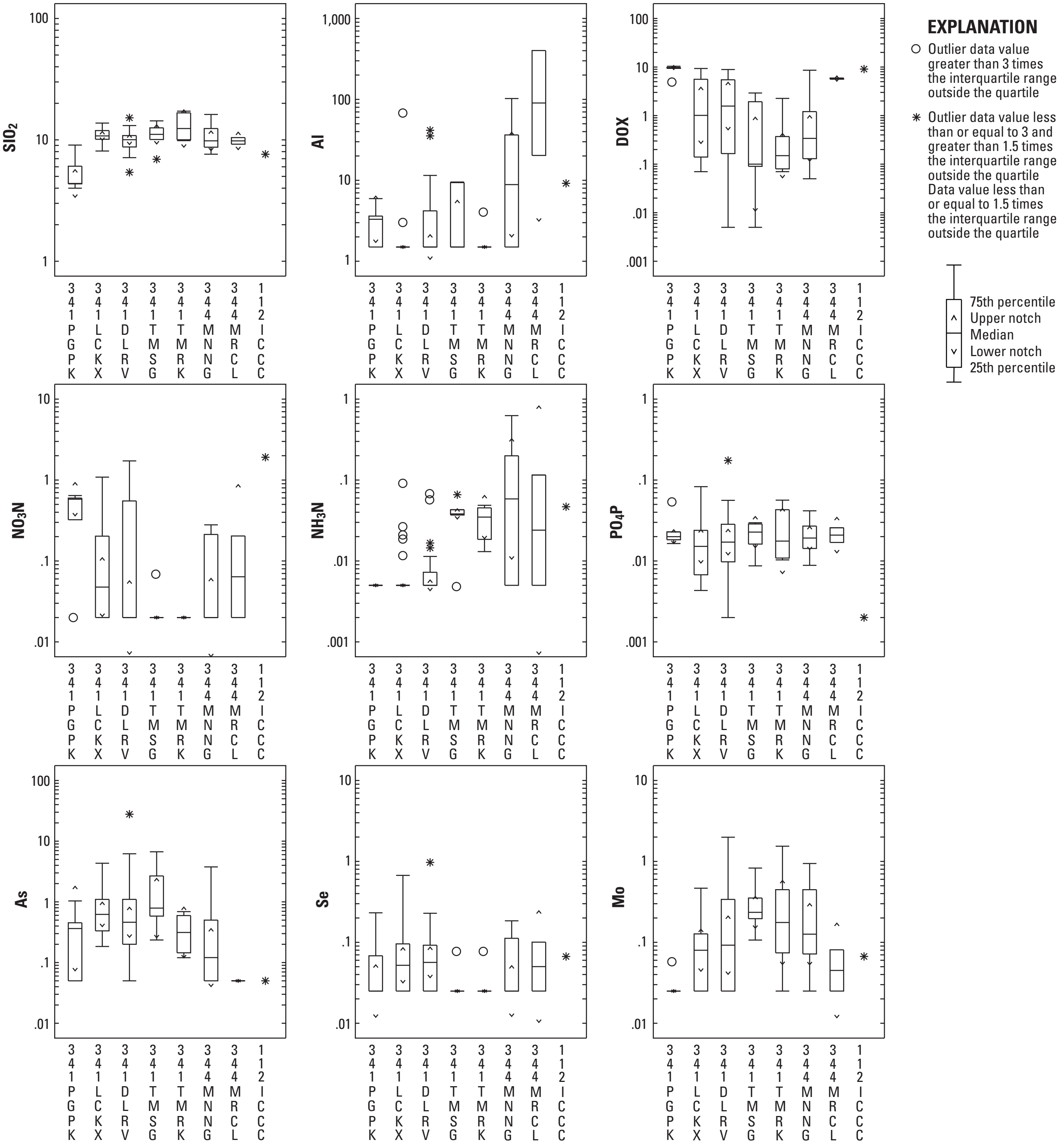
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; ft, feet; SCL, laboratory specific conductance in microsiemens per centimeter at 25 degrees Celsius; TDS, Total dissolved solids in mg/L; Hard, hardness in mg/L as $CaCO_3$; Ca, calcium in mg/L; Mg, magnesium in mg/L; Na, sodium in mg/L; K, potassium in mg/L; ALK, alkalinity in mg/L as $CaCO_3$. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahan- tango Formation; 344MRCL, Marcellus Shale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued



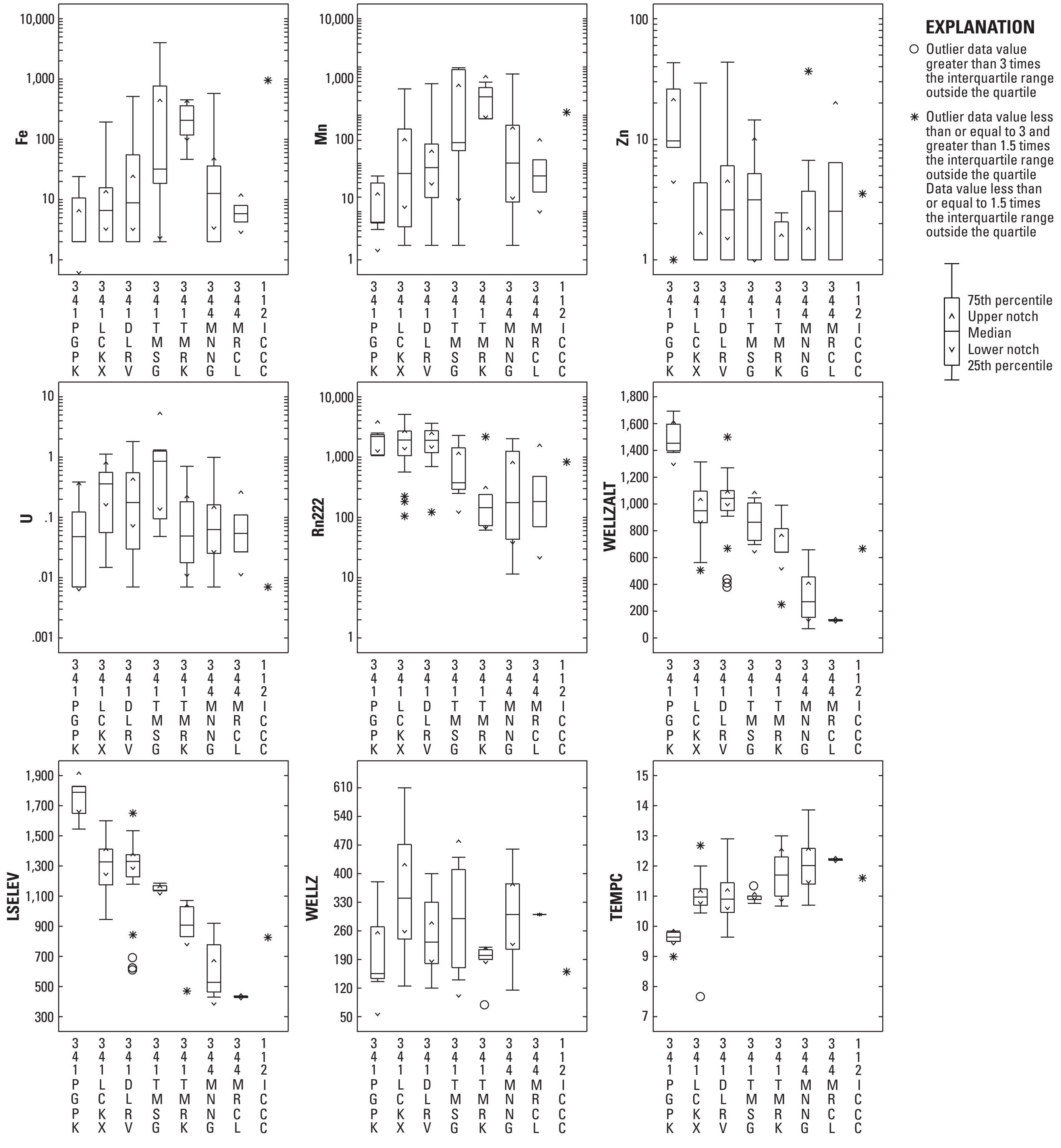
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; SO_4, sulfate in mg/L; Cl, chloride in mg/L; Br, bromide in mg/L; F, fluoride in mg/L; B, boron in µg/L; Li, lithium in ug/L; Methane in mg/L; Ba, barium in ug/L; Sr, strontium in ug/L. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued



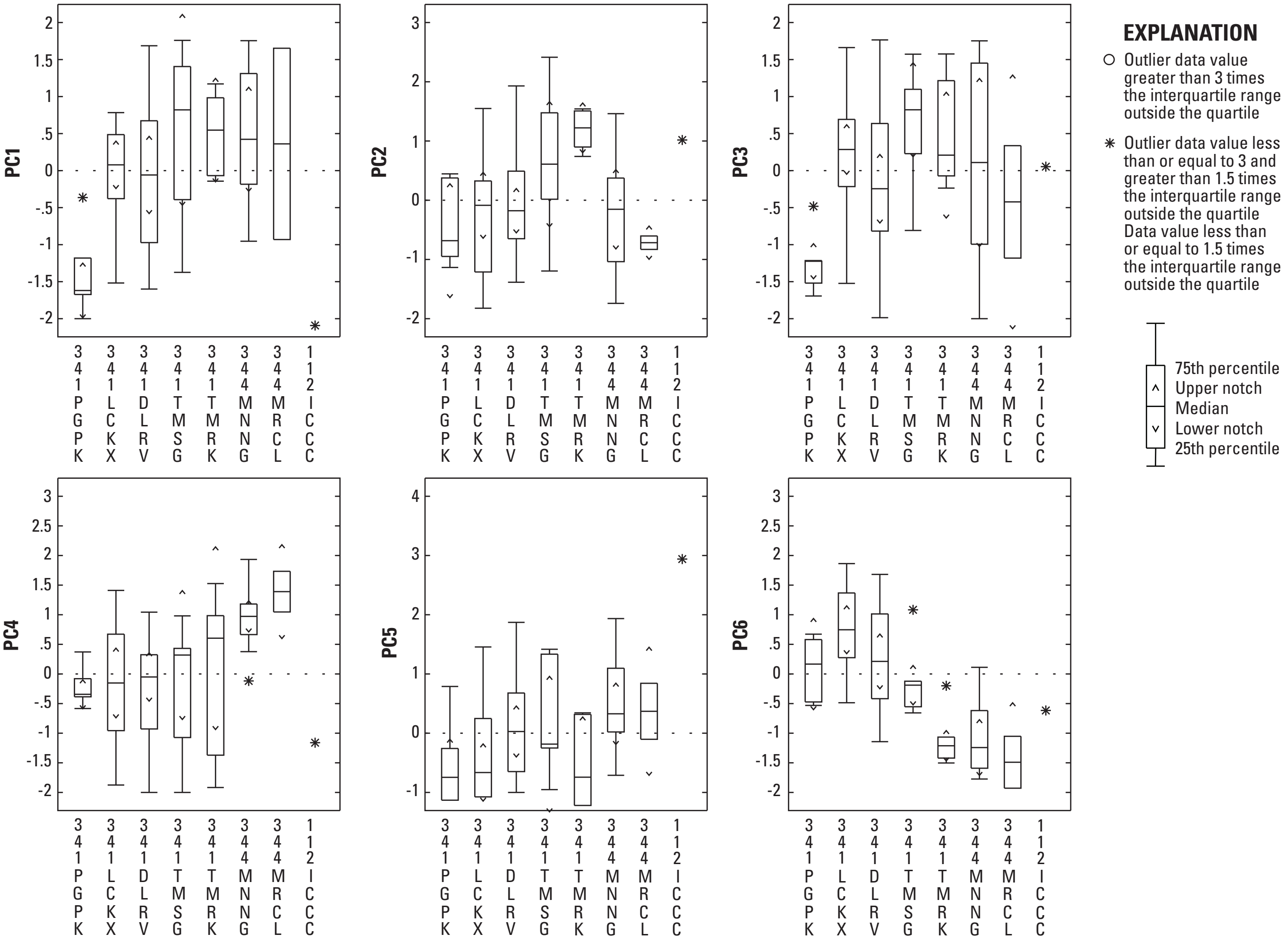
Abbreviations: mg/L, milligrams per liter; ug/L, micrograms per liter; SIO_2, silica in mg/L; Al, aluminum in ug/L; DOX, dissolved oxygen in mg/L; NO_3N, nitrate in mg/L as nitrogen; NH_3N, ammonia in mg/L as nitrogen; PO_4P, orthophosphate in mg/L as phosphorus; As, arsenic in ug/L; Se, selenium in ug/L; Mo, molybdenum in µg/L. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus ShaleShale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued



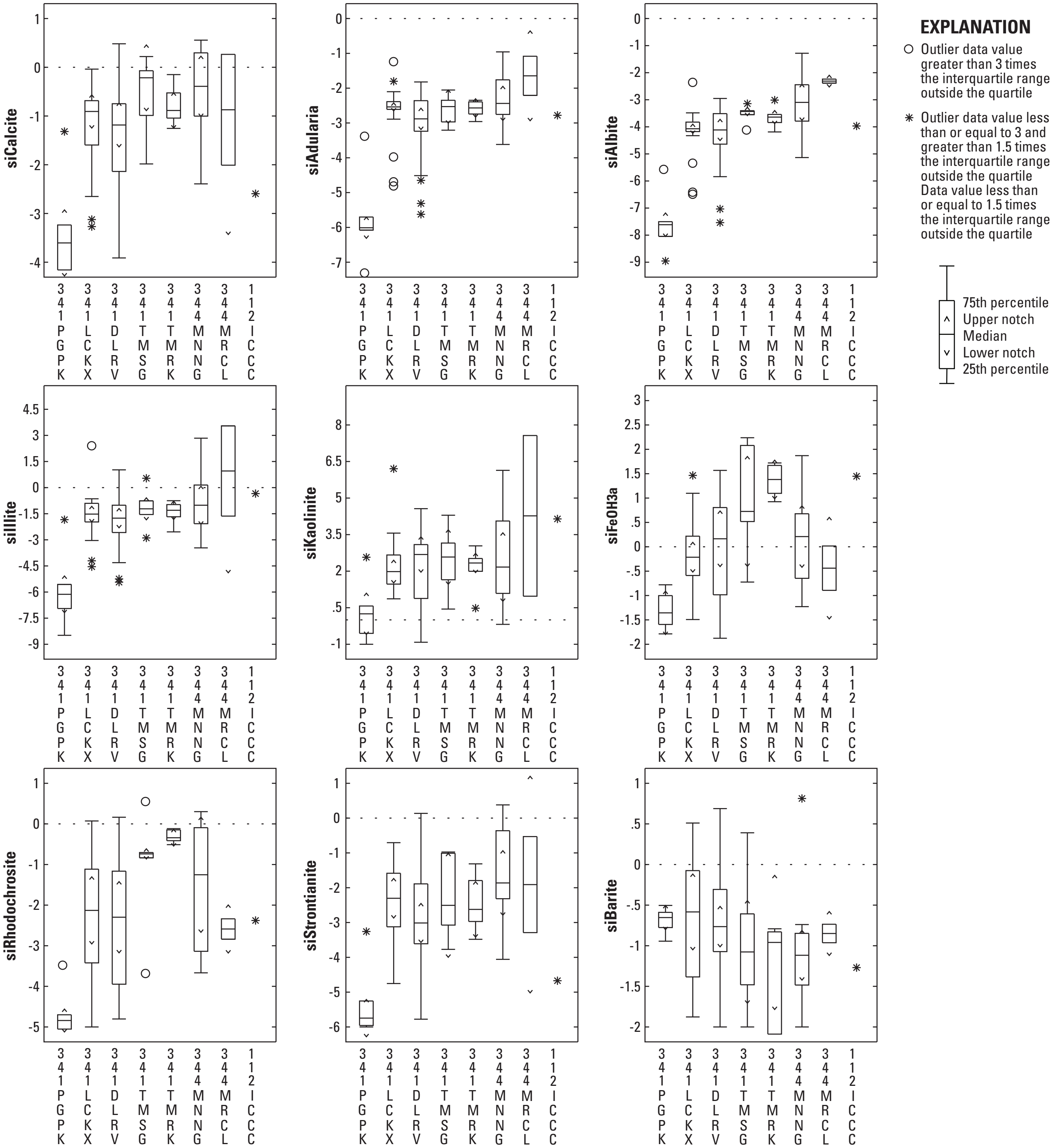
Abbreviations: ug/L, micrograms per liter; pCi/L, picocuries per liter; ft, feet; Fe, iron in ug/L; Mn, manganese in ug/L; Zn, zinc in ug/L; U, uranium in ug/L; Rn222, radon-222 in pCi/L; WELLZALT, altitude of well bottom in ft above North American Vertical Datum, 1988 (NAVD 88); LSELEV, land-surface elevation in ft above NAVD 88; WELLZ, depth of well in ft below land surface; TEMPC, water temperature in degrees Celsius. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued



Abbreviations: PC, principal component. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued



Abbreviations: Si, saturation index of mineral. Geologic unit codes: 341, PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341DLRV, Delaware River Member of the Catskill Formation; 341LCXX, Lackawaxen Member of the Catskill Formation; 341TMSG, Towamensing Member of the Catskill formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale; 112 ICCC, Ice-contact deposits.

