USGS
science for a changing world

Prepared in cooperation with the Pike County Conservation District

A Reconnaissance Spatial and Temporal Baseline Assessment of Methane and Inorganic Constituents in Groundwater in Bedrock Aquifers, Pike County, Pennsylvania, 2012–13

Scientific Investigations Report 2014–5117

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

Cover. Outcrop of the Mahantango Formation and Raymondskill Falls, Pike County, Pennsylvania. Photograph by Leif Olson, U.S. Geological Survey.

A Reconnaissance Spatial and Temporal Baseline Assessment of Methane and Inorganic Constituents in Groundwater in Bedrock Aquifers, Pike County, Pennsylvania, 2012–13

By Lisa A. Senior

Prepared in cooperation with the Pike County Conservation District

Scientific Investigations Report 2014–5117

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:
Senior, L.A., 2014, A reconnaissance spatial and temporal assessment of methane and inorganic constituents in groundwater in bedrock aquifers, Pike County, Pennsylvania, 2012–13: U.S. Geological Survey Scientific Investigations Report 2014–5117, 91 p., *http://dx.doi.org/10.3133/sir20145117*.

ISSN 2328-0328 (online)

Acknowledgments

The assistance of all well owners who allowed their wells to be sampled for this study is appreciated. The assistance of Pike County Conservation District staff, including Susan Beecher, Sally Corrigan, and Lori Colgan, in obtaining permissions from well owners and supporting this study is gratefully acknowledged. Samples were collected by U.S. Geological Survey personnel Leif Olson and Robert Meyer. The study was supported, in part, with the financial contributions from the Pike County Scenic Rural Character Preservation Program.

Contents

Figures

Tables

Conversion Factors and Datums

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	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Pressure	
inch of mercury at 60ºF (in Hg)	3.377	kilopascal (kPa)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

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

°F=(1.8×°C)+32

Pressure in milliliters of mercury may be converted to pascals by multiplying by 1333.32.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). This vertical datum is referenced to a mean sea level.

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

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

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

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

1 milligram per liter is approximately equivalent to 1 part per million (ppm) and 1 microgram per liter is approximately equivalent to 1 part per billion (ppb).

A Reconnaissance Spatial and Temporal Baseline Assessment of Methane and Inorganic Constituents in Groundwater in Bedrock Aquifers, Pike County, Pennsylvania, 2012–13

By Lisa A. Senior

Abstract

Pike County in northeastern Pennsylvania is underlain by the Devonian-age Marcellus Shale and other shale formations that have potential for natural gas development. During 2012–13, the U.S. Geological Survey in cooperation with the Pike County Conservation District conducted a reconnaissance study to assess baseline shallow groundwater quality in bedrock aquifers prior to possible shale-gas development in the county. For the spatial component of the assessment, 20 wells were sampled in summer 2012 to provide data on the occurrence of methane and other aspects of existing groundwater quality throughout the county, including concentrations of inorganic constituents commonly present at low levels in shallow, fresh groundwater but elevated in brines. For the temporal component of the assessment, 4 of the 20 wells sampled in summer 2012 were sampled monthly from July 2012 through June 2013 to provide data on seasonal variability in groundwater quality. All water samples were analyzed for major ions, nutrients, selected inorganic trace constituents (including metals and other elements), stable isotopes of water, radon-222, gross alpha- and gross beta-particle activity, dissolved gases (methane, ethane, and ethene), and, if possible, isotopic composition of methane. Additional analyses for boron and strontium isotopes, age-dating of water, and radium-226 were done on water samples collected from six wells in June 2013.

Results of the summer 2012 sampling show that water from 16 (80 percent) of 20 wells had detectable concentrations of methane, but concentrations were less than 0.1 milligram per liter (mg/L) in most well-water samples; only two well-water samples had concentrations greater than 1 mg/L. The groundwater with elevated methane also had a chemical composition that differed in some respects (pH, selected major ions, and inorganic trace constituents) from groundwater with low methane concentrations. The two well-water samples with the highest methane concentrations (about 3.7 and 5.8 mg/L) also had the highest pH values (8.7 and 8.3, respectively) and the highest concentrations of sodium, lithium, boron, fluoride, and bromide. Elevated concentrations of some other constituents, such as barium, strontium, and chloride, were not limited to well-water samples with elevated methane, although the two samples with elevated methane also had among the highest concentrations of these constituents.

One sample with elevated methane concentrations also had elevated arsenic concentrations, with the arsenic concentration of 30 micrograms per liter (µg/L) exceeding the drinking-water standard of 10 µg/L for arsenic. No other sample from the 20 wells sampled in summer 2012 had concentrations of constituents that exceeded any established primary drinking-water standards. However, radon-222 activities ranging up to 4,500 picocuries per liter (pCi/L) exceeded the proposed drinking-water standard of 300 pCi/L in 85 percent of the 20 well-water samples.

The isotopic composition methane in the two high-methane samples ($\delta^{13}C_{CH4}$ values of -64.55 and -64.41 per mil and δD_{CH4} values of -216.9 and -201.8 per mil, respectively) indicates a predominantly microbial source for the methane formed by a carbon dioxide reduction process. The stable isotopic composition of water (δD_{H20} and $\delta^{18}O_{H20}$) in samples from all 20 wells falls on the local meteoric line, indicating water in the wells was of relatively recent meteoric origin (modern precipitation), including samples with elevated methane concentrations.

Analytical results for 4 of the 20 wells sampled monthly for 1 year ending June 2013 in order to assess temporal variability in groundwater quality show that concentrations of major ions generally varied by less than 20 percent, with most differences less than 4 mg/L. 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. The isotopic composition of methane in water from the one well with relatively high methane varied slightly in the monthly samples, ranging from about -64.5 to -64.8 per mil for $\delta^{13}C_{CH4}$ and from about -217 to -228 per mil for δD_{CH4}. The $\delta^{13}C$ values for dissolved inorganic carbon (DIC) in water from this well were consistent with microbial methane

formation by carbon dioxide reduction (drift-type methane) and varied little in the temporal samples, ranging from -10.5 to -10.1 per mil.

Additional analyses of samples collected in late June 2013 from six wells with a range of methane and trace constituent concentrations provided baseline data on strontium and boron isotopic compositions ($^{87}Sr/^{86}Sr$ ratios and $\delta^{11}B$, respectively) that potentially may be used to differentiate among sources of these constituents. The strontium and boron isotopic composition determined in the six shallow Pike County groundwater samples had $^{87}Sr/^{86}Sr$ ratios of 0.71426 to 0.71531 and $\delta^{11}B$ values of 11.7 to 27.0 per mil, which differ from those reported for brines in Devonian-age formations in Pennsylvania.

The June 2013 samples were also analyzed for radium-226 and dissolved gases for age dating. Activities of radium-226 ranged from 0.041 to 0.29 pCi/L in water samples from the six wells and were less than the drinking-water standard of 5 pCi/L for combined radium-226 and radium-228. Age-dating of groundwater using a method based on the presence of anthropogenic gases (chlorofluorocarbons and sulfur hexafluoride) released into the atmosphere yielded estimated recharge dates for water from these six wells that ranged from the 1940s to early 2000s. The oldest water was in samples from wells that had the highest methane concentrations and the youngest water was in samples from a continuously pumped 300-foot deep production well.

Introduction

Exploration for, and production of, natural gas in the Marcellus Shale geological formation has accelerated since 2007, largely because of the expansion of hydraulic fracturing (unconventional) methods, and is well underway in Pennsylvania and surrounding states. Another formation in the area with potential for natural-gas development is the Utica Shale (Kirschbaum and others, 2012). The proposed drilling of thousands of new gas wells and related activities have the potential to contaminate freshwater aquifers that provide water to drinking-supply wells and the base flow of streams. One of the serious issues associated with natural-gas extraction is the potential migration of methane (the major component of natural gas) from improperly constructed gas wells into freshwater aquifers. The methane may cause degradation of drinking-water aquifers and create an explosion hazard if it migrates to and accumulates in a homeowner's water-supply well. Methane contamination of groundwater used for drinking water has been reported in northeastern Pennsylvania (Dimock Township in Susquehanna County), where the cause was thought to be gas migration along the improperly sealed annulus of a deep gas well into nearby shallow groundwater (Pennsylvania Department of Environmental Protection, 2009). Other concerns associated with the natural-gas drilling, exploration, and development include the potential for groundwater contamination from naturally occurring brines in flow-back waters through spills near the gas well head or along routes used for wastewater transport to disposal sites and (or) migration along the gas-well annulus or other fractures near the gas well. These brines may contain elevated concentrations of radium, barium, strontium, chloride, and other inorganic constituents (Haluszczak and others, 2013; Rowan and others, 2011) that may pose a risk to human health or degrade stream and groundwater quality if released into the environment. Reported maximum concentrations of selected constituents in brines from oil and gas wells collected since 1982 in Pennsylvania (Dresel and Rose, 2010; Haluszczak and others, 2013) are listed in table 1. In addition to the brine-related constituents that potentially

Table 1. Maximum concentrations reported for selected inorganic constituents in oil and gas well brines or flow-back waters in Pennsylvania.

[PA, Pennsylvania; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; TDS, total dissolved solids; pCi/L, picocuries per liter; --, no data]

Constituent	Concentration units	Reported maximum concentration	
		Western PA[1]	Marcellus flow back[2]
Major ions			
Calcium	mg/L	41,600	17,900
Magnesium	mg/L	4,150	--
Potassium	mg/L	4,860	5,240
Sodium	mg/L	83,000	37,800
Chloride	mg/L	207,000	105,000
Sulfate	mg/L	850	420
Alkalinity	mg/L as $CaCO_3$	1,520	939
TDS	mg/L	354,000	197,000
Minor ions, trace elements, and metals			
Barium	mg/L	4,370	6,270
Bromide	mg/L	2,240	613
Copper	mg/L	0.13	--
Iodide	mg/L	56	--
Iron	mg/L	494	--
Lithium	mg/L	315	--
Lead	mg/L	0.04	--
Manganese	mg/L	96	29
Strontium	mg/L	13,100	3,570
Zinc	mg/L	1.3	--
Radionuclides			
Radium-226	pCi/L	5,300	5,830
Radium-228	pCi/L	--	710

[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 Managament reported by Haluszczak and others (2013).

pose risks to human health, radon-222, a radioactive element, has been reported to occur in natural gas, including gas from the Marcellus Shale (Resnikoff, 2012; Rowan and Kraemer, 2012).

In northeastern Pennsylvania, the Delaware River Basin Commission (DRBC) currently (spring 2014) has a temporary moratorium on drilling in the parts of the basin that drain to special-protection waters (Delaware River Basin Commission, 2011), an area which includes Pike County (fig. 1). However, despite the current moratorium, gas exploration and production in the Delaware River Basin, including Pike County, remains a possibility. Since 2007 to date (2014), nine shale-gas wells have been drilled in Wayne County, adjacent to Pike County to the northwest, and many more (about 940 wells as of April 16, 2014 [Pennsylvania Department of Environmental Protection, 2013]) just to the west of Wayne County in Susquehanna County, which lies outside of the Delaware River Basin (fig. 1). Three deep test holes for natural gas exploration were drilled in Pike County (fig. 1) between 1958 and 1971, two of which penetrated the Marcellus Shale, and one of these was deep enough to reach the Utica Shale (Sevon and others, 1989). Continued interest in well drilling is likely in northeastern Pennsylvania, as indicated by the number of permits issued by the Pennsylvania Department of Environmental Protection (PADEP) and the amount of land with gas leases. In Pike County, there is the potential for shale-gas development in the Marcellus and Utica Shales, and as of February 2011, 1,870 acres, mostly in northern and western parts of the county, were leased for shale-gas development (Pike County Marcellus Shale Task Force, 2011).

In areas such as Pike County, where groundwater is the primary source of drinking water and drilling for natural gas is possible but has not commenced, baseline groundwater quality data are needed to characterize conditions prior to gas-well development. The importance of sufficient baseline data is illustrated, for example, by uncertainties in findings about the origin of methane contamination of drinking water in an area in southwestern Susquehanna County (fig. 1) in recent studies using post-drilling data (Osborn and others, 2011; Molofsky and others, 2013). Without baseline data collected using scientifically accepted standard protocols, it is difficult to assess potential effects of future activities, such as gas-well drilling, on the quality of groundwater.

In 2007, the U.S. Geological Survey (USGS) conducted an assessment of groundwater quality in Pike County in cooperation with the Pike County Conservation District (PCCD) by sampling groundwater from 20 domestic wells completed in bedrock aquifers and the glacial aquifer near the Delaware River (Senior, 2009). The assessment focused on possible effects of land use and naturally occurring constituents that might pose a health risk in drinking water. This study did not include all constituents that might be introduced to groundwater in association with natural-gas development, although baseline data on concentrations of chloride and radioactivity were collected and a few samples (4) were analyzed for methane, as part of age-dating the groundwater. Also, wells were sampled only once in the 2007 study and mainly provided a synoptic spatial assessment of groundwater quality in Pike County. A few of the wells sampled by USGS in 2007 had been sampled by USGS once or twice previously since 1982. Little to no data are available to describe the temporal variability of groundwater quality in Pike County. Because groundwater quality may vary seasonally, a single sample may be insufficient to determine pre-development conditions.

To help establish baseline groundwater quality in Pike County before extensive shale-gas development, additional data are needed for spatial and temporal characterization. In 2012, the USGS in cooperation with the PCCD, initiated a reconnaissance study to acquire additional groundwater-quality data, including (1) more groundwater samples in areas likely to experience shale-gas-exploration and development; (2) analyses specifically selected to establish baseline concentrations of shale-gas-related constituents, such as methane and barium, not widely included in earlier assessments (Senior, 2009); and (3) data on temporal variability of groundwater quality.

Purpose and Scope

This report presents results of the 2012–13 reconnaissance assessment of baseline groundwater quality in bedrock aquifers used for drinking-water supply in Pike County prior to potential shale-gas development. The study, conducted by USGS in cooperation with the PCCD, included spatial and temporal components for the reconnaissance groundwater-quality assessment. For the spatial component of the assessment, 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). For the temporal component of the assessment, 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. This report documents spatial and temporal concentrations of constituents in groundwater that may be affected by potential shale-gas development and thereby helps to establish (1) baseline concentrations of methane, ethane, and other hydrocarbon gases present in groundwater and, if possible, isotopic composition of the dissolved methane; (2) baseline general water quality and concentrations of selected inorganic constituents in groundwater, including major ions, trace constituents (metals, other elements), and some radionuclides commonly present in high concentrations in shale-gas brines; and (3) an estimate of temporal variability in groundwater quality as defined by analyzed constituents. Existing groundwater quality is also evaluated with respect to drinking-water standards to determine whether concentrations of analyzed constituents exceed any established maximum contaminant levels.

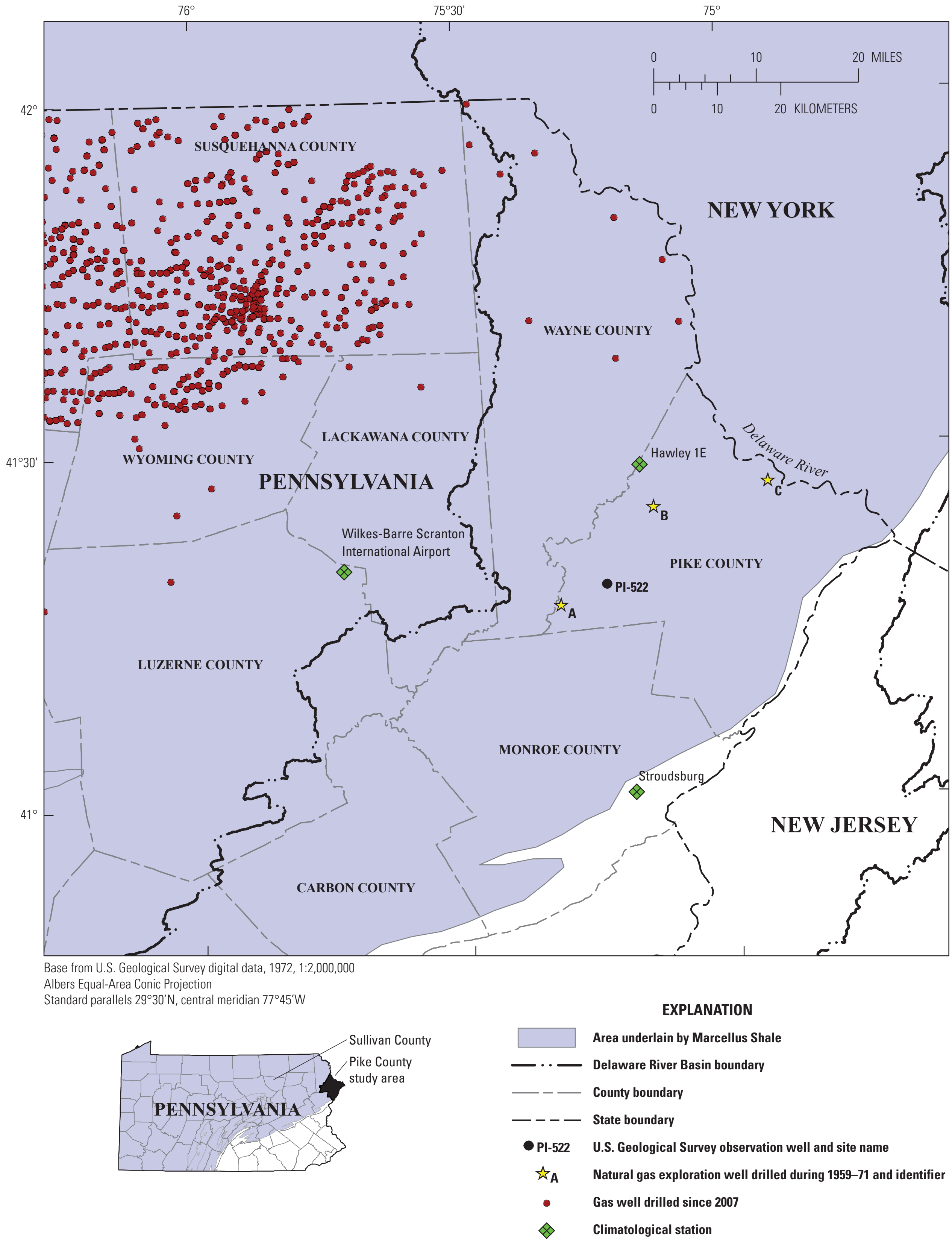


Figure 1. Location of Pike County and area underlain by Marcellus Shale in northeastern Pennsylvania. Also shown are locations of three climatological stations near Pike County, observation well PI-522, and three natural-gas exploration wells drilled during 1958–71 in Pike County, Pennsylvania.

Description of Study Area

Pike County covers 547 square miles in northeastern Pennsylvania and is flanked on the north and east by the Delaware River that forms the boundary between the adjacent states of New York and New Jersey (fig. 1). Land-surface elevations are highest (over 2,000 feet above the North American Vertical Datum of 1988 [NAVD 88]) in the southwestern corner of the county and lowest along the Delaware River (as low as about 320 feet above NAVD 88). The climate and general physical characteristics have been described by Davis (1989).

Hydrogeologic Setting

Most of the county is underlain by Devonian-age fractured-rock aquifers (shales, siltstones, and sandstones) (fig. 2) with high-yielding unconsolidated Quaternary-age glacial deposits in a band parallel to the Delaware River on the eastern edge of the county and in some upland stream valleys. Groundwater in bedrock units and overlying glacial deposits is the main source of water supply used in 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. In Pike County, local, intermediate, and regional groundwater flow systems are thought to be present, with local and intermediate systems discharging to streams and larger tributaries, respectively, and the deeper regional system discharging to the Delaware River (Davis, 1989). Only a small part of recharge is thought to enter and flow through the deeper regional flow system (Davis, 1989). For the surface-water system, streams eventually drain toward the Delaware River, radiating from near the center of Pike County. The rock types, aquifer properties, and hydrogeology of the county are described in detail by Davis (1989).

The bedrock geologic units that underlie and crop out in Pike County have been mapped using the Pennsylvania Geological Survey nomenclature (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. 2). Detailed description of the geology and alternate nomenclature of Catskill Formation members is given by Sevon and others (1989). These Devonian-age sedimentary rock formations 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. The bedrock units generally dip to the west at moderate to low angles, with the steepest dips (up to 20 degrees) in the eastern part of the county and the shallowest dips (0 to 5 degrees) in the western part of the county (Sevon and others, 1989).

The Marcellus Shale (geologic unit currently under development for natural gas in the region and also known as the Marcellus Formation of Hamilton Group) underlies all of Pike County and crops out at the eastern edge of the county near the Delaware River (figs. 1 and 2). 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 to 150 feet 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 (figs. 1 and 2) penetrated the Marcellus Formation at depths of 5,500 to 7,500 feet below land surface, and the deepest (Pennsylvania Department of Forest and Water #1) of the three penetrated the Utica Formation at depth of about 13,000 feet below land surface (fig. 3; Sevon and others, 1989).

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. Additionally, 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 (Sevon and others, 1989).

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 (2 percent), and commercial (2 percent) (fig. 4; 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 in active farms according to U.S. Department of Agriculture, 2012).

Population has been growing in Pike County since 1940 (Davis, 1989). Pike County's percent increase in population from 1990 to 2000 was ranked 36th out of 3,141 counties in the United States, with an increase of 65.6 percent (or 18,336 people) from a 1990 population of 27,966 to a 2000 population of 46,302 (U.S. Census Bureau, 2000). The period from 1970 to 1980 also represents a period of relatively large population growth, increasing 54.6 percent to a population of 18, 271 in 1980 (Davis, 1989). Although the recent rate of population growth has slowed, growth has continued in Pike County. The 2010 population of 57,369 (U.S. Census Bureau, 2013) represents an increase of 24 percent from the population in 2000 and is more than three times the population in 1980. Because much land is public or private forested land, the population growth occurs in limited areas, as can been seen by the distribution of residential land in Pike County (fig. 4).

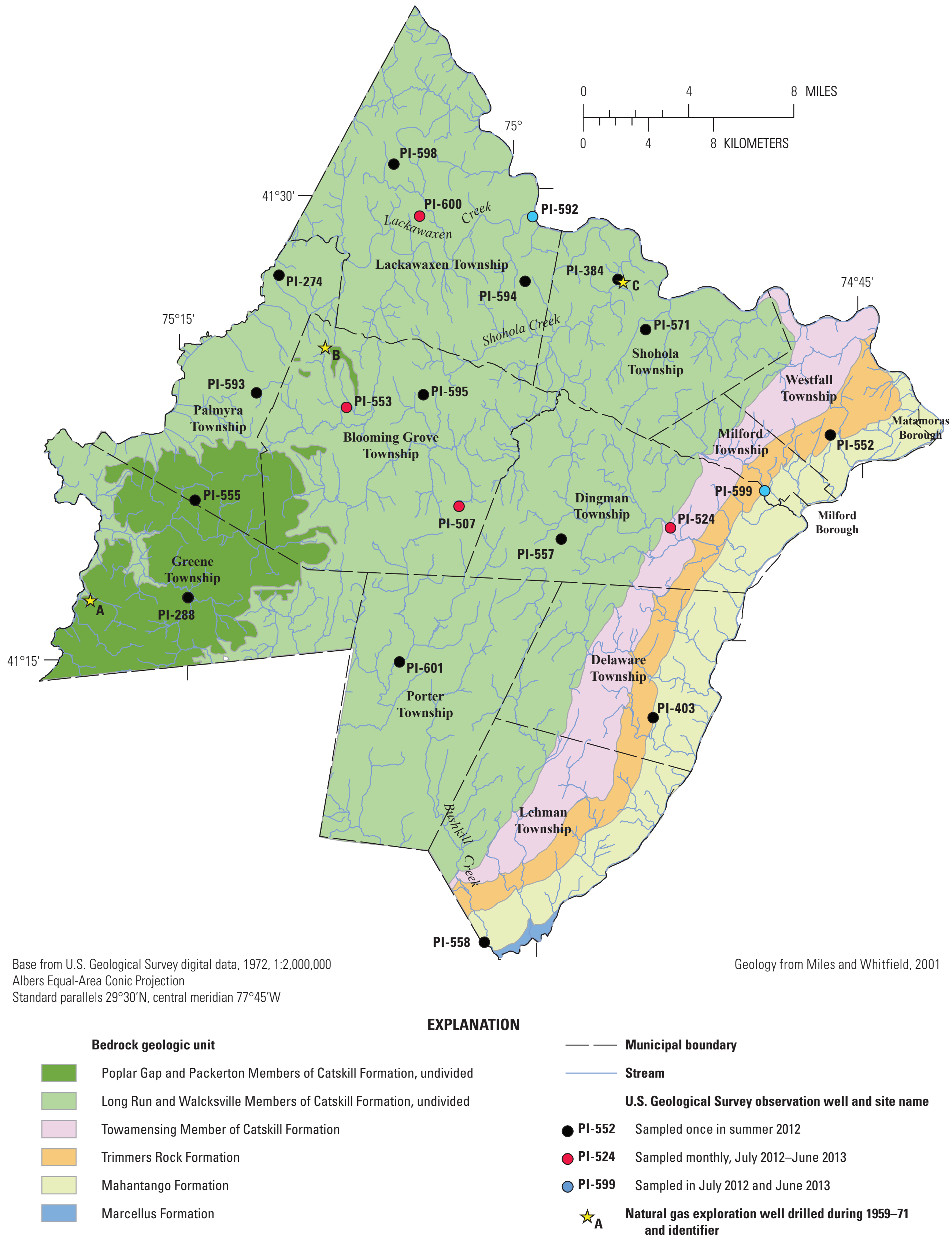


Figure 2. Geology of Pike County, Pennsylvania, showing mapped bedrock units and location of 20 wells sampled by the U.S. Geological Survey during 2012–13.

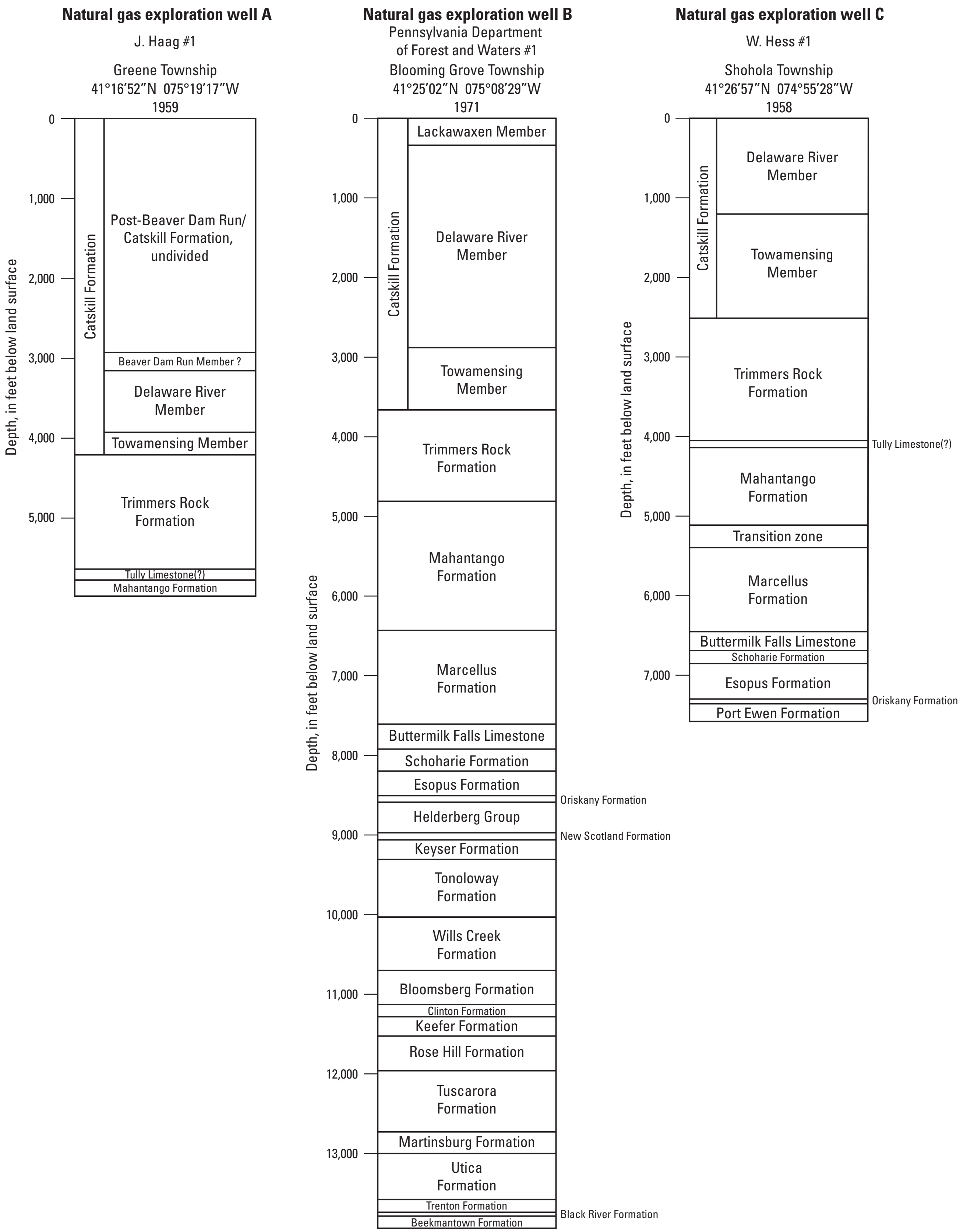
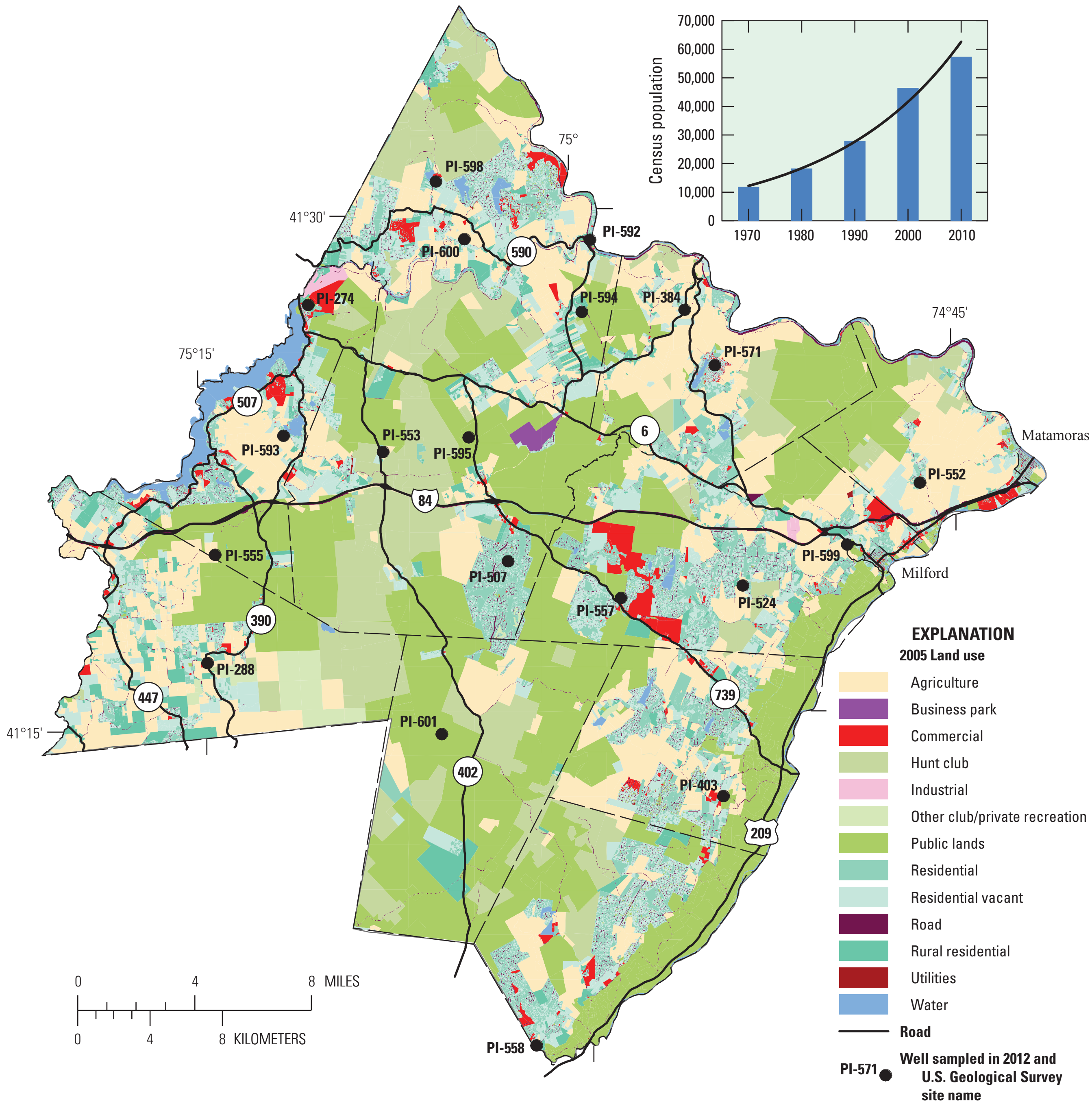


Figure 3. Stratigraphic columns showing summary of rock units penetrated by three natural gas exploration wells in Pike County, Pennsylvania. Geologic nomenclature, well name, location, and date of drilling listed for each well are from Sevon and others, 1989, figure 2, p. 8. Location of wells shown in figure 1.



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

Land use from Pike County Planning Commission, 2006

Figure 4. Land use in 2005 and location of 20 wells sampled in summer 2012 in Pike County, Pennsylvania. Inset shows county population determined by U.S. Census for each decade during 1970–2010.

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 (fig. 4). In addition to the census population, use of land for recreation results in seasonal increases in population and potential stresses on the groundwater system and associated surface waters.

Groundwater is the main source of drinking water in the county. Individual on-site wells are common in many residential areas, although 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, with sand mounds 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

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). No pesticides were detected in the 2001 samples.

In 2007, the USGS in cooperation with the PCCD, sampled 20 domestic wells throughout Pike County to provide a current 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 in 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 proposed drinking-water standard of 300 pCi/L in water from 15 (75 percent) of the 20 wells.

In 2011, six 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.

Study Methods

To provide current data on the occurrence of methane and many inorganic constituents in groundwater in Pike County, 20 wells throughout the county were sampled in summer 2012 for the spatial component of the assessment. Subsequently, 4 of the 20 wells were sampled monthly for 1 year ending in June 2013 to provide data on temporal variability in groundwater quality.

The laboratory analyses selected for the samples were intended to determine existing concentrations of methane and inorganic constituents, including selected radionuclides, that may be in brines or introduced as a result of drilling and hydraulic-fracturing processes (some of which are listed in table 1). Further characterization of existing groundwater quality was supported by additional analyses of well-water samples, including isotopic composition of methane and some other inorganic constituents, and concentrations of dissolved gases to estimate groundwater age.

Selection of Sampling Locations

Twenty wells (table 2) located in each of five main fractured-bedrock aquifers (geologic units) were selected for sampling to spatially represent groundwater quality throughout the county (fig. 2), especially in the northern and western areas where shale-gas development is most likely to occur. The 2012 spatial assessment did not include any wells completed in the unconsolidated aquifers (kame terrace and outwash deposits by the Delaware River and other less-areally extensive glacial or alluvial deposits in upland stream valleys). One well (PI-384) is located near an existing conventional gas exploration well drilled in 1959 (Sevon and others, 1989) in Shohola Township. Four of the 20 wells sampled are production wells

Table 2. Characteristics of 20 wells sampled by the U.S. Geological Survey for baseline assessment of groundwater quality in Pike County, Pennsylvania, summer 2012.

[USGS, U.S. Geological Survey; --, no data; NAVD 88, North American Vertical Datum of 1988; Geologic unit: 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341CSKL, Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344 MNNG, Mahantango Formation]

USGS site name	Geologic unit	Land-surface altitude, in feet above NAVD 88	Well depth, in feet	Casing length, in feet	Year drilled	Sample date	Depth to water level on sample date, in feet below land surface	Township	Type of well
PI-274	341LRBW	1,260	465	--	1975	7/17/2012	--	Palmyra	Production
PI-288	341PGPK	1,650	151	23	1980	7/18/2012	54.9	Greene	Domestic
PI-384	341LRBW	710	135	91	1977	7/24/2012	1.82	Shohola	Domestic
PI-403	344MNNG	850	192	48	1980	8/2/2012	24.74	Delaware	Domestic
PI-507	341LRBW	1,364	[1]300	112	1999	7/25/2012	--	Blooming Grove	Production
PI-524	341TMSG	1,139	380	182	2004	7/25/2012	--	Dingman	Domestic
PI-552	341TMRK	975	--	--	--	7/24/2012	67.29	Westfall	Domestic
PI-553	341LRBW	1,510	610	195	1997	7/25/2012	123.86	Blooming Grove	Domestic
PI-555	341PGPK	1,789	380	40	1999	7/17/2012	120.98	Palmyra	Domestic
PI-557	341LRBW	1,433	350	66	1977	7/25/2012	--	Dingman	Domestic
PI-558	344MNNG	440	300	21	1985	7/26/2012	16.13	Lehman	Domestic
PI-571	341LRBW	1,280	480	--	1980	8/1/2012	97.48	Shohola	Domestic
PI-592	341CSKL	618	200	140	1994	7/26/2012	9.51	Lackawaxen	Domestic
PI-593	341LRBW	1,568	255	--	1978	7/18/2012	45.93	Palmyra	Domestic
PI-594	341LRBW	1,379	--	--	--	7/18/2012	147.74	Lackawaxen	Domestic
PI-595	341LRBW	1,370	443	51	1991	7/19/2012	--	Blooming Grove	Production
PI-598	341LRBW	1,341	190	--	1975	7/18/2012	65.92	Lackawaxen	Production
PI-599	344MNNG	827	400	80	2005	7/24/2012	110.44	Dingman/Milford	Domestic
PI-600	341LRBW	1,290	300	40	2010	7/24/2012	144.66	Lackawaxen	Domestic
PI-601	341LRBW	831	200	60	2001	8/2/2012	25.16	Porter	Domestic

[1]Original depth of well is 565 feet; wooden plug placed in well at 300 feet.

for communities or irrigation and the remainder are domestic wells used to provide water for individual dwellings or buildings. The four production wells range in depth from 190 to 465 feet (ft). For the other 16 wells with known construction information, depths range from 135 to 610 ft.

Subsequent to sampling the 20 wells for spatial assessment in summer 2012, four of the 20 wells were selected to be sampled monthly over the next year for the temporal component of the assessment. The four wells (PI-507, PI-524, PI-593, and PI-600) were selected to represent several characteristics, including a range of methane concentrations, different well types (domestic and production), and (or) location in the northern half of the county where shale-gas exploration is most likely (table 3, fig. 2).

Wells completed in fractured rocks commonly have more than one water-bearing zone. Because of the complex groundwater flow system in fractured-rock aquifers and the occurrence of multiple water-bearing zones, samples collected from domestic and production wells commonly represent a mixture of water from different groundwater flow paths with possible different chemical compositions.