Figure 3–3—Continued

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Geologic unit code	Dissolved oxygen, water, unfiltered, mg/L	pH, water, unfiltered, field, standard units	pH, water, unfiltered, lab, standard units	Specific conductance, water, unfiltered, lab, µS/cm at 25 °C	Specific conductance, water, unfiltered, µS/cm at 25 °C	Temperature, water, °C	Dissolved solids dried at 180 °C, water, filtered, mg/L	Seewald dissolved solids dried at 180 °C, water, filtered, mg/L	Dissolved solids, water, filtered, sum of constituents, mg/L	Seewald dissolved solids dried at 180 °C, water, filtered, mg/L	Dissolved solids, water, filtered, sum of constituents, mg/L
					00300	00400	00403	90095	00095	00010	70300	70300	70301	70300	70301
PI 620	1	7/16/2015	1000	341PGPK	9.4	5.5	E6.6	E65	71	9.5	52	43	E37	43	E37
PI 621	1	7/9/2015	1300	341PGPK	9.8	6	E6.8	E71	70	9.8	44	10	41	10	41
PI 634	2	8/4/2015	930	341LCKX	5.6	7.1	7.5	228	215	11.1	133	118	E135	118	E135
PI 641	2	9/22/2015	1030	341LCKX	0.1	8.1	8.1	233	217	11	136	155	136	155	136
PI 592	3	6/24/2015	1100	341DLRV	0.2	8.7	8.5	333	324	11.1	185	155	188	155	188
PI 592	3	6/24/2015	1101	341DLRV	--	--	8.6	329	--	--	185	164	185	164	185
PI 651	3	9/22/2015	1100	341DLRV	0.1	8.7	8.6	277	267	12.4	157	131	161	131	161
PI 608	4	7/15/2015	930	341DLRV	M	7.5	7.8	218	208	10.5	137	157	E121	157	E121
PI 638	4	8/5/2015	1600	341DLRV	0.1	6.5	7.3	456	440	10.2	272	253	237	253	237
PI 524	5	6/25/2015	1500	341TMSG	<0.01	8.2	8.4	302	287	11.4	162	82	176	82	176
PI 524	5	9/22/2015	1330	341TMSG	0.1	8.4	8.4	297	275	11.4	177	173	166	173	166
PI 524	5	9/22/2015	1331	341TMSG	--	--	8.3	293	--	--	176	179	166	179	166
PI 604	5	9/21/2015	1500	341TMSG	1.9	7.8	8.1	228	215	11	129	138	132	138	132
PI 622	6	7/14/2015	1600	344MNNG	0.1	8.7	8.4	273	267	12.2	161	183	164	183	164
PI 640	6	9/21/2015	1400	344MNNG	1.1	7.2	7.7	282	251	13	161	180	155	180	155
PI 648	7	9/24/2015	1300	344MRCL	5.9	9	8.9	245	229	12.2	153	120	149	120	149
PI 649	7	9/24/2015	1030	344MRCL	5.6	6.4	7.2	252	235	12.2	146	148	148	148	148

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Geologic unit code	Hardness, water, mg/L as $CaCO_3$	Suspended solids, dried at 105 °C, water, mg/L	Calcium, water, filtered, mg/L	Calcium, water, unfiltered, recoverable, mg/L	Magnesium, water, filtered, mg/L	Magnesium, water, unfiltered, recoverable, mg/L	Potassium, water, filtered, mg/L
					00900	70293	00915	00916	00925	00927	00935
PI 620	1	7/16/2015	1000	341PGPK	19.7	19	6.36	6.1	0.914	0.91	0.5
PI 621	1	7/9/2015	1300	341PGPK	26.3	7	8.6	8.38	1.16	1.18	0.5
PI 634	2	8/4/2015	930	341LCKX	89.8	<5	26.9	25.8	5.33	5.06	0.9
PI 641	2	9/22/2015	1030	341LCKX	82.1	<5	24.7	25.9	4.47	4.52	0.79
PI 592	3	6/24/2015	1100	341DLRV	17.2	<5	4.41	4.13	1.36	1.24	0.77
PI 592	3	6/24/2015	1101	341DLRV	16.5	<5	4.23	4.16	1.3	1.25	0.72
PI 651	3	9/22/2015	1100	341DLRV	23.4	5	6.26	6.56	1.82	1.83	0.59
PI 608	4	7/15/2015	930	341DLRV	86.1	<5	21.3	20.4	7.89	7.84	0.45
PI 638	4	8/5/2015	1600	341DLRV	140	<5	32.9	34.2	13.4	14.6	1.12
PI 524	5	6/25/2015	1500	341TMSG	58.9	<5	14.4	14.3	5.39	4.91	0.24
PI 524	5	9/22/2015	1330	341TMSG	55.6	<5	13.7	14.3	5.04	5.31	0.26
PI 524	5	9/22/2015	1331	341TMSG	57.1	<5	14	14.2	5.19	5.31	0.26
PI 604	5	9/21/2015	1500	341TMSG	90.5	161	26.8	26.8	5.74	5.62	0.76
PI 622	6	7/14/2015	1600	344MNNG	43.8	36	12	11.4	3.08	2.42	0.44
PI 640	6	9/21/2015	1400	344MNNG	103	5	27.9	28.8	7.97	8.43	0.34
PI 648	7	9/24/2015	1300	344MRCL	18.1	5	5.79	5.85	0.81	0.83	0.23
PI 649	7	9/24/2015	1030	344MRCL	86.4	<5	25.7	24.8	5.28	5.25	0.66

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Potassium, water, unfiltered, recoverable, mg/L	Sodium adsorption ratio (SAR), water, number	Sodium fraction of cations, water, % in equivalents of major cations	Sodium, water, filtered, mg/L	Sodium, water, unfiltered, recoverable, mg/L	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, lab, mg/L as $CaCO_3$	Bromide, water, filtered, µg/L	Bromide, water, filtered, mg/L	Bromide, water, unfiltered, mg/L
				00937	00931	00932	00930	00929	29801	91000	71870	63689
PI 620	1	7/16/2015	1000	0.5	0.35	28	3.59	3.49	9.8	<10	E0.011	<0.10
PI 621	1	7/9/2015	1300	0.78	0.18	14	2.09	1.9	19.5	<10	--	<0.10
PI 634	2	8/4/2015	930	0.95	0.62	24	13.5	13.4	83.4	24	E0.017	<0.10
PI 641	2	9/22/2015	1030	0.86	0.72	28	14.7	16.3	96.8	10	0.013	<0.10
PI 592	3	6/24/2015	1100	0.71	7.27	89	68.1	63.3	117	360	--	0.16
PI 592	3	6/24/2015	1101	0.71	7.13	89	65.4	63.2	117	350	--	0.16
PI 651	3	9/22/2015	1100	0.63	4.77	83	52.7	53.9	120	170	0.15	0.65
PI 608	4	7/15/2015	930	0.5	0.36	16	7.67	<7.19	44.8	24	E0.019	<0.10
PI 638	4	8/5/2015	1600	1.17	1.03	30	27.8	28	65.3	26	0.023	<0.10
PI 524	5	6/25/2015	1500	<0.50	2.66	63	46.6	45.2	123	220	--	<0.10
PI 524	5	9/22/2015	1330	<0.50	2.35	61	40	43.1	121	170	0.166	<0.10
PI 524	5	9/22/2015	1331	<0.50	2.37	61	40.8	45.2	120	--	0.16	<0.10
PI 604	5	9/21/2015	1500	0.82	0.72	27	15.8	16.5	118	<10	<0.010	<0.10
PI 622	6	7/14/2015	1600	<0.50	3.13	70	47	44.6	114	50	0.042	<0.10
PI 640	6	9/21/2015	1400	<0.50	0.57	22	13.3	14.7	83	23	0.017	<0.10
PI 648	7	9/24/2015	1300	<0.50	5	85	48.4	51.8	114	23	0.02	<0.10
PI 649	7	9/24/2015	1030	0.86	0.69	27	14.7	15.2	49.8	14	0.013	<0.10

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Chloride, water, filtered, mg/L	Chloride, water, unfiltered, mg/L	Fluoride, water, filtered, mg/L	Hydrogen ion, water, unfiltered, calculated, mg/L	Silica, water, filtered, mg/L as SiO_2	Sulfate, water, filtered, mg/L	Sulfate, water, unfiltered, mg/L	Ammonia, water, filtered, mg/L as nitrogen
				00940	99220	00950	00191	00955	00945	00946	00608
PI 620	1	7/16/2015	1000	8.17	8.2	0.03	0.00311	4	5.22	5.3	<0.01
PI 621	1	7/9/2015	1300	4.15	4.2	0.03	0.00106	4.37	5.43	5.5	<0.01
PI 634	2	8/4/2015	930	13	14	0.13	0.00007	13	11	11.7	<0.01
PI 641	2	9/22/2015	1030	9.11	10	0.13	0.00001	12.1	9.43	10.4	0.03
PI 592	3	6/24/2015	1100	33	33	0.51	M	7.14	0.39	<1.0	0.06
PI 592	3	6/24/2015	1101	33	33	0.51	--	7.08	0.39	<1.0	0.06
PI 651	3	9/22/2015	1100	15.3	17	0.29	M	9.67	1.99	2.1	0.01
PI 608	4	7/15/2015	930	33.5	34	0.08	0.00003	15.2	7.5	8.2	0.01
PI 638	4	8/5/2015	1600	84.9	91	0.03	0.0003	13.1	21.3	23.2	0.02
PI 524	5	6/25/2015	1500	23.5	24	0.2	0.00001	10.1	0.89	<1.0	0.07
PI 524	5	9/22/2015	1330	22	23	0.21	M	9.66	1.11	<1.0	0.06
PI 524	5	9/22/2015	1331	21.6	24	0.2	--	9.61	1.15	<1.0	0.06
PI 604	5	9/21/2015	1500	0.88	<1.0	0.14	0.00002	6.92	3.93	4.3	0.04
PI 622	6	7/14/2015	1600	12.5	16	0.14	M	9.24	9.63	14.3	0.23
PI 640	6	9/21/2015	1400	25.9	28	0.08	0.00007	11.1	16.7	17.6	0.01
PI 648	7	9/24/2015	1300	2.33	2.5	0.25	M	10.4	11.7	12.7	0.12
PI 649	7	9/24/2015	1030	22.6	24	0.05	0.00044	9.21	37.8	38	<0.01

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Nitrate plus nitrite, water, filtered, mg/L as nitrogen	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Orthophosphate, water, filtered, mg/L as phosphorus	Escherichia coli, water, MPN per 100 milliliters	Total coliforms, water, MPN per 100 milliliters	Aluminum, water, filtered, µg/L	Aluminum, water, unfiltered, recoverable, µg/L
				00631	00618	00613	00671	31689	31686	01106	01105
PI 620	1	7/16/2015	1000	0.58	0.577	0.002	0.018	<1	<1	3.6	M
PI 621	1	7/9/2015	1300	0.598	0.598	<0.001	0.023	<1	28	<3.0	600
PI 634	2	8/4/2015	930	0.145	0.145	<0.001	0.019	<1	<1	<3.0	<20
PI 641	2	9/22/2015	1030	<0.040	<0.040	<0.001	0.007	<1	>1	<3.0	M
PI 592	3	6/24/2015	1100	<0.040	<0.040	<0.001	0.174	<1	19	<3.0	M
PI 592	3	6/24/2015	1101	<0.040	<0.040	<0.001	0.178	<1	<1	3.5	M
PI 651	3	9/22/2015	1100	<0.040	<0.040	<0.001	0.037	<1	<1	5.8	M
PI 608	4	7/15/2015	930	<0.040	<0.040	<0.001	0.007	<1	<1	<3.0	M
PI 638	4	8/5/2015	1600	<0.040	<0.040	<0.001	0.004	<1	9	3.2	M
PI 524	5	6/25/2015	1500	<0.040	<0.040	<0.001	0.029	<1	<1	<3.0	M
PI 524	5	9/22/2015	1330	<0.040	<0.040	<0.001	0.027	<1	<1	<3.0	M
PI 524	5	9/22/2015	1331	<0.040	<0.040	<0.001	0.027	<1	<1	<3.0	M
PI 604	5	9/21/2015	1500	<0.040	<0.040	<0.001	0.023	<1	<1	9.5	200
PI 622	6	7/14/2015	1600	<0.040	<0.040	<0.001	0.017	<1	3	7.6	M
PI 640	6	9/21/2015	1400	0.235	0.235	<0.001	0.015	<1	43	10.5	100
PI 648	7	9/24/2015	1300	<0.040	<0.040	<0.001	0.017	--	9	20.3	M
PI 649	7	9/24/2015	1030	0.204	0.204	<0.001	0.026	--	10	402	300

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Barium, water, filtered, µg/L	Barium, water, unfiltered, recoverable, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L	Copper, water, filtered, µg/L	Iron, water, filtered, µg/L	Iron, water, unfiltered, recoverable, µg/L
				01005	01007	01010	01025	01030	01035	01040	01046	01045
PI 620	1	7/16/2015	1000	31.6	37	0.025	<0.030	<0.30	0.107	61.8	24.1	4,890
PI 621	1	7/9/2015	1300	42.1	48.6	<0.020	<0.030	<0.30	<0.050	3.2	<4.0	481
PI 634	2	8/4/2015	930	58.2	62.1	<0.020	<0.030	<0.30	<0.050	1.2	<4.0	<10
PI 641	2	9/22/2015	1030	243	237	<0.020	<0.030	<0.30	0.087	<0.80	4.2	32
PI 592	3	6/24/2015	1100	298	292	<0.020	<0.030	<0.30	<0.050	<0.80	72.1	80
PI 592	3	6/24/2015	1101	294	291	<0.020	<0.030	<0.30	<0.050	<0.80	69.7	81
PI 651	3	9/22/2015	1100	124	116	<0.020	<0.030	<0.30	<0.050	<0.80	10.6	32
PI 608	4	7/15/2015	930	200	190	<0.020	<0.030	<0.30	0.1	<0.80	58.3	88
PI 638	4	8/5/2015	1600	383	398	<0.020	<0.030	<0.30	0.265	1.1	514	1,010
PI 524	5	6/25/2015	1500	137	130	<0.020	<0.030	<0.30	<0.050	<0.80	18.6	59
PI 524	5	9/22/2015	1330	130	125	<0.020	<0.030	<0.30	0.09	<0.80	22.4	51
PI 524	5	9/22/2015	1331	132	126	<0.020	<0.030	<0.30	<0.050	<0.80	20.9	37
PI 604	5	9/21/2015	1500	1.23	18.8	<0.020	<0.030	<0.30	0.174	<0.80	32.1	23,000
PI 622	6	7/14/2015	1600	22.2	22.5	<0.020	<0.030	<0.30	0.101	<0.80	16.2	134
PI 640	6	9/21/2015	1400	9.45	11.9	<0.020	<0.030	<0.30	0.078	<0.80	9.9	361
PI 648	7	9/24/2015	1300	13.4	15	<0.020	<0.030	<0.30	0.276	1.5	8	114
PI 649	7	9/24/2015	1030	8.08	13.4	<0.020	0.139	<0.30	0.15	6.1	4.3	1,040

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

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Local identifier	Pair number	Date	Sample start time	Lead, water, filtered, µg/L	Lithium, water, filtered, µg/L	Lithium, water, unfiltered, recoverable, µg/L	Manganese, water, filtered, µg/L	Manganese, water, unfiltered, recoverable, µg/L	Molybdenum, water, filtered, µg/L	Nickel, water, filtered, µg/L	Strontium, water, filtered, µg/L	Strontium, water, unfiltered, recoverable, µg/L
				01049	01130	01132	01056	01055	01060	01065	01080	01082
PI 620	1	7/16/2015	1000	1.38	2.06	<10	5.48	16.8	<0.050	0.78	10.8	11
PI 621	1	7/9/2015	1300	0.096	4.02	<10	0.43	12	<0.050	<0.20	23.8	25
PI 634	2	8/4/2015	930	0.156	42	50	0.82	<10.0	0.127	<0.20	448	459
PI 641	2	9/22/2015	1030	0.06	47.9	50	122	131	0.065	<0.20	1,550	1,590
PI 592	3	6/24/2015	1100	0.377	289	270	83.7	80.9	0.606	<0.20	331	325
PI 592	3	6/24/2015	1101	0.35	282	270	83	80.4	0.623	<0.20	331	327
PI 651	3	9/22/2015	1100	<0.040	184	210	25.2	23.2	0.371	<0.20	185	194
PI 608	4	7/15/2015	930	0.165	10.3	10	318	331	<0.050	<0.20	334	339
PI 638	4	8/5/2015	1600	0.322	68.5	80	450	436	<0.050	0.23	1,830	1,900
PI 524	5	6/25/2015	1500	<0.040	136	140	18.4	18.4	0.353	<0.20	488	490
PI 524	5	9/22/2015	1330	<0.040	118	130	20.3	18.9	0.367	<0.20	472	485
PI 524	5	9/22/2015	1331	<0.040	122	140	19.9	18.2	0.371	<0.20	475	500
PI 604	5	9/21/2015	1500	<0.040	1.85	<10	27	1,850	0.827	0.4	40.2	46
PI 622	6	7/14/2015	1600	0.054	106	110	18.6	19.2	0.156	<0.20	947	958
PI 640	6	9/21/2015	1400	0.088	26.6	30	11.7	22	0.101	<0.20	682	706
PI 648	7	9/24/2015	1300	0.117	115	120	2.55	3.2	0.081	0.23	264	260
PI 649	7	9/24/2015	1030	0.076	11.5	10	11.9	193	<0.050	1.4	402	369

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Zinc, water, filtered, µg/L	Zinc, water, unfiltered, recoverable, µg/L	Antimony, water, filtered, µg/L	Arsenic, water, filtered, µg/L	Arsenic, water, unfiltered, µg/L	Boron, water, filtered, µg/L	Selenium, water, filtered, µg/L	Selenium, water, unfiltered, µg/L
				01090	01092	01095	01000	01002	01020	01145	01147
PI 620	1	7/16/2015	1000	9.7	10	0.038	<0.10	3	<5	<0.05	<2
PI 621	1	7/9/2015	1300	8.6	10	<0.027	1	2	<5	<0.05	<2
PI 634	2	8/4/2015	930	3.4	<5	0.057	0.71	<0.5	23	0.1	<2
PI 641	2	9/22/2015	1030	2.2	420	0.028	1.1	1	22	<0.05	<2
PI 592	3	6/24/2015	1100	<2.0	20	<0.027	27.8	31	117	<0.05	<2
PI 592	3	6/24/2015	1101	<2.0	20	<0.027	27.8	32	118	<0.05	<2
PI 651	3	9/22/2015	1100	<2.0	M	<0.027	6.2	6	73	<0.05	<2
PI 608	4	7/15/2015	930	<2.0	M	0.053	1.1	1	5	<0.05	<2
PI 638	4	8/5/2015	1600	2.3	M	0.04	1	2	31	<0.05	<2
PI 524	5	6/25/2015	1500	<2.0	<0.5	<0.027	0.24	<0.5	84	<0.05	<2
PI 524	5	9/22/2015	1330	<2.0	<0.5	<0.027	0.23	<0.5	79	<0.05	<2
PI 524	5	9/22/2015	1331	<2.0	<0.5	<0.027	0.23	<0.5	79	<0.05	<2
PI 604	5	9/21/2015	1500	<2.0	M	0.087	0.58	1	13	<0.05	<2
PI 622	6	7/14/2015	1600	<2.0	M	0.033	<0.10	<0.5	156	<0.05	4
PI 640	6	9/21/2015	1400	36.7	70	<0.027	0.13	<0.5	41	<0.05	<2
PI 648	7	9/24/2015	1300	<2.0	<0.5	0.05	<0.10	<0.5	139	<0.05	<2
PI 649	7	9/24/2015	1030	6.4	20	<0.027	<0.10	M	15	0.1	<2

Table A4–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, radioactivity, radon-222, and dissolved gases in groundwater samples collected from 7 pairs of two closely-spaced wells in Pike County, Pennsylvania, 2015.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; shading indicates well pairs; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; lab, laboratory; %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; MPN, most probable number; pCi/L, picocuries per liter; Geologic units: 341DLRV, Delaware River Formation; 341LCKX, Lackawaxen Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, Undivided; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 344MNNG, Mahantango Formation; 344MRCL, Marcellus Shale]

Local identifier	Pair number	Date	Sample start time	Ethane, water, dissolved, recoverable, mg/L	Methane, water, dissolved, recoverable, mg/L	Organic carbon, water, unfiltered, mg/L	Propane, water, dissolved, recoverable, mg/L	Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve, pCi/L	Gross alpha radioactivity, 72 hour count, water, unfiltered, Th-230 curve, pCi/L	Gross beta radioactivity, 30 day recount, water, unfiltered, Cs-137 curve, pCi/L	Gross beta radioactivity, 72 hour count, water, unfiltered, Cs-137 curve, pCi/L	Radium-226, water, unfiltered, pCi/L	Radon-222, water, unfiltered, pCi/L	Uranium (natural), water, filtered, µg/L
				68832	68831	00680	68834	63016	63014	63017	63015	09501	82303	22703
PI 620	1	7/16/2015	1000	<0.010	<0.010	<0.7	<0.020	R0.4	1.2	4.2	2.9	--	1,060	<0.014
PI 621	1	7/9/2015	1300	<0.010	<0.010	<0.7	<0.020	1.1	R0.8	2.3	2.3	--	2,360	0.123
PI 634	2	8/4/2015	930	<0.010	0.021	<0.7	<0.020	R-0.3	5.5	1.6	4.9	--	1,730	0.198
PI 641	2	9/22/2015	1030	<0.010	0.03	<0.7	<0.020	1.7	2.1	2.7	3.4	0.45	105	0.136
PI 592	3	6/24/2015	1100	<0.100	1.79	<0.7	<0.100	0.9	R0.9	1.6	2.3	--	1,210	0.015
PI 592	3	6/24/2015	1101	<0.050	1.48	<0.7	<0.100	R0.4	1.4	3.1	R0.7	--	1,240	<0.014
PI 651	3	9/22/2015	1100	<0.010	0.382	<0.7	<0.020	R-0.1	2.5	1.9	4.1	--	1,030	0.187
PI 608	4	7/15/2015	930	<0.010	<0.010	<0.7	<0.020	R0.9	R1.1	4.1	2.9	--	1,060	0.029
PI 638	4	8/5/2015	1600	<0.010	<0.010	<0.7	<0.020	1.2	R0.5	1.9	3.7	--	1,160	0.038
PI 524	5	6/25/2015	1500	<0.100	2.54	<0.7	<0.200	1.4	R1.0	1.5	R1.2	--	380	0.095
PI 524	5	9/22/2015	1330	<0.010	4.12	<0.7	<0.020	3.4	4.7	R1.5	2.7	0.3	450	0.157
PI 524	5	9/22/2015	1331	<0.010	3.28	<0.7	<0.020	1.9	1.3	R1.6	R1.3	0.3	470	0.147
PI 604	5	9/21/2015	1500	<0.010	<0.010	<0.7	<0.020	5.3	10.6	6.9	9.8	0.09	1,420	1.26
PI 622	6	7/14/2015	1600	<0.010	0.936	<0.7	<0.020	R0.8	R0.4	1.9	R0.7	--	34	0.049
PI 640	6	9/21/2015	1400	<0.010	0.031	<0.7	<0.020	R0.3	1.3	1.5	R0.4	--	1,310	0.188
PI 648	7	9/24/2015	1300	<0.010	<0.010	<0.7	<0.020	R-0.5	1.2	R0.1	R0.3	--	70	0.027
PI 649	7	9/24/2015	1030	<0.010	<0.010	<0.7	<0.020	R0.5	1.4	2.2	2.4	--	480	0.11

Table A5–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for groundwater samples collected from 79 wells in 2015 and from 18 of the 79 wells sampled at least once previously by USGS during 1982–2013 in Pike County, Pennsylvania.

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; 2015 methane analyses by Isotech in bold, with time offset of 5 minutes; mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; lab, laboratory; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; VPDB, PeeDee belemnite; VSMOW, Vienna Standard Mean Ocean Water]

Local identifier	Date	Sample time	Barometric pressure, in mm Hg	Temperature, air, °C	Depth to water level, feet below land surface	Dissolved oxygen, water, unfiltered, mg/L	pH, water, unfiltered, field, standard units	pH, water, unfiltered, lab, standard units	Specific conductance, water, unfiltered, lab, µS/cm at 25 °C	Specific conductance, water, unfiltered, µS/cm at 25 °C	Temperature, water, °C
			00025	00020	72019	00300	00400	00403	90095	00095	00010
PI 288	6/2/1982	1615	--	--	--	--	5.7	6.2	66	72	10
PI 288	9/6/2007	1200	747	25.5	49.25	10.8	6	7.8	72	70	9.2
PI 288	7/18/2012	1200	732	--	54.9	9.2	5.8	E6.1	E69	64	9.9
PI 288	6/23/2015	930	736	22.5	--	10.4	5.8	6.5	102	102	9.8
PI 403	8/2/2012	1000	740	--	24.74	2.9	7.6	7.9	405	383	12
PI 403	6/25/2015	1400	755	--	--	0.2	7.5	7.9	458	458	13
PI 507	7/25/2012	1230	740	24.5	--	5.4	6.4	6.8	219	212	10.4
PI 507	9/12/2012	930	752	13	--	5.5	6.4	6.9	215	228	10.2
PI 507	10/16/2012	1000	733	7	--	5.8	6.7	6.9	216	207	10.2
PI 507	11/15/2012	1100	750	3	--	6	6.8	6.7	214	209	10.1
PI 507	12/12/2012	900	749	-1	--	6	6.8	6.8	216	203	10
PI 507	1/8/2013	1100	749	2	--	5.9	6.4	6.7	214	203	10
PI 507	2/13/2013	930	737	-4	--	5.3	6.9	6.8	210	177	10.6
PI 507	3/13/2013	1130	737	4	--	5.2	6.9	6.8	210	177	10.6
PI 507	4/3/2013	1000	749	-1	--	7.9	6.6	6.8	213	191	10.2
PI 507	5/8/2013	1130	743	16	--	7.8	6.1	7	218	226	10.3
PI 507	6/5/2013	1030	746	22	--	8.2	6.4	6.9	213	221	10.2
PI 507	6/27/2013	1130	738	24	--	6	6.3	6.9	218	208	10.4
PI 507	6/23/2015	1100	--	--	--	5.5	6.6	7	296	276	10.4
PI 524	10/1/2007	1400	750	15	56.82	0.1	8.3	8.3	303	299	11.1
PI 524	1/21/2012	1131	756	-2	--	M	8.2	--	--	300	10.7
PI 524	7/26/2012	900	743	21	--	M	8.3	8.3	298	296	11.4
PI 524	7/26/2012	901	743	21	--	M	8.3	8.3	302	296	11.4
PI 524	9/11/2012	1000	755	9	--	0.1	8.2	8.3	297	308	11.4
PI 524	10/16/2012	1330	744	12	--	M	8.5	8.3	287	299	11.1
PI 524	11/14/2012	1130	761	5	--	0.1	8.7	8.3	293	295	10.9
PI 524	12/12/2012	1130	756	-2	55.22	M	8.2	8.3	299	300	10.7
PI 524	12/12/2012	1131	756	-2	--	M	8.2	8.3	296	300	10.7
PI 524	1/8/2013	1300	754	1	56.07	0.2	8.3	8.3	289	285	10.5
PI 524	2/13/2013	1200	741	2	56.2	0.7	8.3	8.4	289	245	10.5
PI 524	3/13/2013	1300	--	3	--	0.8	8.2	8.3	289	243	10.6
PI 524	4/3/2013	1500	750	0	55.59	M	8.3	8.3	300	280	10.6
PI 524	5/8/2013	1400	748	15	55.16	0.2	8	8.3	290	264	10.8
PI 524	6/5/2013	1330	753	22	42.32	0.1	8.1	8.4	283	294	11.4
PI 524	6/26/2013	1230	746	24	42.19	0.1	8.3	8.3	302	290	11.5
PI 524	6/25/2015	1500	756	--	--	<0.01	8.2	8.4	302	287	11.4
PI 524	9/22/2015	1330	--	--	--	0.1	8.4	8.4	297	275	11.4
PI 524	9/22/2015	1331	--	--	--	--	--	8.3	293	--	--

Table A5–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for groundwater samples collected from 79 wells in 2015 and from 18 of the 79 wells sampled at least once previously by USGS during 1982–2013 in Pike County, Pennsylvania.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; 2015 methane analyses by Isotech in bold, with time offset of 5 minutes; mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; lab, laboratory; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; VPDB, PeeDee belemnite; VSMOW, Vienna Standard Mean Ocean Water]

Local identifier	Date	Sample time	Barometric pressure, in mm Hg	Temperature, air, °C	Depth to water level, feet below land surface	Dissolved oxygen, water, unfiltered, mg/L	pH, water, unfiltered, field, standard units	pH, water, unfiltered, lab, standard units	Specific conductance, water, unfiltered, lab, µS/cm at 25 °C	Specific conductance, water, unfiltered, µS/cm at 25 °C	Temperature, water, °C
			00025	00020	72019	00300	00400	00403	90095	00095	00010
PI 552	8/28/2007	1600	746	25	65.88	0.3	7.3	7.6	215	207	11
PI 552	7/24/2012	1530	--	33.5	67.29	M	7.4	7.6	214	200	11.3
PI 552	6/24/2015	1445	753	22	65.72	0.1	7.1	7.8	220	212	11.2
PI 553	8/29/2007	1000	735	25	124.35	0.1	7.2	7.6	98	95	11.5
PI 553	7/25/2012	1000	740	19	123.86	0.1	7.3	7.6	100	96	10.7
PI 553	6/23/2015	1400	739	22	--	0.1	7.2	E7.7	E92	91	11.2
PI 555	8/30/2007	1000	724	25	116.92	4.6	6.8	7.1	149	142	9.2
PI 555	7/17/2012	1200	728	30.5	120.98	4.2	7.1	7.3	140	138	9.4
PI 555	6/23/2015	1100	746	22	--	5.3	7	7.7	146	145	9
PI 556	8/30/2007	1230	750	25	54.05	0.2	7.7	7.9	216	211	11.5
PI 556	8/6/2015	1030	763	--	31.5	0.2	8.3	8.2	190	187	13.9
PI 558	9/5/2007	1100	761	20.5	16.42	8.6	6.5	6.9	93	90	11.6
PI 558	7/25/2012	1000	770	30	16.13	5.9	6.5	6.9	108	111	11.6
PI 558	7/25/2012	1001	--	--	--	--	--	--	--	--	--
PI 558	6/23/2015	1500	--	--	--	8.6	6.6	E7.1	E86	85	12.2
PI 562	10/18/2007	1100	760	18	18.06	0.2	7.3	7.9	149	147	11.7
PI 562	9/23/2015	900	--	10	--	0.1	7.4	7.8	178	172	11
PI 591	7/7/2011	1200	--	--	--	<0.2	8.1	8.9	268	261	11.2
PI 591	8/5/2015	1600	--	--	27.94	0.1	9.1	8.9	274	267	11
PI 592	8/17/2011	1200	--	--	--	<0.2	8	8.5	357	345	11.7
PI 592	7/26/2012	1000	740	27	9.51	0.1	8.7	8.6	337	326	11.7
PI 592	6/25/2013	1100	755	--	6.14	0.2	8.6	8.6	339	325	11.4
PI 592	6/24/2015	1100	768	--	--	0.2	8.7	8.5	333	324	11.1
PI 592	6/24/2015	1101	--	--	--	--	--	8.6	329	--	--
PI 593	7/18/2012	1500	733	32	45.93	M	8	8	179	171	10.9
PI 593	9/12/2012	1200	752	20	--	0.1	7.8	8.1	178	185	10.7
PI 593	10/17/2012	1430	744	9	43.51	0.4	8.3	8	185	173	10.5
PI 593	11/15/2012	1400	751	3	42.51	0.1	8.3	7.9	194	187	10.3
PI 593	12/12/2012	700	747	-3	41.61	0.1	8.3	7.8	589	191	10.2
PI 593	1/9/2013	1130	741	1	42.51	0.1	8.3	7.9	377	191	10.2
PI 593	2/12/2013	1000	731	2	41.5	0.8	7.6	8.1	177	157	10.2
PI 593	3/12/2013	930	731	12	--	0.9	7.7	8.1	200	167	10.2
PI 593	4/4/2013	1150	743	0	41.5	0	7.8	8.1	176	168	10.5
PI 593	4/4/2013	1405	--	--	41.87	0	7.7	8.2	175	166	10.4
PI 593	5/9/2013	1100	735	12	37.19	0.2	7.8	8.1	177	179	10.4
PI 593	6/4/2013	1000	740	20	41.77	0.1	7.7	8.1	194	184	10.6
PI 593	6/25/2013	1100	737	28	41.81	0.1	7.9	8	186	179	10.9
PI 593	6/22/2015	1300	743	--	--	0.1	7.9	8.1	187	172	10.6

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Local identifier	Date	Sample time	Barometric pressure, in mm Hg	Temperature, air, °C	Depth to water level, feet below land surface	Dissolved oxygen, water, unfiltered, mg/L	pH, water, unfiltered, field, standard units	pH, water, unfiltered, lab, standard units	Specific conductance, water, unfiltered, lab, µS/cm at 25 °C	Specific conductance, water, unfiltered, µS/cm at 25 °C	Temperature, water, °C
			00025	**00020**	**72019**	**00300**	**00400**	**00403**	**90095**	**00095**	**00010**
PI 594	7/18/2012	900	739	29.5	147.74	7.7	6.3	E6.6	E90	84	10.8
PI 594	6/25/2015	1130	749	22	146.66	9.3	6.1	E6.9	E88	84	11
PI 595	7/19/2012	1300	740	--	--	0.5	6.9	7.3	214	208	10.6
PI 595	6/23/2015	930	743	20	--	2	7	7.5	270	268	10.8
PI 598	7/19/2012	1000	743	--	65.92	M	6.7	7.2	117	111	10.8
PI 598	6/22/2015	1600	--	26	--	0.1	6.7	7.4	126	114	10.4
PI 600	7/24/2012	1100	765	30	144.66	M	7.8	8	221	216	11.1
PI 600	9/11/2012	1300	752	16	--	0.2	7.9	8	222	216	11
PI 600	10/17/2012	1100	744	11	--	0.2	7.9	8	224	218	10.6
PI 600	11/14/2012	1400	760	7	142.51	0.1	8.2	8.1	222	217	10.6
PI 600	12/13/2012	1100	754	1	162.04	0.2	8.3	8.1	221	207	10.4
PI 600	1/9/2013	1400	746	0	163.36	0.1	7.9	8	226	222	10.4
PI 600	2/12/2013	1400	740	0	151.05	0.6	7.8	8.1	218	183	10.4
PI 600	3/12/2013	1200	738	10	149.58	0.4	7.8	8	221	190	10.4
PI 600	4/2/2013	1500	743	1	140.71	0.1	7.8	8.1	222	211	10.5
PI 600	5/7/2013	1300	748	20	141.13	0.5	7.3	8	220	225	10.5
PI 600	6/4/2013	1300	746	22	141.07	0.4	7.7	8.1	221	226	10.9
PI 600	6/25/2013	1400	744	31	141.11	0.1	7.8	8	227	220	10.7
PI 600	6/24/2015	1400	748	--	--	0.1	8	8.1	230	226	10.4
PI 601	8/2/2012	1400	740	--	25.16	0.4	7.8	7.9	158	148	10.7
PI 601	6/25/2015	1000	750	25.5	--	0.6	7.7	8	146	141	9.9

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Local identifier	Date	Sample time	Dissolved solids dried at 180 °C, water, filtered, mg/L	Dissolved solids, water, filtered, sum of constituents, mg/L	Hardness, water, mg/L as $CaCO_3$	Calcium, water, filtered, mg/L	Magnesium, water, filtered, mg/L	Potassium, water, filtered, mg/L	Sodium fraction of cations, water, percent in equivalents of major cations	Sodium, water, filtered, mg/L
			70300	70301	00900	00915	00925	00935	00932	00930
PI 288	6/2/1982	1615	--	34	22	6.8	1.1	0.5	14	1.6
PI 288	9/6/2007	1200	--	E43	23.1	7.38	1.13	0.41	20	2.71
PI 288	7/18/2012	1200	40	37	21.4	6.76	1.09	0.42	26	3.51
PI 288	6/23/2015	930	60	54	29.2	9.18	1.52	0.49	31	6.29
PI 403	8/2/2012	1000	230	217	160	51.4	7.69	0.51	21	19
PI 403	6/25/2015	1400	280	250	185	60.2	8.28	0.56	19	19.7
PI 507	7/25/2012	1230	134	121	80.3	19.6	7.53	0.71	24	12
PI 507	9/12/2012	930	125	107	78.2	18.8	7.49	0.66	24	11.3
PI 507	10/16/2012	1000	117	100	77.1	18.7	7.27	0.69	24	11.2
PI 507	11/15/2012	1100	121	117	81	20	7.43	0.64	22	10.7
PI 507	12/12/2012	900	125	E114	78.1	19.1	7.31	0.65	23	10.7
PI 507	1/8/2013	1100	119	113	78.8	19.3	7.32	0.67	22	10.5
PI 507	2/13/2013	930	128	119	79.2	18.7	7.79	0.67	23	11.2
PI 507	3/13/2013	1130	133	116	73.7	18.3	6.69	0.67	24	11
PI 507	4/3/2013	1000	123	E117	74.9	18.6	6.83	0.67	23	10.5
PI 507	5/8/2013	1130	130	120	77.4	18.4	7.52	0.69	25	11.9
PI 507	6/5/2013	1030	119	118	76.7	18.4	7.37	0.64	23	10.8
PI 507	6/27/2013	1130	124	114	73.2	17.9	6.8	0.71	25	11.5
PI 507	6/23/2015	1100	176	154	105	25.3	10.1	0.83	22	13.7
PI 524	10/1/2007	1400	--	E165	62.1	15.5	5.69	0.25	58	39.9
PI 524	1/21/2012	1131	--	--	--	--	--	--	--	--
PI 524	7/26/2012	900	165	164	60.7	14.9	5.57	0.27	61	42.8
PI 524	7/26/2012	901	177	164	61.1	15	5.55	0.27	61	43.6
PI 524	9/11/2012	1000	174	173	61.9	15.3	5.6	0.23	61	43.4
PI 524	10/16/2012	1330	161	153	59.6	14.8	5.35	0.27	60	40.4
PI 524	11/14/2012	1130	163	157	61.2	15.2	5.49	0.25	61	43.2
PI 524	12/12/2012	1130	176	147	61.9	15.4	5.54	0.22	59	40
PI 524	12/12/2012	1131	164	168	61.9	15.4	5.52	0.21	59	40.4
PI 524	1/8/2013	1300	174	154	60.8	15.1	5.42	0.26	60	40.9
PI 524	2/13/2013	1200	162	170	62.2	15	5.85	0.26	60	42.1
PI 524	3/13/2013	1300	169	166	58.2	14.8	5.02	0.24	61	41.3
PI 524	4/3/2013	1500	180	169	57.4	14.5	5.02	0.26	61	40.7
PI 524	5/8/2013	1400	169	169	61.2	15	5.64	0.26	60	42.3
PI 524	6/5/2013	1330	167	167	60.5	14.8	5.54	0.26	59	40
PI 524	6/26/2013	1230	184	170	58.5	14.6	5.23	0.26	62	43.9
PI 524	6/25/2015	1500	162	176	58.9	14.4	5.39	0.24	63	46.6
PI 524	9/22/2015	1330	177	166	55.6	13.7	5.04	0.26	61	40
PI 524	9/22/2015	1331	176	166	57.1	14	5.19	0.26	61	40.8