Collection of Samples

Samples from 20 wells were collected from July 17 through August 2, 2012, for the spatial component of the assessment. Subsequently, samples from 4 of the 20 wells were collected monthly from September 11, 2012, to June 28, 2013, for the temporal component of the assessment. Sample collection and processing were done using standard methods (U.S. Geological Survey, variously dated). Groundwater samples were collected from wells using existing pumps and plumbing but bypassing any treatment systems. Water levels in the wells were measured prior to pumping, and wells were pumped until field parameters (pH, temperature, specific conductance, dissolved oxygen concentration) stabilized before sample collection.

Samples for dissolved constituent analysis were filtered in the field using a 0.45-micron pore-size polyethersulfone capsule filter. Samples for major cations, trace elements, gross alpha- and gross beta-particle activity were preserved using nitric acid. Samples for methane analysis were collected using refrigeration-grade copper tubing inserted in two types of sample bottles and allowing water to overflow bottles by at least three volumes. Samples for determination of methane, ethane, and ethene concentrations by TestAmerica, Inc., (TestAmerica) were collected in triplicate 40-milliliter (mL) glass vials and preserved with hydrochloric acid in the field. Additional samples for isotopic characterization of methane and methane concentrations were collected in one-liter plastic bottles, with biocides in the cap, supplied by Isotech Laboratories, Inc. (Isotech).

Samples for age-dating by use of chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6), and other dissolved gases (nitrogen, oxygen, argon, carbon dioxide, and methane) (Plummer and Friedman, 1999) were collected using refrigeration-grade copper tubing in glass bottles by methods described by U.S. Geological Survey (2014). For the gas samples, bottles were filled through tubing connected to existing plumbing near the well head and inserted into the bottle. Bottles were filled from the bottom up and allowed to overflow by at least three volumes before capping. Samples for CFCs were collected through refrigeration-grade copper tubing in 125 mL glass bottles that were filled and capped underwater. Samples for SF_6 were collected in plastic safety-coated 1-liter (L) glass bottles. Samples for the other dissolved gases (such as nitrogen) were collected in 150-mL glass bottles that were filled and capped underwater.

Analysis of Samples

Groundwater quality was determined through both field measurements and laboratory analyses. Selected physical and chemical measurements were made in the field during sampling of each well. The pH, water temperature, acid neutralizing capacity (ANC), specific conductance, and dissolved oxygen concentration for groundwater samples were measured in the field using a Yellow Springs Instruments (YSI) sonde for all field parameters except ANC and following standard methods (U.S. Geological Survey, variously dated). Air temperature and barometric pressure as measured by the YSI sonde were also recorded.

Results of the summer 2012 sampling showed that ANC measured in the field and laboratory were approximately equivalent, and for monthly samples collected from September 2012 through June 2013, only laboratory measurements of ANC were done routinely on the water samples. ANC is considered approximately equal to alkalinity for the groundwater samples.

Other analyses of well-water samples were done at several laboratories. All samples were analyzed for concentrations of methane, major ions, nutrients, selected trace metals, gross alpha- and gross beta-particle activity, and radon-222 concentrations (table 3). The analyses included all of the PADEP Recommended Basic Oil & Gas Pre-Drill Parameters as listed by the PADEP categories of inorganic constituents (alkalinity, chloride, conductivity, hardness, pH, total dissolved solids); trace metals (barium, calcium, iron, magnesium, manganese, potassium, sodium, strontium); organic constituents (methane, ethane), except total suspended solids, non-filterable residue, oil and grease; and bacteria (total coliform or *Escherichia Coli*) (Pennsylvania Department of Environmental Protection, 2012). A few samples underwent additional analyses for isotopic characterization of dissolved methane, stable isotopes of water, carbon isotopic composition of dissolved inorganic carbon (DIC), boron and strontium isotopes, and age-dating by CFCs and SF_6.

Water samples were sent to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analyses of inorganic constituents and radon-222. Analyses for dissolved inorganic constituents included major ions (calcium, magnesium, sodium, potassium, silica, sulfate, chloride, and fluoride), nutrients (nitrate, nitrite, ammonium, and orthophosphate), selected trace elements and metals (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, silver, selenium, strontium, thallium, tungsten, uranium, vanadium, and zinc), and total dissolved solids (TDS). TDS concentrations were determined using a laboratory method to measure the residue on evaporation (ROE) and consist of all dissolved analytes with some potential loss of bicarbonate (Hem, 1985). In addition, analyses for selected total concentrations of metals (arsenic, iron, lead, and manganese) and ANC (using fixed-endpoint method) were done on unfiltered samples from the wells. Unfiltered water samples were collected for determination of gross alpha- and gross beta-particle activity. To allow comparison of dissolved to total gross alpha- and gross beta-particle activity, both filtered and unfiltered samples were collected from seven wells that had previous analyses for dissolved gross alpha- and gross beta-particle activity. All samples for gross alpha-particle and gross beta-particle activity determined at 72-hours and 30-day counting times were sent to a private laboratory (Eberline Services through April 2013; TestAmerica in Richland, Washington in June 2013) under contract to NWQL. Reporting levels for radioactivity measurements are relative to background levels in the laboratory, and reported values preceded by an ”R” are considered non-detects.

Analyses for dissolved concentrations of methane, ethane, and ethene by gas-chromatograph headspace equilibrium method RSKSOP-175 (Hudson, 2004) were sent to a private laboratory (TestAmerica) under contract to NWQL. This dissolved-gas analysis was done on all samples collected for the spatial and temporal assessments (20 wells sampled once in summer 2012 and 4 wells sampled monthly for 1 year ending June 2013, respectively). Samples were analyzed at TestAmerica in Austin, Texas except for the June 25–27, 2013 samples which were analyzed at TestAmerica in Denver Colorado.

Table 3. Laboratory analyses for water samples collected as part of spatial and temporal assessment of groundwater quality, Pike County, Pennsylvania, 2012–13.

[Analysis done by U.S. Geological Survey National Water Quality Laboratory (NWQL) unless otherwise specified. NWQL method in parentheses. SH, schedule; LC, lab code; CAS, Chemical Abstracts Service; PADEP, Pennsylvania Department of Environmental Protection; TDS, total dissolved solids; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pg/kg, picograms per kilogram; fg/kg, femtogram per kilogram; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; %, percent; --, no data or not applicable; $CaCO_3$, calcium carbonate; CFC, chlorofluorocarbon; SF_6, sulfur hexafluoride; DIC, dissolved inorganic carbon ($\delta^{13}C$)]

Analyte	Parameter code	CAS number	Reporting level[1]	Unit	Number of wells sampled: 2012 spatial assessment[2]	Number of wells sampled: 2012–2013 temporal assessment[3]	Number of wells sampled: Late June 2013 additional characterization[4]	PADEP Pre-drill parameter[5]
Major Inorganic constituents, filtered samples (SH-2750)								
Bromide	71870	24959-67-9	0.01	mg/L	20	4	6	Yes
Calcium	00915	7440-70-2	0.022	mg/L	20	4	6	Yes
Chloride	00940	16887-00-6	0.06	mg/L	20	4	6	Yes
Fluoride	00950	16984-48-8	0.08	mg/L	20	4	6	--
Iron	01046	7439-89-6	4	µg/L	20	4	6	Yes
Magnesium	00925	7439-95-4	0.011	mg/L	20	4	6	Yes
Manganese	01056	7439-96-5	0.16	µg/L	20	4	6	Yes
Potassium	00935	2023695	0.03	mg/L	20	4	6	Yes
Silica	00955	7631-86-9	0.018	mg/L	20	4	6	--
Sodium	00930	7440-23-5	0.06	mg/L	20	4	6	Yes
Sulfate	00945	14808-79-8	0.09	mg/L	20	4	6	--
Residue, 180 degrees Celsius (TDS)	70300	--	20	mg/L	20	4	6	Yes
Nutrients, filtered samples (SH-101)								
Nitrogen, ammonia as nitrogen	00608	7664-41-7	0.01	mg/L	20	4	6	--
Nitrogen, nitrite as nitrogen	00613	14797-65-0	0.001	mg/L	20	4	6	--
Nitrogen, nitrite + nitrate as nitrogen	00631	--	0.04	mg/L	20	4	6	--
Phosphate, ortho as phosphorus	00671	14265-44-2	0.004	mg/L	20	4	6	--
Trace elements and metals, filtered samples (SH-2097)								
Aluminum	01106	7429-90-5	2.2	µg/L	20	4	6	--
Antimony	01095	7440-36-0	0.027	µg/L	20	4	6	--
Arsenic	01000	7440-38-2	0.04	µg/L	20	4	6	--
Barium	01005	7440-39-3	0.1	µg/L	20	4	6	Yes
Beryllium	01010	7440-41-7	0.006	µg/L	20	4	6	--
Boron	01020	7440-42-8	3	µg/L	20	4	6	--
Cadmium	01025	7440-43-9	0.016	µg/L	20	4	6	--
Chromium	01030	7440-47-3	0.07	µg/L	20	4	6	--
Cobalt	01035	7440-48-4	0.023	µg/L	20	4	6	--
Copper	01040	7440-50-8	0.8	µg/L	20	4	6	--
Lead	01049	7439-92-1	0.025	µg/L	20	4	6	--
Lithium	01130	7439-93-2	0.22	µg/L	20	4	6	--

Table 3. Laboratory analyses for water samples collected as part of spatial and temporal assessment of groundwater quality, Pike County, Pennsylvania, 2012–13.—Continued

[Analysis done by U.S. Geological Survey National Water Quality Laboratory (NWQL) unless otherwise specified. NWQL method in parentheses. SH, schedule; LC, lab code; CAS, Chemical Abstracts Service; PADEP, Pennsylvania Department of Environmental Protection; TDS, total dissolved solids; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pg/kg, picograms per kilogram; fg/kg, femtogram per kilogram; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; %, percent; --, no data or not applicable; $CaCO_3$, calcium carbonate; CFC, chlorofluorocarbon; SF_6, sulfur hexafluoride; DIC, dissolved inorganic carbon ($\delta^{13}C$)]

Analyte	Parameter code	CAS number	Reporting level[1]	Unit	Number of wells sampled: 2012 spatial assessment[2]	Number of wells sampled: 2012–2013 temporal assessment[3]	Number of wells sampled: Late June 2013 additional characterization[4]	PADEP Pre-drill parameter[5]
Trace elements and metals, filtered samples (SH-2097)—Continued								
Manganese	01056	7439-96-5	0.15	µg/L	20	4	6	--
Molybdenum	01060	7439-98-7	0.014	µg/L	20	4	6	--
Selenium	01145	7782-49-2	0.03	µg/L	20	4	6	--
Silver	01075	7440-22-4	0.005	µg/L	20	4	6	--
Strontium	01080	7440-24-6	0.2	µg/L	20	4	6	Yes
Thallium	01057	7440-28-0	0.01	µg/L	20	4	6	--
Tungsten	01155	7440-33-7	0.01	µg/L	20	4	6	--
Uranium, natural	22703	7440-61-1	0.004	µg/L	20	4	6	--
Vanadium	01085	7440-62-2	0.08	µg/L	20	4	6	--
Zinc	01090	7440-66-6	1.4	µg/L	20	4	6	--
Other analyses, unfiltered samples								
pH, laboratory	00403	--	0.1	pH	20	4	6	Yes
Specific conductance, laboratory	90095	--	5	µS/cm	20	4	6	Yes
ANC, laboratory	90410	471-34-1	4.0	mg/L as $CaCO_3$	20	4	6	Yes
Arsenic	10002	7440-38-2	0.28	µg/L	20	4	6	--
Iron	01045	7439-89-6	4.6	µg/L	20	4	6	--
Lead	10051	7439-92-1	0.04	µg/L	20	4	6	--
Manganese	01055	7439-96-5	0.2	µg/L	20	4	6	--
Radioactive constituents—Radon-222, water, unfiltered, time sensitive, must be received within 48 hours of collection, liquid scintillation (LC-1369)								
Radon-222	82303	14859-67-7	20	pCi/L	20	4	6	--
Radioactive constituents—Gross alpha, gross beta, water, unfiltered, 72 hour/30 day (SH-1793 analyzed at Eberline Services)								
Gross-alpha radioactivity	63014	12587-46-1	3	pCi/L	20	4	6	--
Gross-alpha radioactivity	63016	12587-46-1	3	pCi/L	20	4	6	--
Gross-beta radioactivity	63015	12587-47-2	4	pCi/L	20	4	6	--
Gross-beta radioactivity	63017	12587-47-2	4	pCi/L	20	4	6	--
Radioactive constituents—Gross alpha, gross beta, water, filtered , 72 hour/30 day (SH-1792 analyzed at Eberline Services)								
Gross-alpha radioactivity	63014	12587-46-1	3	pCi/L	7	--	--	--
Gross-alpha radioactivity	63016	12587-46-1	3	pCi/L	7	--	--	--
Gross-beta radioactivity	63015	12587-47-2	4	pCi/L	7	--	--	--
Gross-beta radioactivity	63017	12587-47-2	4	pCi/L	7	--	--	--

Table 3. Laboratory analyses for water samples collected as part of spatial and temporal assessment of groundwater quality, Pike County, Pennsylvania, 2012–13.—Continued

[Analysis done by U.S. Geological Survey National Water Quality Laboratory (NWQL) unless otherwise specified. NWQL method in parentheses. SH, schedule; LC, lab code; CAS, Chemical Abstracts Service; PADEP, Pennsylvania Department of Environmental Protection; TDS, total dissolved solids; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; pg/kg, picograms per kilogram; fg/kg, femtogram per kilogram; ANC, acid neutralizing capacity; pCi/L, picocuries per liter; %, percent; --, no data or not applicable; $CaCO_3$, calcium carbonate; CFC, chlorofluorocarbon; SF_6, sulfur hexafluoride; DIC, dissolved inorganic carbon ($\delta^{13}C$)]

Analyte	Parameter code	CAS number	Reporting level[1]	Unit	Number of wells sampled: 2012 spatial assessment[2]	Number of wells sampled: 2012–2013 temporal assessment[3]	Number of wells sampled: Late June 2013 additional characterization[4]	PADEP Pre-drill parameter[5]
Radioactive constituents—Radium-226, water, filtered, by radon emanation (LC-794 analyzed at Eberline Services)								
Radium-226	09511	13982-63-3	0.1	pCi/L	--	--	6	--
Dissolved gas concentrations (TestAmerica, Inc.)								
Methane	76994	74-82-8	0.211	µg/L	20	4	6	Yes
Ethane	82045	74-80-0	0.0615	µg/L	20	4	6	Yes
Ethene	82044	74-85-1	0.0569	µg/L	20	4	6	--
Dissolved gases and other isotopic analyses (Isotech Laboratories, Inc.)								
Dissolved gases, percent in headspace	--	--	--	volume %	3	1	3	--
Methane concentration	68831	74-82-8	--	mg/L	3	1	3	--
Isotopes of methane ($\delta^{13}C$)	65241	--	--	per mil[6]	2	1	2	--
Isotopes of methane (δD)	65245	--	--	per mil[7]	2	1	2	--
Isotopes of water ($\delta^{18}O$)	82085	--	--	per mil[7]	20	4	6	--
Isotopes of water (δD)	82082	--	--	per mil[7]	20	4	6	--
Isotopes of DIC ($\delta^{13}C$)	65243	--	--	per mil[6]	--	1	3	--
Strontium and boron isotopes	--	--	--	dimensionless or per mil	--	--	6	--
Dissolved gas, SF_6, CFC analysis for age-dating (U.S. Geological Survey chlorofluorocarbon laboratory)								
Methane	85574	74-82-8	0.001	mg/L	--	--	6	--
CFC-11	50281	75-69-4	0.05	pg/kg	--	--	6	--
CFC-12	50282	75-71-8	0.05	pg/kg	--	--	6	--
CFC-13	50283	76-13-1	0.05	pg/kg	--	--	6	--
SF_6	63149	2551-62-4	1.5	fg/kg	--	--	6	--

[1]Reporting levels are long-term method detection levels for all major and trace inorganic constiuents and sample-specific critical level for radioactive constituents.

[2]Twenty wells sampled once during July and August 2012.

[3]Four wells sampled monthly from September 2012 through June 2013.

[4]Additional analyses done on the 4 wells sampled monthly for temporal assessment plus 2 wells sampled in late June 2013.

[5]PADEP Recommended Basic Oil and Gas Pre-Drill Parameters (Pennsylvania Department of Environmental Protection, 2012).

[6]Relative to Vienna PeeDee Belemite.

[7]Relative to Vienna Standard Mean Ocean Water.

Additional analysis for dissolved gases, concentration of methane, isotopic characterization of methane, carbon isotopic composition of DIC, and stables isotopes of water were done by Isotech under subcontract to TestAmerica and NWQL. These additional Isotech analyses for dissolved gases, methane characterization, and isotopic composition of DIC were done on only a few samples collected for the study (table 3) based partly on results of the TestAmerica analyses for methane. Dissolved gas analysis by Isotech was done on samples with at least 1 milligram per liter (mg/L) dissolved methane as determined by TestAmerica and on two other samples with lower concentrations of methane to compare laboratory results. Isotopic characterization of methane was done only on samples with sufficient methane (at least 1 mg/L) for that analysis. The isotopic composition of DIC was analyzed in samples from two wells with elevated methane (greater than 1 mg/L) and on a sample from one well with low methane for comparison. Analyses for stable isotopes of water were done on all samples.

Analyses of water samples collected from six wells in late June 2013 for age-dating by CFCs and SF_6 were done by the USGS chlorofluorocarbon laboratory in Reston, Virginia, using methods described by U.S. Geological Survey (2014) and by Busenberg and others (2006). Analyses of strontium and boron isotopes in water samples collected from six wells in late June 2013 were done by Thomas Bullen and others at a USGS laboratory in Menlo Park, California.

Complete listings of constituents and compounds analyzed and associated parameter codes are given with results of analyses in tables 15–18 at the back of the report. Field measurements of pH, specific conductance, or ANC are shown in figures and discussed in the text, unless otherwise specified. The concentrations of major ions typically are reported in milligrams per liter (mg/L), which are approximately equivalent to parts per million (ppm). Nitrogen compounds, such as nitrate and ammonia, are reported in milligrams per liter as nitrogen (mg/L as N) and phosphorous compounds, such as orthophosphate, in milligrams per liter as phosphorous (mg/L as P). The concentrations of trace elements typically are reported in micrograms per liter (µg/L) which are approximately equivalent to parts per billion (ppb). One milligram per liter (mg/L) is equivalent to 1,000 micrograms per liter (µg/L).

The concentrations of dissolved methane, ethane, and ethene determined by TestAmerica are reported in units of µg/L. Concentrations of dissolved methane determined by Isotech are reported in units of mg/L, and concentrations of dissolved methane and other gases determined by the USGS chlorofluorocarbon laboratory also are reported in units of mg/L. For consistency in this report, all dissolved methane concentrations hereafter will be discussed in common units of mg/L, although original reporting units from individual laboratories are preserved in data tables at the back of the report. Isotech also reported dissolved gases in units of volume percent (in headspace of sample).

Concentrations of radon-222, gross-alpha- and gross-beta particle activity, and other radionuclides are reported in picocuries per liter (pCi/L), which is a measure of the rate of radioactive decay per unit of time in a given volume of water. Isotopic compositions are reported as a difference (delta or δ) in parts per thousand (denoted as ‰ and also known as per mil) relative to a standard, where positive values indicate enrichment of the heavier isotope and negative values indicate depletion of the heavier isotope. Thus, for R = ratio of heavier to lighter isotope, δ (in ‰) = $(R_{sample}/[R_{standard} - 1]) \times (1{,}000)$.

Quality Control and Quality Assurance

For quality assurance, replicate environmental and equipment blank samples were collected to demonstrate analytical reproducibility and level of sampling contamination, respectively. Replicate environmental samples were collected from wells PI-558 and PI-524 in July 2012 and from well PI-524 in December 2012. An equipment blank sample was collected prior to sampling well PI-600 in May 2013, and an equipment blank was collected in September 2013. Replicates and blank samples were analyzed for dissolved inorganic constituents, nutrients, trace metals, gross-alpha and gross-beta activity, radon-222, and methane, and in the case of well PI-524, methane isotopes. Results of laboratory analyses for environmental replicates are listed with results for primary environmental samples collected for this study (table 18).

Results for the May 2013 equipment blank showed that a few constituents (copper, lead, zinc, silica, sodium, and boron) were measured at low concentrations near the detection level but none of the other the constituents or compounds analyzed in the blank were detected (table 18). These results indicate that, for most constituents, field equipment or sampling methodology did not contaminate the sample. However, because some constituents had been detected at low levels in the May equipment blank sample, another equipment blank prepared in the laboratory was sent for analysis in September 2013. Results for the September 2013 equipment blank show no detections for silica, sodium, and boron and low concentrations of copper, lead, and zinc; the metals' concentrations were less than the laboratory reporting level but greater than the long-term method detection level for all but the total lead result of 0.082 µg/L. These results indicate that sampling equipment may introduce low levels of these metals into the samples at concentrations of up to about 1 µg/L for copper, 0.5 µg/L for lead, and 2 µg/L for zinc. Possible low-level contamination of sample water from sampling equipment or existing plumbing for sampled wells should be considered in evaluation of lead, copper, and zinc concentrations in environmental samples.

Computation of cation-anion balance was also used to check accuracy of major ion analyses. The difference in the cation-anion balance was less than 4 percent for all but one sample that had a difference of 6 percent. Differences in cation-anion balances of less than plus or minus 5.5 percent are considered to be acceptable when evaluating accuracy and completeness of water analyses (Brown and others, 2003).

Additionally, both field and laboratory measurements of pH, specific conductance, and ANC are reported for all samples collected in summer 2012 (table 15) for quality assurance purposes. For monthly samples collected from September 2012 through June 2013, field and laboratory measurements are listed only for pH and specific conductance (table 16) because field ANC was not measured regularly. Results of the summer 2012 sampling showed that ANC measured in the field and laboratory were approximately equivalent.

Groundwater Quality—Spatial and Temporal Assessment

The 2012–13 groundwater-quality reconnaissance 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 shale-gas development in Pike County. Many of the inorganic constituents selected for analysis are present in elevated concentrations in brines and produced waters (flow back) associated with unconventional shale-gas development (table 1) but also commonly occur at low to moderate concentrations in shallow, fresh (non-saline) groundwater. Some of the inorganic constituents included in groundwater analyses for this study also 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 but does not necessarily imply any contribution of brines to freshwater. The assessment also may be used to evaluate overall general groundwater quality in the county, identify constituents in groundwater that may pose a health risk, and serve as a baseline for future evaluations to determine the effect of shale-gas development or other land-use changes on groundwater quality.

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

Concerns about groundwater quality are not limited to its use as a drinking-water supply. Because groundwater discharges to and sustains base flow of streams, degraded groundwater quality may result in degraded stream quality. To protect surface-water quality in areas affected by shale-gas development, the PADEP currently regulates direct discharges of flow-back waters to streams. Discharges containing flow-back waters must meet water-quality criteria established for designated uses of streams, and concentrations cannot exceed 500 mg/L for TDS, 250 mg/L for chloride, 10 mg/L for barium, and 10 mg/L for strontium (Pennsylvania Department of Environmental Protection, 2010).

Discussion of analyzed constituents in water from 20 wells sampled in 2012 for the spatial component and the 4 wells sampled during 2012–13 for the temporal component of the groundwater-quality assessment in Pike County follow. Complete results for laboratory analyses of groundwater samples collected during 2012–13 are listed in tables 15–18 at the back of the report.

Spatial Assessment

The spatial component of the assessment provides information about current (2012) baseline groundwater quality in bedrock aquifers throughout the Pike County. However, because of the small sample size (20 wells), results of the spatial assessment are considered to provide a limited, reconnaissance-level estimate of groundwater quality that can be used as the basis for further evaluations.

General Groundwater Quality, Inorganic Constituents, and Relation to Standards

Generally, groundwater in the bedrock aquifers in Pike County, as defined by samples from the 20 wells sampled for this study, has low to moderate concentrations of dissolved constituents and oxygen, and pH values are near neutral to slightly acidic. Of the drinking-water standards or guidelines established for measured physical and chemical properties and concentrations of total dissolved solids (TDS), major ions, and nutrients, SMCLs and (or) HAs were exceeded only for pH and sodium (table 4).

Concentrations of TDS in water samples ranged from 40 to 230 mg/L and were less than the SMCL of 500 mg/L (table 4). TDS concentrations often are used as a measure of salinity. Freshwater commonly 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 occurrence 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 the vicinity of Pike County (Feth, 1965). On the basis of geophysical logs in

Table 4. Minimum, median, and maximum values for well characteristics, field measurements, and concentrations of dissolved major ions and nutrients in water from 20 wells sampled in Pike County, Pennsylvania, summer 2012.

[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; °C, degrees Celsius; SiO_2, silica; mg/L as N, milligrams per liter as nitrogen; mg/L as P, milligrams per liter as phosphorous; M, measured, but concentration less than 1 milligram per liter; --, no data or not applicable; MCL, maximum contaminant level; HA, Health Advisory; SMCL, secondary maximum contaminant level; <, less than; >, greater than]

Characteristic or constituent	Units	Minimum	Median	Maximum	Number (percent) exceeding standard	Drinking-water standard or guideline[1]		
						MCL	HA	SMCL
Field properties								
Water temperature	°C	9.4	11.1	12.4	--	--	--	--
Dissolved oxygen	mg/L	M	0.5	9.2	--	--	--	--
Specific conductance, field	µS/cm	64	186	383	--	--	--	--
pH, field	pH units	5.8	7.4	8.7	5 (25)	6.5–8.5	--	--
Acid neutralizing capacity[2]	mg/L as $CaCO_3$	11	61.5	142	--	--	--	--
Laboratory analyses								
Major ions and related properties								
Calcium	mg/L	4.75	17.6	51.4	--	--	--	--
Magnesium	mg/L	1.09	5.17	8.32	--	--	--	--
Sodium	mg/L	1.36	9.14	69.4	[3]2 (10)	--	20	30–60
Potassium	mg/L	0.24	0.63	1.19	--	--	--	--
Acid neutralizing capacity[4]	mg/L as $CaCO_3$	15.5	65.2	143	--	--	--	--
Bromide	mg/L	0.014	0.020	0.353	--	--	--	--
Chloride	mg/L	0.47	5.14	50.3	0 (0)	--	--	[5]250
Fluoride	mg/L	<0.04	0.11	0.53	0 (0)	4	--	2
Sulfate	mg/L	0.38	7.74	17.1	0 (0)	--	500	250
Silica	mg/L as SiO_2	4.42	9.38	16.4	--	--	--	--
Total dissolved solids	mg/L	40	116	230	0 (0)	--	--	[5]500
Hardness	mg/L as $CaCO_3$	18.6	64	160	--	--	--	--[6]
Nutrients								
Ammonia	mg/L as N	<0.010	<0.010	0.095	0 (0)	--	30	--
Nitrite	mg/L as N	<0.001	<0.001	0.001	0 (0)	1	--	--
Nitrate+Nitrite[7]	mg/L as N	<0.040	<0.040	1.45	0 (0)	10	--	--
Orthophosphate	mg/L as P	<0.004	0.0195	0.177	--	--	--	--

[1]U.S. Environmental Protection Agency (2012) lists standards (MCLs and SMCLs) for public drinking-water supplies; HAs are other health-based guidelines.

[2]Determined by inflection-point method, approximately equivalent to alkalinity.

[3]Two samples exceed 40 mg/L and thus both the HA and SMCL for sodium.

[4]Determined by fixed-endpoint method, approximately equivalent to alkalinity.

[5]Same standard established by Pennsylvania Department of Environmental Protection (2010) for flow-back discharge to streams.

[6]No drinking-watering standard but water characterized as: soft, 0–60 mg/L; moderately hard, 61–120 mg/L; hard, 121–180 mg/L; very hard; >180 mg/L.

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

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 (Carswell and Lloyd, 1979). Results from the 2012 sampling of 20 wells with depths of up to 610 ft and earlier studies in Pike County (Davis, 1989; Senior, 2009) are consistent with these estimates of depth to saline water.

Dissolved oxygen concentrations ranged from just detectable (M or measured concentration less than 0.1 mg/L) to 9.2 mg/L (table 4) and were low (less than 1 mg/L) in 12 (60 percent) of the 20 well samples. Low dissolved oxygen concentrations are related to chemical or biochemical reactions that consume oxygen and may be associated with reducing conditions that promote release of some metals. The chemical reactions that consume oxygen can be naturally occurring in soils or aquifer materials.

Groundwater samples from the 20 wells ranged from moderately acidic to moderately alkaline. The pH ranged from 5.8 to 8.7, with a median of 7.4, just above the neutral value of 7.0 pH units; the pH was less than the SMCL lower limit of 6.5 in 4 (20 percent) and greater than the upper limit of 8.5 in 1(5 percent) of the 20 samples (table 4). Overall, the range of pH in water from the 20 wells sampled in 2012 was similar but somewhat less acidic than in water from wells sampled in 2007 (Senior, 2009).

Precipitation that falls on Pike County is acidic, having an annual average pH of about 4.85 during 2011–12 as measured in Milford (National Atmospheric Deposition Program, 2013); the acidity of precipitation in Pike County has been decreasing for at least 30 years (since 1985 when the annual average pH was 4.23 at Milford). The acidity of precipitation that recharges the aquifers tends to be progressively neutralized by reactions with soils and aquifer minerals. The acid-neutralizing capacity (ANC) and specific conductance are properties that may be related to mineral dissolution under natural conditions. ANC consists largely of bicarbonate alkalinity. The specific conductance is proportional to the amount and type of dissolved charged ions in solution. In the groundwater samples from Pike County, ANC, TDS, and specific conductance generally tend to increase with pH (fig. 5), suggesting that mineral dissolution contributes to reducing acidity of recharge derived from precipitation.

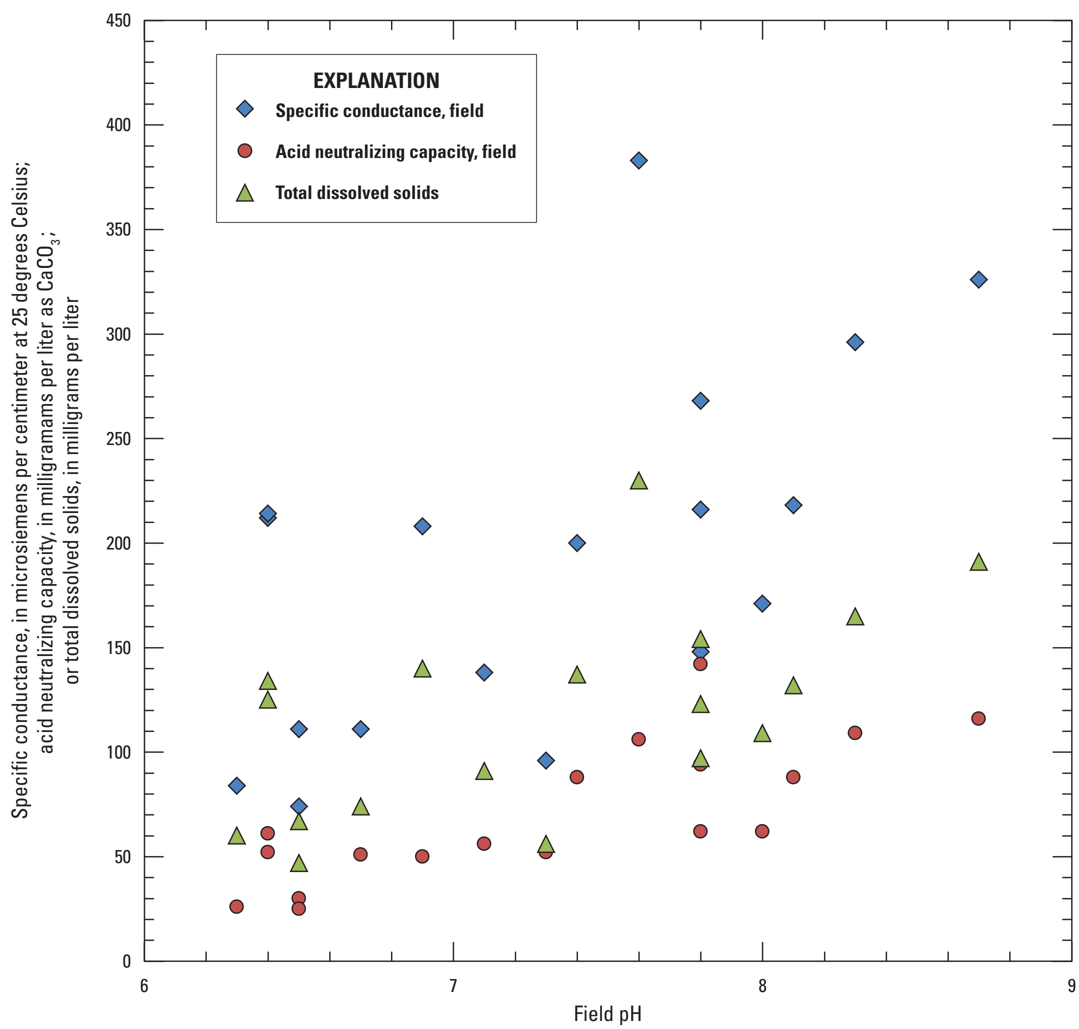


Figure 5. Acid-neutralizing capacity, total dissolved solids concentration, and specific conductance in relation to field pH in groundwater samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

Major Ions

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

In the 20 groundwater samples, the only drinking-water standard or guideline exceeded for major ions (table 4) was the sodium concentration in samples from two wells (PI-524 and PI-592). These relatively elevated sodium concentrations of 42.8 and 69.4 mg/L, respectively, exceeded the HA level of 20 mg/L for individuals on sodium-restricted diets and the taste threshold SMCL value of 30 mg/L. Chloride concentrations in the 20 samples collected in summer 2012 ranged from 0.47 to 50.3 mg/L and were all less than the SMCL of 250 mg/L for drinking water.

Hardness of the 20 well-water samples ranged from 18.6 to 160 mg/L as calcium carbonate ($CaCO_3$), with a median value of 64 mg/L as $CaCO_3$. Hardness reflects the concentrations of calcium and magnesium ions, which are released into groundwater from the dissolution of calcium- and magnesium-bearing minerals. Hard water decreases lathering of soap and increases accumulation of mineral deposits in plumbing and cooking utensils. Using a common hardness classification (Dufor and Becker, 1964), the measured values indicate that about half of the 20 water samples are soft (less than 60 mg/L as $CaCO_3$) and most others are moderately hard (61 to 120 mg/L as $CaCO_3$); only one sample (from well PI-403 with a hardness of 160 mg/L as $CaCO_3$) can be classified as hard (121 to 180 as $CaCO_3$) (table 15 at back of report). There are no health-related standards established specifically for hardness in drinking water.

Nitrate and Other Nutrients

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

Ammonia (and its ionic form, ammonium [NH_4^+]) is a reduced form of nitrogen that is the predominant nitrogen compound present in septic tank effluent and oxidizes to nitrate in the presence of oxygen. NH_4-bearing clay minerals (illite) have been reported to occur in some sedimentary rocks in northeastern Pennsylvania (Juster and others, 1987). Nitrite (NO_2^-) is a less oxidized form of nitrogen than nitrate (NO_3^-) and may be formed during intermediate steps in nitrification (a process in which ammonia is oxidized) or in denitrification (a process in which nitrate is reduced to nitrogen gas, usually in the absence of oxygen). Nitrification and denitrification reactions generally are biologically mediated. Low concentrations of ammonia, nitrite, nitrate and orthophosphate were measured in most of the 20 groundwater samples, and no drinking-water standards for these compounds were exceeded (table 4). Ammonia concentrations were less than the reporting level of 0.01 mg/L as N in 12 of the 20 groundwater samples, and the remaining 8 groundwater samples had concentrations ranging from 0.010 to 0.095 mg/L as N. Nitrite concentrations were less than the reporting level of 0.001 mg/L as N in all but two groundwater samples with concentrations equal to 0.001 mg/L as N. All (9) samples in which nitrite or ammonia concentrations were greater than reporting levels had low dissolved oxygen concentrations (0.5 or less mg/L). Ammonium (NH_4^+) and nitrite (NO_2^-) ions are reduced forms of nitrogen that generally are more stable in low-oxygen conditions, whereas nitrate (NO_3^-) is an oxidized form of nitrogen generally more stable in higher-oxygen conditions.

Nitrate concentrations (calculated by subtracting nitrite concentration from the reported sum of nitrite plus nitrate concentration) were less than the reporting level of 0.04 mg/L as N in 11 of 20 samples and otherwise were less than 0.8 mg/L as N in all but one groundwater sample (from well PI-557) that had a concentration of 1.45 mg/L as N, indicating that most nitrate concentrations are within the range of estimated natural background levels. An estimated concentration of nitrate derived from precipitation in recharge is as much as about 0.8 mg/L as N in Pike County, assuming no nitrogen loss and that all ammonia was converted to nitrate (Senior, 2009). Nitrate can be reduced, however, in low oxygen environments such as were observed in 12 (60 percent) of the 20 well samples that had dissolved oxygen concentrations less than 1 mg/L; therefore, many of the low nitrate concentrations might be attributed to nitrate reduction in soils and the groundwater system.

Orthophosphate concentrations were less than the reporting level of 0.004 mg/L as P in samples from 2 wells and ranged from 0.004 to 0.177 mg/L as P in samples from the 18 other wells. Concentrations of orthophosphate greater than 0.02 mg/L in streams in eastern Pennsylvania commonly represent slight enrichment from human-related sources (Andrew Reif, U.S. Geological Survey, oral commun., 2008), although there may be other sources of elevated orthophosphate in groundwater, such as dissolution of apatite or phosphorus-bearing minerals, and the sources of orthophosphate in the Pike County groundwater samples have not been identified. Orthophosphate concentrations were equal to or greater than 0.02 mg/L as P in water samples from 10 (50 percent) of the 20 wells.

Inorganic Trace Constituents

Most analyses for inorganic trace constituents (metals and other elements) were done on filtered samples (table 5) and represent dissolved concentrations. Analyses for a few constituents—arsenic, lead, iron, and manganese—were done on both filtered and unfiltered samples (table 5) to obtain data on both dissolved and total concentrations. These four constituents were selected for the additional analyses on the basis of results from the previous study in 2007 (Senior, 2009) which showed some substantial differences in dissolved and total concentrations of these constituents, most likely caused by presence of or adsorption of trace metals on particulate iron or manganese oxides. Consequently, concentrations of these four constituents, in some cases may exceed respective MCLs or SMCLs in unfiltered samples but not in filtered samples. Results for dissolved constituents are discussed first in this section, followed by discussion of total constituents.