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Local identifier	Date	Sample time	Dissolved solids dried at 180 °C, water, filtered, mg/L	Dissolved solids, water, filtered, sum of constituents, mg/L	Hardness, water, mg/L as $CaCO_3$	Calcium, water, filtered, mg/L	Magnesium, water, filtered, mg/L	Potassium, water, filtered, mg/L	Sodium fraction of cations, water, percent in equivalents of major cations	Sodium, water, filtered, mg/L
			70300	70301	00900	00915	00925	00935	00932	00930
PI 552	8/28/2007	1600	--	E127	89	23.7	7.22	0.25	14	6.92
PI 552	7/24/2012	1530	137	133	98.5	26.5	7.74	0.24	14	7.24
PI 552	6/24/2015	1445	121	134	97.2	26.1	7.63	0.28	14	7.46
PI 553	8/29/2007	1000	--	E61	32.8	8.03	3.1	0.63	34	7.8
PI 553	7/25/2012	1000	56	62	35.6	8.61	3.37	0.61	32	7.73
PI 553	6/23/2015	1400	48	59	32.7	7.77	3.16	0.61	32	7.33
PI 555	8/30/2007	1000	--	E87	69.5	22.4	3.3	0.59	4	1.42
PI 555	7/17/2012	1200	91	78	67.6	21.5	3.25	0.64	4	1.36
PI 555	6/23/2015	1100	87	85	73.7	23.8	3.42	0.6	4	1.37
PI 556	8/30/2007	1230	--	E125	87.1	24.7	6.18	0.21	19	9.32
PI 556	8/6/2015	1030	111	113	63.2	16.7	4.99	0.19	35	15.2
PI 558	9/5/2007	1100	--	E57	35.7	11	1.98	0.39	16	3.07
PI 558	7/25/2012	1000	67	63	42.9	13.2	2.35	0.4	19	4.55
PI 558	7/25/2012	1001	--	--	--	--	--	--	--	--
PI 558	6/23/2015	1500	39	56	34.5	10.7	1.9	0.37	18	3.57
PI 562	10/18/2007	1100	--	E93	61.1	14.4	6.08	0.3	17	5.59
PI 562	9/23/2015	900	118	111	79.2	19	7.71	0.35	17	7.38
PI 591	7/7/2011	1200	156	158	17.4	5.22	0.951	0.33	87	54.6
PI 591	8/5/2015	1600	152	160	16.6	4.98	0.904	0.36	88	55.9
PI 592	8/17/2011	1200	193	191	19.2	4.85	1.56	0.8	88	68.8
PI 592	7/26/2012	1000	191	192	18.6	4.75	1.47	0.72	89	69.4
PI 592	6/25/2013	1100	187	196	19	4.88	1.5	0.68	88	66.6
PI 592	6/24/2015	1100	185	188	17.2	4.41	1.36	0.77	89	68.1
PI 592	6/24/2015	1101	185	185	16.5	4.23	1.3	0.72	89	65.4
PI 593	7/18/2012	1500	109	102	72.9	22.5	3.91	0.8	20	8.18
PI 593	9/12/2012	1200	105	95	70.6	21.8	3.78	0.82	19	7.85
PI 593	10/17/2012	1430	114	93	72	22.1	3.91	0.75	19	7.81
PI 593	11/15/2012	1400	116	103	82.2	25.7	4.2	0.77	16	7.37
PI 593	12/12/2012	700	342	E273	242	74.7	13.1	1.22	11	13.1
PI 593	1/9/2013	1130	207	183	153	47.4	8.14	1.01	13	10.3
PI 593	2/12/2013	1000	106	97	70.9	21.9	3.79	0.79	19	7.86
PI 593	3/12/2013	930	116	110	76.5	23.9	3.9	0.81	18	7.75
PI 593	4/4/2013	1150	113	105	71.6	22.5	3.6	0.81	19	7.68
PI 593	4/4/2013	1405	97	103	71.1	22.3	3.57	0.79	19	7.55
PI 593	5/9/2013	1100	104	104	70.7	21.7	3.87	0.82	20	8.12
PI 593	6/4/2013	1000	127	110	73.6	22.6	3.99	0.79	19	8.07
PI 593	6/25/2013	1100	107	103	71.7	22.2	3.78	0.77	19	7.62
PI 593	6/22/2015	1300	112	109	78.2	24.1	4.2	0.86	18	8.08

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Local identifier	Date	Sample time	Dissolved solids dried at 180 °C, water, filtered, mg/L	Dissolved solids, water, filtered, sum of constituents, mg/L	Hardness, water, mg/L as $CaCO_3$	Calcium, water, filtered, mg/L	Magnesium, water, filtered, mg/L	Potassium, water, filtered, mg/L	Sodium fraction of cations, water, percent in equivalents of major cations	Sodium, water, filtered, mg/L
			70300	70301	00900	00915	00925	00935	00932	00930
PI 594	7/18/2012	900	60	55	34.2	8.19	3.31	0.59	16	3
PI 594	6/25/2015	1130	38	54	32.7	7.66	3.28	0.65	18	3.45
PI 595	7/19/2012	1300	140	119	77.9	21.4	5.69	1.19	25	12.3
PI 595	6/23/2015	930	162	141	92	25.4	6.68	1.23	24	13.6
PI 598	7/19/2012	1000	74	68	42.7	9.73	4.46	0.77	29	8.12
PI 598	6/22/2015	1600	82	76	47.7	11.1	4.84	0.79	26	7.9
PI 600	7/24/2012	1100	123	128	101	27.7	7.58	0.7	13	6.85
PI 600	9/11/2012	1300	141	126	106	29.2	7.81	0.69	12	6.85
PI 600	10/17/2012	1100	131	116	101	27.2	7.71	0.7	13	6.67
PI 600	11/14/2012	1400	123	120	104	28.8	7.58	0.67	13	7.12
PI 600	12/13/2012	1100	127	120	106	29.1	7.75	0.68	13	7.28
PI 600	1/9/2013	1400	126	118	103	28.4	7.56	0.68	12	6.71
PI 600	2/12/2013	1400	136	132	101	27.6	7.66	0.65	13	6.89
PI 600	3/12/2013	1200	128	130	100	27.9	7.22	0.67	12	6.44
PI 600	4/2/2013	1500	128	E131	96.5	26.6	7.07	0.7	14	7.01
PI 600	5/7/2013	1300	138	130	98.4	26.2	7.79	0.72	14	7.12
PI 600	6/4/2013	1300	145	133	102	27.8	7.65	0.7	13	6.94
PI 600	6/25/2013	1400	136	127	99.8	27.7	7.23	0.63	13	6.68
PI 600	6/24/2015	1400	130	134	102	28.3	7.45	0.65	14	7.71
PI 601	8/2/2012	1400	97	91	49.3	10	5.78	0.38	37	13.1
PI 601	6/25/2015	1000	82	91	50.8	10.6	5.83	0.4	36	13.2

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Local identifier	Date	Sample time	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, lab, mg/L as $CaCO_3$	ANC, water, unfiltered, inflection-point (incremental) titration method, field, mg/L as $CaCO_3$	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, lab, mg/L as $CaCO_3$	Bromide, water, filtered, µg/L	Bromide, water, filtered, mg/L	Fluoride, water, filtered, mg/L	Sulfate, water, filtered, mg/L	Ammonia, water, filtered, mg/L as NH4	Ammonia, water, filtered, mg/L as nitrogen
			90410	**00419**	**29801**	**91000**	**71870**	**00950**	**00945**	**71846**	**00608**
PI 288	6/2/1982	1615	12	--	--	--	--	<0.10	9	0.01	<0.010
PI 288	9/6/2007	1200	--	21	--	--	--	<0.10	6.74	E0.013	E0.01
PI 288	7/18/2012	1200	15.5	11	--	--	0.018	<0.04	6.69	<0.013	<0.01
PI 288	6/23/2015	930	--	--	12.6	34	--	0.03	5.86	<0.013	<0.01
PI 403	8/2/2012	1000	110	106	--	--	0.017	0.1	10.3	0.058	0.04
PI 403	6/25/2015	1400	--	--	110	43	--	0.12	10.5	0.063	0.05
PI 507	7/25/2012	1230	52.1	52	--	--	0.026	0.04	11.6	<0.013	<0.01
PI 507	9/12/2012	930	51.2	33	--	--	0.023	<0.04	11.2	<0.013	<0.01
PI 507	10/16/2012	1000	51	21	--	--	0.026	<0.04	11.5	<0.013	<0.01
PI 507	11/15/2012	1100	51.2	47	--	--	0.025	<0.04	11.3	<0.013	<0.01
PI 507	12/12/2012	900	52.4	46	--	--	E0.025	0.04	11.6	<0.013	<0.01
PI 507	1/8/2013	1100	52.9	42	--	--	0.022	0.05	11.8	<0.013	<0.01
PI 507	2/13/2013	930	53	--	--	--	0.021	<0.04	11.7	<0.013	<0.01
PI 507	3/13/2013	1130	51.1	--	--	--	0.024	<0.04	11.6	<0.013	<0.01
PI 507	4/3/2013	1000	51	--	--	--	0.024	E0.04	11.6	<0.013	<0.01
PI 507	5/8/2013	1130	50.6	--	--	--	0.02	0.04	11.5	<0.013	<0.01
PI 507	6/5/2013	1030	48.9	--	--	--	0.022	0.05	11.1	<0.013	<0.01
PI 507	6/27/2013	1130	49.7	44	--	--	0.026	0.04	10.9	<0.013	<0.01
PI 507	6/23/2015	1100	--	--	51.5	34	--	0.04	11.1	<0.013	<0.01
PI 524	10/1/2007	1400	--	114	--	--	--	0.21	0.36	0.076	0.06
PI 524	1/21/2012	1131	--	86	--	--	--	--	--	--	--
PI 524	7/26/2012	900	123	109	--	--	0.18	0.2	0.76	0.083	0.06
PI 524	7/26/2012	901	--	107	--	--	0.19	0.2	0.87	--	--
PI 524	9/11/2012	1000	122	124	--	--	0.169	0.17	0.93	0.08	0.06
PI 524	10/16/2012	1330	121	99	--	--	0.182	0.17	0.94	0.105	0.08
PI 524	11/14/2012	1130	121	98	--	--	0.162	0.19	0.81	0.076	0.06
PI 524	12/12/2012	1130	122	86	--	--	0.159	0.19	0.82	0.076	0.06
PI 524	12/12/2012	1131	122	--	--	--	0.154	0.18	0.86	0.074	0.06
PI 524	1/8/2013	1300	121	98	--	--	0.182	0.2	0.93	0.075	0.06
PI 524	2/13/2013	1200	122	--	--	--	0.168	0.19	0.96	0.101	0.08
PI 524	3/13/2013	1300	120	--	--	--	0.172	0.17	1.06	0.076	0.06
PI 524	4/3/2013	1500	123	--	--	--	0.172	--	1.07	0.076	0.06
PI 524	5/8/2013	1400	120	--	--	--	0.161	0.2	1.16	0.074	0.06
PI 524	6/5/2013	1330	120	--	--	--	0.176	0.22	1.04	0.081	0.06
PI 524	6/26/2013	1230	123	117	--	--	0.191	0.2	0.94	0.083	0.06
PI 524	6/25/2015	1500	--	--	123	220	--	0.2	0.89	0.085	0.07
PI 524	9/22/2015	1330	--	--	121	170	0.166	0.21	1.11	0.081	0.06
PI 524	9/22/2015	1331	--	--	120	--	0.16	0.2	1.15	0.078	0.06

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Local identifier	Date	Sample time	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, lab, mg/L as CaCO$_3$	ANC, water, unfiltered, inflection-point (incremental) titration method, field, mg/L as CaCO$_3$	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, lab, mg/L as CaCO$_3$	Bromide, water, filtered, µg/L	Bromide, water, filtered, mg/L	Fluoride, water, filtered, mg/L	Sulfate, water, filtered, mg/L	Ammonia, water, filtered, mg/L as NH4	Ammonia, water, filtered, mg/L as nitrogen
			90410	00419	29801	91000	71870	00950	00945	71846	00608
PI 552	8/28/2007	1600	--	89	--	--	--	0.13	15.7	E0.021	E0.02
PI 552	7/24/2012	1530	89.4	88	--	--	0.017	0.13	17.1	0.05	0.04
PI 552	6/24/2015	1445	--	--	89.1	13	--	0.14	17.4	0.052	0.04
PI 553	8/29/2007	1000	--	50	--	--	--	0.11	1.07	<0.026	<0.02
PI 553	7/25/2012	1000	52.8	52	--	--	0.014	0.12	0.96	<0.013	<0.01
PI 553	6/23/2015	1400	--	--	47.9	32	--	0.11	0.85	<0.013	<0.01
PI 555	8/30/2007	1000	--	71	--	--	--	E0.06	7.61	<0.026	<0.02
PI 555	7/17/2012	1200	64.2	56	--	--	0.014	0.07	8.06	<0.013	<0.01
PI 555	6/23/2015	1100	--	--	66.4	19	--	0.06	7.75	<0.013	<0.01
PI 556	8/30/2007	1230	--	90	--	--	--	E0.09	14	0.081	0.06
PI 556	8/6/2015	1030	--	--	76.9	24	0.021	0.11	13.1	0.112	0.09
PI 558	9/5/2007	1100	--	24	--	--	--	E0.06	14.9	<0.026	<0.02
PI 558	7/25/2012	1000	33.5	25	--	--	0.021	0.05	14.4	<0.013	<0.01
PI 558	7/25/2012	1001	--	--	--	--	--	--	--	<0.013	<0.01
PI 558	6/23/2015	1500	--	--	26.3	26	--	0.05	12.1	<0.013	<0.01
PI 562	10/18/2007	1100	--	57	--	--	--	E0.10	11.7	0.032	0.02
PI 562	9/23/2015	900	--	--	72.2	11	0.016	0.12	11.1	0.024	0.02
PI 591	7/7/2011	1200	--	--	127	--	0.024	0.28	1.78	0.367	0.29
PI 591	8/5/2015	1600	--	--	122	27	0.025	0.26	1.7	0.416	0.32
PI 592	8/17/2011	1200	--	--	110	--	0.38	0.54	0.12	0.077	0.06
PI 592	7/26/2012	1000	118	116	--	--	0.353	0.53	0.38	0.073	0.06
PI 592	6/25/2013	1100	118	124	--	--	0.341	0.53	0.36	0.077	0.06
PI 592	6/24/2015	1100	--	--	117	360	--	0.51	0.39	0.076	0.06
PI 592	6/24/2015	1101	--	--	117	350	--	0.51	0.39	0.077	0.06
PI 593	7/18/2012	1500	67.5	62	--	--	0.021	0.11	9.3	<0.013	<0.01
PI 593	9/12/2012	1200	67	50	--	--	0.018	0.08	8.85	<0.013	<0.01
PI 593	10/17/2012	1430	67.1	47	--	--	0.021	0.07	9.18	<0.013	<0.01
PI 593	11/15/2012	1400	66.8	53	--	--	0.02	0.07	8.63	<0.013	<0.01
PI 593	12/12/2012	700	66.7	22.2	--	--	E0.049	0.07	9.87	<0.013	<0.01
PI 593	1/9/2013	1130	67.1	53.9	--	--	0.035	0.08	9.43	<0.013	<0.01
PI 593	2/12/2013	1000	67.4	56	--	--	0.015	0.09	8.74	<0.013	<0.01
PI 593	3/12/2013	930	67.4	--	--	--	0.02	0.11	8.62	<0.013	<0.01
PI 593	4/4/2013	1150	67.9	--	--	--	0.014	0.1	8.8	<0.013	<0.01
PI 593	4/4/2013	1405	67.8	--	--	--	0.016	0.11	8.78	<0.013	<0.01
PI 593	5/9/2013	1100	67.2	--	--	--	0.015	0.1	9.02	<0.013	<0.01
PI 593	6/4/2013	1000	67.8	--	--	--	0.017	0.09	9.11	<0.013	<0.01
PI 593	6/25/2013	1100	66.9	65	--	--	0.015	0.1	8.89	<0.013	<0.01
PI 593	6/22/2015	1300	--	--	67.6	18	--	0.09	8.54	<0.013	<0.01

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Local identifier	Date	Sample time	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, lab, mg/L as $CaCO_3$	ANC, water, unfiltered, inflection-point (incremental) titration method, field, mg/L as $CaCO_3$	Alkalinity, water, filtered, fixed endpoint (pH 4.5) titration, lab, mg/L as $CaCO_3$	Bromide, water, filtered, µg/L	Bromide, water, filtered, mg/L	Fluoride, water, filtered, mg/L	Sulfate, water, filtered, mg/L	Ammonia, water, filtered, mg/L as NH4	Ammonia, water, filtered, mg/L as nitrogen
			90410	00419	29801	91000	71870	00950	00945	71846	00608
PI 594	7/18/2012	900	26.8	26	--	--	0.014	0.06	10.2	<0.013	<0.01
PI 594	6/25/2015	1130	--	--	22.1	<10	--	0.05	8.84	<0.013	<0.01
PI 595	7/19/2012	1300	55.7	50	--	--	0.033	0.12	7.41	<0.013	<0.01
PI 595	6/23/2015	930	--	--	50.5	35	--	0.11	6.64	<0.013	<0.01
PI 598	7/19/2012	1000	55.4	51	--	--	0.028	0.1	0.65	0.123	0.1
PI 598	6/22/2015	1600	--	--	56.8	27	--	0.1	0.77	0.12	0.09
PI 600	7/24/2012	1100	100	94	--	--	0.015	0.05	11.3	<0.013	<0.01
PI 600	9/11/2012	1300	99.4	86	--	--	0.017	0.05	11.4	<0.013	<0.01
PI 600	10/17/2012	1100	98.4	74	--	--	0.016	0.06	11.4	<0.013	<0.01
PI 600	11/14/2012	1400	100	76.7	--	--	0.018	0.06	11.2	<0.013	<0.01
PI 600	12/13/2012	1100	100	76.5	--	--	<0.010	0.07	11.3	<0.013	<0.01
PI 600	1/9/2013	1400	99.9	75.2	--	--	<0.050	0.06	11.3	<0.013	<0.01
PI 600	2/12/2013	1400	101	--	--	--	0.013	0.05	10.8	<0.013	<0.01
PI 600	3/12/2013	1200	98.7	--	--	--	0.014	0.07	10.7	<0.013	<0.01
PI 600	4/2/2013	1500	100	--	--	--	<0.010	E0.07	10.9	<0.013	<0.01
PI 600	5/7/2013	1300	96.3	--	--	--	0.016	0.06	10.8	<0.013	<0.01
PI 600	6/4/2013	1300	98.5	--	--	--	<0.010	0.06	11.2	<0.013	<0.01
PI 600	6/25/2013	1400	101	94	--	--	0.014	0.06	10.9	<0.013	<0.01
PI 600	6/24/2015	1400	--	--	101	13	--	0.06	10.9	<0.013	<0.01
PI 601	8/2/2012	1400	66.1	62	--	--	0.052	0.1	6.82	<0.013	<0.01
PI 601	6/25/2015	1000	--	--	61.5	50	--	0.11	6.44	<0.013	<0.01

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Local identifier	Date	Sample time	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Ortho-phosphate, water, filtered, mg/L as phosphorus	Aluminum, water, filtered, µg/L	Barium, water, filtered, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L	Copper, water, filtered, µg/L
			00618	00613	00671	01106	01005	01010	01025	01030	01035	01040
PI 288	6/2/1982	1615	0.55	<0.010	0.01	--	--	--	--	--	--	--
PI 288	9/6/2007	1200	E0.555	E0.001	0.016	E1.4	--	--	0.079	0.14	--	72.2
PI 288	7/18/2012	1200	0.518	<0.001	0.023	<2.2	14.2	0.016	0.08	0.14	0.034	14.3
PI 288	6/23/2015	930	0.643	<0.001	0.02	3.3	20.7	0.021	0.145	<0.30	<0.050	9.2
PI 403	8/2/2012	1000	<0.040	<0.001	0.032	<2.2	11.5	<0.006	<0.016	<0.07	0.256	<0.80
PI 403	6/25/2015	1400	<0.040	<0.001	0.028	<3.0	11.9	<0.020	<0.030	<0.30	0.253	<0.80
PI 507	7/25/2012	1230	0.503	<0.001	0.011	<2.2	47.4	<0.006	0.043	0.18	0.079	2.6
PI 507	9/12/2012	930	0.516	<0.001	0.01	<2.2	48.8	<0.006	<0.016	<0.07	<0.021	<0.80
PI 507	10/16/2012	1000	0.544	0.01	0.01	<2.2	49	<0.006	0.018	0.08	0.054	1.3
PI 507	11/15/2012	1100	0.533	<0.001	0.01	<2.2	46.2	<0.006	<0.016	<0.07	0.026	1.3
PI 507	12/12/2012	900	0.57	<0.001	0.011	<2.2	48.2	<0.006	0.054	<0.07	0.063	1
PI 507	1/8/2013	1100	0.573	<0.001	0.012	<2.2	47.5	<0.006	0.039	<0.07	0.061	1.2
PI 507	2/13/2013	930	0.56	<0.001	0.01	<2.2	48.6	<0.006	0.028	<0.07	0.072	0.92
PI 507	3/13/2013	1130	0.53	<0.001	0.011	<2.2	48.3	<0.006	0.026	<0.07	0.046	<0.80
PI 507	4/3/2013	1000	0.531	<0.001	0.011	<2.2	52	<0.006	<0.016	<0.07	0.269	<0.80
PI 507	5/8/2013	1130	0.538	<0.001	0.011	<2.2	47.6	<0.006	0.027	<0.07	0.055	<0.80
PI 507	6/5/2013	1030	0.566	<0.001	0.01	<2.2	48	<0.006	<0.016	<0.07	0.058	<0.80
PI 507	6/27/2013	1130	0.574	<0.001	0.01	<2.2	47.4	<0.006	<0.016	<0.07	0.027	<0.80
PI 507	6/23/2015	1100	0.612	<0.001	0.013	<3.0	62.6	<0.020	<0.030	<0.30	0.146	<0.80
PI 524	10/1/2007	1400	<0.039	E0.001	0.02	E1.2	--	--	<0.040	<0.12	--	<1.0
PI 524	1/21/2012	1131	--	--	--	--	--	--	--	--	--	--
PI 524	7/26/2012	900	<0.040	<0.001	0.027	<2.2	138	<0.006	<0.016	<0.07	0.024	<0.80
PI 524	7/26/2012	901	--	--	--	<2.2	138	0.006	<0.016	<0.07	<0.021	<0.80
PI 524	9/11/2012	1000	<0.040	<0.001	0.026	<2.2	132	<0.006	<0.016	<0.07	0.054	<0.80
PI 524	10/16/2012	1330	<0.040	<0.001	0.024	<2.2	129	<0.006	<0.016	<0.07	<0.023	<0.80
PI 524	11/14/2012	1130	<0.040	<0.001	0.026	<2.2	135	0.008	<0.016	0.27	<0.023	<0.80
PI 524	12/12/2012	1130	<0.040	<0.001	0.026	<2.2	136	<0.006	<0.032	<0.07	<0.023	<0.80
PI 524	12/12/2012	1131	<0.040	<0.001	0.026	<2.2	137	<0.006	<0.032	<0.07	0.04	<0.80
PI 524	1/8/2013	1300	<0.040	<0.001	0.028	<4.4	133	<0.006	<0.016	<0.07	0.04	<0.80
PI 524	2/13/2013	1200	<0.040	<0.001	0.025	<2.2	134	0.007	<0.016	<0.07	0.029	<0.80
PI 524	3/13/2013	1300	<0.040	<0.001	0.025	<2.2	135	0.007	<0.016	<0.07	0.084	<0.80
PI 524	4/3/2013	1500	<0.040	<0.001	0.026	<2.2	138	0.009	<0.016	<0.07	0.027	<0.80
PI 524	5/8/2013	1400	<0.040	<0.001	0.026	<2.2	127	0.006	<0.016	<0.07	0.031	<0.80
PI 524	6/5/2013	1330	<0.040	<0.001	0.025	<2.2	131	<0.006	<0.016	<0.07	0.058	<0.80
PI 524	6/26/2013	1230	<0.040	<0.001	0.027	<2.2	133	0.007	<0.016	<0.07	<0.023	<0.80
PI 524	6/25/2015	1500	<0.040	<0.001	0.029	<3.0	137	<0.020	<0.030	<0.30	<0.050	<0.80
PI 524	9/22/2015	1330	<0.040	<0.001	0.027	<3.0	130	<0.020	<0.030	<0.30	0.09	<0.80
PI 524	9/22/2015	1331	<0.040	<0.001	0.027	<3.0	132	<0.020	<0.030	<0.30	<0.050	<0.80

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			00618	00613	00671	01106	01005	01010	01025	01030	01035	01040
PI 552	8/28/2007	1600	<0.060	<0.002	0.011	<1.6	--	--	<0.040	<0.12	--	<0.40
PI 552	7/24/2012	1530	<0.040	<0.001	0.007	<2.2	11.9	0.009	<0.016	<0.07	0.093	<0.80
PI 552	6/24/2015	1445	<0.040	<0.001	0.011	<3.0	12.8	<0.020	<0.030	<0.30	0.051	<0.80
PI 553	8/29/2007	1000	<0.060	<0.002	0.02	<1.6	--	--	<0.040	<0.12	--	10.8
PI 553	7/25/2012	1000	<0.040	<0.001	0.019	<2.2	57.7	<0.006	<0.016	0.11	0.105	1.7
PI 553	6/23/2015	1400	<0.040	<0.001	0.018	<3.0	46.9	<0.020	<0.030	<0.30	0.064	1.3
PI 555	8/30/2007	1000	0.356	<0.002	0.021	<1.6	--	--	<0.040	<0.12	--	5.3
PI 555	7/17/2012	1200	0.428	<0.001	0.025	<2.2	70.9	<0.006	<0.016	<0.07	<0.021	<0.80
PI 555	6/23/2015	1100	0.323	<0.001	0.016	<3.0	48.4	<0.020	<0.030	<0.30	0.066	3
PI 556	8/30/2007	1230	E0.040	0.005	0.016	2.8	--	--	<0.040	<0.12	--	0.97
PI 556	8/6/2015	1030	<0.040	<0.001	0.019	<3.0	17	<0.020	<0.030	<0.30	0.059	<0.80
PI 558	9/5/2007	1100	E0.040	E0.001	0.018	<1.6	--	--	<0.040	E0.07	--	25.7
PI 558	7/25/2012	1000	0.107	<0.001	0.01	<2.2	3.51	<0.006	<0.016	0.09	0.059	38.1
PI 558	7/25/2012	1001	0.107	0.002	0.011	--	--	--	--	--	--	--
PI 558	6/23/2015	1500	0.088	<0.001	0.014	<3.0	2.63	<0.020	<0.030	<0.30	0.068	40
PI 562	10/18/2007	1100	<0.040	<0.002	E0.004	<1.6	--	--	<0.040	E0.11	--	4.7
PI 562	9/23/2015	900	<0.040	<0.001	0.014	<3.0	10.6	<0.020	<0.030	<0.30	0.065	<0.80
PI 591	7/7/2011	1200	<0.020	<0.001	0.032	27.9	20.5	0.007	<0.016	<0.06	0.033	<0.50
PI 591	8/5/2015	1600	<0.040	<0.001	0.037	56.3	24.1	0.036	<0.030	<0.30	0.63	<0.80
PI 592	8/17/2011	1200	<0.020	<0.001	0.176	<1.7	327	<0.006	<0.016	<0.06	0.301	<0.50
PI 592	7/26/2012	1000	<0.040	<0.001	0.177	<2.2	318	<0.006	<0.016	<0.07	<0.021	<0.80
PI 592	6/25/2013	1100	<0.040	<0.001	0.185	<2.2	312	0.007	<0.016	<0.07	<0.023	<0.80
PI 592	6/24/2015	1100	<0.040	<0.001	0.174	<3.0	298	<0.020	<0.030	<0.30	<0.050	<0.80
PI 592	6/24/2015	1101	<0.040	<0.001	0.178	3.5	294	<0.020	<0.030	<0.30	<0.050	<0.80
PI 593	7/18/2012	1500	<0.040	<0.001	0.006	<2.2	73.5	<0.006	<0.016	<0.07	0.03	<0.80
PI 593	9/12/2012	1200	<0.040	<0.001	0.006	<2.2	76.2	<0.006	<0.016	<0.07	<0.021	<0.80
PI 593	10/17/2012	1430	<0.040	<0.001	0.007	<2.2	74.3	<0.006	<0.016	<0.07	<0.023	0.9
PI 593	11/15/2012	1400	<0.040	<0.001	0.006	<2.2	74.2	<0.006	<0.016	<0.07	<0.023	1
PI 593	12/12/2012	700	<0.040	<0.001	0.006	<2.2	191	<0.006	<0.016	<0.07	0.182	1.8
PI 593	1/9/2013	1130	0.072	<0.001	0.006	<2.2	126	<0.006	<0.016	<0.07	0.07	<0.80
PI 593	2/12/2013	1000	<0.040	<0.001	0.006	<2.2	75.1	<0.006	<0.016	<0.07	0.04	1.7
PI 593	3/12/2013	930	<0.040	<0.001	0.005	<2.2	75.5	<0.006	<0.016	<0.07	0.044	1.6
PI 593	4/4/2013	1150	<0.040	<0.001	0.007	<2.2	80.8	<0.006	<0.016	<0.07	0.036	<0.80
PI 593	4/4/2013	1405	<0.040	<0.001	0.007	2.9	80.7	<0.006	<0.016	<0.07	<0.023	<0.80
PI 593	5/9/2013	1100	<0.040	<0.001	0.007	<2.2	72.5	<0.006	<0.016	<0.07	0.296	<0.80
PI 593	6/4/2013	1000	<0.040	<0.001	0.006	<2.2	74.1	<0.006	<0.016	<0.07	0.032	1.1
PI 593	6/25/2013	1100	<0.040	<0.001	0.006	<2.2	71.1	<0.006	<0.016	<0.07	<0.023	0.88
PI 593	6/22/2015	1300	<0.040	<0.001	0.007	<3.0	77.7	<0.020	<0.030	<0.30	<0.050	<0.80

Table A5–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for groundwater samples collected from 79 wells in 2015 and from 18 of the 79 wells sampled at least once previously by USGS during 1982–2013 in Pike County, Pennsylvania.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; 2015 methane analyses by Isotech in bold, with time offset of 5 minutes; mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; lab, laboratory; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; VPDB, PeeDee belemnite; VSMOW, Vienna Standard Mean Ocean Water]

Local identifier	Date	Sample time	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Ortho-phosphate, water, filtered, mg/L as phosphorus	Aluminum, water, filtered, µg/L	Barium, water, filtered, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L	Copper, water, filtered, µg/L
			00618	**00613**	**00671**	**01106**	**01005**	**01010**	**01025**	**01030**	**01035**	**01040**
PI 594	7/18/2012	900	0.883	<0.001	0.02	<2.2	5.36	0.007	0.05	<0.07	0.044	2.9
PI 594	6/25/2015	1130	0.816	<0.001	0.022	<3.0	5.09	<0.020	0.053	<0.30	<0.050	3.2
PI 595	7/19/2012	1300	<0.039	0.001	<0.004	<2.2	92.3	<0.006	<0.016	0.27	0.047	<0.80
PI 595	6/23/2015	930	0.048	<0.001	0.005	<3.0	143	<0.020	<0.030	<0.30	0.174	0.8
PI 598	7/19/2012	1000	<0.040	<0.001	0.076	<2.2	18.1	<0.006	0.048	0.26	0.113	0.83
PI 598	6/22/2015	1600	<0.040	<0.001	0.083	3.1	20.2	<0.020	0.031	<0.30	0.117	<0.80
PI 600	7/24/2012	1100	<0.040	<0.001	0.005	<2.2	162	<0.006	<0.016	<0.07	0.081	16.5
PI 600	9/11/2012	1300	<0.040	<0.001	0.005	<2.2	158	<0.006	<0.016	<0.07	<0.021	19.9
PI 600	10/17/2012	1100	<0.037	0.003	0.005	<2.2	157	<0.006	<0.016	0.1	<0.023	27.6
PI 600	11/14/2012	1400	<0.040	<0.001	0.005	<2.2	166	<0.006	<0.016	<0.07	<0.023	15.9
PI 600	12/13/2012	1100	<0.040	<0.001	0.007	<2.2	165	<0.006	<0.016	<0.07	0.087	14.9
PI 600	1/9/2013	1400	<0.040	<0.001	0.006	<2.2	161	<0.006	<0.016	<0.07	0.042	16.5
PI 600	2/12/2013	1400	<0.040	<0.001	0.005	<2.2	165	<0.006	<0.016	<0.07	0.06	13.1
PI 600	3/12/2013	1200	<0.038	0.002	0.005	<2.2	159	<0.006	<0.016	<0.07	0.05	1.4
PI 600	4/2/2013	1500	<0.040	<0.001	0.006	<2.2	168	<0.006	<0.016	<0.07	<0.023	14.1
PI 600	5/7/2013	1300	0.054	<0.001	0.006	<2.2	144	<0.006	<0.016	<0.07	0.122	2.6
PI 600	6/4/2013	1300	<0.040	<0.001	0.005	<2.2	149	<0.006	<0.016	<0.07	0.058	27.2
PI 600	6/25/2013	1400	<0.040	<0.001	0.005	<2.2	159	<0.006	<0.016	<0.07	<0.023	0.94
PI 600	6/24/2015	1400	<0.040	<0.001	0.006	<3.0	160	<0.020	<0.030	<0.30	<0.050	<0.80
PI 601	8/2/2012	1400	<0.040	<0.001	0.027	<2.2	30.2	<0.006	<0.016	<0.07	0.021	<0.80
PI 601	6/25/2015	1000	<0.040	<0.001	0.029	4.8	28.2	<0.020	<0.030	<0.30	<0.050	<0.80

Table A5–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for groundwater samples collected from 79 wells in 2015 and from 18 of the 79 wells sampled at least once previously by USGS during 1982–2013 in Pike County, Pennsylvania.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; 2015 methane analyses by Isotech in bold, with time offset of 5 minutes; mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; lab, laboratory; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; VPDB, PeeDee belemnite; VSMOW, Vienna Standard Mean Ocean Water]