Of the 23 inorganic trace constituents (metals and other elements) included in 2012 analyses of filtered water samples, 21 were measured in concentrations greater than the reporting level in at least one sample (table 5). Arsenic, barium, lead, lithium, manganese, and strontium were the most frequently detected dissolved inorganic trace constituents, measured in concentrations greater than respective reporting levels in samples from all 20 wells. Dissolved boron, cobalt, iron, lead, and molybdenum also were detected relatively frequently, measured in concentrations greater than reporting levels in at least 85 percent of the samples. Other detected inorganic trace constituents, listed in order of detection frequency, were nickel, zinc, antimony, copper, selenium, chromium, cadmium, tungsten, beryllium, vanadium, and aluminum. Concentrations of the most frequently detected inorganic trace constituents generally were higher than the less frequently detected constituents. The median concentrations of dissolved inorganic trace constituents detected in at least 85 percent of the samples were highest, in decreasing order, for strontium, barium, manganese, boron, lithium, iron, arsenic, lead, molybdenum, and cobalt (table 5).

Arsenic, iron, and manganese were the only inorganic trace constituents analyzed in filtered samples that exceeded drinking-water standards (table 5). The concentration of dissolved arsenic exceeded the MCL of 10 µg/L in a sample from one well (PI-592), which had an arsenic concentration of 30.1 µg/L. The dissolved iron concentration exceeded the SMCL of 300 µg/L in a sample from one well (PI-599), which had a concentration of 696 µg/L. Dissolved manganese concentrations exceeded the SMCL of 50 µg/L in samples from six wells and the HA of 300 µg/L in two of those six wells. The two wells that had arsenic or iron concentrations exceeding drinking-water standards also had manganese concentrations greater than SMCL or HA levels (table 15 at back of report).

Isotopic Characterization of Water

Isotopic characterization of water was done on water samples collected from all 20 wells in summer 2012. The analysis determines the isotopic ratios relative to standard reference materials (Vienna Mean Standard Ocean Water [VSMOW]) for oxygen ($\delta^{18}O$) and hydrogen (δD) atoms that form water. The $\delta^{18}O$ values ranged from -9.74 to -7.76 per mil and δD values ranged from -65.5 to -49.9 per mil (table 15 at back of report). These isotopic values plot on or near the line for Pennsylvania rivers (fig. 6), indicating the groundwater is

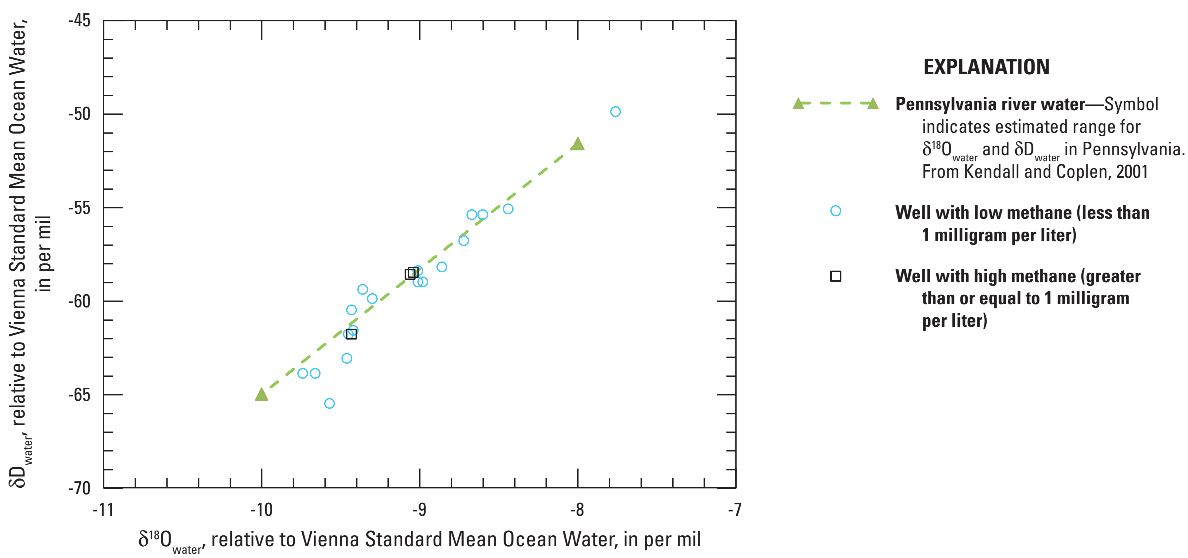


Figure 6. Stable isotopic composition of oxygen and hydrogen for water in samples collected from 20 wells in Pike County, Pennsylvania, summer 2012. Line showing relation between δD and $\delta^{18}O$ for Pennsylvania rivers determined through regression of measured values is from Kendall and Coplen (2001).

Table 5. Minimum, median, and maximum concentrations of selected inorganic trace constituents in water from 20 wells sampled in Pike County, Pennsylvania, summer 2012.

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

Constituent	Unit	Number (percent) above reporting level	Concentration			Number (percent) exceeding standard	Drinking-water standard or guideline[1]		
			Minimum	Median	Maximum		MCL	HA	SMCL
Dissolved inorganic trace constituent (filtered samples)									
Aluminum	µg/L	1 (5)	<2.2	<2.2	2.8	0 (0)	--	--	50–200
Antimony	µg/L	9 (45)	<0.027	<0.027	0.099	0 (0)	6	--	--
Barium	µg/L	20 (100)	3.51	52.6	318	0 (0)	[2]2,000	--	--
Beryllium	µg/L	3 (15)	<0.006	<0.006	0.016	0 (0)	4	--	--
Boron	µg/L	19 (95)	<3	17	119	0 (0)	--	7,000	--
Cadmium	µg/L	5 (25)	<0.016	<0.016	0.08	0 (0)	5	--	--
Chromium	µg/L	7 (35)	<0.07	<0.07	0.27	0 (0)	100	--	--
Cobalt	µg/L	17 (85)	<0.021	0.054	0.256	--	--	--	--
Copper	µg/L	9 (45)	<0.08	<0.08	38.1	0 (0)	[3]1,300	1,000	--
Lithium	µg/L	20 (100)	0.98	10.8	248	--	--	--	--
Molybdenum	µg/L	17 (85)	<0.014	0.323	3.45	0 (0)	--	40	--
Nickel	µg/L	11 (55)	<0.09	0.12	0.69	0 (0)	--	100	--
Selenium	µg/L	9 (45)	<0.03	<0.03	0.49	0 (0)	50	--	--
Silver	µg/L	0 (0)	<0.005	<0.005	<0.005	0 (0)	--	--	100
Strontium	µg/L	20 (100)	13.9	328	1,690	0 (0)	--	[2]4,000	--
Thallium	µg/L	0 (0)	<0.010	<0.010	<0.010	0 (0)	2	--	--
Tungsten	µg/L	4 (20)	<0.010	<0.010	0.386	--	--	--	--
Vanadium	µg/L	3 (15)	<0.08	<0.08	0.51	--	--	--	--
Zinc	µg/L	11 (55)	<1.4	1.75	292	0 (0)	--	2,000	5,000
Dissolved and total inorganic trace constituents (filtered and unfiltered samples)									
Arsenic, dissolved	µg/L	20 (100)	0.07	0.53	30.1	[4]1 (5)	10	2	--
Arsenic, total	µg/L	16 (80)	<0.28	0.56	27.6	[4]1 (5)	10	2	--
Iron, dissolved	µg/L	17 (85)	<3.2	9.6	696	1 (5)	--	--	300
Iron, total	µg/L	17 (85)	<4.6	78.6	1,310	5 (25)	--	--	300
Lead, dissolved	µg/L	19 (95)	<0.025	0.49	2.15	0 (0)	[3]15	--	--
Lead, total	µg/L	20 (100)	0.1	0.56	4.08	0 (0)	[3]15	--	--
Manganese, dissolved	µg/L	20 (100)	0.19	18.2	615	[5]6 (30)	--	300	50
Manganese, total	µg/L	20 (100)	0.2	20.9	654	[5]6 (30)	--	300	50

[1]U.S. Environmental Protection Agency (2012) lists standards (MCLs and SMCLs) for public drinking-water supplies; HAs are other health-based guidelines.

[2]Pennsylvania Department of Environmental Protection (2010) established standard is 10 mg/L (10,000 µg/L) for barium and 10 mg/L (10,000 µg/L) for strontium in flow-back discharge to streams.

[3]Action level.

[4]One sample exceeds the MCL of 10 µg/L, and three samples exceed the HA of 2 µg/L for arsenic.

[5]Six samples exceed the SMCL level of 50 µg/L, and two samples exceed the HA of 300 µg/L for manganese.

of recent origin as isotopic composition of river water may be used as a proxy for modern precipitation (Kendall and Coplen, 2001). The range in isotopic composition of water samples from the 20 wells likely reflects differences in the temperature or seasonal rates of recharge. Precipitation recharged at cooler temperatures and (or) at higher altitudes tends to have more negative $\delta^{18}O$ and δD values (Kendall and Coplen, 2001).

The isotopic composition of water from wells sampled for this study is substantially different from that reported for oxygen and hydrogen isotopes in Appalachian brines in northwestern Pennsylvania and vicinity; in the brines, $\delta^{18}O$ values ranged from 7.1 to -0.4 per mil and δD values ranged from -55.6 to -30.2 per mil, respectively (Osborn and McIntosh, 2010).

Radionuclides

Radionuclides naturally present in rocks and soils may be dissolved and enter into groundwater. These radionuclides are derived primarily from the radioactive decay of uranium-238 or thorium-232. Each radionuclide has a unique half-life, position in the decay series, and chemical properties, and each emits primarily alpha or beta particles during radioactive decay. Radium-226 and its daughter product radon-222 are progeny in the uranium-238 decay series. Radium-228 is part of the thorium-232 decay series.

Of the radioactive constituents analyzed in 2012 groundwater samples from 20 wells, only activities of radon-222 exceeded any MCL (proposed MCL for radon-222) (table 6). These results are consistent with a recent previous study in Pike County (Senior, 2009).

Gross Alpha-Particle and Beta-Particle Activity

Gross alpha-particle and beta-particle activities are a measure of alpha and beta particles produced by the decay of all radionuclides in a sample and commonly are used as a screen to determine the likelihood of elevated activities of an individual radionuclide, such as radium-226, an alpha-particle emitter, or radium-228, a beta-particle emitter. Because radionuclides have different half-lives, gross alpha- and gross beta-particle activities (or concentrations) in a sample change over time. If relatively short-lived radionuclides are present in

Table 6. Minimum, median, and maximum concentrations of selected radioactive constituents determined in the laboratory for water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

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

Radioactive constituent[1]	Units	Number (percent) above reporting level	Concentration			Number (percent) exceeding standard	Drinking-water standard or guideline[2]		
			Minimum	Median	Maximum		MCL	HA	SMCL
Total (unfiltered sample)									
Gross alpha radioactivity, 30-day recount	pCi/L	10 (50)	nd	0.6	1.7	0 (0)	15	--	--
Gross alpha radioactivity, 72-hour count	pCi/L	18 (90)	nd	1.4	8.0	0 (0)	15	--	--
Gross beta radioactivity, 30-day recount	pCi/L	12 (60)	nd	1.0	3.0	0 (0)	[3]4 mrem/yr	--	--
Gross beta radioactivity, 72-hour count	pCi/L	10 (50)	0.7	1.2	2.5	0 (0)	[3]4 mrem/yr	--	--
Radon-222	pCi/L	20 (100)	104	1,365	4,500	17 (85)	[4]300	--	--
Dissolved (filtered sample)									
Uranium (natural)	µg/L	18 (90)	<0.004	0.119	1.11	0 (0)	30	20	--

[1]Gross alpha-particle radioactivity measured using Thorium-230 curve; gross beta-particle radioactivity measured using Cesium-137 curve.

[2]U.S. Environmental Protection Agency (2012) lists standards (MCLs and SMCLs) for public drinking-water supplies; HAs are other health-based guidelines.

[3]MCL expressed as a dose.

[4]Proposed MCL is 300 pCi/L, and proposed alternative MCL is 4,000 pCi/L. Two of 20 (10 percent) samples had radon-222 concentrations greater than 4,000 pCi/L.

the initial sample, gross alpha- and gross beta-particle activities may decrease over time. If relatively short-lived radionuclides are produced from decay of radionuclides in the initial sample, gross alpha- and beta-particle activities may increase through time. Water samples for this study were analyzed at two times—72 hours and 30 days after sample collection. Unfiltered water samples were analyzed for all 20 samples to measure the total contribution of radioactivity from dissolved and any particulate sources.

The gross alpha- and gross beta-particle activities measured at 72 hours and 30 days in water samples from 20 wells were generally relatively low (table 6), indicating low potential for elevated activities of individual radionuclides. Most measured values were less than the method reporting level of 3 pCi/L and are considered to be estimated values that have larger uncertainty than those quantified above this level. Values considered "non-detects" are listed with an "R" preceding the value (table 15 at back of report).

All gross alpha-particle activities were less than the drinking-water MCL of 15 pCi/L. Gross alpha-particle activities measured at 72 hours were greater than those measured at 30 days in most (18 of 20) samples, indicating the presence of short-lived alpha-emitting radionuclides in the initial water sample. The highest measured gross alpha-particle activities were 8 and 6.4 pCi/L at 72 hours. In these two samples, however, measured gross alpha-particle activities decreased to 0.8 and 1.7 pCi/L after 30 days, respectively, showing how delay in laboratory analyses may result in a lower estimate of potential health risks associated with short-lived radionuclides.

Gross alpha- and gross beta-particle activities were analyzed in both filtered and unfiltered water samples collected in 2012 from seven wells that had been sampled previously in 2007 to allow comparison of total and dissolved gross alpha- and gross beta-particle activities in the 2012 samples as a dataset and relative to results for 2007 samples. The 2007 samples were analyzed only for dissolved gross alpha- and gross beta-particle activities (filtered samples). A plot of gross alpha- and gross beta-particle activities in filtered and unfiltered samples from 7 wells measured at 72 hours and 30 days shows that most activities in filtered samples generally were similar (within ±1 pCi/L) to activities in unfiltered samples (fig. 7), indicating that the dissolved phase of radionuclides

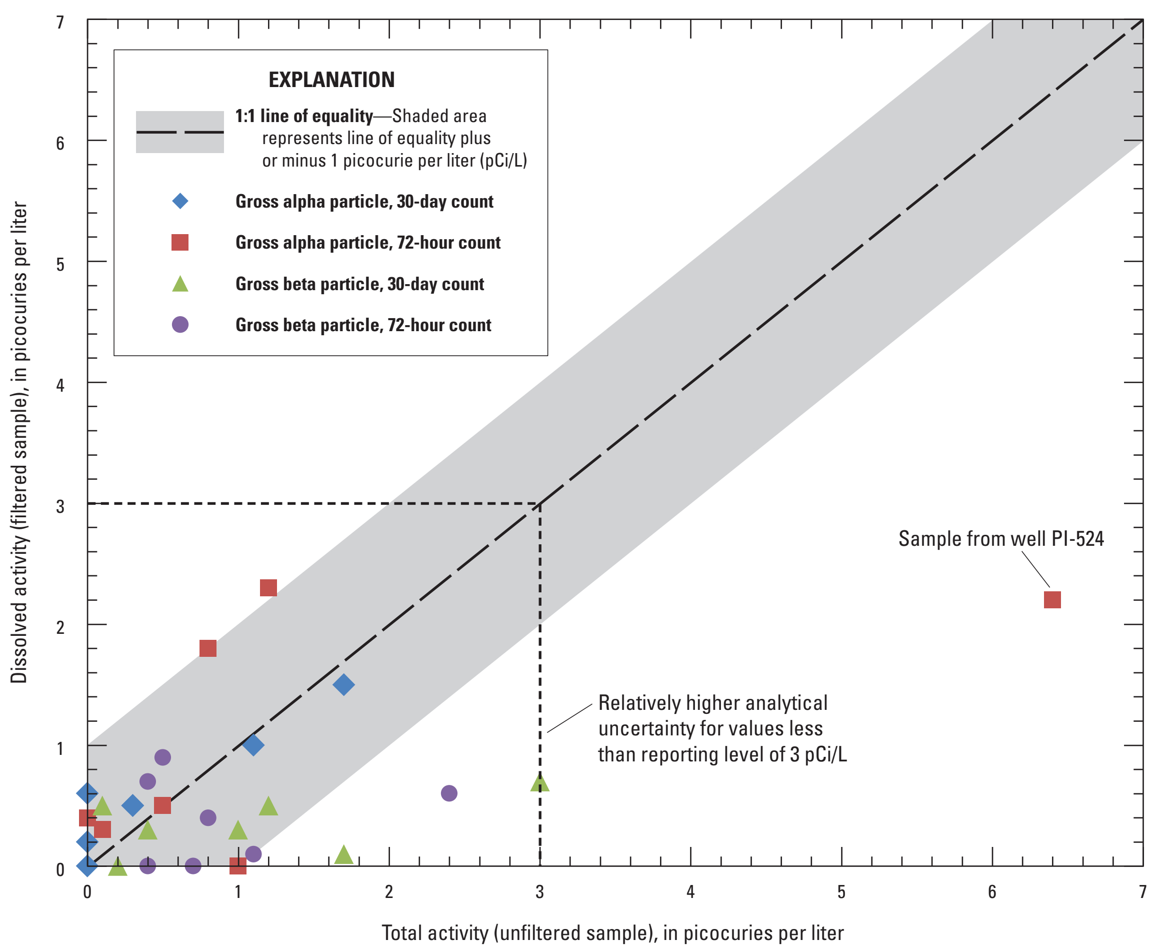


Figure 7. Gross alpha- and gross-beta particle activities in filtered and unfiltered samples collected from seven wells in Pike County, Pennsylvania, summer 2012.

predominates and that most activities in filtered samples are roughly equivalent to activities in unfiltered samples. However, for samples from one well (PI-524), the gross alpha-particle activity at 72 hours was much greater in the unfiltered sample than in the filtered sample (6.4 compared to 2.2 pCi/L, respectively), and the gross beta-particle activities at both 72 hours and 30 days were slightly greater in the unfiltered sample than in the filtered sample. The results for the overall comparison of dissolved and total gross alpha- and gross beta-activities should be interpreted with caution because of the small sample size and the fact that most of the measured dissolved and total gross alpha- and beta-particle activities were less than the reporting level of 3 pCi/L; values less than the reporting level are more uncertain than values above the reporting level. The gross alpha- and gross beta-particle activities in filtered samples measured in 2012 were generally within 1 to 2 pCi/L of those measured in 2007, but as previously noted, the measured activities were less than the reporting level of 3 pCi/L and probably have uncertainty of about the same magnitude as the range of differences between samples analyzed at two different times. Therefore, the 2007 and 2012 values are considered to be quite similar.

Radon-222

Radon-222, a daughter product of radium-226, is an inert gas that dissolves in water. Radon-222 concentrations ranged from 104 to 4,500 pCi/L and exceeded the proposed MCL of 300 pCi/L in samples from 17 (85 percent) of the 20 wells (table 6). Radon-222 concentrations exceeded the higher alternative MCL of 4,000 pCi/L (proposed by EPA for dwellings with remediation for radon in air) in samples from 2 (10 percent) of the 20 wells. The EPA has set an action level for radon-222 in indoor air of 4 pCi/L (U.S. Environmental Protection Agency, 2012b).

Radon-222 concentrations are partly controlled by the presence of its parent, radium-226, and preceding radionuclides in the decay chain within aquifer materials. Both radon-222 and its parent radium-226 emit alpha particles during radioactive decay. However, radon-222 concentrations do not appear to correlate with gross alpha-particle activities, suggesting that other alpha-emitting radionuclides, such as radium-226 or radium-224, are present. The distribution of radon-222 activities in the 2012 samples are similar to results from a 2007 study in Pike County, in which radon-222 activities in groundwater appeared to differ by geologic unit and were highest in water samples from wells completed in Catskill Formation units (Senior, 2009).

Uranium

Uranium concentrations in the 20 well-water samples collected in 2012 were low, ranging from 0.011 to 1.11 μg/L. No sample had uranium concentrations close to or greater than the drinking-water MCL of 30 μg/L.

Water Types and Relations among Inorganic Constituents

The concentrations of many major ions may be related to the concentrations of other major or minor constituents or to water-quality characteristics, such as pH. These relations provide information about the sources of the ions and chemical controls on these constituents in groundwater.

Piper diagrams show the relative proportions of major ions in water samples and may be used to distinguish different types of water. Major cations are calcium, magnesium, and sodium (plotted with potassium that usually is less than the sodium component). Major anions are bicarbonate (HCO_3^-), sulfate, and chloride (plotted with nitrate and fluoride, both usually less than the chloride component). The major ion composition of water samples collected in summer 2012 in Pike County as plotted on a piper diagram (fig. 8) is predominantly mixed cations (with about 20–40 percent sodium plus potassium and the balance calcium plus magnesium) and mixed anions (with 50 or more percent bicarbonate). Two samples plot as much higher in sodium than the other samples and can be categorized as sodium-bicarbonate-type waters (fig. 8).

The two well-water samples with relatively high concentrations of sodium also have relatively high pH (above 8.2) and relatively high concentrations of some minor ions and inorganic trace constituents, including bromide, fluoride, lithium, and boron (fig. 9). Sodium-bicarbonate waters with elevated pH may form as a result of ion-exchange (sodium for calcium) as has been reported for shallow shale aquifers elsewhere (Kresse and others, 2012). A plot of sodium, lithium, boron, bromide, and fluoride concentrations in relation to pH for all 20 well-water samples shows few or slight trends of constituents with increase in pH below pH of about 8 (fig. 9).

The highest sodium concentration is associated with the highest boron concentration and with elevated but not the highest chloride concentration. Although sodium concentrations are generally related to both chloride and boron concentrations (fig. 9), suggesting possible anthropogenic sources of sodium including salt (sodium chloride) and borax (a sodium borate compound) in groundwater, other sources of sodium also are indicated. Samples with the highest concentrations of sodium also have the highest concentrations of several other trace elements, such as lithium, fluoride, and bromide (fig. 9), that are associated with naturally occurring brines or other high TDS waters, suggesting natural sources for the most elevated sodium concentrations.

Chloride is a conservative ion (tends to remain in solution once dissolved) that occurs naturally at low concentrations in freshwater systems and at higher concentrations in brines (table 1) and saline waters, but it also may be introduced as a result of human land-use activities such as application of road salt (commonly composed of sodium chloride or calcium chloride) or on-site wastewater disposal (septic systems). Precipitation probably contributes on average less than 1 mg/L of

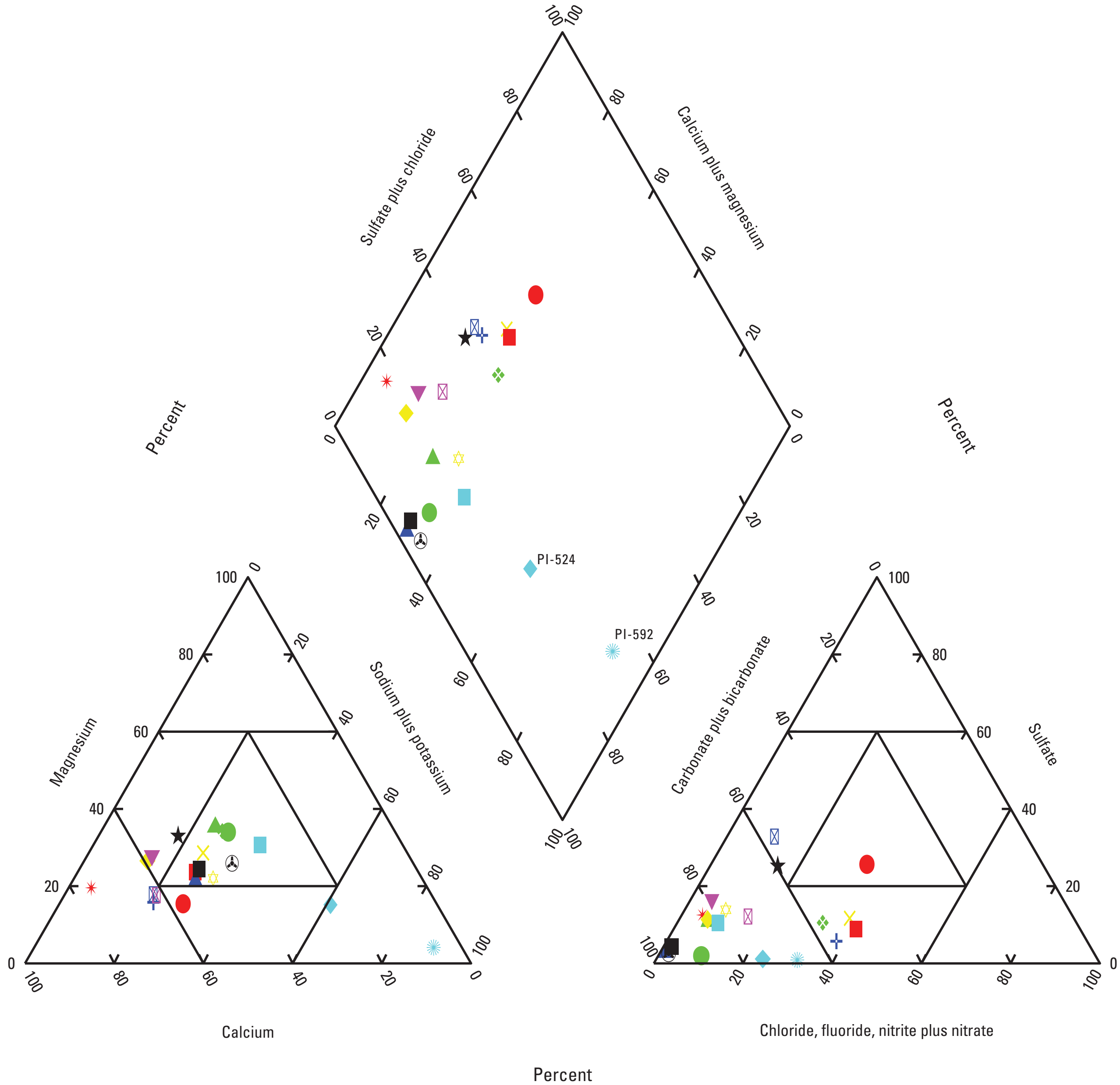


Figure 8. Piper diagram showing major ion composition in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012. The composition of each well-water sample is plotted using a unique symbol.

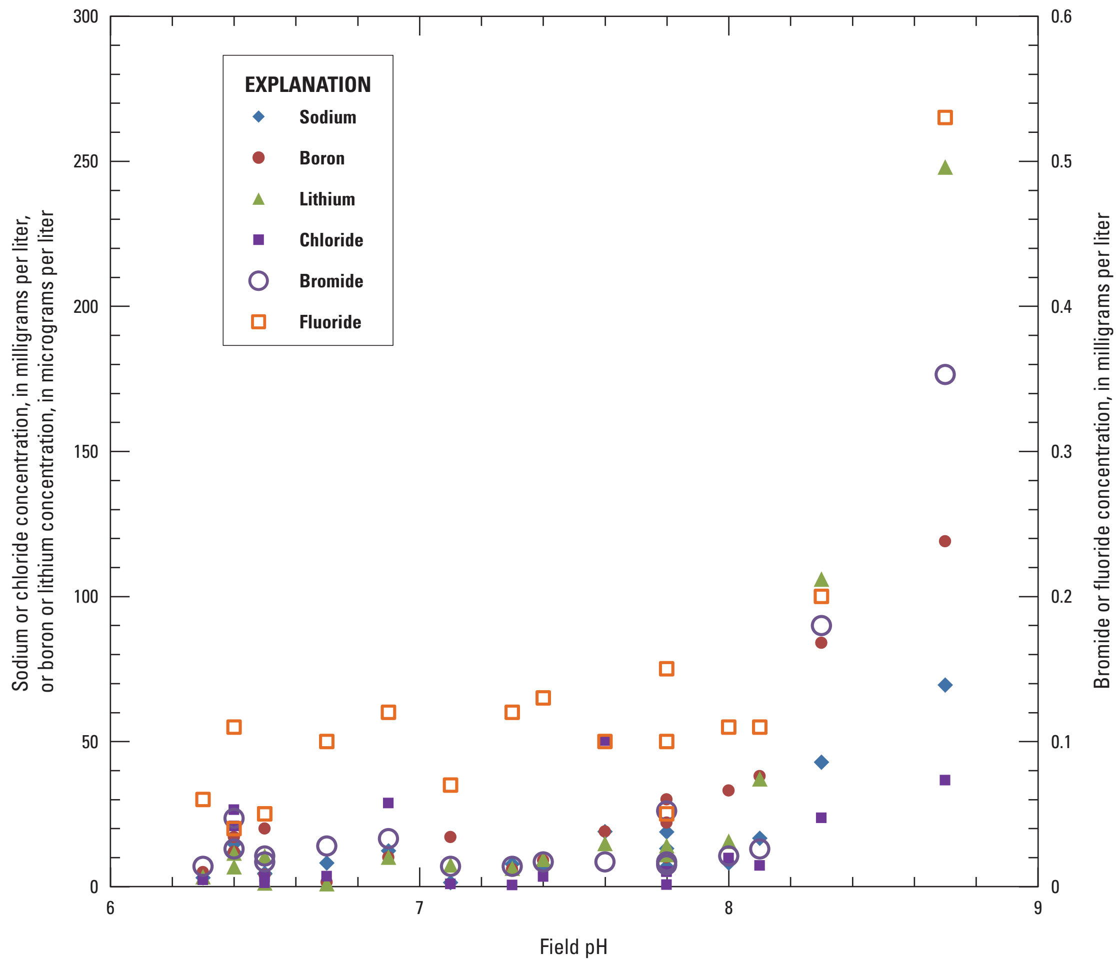


Figure 9. Sodium, chloride, lithium, boron, bromide, and fluoride concentrations in relation to field pH in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

chloride to recharge concentrations, and on the basis of chloride concentrations in precipitation and base flow of streams draining undeveloped land, natural background concentrations of chloride in shallow groundwater in Pike County are estimated to range from 1 to 5 mg/L (Senior, 2009). In Pike County, chloride concentrations greater than a few milligrams per liter in shallow groundwater may represent the effects of human land-use activities or contributions from naturally occurring deeper, more saline groundwater. Recent studies of groundwater quality in nearby Susquehanna County in northeastern Pennsylvania (Warner and others, 2012; Llwellyn, 2014) have identified some areas where shallow groundwater has relatively elevated concentrations of chloride and chloride/bromide ratios that indicate possible mixing with higher TDS or brine-type waters; these brine-type waters are postulated to be discharging from undetermined depths to shallow groundwater.

Chloride/bromide ratios often are used to distinguish different sources of chloride. Bromide, like chloride, is a soluble anion that exhibits conservative properties and can be used as a tracer. Some sources of chloride introduced by human activities into the environment, such as salt (sodium chloride) used for road deicing or present in septic effluent, typically have relatively low amounts of bromide and consequently relatively high chloride/bromide mass ratios. The chloride/bromide mass ratios for the 20 well-water samples are shown in relation to chloride concentrations in figure 10, which also shows lines representing estimates of the relation if either (1) low-bromide salt (such as sodium chloride used for road salt or in septic effluent) or (2) Marcellus-type brines were added to background groundwater recharged by precipitation having low chloride concentrations. Several Pike County well-water samples have chloride/bromide mass ratios (of about 100) that are relatively low in relation to chloride concentrations (fig. 10), indicating enrichment in bromide and probable differences in sources of chloride. These well-water samples plot near or on the mixing line for precipitation to brines, suggesting a possible small contribution of chloride from a brine-like source. Also plotting on this line is Salt Spring, a naturally occurring saline spring in Susquehanna County. Most other well-water samples plot on or near the line representing estimates of chloride/bromide mass ratios for addition of

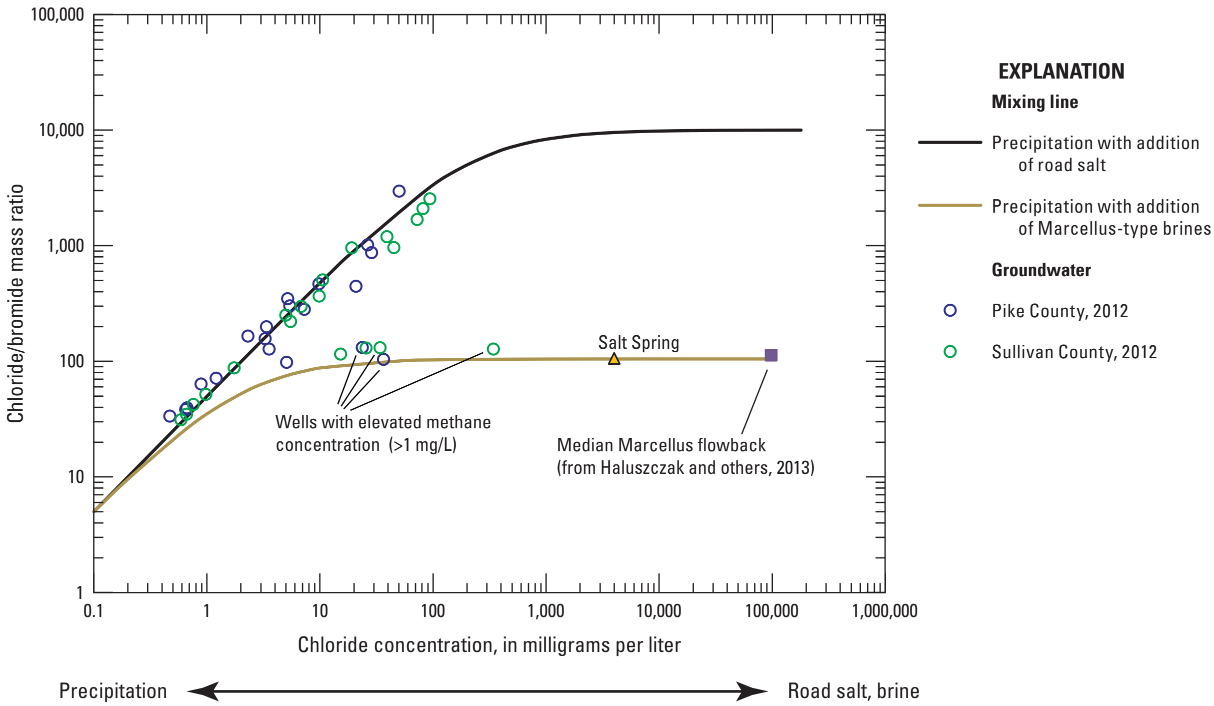


Figure 10. Chloride/bromide mass ratios in relation to chloride concentrations in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012. Data for 20 well-water samples collected in Sullivan County, Pennsylvania, 2012 (Sloto, 2013), are also shown. Groundwater samples containing greater than 1 milligram per liter methane are indicated. (mg/L, milligrams per liter; >, greater than)

low-bromide salt (sodium chloride), such as road salt or septic effluent. These chloride/bromide relations are similar to those for 20 groundwater samples collected in 2012 in Sullivan County (fig. 10), showing that groundwater with elevated bromide (and methane) concentrations occurs elsewhere in northeastern Pennsylvania.

Methane

Methane is a colorless, odorless 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 breakdown of organic matter and can be broadly classified as thermogenic or microbial (biogenic) in origin. Thermogenic methane is formed from breakdown of organic material in sediments under high-temperature conditions caused by deep burial; 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. Sources of methane may be inferred from isotopic composition of 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 7 are guidelines, but site-specific conditions need to be considered when evaluating potential risks (Eltschlager and others, 2001).

Occurrence and Other Hydrocarbon Gases

Methane was detected in 16 (80 percent) of the 20 well-water samples collected in summer 2012, but most concentrations were low (less than 0.1 mg/L) (table 7) and not considered hazardous. Methane concentrations quantified above the

Table 7. Minimum, median, and maximum concentrations of methane, ethane, and ethene determined in the laboratory for water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

[Dissolved gas analyses conducted by TestAmerica, Inc.; µg/L, micrograms per liter; --, no data or not applicable; >, greater than; <, less than]

Dissolved gas	Unit	Number (percent) above reporting level	Concentration			Number (percent) exceeding standard	Well-water action level, in micrograms per liter[1]		
			Minimum	Median	Maximum		Immediate	Warning—investigate	No immediate action—periodic monitoring
Methane	µg/L	16 (80)	<0.211	2.11	4,650	0 (0)	>28, 000	>10,000 but <28,000	<10,000
Ethane	µg/L	3 (15)	<0.0615	<0.0615	0.400	0 (0)	--	--	--
Ethene	µg/L	0 (0)	<0.0569	<0.0569	<0.0569	0 (0)	--	--	--

[1]Recommended action level to minimize hazard of explosion (Eltschlager and others, 2001); converted from milligrams per liter to micrograms per liter for this table.

detection level of 0.211 µg/L (about 0.0002 mg/L) ranged from 0.415 to 4,650 µg/L (0.0004 to 4.65 mg/L) and were less than 60 µg/L (0.060 mg/L) in all but two samples (as measured by TestAmerica). Water samples from these two wells had methane concentrations of 2,780 and 4,650 µg/L (equivalent to 2.78 and 4.65 mg/L) (as measured by TestAmerica). Methane concentrations analyzed by a different laboratory (Isotech) in replicate samples from these two wells were 3.8 and 5.8 mg/L, about 1 mg/L higher. As discussed in the section "Quality Assurance and Quality Control," methane concentrations determined in replicate samples by two other laboratories (Isotech and the USGS CFC laboratory) were similar to or somewhat higher (about 20 percent) than those reported by TestAmerica. Therefore, the methane concentrations reported by TestAmerica may represent the lower end of the range of probable values.

No sample had methane in concentrations with recommended actions other than periodic monitoring (table 7). The percentage of well-water samples with methane concentrations greater than 1 mg/L (2 of 20, or 10 percent) in Pike County is similar to that (1 of 4, or 25 percent) reported in the region for wells in Devonian-age Catskill Formation bedrock aquifers in reconnaissance baseline studies of groundwater quality in Sullivan County, Pennsylvania (Sloto, 2013), but about one-half to one-third of that for wells in Devonian-age bedrock aquifers in the area of Delaware County, New York (Kappel and Nystrom, 2012; Kappel, 2013), which borders Wayne County, Pennsylvania (fig. 1).

Ethane was the only hydrocarbon gas other than methane detected of the three gases (methane, ethane, and ethene) included in the analysis by TestAmerica. Ethane was detected in water samples from three wells (PI-571, PI-592, and PI-524), two of which had the highest measured methane concentrations in the spatial assessment. Ethane concentrations were 0.191, 0.241, and 0.400 µg/L in water from the three wells that had methane concentrations of 21.1, 2,780, and 4,650 µg/L (0.021, 2.78, and 4.65 mg/L), respectively. Samples from three wells (PI-599, PI-592, and PI-524) were selected for additional dissolved gas analysis by Isotech, which included determination of methane concentration, isotopic composition of methane if sufficient methane were present, and the presence of higher chain hydrocarbon compounds, such as ethane (2 carbon atoms or C_2H_6) or propane (3 carbon atoms or C_3H_8); however, of the higher chain carbon compounds analyzed, only ethane was detected by Isotech (and reported as "C2" for two carbon atoms in molecule; table 17) in the samples from PI-592 and PI-524, which agreed with results from TestAmerica (table 15).

The ratio of methane to higher chain carbon compounds (commonly denoted as C1/C2 for ratio of methane to ethane or C1/ΣC2+ for ratio of methane to sum of all higher chain carbon compounds) has been used to identify origins of methane; C1/C2 ratios (calculated for gases reported in units of volume or molar percent) greater than 1,000 indicate microbial origins and ratios less than 1,000 indicate thermogenic origins (Taylor and others, 2000). The C1/C2 ratios for the three Pike County groundwater samples with detectable ethane were greater than 9,000 for samples from two wells with elevated methane concentrations (PI-524 and PI-592), indicating a predominantly microbial origin; however, the ratio was less than 200 for the PI-571 well-water sample with the low methane concentration of 21.1 µg/L (0.021 mg/L), indicating a thermogenic origin.

Methane concentrations in groundwater, as indicated by the limited data, appear to vary spatially in Pike County. Methane concentrations generally tended to be lower in the west-central part of the county and higher along the eastern edge of the county (fig. 11). The highest methane concentration was in the eastern part of the county. Methane concentrations in the northern part of the county ranged widely from less than detectable to the second highest methane concentration.

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 upland unconfined settings (Heisig and Scott, 2013). These findings are generally consistent with and may be applicable to the Pike County data collected for this study. A plot of altitude of the

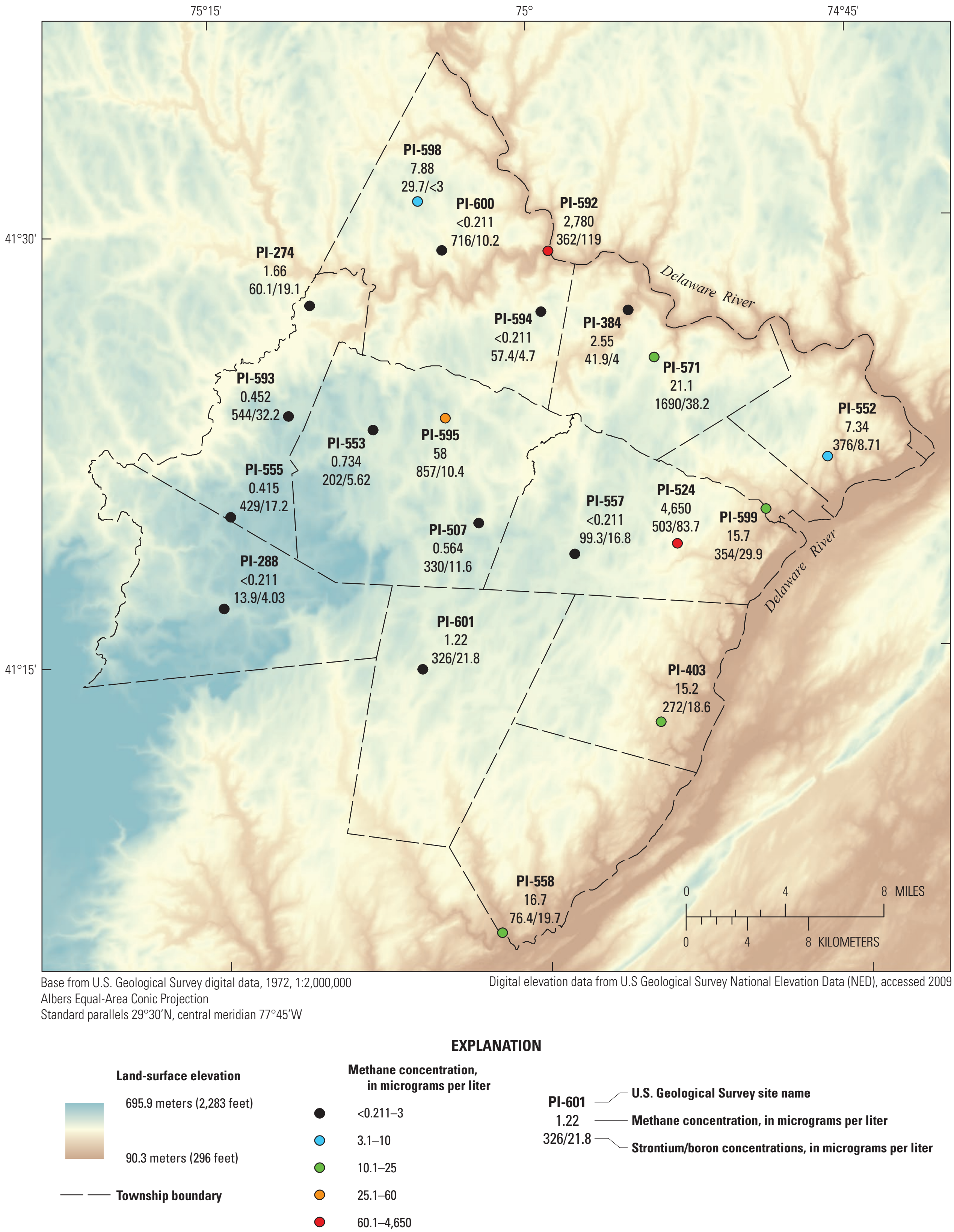


Figure 11. Location of 20 sampled wells and methane, strontium, and boron concentrations in water samples collected from the wells, Pike County, Pennsylvania, summer 2012. (<, less than)

well bottom (to show lowest possible altitude of water-bearing zones open to the well) and methane concentrations in groundwater shows concentrations generally were least in wells having highest well-bottom altitudes (above about 1,000 ft) in Pike County (fig. 12).

Isotopic Composition

Isotopic characterization of methane was done on the only two water samples with sufficient (at least 1 mg/L) methane to perform the analysis. Samples from wells PI-524 and PI-592 had 4.65 and 2.78 mg/L (reported as 4,650 and 2,780 µg/L by TestAmerica), respectively. The analysis determines the isotopic ratios relative to standards for carbon ($\delta^{13}C$) and hydrogen (δD) atoms that form methane. For methane in the two samples, the $\delta^{13}C$ values were -64.55 and -64.41 per mil and δD values were -216.9 and -201.8 per mil, respectively.

The type of methane sources, thermogenic or microbial, may be inferred from the distribution of both carbon and hydrogen isotopes. Methane from different sources tends to plot within characteristic ranges of isotopic compositions (Breen and others, 2007). The isotopic composition of methane in the two Pike County samples plot in the range for microbial subsurface methane generated by carbon dioxide reduction (fig. 13); this composition typically is associated with methane in glacial deposits and sometimes is referred to as drift gas (Coleman and others, 1988). The Pike County data plot near the end of this microbial range, towards the thermogenic range and the area between the thermogenic and microbial ranges, which indicates a mixture of methane from different sources. Thus, the methane in the two Pike County groundwater samples appears to be predominantly of a microbial origin, with some possibility of smaller contributions from thermogenic sources.

Relation to Other Constituents in Groundwater

The two groundwater samples (from wells PI-524 and PI-592) with elevated methane concentrations (greater than 1 mg/L) differed in chemical composition from samples with low to undetectable methane concentrations, having higher pH (values greater than 8.2); relatively elevated concentrations of sodium, lithium, boron, bromide, fluoride, and tungsten; and relatively low concentrations of sulfate. One of the two groundwater samples (from well PI-592) also had the highest measured arsenic (30 µg/L), barium (318 µg/L), and orthophosphate (0.177 µg/L) concentrations of the spatial assessment; the highest arsenic concentration exceeded the drinking-water MCL of 10 µg/L. Chloride concentrations in the samples were among the highest, but, notably, the relation between sodium and chloride in the two samples differed from that in the other samples in the assessment by having more sodium (fig. 14). The groundwater samples with elevated methane may be characterized as sodium-bicarbonate type water (fig. 8). These samples also had very low concentrations of oxygen (less than or equal to 0.1 mg/L), but ammonia concentrations (about 0.06 mg/L as N) were among the highest measured in summer 2012 samples. The low oxygen and

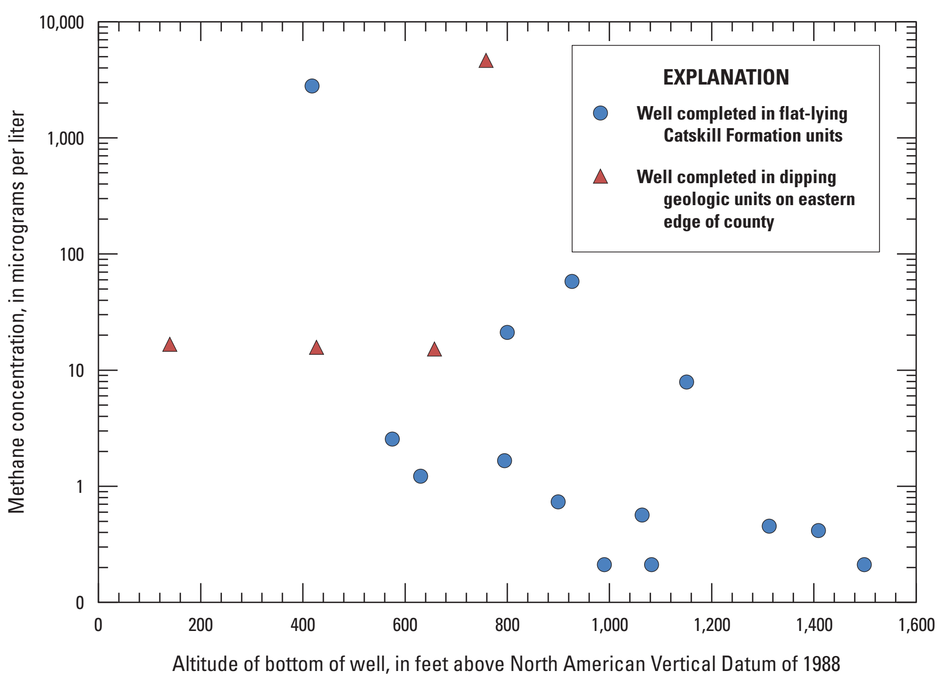


Figure 12. Methane concentrations in water samples from 20 wells sampled in summer 2012 in relation to altitude of well bottoms, Pike County, Pennsylvania.

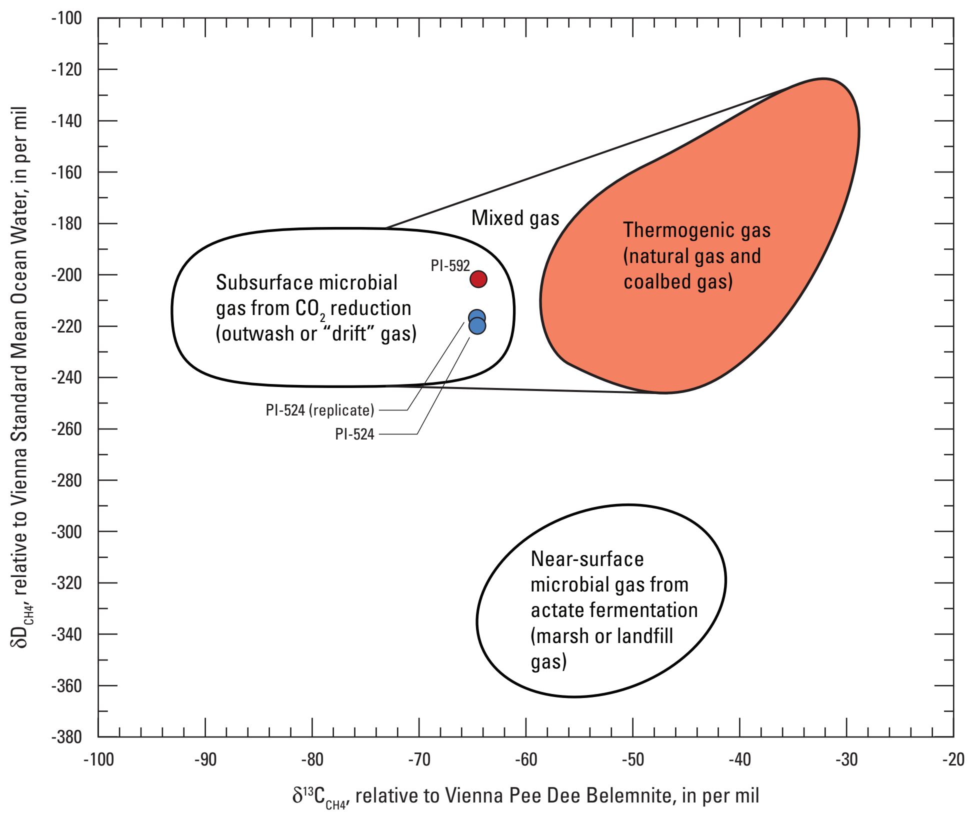


Figure 13. Stable isotopic composition of carbon and hydrogen for methane dissolved in groundwater samples from two wells in Pike County, Pennsylvania, 2012. Diagram shows isotopic compositions observed for microbial or thermogenic sources of methane (modified from Breen and others 2007, fig. 10, that was based on Coleman and others, 1993, using dataset of Shoell, 1980). Isotope analyses were done by Isotech Laboratories, Inc., in Champaign, Illinois.

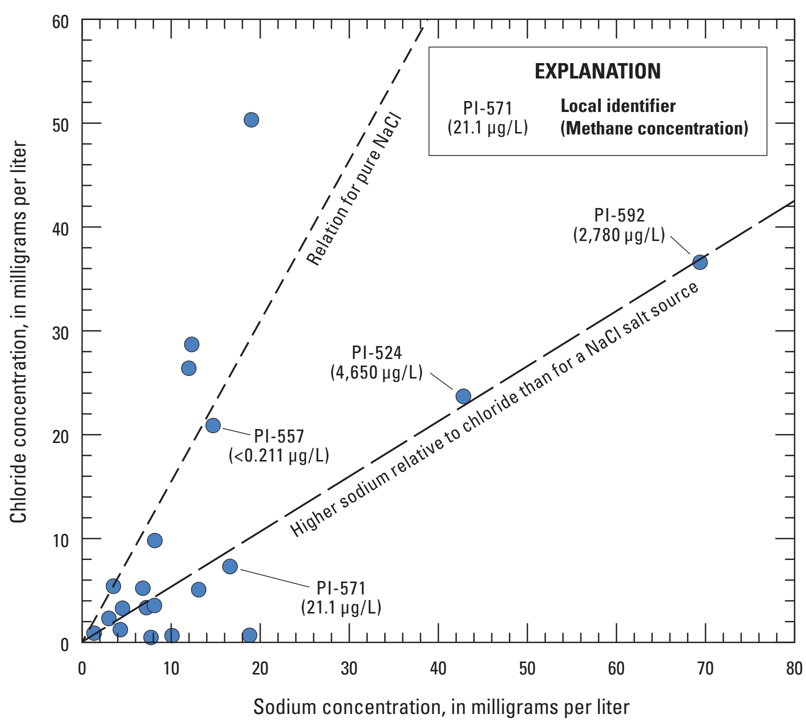


Figure 14. Relation of sodium concentrations to chloride concentrations and elevated methane concentrations in water samples from 20 wells in Pike County, Pennsylvania, summer 2012. (NaCl, sodium chloride; µg/L, micrograms per liter; <, less than)

detectable ammonia concentrations are indicative of reducing conditions in the groundwater that often are associated with high concentrations of dissolved iron and manganese, as was observed in some of the 2012 well-water samples. However, compared to the other four well-water samples with relatively high ammonia concentrations (0.039 to 0.095 mg/L as N), the two samples with elevated methane did not have particularly high iron or manganese concentrations but rather had similar or lower concentrations of iron and much lower concentrations of manganese (table 15).

The source or cause of the elevated concentrations of inorganic constituents in samples with elevated methane concentrations is unknown, although upward leakage of deep brine-like waters or mixing with high TDS waters from flow-restricted zones is possible. Relations among elevated methane, pH, and many of the same inorganic constituents was reported for well-water samples with thermogenic methane from Devonian shales in Sullivan County, Pennsylvania (Sloto, 2013). Other processes that have been postulated for the occurrence of these types of waters include mixing with vestiges of remnant brines and (or) chemical reactions along flow paths in the aquifers (Heisig and Scott, 2013; Kresse and others, 2012).

The two well-water samples with elevated methane concentrations have a stable isotopic water composition that falls on a line for Pennsylvania rivers (fig. 6), indicating that the water is of recent meteoric origin, as is water from the other wells sampled in summer 2012. Thus, isotopic composition of water in well-water samples with relatively elevated methane concentrations does not differ from that in well-water samples with low methane concentrations. Methane gas, however, possibly may migrate independently of water flow and therefore may or may not be of recent age or age similar to the age of the groundwater.

Temporal Assessment

The temporal component of the assessment provides reconnaissance-level information about the amount of seasonal variability in groundwater quality that can be used to evaluate the representativeness of a single sample. Sampling on a single date may not adequately characterize groundwater quality if seasonal or other temporal variability is substantial. Analytical variability of about 5 percent or less is typical and generally considered acceptable. However, the amount of environmental variability commonly is unknown. Groundwater quality may be affected by a number of temporal factors, including changes in water levels and recharge rates or changes in local land use or seasonal vegetation; for example, the amount of water contributed to a well from shallow water-bearing zones may change in relation to water levels and recharge rates and thus affect overall quality of water pumped from that well.

To investigate seasonal or other temporal variability, samples from 4 of the 20 wells sampled in summer 2012 were collected monthly for 1 year ending in summer 2013. The wells were selected to represent a range in concentrations of methane and inorganic constituents measured in groundwater in Pike County. However, because of the limited sampling duration and number of wells that were sampled, water samples from these wells may not necessarily be representative of the possible range in seasonal variability of groundwater quality elsewhere in the county or for other time periods. Additional limited temporal groundwater-quality data are available from USGS databases for 9 of the 20 wells that had been sampled one or more times by USGS before 2012 as part of other investigations (Davis, 1989; Senior, 2009; Eckhardt and Sloto, 2012); these historical data are compiled with results from this study in Appendix 1.

Hydrologic conditions leading up to and during the sampling period from July 2012 through June 2013 generally were about average as indicated by groundwater levels in a long-term observation well in Pike County and annual precipitation. Groundwater levels from July 2012 through June 2013 in observation well PI-522 (fig. 1) were similar to long-term (12 years) median daily values, except for December 2012 when water levels were lower than long-term median daily values (fig. 15*A*). Annual precipitation for 2012 was near the long-term (30-year) average as measured at three nearby climatological stations, although for the 12-month period of July 2012 through June 2013 when samples were collected for the temporal assessment, total precipitation was above the long-term annual average at the two nearest stations (fig. 1; table 8), mostly because of unusually high precipitation in June 2013 (fig. 15*B*). Precipitation in June 2013 was about 5 inches above average at Hawley and Stroudsburg stations but only about 1 inch above average at Wilkes Barre Scranton station. During the sampling period prior to June 2013, precipitation also varied above and below average monthly values, including a wet October 2012, followed by a dry November 2012 when precipitation was 2 to 3 inches below average at all three stations.

Table 8. Precipitation measured at three climatological stations near Pike County, Pennsylvania, 2012–13.

[Location of stations shown in figure 1; data from National Oceanic and Atmospheric Administration, National Climactic Data Center; PA, Pennsylvania; US, United States]

Station	Precipitation, in inches		
	2012 total	July 2012–June 2013 (12-month total)	Long-term (1981–2010 average annual total
Hawley 1E, PA, US	44.68	48.81	42.79
Stroudsburg, PA, US	50.68	56.38	50.79
Wilkes Barre Scranton International Airport, PA, US	38.13	36.82	38.26

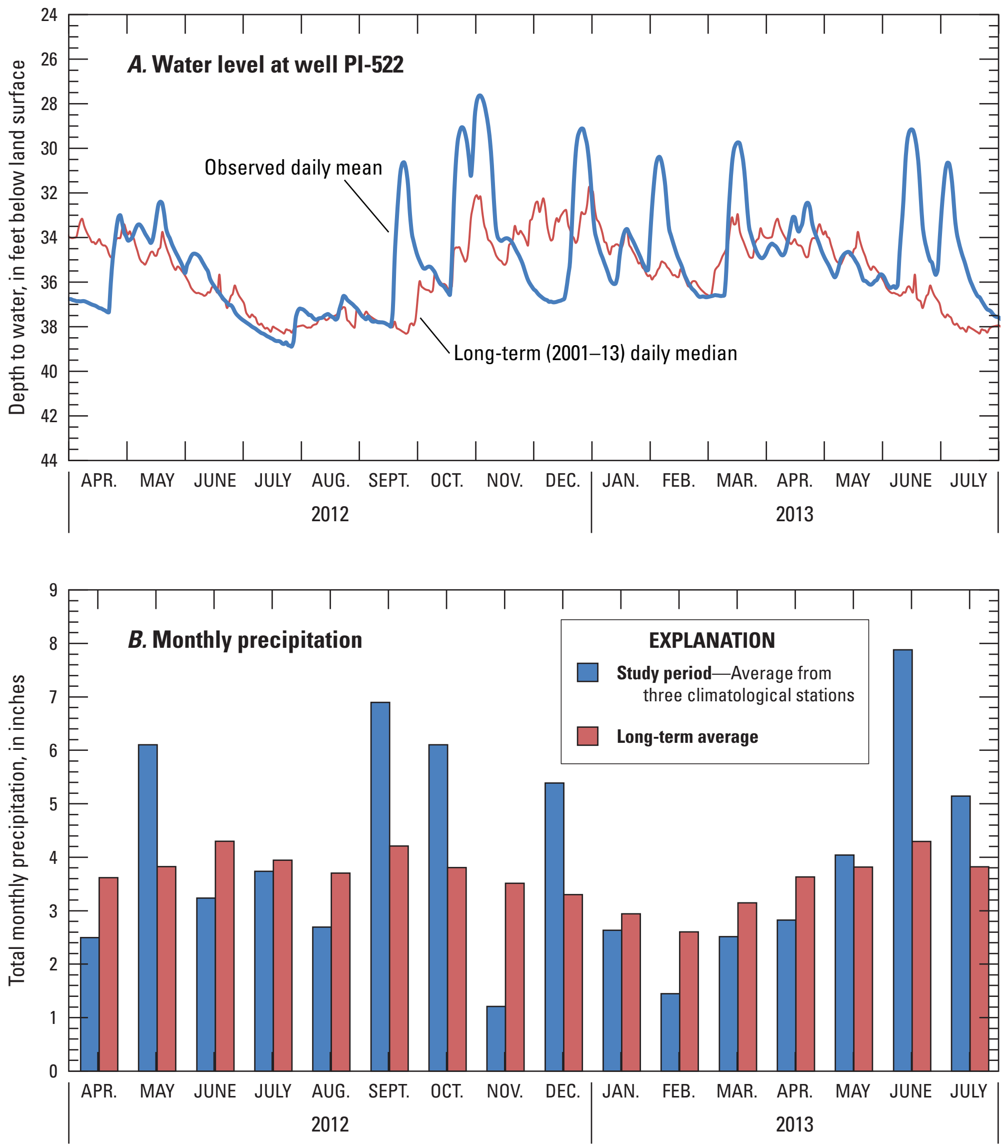


Figure 15. *A*, Daily mean and long-term median of continuously measured groundwater levels in observation well PI-522, April 2012–August 2013 and, *B*, average of total monthly precipitation measured at three climatological stations near Pike County, Pennsylvania, January 2012–September 2013. Long-term median daily values were calculated from water-level data collected in well PI-522 since 2001 (12 years of data). Long-term average monthly values for precipitation are the 30-year normal at the three climatological stations. Locations of well PI-522 and three climatological stations are shown in figure 1.

In observation well PI-522, depth to groundwater tends to be greatest during July, August, and September and least in December, reflecting seasonal changes in recharge. Recharge commonly increases during the fall to spring when evapotranspiration rates decline, and decreases from spring to fall when evapotranspiration rates rise. In winter months, frozen ground may sometimes also reduce recharge. The seasonal pattern in groundwater levels, related to differences in net recharge, is present throughout Pike County and is shown, for example, in the hydrograph of monthly water levels in a well (PI-571) sampled for this study and which is also part of a county-wide observation well network (fig. 16).

Water levels in three of the four wells sampled monthly were measured before well purging. However, water levels could not be measured during all monthly sampling events of the three wells (PI-524, PI-593, and PI-600) because of access issues; therefore, the monthly water-level record is incomplete. Water levels could not be measured in well PI-507, a continuously pumped production well. All four wells sampled monthly were in use, and although an effort was made to measure levels prior to pumping, water levels may have been affected by pumping. Available water-level data for the three wells sampled monthly shown with monthly water levels in PI-571 in figure 16 indicate that groundwater levels rose during the fall of 2012, declined during winter, and rose again in spring 2013. The timing and magnitude of changes in water levels differs among the wells, reflecting differences in timing of recharge and local aquifer characteristics or possible effects of pumping.

Inorganic Constituents and General Water Quality

Differences in water quality throughout the year are described using the statistics of minimum, mean, median, maximum and maximum percent differences. The maximum percent difference is calculated by dividing the range (maximum-minimum) by the minimum values. The maximum percent difference for pH and temperature was less than 15 percent in samples for all four wells sampled monthly. The maximum percent difference for TDS concentrations and specific conductance (unfiltered water) was less than 20 percent in samples from three of the four wells, including wells PI-507, PI-524, and PI-600 (table 9); the maximum percent difference (and range) in TDS concentrations and specific conductance in samples from the fourth well, PI-593, were larger and were related to changes in water quality during the winter months of December and January, as discussed in the following section "Major Ions."

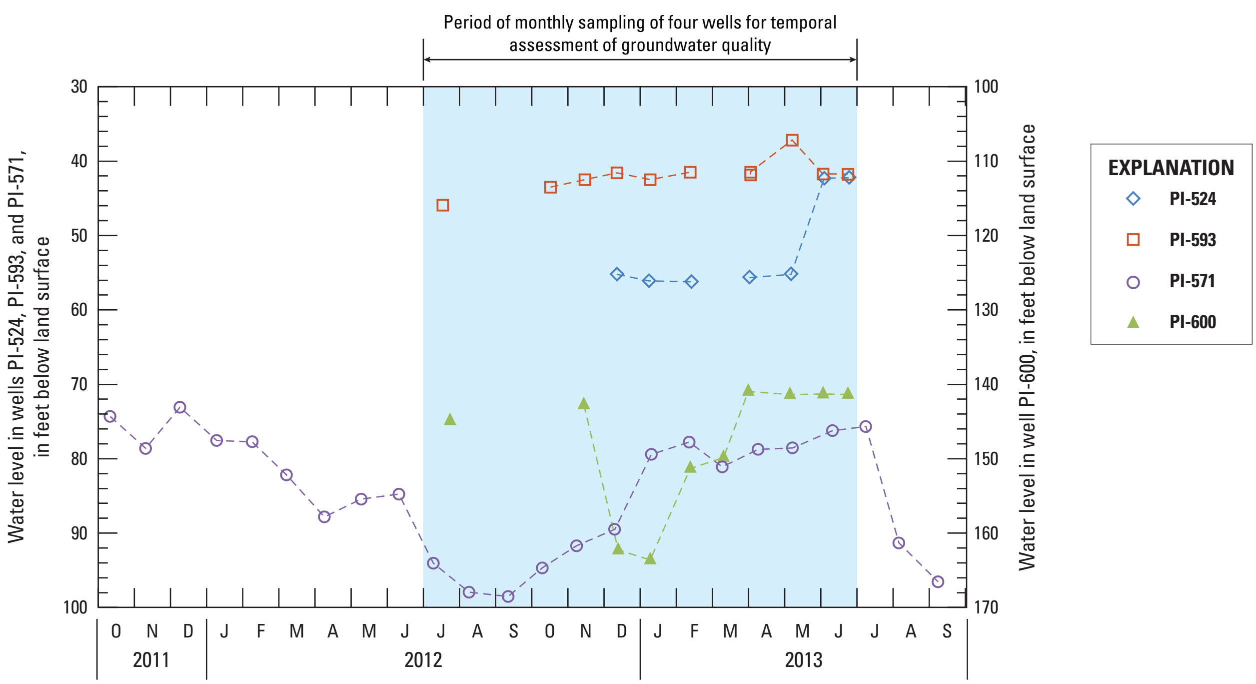


Figure 16. Water levels measured monthly in observation well PI-571 during 2012–13 and in three wells sampled monthly from July 2012 through June 2013 for temporal assessment of groundwater quality, Pike County, Pennsylvania. Locations of wells shown in figure 2.

Table 9. Minimum, mean, median, maximum, and maximum percent difference in dissolved oxygen concentrations, pH, specific conductance, and total dissolved solids concentrations in water samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

[USGS, U.S. Geological Survey; maximum percent difference calculated by dividing the range (difference between maximum and minimum values) by the minimum and multiplying by 100; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Max % dif, maximum percent difference; --, no data or not applicable; <, less than; >, greater than]

USGS site name	Statistic	Dissolved oxygen, water, unfiltered, in mg/L	pH, water, unfiltered, field, in standard units	pH, water, unfiltered, laboratory, in standard units	Specific conductance, water, unfiltered, laboratory, in µS/cm	Specific conductance, water, unfiltered, field, in µS/cm	Temperature, water, in °C	Dissolved solids dried at 180 °C, filtered, in mg/L
Parameter code:		00300	00400	00403	90095	00095	00010	70300
PI-507	Minimum	5.2	6.1	6.7	210	177	10.0	117
PI-507	Mean	6.3	6.6	6.8	215	205	10.3	125
PI-507	Median	6.0	6.5	6.8	215	208	10.2	125
PI-507	Maximum	8.2	6.9	7.0	219	228	10.6	134
PI-507	Range	3.0	0.8	0.3	9	51	0.6	17
PI-507	Max % diff	57.7	13.1	4.5	4.3	28.8	6.0	14.5
PI-524	Minimum	0.1	8.0	8.3	283	243	10.5	161
PI-524	Mean	0.3	8.3	8.3	293	283	11.0	170
PI-524	Median	0.2	8.3	8.3	292	292	10.9	169
PI-524	Maximum	0.8	8.7	8.4	302	308	11.5	184
PI-524	Range	0.7	0.7	0.1	19	65	1.0	23
PI-524	Max % diff	700	8.7	1.2	6.7	26.7	9.5	14.3
PI-593	Minimum	<0.1	7.6	7.8	175	157	10.2	97
PI-593	Mean	0.2	7.9	8.0	230	177	10.5	136
PI-593	Median	0.1	7.8	8.1	186	179	10.4	114
PI-593	Maximum	0.9	8.3	8.2	589	[1]191	10.9	342
PI-524	Range	>0.8	0.7	0.4	414	34	0.7	245
PI-593	Max % diff	--	9.2	5.1	237	21.7	6.9	253
PI-600	Minimum	0.1	7.3	8.0	218	183	10.4	123
PI-600	Mean	0.3	7.8	8.0	222	213	10.6	132
PI-600	Median	0.2	7.8	8.0	222	217	10.6	130
PI-600	Maximum	0.6	8.3	8.1	227	226	11.1	145
PI-600	Range	0.5	1.0	0.1	9	43	0.7	22
PI-600	Max % diff	500	13.7	1.2	4.1	23.5	6.7	17.9

[1]Specific conductance measured in the field differed from that measured in the laboratory for samples collected in December 2012 and January 2013 from well PI-593 because of apparently rapid changes in water quality likely related to infiltration of surface water during sampling

Major Ions

Concentrations of major ions generally varied by less than 20 percent in the samples collected monthly for 1 year from three of the four wells with differences in major ion concentrations generally less than 4 mg/L (table 10). For some ions that occurred in low concentrations, the maximum percent difference was more than 20 percent although the actual differences in concentration range were relatively small, such as 1.9 mg/L for chloride concentrations in samples from well PI-600. An example of seasonal fluctuations in constituent concentrations is shown for chloride in figure 17.

Differences in major ion concentrations among samples collected in 2012 and in previous years (1982, 2007, 2011) in nine wells (Appendix 1) were similar in magnitude to differences among monthly samples (table 17), suggesting monthly variability may be similar to longer-term (20 year) variability under certain conditions (undeveloped or low-density land use). However, an apparent trend of increasing chloride concentrations indicated by the few data at well PI-288, sampled in 1982, 2007, and 2012, and increases in chloride concentrations observed in wells sampled along the developed Route 209 corridor (Senior, 2009) suggest that groundwater quality may change and variability may be larger over time because of land use.

Concentrations of major ions in samples from one (PI-593) of the four wells also varied less than 20 percent, except for some ions in samples collected in 2 months, December 2012 and January 2013, when concentrations of calcium, magnesium, potassium, sodium, and chloride (fig. 17) spiked while concentrations of silica, sulfate, and bicarbonate (as estimated by ANC) remained within the range for other monthly samples from this well (table 16). Concentrations of some other inorganic trace constituents (such as barium, cobalt, iron, manganese, nickel, strontium, vanadium, and uranium) also increased substantially in these winter-time samples from well PI-593, whereas concentrations of orthophosphate were constant, and concentrations of radon-222 declined (table 16). The timing of large increases in concentrations of only some ions in the December and January samples suggests an influx of salts and selected metals to the well water. This well is located at a township building near where deicing salts are stored, transported, and rinsed off trucks used for deicing roads. December 2012 samples were collected after a cold spell when deicing salts had been applied, including a calcium chloride solution and magnesium additive to the solid sodium chloride road salt (Brian Matthews, Palmyra Township, oral commun., 2013). Although the proximity of the well to the storage and use area of large amounts of deicing salts may make groundwater more vulnerable to contamination by road salt, contamination of groundwater by road salt may occur in other settings.

Differences in the sources of chloride can be determined using differences in chloride/bromide ratios. As shown in figure 18, the chloride bromide ratios for samples from three of the four wells were relatively constant, but two samples

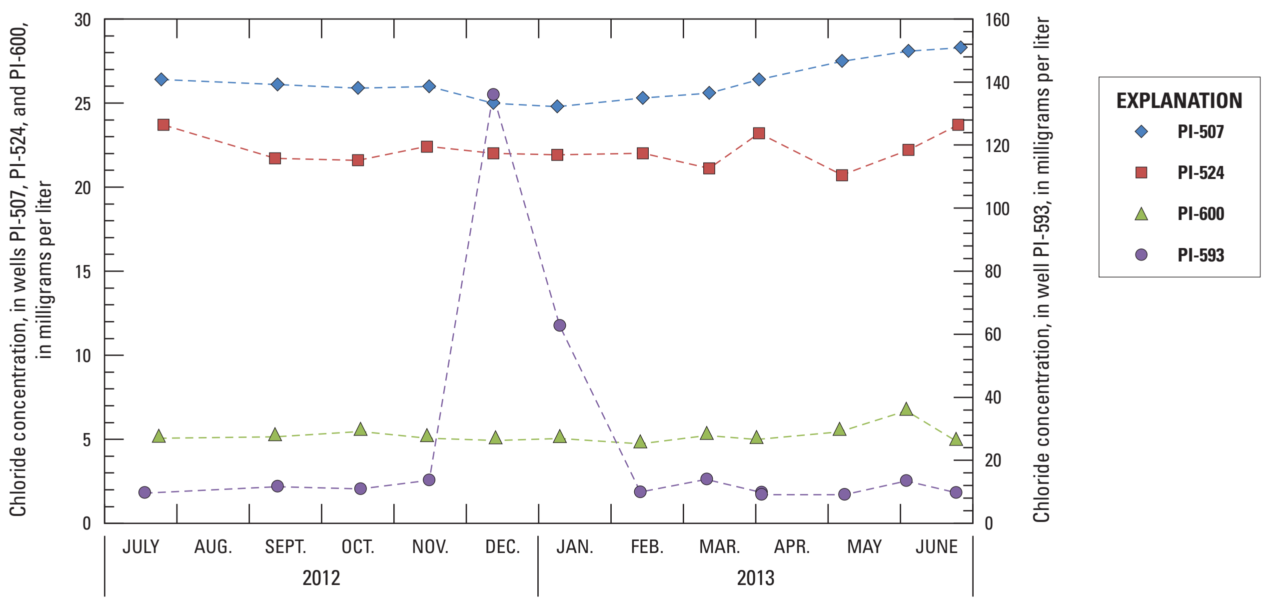


Figure 17. Chloride concentrations in samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

Table 10. Minimum, mean, median, maximum, and maximum percent difference in concentrations of major ions in water samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

[USGS, U.S. Geological Survey; maximum percent difference calculated by dividing the range (difference between maximum and minimum values) by the minimum and multiplying by 100; ANC, acid neutralizing capacity; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen, P, phosphorus; Max % dif, maximum percent difference; <, less than; >, greater than; --, no data or not applicable]

USGS site name	Statistic	Calcium, in mg/L	Magnesium, in mg/L	Potassium, in mg/L	Sodium, in mg/L	ANC[1], fixed endpoint (pH 4.5) titration, in mg/L as $CaCO_3$	Bromide, in mg/L	Chloride, in mg/L	Fluoride, in mg/L	Silica, in mg/L as SiO_2	Sulfate, in mg/L	Ammonia, in mg/L as N	Nitrate plus nitrite[2], in mg/L as N	Orthophosphate, in mg/L as P
Parameter code:		00915	00925	00935	00930	90410	71870	00940	00950	00955	00945	00608	00631	00671
PI-507	Minimum	17.9	6.69	0.64	10.5	48.9	0.020	24.8	0.04	8.19	10.90	<0.010	0.503	0.010
PI-507	Mean	18.8	7.28	0.67	11.1	51.3	0.024	26.3	0.04	9.20	11.45	--	0.546	0.011
PI-507	Median	18.7	7.35	0.67	11.1	51.2	0.024	26.1	0.04	9.31	11.55	--	0.546	0.011
PI-507	Maximum	20.0	7.79	0.71	12.0	53.0	0.026	28.3	0.05	9.73	11.80	<0.010	0.574	0.012
PI-507	Range	2.1	1.10	0.07	1.5	4.1	0.006	3.5	0.01	1.54	0.9	--	0.071	0.002
PI-507	Max % diff	11.7	16.4	10.9	14.3	8.4	30.0	14.1	25.0	18.8	8.3	--	14.1	20.0
PI-524	Minimum	14.5	5.02	0.22	40.0	120.0	0.159	20.7	0.17	9.20	0.76	0.058	<0.040	0.024
PI-524	Mean	15.0	5.44	0.25	41.8	121.5	0.173	22.2	0.19	9.50	0.95	0.064	--	0.026
PI-524	Median	15.0	5.52	0.26	41.7	121.5	0.172	22.0	0.19	9.49	0.94	0.061	--	0.026
PI-524	Maximum	15.4	5.85	0.27	43.9	123.0	0.191	23.7	0.22	9.85	1.16	0.082	<0.040	0.028
PI-524	Range	0.9	0.83	0.05	3.9	3.0	0.032	3.0	0.05	0.65	0.4	0.024	--	0.004
PI-524	Max % diff	6.2	16.5	22.7	9.7	2.5	20.1	14.5	29.4	7.1	52.6	41.4	--	16.7
PI-593	Minimum	21.7	3.57	0.75	7.4	66.7	0.014	9.2	0.07	9.35	8.62	<0.010	<0.040	0.005
PI-593	Mean	28.6	4.89	0.84	8.4	67.3	0.019	24.7	0.09	10.05	9.02	--	--	0.006
PI-593	Median	22.4	3.89	0.80	7.8	67.2	0.017	11.4	0.09	10.20	8.87	--	<0.040	0.006
PI-593	Maximum	74.7	13.10	1.22	13.1	67.9	0.035	136.0	0.11	10.60	9.87	<0.010	0.072	0.007
PI-593	Range	53.0	9.53	0.47	5.7	1.2	0.021	126.8	0.04	1.25	1.3	--	>0.032	0.002
PI-593	Max % diff	244.2	266.9	62.7	77.7	1.8	150.0	1,384.7	57.1	13.4	14.5	--	--	40.0
PI-600	Minimum	26.2	7.07	0.63	6.4	96.3	0.013	4.9	0.05	11.50	10.70	<0.010	<0.040	0.005
PI-600	Mean	27.9	7.55	0.68	6.9	99.4	0.015	5.4	0.06	12.03	11.10	--	--	0.005
PI-600	Median	27.8	7.62	0.69	6.9	100.0	0.016	5.2	0.06	12.00	11.20	--	<0.040	0.005
PI-600	Maximum	29.2	7.81	0.72	7.3	101.0	0.018	6.8	0.07	12.90	11.40	<0.010	0.054	0.007
PI-600	Range	3.0	0.74	0.09	0.8	4.7	0.005	1.9	0.02	1.40	0.7	--	>0.014	0.002
PI-600	Max % diff	11.5	10.5	14.3	13.0	4.9	38.5	39.5	40.0	12.2	6.5	--	--	40.0

[1]Determined in unfiltered sample in laboratory.