Local identifier	Date	Sample time	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Ortho-phosphate, water, filtered, mg/L as phosphorus	Aluminum, water, filtered, µg/L	Barium, water, filtered, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L
			00618	**00613**	**00671**	**01106**	**01005**	**01010**	**01025**	**01030**	**01035**
PI 288	6/2/1982	1615	0.55	<0.010	0.01	--	--	--	--	--	--
PI 288	9/6/2007	1200	E0.555	E0.001	0.016	E1.4	--	--	0.079	0.14	--
PI 288	7/18/2012	1200	0.518	<0.001	0.023	<2.2	14.2	0.016	0.08	0.14	0.034
PI 288	6/23/2015	930	0.643	<0.001	0.02	3.3	20.7	0.021	0.145	<0.30	<0.050
PI 403	8/2/2012	1000	<0.040	<0.001	0.032	<2.2	11.5	<0.006	<0.016	<0.07	0.256
PI 403	6/25/2015	1400	<0.040	<0.001	0.028	<3.0	11.9	<0.020	<0.030	<0.30	0.253
PI 507	7/25/2012	1230	0.503	<0.001	0.011	<2.2	47.4	<0.006	0.043	0.18	0.079
PI 507	9/12/2012	930	0.516	<0.001	0.01	<2.2	48.8	<0.006	<0.016	<0.07	<0.021
PI 507	10/16/2012	1000	0.544	0.01	0.01	<2.2	49	<0.006	0.018	0.08	0.054
PI 507	11/15/2012	1100	0.533	<0.001	0.01	<2.2	46.2	<0.006	<0.016	<0.07	0.026
PI 507	12/12/2012	900	0.57	<0.001	0.011	<2.2	48.2	<0.006	0.054	<0.07	0.063
PI 507	1/8/2013	1100	0.573	<0.001	0.012	<2.2	47.5	<0.006	0.039	<0.07	0.061
PI 507	2/13/2013	930	0.56	<0.001	0.01	<2.2	48.6	<0.006	0.028	<0.07	0.072
PI 507	3/13/2013	1130	0.53	<0.001	0.011	<2.2	48.3	<0.006	0.026	<0.07	0.046
PI 507	4/3/2013	1000	0.531	<0.001	0.011	<2.2	52	<0.006	<0.016	<0.07	0.269
PI 507	5/8/2013	1130	0.538	<0.001	0.011	<2.2	47.6	<0.006	0.027	<0.07	0.055
PI 507	6/5/2013	1030	0.566	<0.001	0.01	<2.2	48	<0.006	<0.016	<0.07	0.058
PI 507	6/27/2013	1130	0.574	<0.001	0.01	<2.2	47.4	<0.006	<0.016	<0.07	0.027
PI 507	6/23/2015	1100	0.612	<0.001	0.013	<3.0	62.6	<0.020	<0.030	<0.30	0.146
PI 524	10/1/2007	1400	<0.039	E0.001	0.02	E1.2	--	--	<0.040	<0.12	--
PI 524	1/21/2012	1131	--	--	--	--	--	--	--	--	--
PI 524	7/26/2012	900	<0.040	<0.001	0.027	<2.2	138	<0.006	<0.016	<0.07	0.024
PI 524	7/26/2012	901	--	--	--	<2.2	138	0.006	<0.016	<0.07	<0.021
PI 524	9/11/2012	1000	<0.040	<0.001	0.026	<2.2	132	<0.006	<0.016	<0.07	0.054
PI 524	10/16/2012	1330	<0.040	<0.001	0.024	<2.2	129	<0.006	<0.016	<0.07	<0.023
PI 524	11/14/2012	1130	<0.040	<0.001	0.026	<2.2	135	0.008	<0.016	0.27	<0.023
PI 524	12/12/2012	1130	<0.040	<0.001	0.026	<2.2	136	<0.006	<0.032	<0.07	<0.023
PI 524	12/12/2012	1131	<0.040	<0.001	0.026	<2.2	137	<0.006	<0.032	<0.07	0.04
PI 524	1/8/2013	1300	<0.040	<0.001	0.028	<4.4	133	<0.006	<0.016	<0.07	0.04
PI 524	2/13/2013	1200	<0.040	<0.001	0.025	<2.2	134	0.007	<0.016	<0.07	0.029
PI 524	3/13/2013	1300	<0.040	<0.001	0.025	<2.2	135	0.007	<0.016	<0.07	0.084
PI 524	4/3/2013	1500	<0.040	<0.001	0.026	<2.2	138	0.009	<0.016	<0.07	0.027
PI 524	5/8/2013	1400	<0.040	<0.001	0.026	<2.2	127	0.006	<0.016	<0.07	0.031
PI 524	6/5/2013	1330	<0.040	<0.001	0.025	<2.2	131	<0.006	<0.016	<0.07	0.058
PI 524	6/26/2013	1230	<0.040	<0.001	0.027	<2.2	133	0.007	<0.016	<0.07	<0.023
PI 524	6/25/2015	1500	<0.040	<0.001	0.029	<3.0	137	<0.020	<0.030	<0.30	<0.050
PI 524	9/22/2015	1330	<0.040	<0.001	0.027	<3.0	130	<0.020	<0.030	<0.30	0.09
PI 524	9/22/2015	1331	<0.040	<0.001	0.027	<3.0	132	<0.020	<0.030	<0.30	<0.050

Table A5–1. Field measurements and results of laboratory analyses for major and minor ions, nutrients, bacteria, trace metals, volatile organic compounds radioactivity, radon-222, and dissolved gases for groundwater samples collected from 79 wells in 2015 and from 18 of the 79 wells sampled at least once previously by USGS during 1982–2013 in Pike County, Pennsylvania.—Continued

[Constituents listed with associated 5-digit U.S. Geological Survey parameter code; 2015 methane analyses by Isotech in bold, with time offset of 5 minutes; mm Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; lab, laboratory; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; --, no data; <, less than; >, greater than; E, estimated; M, presence verified but not quantified; R, non-detect for radiological analysis; U, analyzed for but not detected; VPDB, PeeDee belemnite; VSMOW, Vienna Standard Mean Ocean Water]

Local identifier	Date	Sample time	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Ortho-phosphate, water, filtered, mg/L as phosphorus	Aluminum, water, filtered, µg/L	Barium, water, filtered, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L
			00618	00613	00671	01106	01005	01010	01025	01030	01035
PI 552	8/28/2007	1600	<0.060	<0.002	0.011	<1.6	--	--	<0.040	<0.12	--
PI 552	7/24/2012	1530	<0.040	<0.001	0.007	<2.2	11.9	0.009	<0.016	<0.07	0.093
PI 552	6/24/2015	1445	<0.040	<0.001	0.011	<3.0	12.8	<0.020	<0.030	<0.30	0.051
PI 553	8/29/2007	1000	<0.060	<0.002	0.02	<1.6	--	--	<0.040	<0.12	--
PI 553	7/25/2012	1000	<0.040	<0.001	0.019	<2.2	57.7	<0.006	<0.016	0.11	0.105
PI 553	6/23/2015	1400	<0.040	<0.001	0.018	<3.0	46.9	<0.020	<0.030	<0.30	0.064
PI 555	8/30/2007	1000	0.356	<0.002	0.021	<1.6	--	--	<0.040	<0.12	--
PI 555	7/17/2012	1200	0.428	<0.001	0.025	<2.2	70.9	<0.006	<0.016	<0.07	<0.021
PI 555	6/23/2015	1100	0.323	<0.001	0.016	<3.0	48.4	<0.020	<0.030	<0.30	0.066
PI 556	8/30/2007	1230	E0.040	0.005	0.016	2.8	--	--	<0.040	<0.12	--
PI 556	8/6/2015	1030	<0.040	<0.001	0.019	<3.0	17	<0.020	<0.030	<0.30	0.059
PI 558	9/5/2007	1100	E0.040	E0.001	0.018	<1.6	--	--	<0.040	E0.07	--
PI 558	7/25/2012	1000	0.107	<0.001	0.01	<2.2	3.51	<0.006	<0.016	0.09	0.059
PI 558	7/25/2012	1001	0.107	0.002	0.011	--	--	--	--	--	--
PI 558	6/23/2015	1500	0.088	<0.001	0.014	<3.0	2.63	<0.020	<0.030	<0.30	0.068
PI 562	10/18/2007	1100	<0.040	<0.002	E0.004	<1.6	--	--	<0.040	E0.11	--
PI 562	9/23/2015	900	<0.040	<0.001	0.014	<3.0	10.6	<0.020	<0.030	<0.30	0.065
PI 591	7/7/2011	1200	<0.020	<0.001	0.032	27.9	20.5	0.007	<0.016	<0.06	0.033
PI 591	8/5/2015	1600	<0.040	<0.001	0.037	56.3	24.1	0.036	<0.030	<0.30	0.63
PI 592	8/17/2011	1200	<0.020	<0.001	0.176	<1.7	327	<0.006	<0.016	<0.06	0.301
PI 592	7/26/2012	1000	<0.040	<0.001	0.177	<2.2	318	<0.006	<0.016	<0.07	<0.021
PI 592	6/25/2013	1100	<0.040	<0.001	0.185	<2.2	312	0.007	<0.016	<0.07	<0.023
PI 592	6/24/2015	1100	<0.040	<0.001	0.174	<3.0	298	<0.020	<0.030	<0.30	<0.050
PI 592	6/24/2015	1101	<0.040	<0.001	0.178	3.5	294	<0.020	<0.030	<0.30	<0.050
PI 593	7/18/2012	1500	<0.040	<0.001	0.006	<2.2	73.5	<0.006	<0.016	<0.07	0.03
PI 593	9/12/2012	1200	<0.040	<0.001	0.006	<2.2	76.2	<0.006	<0.016	<0.07	<0.021
PI 593	10/17/2012	1430	<0.040	<0.001	0.007	<2.2	74.3	<0.006	<0.016	<0.07	<0.023
PI 593	11/15/2012	1400	<0.040	<0.001	0.006	<2.2	74.2	<0.006	<0.016	<0.07	<0.023
PI 593	12/12/2012	700	<0.040	<0.001	0.006	<2.2	191	<0.006	<0.016	<0.07	0.182
PI 593	1/9/2013	1130	0.072	<0.001	0.006	<2.2	126	<0.006	<0.016	<0.07	0.07
PI 593	2/12/2013	1000	<0.040	<0.001	0.006	<2.2	75.1	<0.006	<0.016	<0.07	0.04
PI 593	3/12/2013	930	<0.040	<0.001	0.005	<2.2	75.5	<0.006	<0.016	<0.07	0.044
PI 593	4/4/2013	1150	<0.040	<0.001	0.007	<2.2	80.8	<0.006	<0.016	<0.07	0.036
PI 593	4/4/2013	1405	<0.040	<0.001	0.007	2.9	80.7	<0.006	<0.016	<0.07	<0.023
PI 593	5/9/2013	1100	<0.040	<0.001	0.007	<2.2	72.5	<0.006	<0.016	<0.07	0.296
PI 593	6/4/2013	1000	<0.040	<0.001	0.006	<2.2	74.1	<0.006	<0.016	<0.07	0.032
PI 593	6/25/2013	1100	<0.040	<0.001	0.006	<2.2	71.1	<0.006	<0.016	<0.07	<0.023
PI 593	6/22/2015	1300	<0.040	<0.001	0.007	<3.0	77.7	<0.020	<0.030	<0.30	<0.050

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Local identifier	Date	Sample time	Nitrate, water, filtered, mg/L as nitrogen	Nitrite, water, filtered, mg/L as nitrogen	Orthophosphate, water, filtered, mg/L as phosphorus	Aluminum, water, filtered, µg/L	Barium, water, filtered, µg/L	Beryllium, water, filtered, µg/L	Cadmium, water, filtered, µg/L	Chromium, water, filtered, µg/L	Cobalt, water, filtered, µg/L
			00618	**00613**	**00671**	**01106**	**01005**	**01010**	**01025**	**01030**	**01035**
PI 594	7/18/2012	900	0.883	<0.001	0.02	<2.2	5.36	0.007	0.05	<0.07	0.044
PI 594	6/25/2015	1130	0.816	<0.001	0.022	<3.0	5.09	<0.020	0.053	<0.30	<0.050
PI 595	7/19/2012	1300	<0.039	0.001	<0.004	<2.2	92.3	<0.006	<0.016	0.27	0.047
PI 595	6/23/2015	930	0.048	<0.001	0.005	<3.0	143	<0.020	<0.030	<0.30	0.174
PI 598	7/19/2012	1000	<0.040	<0.001	0.076	<2.2	18.1	<0.006	0.048	0.26	0.113
PI 598	6/22/2015	1600	<0.040	<0.001	0.083	3.1	20.2	<0.020	0.031	<0.30	0.117
PI 600	7/24/2012	1100	<0.040	<0.001	0.005	<2.2	162	<0.006	<0.016	<0.07	0.081
PI 600	9/11/2012	1300	<0.040	<0.001	0.005	<2.2	158	<0.006	<0.016	<0.07	<0.021
PI 600	10/17/2012	1100	<0.037	0.003	0.005	<2.2	157	<0.006	<0.016	0.1	<0.023
PI 600	11/14/2012	1400	<0.040	<0.001	0.005	<2.2	166	<0.006	<0.016	<0.07	<0.023
PI 600	12/13/2012	1100	<0.040	<0.001	0.007	<2.2	165	<0.006	<0.016	<0.07	0.087
PI 600	1/9/2013	1400	<0.040	<0.001	0.006	<2.2	161	<0.006	<0.016	<0.07	0.042
PI 600	2/12/2013	1400	<0.040	<0.001	0.005	<2.2	165	<0.006	<0.016	<0.07	0.06
PI 600	3/12/2013	1200	<0.038	0.002	0.005	<2.2	159	<0.006	<0.016	<0.07	0.05
PI 600	4/2/2013	1500	<0.040	<0.001	0.006	<2.2	168	<0.006	<0.016	<0.07	<0.023
PI 600	5/7/2013	1300	0.054	<0.001	0.006	<2.2	144	<0.006	<0.016	<0.07	0.122
PI 600	6/4/2013	1300	<0.040	<0.001	0.005	<2.2	149	<0.006	<0.016	<0.07	0.058
PI 600	6/25/2013	1400	<0.040	<0.001	0.005	<2.2	159	<0.006	<0.016	<0.07	<0.023
PI 600	6/24/2015	1400	<0.040	<0.001	0.006	<3.0	160	<0.020	<0.030	<0.30	<0.050
PI 601	8/2/2012	1400	<0.040	<0.001	0.027	<2.2	30.2	<0.006	<0.016	<0.07	0.021
PI 601	6/25/2015	1000	<0.040	<0.001	0.029	4.8	28.2	<0.020	<0.030	<0.30	<0.050

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Local identifier	Date	Sample time	Copper, water, filtered, µg/L	Iron, water, filtered, µg/L	Iron, water, unfiltered, recoverable, µg/L	Lead, water, filtered, µg/L	Lead, water, unfiltered, recoverable, µg/L	Lithium, water, filtered, µg/L	Manganese, water, filtered, µg/L	Manganese, water, unfiltered, recoverable, µg/L	Molybdenum, water, filtered, µg/L
			01040	01046	01045	01049	01051	01130	01056	01055	01060
PI 288	6/2/1982	1615	--	M	--	--	--	--	M	--	--
PI 288	9/6/2007	1200	72.2	23.4	--	1.6	--	--	0.65	--	<0.120
PI 288	7/18/2012	1200	14.3	6.2	4.9	2.15	1.96	1.25	0.3	0.49	<0.014
PI 288	6/23/2015	930	9.2	<4.0	10	1.45	--	2.48	0.58	0.8	<0.050
PI 403	8/2/2012	1000	<0.80	91	426	0.276	0.55	14.9	615	654	0.496
PI 403	6/25/2015	1400	<0.80	75.9	2,250	<0.040	--	13.9	715	901	0.469
PI 507	7/25/2012	1230	2.6	3.3	<4.6	0.554	0.35	11.6	0.19	0.2	0.02
PI 507	9/12/2012	930	<0.80	<3.2	8.2	0.328	0.24	11.6	<0.16	<0.20	0.017
PI 507	10/16/2012	1000	1.3	<4.0	<4.6	0.284	0.22	10.9	<0.16	<0.20	0.017
PI 507	11/15/2012	1100	1.3	<4.0	<4.6	0.428	0.37	12.5	<0.16	<0.20	0.015
PI 507	12/12/2012	900	1	7	21.7	0.353	0.29	12.1	<0.16	0.26	<0.014
PI 507	1/8/2013	1100	1.2	<4.0	<4.6	0.302	0.28	11.7	0.22	<0.20	0.018
PI 507	2/13/2013	930	0.92	5.2	4.7	0.212	0.21	12.5	0.21	<0.20	0.02
PI 507	3/13/2013	1130	<0.80	<4.0	<4.6	0.596	0.56	11.5	<0.16	<0.20	0.021
PI 507	4/3/2013	1000	<0.80	4.1	25.8	0.411	0.35	12.3	0.42	<0.20	<0.014
PI 507	5/8/2013	1130	<0.80	<4.0	6.8	0.258	0.23	11.6	<0.16	<0.20	0.017
PI 507	6/5/2013	1030	<0.80	4.1	<4.6	0.24	0.2	11.2	<0.16	<0.20	0.015
PI 507	6/27/2013	1130	<0.80	<4.0	<4.6	0.249	0.24	11.2	<0.16	<0.20	0.015
PI 507	6/23/2015	1100	<0.80	<4.0	<10	0.225	--	14.5	<0.40	<0.5	<0.050
PI 524	10/1/2007	1400	<1.0	32.4	--	<0.080	--	--	20.5	--	0.333
PI 524	1/21/2012	1131	--	--	--	--	--	--	--	--	--
PI 524	7/26/2012	900	<0.80	25.6	91.1	0.039	0.1	106	20.2	18.9	0.324
PI 524	7/26/2012	901	<0.80	25.8	--	0.027	--	119	20.3	20.4	0.313
PI 524	9/11/2012	1000	<0.80	27.6	59.7	0.027	0.15	128	19.5	19.3	0.397
PI 524	10/16/2012	1330	<0.80	28.5	50.8	<0.025	0.06	73.1	19.7	19.2	0.416
PI 524	11/14/2012	1130	<0.80	27.3	41.6	0.031	0.27	103	19.2	18.2	0.414
PI 524	12/12/2012	1130	<0.80	23.3	60.3	<0.025	0.07	143	18	17.6	0.367
PI 524	12/12/2012	1131	<0.80	25.9	57.5	<0.025	0.07	140	18.5	18.2	0.388
PI 524	1/8/2013	1300	<0.80	29	75.2	0.031	0.11	130	19.5	19.9	0.373
PI 524	2/13/2013	1200	<0.80	37.6	53.1	0.083	0.18	126	16.1	19.2	0.429
PI 524	3/13/2013	1300	<0.80	26.5	67.7	0.096	0.32	127	19.6	20.6	0.413
PI 524	4/3/2013	1500	<0.80	23.3	73	<0.025	0.06	138	18.3	18.6	0.427
PI 524	5/8/2013	1400	<0.80	39.1	92.4	0.031	0.22	121	21.7	20.4	0.435
PI 524	6/5/2013	1330	<0.80	33.6	77.2	0.028	0.09	120	19.3	19.9	0.408
PI 524	6/26/2013	1230	<0.80	22.3	45.4	<0.025	0.05	130	18.5	17.9	0.374
PI 524	6/25/2015	1500	<0.80	18.6	59	<0.040	--	136	18.4	18.4	0.353
PI 524	9/22/2015	1330	<0.80	22.4	51	<0.040	--	118	20.3	18.9	0.367
PI 524	9/22/2015	1331	<0.80	20.9	37	<0.040	--	122	19.9	18.2	0.371