[2]Nitrite measured above detection level of 0.001 mg/L as N in only three samples, one from well PI-507 and two from well PI-600, with concentrations up to 0.003 mg/L as N.

from well PI-593 have chloride/bromide ratios that differ from the ratios for other monthly samples. These two samples were collected in December 2012 and January 2013 and provide evidence, in addition to the associated large increases in calcium, magnesium, chloride and other constituent concentrations (table 17), to support a transient source of chloride, such as contamination from runoff or surface waters containing deicing salts.

Nutrients

Of the nutrients analyzed, nitrite was detected least frequently and orthophosphate most frequently. Nitrite was measured in concentrations greater than the reporting level of 0.001 mg/L as N in only three samples, one from well PI-507 and two from well PI-600, with concentrations as much as 0.003 mg/L as N. Nitrate was measured in concentrations greater than the reporting level in samples from only one well (PI-507), with a maximum percent difference in concentration of about 14 percent throughout the year (table 10). Ammonia was measured in concentrations greater than the reporting level in samples from only one (PI-524) of the four wells, with a maximum percent difference in concentration of 41 percent throughout the year. Orthophosphate was measured in concentrations greater than the reporting level in all samples collected from all four wells. The maximum percent difference in orthophosphate concentration ranged from about 17 to 40 percent and was smaller for wells with higher concentrations (table 10). Despite the large changes in major ion and some inorganic trace constituent concentrations in winter-time samples from well PI-593 that appear to have been affected by deicing compounds, the only change in nutrient concentrations during that period was a small increase (0.03 mg/L as N) in nitrate in the January 2013 sample; nutrients typically are not associated with deicing compounds.

Inorganic Trace Constituents

The maximum percent difference in inorganic trace constituent (metals and other elements) concentrations (table 11) generally was greater than that for major ions, partly because small changes represent large percent differences for low concentrations. As noted in a previous section on temporal changes in major ions, concentrations of some inorganic trace constituents (such as barium, cobalt, iron, manganese, nickel, strontium, vanadium, and uranium) also increased substantially, but temporarily, in winter samples from well PI-593, likely as a result of infiltration of deicing compounds. Other temporal changes in concentrations of several inorganic trace constituents appear to be associated with changes in the isotopic composition of water that may indicate periods of recharge as discussed in a following section "Isotopic Composition of Water and Dissolved Inorganic Carbon." For example, in water samples from well PI-524, concentrations of chloride, barium, boron, and lithium declined in October 2012 and again in May and early June 2013 (fig. 19), periods when isotopic values for δD and $\delta^{18}O$ also declined slightly.

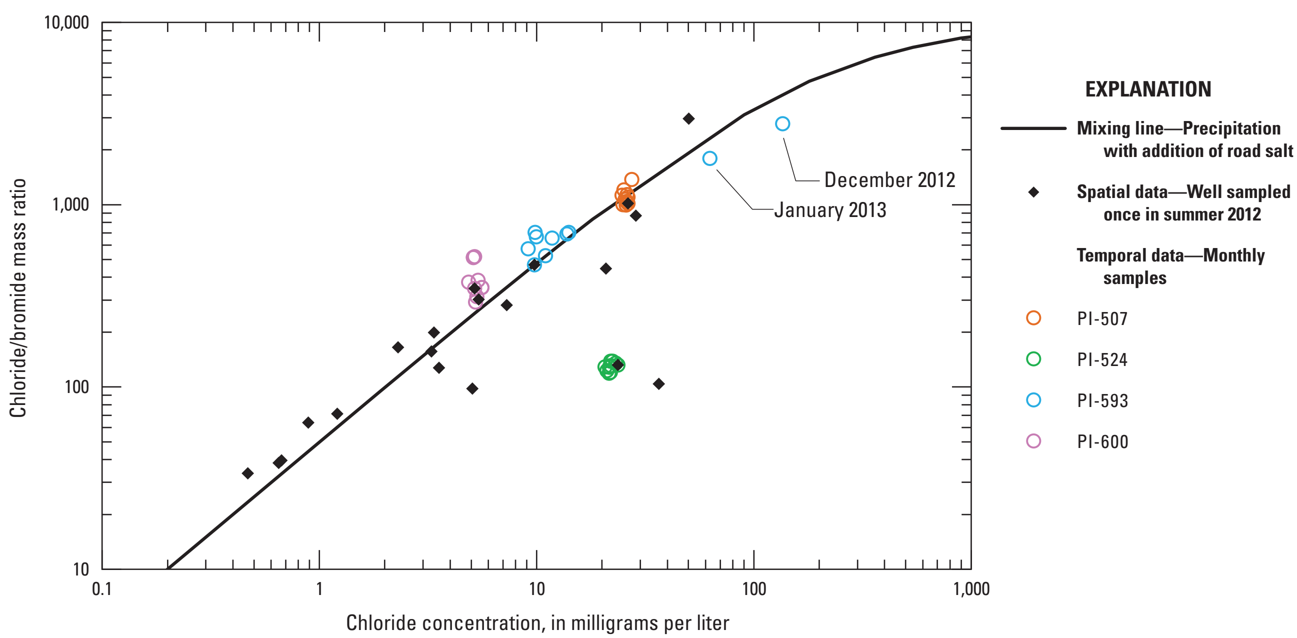


Figure 18. Chloride/bromide mass ratios in relation to chloride concentrations in samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

Table 11. Minimum, mean, median, maximum, and maximum percent difference in concentrations of inorganic trace constituents (metals and other elements) in water samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

[Statistics not shown for some metals that were analyzed but were only detected in a few samples[1]. All analyses done on filtered water samples unless otherwise indicated. Maximum percent difference calculated by dividing the range (difference between maximum and minimum values) by the minimum and multiplying by 100; USGS, U.S. Geological Survey; Max % dif, maximum percent difference; <, less than; >, greater than; --, no data or not applicable; µg/L, micrograms per liter]

USGS site name	Statistic[1]	Barium, in µg/L	Cobalt, in µg/L	Copper, in µg/L	Iron, in µg/L	Iron, water, unfiltered, recoverable, in µg/L	Lead, in µg/L	Lead, water, unfiltered, recoverable, in µg/L	Lithium, in µg/L	Manganese, in µg/L	Manganese, water, unfiltered, recoverable, in µg/L
Parameter code:		**01005**	**01035**	**01040**	**01046**	**01045**	**01049**	**01051**	**01130**	**01056**	**01055**
PI-507	Minimum	46.2	<0.021	<0.08	3.3	<3.2	0.212	0.20	10.9	<0.16	<0.20
PI-507	Mean	48.3	--	--	4.7	--	0.351	0.30	11.7	--	--
PI-507	Median	48.1	0.060	<0.08	4.1	<4.0	0.315	0.26	11.6	<0.16	<0.20
PI-507	Maximum	52.0	0.269	2.6	7.0	25.8	0.596	0.56	12.5	0.42	0.26
PI-507	Range	5.8	>0.248	>2.52	3.7	>22.6	0.384	0.36	1.6	>0.26	>0.06
PI-507	Max % diff	12.6	--	--	112	--	181	180	14.7	--	--
PI-524	Minimum	127.0	<0.023	<0.08	22.3	41.6	<0.025	0.05	73.1	16.1	17.6
PI-524	Mean	133.4	--	--	28.6	65.6	--	0.14	120	19.1	19.1
PI-524	Median	133.5	0.029	--	27.5	64.0	0.030	0.11	127	19.4	19.2
PI-524	Maximum	138.0	0.084	<0.08	39.1	92.4	0.096	0.32	143	21.7	20.6
PI-524	Range	11.0	>0.061	--	16.8	50.8	>0.071	0.27	69.9	5.6	3.0
PI-524	Max % diff	8.7	--	--	75	122	--	540	95.6	34.8	17.0
PI-593	Minimum	71.1	<0.023	<0.08	4.2	<3.2	0.15	0.19	14.8	13.9	13.4
PI-593	Mean	88.1	--	--	10.1	--	0.48	0.79	17.3	21.2	20.7
PI-593	Median	75.3	0.031	1.1	6.9	<4.0	0.44	0.46	17.2	15.3	15.8
PI-593	Maximum	191.0	0.296	<0.08	22.4	35.9	1.00	3.24	21.1	56.5	58.5
PI-593	Range	119.9	>0.273	--	18.2	>32.7	0.85	3.05	6.3	42.6	45.1
PI-593	Max % diff	169	--	--	433	--	567	1,605	42.6	306	337
PI-600	Minimum	144.0	<0.021	0.94	4.3	<3.2	0.21	0.20	10.4	0.17	0.39
PI-600	Mean	159.4	--	14.2	5.2	--	0.56	0.54	12.3	0.38	0.65
PI-600	Median	160.0	0.050	15.4	5.2	<4.0	0.42	0.40	12.4	0.39	0.63
PI-600	Maximum	168.0	0.122	27.6	6.0	57.5	1.30	1.30	13.8	0.87	1.49
PI-600	Range	24.0	>0.101	26.7	1.7	>54.4	1.09	1.10	3.4	0.70	1.10
PI-600	Max % diff	16.7	--	2,836	39.5	--	522	550	32.7	412	282

Table 11. Minimum, mean, median, maximum, and maximum percent difference in concentrations of inorganic trace constituents (metals and other elements) in water samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.—Continued

[Statistics not shown for some metals that were analyzed but were only detected in a few samples[1]. All analyses done on filtered water samples unless otherwse indicated. Maximum percent difference calculated by dividing the range (difference between maximum and minimum values) by the minimum and multiplying by 100; USGS, U.S. Geological Survey; Max % dif, maximum percent difference; <, less than; >, greater than; --, no data or not applicable; µg/L, micrograms per liter]

USGS site name	Statistic[1]	Molybdenum, in µg/L	Nickel, in µg/L	Strontium, in µg/L	Tungsten, in µg/L	Zinc, in µg/L	Antimony, in µg/L	Arsenic, in µg/L	Arsenic, water, unfiltered, in µg/L	Boron, in µg/L	Selenium, in µg/L
Parameter code:		01060	01065	01080	01155	01090	01095	01000	01002	01020	01145
PI-507	Minimum	<0.014	0.14	330	<0.010	31	<0.027	0.28	<0.28	10	0.08
PI-507	Mean	--	0.20	341	--	148	--	0.31	--	12	0.10
PI-507	Median	0.017	0.18	343	--	108	0.029	0.31	0.36	12	0.10
PI-507	Maximum	0.021	0.26	350	<0.010	301	0.040	0.33	0.39	13	0.12
PI-507	Range	>0.07	0.12	20		270	>0.013	0.05	>0.21	3	0.04
PI-507	Max % diff	--	85.7	6.1	--	877	--	17.9	--	30.0	50.0
PI-524	Minimum	0.324	<0.09	460	0.045	<1.4	<0.027	0.25	<0.28	72	<0.03
PI-524	Mean	0.398	--	476	0.054	--	--	0.28	--	80	--
PI-524	Median	0.411	<0.09	475	0.051	<1.4	--	0.28	0.31	82	--
PI-524	Maximum	0.435	0.19	502	0.094	1.5	<0.027	0.31	0.35	86	<0.03
PI-524	Range	0.111	>0.10	42	0.049	>0.1	--	0.06	>0.07	14	--
PI-524	Max % diff	34.3	--	9.1	109	--	--	24.0	--	19.4	--
PI-593	Minimum	0.231	<0.09	514	<0.010	<1.4	0.061	1.6	1.5	27	<0.03
PI-593	Mean	0.315	--	588	--	--	0.067	1.9	1.8	31	--
PI-593	Median	0.326	0.13	539	--	2.5	0.065	1.9	1.8	31	<0.03
PI-593	Maximum	0.339	0.39	991	<0.010	5.1	0.086	2.0	2.2	34	0.04
PI-593	Range	0.108	>0.30	477	--	>3.7	0.025	0.4	0.7	7	>0.01
PI-593	Max % diff	46.8	--	92.8	--	--	41.0	25.0	46.7	25.9	--
PI-600	Minimum	0.325	0.15	594	<0.010	<1.4	0.068	1.5	1.5	8	<0.03
PI-600	Mean	0.359	0.27	709	--	--	0.085	1.7	1.7	10	--
PI-600	Median	0.352	0.24	716	--	2.9	0.085	1.7	1.7	10	<0.03
PI-600	Maximum	0.410	0.78	777	<0.010	4.5	0.099	1.8	2.0	11	0.05
PI-600	Range	0.085	0.63	183	--	>3.1	>0.013	0.3	0.5	3	>0.02
PI-600	Max % diff	26.2	420	30.8	--	--	--	20.0	33.3	37.5	--

[1]Statistics not shown for the following metals:
Aluminum measured above detection level of 2.2 µg/L in only one sample at 2.9 µg/L, from well PI-593
Beryllium measured above detection level of 0.006 µg/L in samples from only one well (PI-524) with concentrations up to 0.009 µg/L
Cadmium measured above detection level of 0.016 µg/L in samples from only one well (PI-507) with concentrations up to 0.054 µg/L
Chromium measured above detection level of 0.07 µg/L in only three samples, two from well PI-507 and one from well PI-524, with concentrations up to 0.27 µg/L
Silver measured above detection level of 0.007 µg/L in only one sample at 0.009 µg/L, from well PI-600
Thallium measured above detection level of 0.010 µg/L in only one sample at 0.012 µg/L, from well PI-593
Vanadium measured above detection level of 0.08 µg/L in only seven samples, two from well PI-507 and five from well PI-593, with concentrations up to 0.19 µg/L.

Radionuclides

Radioactivity levels were consistently low in water from all four wells sampled, with the lowest values in samples from well PI-507 and the highest values in samples from well PI-524. Gross alpha-particle activities were measured at greater than reporting levels in all samples from three wells (30-day and 72-hour counts for well PI-524, 30-day counts for well PI-593, and 72-hour counts for well PI-600). Gross beta-particle activities were measured at greater than reporting levels in all samples from only one well (30-day count for well PI-524). The maximum percent differences in activities were greater than 100 percent (factor of two) when this statistic could be calculated (table 12). The large variability in gross alpha- and beta-particle activities is partly related to the uncertainty of the measurement itself and to the relatively low activities.

The maximum percent difference in monthly radon-222 activities over 1 year ranged from about 11 to 27 percent in samples from three wells (PI-507, PI-524, and PI-600) but was greater (up to 300 percent) in samples from well PI-593 (table 12) because of markedly low radon-222 values that occurred during winter-time (December 2012 and January 2013) spikes in calcium chloride concentrations; causes of low radon-222 in these two monthly samples are unknown but possibly may be related to infiltration of parking-lot runoff (or truck wash water) near the well head. The maximum percent difference for uranium concentrations (table 12) was similarly lower in samples from the three wells (PI-507, PI-524, and PI-600) than in samples from well PI-593 because of large changes in water quality in December 2012 and January 2013 relative to other monthly samples from well PI-593.

Isotopic Composition of Water and Dissolved Inorganic Carbon

The isotopic composition of water fluctuated in samples from each of the four wells sampled monthly for 1 year (fig. 20) and plot on or near the line for Pennsylvania rivers, except for samples from one well (PI-600), which have slightly more negative δD values relative to $\delta^{18}O$ values (and thus plot slightly below this line) (fig. 21). The patterns in fluctuation differed among the wells, with more negative δD and $\delta^{18}O$ values probably associated with recent recharge.

The isotopic composition of stable carbon ($\delta^{13}C$) in dissolved inorganic carbon (DIC) was determined for 8 of the 12 monthly samples collected from well PI-524, the well with highest methane concentrations, to provide data on the possible origin and fate of methane. The $\delta^{13}C_{DIC}$ values ranged from -10.5 to -10.1 per mil in samples from well PI-524. These $\delta^{13}C_{DIC}$ values are similar to those reported by Osborn and others (2011) for groundwater samples from the Catskill Formation in areas of northeastern Pennsylvania with no active shale-gas drilling; the values are typical for shallow recharge waters acquiring carbon dioxide produced from respiration in the soil zone (Osborn and others, 2011). The range in $\delta^{13}C_{DIC}$ values in monthly water samples from well PI-524 is small in comparison to the range in $\delta^{13}C_{DIC}$ values for shallow groundwater in north-central Pennsylvania reported by Breen and others (2007).

Methane

All samples from the four wells sampled monthly during July 2012–June 2013 were analyzed for dissolved methane,

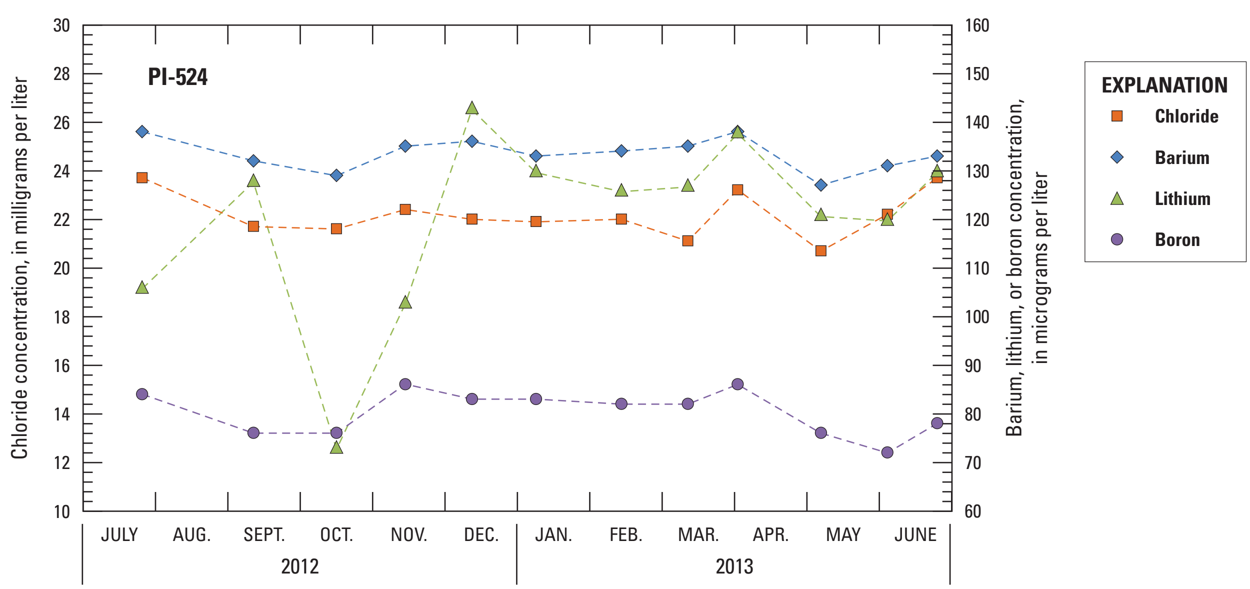


Figure 19. Chloride, barium, boron, and lithium concentrations in samples collected monthly from well PI-524 in Pike County, Pennsylvania, 2012–13.

Table 12. Minimum, mean, median, maximum, and maximum percent difference in concentrations of gross alpha- and beta-particle activities, radon-222 activities, and uranium concentrations in water samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

[Maximum percent difference calculated by dividing the range (difference between maximum and minimum values) by the minimum and multiplying by 100. All analyses done on unfiltered water samples unless otherwise indicated; USGS, U.S. Geological Survey; Max % dif, maximum percent difference; R, indicates radioactivity was not detected above background level in laboratory; Th-230, thorium-230; Cs-137, cesium-137; ≥, greater than or equal to; --, no data or not applicable; pCi/L, picocuries per liter; µg/L, micrograms per liter]

USGS site name	Statistic	Gross alpha radioactivity, 30-day recount, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, Th-230 curve, in pCi/L	Gross beta radioactivity, 30-day recount, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, Cs-137 curve, in pCi/L	Radon-222, in pCi/L	Uranium (natural), water, filtered, in µg/L
Parameter code:		**63016**	**63014**	**63017**	**63015**	**82303**	**22703**
PI-507	Minimum	R	R	R	R	1,760	0.097
PI-507	Mean	--	--	--	--	1,878	0.115
PI-507	Median	R	0.8	1.2	R	1,890	0.116
PI-507	Maximum	1.3	7.0	1.4	3.6	1,960	0.136
PI-507	Range	≥1.3	≥7.0	≥1.4	≥3.6	200	0.039
PI-507	Max % diff	--	--	--	--	11.4	40.2
PI-524	Minimum	1.4	1.5	0.9	R	450	0.131
PI-524	Mean	2.2	5.1	1.8	--	506	0.173
PI-524	Median	2.3	5.4	1.6	1.6	505	0.176
PI-524	Maximum	3.0	9.1	3.0	2.5	550	0.225
PI-524	Range	1.6	7.6	2.1	≥2.5	100	0.094
PI-524	Max % diff	114	507	233	--	22.2	71.8
PI-593	Minimum	0.7	R	R	R	350	0.547
PI-593	Mean	1.6	--	--	--	1,128	0.677
PI-593	Median	1.7	1.4	1.3	1.7	1,160	0.609
PI-593	Maximum	2.7	5.3	2.1	2.6	1,400	1.31
PI-593	Range	2.0	≥5.3	≥2.1	≥2.6	1,050	0.763
PI-593	Max % diff	286	--	--	--	300	139
PI-600	Minimum	R	1.2	R	R	860	0.926
PI-600	Mean	--	2.2	--	--	988	1.07
PI-600	Median	1.4	2.2	1.0	0.8	1,000	1.10
PI-600	Maximum	2.7	3.7	1.4	3.4	1,090	1.15
PI-600	Range	≥2.7	2.5	≥2.4	≥3.4	230	0.224
PI-600	Max % diff	--	208	--	--	26.7	24.2

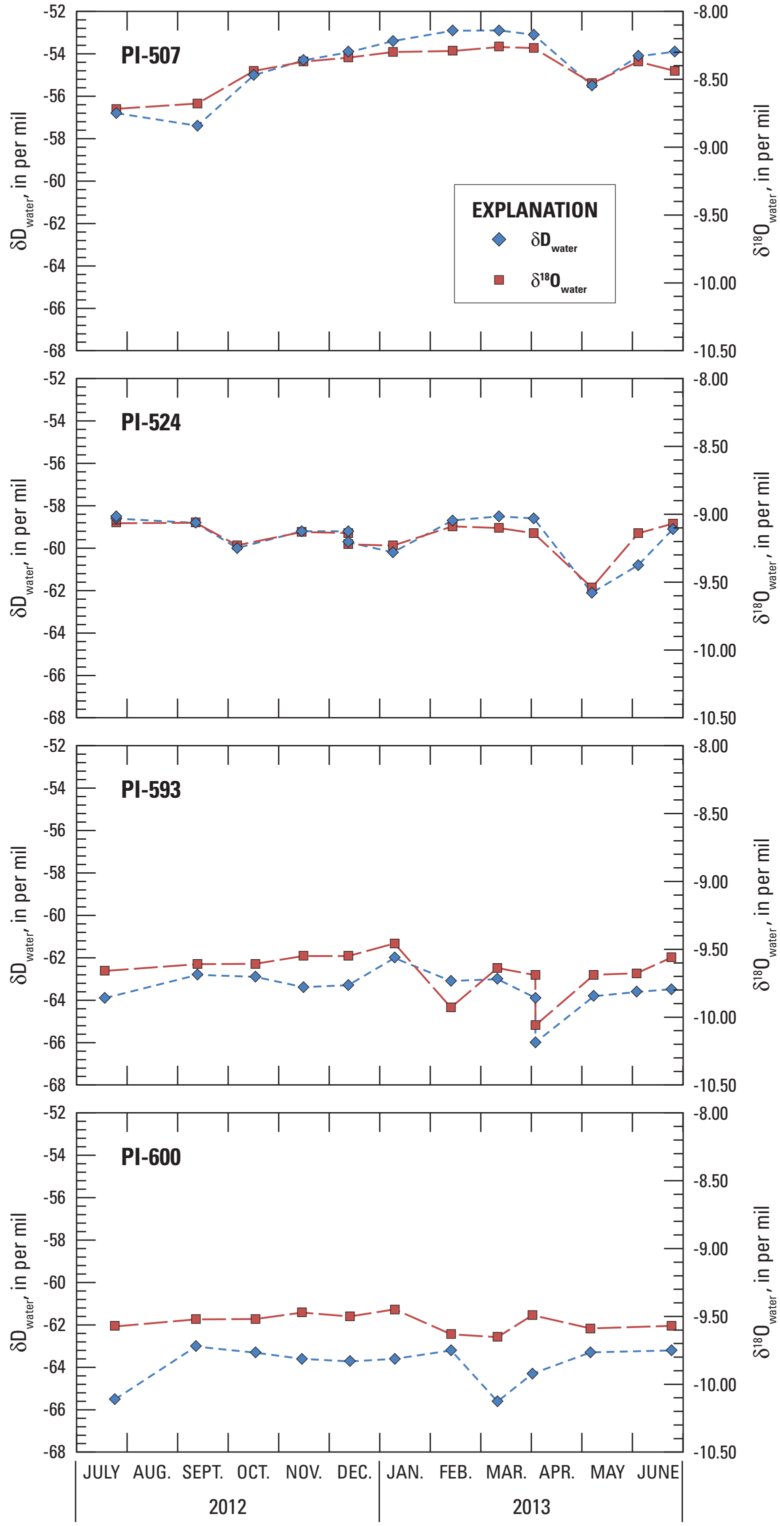


Figure 20. Isotopic composition of water in samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13.

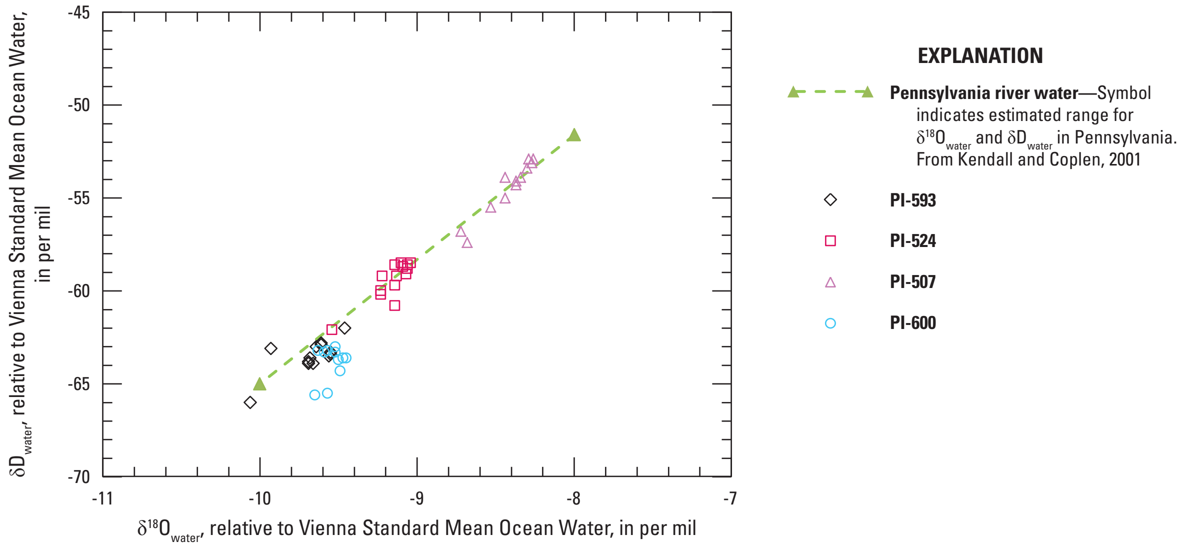


Figure 21. Isotopic composition of water in samples collected monthly from four wells in Pike County, Pennsylvania, 2012–13, with estimated isotopic composition for Pennsylvania rivers.

ethane, and ethene concentrations by TestAmerica. In addition, both isotopic characterization and concentration of methane were determined by Isotech for samples from one well (PI-524) with sufficient methane to permit the isotopic analysis.

Concentrations

In the four wells sampled monthly for 1 year, dissolved methane concentrations ranged from near the detection level of 0.211 µg/L (about 0.0002 mg/L)(PI-600) to less than 2 µg/L (0.002 mg/L)(PI-507 and PI-593) and up to about 6,000 µg/L (6.0 mg/L) (PI-524) (fig. 22). Concentrations in the three wells with low methane concentrations (less than 1 mg/L) varied by a few tenths up to about 1 µg/L (0.001 mg/L) in the monthly samples, probably within the range of sampling and analysis variability. Concentrations in samples from the well (PI-524) with elevated methane varied by 20 to 40 percent, depending on the analyzing laboratory. Methane concentrations reported by Isotech were about 20 percent higher and varied less than those reported by TestAmerica. Sampling and analysis variability and error may contribute to overall variability in reported methane concentrations. Direct comparison of methane concentrations in well-water samples determined by different methods may be problematic (Gorody, 2012).

Isotopic Composition

The isotopic composition of methane in water from well PI-524 varied little in monthly samples, ranging from -64.52 to -64.82 per mil for $\delta^{13}C_{CH4}$ and -216.9 to -226.0 per mil for δD_{CH4}. This range of isotopic compositions indicates a microbial origin for the methane, as discussed in section spatial assessment section “Isotopic Composition.” The small fluctuations in the isotopic composition of methane in the monthly samples over time are shown in figure 23. Differences in isotopic composition of methane between replicate samples in collected in July and December 2012 were larger for δD_{CH4} than for $\delta^{13}C_{CH4}$ but were less than the overall range in composition for monthly samples.

Groundwater Quality—Additional Assessment for Selected Wells

Additional analyses were done on samples collected from six wells, including the four sampled monthly for 1 year (PI-507, PI-524, PI-593, PI-600) and two more (PI-592, PI-599) sampled in late June 2013 to provide more information about baseline water quality. The additional analyses included determination of boron and strontium isotopes, radium-226 concentrations, isotopic composition of DIC, and age-dating of water using CFCs and SF_6. The wells selected for the additional analyses had all been sampled in summer 2012 and had groundwater quality that was representative of the 2012 measured range in concentrations of methane and (or) selected inorganic constituents that are present in low to moderate levels in fresh groundwater but typically are extremely elevated in brines, such as strontium and barium. Although the selected inorganic constituents were not extremely elevated in the summer 2012 groundwater samples, information about natural

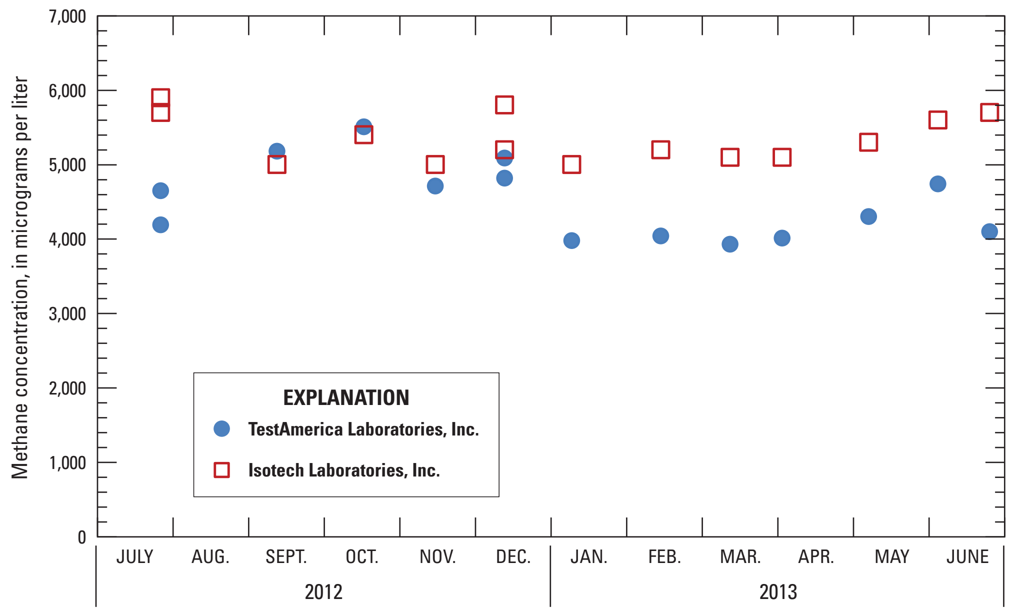


Figure 22. Methane concentrations in water samples collected monthly from well PI-524 in Pike County, Pennsylvania, 2012–13. Concentrations were determined by two laboratories, TestAmerica, Inc., and Isotech Laboratories, Inc.

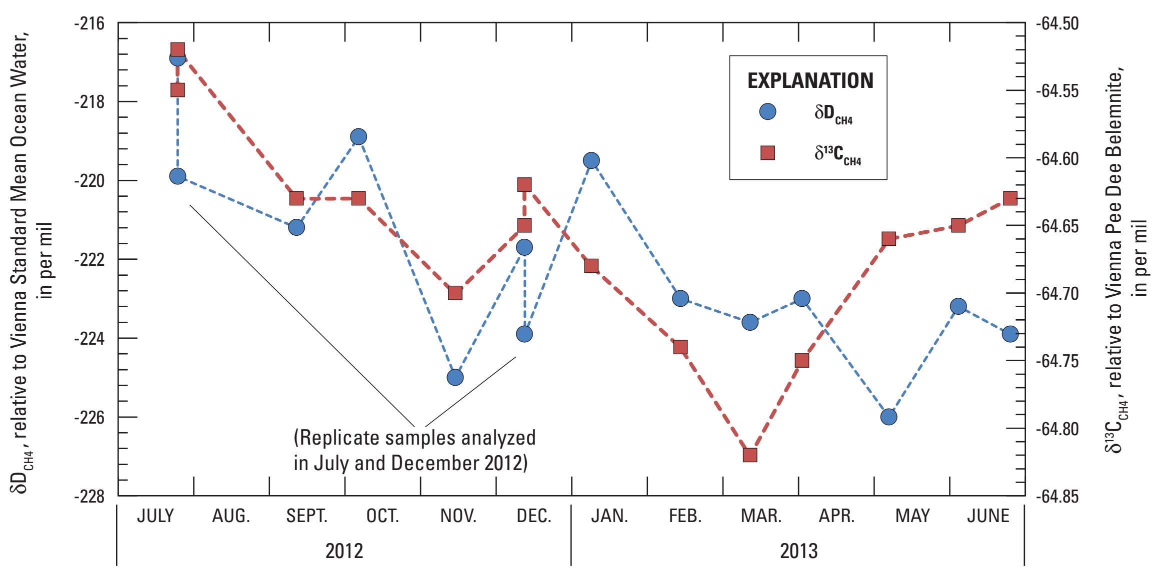


Figure 23. Isotopic composition of methane in water samples collected monthly from well PI-524 in Pike County, Pennsylvania, 2012–13.

fluctuations in these constituents is needed to establish baseline groundwater quality. Isotopic compositions may be used to characterize groundwater and (or) sources of constituents in groundwater.

Strontium and Boron Isotopes

The strontium isotopic ratios ($^{87}Sr/^{86}Sr$) in samples from the six wells ranged from 0.71426 to 0.71531 (table 13). These ratios and the relation between $^{87}Sr/^{86}Sr$ and strontium concentrations were within the range reported by Warner and others (2012) for shallow groundwaters in similar geologic units in Wayne and Susquehanna Counties to the immediate northwest of Pike County (fig. 1). Chapman and others (2012) found that produced (flow back) water from the Marcellus Formation in Pennsylvania has distinct $^{87}Sr/^{86}Sr$ ratios (ranging from 0.710270 to 0.712117) that may be used to differentiate between sources of dissolved solids. The $^{87}Sr/^{86}Sr$ ratios in shallow groundwater samples collected in Pike County (this report) fall in between the $^{87}Sr/^{86}Sr$ ratios reported by Chapman and others (2012) for produced (flow back) water from the Marcellus Formation and brines from the Upper Devonian Venango Group (western Pennsylvania formation equivalent to Catskill Formation in eastern Pennsylvania) in Pennsylvania.

The isotopic composition of boron ($\delta^{11}B$) ranged from 11.7 to 27 per mil, with all but one value greater than 21 per mil. The heavier (more positive) $\delta^{11}B$ values for five of six Pike County groundwater samples are within the range (about 23 ±6) reported for water samples from shallow drinking-water wells in the Catskill Formation near Pike County (Osborn and others, 2011), indicating probable natural sources of boron within the aquifer. Boron present in some laundry additives commonly is derived from non-marine evaporite deposits that are depleted in boron-11 ($\delta^{11}B$ values of 0 to -21 per mil [Swihart and others, 1986]); therefore, a lighter (more negative) boron isotopic composition sometimes may be used as a tracer of domestic wastewater (Bassett and others, 1995; Barth, 1998; Vengosh and others, 1994). Reported $\delta^{11}B$ values of 39 ±6 per mil for Appalachian brines (Osborn and others, 2011) and about 28–34 per mil for Marcellus Formation brines (Warner, 2011; Warner and others, 2013) are slightly to moderately more enriched in boron-11 than $\delta^{11}B$ values in the Pike County shallow groundwater samples (fig. 24).

Radium-226

Gross alpha-particle and gross-beta particle activity indicate the presence of, but do not identify, specific radioactive elements (radionuclides). Analysis for radium-226 was selected for the additional baseline assessment because

Table 13. Strontium and boron isotopic ratios in water samples collected from six wells in Pike County, Pennsylvania, June 25–27, 2013.

[Isotopic analyses done by Thomas Bullen, U.S. Geological Survey, Menlo Park, Calif., USGS, U.S. Geological Survey; µg/L, microgram per liter; --, no data; NIST, National Institute of Standards and Technology]

USGS site name	Date	Sample time	Strontium, in µg/L	Boron, in µg/L	$^{87}Sr/^{86}Sr$ ratio[1]	$\delta^{11}B$, in per mil relative to NIST 951[2]
PI-592	6/25/2013	1100	349	116	0.71441	23.2
PI-592	6/25/2013	[3]1101	--	--	0.71441	23.0
PI-599	6/25/2013	1430	344	28.3	0.71426	23.2
PI-600	6/25/2013	1400	717	9.5	0.71431	11.7
PI-593	6/25/2013	1100	514	28.2	0.71527	25.0
PI-524	6/26/2013	1230	472	77.9	0.71518	27.0
PI-507	6/27/2013	1130	333	10.4	0.71531	21.7
			Modern seawater:		[4]0.70907	[5]39.61

[1] $^{87}Sr/^{86}Sr$ is precise to better than 0.00002 at the 95-percent confidence level (2 sigma).

[2] $\delta^{11/10}B$ is precise to better than 0.5 per mil based on replicate analyses of each sample; NIST 951 refers to standard reference material 951.

[3]Replicate sample.

[4]Burke and others, 1982.

[5]Foster and others, 2010.

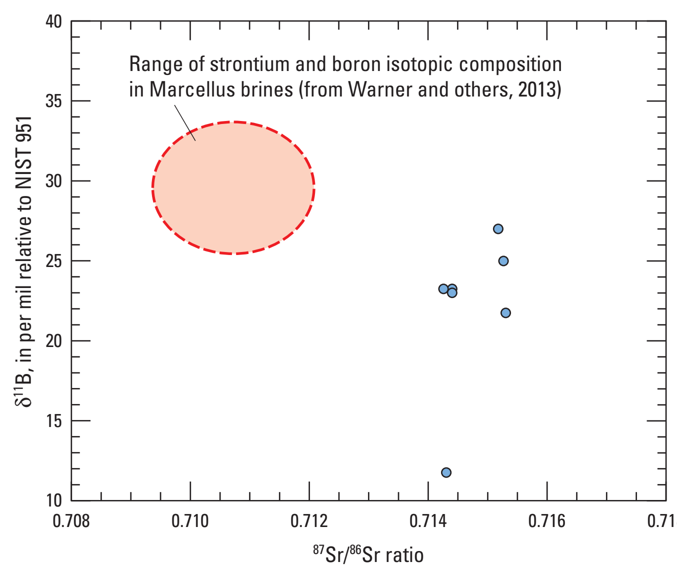


Figure 24. Relation between strontium isotopic ratio ($^{87}Sr/^{86}Sr$) and boron isotopic composition ($\delta^{11}B$) in water samples collected from six wells in Pike County, Pennsylvania, June 25–27, 2013. Range of isotopic composition of Marcellus Formation brines is from Warner and others (2013).

elevated radium-226 has been reported to occur in brines and flow-back waters from shale-gas reservoirs and may also indicate the presence of radium-228, which also may be elevated in brines and flow-back waters (Rowan and others, 2011). Radium-226 has a long half-life (1,600 years) and emits alpha particles during radioactive decay; radium-228 has a shorter half-life (5.76 years) and emits beta-particles during decay.

In the six well-water samples collected in June 2013, radium-226 concentrations (activities) ranged from 0.041 to 0.29 pCi/L (table 16), at least one order of magnitude lower than the drinking-water MCL of 5 pCi/L for combined radium-226 and radium-228. Although radium-226 is an alpha-particle emitter, radium-226 activities do not appear to correlate strongly with either the 30-day gross alpha-particle activity or the 72-hour gross alpha-particle activity (fig. 25), possibly because other alpha-emitting radionuclides were present in the samples and (or) because relations were masked by analytical uncertainty associated with the low levels of gross alpha-particle activity. In the two samples with the highest radium-226 activities, the 30-day gross beta-particle activities also were the highest measured and were similar to the 72-hour gross-beta particle activities. The relatively elevated gross-beta particle activities may indicate the presence of radium-228 or another beta-particle emitter.

Of the six well samples, radium-226 activities were highest in water from the wells with the highest methane concentrations (PI-524 and PI-592). Radium-226 activities generally were correlated with barium activities (fig. 26). Barium and radium have similar chemical properties and will be soluble under similar geochemical conditions. Activities of radium-226 do not appear to be correlated with those of its daughter product, radon-222 in the six well-water samples. Radium and radon have different chemical properties.

Isotopic Composition of Dissolved Inorganic Carbon

The isotopic composition of DIC ($\delta^{13}C_{DIC}$) had been determined in monthly samples from well PI-524 that had elevated methane concentrations. In late June 2013, samples collected from well PI-592, which had a relatively elevated methane concentration (about 2,800 µg/L or 2.8 mg/L), and well PI-599, which had a moderately low methane concentration (about 10 µg/L or 0.010 mg/L), also were analyzed for $\delta^{13}C_{DIC}$ to provide more data on possible origin and fate of methane. The $\delta^{13}C_{DIC}$ values ranged from -10.5 to -10.1 per mil in monthly samples from well PI-524 and were -16.3 per mil in the sample from well PI-592 and -14 per mil in the sample from well PI-599. These values fall near or within the range for groundwaters that receive carbon in equal amounts from soil carbon dioxide in vegetated temporal regions and carbonate mineral dissolution (Sharma and others, 2014).

The $\delta^{13}C_{DIC}$ values of -10 to -16 per mil measured in Pike County groundwater samples appear too low to indicate local methanogenesis by fermentation process in the aquifer on the basis of isotopic ranges described by Osborn and others (2011), who state that $\delta^{13}C_{DIC}$ values greater than +10 per mil are associated with microbial methanogenesis (fermentation process) as a source of methane in shallow groundwaters. Thus, both the isotopic composition of methane itself (fig. 13)

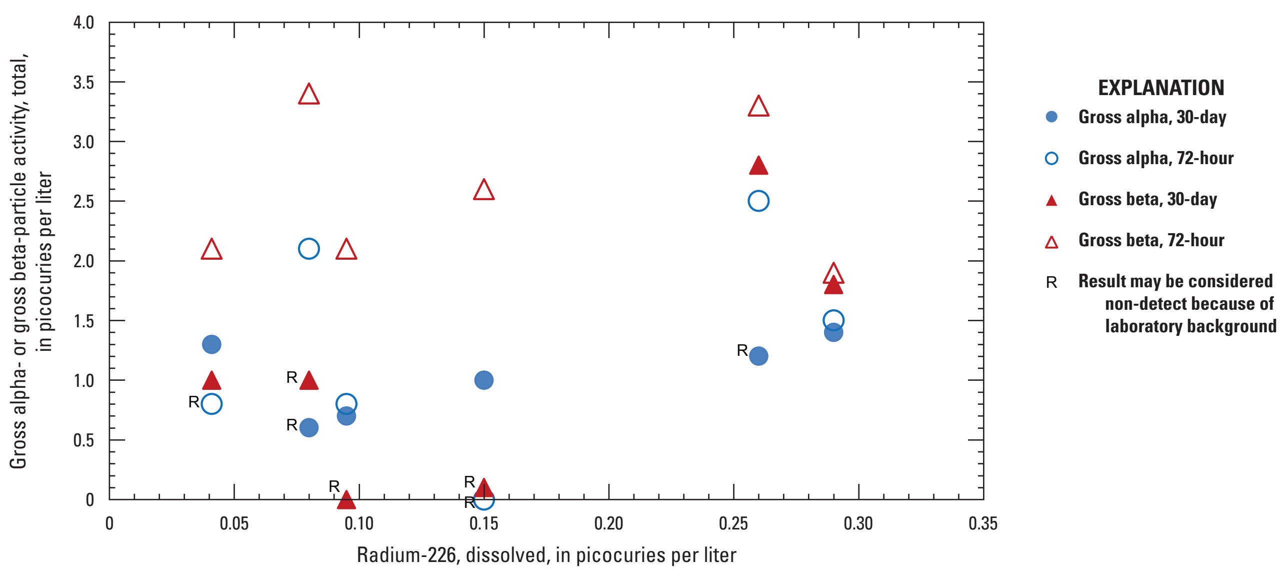


Figure 25. Relation between dissolved radium-226 activities and total gross alpha-particle and gross beta-particle activities measured at 72 hours and 30 days in water samples collected from six wells in Pike County, Pennsylvania, June 25–27, 2013.

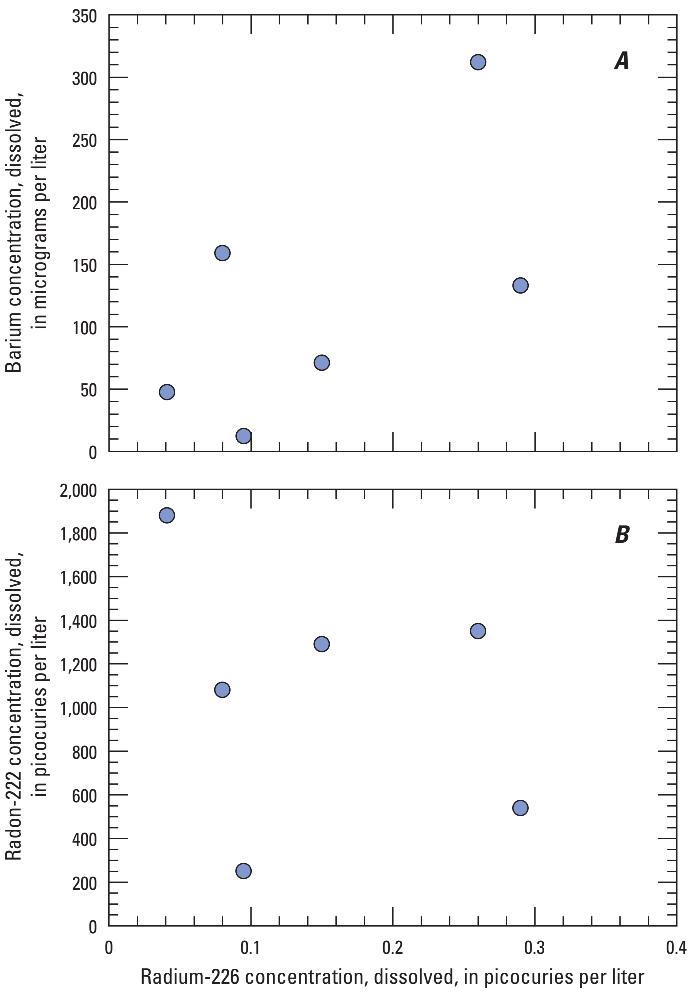


Figure 26. Relation between dissolved radium-226 activities and *A*, barium concentrations and *B,* radon-222 activities in water samples collected from six wells in Pike County, Pennsylvania, June 25–27, 2013.

and the $\delta^{13}C_{DIC}$ values indicate a microbial source of methane formed by carbon dioxide reduction processes. In previous studies, $\delta^{13}C_{DIC}$ and $\delta^{13}C_{CH4}$ values, as well as δD_{H20} and δD_{CH4} values, in the ranges observed in the Pike County groundwater samples are associated with methane formed by carbon dioxide processes in saline or marine environments (Whiticar, 1999). Methane is stable in anoxic groundwater and may be relatively stable in very low oxygen groundwater, such as that observed in many of the Pike County well-water samples; if oxidation of methane is an active process, $\delta^{13}C_{DIC}$ values would be more negative, near -25 per mil (Breen and others, 2007). The presence of methane in groundwater samples with detectable concentrations of oxygen suggests mixing of oxygenated and anoxic water.

Age-Dating by Chlorofluorocarbons and Sulfur Hexafluoride

The age of relatively young (less than 60 years old) groundwater may be estimated from the groundwater concentrations of some anthropogenic gases that were released into the atmosphere after the 1940s; the method assumes that these anthropogenic gases were incorporated in date-specific proportions into precipitation that recharged the aquifers (Busenberg and Plummer, 1992; Busenberg and Plummer, 2000). For this study, water samples collected from six wells in late June 2013 were analyzed for SF_6 and the chlorofluorocarbons CFC-11, CFC-12, and CFC-113. Concentrations of these gases measured in the June 2013 samples are listed in Appendix 2.

The determination of estimated groundwater age requires additional information regarding recharge conditions that use dissolved gas analysis for nitrogen, oxygen, argon, carbon dioxide, and methane. As noted previously, the USGS CFC laboratory completed the SF_6 and CFC analyses and the supporting dissolved gas analysis, in addition to providing estimated ages based on the results. The methane concentrations determined by the USGS CFC laboratory were greater than those determined by two other laboratories. For the three samples in which methane concentration was above detection level, methane concentrations determined by the USGS CFC laboratory consistently were about 30 percent greater than those determined by Isotech and about 80 percent greater than those determined by TestAmerica (table 16). The different results for samples collected at the same time shows that methane concentrations determined by different laboratories may not be directly comparable.

Some of the samples had elevated concentrations of CFCs or SF_6 that precluded age-determination because the concentrations are too large for recharge water that is in equilibrium with atmospheric concentrations of gases. Samples from two wells (PI-507 and PI-593) had CFC concentrations that were sufficiently high to indicate contamination with CFC-11 and (or) CFC-12, and samples from two other wells (PI-599 and PI-600) had extremely high concentrations of SF_6 that might indicate contamination or an unusual natural source. SF_6 has been reported to occur in large concentrations in some geologic settings, including the mineral fluorite and in groundwater in some granitic rocks (Busenberg and Plummer, 2000).

The dates of recharge estimated using SF_6 and CFCs range from as old as the 1940s to mid-2000s (table 14). The dates estimated using SF_6 generally were younger than those estimated using CFCs but the relative ages determined using the different gases generally were in the same order for water samples from the six wells. The order of estimated age of recharge for the samples, from oldest to youngest, was PI-599, PI-592, PI-524, PI-593, PI-600, and PI-507. Well PI-507 with the youngest water (10 to 30 years old) is an active production well that is pumped continuously year round. Wells with elevated methane, PI-524 and PI-592, had water that was among the three oldest of the samples (35 to 70 years old).

Table 14. Summary of age and year of recharge for water samples collected from six wells in Pike County, Pennsylvania, June 25–27, 2013.

[Recharge year and age shown for duplicate samples analyzed for sulfur hexafluoride (SF_6); recharge year calculated on basis of composite results for chlorofluorocarbon (CFC) sample collected in triplicate; concentrations for all samples shown in appendix 2; recharge ages based on concentrations of SF_6, CFC-11, CFC-12, and CFC-113 analyzed in replicate samples. Analyses and age estimates done by U.S. Geological Survey Chlorofluorocarbon Laboratory, Reston, Va.; USGS, U.S. Geological Survey; HI C, high concentrations; DO, dissolved oxygen; ~, approximately; <, less than]

USGS site name	Date	Piston flow model SF_6 estimated ages[1]			Piston flow model CFC estimated ages[1]			
		Recharge year	Recharge age, in years	Comments on SF_6 ages	Recharge year	Recharge age, in years	Basis of CFC ages	Comments on CFC ages
PI-507	6/27/13	2004.0	9.49		Mid 1980s	~30	CFC-113	CFC-11 and CFC-12 concentrations almost twice that of modern air.
PI-507	6/27/13	2003.5	9.99					
PI-524	6/26/13	1978.0	35.49	2nd sample broken, not analyzed	After 1945	<70	CFC-11,12,113	Low DO. Possible CFC degradation.
PI-592	6/25/13	1966.5	46.98	Possibly older than result	Mid to late 1940s	~68	CFC-11,12,113	Low DO. Possible CFC degradation.
PI-592	6/25/13	1965.5	47.98	Possibly older than result				
PI-593	6/25/13	1986.0	27.48	2nd sample broken, not analyzed	Early 1970s	~40	CFC-12,113	CFC-11 concentration several times that of modern air.
PI-599	6/25/13	HI C	HI C	2nd sample not analyzed	Mid 1940s	~70	CFC-11,12,113	Low DO, possible CFC degradation.
PI-600	6/25/13	HI C	HI C	2nd sample broken, not analyzed	Early to mid 1970s	~40	CFC-12	

[1]Age dates could not be calculated for some samples with high level of gases: samples from well PI-507 had high levels of CFC-11 and CFC-12, and samples from PI-593 had high levels of CFC-11, indicating contamination; samples from well PI-599 and PI-600 had high levels of SF_6, indicating contamination or unusual natural source.

The relatively older age of groundwater with elevated methane suggests that methane may accumulate along flow paths or that these wells tap parts of the aquifer with relatively restricted circulation. Areas in Pike County where deep groundwater may be discharging, such as along the Delaware River, may have relatively higher concentrations of methane and selected inorganic constituents (some of which occur in elevated concentrations in brines) than elsewhere in the County. For example, in an assessment of groundwater resources in Pike County, pH values of 8.3 to 9.0 and specific conductance values from 240 up to 3,200 microsiemens per centimeter at 25 degrees Celsius (µS/cm) reported for water from bedrock wells located near the Delaware River on the eastern edge of the county (Davis, 1989) suggest the potential presence of relatively elevated methane and selected inorganic (some possibly brine-related) constituents in groundwater. A well sampled in 2011 in this setting along the eastern edge of Pike County had 2.52 mg/L methane and relatively elevated concentrations of sodium, boron, and lithium (54.6, 264, and 98.4 µg/L, respectively) but not elevated chloride or TDS concentrations (9.96 and 156 mg/L, respectively) (Eckhardt and Sloto, 2012); the sample from this well also had low dissolved oxygen concentration, relatively elevated pH (8.1), and relatively elevated fluoride (0.28 mg/L) and ammonia (0.285 mg/L as N) concentrations, and thus had a chemical composition similar to water from the two wells with elevated methane that were sampled for the 2012–13 Pike County study.

Summary and Conclusions

Pike County in northeastern Pennsylvania is underlain by the Devonian-age Marcellus Shale and Ordovician-age Utica Shale, formations that have potential for natural gas development. In northeastern Pennsylvania, the Delaware River Basin Commission currently (2014) has a temporary moratorium on drilling in the parts of the basin that drain to special-protection waters, an area which includes Pike County, but despite the current moratorium, gas exploration and production in the Delaware River Basin remains a possibility.

In 2012, the U.S. Geological Survey in cooperation with the Pike County Conservation District conducted a reconnaissance study to assess baseline shallow groundwater quality in bedrock aquifers prior to possible shale-gas development in the county. The 2012 study extended previous investigations by sampling in areas likely to have shale-gas development and including methane and inorganic constituents known to be elevated in brines (brine-related) in laboratory analyses of the groundwater samples. The baseline assessment consisted of spatial and temporal components. For the spatial component of the assessment, 20 wells ranging in depth from 135 to 610 feet (ft) were sampled in summer 2012 and water samples were analyzed for major ions, nutrients, inorganic trace constituents (selected metals and other elements), stable isotopes of water, radon -222, gross alpha- and beta-particle activity, dissolved gases (methane, ethane, and ethene), and if possible, isotopic composition of methane. For the temporal component of the assessment, 4 of the 20 wells sampled in summer 2012 representing a range of methane and inorganic constituents concentrations were sampled monthly from July 2012 through June 2013 to provide data on seasonal variability in groundwater quality.

Results of the summer 2012 sampling showed that water from 16 (80 percent) of 20 wells had detectable concentrations of methane, but concentrations were less than 0.1 milligrams per liter (mg/L) in most well-water samples; only 2 well-water samples had concentrations greater than 1 mg/L. The groundwater with elevated methane concentrations also had a chemical composition that differed in some respects (pH, some inorganic trace constituents, and detectable concentrations of tungsten) from groundwater with low methane concentrations. The two well-water samples with the highest methane concentrations (about 3.7 and 5.8 mg/L) also had the highest pH values (8.7 and 8.3, respectively) and concentrations of sodium (up to 69.4 mg/L), lithium (up to 248 micrograms per liter [µg/L]), boron (up to 119 µg/L), fluoride (0.53 mg/L), and bromide (up to 0.353 mg/L), inorganic constituents that can occur in low to moderate concentrations in fresh groundwater but in extremely high concentrations in brines associated with gas-producing Devonian shales in Pennsylvania. The two samples also had among the highest concentrations of other brine-related inorganic constituents, such as barium, strontium and chloride, but samples from several other wells with low methane concentrations also had similar or higher concentrations of these constituents. Relatively elevated concentrations of these other inorganic constituents (as much as 318 µg/L for barium, 1,690 µg/L for strontium, and 50 mg/L for chloride) were present in groundwater with a range of methane concentrations. Sources of many inorganic trace constituents, such as barium and strontium, in the groundwater likely are natural, whereas sources of chloride may be natural or related to human activities, such as road salting or on-site wastewater disposal (septic systems).

Groundwater quality generally is good, with few exceedances of drinking-water standards or guidelines in the 2012 samples. One of the well-water samples with elevated methane concentrations also had an elevated arsenic concentration of 30 µg/L that exceeded the maximum contaminant level (MCL) of 10 µg/L for arsenic in drinking water and a pH that exceeded the secondary maximum contaminant level (SMCL) upper limit of 8.5. No other sample from the 20 wells sampled in summer 2012 had concentrations of constituents that exceeded any established primary drinking-water standards (MCLs). However, radon-222 activities ranging up to 4,500 picocuries per liter (pCi/L) exceeded the proposed MCL of 300 pCi/L for drinking water in 85 percent of the 20 well-water samples, and activities were greater than the alternate proposed MCL of 4,000 pCi/L in 10 percent of the samples. Manganese concentrations exceeded the SMCL of 50 µg/L in six samples, total iron concentrations exceeded the SMCL of 300 µg/L in five samples, and pH values were less than the SMCL lower limit of 6.5 in four samples. The two well-water samples with elevated methane had sodium concentrations of 42.8 and 69.4 mg/L, respectively, that exceeded the health advisory guideline level of 20 mg/L for individuals on sodium-restricted diets and the taste threshold SMCL value of 30 mg/L.

The isotopic composition of methane in the two high-methane samples ($\delta^{13}C_{CH4}$ values of -64.55 and -64.41 per mil and δD_{CH4} values of -216.9 and -201.8 per mil, respectively), indicates a predominantly microbial source for the methane formed by a carbon dioxide reduction process; this type of methane is commonly called drift gas because of its occurrence in glacial sediments. The stable isotopic composition of water (δD_{H20} and $\delta^{18}O_{H20}$) in samples from all 20 wells plots on the local meteoric line, indicating water in the wells was of relatively recent meteoric origin (modern precipitation), including samples with elevated methane concentrations. The age of the water and the age of the methane in the water may differ. Although the origin of the elevated methane in two well-water samples was identified as microbial, the source of the methane in the aquifer is unknown; however, isotopic composition of the methane suggests possible generation from organic material within glacial deposits that overlie bedrock aquifers in Pike County with some possible small contribution of thermogenic methane from greater depths.

The temporal variability in groundwater quality observed in samples from the four wells during 1 year provides data needed to assess the representativeness of single samples commonly used to describe baseline conditions for evaluation of potential future changes in groundwater quality. Results for 4 of the 20 wells sampled monthly from July 2012 through June 2013 to describe temporal variability in groundwater quality showed that concentrations of major ions in monthly samples generally varied less than 20 percent, with most differences less than 4 mg/L. However, samples collected from one well during 2 winter months were affected by apparent infiltration of deicing material (calcium chloride), which resulted in a short-term transient change in concentrations of salt-related constituents. Concentrations of methane varied by less than 1 µg/L (0.001 mg/L) in samples from three wells with low methane concentrations and as much as 1 mg/L (1,000 µg/L) in samples from one well with a relatively high methane concentration. The isotopic composition of methane in the water from the well with relatively high methane concentrations varied slightly in the monthly samples, ranging from about -64.5 to -64.8 per mil for $\delta^{13}C_{CH4}$ and from about -216.9 to -226.0 per mil for δD_{CH4}. The $\delta^{13}C$ values for dissolved inorganic carbon (DIC) in water from this well were consistent with microbial methane formation by carbon dioxide reduction and also varied little in the temporal samples, ranging from -10.5 to -10.1 per mil.

In addition to possible temporal variation in methane concentrations, variability in methane concentrations related to sampling and analysis of a sample collected at a single time needs to be considered. Methane concentrations varied in two pairs of replicate samples collected and analyzed using the same methods and laboratories by 3 to 11 percent. Methane concentrations varied in six sets of replicate samples collected and analyzed using three different methods and laboratories by as much as 80 percent. Therefore, temporal variability in methane concentrations is to be interpreted with caution, especially when comparing results collected and analyzed by different methods.

Additional analyses were done on samples collected from six wells in June 2013, including four sampled monthly for 1 year and two sampled once before in summer 2012 to provide more information about baseline water quality. The additional analyses included determination of boron and strontium isotopes, radium-226 concentrations, and age-dating of water using CFCs and SF_6. The strontium and boron isotopic compositions ranged from 0.71426 to 0.71531 for $^{87}Sr/^{86}Sr$ ratios and 11.7 to 27.0 per mil for $\delta^{11}B$ values, respectively; these values potentially may be used as limited baseline data and to differentiate among sources of strontium and boron. The isotopic composition of strontium and boron determined for the six Pike County shallow groundwater samples differed from that reported for brines from the Marcellus Formation. The boron in the six samples also differed from an artificial source of boron, being more enriched in the isotope boron-11 than the boron typically used in laundry products, indicating a natural origin for the boron in these samples. Radium-226 activities (concentrations) were low in samples from all six wells, ranging from 0.041 to 0.29 pCi/L, at least one order of magnitude less than the drinking-water MCL of 5 pCi/L for combined radium-226 and radium-228. The highest radium-226 activities were in samples that had the highest methane concentrations.

Age-dating of groundwater using a method based on the presence of anthropogenic gases (chlorofluorocarbons [CFCs], and sulfur hexafluoride [SF_6]) released into the atmosphere yielded estimated recharge dates for water from these six wells that ranged from the 1940s to early 2000s, with the oldest water in samples from wells that had the highest methane concentrations and the youngest water in samples from a continuously pumped 300-ft deep production well. Concentrations of SF_6 in samples from two wells were extremely high; sources for these unusually elevated SF_6 concentrations are unknown but could be natural or caused by anthropogenic contamination. The relatively older age of groundwater with elevated methane suggests that methane may accumulate along flow paths or that these wells tap parts of the aquifer with relatively restricted circulation. Areas in Pike County where deep groundwater may be discharging, such as along the Delaware River, may have relatively higher concentrations of methane and some brine-related constituents than elsewhere in the county.

Overall results of the reconnaissance assessment show that methane and brine-related constituents are present in low to moderate concentrations in shallow groundwater in bedrock aquifers in Pike County prior to shale gas development. The assessment provides an estimate of the ranges in concentrations for these constituents but, because of the reconnaissance nature of the study, may not fully characterize the frequency, magnitude, or spatial distribution of relatively elevated concentrations of these constituents in groundwater. Groundwater with pH values greater than 8 appear more likely to have relatively higher concentrations of methane and some inorganic constituents, such as sodium, lithium, boron, bromide, and fluoride. Similar types of waters have been reported elsewhere in northeastern Pennsylvania, although in those areas, isotopic compositions indicated a thermogenic origin for methane rather than the microbial source indicated for methane in Pike County groundwater samples.

References Cited

Barth, Susanne, 1998, Application of boron isotopes for tracing sources of anthropogenic contamination in groundwater: Water Research, v. 32, issue 3, p. 685–690.

Bassett, R.L., Buszka, P.M., Davidson, G.R., and Chong-Diaz, Damaris, 1995, Identification of groundwater solutes sources using boron isotopic composition: Environmental Science & Technology, v. 29, no. 12, p. 2915–2922.

Berg, T.M., and Dodge, C.M., eds., 1981, Atlas of preliminary geologic quadrangle maps of Pennsylvania: Pennsylvania Geological Survey, 4th Series, Map 61, scale 1:62,500.

Breen, K.J., Revesz, Kinga, Baldassare, F.J., and McAuley, S.D., 2007, Natural gases in ground water near Tioga Junction, Tioga County, North-Central Pennsylvania—Occurrence and use of isotopes to determine origins, 2005: U.S. Geological Survey Scientific Investigations Report 2007–5085, 65 p.

Brown, G.A., Pustay, E.A., and Gibs, Jacob, 2003, Methods for quality-assurance review of water-quality data in New Jersey: U.S. Geological Survey Open-File Report 02–383, 74 p.

Burke, W.H., Denison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, H.F., and Otto, J.B., 1982, Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time: Geology, v. 10, p. 516–519.

Busenberg, Eurybiades, and Plummer, L.N., 1992, Use of chlorofluorocarbons (CCL3F and CCl2F2) as hydrologic tracers and age-dating tools: the alluvium and terrace system of central Oklahoma: Water Resources Research, v. 28, no. 9, p. 2257–2283.

Busenberg, E., Plummer, L.N., Cook, P.G., Solomon, D.K., Han, L.F., Gröning, M., and Oster, H., 2006, Chapter 12, Sampling and analytical methods, *in* International Atomic Energy Agency, Use of Chlorofluorocarbons in hydrology, A guidebook, p. 199–220.

Busenberg, Eurybiades, and Plummer, L.N., 2000, Dating young groundwater with sulfur hexafluoride: natural and anthropogenic sources of sulfur hexafluoride: Water Resources Research, v. 36, no. 10, p. 3011–3010.

Carswell, L.D., and Lloyd, O.B., Jr., 1979, Geology and groundwater resources of Monroe County, Pennsylvania: Pennsylvania Geological Survey, 4th Series, Water Resource Report 47, 61 p.

Chapman, E.C., Capo, R.C., Stewart, B.W., Kirby, C.S., Hammack, R.W., Shroeder, K.T., and Edenborn, H.M., 2012, Geochemical and strontium isotope characterization of produced waters from Marcellus Shale natural gas extraction: Environmental Science & Technology, v. 46, p. 3545–3553.

Coleman, D.D., Liu, Chao-Li, and Riley, K.M., 1988, Microbial methane in the shallow Paleozoic sediments and glacial deposits of Illinois: Chemical Geology, v. 71, iss. 1–3, p. 23–40.

Coleman, D.D., Liu, C.L., Hackley, K.C., and Benson, L.J., 1993, Identification of landfill methane using carbon and hydrogen isotope analysis: Proceedings of Sixteenth International Madison Waste Conference, University of Wisconsin, September 22–23, 1993, p. 303–314.

Davis, D.K., 1989, Groundwater resources of Pike County, Pennsylvania: Pennsylvania Geological Survey, 4th Series, Water Resource Report 65, 63 p.

Delaware River Basin Commission, 2011, Natural Gas Drilling in the Delaware River Basin, accessed June 15, 2011, at *http://www.state.nj.us/drbc/naturalgas.htm*.

Dresel, E.P., and Rose, A.W., 2010, Chemistry and origin of oil and gas well brines in western Pennsylvania: Pennsylvania Geological Survey, 4th Series, Open-File Oil and Gas Report 10-01.0, 48 p.

Dufor, C.N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Durlin, R.R, and Schaffstall, W.P., 2002, Water resources data, Pennsylvania, water year 2001, volume 1. Delaware River Basin: U.S. Geological Survey Water Data Report PA-01-1, 615 p.

Eckhardt, D.A.V., and Sloto, R.A., 2012, baseline groundwater quality in national park units within the Marcellus and Utica Shale gas plays, New York, Pennsylvania, and West Virginia, 2011: U.S. Geological Survey Open-File Report 2012–1150, 20 p.

Eltschlager, K.K., Hawkins, J.W., Ehler, W.C., and Baldassare, Fred, 2001, Technical measures for the investigation and mitigation of fugitive methane hazards in areas of coal mining: U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement, 129 p., accessed June 11, 2014, at *http://arblast.osmre.gov/downloads/Mine%20Gases%20and%20Dust/FINAL-Methane.pdf*.

Feth, J.H., 1965, Preliminary map of the conterminous United States showing depth to and quality of shallowest groundwater containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Atlas 199, 31 p., 2 pls., scale 1:3,000,000.

Foster, G.L., Pogge von Strandmann, P.A.E., and Rae, J.W.B., 2010, Boron and magnesium isotopic composition of seawater: Geochemistry, Geophysics, Geosystems, v. 11, no. 8, p. 1525–2027.

Gorody, A.W., 2012, Factors affecting the variability of stray gas concentration and composition in groundwater: Environmental Sciences, v. 19, no. 1, p. 17–31.

Haluszczak, L.O., Rose, A.W., and Krump, L.R., 2013, Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA: Applied Geochemistry, v. 28, p. 55–61.

Heisig, Paul, and Scott, Tia-Marie, 2013, Methane occurrence in groundwater of south-central New York, 2012: U.S. Geological Survey Scientific Investigations Report 2013–5190, 44 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 264 p.

Hudson, Felisa, 2004, RSKSOP-175 Revision No. 2, May 2004, Standard operating procedure, sample preparation and calculations for dissolved gas analysis in water samples using a GC headspace equilibration technique: U.S. Environmental Protection Agency, accessed March 16, 2010, at *http://www.epa.gov/ne/info/testmethods/pdfs/RSKsop175v2.pdf*.

Juster, T.C., Brown, P.E., and Bailey, S.W., 1987, NH_4-bearing illite in very low grade metamorphic rocks associated with coal, northeastern Pennsylvania: American Mineralogist, v. 72, p. 555–567.

Kappel, W.M., and Nystrom, E.A., 2012, Dissolved methane in New York groundwater: U.S. Geological Survey Open-File Report 2012–1162, 6 p.

Kappel, W.M., 2013, Dissolved methane in groundwater, upper Delaware River basin, Pennsylvania and New York, 2007–2012: U.S. Geological Survey Open-File Report 2012–1167, 6 p.

Kendall, Carol, and Coplen, T.B., 2001, Distribution of oxygen-18 and deuterium in river waters across the United States: Hydrological Processes, v. 15, p. 1363–1393.

Kirschbaum, M.A., Schenk, C.J., Cook, T.A., Ryder, R.T., Charpentier, R.R., Klett, T.R., Gaswirth, S.B., Tennyson, M.E., and Whidden, K.J., 2012, Assessment of undiscovered oil and gas resources of the Ordovician Utica Shale of the Appalachian Basin Province, 2012: U.S. Geological Survey Fact Sheet 2012–3116, 6 p.

Kresse, T.M., Warner, N.R., Hays, P.D., Down, Adrian, Vengosh, Avner, and Jackson, R.B., 2012, Shallow groundwater quality and geochemistry in the Fayetteville Shale gas-production area, north-central Arkansas, 2011: U.S. Geological Survey Scientific Investigations Report 2012–5273, 31 p.

Llewellyn, G.T., 2014, Evidence and mechanisms for Appalachian Basin brine migration into shallow aquifers in NE Pennsylvania, USA: Hydrogeology Journal, published online 21 March 2014 DOI 10.1007/s10040-014-1125-1.

Miles, C.E., and Whitfield, T.G., compilers, 2001, Bedrock geology of Pennsylvania: Pennsylvania Geological Survey, 4th ser., dataset, scale 1:250,000.

Molofsky, L.J., Connor, J.A., Wylie, A.S., Wagner, Tom, and Farhat, S.K., 2013, Evaluation of methane sources in groundwater in northeastern Pennsylvania: Groundwater, v. 51, no. 3, p. 333–349.

National Atmospheric Deposition Program, 2013, NADP/NTN monitoring location PA72, accessed November 12, 2013, at *http:/nadp.sws.uiuc.edu/sites/siteinfo.asp?net=NTN&id=PA72*.

Osborn, S.G., and McIntosh, J.C., 2010, Chemical and isotopic tracers of the contribution of microbial gas in Devonian-rich shales and reservoir sandstones, northern Appalachian Basin: Applied Geochemistry, v. 25, p. 456–471.

Osborn, S.G., Vengosh, Avner, Warner, N.R., and Jackson, R.B., 2011, Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing: Proceedings of the National Academy of Sciences, v. 108, no. 20, p. 8172–8176.

Pennsylvania Department of Environmental Protection, 2009, DEP Reaches Agreement with Cabot to Prevent Gas Migration, Restore Water Supplies in Dimock Township, News Release November 29, 2009, accessed June 15, 2001, at *http://www.portal.state.pa.us/portal/server.pt/community/newsroom/14287?id=2418&typeid=1*.

Pennsylvania Department of Environmental Protection, 2010, The Pennsylvania Code, Chapter 95, Wastewater Treatment Requirements, Section 95.10, Treatment requirements for new and expanding loadings of Total Dissolved Solids (TDS), adopted August 20, 2010.

Pennsylvania Department of Environmental Protection, 2011, 2011 Permit & rig activity report, accessed June 15, 2011, at *http://www.dep.state.pa.us/dep/deputate/minres/oilgas/RIG11.htm*.

Pennsylvania Department of Environmental Protection, 2012, PA-DEP recommended basic oil and gas pre-drill parameters, accessed July 8, 2013, at *http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-91717/*.

Pennsylvania Department of Environmental Protection, 2013, DEP Office of Oil and Gas Management Wells Drilled by County, accessed August 14, 2013, at *http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Wells_Drilled_By_County*.

Pike County Conservation District, 2014, Pike County: Where people, land, and water meet; a citizen's guide to clean water, accessed June 9, 2014, at *http://www.pikeconservation.org/Resource%20Guide/Pike%20CD%20Citizens's%20Guide%20-%20Full%20Document.pdf*.

Pike County Planning Commission, 2006, Pike County Comprehensive Plan update: Pike County, PA, accessed March 20, 2009, at *http://www.pikepa.org/Compplan.htm*.

Pike County Marcellus Task Force, 2011, Planning and Government Committee Meeting Minutes, February 24, 2011: Pike County, PA, accessed June 25, 2013, at *http://www.pikepa.org/marcellus.html*.

Piotrowski, R.G., and Harper, J.A., 1979, Black shale and sandstone facies of the Devonian “Catskill” clastic wedge in the subsurface of western Pennsylvania: United States Department of Energy Eastern Gas Shales Project, EGSP Series 13, 40 p.

Plummer, L.N., and Friedman, L.C., 1999, Tracing and dating young water: U.S. Geological Survey Fact Sheet FS-134-99, 4 p.

Resnikoff, Marvin, 2012, Radon in natural gas from Marcellus Shale: Network for Oil & Gas Accountability and Protection report, accessed January 7, 2014, at *http://www.neogap.org/neogap/wp-content/uploads/2012/01/Marcellus_Radon.pdf*.

Rowan, E.L., Engle, M.A., Kirby, C.S., and Kraemer, T.F., 2011, Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA): summary and discussion of data: U.S. Geological Survey Scientific Investigations Report 2011–5135, 31 p.

Rowan, E.L, and Kraemer, T.F., 2012, Radon-222 content of natural gas samples from Upper and Middle Devonian Sandstone and Shale reservoirs in Pennsylvania: Preliminary data: U.S. Geological Survey Open-File Report 2012–1159, 6 p.

Schoell, M., 1980, The hydrogen and carbon isotopic composition of methane from natural gases of various origins: Geochimica et Cosmochimica Acta, v. 44, p. 649–661.

Senior, L.A., 1994, Geohydrology of, and nitrogen and chloride in, the glacial aquifer, Milford-Matamoras area, Pike County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 93–4109, 43 p.