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Local identifier	Date	Sample time	Copper, water, filtered, µg/L	Iron, water, filtered, µg/L	Iron, water, unfiltered, recoverable, µg/L	Lead, water, filtered, µg/L	Lead, water, unfiltered, recoverable, µg/L	Lithium, water, filtered, µg/L	Manganese, water, filtered, µg/L	Manganese, water, unfiltered, recoverable, µg/L	Molybdenum, water, filtered, µg/L
			01040	01046	01045	01049	01051	01130	01056	01055	01060
PI 552	8/28/2007	1600	<0.40	67.1	--	E0.090	--	--	292	--	0.39
PI 552	7/24/2012	1530	<0.80	52.4	68.6	0.211	0.38	9.34	464	495	0.503
PI 552	6/24/2015	1445	<0.80	132	152	0.041	--	10.8	484	471	0.347
PI 553	8/29/2007	1000	10.8	14.2	1,060	E0.087	0.34	--	215	234	E0.106
PI 553	7/25/2012	1000	1.7	4.8	1,310	0.81	3.67	6.29	170	191	0.074
PI 553	6/23/2015	1400	1.3	8.1	6,170	<0.040	--	5.34	158	446	0.064
PI 555	8/30/2007	1000	5.3	<6.0	--	<0.120	--	--	3.97	--	<0.120
PI 555	7/17/2012	1200	<0.80	<3.2	8	<0.025	0.29	7.47	0.74	8.34	3.45
PI 555	6/23/2015	1100	3	<4.0	42	0.124	--	5.46	0.6	22	0.06
PI 556	8/30/2007	1230	0.97	146	237	<0.120	11.8	--	248	230	E0.100
PI 556	8/6/2015	1030	<0.80	18.5	33	<0.040	--	39.5	69.5	64.3	0.07
PI 558	9/5/2007	1100	25.7	E3.8	--	0.892	--	--	1.7	--	<0.120
PI 558	7/25/2012	1000	38.1	15.6	14.8	0.484	0.43	10.6	7.42	7.47	0.114
PI 558	7/25/2012	1001	--	--	--	--	--	--	--	--	--
PI 558	6/23/2015	1500	40	4.3	<10	0.135	--	9.46	3.17	2.8	<0.050
PI 562	10/18/2007	1100	4.7	474	8,760	0.146	2.86	--	199	361	1.53
PI 562	9/23/2015	900	<0.80	360	1,910	0.065	--	10.4	184	235	<0.050
PI 591	7/7/2011	1200	<0.50	21.6	--	<0.015	--	98.4	7.97	--	0.466
PI 591	8/5/2015	1600	<0.80	59.3	1,970	0.073	--	96.8	8.81	38.3	0.454
PI 592	8/17/2011	1200	<0.50	83.1	--	0.239	--	7.39	95.1	--	0.582
PI 592	7/26/2012	1000	<0.80	75.7	94.1	0.32	0.39	248	89.2	85.9	0.535
PI 592	6/25/2013	1100	<0.80	84.7	84.6	0.343	0.41	278	85.3	83.6	0.663
PI 592	6/24/2015	1100	<0.80	72.1	80	0.377	--	289	83.7	80.9	0.606
PI 592	6/24/2015	1101	<0.80	69.7	81	0.35	--	282	83	80.4	0.623
PI 593	7/18/2012	1500	<0.80	<3.2	5.5	0.54	0.76	15.6	16.2	15.7	0.322
PI 593	9/12/2012	1200	<0.80	<3.2	<4.6	0.453	0.39	16.5	15.3	16.1	0.334
PI 593	10/17/2012	1430	0.9	<4.0	<4.6	0.284	0.26	14.8	14.9	15.8	0.337
PI 593	11/15/2012	1400	1	<4.0	<4.6	0.431	0.5	19.2	17.6	18.6	0.323
PI 593	12/12/2012	700	1.8	22.4	35.9	0.616	3.24	21.1	56.5	58.5	0.231
PI 593	1/9/2013	1130	<0.80	8.8	<4.6	1	1.24	19	48.1	39.7	0.276
PI 593	2/12/2013	1000	1.7	<4.0	<4.6	0.15	0.19	18.1	15.2	14.6	0.337
PI 593	3/12/2013	930	1.6	4.2	<4.6	0.756	0.91	16.6	19.2	18.3	0.33
PI 593	4/4/2013	1150	<0.80	<4.0	<4.6	0.498	1.23	17.6	15.2	14.1	0.339
PI 593	4/4/2013	1405	<0.80	<4.0	<4.6	0.593	0.49	17.7	13.9	14.3	0.327
PI 593	5/9/2013	1100	<0.80	<4.0	<4.6	0.373	0.43	16.7	14.4	13.4	0.325
PI 593	6/4/2013	1000	1.1	4.9	<4.6	0.344	0.32	15.8	15.6	15.7	0.305
PI 593	6/25/2013	1100	0.88	<4.0	<4.6	0.208	0.27	15.9	13.9	13.8	0.313
PI 593	6/22/2015	1300	<0.80	<4.0	<10	1.2	--	16.1	13.5	14.6	0.31

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			01040	**01046**	**01045**	**01049**	**01051**	**01130**	**01056**	**01055**	**01060**
PI 594	7/18/2012	900	2.9	5.6	88.6	0.974	4.08	3.45	0.4	10.1	<0.014
PI 594	6/25/2015	1130	3.2	<4.0	14	0.761	--	3.26	<0.40	1.1	<0.050
PI 595	7/19/2012	1300	<0.80	83.9	124	0.365	0.82	10.2	42	37.1	0.047
PI 595	6/23/2015	930	0.8	7.4	37	0.224	--	19.7	7.47	6.8	<0.050
PI 598	7/19/2012	1000	0.83	13.2	338	0.595	0.57	0.98	246	226	0.061
PI 598	6/22/2015	1600	<0.80	27.2	148	0.619	--	2.16	262	282	0.066
PI 600	7/24/2012	1100	16.5	6	<4.6	1.28	0.86	12.9	0.42	0.4	0.351
PI 600	9/11/2012	1300	19.9	<3.2	8.2	0.433	0.33	12.1	0.23	0.64	0.346
PI 600	10/17/2012	1100	27.6	<4.0	57.5	0.342	0.24	10.4	0.5	1.49	0.326
PI 600	11/14/2012	1400	15.9	<4.0	<4.6	0.68	0.49	12.4	0.17	0.65	0.352
PI 600	12/13/2012	1100	14.9	<4.0	10.2	0.293	0.32	13.1	0.36	0.47	0.369
PI 600	1/9/2013	1400	16.5	<4.0	<4.6	0.335	0.33	12.9	0.18	0.39	0.351
PI 600	2/12/2013	1400	13.1	<4.0	<4.6	0.209	0.2	13.8	0.22	0.67	0.41
PI 600	3/12/2013	1200	1.4	<4.0	9	1.3	1.13	12.6	0.46	0.71	0.37
PI 600	4/2/2013	1500	14.1	4.3	8.8	0.496	0.46	12.3	0.48	0.49	0.401
PI 600	5/7/2013	1300	2.6	<4.0	<4.6	0.59	1.3	11.3	0.87	0.61	0.325
PI 600	6/4/2013	1300	27.2	<4.0	<4.6	0.405	0.31	11.1	0.42	0.92	0.342
PI 600	6/25/2013	1400	0.94	<4.0	4.6	0.368	0.47	12.1	0.19	0.41	0.368
PI 600	6/24/2015	1400	<0.80	<4.0	<10	0.662	--	14.3	0.48	1.2	0.466
PI 601	8/2/2012	1400	<0.80	10	729	1.39	2.22	14.1	4.77	29.1	2.04
PI 601	6/25/2015	1000	<0.80	15.8	2,500	0.083	--	15.1	5.93	73.3	1.99

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Local identifier	Date	Sample time	Nickel, water, filtered, µg/L	Silver, water, filtered, µg/L	Strontium, water, filtered, µg/L	Thallium, water, filtered, µg/L	Tungsten, water, filtered, µg/L	Vanadium, water, filtered, µg/L	Zinc, water, filtered, µg/L	Antimony, water, filtered, µg/L	Arsenic, water, filtered, µg/L	Arsenic, water, unfiltered, µg/L
			01065	01075	01080	01057	01155	01085	01090	01095	01000	01002
PI 288	6/2/1982	1615	--	--	--	--	--	--	--	--	--	--
PI 288	9/6/2007	1200	0.71	--	--	--	--	--	73.3	--	E0.11	--
PI 288	7/18/2012	1200	0.46	<0.005	13.9	<0.010	<0.010	<0.08	27.6	<0.027	0.07	<0.28
PI 288	6/23/2015	930	0.61	--	19.1	--	--	--	26.1	<0.027	<0.10	<0.5
PI 403	8/2/2012	1000	0.42	<0.005	272	<0.010	<0.010	<0.08	2	0.03	1.1	1.5
PI 403	6/25/2015	1400	0.5	--	281	--	--	--	<2.0	0.028	0.98	3
PI 507	7/25/2012	1230	0.17	<0.005	330	<0.010	<0.010	<0.08	292	0.032	0.32	0.36
PI 507	9/12/2012	930	0.14	<0.005	343	<0.010	<0.010	<0.08	70	<0.027	0.3	0.36
PI 507	10/16/2012	1000	0.14	<0.005	345	<0.010	<0.010	<0.08	94.2	0.028	0.29	0.39
PI 507	11/15/2012	1100	0.17	<0.005	344	<0.010	<0.010	<0.08	85.5	<0.027	0.31	0.36
PI 507	12/12/2012	900	0.25	<0.005	342	<0.010	<0.010	0.1	301	<0.027	0.31	0.3
PI 507	1/8/2013	1100	0.25	<0.005	334	<0.010	<0.010	<0.08	294	0.031	0.3	0.37
PI 507	2/13/2013	930	0.25	<0.005	350	<0.010	<0.010	<0.08	175	0.029	0.31	0.32
PI 507	3/13/2013	1130	0.17	<0.005	345	<0.010	<0.010	<0.08	109	<0.027	0.31	0.38
PI 507	4/3/2013	1000	0.23	<0.005	337	<0.010	<0.010	<0.08	86.7	0.04	0.33	0.39
PI 507	5/8/2013	1130	0.18	<0.005	345	<0.010	<0.010	0.1	130	0.028	0.31	0.3
PI 507	6/5/2013	1030	0.26	<0.005	339	<0.010	<0.010	<0.08	107	0.03	0.28	0.3
PI 507	6/27/2013	1130	0.17	<0.005	333	<0.010	<0.010	<0.08	30.8	<0.027	0.29	<0.28
PI 507	6/23/2015	1100	0.31	--	460	--	--	--	35.8	0.038	0.27	M
PI 524	10/1/2007	1400	<0.20	--	--	--	--	--	<4.0	--	0.29	--
PI 524	1/21/2012	1131	--	--	--	--	--	--	--	--	--	--
PI 524	7/26/2012	900	<0.09	<0.005	502	<0.010	0.094	<0.08	<1.4	<0.027	0.26	0.35
PI 524	7/26/2012	901	0.1	<0.005	493	<0.010	0.101	<0.08	<1.4	<0.027	0.27	--
PI 524	9/11/2012	1000	<0.09	<0.005	478	<0.010	0.053	<0.08	<1.4	<0.027	0.25	0.29
PI 524	10/16/2012	1330	<0.09	<0.005	466	<0.010	0.047	<0.08	<1.4	<0.027	0.28	0.31
PI 524	11/14/2012	1130	<0.09	<0.005	470	<0.010	0.059	<0.08	<1.4	<0.027	0.31	0.28
PI 524	12/12/2012	1130	<0.09	<0.010	495	<0.010	0.051	<0.08	<1.4	<0.027	0.26	0.32
PI 524	12/12/2012	1131	<0.09	<0.010	499	<0.010	0.047	<0.08	<1.4	<0.027	0.24	<0.28
PI 524	1/8/2013	1300	0.12	<0.005	466	<0.010	0.052	<0.08	<1.4	<0.027	0.28	0.35
PI 524	2/13/2013	1200	<0.09	<0.005	484	<0.010	0.049	<0.08	<1.4	<0.027	0.31	0.28
PI 524	3/13/2013	1300	0.12	<0.005	482	<0.010	0.048	<0.08	1.5	<0.054	0.28	0.32
PI 524	4/3/2013	1500	<0.09	<0.005	479	<0.010	0.051	<0.08	<1.4	<0.027	0.28	0.31
PI 524	5/8/2013	1400	0.1	<0.005	460	<0.010	0.045	<0.08	<1.4	<0.027	0.31	0.33
PI 524	6/5/2013	1330	0.19	<0.005	462	<0.010	0.051	<0.08	<1.4	<0.027	0.29	0.3
PI 524	6/26/2013	1230	0.13	<0.005	472	<0.010	0.052	<0.08	<1.4	<0.027	0.27	<0.28
PI 524	6/25/2015	1500	<0.20	--	488	--	--	--	<2.0	<0.027	0.24	<0.5
PI 524	9/22/2015	1330	<0.20	--	472	--	--	--	<2.0	<0.027	0.23	<0.5
PI 524	9/22/2015	1331	<0.20	--	475	--	--	--	<2.0	<0.027	0.23	<0.5

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Local identifier	Date	Sample time	Nickel, water, filtered, µg/L	Silver, water, filtered, µg/L	Strontium, water, filtered, µg/L	Thallium, water, filtered, µg/L	Tungsten, water, filtered, µg/L	Vanadium, water, filtered, µg/L	Zinc, water, filtered, µg/L	Antimony, water, filtered, µg/L	Arsenic, water, filtered, µg/L	Arsenic, water, unfiltered, µg/L
			01065	01075	01080	01057	01155	01085	01090	01095	01000	01002
PI 552	8/28/2007	1600	0.09	--	--	--	--	--	<6.0	--	0.34	--
PI 552	7/24/2012	1530	0.1	<0.005	376	<0.010	<0.010	<0.08	<1.4	<0.027	0.39	0.48
PI 552	6/24/2015	1445	<0.20	--	410	--	--	--	2.1	<0.027	0.42	<0.5
PI 553	8/29/2007	1000	0.13	--	--	--	--	--	<6.0	--	0.69	0.92
PI 553	7/25/2012	1000	<0.09	<0.005	202	<0.010	<0.010	<0.08	<1.4	0.057	0.69	0.95
PI 553	6/23/2015	1400	<0.20	--	188	--	--	--	<2.0	0.041	0.45	1
PI 555	8/30/2007	1000	0.15	--	--	--	--	--	<6.0	--	0.31	--
PI 555	7/17/2012	1200	<0.09	<0.005	429	<0.010	0.01	<0.08	<1.4	<0.027	0.19	0.43
PI 555	6/23/2015	1100	<0.20	--	77.8	--	--	--	<2.0	0.067	0.36	M
PI 556	8/30/2007	1230	2.2	--	--	--	--	--	7.8	--	0.55	0.65
PI 556	8/6/2015	1030	<0.20	--	820	--	--	--	<2.0	0.029	<0.10	<0.5
PI 558	9/5/2007	1100	0.72	--	--	--	--	--	9.6	--	<0.12	--
PI 558	7/25/2012	1000	0.69	<0.005	76.4	<0.010	<0.010	<0.08	5.8	<0.027	0.08	<0.28
PI 558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--
PI 558	6/23/2015	1500	0.52	--	69	--	--	--	6.7	<0.027	<0.10	<0.5
PI 562	10/18/2007	1100	<0.20	--	--	--	--	--	<4.0	--	0.55	3.9
PI 562	9/23/2015	900	<0.20	--	60	--	--	--	<2.0	<0.027	0.6	M
PI 591	7/7/2011	1200	<0.09	<0.005	395	<0.010	--	<0.08	<1.4	<0.027	0.03	--
PI 591	8/5/2015	1600	0.23	--	397	--	--	--	<2.0	0.128	<0.10	<0.5
PI 592	8/17/2011	1200	<0.09	<0.005	375	<0.010	--	<0.08	4.1	<0.027	32.3	--
PI 592	7/26/2012	1000	<0.09	<0.005	362	<0.010	0.386	<0.08	1.5	<0.027	30.1	27.6
PI 592	6/25/2013	1100	<0.09	<0.005	349	<0.010	0.193	<0.08	<1.4	<0.027	27.9	28.4
PI 592	6/24/2015	1100	<0.20	--	331	--	--	--	<2.0	<0.027	27.8	31
PI 592	6/24/2015	1101	<0.20	--	331	--	--	--	<2.0	<0.027	27.8	32
PI 593	7/18/2012	1500	<0.09	<0.005	544	<0.010	<0.010	<0.08	<1.4	0.059	1.9	1.7
PI 593	9/12/2012	1200	0.12	<0.005	531	<0.010	<0.010	<0.08	4.5	0.061	2	1.9
PI 593	10/17/2012	1430	0.1	<0.005	536	<0.010	<0.010	<0.08	2.6	0.061	2	1.8
PI 593	11/15/2012	1400	0.13	<0.005	566	<0.010	<0.010	<0.08	4.8	0.063	2	1.8
PI 593	12/12/2012	700	0.39	<0.005	991	<0.010	<0.010	0.19	5.1	0.072	1.6	1.7
PI 593	1/9/2013	1130	0.28	<0.005	739	<0.010	<0.010	0.11	1.8	0.073	1.8	1.5
PI 593	2/12/2013	1000	0.14	<0.005	548	<0.010	<0.010	<0.08	1.4	0.07	2	2
PI 593	3/12/2013	930	0.17	<0.005	527	<0.010	<0.010	0.1	2.5	0.071	1.8	1.6
PI 593	4/4/2013	1150	0.11	<0.005	541	<0.010	<0.010	<0.08	2.4	0.066	1.9	1.7
PI 593	4/4/2013	1405	0.17	<0.005	542	<0.010	<0.010	<0.08	3.1	0.064	1.9	2.2
PI 593	5/9/2013	1100	0.12	<0.005	533	0.012	<0.010	<0.08	2.3	0.086	1.9	1.9
PI 593	6/4/2013	1000	0.13	<0.005	536	<0.010	<0.010	0.12	2.1	0.064	2	1.8
PI 593	6/25/2013	1100	0.1	<0.005	514	<0.010	<0.010	0.09	<1.4	0.062	1.8	1.9
PI 593	6/22/2015	1300	<0.20	--	574	--	--	--	<2.0	0.067	1.8	2

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Local identifier	Date	Sample time	Nickel, water, filtered, µg/L	Silver, water, filtered, µg/L	Strontium, water, filtered, µg/L	Thallium, water, filtered, µg/L	Tungsten, water, filtered, µg/L	Vanadium, water, filtered, µg/L	Zinc, water, filtered, µg/L	Antimony, water, filtered, µg/L	Arsenic, water, filtered, µg/L	Arsenic, water, unfiltered, µg/L
			01065	**01075**	**01080**	**01057**	**01155**	**01085**	**01090**	**01095**	**01000**	**01002**
PI 594	7/18/2012	900	0.14	<0.005	57.4	<0.010	<0.010	<0.08	7.6	<0.027	0.31	0.42
PI 594	6/25/2015	1130	<0.20	--	53	--	--	--	8.2	<0.027	0.33	<0.5
PI 595	7/19/2012	1300	<0.09	<0.005	857	<0.010	<0.010	<0.08	81.6	0.072	0.2	<0.28
PI 595	6/23/2015	930	0.24	--	987	--	--	--	29.3	0.065	0.18	<0.5
PI 598	7/19/2012	1000	<0.09	<0.005	29.7	<0.010	<0.010	<0.08	23.1	<0.027	0.27	0.37
PI 598	6/22/2015	1600	<0.20	--	31.3	--	--	--	16.1	<0.027	0.28	M
PI 600	7/24/2012	1100	0.15	<0.005	716	<0.010	<0.010	<0.08	<1.4	0.099	1.8	2
PI 600	9/11/2012	1300	0.28	<0.005	697	<0.010	<0.010	<0.08	4.2	0.081	1.7	1.8
PI 600	10/17/2012	1100	0.38	<0.005	666	<0.010	<0.010	<0.08	4.1	0.093	1.7	1.7
PI 600	11/14/2012	1400	0.21	<0.005	733	<0.010	<0.010	<0.08	4.5	0.084	1.8	1.7
PI 600	12/13/2012	1100	0.19	<0.005	755	<0.010	<0.010	<0.08	3.4	0.077	1.7	1.5
PI 600	1/9/2013	1400	0.27	<0.005	748	<0.010	<0.010	<0.08	3.1	0.081	1.7	1.6
PI 600	2/12/2013	1400	0.26	<0.005	766	<0.010	<0.010	<0.08	2.2	0.085	1.7	1.6
PI 600	3/12/2013	1200	0.15	<0.005	700	<0.010	<0.010	<0.08	1.7	0.093	1.8	1.9
PI 600	4/2/2013	1500	0.17	<0.005	777	<0.010	<0.010	<0.08	1.9	0.075	1.7	1.6
PI 600	5/7/2013	1300	0.27	0.007	594	<0.010	<0.010	<0.08	2.3	0.09	1.5	1.7
PI 600	6/4/2013	1300	0.78	<0.005	637	<0.010	<0.010	<0.08	3.3	0.088	1.7	1.5
PI 600	6/25/2013	1400	0.18	<0.005	716	<0.010	<0.010	<0.08	2.4	0.068	1.5	1.6
PI 600	6/24/2015	1400	<0.20	--	803	--	--	--	<2.0	0.069	1.7	2
PI 601	8/2/2012	1400	<0.09	<0.005	326	<0.010	<0.010	0.12	7.2	0.052	2.5	2.7
PI 601	6/25/2015	1000	<0.20	--	332	--	--	--	3.7	0.036	2.6	3