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

Sevon, W.D., Berg, T.M., Schultz, L.D., and Crowl, G.H., 1989, Geology and mineral resources of Pike County, Pennsylvania: Pennsylvania Geological Survey, 4th Series, County Report 65, 141 p., 2 pls.

Sharma, Shihika, Mulder, M.L., Sack, Andrea, Schroeder, Karl, and Hammack, Richard, 2014, Isotope approach to assess hydrologic connections during Marcellus Shale drilling: Groundwater, v. 52, no. 3, p. 424–443.

Sloto, R.A., 2013, Baseline groundwater quality from 20 domestic wells in Sullivan County, Pennsylvania, 2012: U.S. Geological Survey Scientific Investigations Report 2013–5085, 27 p.

Swihart , G.H., Moore, P.B., and Callis, E.L., 1986, Boron isotopic composition of marine and non-marine evaporate borates: Geochimica et Cosmochimica Acta, v. 50, p. 1297–1301.

Taylor, S.W., Lollar, B.S., and Wassenaar, L.I., 2000, Bacteriogenic ethane in near-surface aquifers: Implications for leaking hydrocarbon well bores: Environmental Science & Technology, v. 34, p. 4727–4732.

U.S. Census Bureau, 2000, United States Census 2000 ranking tables for counties: Population in 2000 and population change from 1990 to 2000 (PHC-T-4), accessed March 3, 2009, at *http://www.census.gov/population/www/cen2000/briefs/phc-t4/index.html*.

U.S. Census Bureau, 2013, State and county quick facts: Last revised 27 June 2013, accessed November 7, 2013, at *http:/quickfacts.census.gov/qfd/states/42013.html*.

U.S. Department of Agriculture, 2012, Census of agriculture, 2012 census volume 1, chapter 2: county level data, Pennsylvania, accessed May 5, 2014, at *http://agcensus.usda.gov/Publications/2012/Full_report/Volume1,Chapter_2_County_Level/Pennsylvania/st42_2_001_00*.

U.S. Environmental Protection Agency, 2012a, 2012 Edition of the drinking water standards and health advisories: U.S. Environmental Protection Agency EPA 822-S-12-001, accessed June 10, 2014, at *http://water.epa.gov/action/advisories/drinking/upload/dwstandards2012.pdf*.

U.S. Environmental Protection Agency, 2012b, A citizens guide to radon: U.S. Environmental Protection Agency EPA402/K-12/002, accessed June 10, 2014, at *http://www.epa.gov/radon/pdfs/citizensguide.pdf*.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9, at *http://pubs.water.usgs.gov/twri9A*.

U.S. Geological Survey, 2002, Marcellus Shale Assessment Unit—National Assessment of Oil and Gas Project—Appalachian Basin Province (067) Assessment Units: USGS Central Energy Resources Team, accessed June 1, 2014, at *http://certmapper.cr.usgs.gov/data/noga00/prov67/spatial/doc/au67g.htm*.

U.S. Geological Survey, 2014, The Reston Chlorofluorocarbon Laboratory, accessed June 10, 2014, at *http://water.usgs.gov/lab/*.

Vengosh , A., Heumann, K.G., Juraske, S., and Kasher, R., 1994, Boron isotope applications for tracing sources of contamination in groundwater: Environmental Science & Technology, v. 28, p. 1968–1974.

Warner, N.R., Jackson, R.B., Darrah, T.H., Osborn, S.G., Down, Adrian, Zhao, Kaiguang, White, Alissa, and Vengosh, Avner, 2012, Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania: Proceedings of the National Academy of Sciences, v. 109, no. 30, p. 11961–11966, accessed December 16, 2013, at *http://dx.doi.org/10.1073/pnas.1121181109*.

Warner, Nathaniel, Jackson, Robert, Darrah, Tom, Dwyer, G.S., and Vengosh, Avner, 2013, New isotopic tracers for shale gas and hydraulic fracturing fluids: U.S. Environmental Protection Agency, accessed January 10, 2014, at *http://www2.epa.gov/sites/production/files/documents/vengosh.pdf*.

Warner, Nathaniel, 2011, Boron and strontium isotopes as sensitive tracers for indicating potential shallow groundwater contamination from Marcellus Formation brines: Geological Society of America Abstracts with Programs, v. 43, no. 5, p. 566.

Whiticar, M.J., 1999, Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane: Chemical Geology, v. 161, p. 291–314.

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Geologic unit code[1]	Barometric pressure, in mmHg	Temperature, air, in °C	Depth to water level, in ft bls	Dissolved oxygen, water, unfiltered, in mg/L	Dissolved oxygen, water, unfiltered, in % of saturation	pH, water, unfiltered, field, in standard units	pH, water, unfiltered, laboratory, in standard units	Specific conductance, water, unfiltered, laboratory, in µS/cm	Specific conductance, water, unfiltered, in µS/cm	Temperature, water, in °C
			Parameter code:	00025	00020	72019	00300	00301	00400	00403	90095	00095	00010
PI-274	7/17/2012	1600	341LRBW	739	34	--	0.7	6	7.7	7.8	158	151	11.8
PI-288	7/18/2012	1200	341PGPK	732	--	54.9	9.2	84	5.8	E 6.1	E 69	64	9.9
PI-384	7/24/2012	1500	341DLRV	769	32	1.82	6.2	57	6.5	E 7.0	E 76	74	12.2
PI-403	8/2/2012	1000	344MNNG	740	--	24.74	2.9	27	7.6	7.9	405	383	12.0
PI-507	7/25/2012	1230	341DLRV	740	24.5	--	5.4	50	6.4	6.8	219	212	10.4
PI-524	7/26/2012	0900	341TMSG	743	21	--	M	0	8.3	8.3	298	296	11.4
PI-552	7/24/2012	1530	341TMRK	--	33.5	67.29	M	--	7.4	7.6	214	200	11.3
PI-553	7/25/2012	1000	341LRBW	740	19	123.86	0.1	0	7.3	7.6	100	96	10.7
PI-555	7/17/2012	1200	341PGPK	728	30.5	120.98	4.2	38	7.1	7.3	140	138	9.4
PI-557	7/25/2012	1700	341LRBW	740	25.5	--	2.9	27	6.4	6.7	224	214	11.1
PI-558	7/25/2012	1000	344MNNG	770	30	16.13	5.9	54	6.5	6.9	108	111	11.6
PI-571	8/1/2012	1600	341LRBW	740	21.5	97.48	0.1	1	8.1	8.1	225	218	10.9
PI-592	7/26/2012	1000	341CSKL	740	27	9.51	0.1	1	8.7	8.6	337	326	11.7
PI-593	7/18/2012	1500	341LRBW	733	32	45.93	M	0	8.0	8.0	179	171	10.9
PI-594	7/18/2012	0900	341LRBW	739	29.5	147.74	7.7	72	6.3	E 6.6	E 90	84	10.8
PI-595	7/19/2012	1300	341LRBW	740	--	--	0.5	5	6.9	7.3	214	208	10.6
PI-598	7/19/2012	1000	341LRBW	743	--	65.92	M	0	6.7	7.2	117	111	10.8
PI-599	7/24/2012	1230	344MNNG	743	33.5	110.44	0.3	3	7.8	8.0	265	268	12.4
PI-600	7/24/2012	1100	341LRBW	765	30	144.66	M	0	7.8	8.0	221	216	11.1
PI-601	8/2/2012	1400	341LRBW	740	--	25.16	0.4	4	7.8	7.9	158	148	10.7

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Dissolved solids dried at 180 °C, water, filtered, in mg/L	Hardness, water, in mg/L as $CaCO_3$	Calcium, water, filtered, in mg/L	Magnesium, water, filtered, in mg/L	Potassium, water, filtered, in mg/L	Sodium, water, filtered, in mg/L	Sodium fraction of cations, water, in percent in equivalents of major cations	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, in mg/L as $CaCO_3$	ANC, water, unfiltered, inflection-point titration method (incremental titration method), field, in mg/L as $CaCO_3$
	Parameter code:		70300	00900	00915	00925	00935	00930	00932	90410	00419
PI-274	7/17/2012	1600	95	61.1	16.6	4.76	0.93	10.1	26	82.8	82
PI-288	7/18/2012	1200	40	21.4	6.76	1.09	0.42	3.51	26	15.5	11
PI-384	7/24/2012	1500	47	29.9	6.54	3.29	0.53	4.32	24	34.6	30
PI-403	8/2/2012	1000	230	160	51.4	7.69	0.51	19.0	21	110	106
PI-507	7/25/2012	1230	134	80.3	19.6	7.53	0.71	12.0	24	52.1	52
PI-524	7/26/2012	0900	165	60.7	14.9	5.57	0.27	42.8	61	123	109
PI-552	7/24/2012	1530	137	98.5	26.5	7.74	0.24	7.24	14	89.4	88
PI-553	7/25/2012	1000	56	35.6	8.61	3.37	0.61	7.73	32	52.8	52
PI-555	7/17/2012	1200	91	67.6	21.5	3.25	0.64	1.36	4	64.2	56
PI-557	7/25/2012	1700	125	80.8	18.6	8.32	0.74	14.7	28	63.1	61
PI-558	7/25/2012	1000	67	42.9	13.2	2.35	0.4	4.55	19	33.5	25
PI-571	8/1/2012	1600	132	81.9	22.2	5.92	0.94	16.6	31	92.7	88
PI-592	7/26/2012	1000	191	18.6	4.75	1.47	0.72	69.4	89	118	116
PI-593	7/18/2012	1500	109	72.9	22.5	3.91	0.8	8.18	20	67.5	62
PI-594	7/18/2012	0900	60	34.2	8.19	3.31	0.59	3.0	16	26.8	26
PI-595	7/19/2012	1300	140	77.9	21.4	5.69	1.19	12.3	25	55.7	50
PI-598	7/19/2012	1000	74	42.7	9.73	4.46	0.77	8.12	29	55.4	51
PI-599	7/24/2012	1230	154	109	30.9	7.56	0.42	18.8	27	143	142
PI-600	7/24/2012	1100	123	101	27.7	7.58	0.7	6.85	13	100	94
PI-601	8/2/2012	1400	97	49.3	10	5.78	0.38	13.1	37	66.1	62

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Bromide, water, filtered, in mg/L	Chloride, water, filtered, in mg/L	Fluoride, water, filtered, in mg/L	Silica, water, filtered, in mg/L as SiO_2	Sulfate, water, filtered, in mg/L	Ammonia, water, filtered, in mg/L as N	Nitrate plus nitrite, water, filtered, in mg/L as N	Nitrite, water, filtered, in mg/L as N	Orthophosphate, water, filtered, in mg/L as P
	Parameter code:		71870	00940	00950	00955	00945	00608	00631	00613	00671
PI-274	7/17/2012	1600	0.017	0.65	0.14	9.40	3.22	0.012	0.055	0.001	0.030
PI-288	7/18/2012	1200	0.018	5.42	<0.04	4.42	6.69	<0.010	0.518	<0.001	0.023
PI-384	7/24/2012	1500	0.017	1.21	0.05	8.16	3.61	<0.010	0.161	<0.001	0.008
PI-403	8/2/2012	1000	0.017	50.3	0.10	13.2	10.3	0.045	<0.040	<0.001	0.032
PI-507	7/25/2012	1230	0.026	26.4	0.04	9.07	11.6	<0.010	0.503	<0.001	0.011
PI-524	7/26/2012	0900	0.180	23.7	0.20	9.36	0.76	0.064	<0.040	<0.001	0.027
PI-552	7/24/2012	1530	0.017	3.37	0.13	16.4	17.1	0.039	<0.040	<0.001	0.007
PI-553	7/25/2012	1000	0.014	0.47	0.12	8.69	0.96	<0.010	<0.040	<0.001	0.019
PI-555	7/17/2012	1200	0.014	0.89	0.07	6.11	8.06	<0.010	0.428	<0.001	0.025
PI-557	7/25/2012	1700	0.047	20.9	0.11	10.4	9.63	<0.010	1.45	<0.001	0.039
PI-558	7/25/2012	1000	0.021	3.29	0.05	9.17	14.4	<0.010	0.107	<0.001	0.010
PI-571	8/1/2012	1600	0.026	7.29	0.11	11.7	14.7	0.010	0.071	<0.001	0.004
PI-592	7/26/2012	1000	0.353	36.6	0.53	6.72	0.38	0.057	<0.040	<0.001	0.177
PI-593	7/18/2012	1500	0.021	9.80	0.11	9.43	9.30	<0.010	<0.040	<0.001	0.006
PI-594	7/18/2012	0900	0.014	2.31	0.06	7.83	10.2	<0.010	0.883	<0.001	0.020
PI-595	7/19/2012	1300	0.033	28.7	0.12	10.7	7.41	<0.010	<0.040	0.001	<0.004
PI-598	7/19/2012	1000	0.028	3.56	0.10	9.10	0.65	0.095	<0.040	<0.001	0.076
PI-599	7/24/2012	1230	0.017	0.67	0.15	11.2	3.59	0.058	<0.040	<0.001	<0.004
PI-600	7/24/2012	1100	0.015	5.20	0.05	11.5	11.3	<0.010	<0.040	<0.001	0.005
PI-601	8/2/2012	1400	0.052	5.08	0.10	11.7	6.82	<0.010	<0.040	<0.001	0.027

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Aluminum, water, filtered, in µg/L	Barium, water, filtered, in µg/L	Beryllium, water, filtered, in µg/L	Cadmium, water, filtered, in µg/L	Chromium, water, filtered, in µg/L	Cobalt, water, filtered, in µg/L	Copper, water, filtered, in µg/L	Iron, water, filtered, in µg/L	Iron, water, unfiltered, recoverable, in µg/L	Lead, water, filtered, in µg/L	Lead, water, unfiltered, recoverable, in µg/L	Lithium, water, filtered, in µg/L
	Parameter code:		01106	01005	01010	01025	01030	01035	01040	01046	01045	01049	01051	01130
PI-274	7/17/2012	1600	2.8	143	<0.006	<0.016	<0.07	0.182	<0.80	<3.2	<4.6	0.361	0.48	61.2
PI-288	7/18/2012	1200	<2.2	14.2	0.016	0.080	0.14	0.034	14.3	6.2	4.9	2.15	1.96	1.25
PI-384	7/24/2012	1500	<2.2	5.63	<0.006	<0.016	<0.07	<0.021	2.8	9.2	10.1	0.411	0.36	1.24
PI-403	8/2/2012	1000	<2.2	11.5	<0.006	<0.016	<0.07	0.256	<0.80	91	426	0.276	0.55	14.9
PI-507	7/25/2012	1230	<2.2	47.4	<0.006	0.043	0.18	0.079	2.6	3.3	<4.6	0.554	0.35	11.6
PI-524	7/26/2012	0900	<2.2	138	<0.006	<0.016	<0.07	0.024	<0.80	25.6	91.1	0.039	0.10	106
PI-552	7/24/2012	1530	<2.2	11.9	0.009	<0.016	<0.07	0.093	<0.80	52.4	68.6	0.211	0.38	9.34
PI-553	7/25/2012	1000	<2.2	57.7	<0.006	<0.016	0.11	0.105	1.7	4.8	1,310	0.81	3.67	6.29
PI-555	7/17/2012	1200	<2.2	70.9	<0.006	<0.016	<0.07	<0.021	<0.80	<3.2	8.0	<0.025	0.29	7.47
PI-557	7/25/2012	1700	<2.2	63.2	<0.006	<0.016	0.26	0.059	4.8	4.1	112	0.604	0.86	6.86
PI-558	7/25/2012	1000	<2.2	3.51	<0.006	<0.016	0.09	0.059	38.1	15.6	14.8	0.484	0.43	10.6
PI-571	8/1/2012	1600	<2.2	268	<0.006	<0.016	<0.07	0.048	<0.80	14.6	53.9	0.244	0.28	37.1
PI-592	7/26/2012	1000	<2.2	318	<0.006	<0.016	<0.07	<0.021	<0.80	75.7	94.1	0.32	0.39	248
PI-593	7/18/2012	1500	<2.2	73.5	<0.006	<0.016	<0.07	0.03	<0.80	<3.2	5.5	0.54	0.76	15.6
PI-594	7/18/2012	0900	<2.2	5.36	0.007	0.05	<0.07	0.044	2.9	5.6	88.6	0.974	4.08	3.45
PI-595	7/19/2012	1300	<2.2	92.3	<0.006	<0.016	0.27	0.047	<0.80	83.9	124	0.365	0.82	10.2
PI-598	7/19/2012	1000	<2.2	18.1	<0.006	0.048	0.26	0.113	0.83	13.2	338	0.595	0.57	0.98
PI-599	7/24/2012	1230	<2.2	12.4	<0.006	0.044	<0.07	0.064	<0.80	696	746	0.487	0.70	11.0
PI-600	7/24/2012	1100	<2.2	162	<0.006	<0.016	<0.07	0.081	16.5	6.0	<4.6	1.28	0.86	12.9
PI-601	8/2/2012	1400	<2.2	30.2	<0.006	<0.016	<0.07	0.021	<0.80	10	729	1.39	2.22	14.1

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Manganese, water, filtered, in µg/L	Manganese, water, unfiltered, recoverable, in µg/L	Molybdenum, water, filtered, in µg/L	Nickel, water, filtered, in µg/L	Silver, water, filtered, in µg/L	Strontium, water, filtered, in µg/L	Thallium, water, filtered, in µg/L	Tungsten, water, filtered, in µg/L	Vanadium, water, filtered, in µg/L	Zinc, water, filtered, in µg/L	Antimony, water, filtered, in µg/L
	Parameter code:		01056	01055	01060	01065	01075	01080	01057	01155	01085	01090	01095
PI-274	7/17/2012	1600	33.6	33.1	0.481	0.62	<0.005	60.1	<0.010	0.038	0.51	<1.4	<0.027
PI-288	7/18/2012	1200	0.30	0.49	<0.014	0.46	<0.005	13.9	<0.010	<0.010	<0.08	27.6	<0.027
PI-384	7/24/2012	1500	1.92	1.8	<0.014	<0.09	<0.005	41.9	<0.010	<0.010	<0.08	<1.4	<0.027
PI-403	8/2/2012	1000	615	654	0.496	0.42	<0.005	272	<0.010	<0.010	<0.08	2.0	0.030
PI-507	7/25/2012	1230	0.19	0.20	0.020	0.17	<0.005	330	<0.010	<0.010	<0.08	292	0.032
PI-524	7/26/2012	0900	20.2	18.9	0.324	<0.09	<0.005	502	<0.010	0.094	<0.08	<1.4	<0.027
PI-552	7/24/2012	1530	464	495	0.503	0.10	<0.005	376	<0.010	<0.010	<0.08	<1.4	<0.027
PI-553	7/25/2012	1000	170	191	0.074	<0.09	<0.005	202	<0.010	<0.010	<0.08	<1.4	0.057
PI-555	7/17/2012	1200	0.74	8.34	3.45	<0.09	<0.005	429	<0.010	0.010	<0.08	<1.4	<0.027
PI-557	7/25/2012	1700	0.99	2.02	0.754	0.45	<0.005	99.3	<0.010	<0.010	0.08	3.4	0.040
PI-558	7/25/2012	1000	7.42	7.47	0.114	0.69	<0.005	76.4	<0.010	<0.010	<0.08	5.8	<0.027
PI-571	8/1/2012	1600	21.8	22.8	0.234	0.19	<0.005	1,690	<0.010	<0.010	<0.08	2.0	0.092
PI-592	7/26/2012	1000	89.2	85.9	0.535	<0.09	<0.005	362	<0.010	0.386	<0.08	1.5	<0.027
PI-593	7/18/2012	1500	16.2	15.7	0.322	<0.09	<0.005	544	<0.010	<0.010	<0.08	<1.4	0.059
PI-594	7/18/2012	0900	0.40	10.1	<0.014	0.14	<0.005	57.4	<0.010	<0.010	<0.08	7.6	<0.027
PI-595	7/19/2012	1300	42.0	37.1	0.047	<0.09	<0.005	857	<0.010	<0.010	<0.08	81.6	0.072
PI-598	7/19/2012	1000	246	226	0.061	<0.09	<0.005	29.7	<0.010	<0.010	<0.08	23.1	<0.027
PI-599	7/24/2012	1230	274	262	1.28	0.22	<0.005	354	<0.010	<0.010	<0.08	<1.4	<0.027
PI-600	7/24/2012	1100	0.42	0.40	0.351	0.15	<0.005	716	<0.010	<0.010	<0.08	<1.4	0.099
PI-601	8/2/2012	1400	4.77	29.1	2.04	<0.09	<0.005	326	<0.010	<0.010	0.12	7.2	0.052

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Arsenic, water, filtered, in µg/L	Arsenic, water, unfiltered, in µg/L	Boron, water, filtered, in µg/L	Selenium, water, filtered, in µg/L	Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 30-day count, water, filtered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, filtered, Th-230 curve, in pCi/L	Gross beta radioactivity, 30-day recount, water, unfiltered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 30-day count, water, filtered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, water, unfiltered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, water, filtered, Cs-137 curve, in pCi/L
	Parameter code:		01000	01002	01020	01145	63016	62639	63014	62636	63017	62645	63015	62642
PI-274	7/17/2012	1600	1.8	1.7	19	0.49	R 0.1	--	1.3	--	1.4	--	R 0.3	--
PI-288	7/18/2012	1200	0.07	<0.28	4	0.09	R 0.3	0.5	1	R 0	R 0.1	R 0.5	0.7	R 0.0
PI-384	7/24/2012	1500	0.08	<0.28	4	0.28	R 0.3	0.5	R 0.1	R 0.3	1	R 0.3	R 0.4	R 0.7
PI-403	8/2/2012	1000	1.1	1.5	19	<0.03	1.3	--	2.5	--	R 0.3	--	R 0.4	--
PI-507	7/25/2012	1230	0.32	0.36	12	0.10	R 0.4	--	0.6	--	1.2	--	R 0.8	--
PI-524	7/26/2012	0900	0.26	0.35	84	<0.03	1.7	1.5	6.4	2.2	3	R 0.7	2.4	R 0.6
PI-552	7/24/2012	1530	0.39	0.48	9	<0.03	R -0.2	R -0.4	1.2	2.3	1.7	R 0.1	R 0.8	R 0.4
PI-553	7/25/2012	1000	0.69	0.95	6	<0.03	R -0.1	R 0.2	0.5	0.5	R 0.4	R 0.3	R 0.5	0.9
PI-555	7/17/2012	1200	0.19	0.43	17	<0.03	1.1	1	0.8	1.8	1.2	R 0.5	1.1	R 0.1
PI-557	7/25/2012	1700	0.67	0.64	17	0.20	1.5	--	1.9	--	1.7	--	1.1	--
PI-558	7/25/2012	1000	0.08	<0.28	20	0.04	R -0.2	0.6	R -0.1	R 0.4	R 0.2	R -0.1	R 0.4	R -0.2
PI-571	8/1/2012	1600	2.3	2.5	38	<0.03	1.2	--	2.9	--	1.4	--	2.1	--
PI-592	7/26/2012	1000	30.1	27.6	119	<0.03	R 0.7	--	2.1	--	R 0.7	--	1.2	--
PI-593	7/18/2012	1500	1.9	1.7	33	<0.03	0.8	--	0.7	--	R 0.7	--	0.7	--
PI-594	7/18/2012	0900	0.31	0.42	5	0.08	0.5	--	1.5	--	1	--	R -0.2	--
PI-595	7/19/2012	1300	0.20	<0.28	10	0.33	1	--	2.5	--	1.1	--	1.6	--
PI-598	7/19/2012	1000	0.27	0.37	<3	<0.03	R 0.12	--	2	--	0.7	--	0.8	--
PI-599	7/24/2012	1230	0.76	0.85	30	<0.03	R -0.4	--	0.9	--	R 0.3	--	R 0.6	--
PI-600	7/24/2012	1100	1.8	2.0	10	<0.03	1.1	--	3.3	--	R 0.7	--	R 0.0	--
PI-601	8/2/2012	1400	2.5	2.7	22	0.12	0.8	--	8	--	1.3	--	2.5	--

Table 15. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level]

USGS site name	Date	Sample time	Radon-222, water, unfiltered, in pCi/L	Uranium (natural), water, filtered, in µg/L	Methane, in mg/L (Isotech)	Methane, in µg/L (TA)	Ethane, in µg/L (TA)	Ethene, in µg/L (TA)	δD_{H2O}, in per mil	$\delta^{18}O_{H2O}$, in per mil
Parameter code:			82303	22703	68831	76994	82045	82044	82082	82085
PI-274	7/17/2012	1600	2,000	0.055	--	1.66	<0.0615	<0.0569	-63.1	-9.46
PI-288	7/18/2012	1200	2,840	0.05	--	<0.211	<0.0615	<0.0569	-55.4	-8.67
PI-384	7/24/2012	1500	4,500	0.011	--	2.55	<0.0615	<0.0569	-59.0	-9.01
PI-403	8/2/2012	1000	310	0.912	--	15.2	<0.0615	<0.0569	-55.1	-8.44
PI-507	7/25/2012	1230	1,960	0.136	--	0.564	<0.0615	<0.0569	-56.8	-8.72
PI-524	7/26/2012	0900	460	0.137	5.9	4,650	0.4	<0.0569	-58.6	-9.06
PI-552	7/24/2012	1530	121	0.102	--	7.34	<0.0615	<0.0569	-59.0	-8.98
PI-553	7/25/2012	1000	242	0.034	--	0.734	<0.0615	<0.0569	-63.9	-9.74
PI-555	7/17/2012	1200	2,690	<0.004	--	0.415	<0.0615	<0.0569	-60.5	-9.43
PI-557	7/25/2012	1700	2,620	0.682	--	<0.211	<0.0615	<0.0569	-55.4	-8.60
PI-558	7/25/2012	1000	1,410	<0.004	--	16.7	<0.0615	<0.0569	-49.9	-7.76
PI-571	8/1/2012	1600	104	0.238	--	21.1	0.191	<0.0569	-59.9	-9.30
PI-592	7/26/2012	1000	1,320	0.012	3.8	2,780	0.241	<0.0569	-61.8	-9.43
PI-593	7/18/2012	1500	1,240	0.59	--	0.452	<0.0615	<0.0569	-63.9	-9.66
PI-594	7/18/2012	0900	4,100	0.073	--	<0.211	<0.0615	<0.0569	-58.4	-9.01
PI-595	7/19/2012	1300	1,050	0.193	--	58	<0.0615	<0.0569	-61.8	-9.45
PI-598	7/19/2012	1000	3,000	0.017	--	7.88	<0.0615	<0.0569	-61.6	-9.42
PI-599	7/24/2012	1230	320	0.586	0.011	15.7	<0.0615	<0.0569	-58.2	-8.86
PI-600	7/24/2012	1100	880	1.11	--	<0.211	<0.0615	<0.0569	-65.5	-9.57
PI-601	8/2/2012	1400	2,190	0.424	--	1.22	<0.0615	<0.0569	-59.4	-9.36

[1]341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 341LRBW, Long Run and Walcksville Members of Catskill Formation, undivided; 341CSKL, Catskill Formation, undivided; 341TMSG Towamensing Member of the Catskill Formation; 341TMRK, Trimmers Rock Formation; 344MNNG, Mahantango Formation; 341DLRV, Delaware River Member of the Catskill Formation, which is equivalent to Long Run and Walcksville Members of the Catskill Formation, according to Sevon and other (1989).

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Barometric pressure, in mmHg	Temperature, air, in °C	Depth to water level, in ft bls	Dissolved oxygen, water, unfiltered, in mg/L	Dissolved oxygen, water, unfiltered, in % of saturation	pH, water, unfiltered, field, in standard units	pH, water, unfiltered, laboratory, in standard units
Parameter code:		00025	00020	72019	00300	00301	00400	00403
USGS site name PI-507								
7/25/2012	1230	740	24.5	--	5.4	50	6.4	6.8
9/12/2012	0930	752	13	--	5.5	50	6.4	6.9
10/16/2012	1000	733	7	--	5.8	54	6.7	6.9
11/15/2012	1100	750	3	--	6.0	54	6.8	6.7
12/12/2012	0900	749		--	6.0	54	6.8	6.8
1/8/2013	1100	749	2	--	5.9	53	6.4	6.7
2/13/2013	0930	737	-4	--	5.3	49	6.9	6.8
3/13/2013	1130	737	4	--	5.2	48	6.9	6.8
4/3/2013	1000	749		--	7.9	71	6.6	6.8
5/8/2013	1130	743	16	--	7.8	72	6.1	7.0
6/5/2013	1030	746	22	--	8.2	74	6.4	6.9
6/27/2013	1130	738	24	--	6.0	55	6.3	6.9
USGS site name PI-524								
7/26/2012	0900	743	21	--	M	0	8.3	8.3
9/11/2012	1000	755	9	--	0.1	0	8.2	8.3
10/16/2012	1330	744	12	--	M	0	8.5	8.3
11/14/2012	1130	761	5	--	0.1	0	8.7	8.3
12/12/2012	1130	756	-2	55.22	M	0	8.2	8.3
1/8/2013	1300	754	1	56.07	0.2	2	8.3	8.3
2/13/2013	1200	741	2	56.2	0.7	6	8.3	8.4
3/13/2013	1300	--	3	--	0.8	--	8.2	8.3
4/3/2013	1500	750	0	55.59	M	0	8.3	8.3
5/8/2013	1400	748	15	55.16	0.2	2	8.0	8.3
6/5/2013	1330	753	22	42.32	0.1	1	8.1	8.4
6/26/2013	1230	746	24	42.19	0.1	0	8.3	8.3
USGS site name PI-592								
7/26/2012	1000	740	27	9.51	0.1	1	8.7	8.6
6/25/2013	1100	755	--	6.14	0.2	2	8.6	8.6
USGS site name PI-593								
7/18/2012	1500	733	32	45.93	M	0	8.0	8.0
9/12/2012	1200	752	20	--	0.1	0	7.8	8.1
10/17/2012	1430	744	9	43.51	0.4	4	8.3	8.0
11/15/2012	1400	751	3	42.51	0.1	0	8.3	7.9
12/12/2012	0700	747	-3	41.61	0.1	0	8.3	7.8
1/9/2013	1130	741	1	42.51	0.1	0	8.3	7.9
2/12/2013	1000	731	2	41.5	0.8	7	7.6	8.1
3/12/2013	0930	731	12	--	0.9	8	7.7	8.1
4/4/2013	1150	743	0	41.5	0	0	7.8	8.1
4/4/2013	1405	--	--	41.87	0	--	7.7	8.2
5/9/2013	1100	735	12	37.19	0.2	2	7.8	8.1
6/4/2013	1000	740	20	41.77	0.1	0	7.7	8.1
6/25/2013	1100	737	28	41.81	0.1	0	7.9	8.0
USGS site name PI-599								
7/24/2012	1230	743	33.5	110.44	0.3	3	7.8	8.0
6/25/2013	1430	755	--	114.18	0.2	2	7.8	8.0
USGS site name PI-600								
7/24/2012	1100	765	30	144.66	M	0	7.8	8.0
9/11/2012	1300	752	16	--	0.2	2	7.9	8.0
10/17/2012	1100	744	11	--	0.2	2	7.9	8.0
11/14/2012	1400	760	7	142.51	0.1	1	8.2	8.1
12/13/2012	1100	754	1	162.04	0.2	2	8.3	8.1
1/9/2013	1400	746	0	163.36	0.1	1	7.9	8.0
2/12/2013	1400	740	0	151.05	0.6	6	7.8	8.1
3/12/2013	1200	738	10	149.58	0.4	4	7.8	8.0
4/2/2013	1500	743	1	140.71	0.1	0	7.8	8.1
5/7/2013	1300	748	20	141.13	0.5	5	7.3	8.0
6/4/2013	1300	746	22	141.07	0.4	4	7.7	8.1
6/25/2013	1400	744	31	141.11	0.1	1	7.8	8.0

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Specific conductance, water, unfiltered, laboratory, in µS/cm	Specific conductance, water, unfiltered, in µS/cm	Temperature, water, in °C	Dissolved solids dried at 180 °C, water, filtered, in mg/L	Hardness, water, in mg/L as $CaCO_3$	Calcium, water, filtered, in mg/L	Magnesium, water, filtered, in mg/L	Potassium, water, filtered, in mg/L
Parameter code:		**90095**	**00095**	**00010**	**70300**	**00900**	**00915**	**00925**	**00935**
USGS site name PI-507									
7/25/2012	1230	219	212	10.4	134	80.3	19.6	7.53	0.71
9/12/2012	0930	215	228	10.2	125	78.2	18.8	7.49	0.66
10/16/2012	1000	216	207	10.2	117	77.1	18.7	7.27	0.69
11/15/2012	1100	214	209	10.1	121	81.0	20.0	7.43	0.64
12/12/2012	0900	216	203	10.0	125	78.1	19.1	7.31	0.65
1/8/2013	1100	214	203	10.0	119	78.8	19.3	7.32	0.67
2/13/2013	0930	210	177	10.6	128	79.2	18.7	7.79	0.67
3/13/2013	1130	210	177	10.6	133	73.7	18.3	6.69	0.67
4/3/2013	1000	213	191	10.2	123	74.9	18.6	6.83	0.67
5/8/2013	1130	218	226	10.3	130	77.4	18.4	7.52	0.69
6/5/2013	1030	213	221	10.2	119	76.7	18.4	7.37	0.64
6/27/2013	1130	218	208	10.4	124	73.2	17.9	6.80	0.71
USGS site name PI-524									
7/26/2012	0900	298	296	11.4	165	60.7	14.9	5.57	0.27
9/11/2012	1000	297	308	11.4	174	61.9	15.3	5.60	0.23
10/16/2012	1330	287	299	11.1	161	59.6	14.8	5.35	0.27
11/14/2012	1130	293	295	10.9	163	61.2	15.2	5.49	0.25
12/12/2012	1130	299	300	10.7	176	61.9	15.4	5.54	0.22
1/8/2013	1300	289	285	10.5	174	60.8	15.1	5.42	0.26
2/13/2013	1200	289	245	10.5	162	62.2	15.0	5.85	0.26
3/13/2013	1300	289	243	10.6	169	58.2	14.8	5.02	0.24
4/3/2013	1500	300	280	10.6	180	57.4	14.5	5.02	0.26
5/8/2013	1400	290	264	10.8	169	61.2	15.0	5.64	0.26
6/5/2013	1330	283	294	11.4	167	60.5	14.8	5.54	0.26
6/26/2013	1230	302	290	11.5	184	58.5	14.6	5.23	0.26
USGS site name PI-592									
7/26/2012	1000	337	326	11.7	191	18.6	4.75	1.47	0.72
6/25/2013	1100	339	325	11.4	187	19.0	4.88	1.50	0.68
USGS site name PI-593									
7/18/2012	1500	179	171	10.9	109	72.9	22.5	3.91	0.80
9/12/2012	1200	178	185	10.7	105	70.6	21.8	3.78	0.82
10/17/2012	1430	185	173	10.5	114	72.0	22.1	3.91	0.75
11/15/2012	1400	194	187	10.3	116	82.2	25.7	4.20	0.77
12/12/2012	0700	589	191	10.2	342	242	74.7	13.1	1.22
1/9/2013	1130	377	191	10.2	207	153	47.4	8.14	1.01
2/12/2013	1000	177	157	10.2	106	70.9	21.9	3.79	0.79
3/12/2013	0930	200	167	10.2	116	76.5	23.9	3.90	0.81
4/4/2013	1150	176	168	10.5	113	71.6	22.5	3.60	0.81
4/4/2013	1405	175	166	10.4	97	71.1	22.3	3.57	0.79
5/9/2013	1100	177	179	10.4	104	70.7	21.7	3.87	0.82
6/4/2013	1000	194	184	10.6	127	73.6	22.6	3.99	0.79
6/25/2013	1100	186	179	10.9	107	71.7	22.2	3.78	0.77
USGS site name PI-599									
7/24/2012	1230	265	268	12.4	154	109	30.9	7.56	0.42
6/25/2013	1430	266	259	11.6	148	104	29.2	7.38	0.37
USGS site name PI-600									
7/24/2012	1100	221	216	11.1	123	101	27.7	7.58	0.70
9/11/2012	1300	222	216	11.0	141	106	29.2	7.81	0.69
10/17/2012	1100	224	218	10.6	131	101	27.2	7.71	0.70
11/14/2012	1400	222	217	10.6	123	104	28.8	7.58	0.67
12/13/2012	1100	221	207	10.4	127	106	29.1	7.75	0.68
1/9/2013	1400	226	222	10.4	126	103	28.4	7.56	0.68
2/12/2013	1400	218	183	10.4	136	101	27.6	7.66	0.65
3/12/2013	1200	221	190	10.4	128	100	27.9	7.22	0.67
4/2/2013	1500	222	211	10.5	128	96.5	26.6	7.07	0.70
5/7/2013	1300	220	225	10.5	138	98.4	26.2	7.79	0.72
6/4/2013	1300	221	226	10.9	145	102	27.8	7.65	0.70
6/25/2013	1400	227	220	10.7	136	99.8	27.7	7.23	0.63