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Local identifier	Date	Sample time	Boron, water, filtered, µg/L	Selenium, water, filtered, µg/L	Methane, water, dissolved, recoverable, µg/L	Methane by Isotech, water, dissolved, recoverable, mg/L	Methane by Seewald, water, dissolved, recoverable, mg/L	Methane, water, dissolved, recoverable, mg/L
			01020	01145	76994	68831	68831	85574
PI 288	6/2/1982	1615	--	--	--	--	--	--
PI 288	9/6/2007	1200	5	0.12	--	--	--	--
PI 288	7/18/2012	1200	4	0.09	U	--	--	--
PI 288	6/23/2015	930	<5	0.07	--	--	<0.010	--
PI 403	8/2/2012	1000	19	<0.03	15.2	--	--	--
PI 403	6/25/2015	1400	16	<0.05	--	--	0.012	--
PI 507	7/25/2012	1230	12	0.1	0.564	--	--	--
PI 507	9/12/2012	930	12	0.1	0.585	--	--	--
PI 507	10/16/2012	1000	12	0.09	0.815	--	--	--
PI 507	11/15/2012	1100	11	0.09	0.621	--	--	--
PI 507	12/12/2012	900	12	0.08	0.766	--	--	--
PI 507	1/8/2013	1100	12	0.1	0.832	--	--	--
PI 507	2/13/2013	930	12	0.11	E0.420	--	--	--
PI 507	3/13/2013	1130	13	0.11	0.837	--	--	--
PI 507	4/3/2013	1000	13	0.1	0.541	--	--	--
PI 507	5/8/2013	1130	12	0.12	0.567	--	--	--
PI 507	6/5/2013	1030	11	0.11	0.827	--	--	--
PI 507	6/27/2013	1130	10	0.09	U	--	--	--
PI 507	6/23/2015	1100	11	0.14	--	--	<0.010	--
PI 524	10/1/2007	1400	77	<0.04	--	--	--	--
PI 524	1/21/2012	1131	--	--	--	--	--	--
PI 524	7/26/2012	900	84	<0.03	4,650	5.9	--	--
PI 524	7/26/2012	901	83	<0.03	4,190	5.7	--	--
PI 524	9/11/2012	1000	76	<0.03	5,180	5	--	--
PI 524	10/16/2012	1330	76	<0.03	5,510	5.4	--	--
PI 524	11/14/2012	1130	86	<0.03	4,710	5	--	--
PI 524	12/12/2012	1130	83	<0.03	4,820	5.8	--	--
PI 524	12/12/2012	1131	86	<0.03	5,090	5.2	--	--
PI 524	1/8/2013	1300	83	<0.03	3,980	5	--	--
PI 524	2/13/2013	1200	82	<0.03	4,040	5.2	--	--
PI 524	3/13/2013	1300	82	<0.03	3,930	5.1	--	--
PI 524	4/3/2013	1500	86	<0.03	4,010	5.1	--	--
PI 524	5/8/2013	1400	76	<0.03	4,300	5.3	--	--
PI 524	6/5/2013	1330	72	<0.03	4,740	5.6	--	--
PI 524	6/26/2013	1230	78	<0.03	4,100	5.7	--	--
PI 524	6/25/2015	1500, **1505**	84	<0.05	--	-- 5.9	2.54	--
PI 524	9/22/2015	1330, **1335**	79	<0.05	--	-- 5.3	4.12	--
PI 524	9/22/2015	1331, **1336**	79	<0.05	--	-- 5.9	3.28	--

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			01020	01145	76994	68831	68831	85574
PI 552	8/28/2007	1600	8.9	<0.08	--	--	--	--
PI 552	7/24/2012	1530	9	<0.03	7.34	--	--	--
PI 552	6/24/2015	1445	8	<0.05	--	--	<0.010	--
PI 553	8/29/2007	1000	5.3	<0.08	--	--	--	--
PI 553	7/25/2012	1000	6	<0.03	0.734	--	--	--
PI 553	6/23/2015	1400	<5	<0.05	--	--	<0.010	--
PI 555	8/30/2007	1000	6	0.14	--	--	--	--
PI 555	7/17/2012	1200	17	<0.03	E0.415	--	--	--
PI 555	6/23/2015	1100	5	0.23	--	--	<0.010	--
PI 556	8/30/2007	1230	33	<0.08	--	--	--	--
PI 556	8/6/2015	1030, **1035**	43	<0.05	--	-- 0.11	0.084	--
PI 558	9/5/2007	1100	8.7	E0.06	--	--	--	--
PI 558	7/25/2012	1000	20	0.04	16.7	--	--	--
PI 558	7/25/2012	1001	--	--	--	--	--	--
PI 558	6/23/2015	1500	19	<0.05	--	--	<0.010	--
PI 562	10/18/2007	1100	7.3	<0.04	--	--	--	--
PI 562	9/23/2015	900	8	<0.05	<2	--	--	--
PI 591	7/7/2011	1200	264	<0.03	--	--	--	2.52
PI 591	8/5/2015	1600, **1605**	257	<0.05	--	2.3	0.95	--
PI 592	8/17/2011	1200	109	<0.03	--		--	4.77
PI 592	7/26/2012	1000	119	<0.03	2,780	3.8	--	--
PI 592	6/25/2013	1100	116	0.04	2,800	3.9	--	--
PI 592	6/24/2015	1100, **1105**	117	<0.05	--	-- 4.1	1.79	--
PI 592	6/24/2015	1101, **1106**	118	<0.05	--	-- 4.0	1.48	--
PI 593	7/18/2012	1500	33	<0.03	E0.452	--	--	--
PI 593	9/12/2012	1200	31	<0.03	E0.316	--	--	--
PI 593	10/17/2012	1430	28	<0.03	E0.359	--	--	--
PI 593	11/15/2012	1400	30	<0.03	E0.388	--	--	--
PI 593	12/12/2012	700	27	<0.03	0.549	--	--	--
PI 593	1/9/2013	1130	31	<0.03	E0.461	--	--	--
PI 593	2/12/2013	1000	34	<0.03	E0.382	--	--	--
PI 593	3/12/2013	930	33	<0.03	E0.414	--	--	--
PI 593	4/4/2013	1150	34	<0.03	1.76	--	--	--
PI 593	4/4/2013	1405	34	<0.03	0.822	--	--	--
PI 593	5/9/2013	1100	30	0.04	E0.427	--	--	--
PI 593	6/4/2013	1000	27	<0.03	E0.462	--	--	--
PI 593	6/25/2013	1100	28	<0.03	U	--	--	--
PI 593	6/22/2015	1300	31	<0.05	--	--	<0.010	--

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Local identifier	Date	Sample time	Boron, water, filtered, µg/L	Selenium, water, filtered, µg/L	Methane, water, dissolved, recoverable, µg/L	Methane by Isotech, water, dissolved, recoverable, mg/L	Methane by Seewald, water, dissolved, recoverable, mg/L	Methane, water, dissolved, recoverable, mg/L
			01020	**01145**	**76994**	**68831**	**68831**	**85574**
PI 594	7/18/2012	900	5	0.08	U	--	--	--
PI 594	6/25/2015	1130	<5	0.05	--	--	<0.010	--
PI 595	7/19/2012	1300	10	0.33	58	--	--	--
PI 595	6/23/2015	930	11	0.08	--	--	<0.010	--
PI 598	7/19/2012	1000	<3	<0.03	7.88	--	--	--
PI 598	6/22/2015	1600	<5	<0.05	--	--	<0.010	--
PI 600	7/24/2012	1100	10	<0.03	U	--	--	--
PI 600	9/11/2012	1300	9	<0.03	0.865	--	--	--
PI 600	10/17/2012	1100	9	<0.03	U	--	--	--
PI 600	11/14/2012	1400	10	<0.03	E0.264	--	--	--
PI 600	12/13/2012	1100	11	<0.03	U	--	--	--
PI 600	1/9/2013	1400	10	<0.03	E0.262	--	--	--
PI 600	2/12/2013	1400	11	<0.03	U	--	--	--
PI 600	3/12/2013	1200	11	0.04	U	--	--	--
PI 600	4/2/2013	1500	11	0.05	U	--	--	--
PI 600	5/7/2013	1300	9	0.04	E0.229	--	--	--
PI 600	6/4/2013	1300	8	0.05	U	--	--	--
PI 600	6/25/2013	1400	9	<0.03	--	--	--	--
PI 600	6/24/2015	1400	11	0.08	--	--	0.01	--
PI 601	8/2/2012	1400	22	0.12	1.22	--	--	--
PI 601	6/25/2015	1000	21	0.1	--	--	<0.010	--

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Local identifier	Date	Sample time	Radium-226, water, filtered, radon method, pCi/L	Radium-226, water, unfiltered, pCi/L	Radon-222, water, unfiltered, pCi/L	Uranium (natural), water, filtered, µg/L	delta C-13/C-12 of methane, water, dissolved, relative to VPDB, per mil	delta H-2/H-1 of methane, water, dissolved, relative to VSMOW, per mil
			09511	09501	82303	22703	65241	65245
PI 288	6/2/1982	1615	--	--	--	--	--	--
PI 288	9/6/2007	1200	--	--	2,650	0.047	--	--
PI 288	7/18/2012	1200	--	--	2,840	0.05	--	--
PI 288	6/23/2015	930	--	--	2,200	0.048	--	--
PI 403	8/2/2012	1000	--	--	310	0.912	--	--
PI 403	6/25/2015	1400	--	0.25	330	0.991	--	--
PI 507	7/25/2012	1230	--	--	1,960	0.136	--	--
PI 507	9/12/2012	930	--	--	1,760	0.127	--	--
PI 507	10/16/2012	1000	--	--	1,840	0.118	--	--
PI 507	11/15/2012	1100	--	--	1,920	0.11	--	--
PI 507	12/12/2012	900	--	--	1,900	0.119	--	--
PI 507	1/8/2013	1100	--	--	1,900	0.114	--	--
PI 507	2/13/2013	930	--	--	1,910	0.122	--	--
PI 507	3/13/2013	1130	--	--	1,890	0.112	--	--
PI 507	4/3/2013	1000	--	--	500	0.12	--	--
PI 507	5/8/2013	1130	--	--	1,840	0.105	--	--
PI 507	6/5/2013	1030	--	--	1,850	0.097	--	--
PI 507	6/27/2013	1130	0.041	--	1,880	0.097	--	--
PI 507	6/23/2015	1100	--	--	1,590	0.136	--	--
PI 524	10/1/2007	1400	--	--	470	0.222	--	--
PI 524	1/21/2012	1131	--	--	--	--	--	--
PI 524	7/26/2012	900	--	--	460	0.137	-64.55	-216.9
PI 524	7/26/2012	901	--	--	--	0.138	-64.52	-219.9
PI 524	9/11/2012	1000	--	--	510	0.184	-64.63	-221.2
PI 524	10/16/2012	1330	--	--	540	0.202	-64.63	-218.9
PI 524	11/14/2012	1130	--	--	480	0.184	-64.7	-225
PI 524	12/12/2012	1130	--	--	450	0.131	-64.65	-221.7
PI 524	12/12/2012	1131	--	--	470	0.157	-64.62	-223.9
PI 524	1/8/2013	1300	--	--	550	0.162	-64.68	-219.5
PI 524	2/13/2013	1200	--	--	470	0.182	-64.74	-223
PI 524	3/13/2013	1300	--	--	540	0.169	-64.82	-223.6
PI 524	4/3/2013	1500	--	--	1,890	0.146	-64.75	-223
PI 524	5/8/2013	1400	--	--	500	0.225	-64.66	-226
PI 524	6/5/2013	1330	--	--	530	0.202	-64.65	-223.2
PI 524	6/26/2013	1230	0.29	--	540	0.149	-64.63	-223.9
PI 524	6/25/2015	1500	--	--	380	0.095	-63.44	-219.4
PI 524	9/22/2015	1330	--	0.3	450	0.157	-63.28	-221.2
PI 524	9/22/2015	1331	--	0.3	470	0.147	-63.12	-221.6

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Local identi-fier	Date	Sample time	Radium-226, water, filtered, radon method, pCi/L	Radium-226, water, unfiltered, pCi/L	Radon-222, water, unfiltered, pCi/L	Uranium (natural), water, filtered, µg/L	delta C-13/C-12 of methane, water, dissolved, relative to VPDB, per mil	delta H-2/H-1 of methane, water, dissolved, relative to VSMOW, per mil
			09511	09501	82303	22703	65241	65245
PI 552	8/28/2007	1600	--	--	150	0.21	--	--
PI 552	7/24/2012	1530	--	--	121	0.102	--	--
PI 552	6/24/2015	1445	--	--	73	0.095	--	--
PI 553	8/29/2007	1000	--	--	300	E0.038	--	--
PI 553	7/25/2012	1000	--	--	242	0.034	--	--
PI 553	6/23/2015	1400	--	0.24	223	0.019	--	--
PI 555	8/30/2007	1000	--	--	2,430	0.332	--	--
PI 555	7/17/2012	1200	--	--	2,690	<0.004	--	--
PI 555	6/23/2015	1100	--	0.16	2,510	0.386	--	--
PI 556	8/30/2007	1230	--	--	330	0.134	--	--
PI 556	8/6/2015	1030	--	--	56	0.139	-48.04	--
PI 558	9/5/2007	1100	--	--	1,730	<0.040	--	--
PI 558	7/25/2012	1000	--	--	1,410	<0.004	--	--
PI 558	7/25/2012	1001	--	--	1,480	--	--	--
PI 558	6/23/2015	1500	--	--	1,190	<0.014	--	--
PI 562	10/18/2007	1100	--	--	150	0.276	--	--
PI 562	9/23/2015	900	--	--	138	0.018	--	--
PI 591	7/7/2011	1200	--	--	77	0.009	--	--
PI 591	8/5/2015	1600	--	0.71	94	0.015	-58.97	-203.2
PI 592	8/17/2011	1200	--	--	1,210	0.014	--	--
PI 592	7/26/2012	1000	--	--	1,320	0.012	-64.41	-201.8
PI 592	6/25/2013	1100	0.26	--	1,350	0.013	-64.52	-204.5
PI 592	6/24/2015	1100	--	--	1,210	0.015	-63.25	-198.0
PI 592	6/24/2015	1101	--	--	1,240	<0.014	-63.32	-199.7
PI 593	7/18/2012	1500	--	--	1,240	0.59	--	--
PI 593	9/12/2012	1200	--	--	1,300	0.613	--	--
PI 593	10/17/2012	1430	--	--	1,170	0.611	--	--
PI 593	11/15/2012	1400	--	--	1,400	0.6	--	--
PI 593	12/12/2012	700	--	--	350	1.31	--	--
PI 593	1/9/2013	1130	--	--	880	0.906	--	--
PI 593	2/12/2013	1000	--	--	1,180	0.604	--	--
PI 593	3/12/2013	930	--	--	1,130	0.606	--	--
PI 593	4/4/2013	1150	--	--	1,130	0.635	--	--
PI 593	4/4/2013	1405	--	--	1,130	0.627	--	--
PI 593	5/9/2013	1100	--	--	1,150	0.571	--	--
PI 593	6/4/2013	1000	--	--	1,320	0.583	--	--
PI 593	6/25/2013	1100	0.15	--	1,290	0.547	--	--
PI 593	6/22/2015	1300	--	--	1,100	0.558	--	--

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Local identifier	Date	Sample time	Radium-226, water, filtered, radon method, pCi/L	Radium-226, water, unfiltered, pCi/L	Radon-222, water, unfiltered, pCi/L	Uranium (natural), water, filtered, µg/L	delta C-13/C-12 of methane, water, dissolved, relative to VPDB, per mil	delta H-2/H-1 of methane, water, dissolved, relative to VSMOW, per mil
			09511	09501	82303	22703	65241	65245
PI 594	7/18/2012	900	--	--	4,100	0.073	--	--
PI 594	6/25/2015	1130	--	--	2,630	0.056	--	--
PI 595	7/19/2012	1300	--	--	1,050	0.193	--	--
PI 595	6/23/2015	930	--	--	1,060	0.131	--	--
PI 598	7/19/2012	1000	--	--	3,000	0.017	--	--
PI 598	6/22/2015	1600	--	--	2,710	0.015	--	--
PI 600	7/24/2012	1100	--	--	880	1.11	--	--
PI 600	9/11/2012	1300	--	--	860	1.11	--	--
PI 600	10/17/2012	1100	--	--	--	1.09	--	--
PI 600	11/14/2012	1400	--	--	920	1.14	--	--
PI 600	12/13/2012	1100	--	--	930	1.15	--	--
PI 600	1/9/2013	1400	--	--	1,080	1.1	--	--
PI 600	2/12/2013	1400	--	--	1,090	1.12	--	--
PI 600	3/12/2013	1200	--	--	1,000	1.04	--	--
PI 600	4/2/2013	1500	--	--	1,030	1.1	--	--
PI 600	5/7/2013	1300	--	--	920	0.926	--	--
PI 600	6/4/2013	1300	--	--	1,080	0.975	--	--
PI 600	6/25/2013	1400	0.08	--	1,080	1.01	--	--
PI 600	6/24/2015	1400	--	--	1,240	1.12	--	--
PI 601	8/2/2012	1400	--	--	2,190	0.424	--	--
PI 601	6/25/2015	1000	--	--	2,060	0.427	--	--

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