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Sodium, water, filtered, in mg/L	Sodium fraction of cations, water, percent in equivalents of major cations	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, in mg/L as $CaCO_3$	Bromide, water, filtered, in mg/L	Chloride, water, filtered, in mg/L	Fluoride, water, filtered, in mg/L	Silica, water, filtered, in mg/L as SiO_2	Sulfate, water, filtered, in mg/L
Parameter code:		00930	00932	90410	71870	00940	00950	00955	00945
USGS site name PI-507									
7/25/2012	1230	12.0	24	52.1	0.026	26.4	0.04	9.07	11.6
9/12/2012	0930	11.3	24	51.2	0.023	26.1	<0.04	9.38	11.2
10/16/2012	1000	11.2	24	51.0	0.026	25.9	<0.04	9.32	11.5
11/15/2012	1100	10.7	22	51.2	0.025	26.0	<0.04	9.73	11.3
12/12/2012	0900	10.7	23	52.4	E 0.025	25.0	0.04	9.29	11.6
1/8/2013	1100	10.5	22	52.9	0.022	24.8	0.05	9.52	11.8
2/13/2013	0930	11.2	23	53.0	0.021	25.3	<0.04	9.13	11.7
3/13/2013	1130	11.0	24	51.1	0.024	25.6	<0.04	8.19	11.6
4/3/2013	1000	10.5	23	51.0	0.024	26.4	E 0.04	9.14	11.6
5/8/2013	1130	11.9	25	50.6	0.020	27.5	0.04	9.52	11.5
6/5/2013	1030	10.8	23	48.9	0.022	28.1	0.05	9.45	11.1
6/27/2013	1130	11.5	25	49.7	0.026	28.3	0.04	8.70	10.9
USGS site name PI-524									
7/26/2012	0900	42.8	61	123	0.18	23.7	0.20	9.36	0.76
9/11/2012	1000	43.4	61	122	0.169	21.7	0.17	9.59	0.93
10/16/2012	1330	40.4	60	121	0.182	21.6	0.17	9.44	0.94
11/14/2012	1130	43.2	61	121	0.162	22.4	0.19	9.53	0.81
12/12/2012	1130	40.0	59	122	0.159	22.0	0.19	9.56	0.82
1/8/2013	1300	40.9	60	121	0.182	21.9	0.20	9.43	0.93
2/13/2013	1200	42.1	60	122	0.168	22.0	0.19	9.39	0.96
3/13/2013	1300	41.3	61	120	0.172	21.1	0.17	9.20	1.06
4/3/2013	1500	40.7	61	123	0.172	23.2	--	9.32	1.07
5/8/2013	1400	42.3	60	120	0.161	20.7	0.20	9.85	1.16
6/5/2013	1330	40.0	59	120	0.176	22.2	0.22	9.68	1.04
6/26/2013	1230	43.9	62	123	0.191	23.7	0.20	9.67	0.94
USGS site name PI-592									
7/26/2012	1000	69.4	89	118	0.353	36.6	0.53	6.72	0.38
6/25/2013	1100	66.6	88	118	0.341	37.7	0.53	6.83	0.36
USGS site name PI-593									
7/18/2012	1500	8.18	20	67.5	0.021	9.8	0.11	9.43	9.30
9/12/2012	1200	7.85	19	67.0	0.018	11.8	0.08	9.35	8.85
10/17/2012	1430	7.81	19	67.1	0.021	11.0	0.07	9.71	9.18
11/15/2012	1400	7.37	16	66.8	0.020	13.8	0.07	10.2	8.63
12/12/2012	0700	13.1	11	66.7	E 0.049	136	0.07	10.3	9.87
1/9/2013	1130	10.3	13	67.1	0.035	62.8	0.08	10.3	9.43
2/12/2013	1000	7.86	19	67.4	0.015	10.0	0.09	9.79	8.74
3/12/2013	0930	7.75	18	67.4	0.020	14.1	0.11	10.2	8.62
4/4/2013	1150	7.68	19	67.9	0.014	9.85	0.10	10.6	8.80
4/4/2013	1405	7.55	19	67.8	0.016	9.16	0.11	9.81	8.78
5/9/2013	1100	8.12	20	67.2	0.015	9.21	0.10	10.6	9.02
6/4/2013	1000	8.07	19	67.8	0.017	13.6	0.09	10.6	9.11
6/25/2013	1100	7.62	19	66.9	0.015	9.79	0.10	9.81	8.89
USGS site name PI-599									
7/24/2012	1230	18.8	27	143	0.017	0.67	0.15	11.2	3.59
6/25/2013	1430	17.6	27	142	0.013	0.73	0.15	11.0	3.13
USGS site name PI-600									
7/24/2012	1100	6.85	13	100	0.015	5.20	0.05	11.5	11.3
9/11/2012	1300	6.85	12	99.4	0.017	5.31	0.05	12.0	11.4
10/17/2012	1100	6.67	13	98.4	0.016	5.61	0.06	11.6	11.4
11/14/2012	1400	7.12	13	100	0.018	5.25	0.06	12.0	11.2
12/13/2012	1100	7.28	13	100	<0.010	5.12	0.07	12.2	11.3
1/9/2013	1400	6.71	12	99.9	<0.050	5.19	0.06	12.4	11.3
2/12/2013	1400	6.89	13	101	0.013	4.88	0.05	11.7	10.8
3/12/2013	1200	6.44	12	98.7	0.014	5.38	0.07	12.0	10.7
4/2/2013	1500	7.01	14	100	<0.010	5.13	E 0.07	12.1	10.9
5/7/2013	1300	7.12	14	96.3	0.016	5.61	0.06	12.9	10.8
6/4/2013	1300	6.94	13	98.5	<0.010	6.81	0.06	12.4	11.2
6/25/2013	1400	6.68	13	101	0.014	5.03	0.06	11.6	10.9

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Ammonia, water, filtered, in mg/L as N	Nitrate plus nitrite, water, filtered, in mg/L as N	Nitrite, water, filtered, in mg/L as N	Orthophosphate, water, filtered, in mg/L as P	Aluminum, water, filtered, in µg/L	Barium, water, filtered, in µg/L	Beryllium, water, filtered, in µg/L	Cadmium, water, filtered, in µg/L
Parameter code:		00608	00631	00613	00671	01106	01005	01010	01025
USGS site name PI-507									
7/25/2012	1230	<0.010	0.503	<0.001	0.011	<2.2	47.4	<0.006	0.043
9/12/2012	0930	<0.010	0.516	<0.001	0.010	<2.2	48.8	<0.006	<0.016
10/16/2012	1000	<0.010	0.553	0.010	0.010	<2.2	49.0	<0.006	0.018
11/15/2012	1100	<0.010	0.533	<0.001	0.010	<2.2	46.2	<0.006	<0.016
12/12/2012	0900	<0.010	0.570	<0.001	0.011	<2.2	48.2	<0.006	0.054
1/8/2013	1100	<0.010	0.573	<0.001	0.012	<2.2	47.5	<0.006	0.039
2/13/2013	0930	<0.010	0.560	<0.001	0.010	<2.2	48.6	<0.006	0.028
3/13/2013	1130	<0.010	0.530	<0.001	0.011	<2.2	48.3	<0.006	0.026
4/3/2013	1000	<0.010	0.531	<0.001	0.011	<2.2	52.0	<0.006	<0.016
5/8/2013	1130	<0.010	0.538	<0.001	0.011	<2.2	47.6	<0.006	0.027
6/5/2013	1030	<0.010	0.566	<0.001	0.010	<2.2	48.0	<0.006	<0.016
6/27/2013	1130	<0.010	0.574	<0.001	0.010	<2.2	47.4	<0.006	<0.016
USGS site name PI-524									
7/26/2012	0900	0.064	<0.040	<0.001	0.027	<2.2	138	<0.006	<0.016
9/11/2012	1000	0.062	<0.040	<0.001	0.026	<2.2	132	<0.006	<0.016
10/16/2012	1330	0.082	<0.040	<0.001	0.024	<2.2	129	<0.006	<0.016
11/14/2012	1130	0.059	<0.040	<0.001	0.026	<2.2	135	0.008	<0.016
12/12/2012	1130	0.059	<0.040	<0.001	0.026	<2.2	136	<0.006	<0.032
1/8/2013	1300	0.058	<0.040	<0.001	0.028	<4.4	133	<0.006	<0.016
2/13/2013	1200	0.079	<0.040	<0.001	0.025	<2.2	134	0.007	<0.016
3/13/2013	1300	0.059	<0.040	<0.001	0.025	<2.2	135	0.007	<0.016
4/3/2013	1500	0.059	<0.040	<0.001	0.026	<2.2	138	0.009	<0.016
5/8/2013	1400	0.058	<0.040	<0.001	0.026	<2.2	127	0.006	<0.016
6/5/2013	1330	0.063	<0.040	<0.001	0.025	<2.2	131	<0.006	<0.016
6/26/2013	1230	0.064	<0.040	<0.001	0.027	<2.2	133	0.007	<0.016
USGS site name PI-592									
7/26/2012	1000	0.057	<0.040	<0.001	0.177	<2.2	318	<0.006	<0.016
6/25/2013	1100	0.060	<0.040	<0.001	0.185	<2.2	312	0.007	<.016
USGS site name PI-593									
7/18/2012	1500	<0.010	<0.040	<0.001	0.006	<2.2	73.5	<0.006	<0.016
9/12/2012	1200	<0.010	<0.040	<0.001	0.006	<2.2	76.2	<0.006	<0.016
10/17/2012	1430	<0.010	<0.040	<0.001	0.007	<2.2	74.3	<0.006	<0.016
11/15/2012	1400	<0.010	<0.040	<0.001	0.006	<2.2	74.2	<0.006	<0.016
12/12/2012	0700	<0.010	<0.040	<0.001	0.006	<2.2	191	<0.006	<0.016
1/9/2013	1130	<0.010	0.072	<0.001	0.006	<2.2	126	<0.006	<0.016
2/12/2013	1000	<0.010	<0.040	<0.001	0.006	<2.2	75.1	<0.006	<0.016
3/12/2013	0930	<0.010	<0.040	<0.001	0.005	<2.2	75.5	<0.006	<0.016
4/4/2013	1150	<0.010	<0.040	<0.001	0.007	<2.2	80.8	<0.006	<0.016
4/4/2013	1405	<0.010	<0.040	<0.001	0.007	2.9	80.7	<0.006	<0.016
5/9/2013	1100	<0.010	<0.040	<0.001	0.007	<2.2	72.5	<0.006	<0.016
6/4/2013	1000	<0.010	<0.040	<0.001	0.006	<2.2	74.1	<0.006	<0.016
6/25/2013	1100	<0.010	<0.040	<0.001	0.006	<2.2	71.1	<0.006	<0.016
USGS site name PI-599									
7/24/2012	1230	0.058	<0.040	<0.001	<0.004	<2.2	12.4	<0.006	0.044
6/25/2013	1430	0.060	<0.040	<0.001	0.005	<2.2	12.2	<0.006	<0.016
USGS site name PI-600									
7/24/2012	1100	<0.010	<0.040	<0.001	0.005	<2.2	162	<0.006	<0.016
9/11/2012	1300	<0.010	<0.040	<0.001	0.005	<2.2	158	<0.006	<0.016
10/17/2012	1100	<0.010	<0.040	0.003	0.005	<2.2	157	<0.006	<0.016
11/14/2012	1400	<0.010	<0.040	<0.001	0.005	<2.2	166	<0.006	<0.016
12/13/2012	1100	<0.010	<0.040	<0.001	0.007	<2.2	165	<0.006	<0.016
1/9/2013	1400	<0.010	<0.040	<0.001	0.006	<2.2	161	<0.006	<0.016
2/12/2013	1400	<0.010	<0.040	<0.001	0.005	<2.2	165	<0.006	<0.016
3/12/2013	1200	<0.010	<0.040	0.002	0.005	<2.2	159	<0.006	<0.016
4/2/2013	1500	<0.010	<0.040	<0.001	0.006	<2.2	168	<0.006	<0.016
5/7/2013	1300	<0.010	0.054	<0.001	0.006	<2.2	144	<0.006	<0.016
6/4/2013	1300	<0.010	<0.040	<0.001	0.005	<2.2	149	<0.006	<0.016
6/25/2013	1400	<0.010	<0.040	<0.001	0.005	<2.2	159	<0.006	<0.016

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Chromium, water, filtered, in µg/L	Cobalt, water, filtered, in µg/L	Copper, water, filtered, in µg/L	Iron, water, filtered, in µg/L	Iron, water, unfiltered, recoverable, in µg/L	Lead, water, filtered, in µg/L	Lead, water, unfiltered, recoverable, in µg/L	Lithium, water, filtered, in µg/L
Parameter code:		01030	01035	01040	01046	01045	01049	01051	01130
USGS site name PI-507									
7/25/2012	1230	0.18	0.079	2.6	3.3	<4.6	0.554	0.35	11.6
9/12/2012	0930	<0.07	<0.021	<0.80	<3.2	8.2	0.328	0.24	11.6
10/16/2012	1000	0.08	0.054	1.3	<4.0	<4.6	0.284	0.22	10.9
11/15/2012	1100	<0.07	0.026	1.3	<4.0	<4.6	0.428	0.37	12.5
12/12/2012	0900	<0.07	0.063	1.0	7.0	21.7	0.353	0.29	12.1
1/8/2013	1100	<0.07	0.061	1.2	<4.0	<4.6	0.302	0.28	11.7
2/13/2013	0930	<0.07	0.072	0.92	5.2	4.7	0.212	0.21	12.5
3/13/2013	1130	<0.07	0.046	<0.80	<4.0	<4.6	0.596	0.56	11.5
4/3/2013	1000	<0.07	0.269	<0.80	4.1	25.8	0.411	0.35	12.3
5/8/2013	1130	<0.07	0.055	<0.80	<4.0	6.8	0.258	0.23	11.6
6/5/2013	1030	<0.07	0.058	<0.80	4.1	<4.6	0.240	0.20	11.2
6/27/2013	1130	<0.07	0.027	<0.80	<4.0	<4.6	0.249	0.24	11.2
USGS site name PI-524									
7/26/2012	0900	<0.07	0.024	<0.80	25.6	91.1	0.039	0.10	106
9/11/2012	1000	<0.07	0.054	<0.80	27.6	59.7	0.027	0.15	128
10/16/2012	1330	<0.07	<0.023	<0.80	28.5	50.8	<0.025	0.06	73.1
11/14/2012	1130	0.27	<0.023	<0.80	27.3	41.6	0.031	0.27	103
12/12/2012	1130	<0.07	<0.023	<0.80	23.3	60.3	<0.025	0.07	143
1/8/2013	1300	<0.07	0.040	<0.80	29.0	75.2	0.031	0.11	130
2/13/2013	1200	<0.07	0.029	<0.80	37.6	53.1	0.083	0.18	126
3/13/2013	1300	<0.07	0.084	<0.80	26.5	67.7	0.096	0.32	127
4/3/2013	1500	<0.07	0.027	<0.80	23.3	73.0	<0.025	0.06	138
5/8/2013	1400	<0.07	0.031	<0.80	39.1	92.4	0.031	0.22	121
6/5/2013	1330	<0.07	0.058	<0.80	33.6	77.2	0.028	0.09	120
6/26/2013	1230	<0.07	0.023	<0.80	22.3	45.4	<0.025	0.05	130
USGS site name PI-592									
7/26/2012	1000	<0.07	<0.021	<0.80	75.7	94.1	0.320	0.39	248
6/25/2013	1100	<.07	<.23	<.80	84.7	84.6	0.343	0.41	278
USGS site name PI-593									
7/18/2012	1500	<0.07	0.030	<0.80	<3.2	5.5	0.540	0.76	15.6
9/12/2012	1200	<0.07	<0.021	<0.80	<3.2	<4.6	0.453	0.39	16.5
10/17/2012	1430	<0.07	<0.023	0.9	<4.0	<4.6	0.284	0.26	14.8
11/15/2012	1400	<0.07	<0.023	1.0	<4.0	<4.6	0.431	0.50	19.2
12/12/2012	0700	<0.07	0.182	1.8	22.4	35.9	0.616	3.24	21.1
1/9/2013	1130	<0.07	0.070	<0.80	8.8	<4.6	1.00	1.24	19.0
2/12/2013	1000	<0.07	0.040	1.7	<4.0	<4.6	0.15	0.19	18.1
3/12/2013	0930	<0.07	0.044	1.6	4.2	<4.6	0.756	0.91	16.6
4/4/2013	1150	<0.07	0.036	<0.80	<4.0	<4.6	0.498	1.23	17.6
4/4/2013	1405	<0.07	<0.023	<0.80	<4.0	<4.6	0.593	0.49	17.7
5/9/2013	1100	<0.07	0.296	<0.80	<4.0	<4.6	0.373	0.43	16.7
6/4/2013	1000	<0.07	0.032	1.1	4.9	<4.6	0.344	0.32	15.8
6/25/2013	1100	<0.07	<0.023	0.88	<4.0	<4.6	0.208	0.27	15.9
USGS site name PI-599									
7/24/2012	1230	<0.07	0.064	<0.80	696	746	0.487	0.70	11.0
6/25/2013	1430	<0.07	0.156	<.80	804	945	0.157	0.36	11.5
USGS site name PI-600									
7/24/2012	1100	<0.07	0.081	16.5	6.0	<4.6	1.280	0.86	12.9
9/11/2012	1300	<0.07	<0.021	19.9	<3.2	8.2	0.433	0.33	12.1
10/17/2012	1100	0.10	<0.023	27.6	<4.0	57.5	0.342	0.24	10.4
11/14/2012	1400	<0.07	<0.023	15.9	<4.0	<4.6	0.680	0.49	12.4
12/13/2012	1100	<0.07	0.087	14.9	<4.0	10.2	0.293	0.32	13.1
1/9/2013	1400	<0.07	0.042	16.5	<4.0	<4.6	0.335	0.33	12.9
2/12/2013	1400	<0.07	0.060	13.1	<4.0	<4.6	0.209	0.20	13.8
3/12/2013	1200	<0.07	0.050	1.4	<4.0	9.0	1.300	1.13	12.6
4/2/2013	1500	<0.07	<0.023	14.1	4.3	8.8	0.496	0.46	12.3
5/7/2013	1300	<0.07	0.122	2.6	<4.0	<4.6	0.590	1.3	11.3
6/4/2013	1300	<0.07	0.058	27.2	<4.0	<4.6	0.405	0.31	11.1
6/25/2013	1400	<0.07	<0.023	0.94	<4.0	4.6	0.368	0.47	12.1

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Manganese, water, filtered, in µg/L	Manganese, water, unfiltered, recoverable, in µg/L	Molybdenum, water, filtered, in µg/L	Nickel, water, filtered, in µg/L	Silver, water, filtered, in µg/L	Strontium, water, filtered, in µg/L	Thallium, water, filtered, in µg/L	Tungsten, water, filtered, in µg/L
Parameter code:		01056	01055	01060	01065	01075	-01080	01057	01155
USGS site name PI-507									
7/25/2012	1230	0.19	0.20	0.020	0.17	<0.005	330	<0.010	<0.010
9/12/2012	0930	<0.16	<0.20	0.017	0.14	<0.005	343	<0.010	<0.010
10/16/2012	1000	<0.16	<0.20	0.017	0.14	<0.005	345	<0.010	<0.010
11/15/2012	1100	<0.16	<0.20	0.015	0.17	<0.005	344	<0.010	<0.010
12/12/2012	0900	<0.16	0.26	<0.014	0.25	<0.005	342	<0.010	<0.010
1/8/2013	1100	0.22	<0.20	0.018	0.25	<0.005	334	<0.010	<0.010
2/13/2013	0930	0.21	<0.20	0.020	0.25	<0.005	350	<0.010	<0.010
3/13/2013	1130	<0.16	<0.20	0.021	0.17	<0.005	345	<0.010	<0.010
4/3/2013	1000	0.42	<0.20	<0.014	0.23	<0.005	337	<0.010	<0.010
5/8/2013	1130	<0.16	<0.20	0.017	0.18	<0.005	345	<0.010	<0.010
6/5/2013	1030	<0.16	<0.20	0.015	0.26	<0.005	339	<0.010	<0.010
6/27/2013	1130	<0.16	<0.20	0.015	0.17	<0.005	333	<0.010	<0.010
USGS site name PI-524									
7/26/2012	0900	20.2	18.9	0.324	<0.09	<0.005	502	<0.010	0.094
9/11/2012	1000	19.5	19.3	0.397	<0.09	<0.005	478	<0.010	0.053
10/16/2012	1330	19.7	19.2	0.416	<0.09	<0.005	466	<0.010	0.047
11/14/2012	1130	19.2	18.2	0.414	<0.09	<0.005	470	<0.010	0.059
12/12/2012	1130	18.0	17.6	0.367	<0.09	<0.010	495	<0.010	0.051
1/8/2013	1300	19.5	19.9	0.373	0.12	<0.005	466	<0.010	0.052
2/13/2013	1200	16.1	19.2	0.429	<0.09	<0.005	484	<0.010	0.049
3/13/2013	1300	19.6	20.6	0.413	0.12	<0.005	482	<0.010	0.048
4/3/2013	1500	18.3	18.6	0.427	<0.09	<0.005	479	<0.010	0.051
5/8/2013	1400	21.7	20.4	0.435	0.10	<0.005	460	<0.010	0.045
6/5/2013	1330	19.3	19.9	0.408	0.19	<0.005	462	<0.010	0.051
6/26/2013	1230	18.5	17.9	0.374	0.13	<0.005	472	<0.010	0.052
USGS site name PI-592									
7/26/2012	1000	89.2	85.9	0.535	<0.09	<0.005	362	<0.010	0.386
6/25/2013	1100	85.3	83.6	0.663	<.09	<.005	349	<.010	0.193
USGS site name PI-593									
7/18/2012	1500	16.2	15.7	0.322	<0.09	<0.005	544	<0.010	<0.010
9/12/2012	1200	15.3	16.1	0.334	0.12	<0.005	531	<0.010	<0.010
10/17/2012	1430	14.9	15.8	0.337	0.1	<0.005	536	<0.010	<0.010
11/15/2012	1400	17.6	18.6	0.323	0.13	<0.005	566	<0.010	<0.010
12/12/2012	0700	56.5	58.5	0.231	0.39	<0.005	991	<0.010	<0.010
1/9/2013	1130	48.1	39.7	0.276	0.28	<0.005	739	<0.010	<0.010
2/12/2013	1000	15.2	14.6	0.337	0.14	<0.005	548	<0.010	<0.010
3/12/2013	0930	19.2	18.3	0.330	0.17	<0.005	527	<0.010	<0.010
4/4/2013	1150	15.2	14.1	0.339	0.11	<0.005	541	<0.010	<0.010
4/4/2013	1405	13.9	14.3	0.327	0.17	<0.005	542	<0.010	<0.010
5/9/2013	1100	14.4	13.4	0.325	0.12	<0.005	533	0.012	<0.010
6/4/2013	1000	15.6	15.7	0.305	0.13	<0.005	536	<0.010	<0.010
6/25/2013	1100	13.9	13.8	0.313	0.10	<0.005	514	<0.010	<0.010
USGS site name PI-599									
7/24/2012	1230	274	262	1.28	0.22	<0.005	354	<0.010	<0.010
6/25/2013	1430	259	255	1.16	0.16	<.005	344	<.010	0.012
USGS site name PI-600									
7/24/2012	1100	0.42	0.40	0.351	0.15	<0.005	716	<0.010	<0.010
9/11/2012	1300	0.23	0.64	0.346	0.28	<0.005	697	<0.010	<0.010
10/17/2012	1100	0.50	1.49	0.326	0.38	<0.005	666	<0.010	<0.010
11/14/2012	1400	0.17	0.65	0.352	0.21	<0.005	733	<0.010	<0.010
12/13/2012	1100	0.36	0.47	0.369	0.19	<0.005	755	<0.010	<0.010
1/9/2013	1400	0.18	0.39	0.351	0.27	<0.005	748	<0.010	<0.010
2/12/2013	1400	0.22	0.67	0.410	0.26	<0.005	766	<0.010	<0.010
3/12/2013	1200	0.46	0.71	0.370	0.15	<0.005	700	<0.010	<0.010
4/2/2013	1500	0.48	0.49	0.401	0.17	<0.005	777	<0.010	<0.010
5/7/2013	1300	0.87	0.61	0.325	0.27	0.007	594	<0.010	<0.010
6/4/2013	1300	0.42	0.92	0.342	0.78	<0.005	637	<0.010	<0.010
6/25/2013	1400	0.19	0.41	0.368	0.18	<0.005	716	<0.010	<0.010

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Vanadium, water, filtered, in µg/L	Zinc, water, filtered, in µg/L	Antimony, water, filtered, in µg/L	Arsenic, water, filtered, in µg/L	Arsenic, water, unfiltered, in µg/L	Boron, water, filtered, in µg/L	Selenium, water, filtered, in µg/L
Parameter code:		**01085**	**01090**	**01095**	**01000**	**01002**	**01020**	**01145**
				USGS site name PI-507				
7/25/2012	1230	<0.08	292	0.032	0.32	0.36	12	0.10
9/12/2012	0930	<0.08	70.0	<0.027	0.30	0.36	12	0.10
10/16/2012	1000	<0.08	94.2	0.028	0.29	0.39	12	0.09
11/15/2012	1100	<0.08	85.5	<0.027	0.31	0.36	11	0.09
12/12/2012	0900	0.10	301	<0.027	0.31	0.30	12	0.08
1/8/2013	1100	<0.08	294	0.031	0.30	0.37	12	0.10
2/13/2013	0930	<0.08	175	0.029	0.31	0.32	12	0.11
3/13/2013	1130	<0.08	109	<0.027	0.31	0.38	13	0.11
4/3/2013	1000	<0.08	86.7	0.040	0.33	0.39	13	0.10
5/8/2013	1130	0.10	130	0.028	0.31	0.30	12	0.12
6/5/2013	1030	<0.08	107	0.030	0.28	0.30	11	0.11
6/27/2013	1130	<0.08	30.8	<0.027	0.29	<0.28	10	0.09
				USGS site name PI-524				
7/26/2012	0900	<0.08	<1.4	<0.027	0.26	0.35	84	<0.03
9/11/2012	1000	<0.08	<1.4	<0.027	0.25	0.29	76	<0.03
10/16/2012	1330	<0.08	<1.4	<0.027	0.28	0.31	76	<0.03
11/14/2012	1130	<0.08	<1.4	<0.027	0.31	0.28	86	<0.03
12/12/2012	1130	<0.08	<1.4	<0.027	0.26	0.32	83	<0.03
1/8/2013	1300	<0.08	<1.4	<0.027	0.28	0.35	83	<0.03
2/13/2013	1200	<0.08	<1.4	<0.027	0.31	0.28	82	<0.03
3/13/2013	1300	<0.08	1.5	<0.054	0.28	0.32	82	<0.03
4/3/2013	1500	<0.08	<1.4	<0.027	0.28	0.31	86	<0.03
5/8/2013	1400	<0.08	<1.4	<0.027	0.31	0.33	76	<0.03
6/5/2013	1330	<0.08	<1.4	<0.027	0.29	0.30	72	<0.03
6/26/2013	1230	<0.08	<1.4	<0.027	0.27	<0.28	78	<0.03
				USGS site name PI-592				
7/26/2012	1000	<0.08	1.5	<0.027	30.1	27.6	119	<0.03
6/25/2013	1100	<.08	<1.4	<0.027	27.9	28.4	116	0.04
				USGS site name PI-593				
7/18/2012	1500	<0.08	<1.4	0.059	1.9	1.7	33	<0.03
9/12/2012	1200	<0.08	4.5	0.061	2.0	1.9	31	<0.03
10/17/2012	1430	<0.08	2.6	0.061	2.0	1.8	28	<0.03
11/15/2012	1400	<0.08	4.8	0.063	2.0	1.8	30	<0.03
12/12/2012	0700	0.19	5.1	0.072	1.6	1.7	27	<0.03
1/9/2013	1130	0.11	1.8	0.073	1.8	1.5	31	<0.03
2/12/2013	1000	<0.08	1.4	0.070	2.0	2.0	34	<0.03
3/12/2013	0930	0.10	2.5	0.071	1.8	1.6	33	<0.03
4/4/2013	1150	<0.08	2.4	0.066	1.9	1.7	34	<0.03
4/4/2013	1405	<0.08	3.1	0.064	1.9	2.2	34	<0.03
5/9/2013	1100	<0.08	2.3	0.086	1.9	1.9	30	0.04
6/4/2013	1000	0.12	2.1	0.064	2.0	1.8	27	<0.03
6/25/2013	1100	0.09	<1.4	0.062	1.8	1.9	28	<0.03
				USGS site name PI-599				
7/24/2012	1230	<0.08	<1.4	<0.027	0.76	0.85	30	<0.03
6/25/2013	1430	<0.08	3.3	<0.027	0.72	0.65	28	<0.03
				USGS site name PI-600				
7/24/2012	1100	<0.08	<1.4	0.099	1.8	2.0	10	<0.03
9/11/2012	1300	<0.08	4.2	0.081	1.7	1.8	9	<0.03
10/17/2012	1100	<0.08	4.1	0.093	1.7	1.7	9	<0.03
11/14/2012	1400	<0.08	4.5	0.084	1.8	1.7	10	<0.03
12/13/2012	1100	<0.08	3.4	0.077	1.7	1.5	11	<0.03
1/9/2013	1400	<0.08	3.1	0.081	1.7	1.6	10	<0.03
2/12/2013	1400	<0.08	2.2	0.085	1.7	1.6	11	<0.03
3/12/2013	1200	<0.08	1.7	0.093	1.8	1.9	11	0.04
4/2/2013	1500	<0.08	1.9	0.075	1.7	1.6	11	0.05
5/7/2013	1300	<0.08	2.3	0.090	1.5	1.7	9	0.04
6/4/2013	1300	<0.08	3.3	0.088	1.7	1.5	8	0.05
6/25/2013	1400	<0.08	2.4	0.068	1.5	1.6	9	<0.03

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Gross alpha radioactivity, 30-day recount, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 30-day count, water, filtered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, filtered, Th-230 curve, in pCi/L	Gross beta radioactivity, 30-day recount, water, unfiltered, Cs-137 curve, in pCi/L
Parameter code:		**63016**	**62639**	**63014**	**62636**	**63017**
			USGS site name PI-507			
7/25/2012	1230	R 0.4	--	0.6	--	1.2
9/12/2012	0930	R -0.2	--	0.6	--	1.1
10/16/2012	1000	R 0.4	--	0.8	--	1.2
11/15/2012	1100	0.4	--	7.0	--	1.2
12/12/2012	0900	R 0.0	--	R 0.1	--	R 0
1/8/2013	1100	R -0.1	--	1.1	--	R 0.8
2/13/2013	0930	R -0.3	--	R -0.3	--	1.2
3/13/2013	1130	R -0.2	--	R -0.2	--	1.4
4/3/2013	1000	R 0.2	--	4.9	--	1.1
5/8/2013	1130	--	--	--	--	--
6/5/2013	1030	--	--	--	--	--
6/27/2013	1130	1.3	--	0.8	--	R1.0
			USGS site name PI-524			
7/26/2012	0900	1.7	1.5	6.4	2.2	3.0
9/11/2012	1000	3.0	--	9.1	--	1.5
10/16/2012	1330	2.7	--	4.4	--	0.9
11/14/2012	1130	2.5	--	7.2	--	1.5
12/12/2012	1130	1.5	--	3.0	--	1.4
1/8/2013	1300	--	--	--	--	--
2/13/2013	1200	--	--	--	--	--
3/13/2013	1300	2.1	--	2.2	--	2.6
4/3/2013	1500	2.6	--	7.1	--	1.7
5/8/2013	1400	--	--	--	--	--
6/5/2013	1330	--	--	--	--	--
6/26/2013	1230	1.4	--	1.5	--	1.8
			USGS site name PI-592			
7/26/2012	1000	R 0.7	--	2.1	--	R 0.7
6/25/2013	1100	R1.2	--	2.5	--	2.8
			USGS site name PI-593			
7/18/2012	1500	0.8	--	0.7	--	R 0.7
9/12/2012	1200	1.6	--	1.5	--	1.7
10/17/2012	1430	1.7	--	1.3	--	1.7
11/15/2012	1400	0.7	--	5.3	--	0.9
12/12/2012	0700	1.2	--	1.6	--	1.0
1/9/2013	1130	2.3	--	1.9	--	1.3
2/12/2013	1000	2.1	--	1.0	--	1.3
3/12/2013	0930	1.8	--	1.3	--	R 0.8
4/4/2013	1150	1.3	--	2.7	--	2.1
4/4/2013	1405	2.7	--	4.2	--	1.6
5/9/2013	1100	--	--	--	--	--
6/4/2013	1000	--	--	--	--	--
6/25/2013	1100	1.0	--	R -0.1	--	R0.1
			USGS site name PI-599			
7/24/2012	1230	R -0.4	--	0.9	--	R 0.3
6/25/2013	1430	0.7	--	0.8	--	R0
			USGS site name PI-600			
7/24/2012	1100	1.1	--	3.3	--	R 0.7
9/11/2012	1300	1.8	--	1.4	--	1.2
10/17/2012	1100	2.3	--	2.3	--	1.1
11/14/2012	1400	2.5	--	3.7	--	0.8
12/13/2012	1100	1	--	2.6	--	R 0.2
1/9/2013	1400	R 0.1	--	1.5	--	1.3
2/12/2013	1400	1.2	--	1.2	--	0.9
3/12/2013	1200	1.5	--	1.2	--	1.4
4/2/2013	1500	2.7	--	3.0	--	1.0
5/7/2013	1300	--	--	--	--	--
6/4/2013	1300	--	--	--	--	--
6/25/2013	1400	R0.6	--	2.1	--	R1.0

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Gross beta radioactivity, 30-day count, water, filtered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, water, unfiltered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, water, filtered, Cs-137 curve, in pCi/L	Radium-226, water, filtered, radon method, in pCi/L	Radon-222, water, unfiltered, in pCi/L	Uranium (natural), water, filtered, in µg/L
Parameter code:		**62645**	**63015**	**62642**	**09511**	**82303**	**22703**
				USGS site name PI-507			
7/25/2012	1230	--	R 0.8	--	--	1,960	0.136
9/12/2012	0930	--	R 0.2	--	--	1,760	0.127
10/16/2012	1000	--	R 0.2	--	--	1,840	0.118
11/15/2012	1100	--	3.6	--	--	1,920	0.110
12/12/2012	0900	--	R 0.5	--	--	1,900	0.119
1/8/2013	1100	--	R 0.4	--	--	1,900	0.114
2/13/2013	0930	--	R 0.4	--	--	1,910	0.122
3/13/2013	1130	--	1.1	--	--	1,890	0.112
4/3/2013	1000	--	1.6	--	--	1,890	0.120
5/8/2013	1130	--	--	--	--	1,840	0.105
6/5/2013	1030	--	--	--	--	1,850	0.097
6/27/2013	1130	--	2.1	--	0.041	1,880	0.097
				USGS site name PI-524			
7/26/2012	0900	R 0.7	2.4	R 0.6	--	460	0.137
9/11/2012	1000	--	1.6	--	--	510	0.184
10/16/2012	1330	--	1.4	--	--	540	0.202
11/14/2012	1130	--	2.5	--	--	480	0.184
12/12/2012	1130	--	R 0.2	--	--	450	0.131
1/8/2013	1300	--	--	--	--	550	0.162
2/13/2013	1200	--	--	--	--	470	0.182
3/13/2013	1300	--	1.6	--	--	540	0.169
4/3/2013	1500	--	2.4	--	--	500	0.146
5/8/2013	1400	--	--	--	--	500	0.225
6/5/2013	1330	--	--	--	--	530	0.202
6/26/2013	1230	--	1.9	--	0.29	540	0.149
				USGS site name PI-592			
7/26/2012	1000	--	1.2	--	--	1,320	0.012
6/25/2013	1100	--	3.3	--	0.26	1,350	0.013
				USGS site name PI-593			
7/18/2012	1500	--	0.7	--	--	1,240	0.590
9/12/2012	1200	--	1.1	--	--	1,300	0.613
10/17/2012	1430	--	1.4	--	--	1,170	0.611
11/15/2012	1400	--	2.6	--	--	1,400	0.600
12/12/2012	0700	--	1.4	--	--	350	1.31
1/9/2013	1130	--	0.8	--	--	880	0.906
2/12/2013	1000	--	R 0.3	--	--	1,180	0.604
3/12/2013	0930	--	1.7	--	--	1,130	0.606
4/4/2013	1150	--	2.5	--	--	1,130	0.635
4/4/2013	1405	--	2.5	--	--	1,130	0.627
5/9/2013	1100	--	--	--	--	1,150	0.571
6/4/2013	1000	--	--	--	--	1,320	0.583
6/25/2013	1100	--	2.6	--	0.15	1,290	0.547
				USGS site name PI-599			
7/24/2012	1230	--	R 0.6	--	--	320	0.586
6/25/2013	1430	--	2.1	--	0.095	251	0.545
				USGS site name PI-600			
7/24/2012	1100	--	R 0.0	--	--	880	1.11
9/11/2012	1300	--	R 1.0	--	--	860	1.11
10/17/2012	1100	--	1.4	--	--	--	1.09
11/14/2012	1400	--	0.7	--	--	920	1.14
12/13/2012	1100	--	0.9	--	--	930	1.15
1/9/2013	1400	--	0.7	--	--	1,080	1.10
2/12/2013	1400	--	R 0.3	--	--	1,090	1.12
3/12/2013	1200	--	0.6	--	--	1,000	1.04
4/2/2013	1500	--	1.3	--	--	1,030	1.10
5/7/2013	1300	--	--	--	--	920	0.926
6/4/2013	1300	--	--	--	--	1,080	0.975
6/25/2013	1400	--	3.4	--	0.08	1,080	1.01

Table 16. Results of laboratory analysis for inorganic constituent and methane concentrations and stable isotopes of water in water samples collected from four wells sampled monthly in Pike County, Pennsylvania, 2012–13.—Continued

[Analyses for inorganic constituents done by U.S. Geological Survey National Water Quality Laboratory; dissolved methane, ethane, and ethene in micrograms per liter by TestAmerica, Inc. (TA); dissolved methane in milligrams per liter and stable isotopes of water by Isotech Laboratories, Inc.; USGS, U.S. Geological Survey; --, no data; M, measured below reporting level of 0.1 milligrams per liter; E, estimated value; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; R, radioactivity level not detected above laboratory background level; J, estimated value from TestAmerica laboratory; USGS CFC lab, U.S. Geological Survey chlorofluorocarbon laboratory]

Date	Sample time	Methane, in mg/L (USGS CFC lab)	Methane, in mg/L (Isotech)	Methane, in µg/L (TA)	Ethane, in µg/L (TA)	Ethene, in µg/L (TA)	δD_{H2O}, in per mil	$\delta^{18}O_{H2O}$, in per mil
Parameter code:		**85574**	**68831**	**76994**	**82045**	**82044**	**82082**	**82085**
USGS site name PI-507								
7/25/2012	1230	--	--	0.564	<0.0615	<0.0569	-56.8	-8.72
9/12/2012	0930	--	--	0.585	<0.0615	<0.0569	-57.4	-8.68
10/16/2012	1000	--	--	0.815	<0.0615	<0.0569	-55.0	-8.44
11/15/2012	1100	--	--	0.621	<0.0615	<0.0569	-54.3	-8.37
12/12/2012	0900	--	--	0.766	<0.0615	<0.0569	-53.9	-8.34
1/8/2013	1100	--	--	0.832	<0.0615	<0.0569	-53.4	-8.30
2/13/2013	0930	--	--	0.420	<0.0615	<0.0569	-52.9	-8.29
3/13/2013	1130	--	--	0.837	<0.0615	<0.0569	-52.9	-8.26
4/3/2013	1000	--	--	0.541	<0.0615	<0.0569	-53.1	-8.27
5/8/2013	1130	--	--	0.567	<0.0615	<0.0569	-55.5	-8.53
6/5/2013	1030	--	--	0.827	<0.0615	<0.0569	-54.1	-8.37
6/27/2013	1130	0.0006	--	<0.22	--	--	-53.9	-8.44
USGS site name PI-524								
7/26/2012	0900	--	5.9	4,650	0.400	<0.0569	-58.6	-9.06
9/11/2012	1000	--	5.0	5,180	0.401	<0.0569	-58.8	-9.06
10/16/2012	1330	--	5.4	5,510	0.312	<0.0569	-60.0	-9.23
11/14/2012	1130	--	5.0	4,710	0.339	<0.0569	-59.2	-9.13
12/12/2012	1130	--	5.8	4,820	0.345	<0.0569	-59.7	-9.14
1/8/2013	1300	--	5.0	3,980	0.398	<0.0569	-60.2	-9.23
2/13/2013	1200	--	5.2	4,040	0.405	<0.0569	-58.7	-9.09
3/13/2013	1300	--	5.1	3,930	0.864	<0.0569	-58.5	-9.10
4/3/2013	1500	--	5.1	4,010	0.829	<0.0569	-58.6	-9.14
5/8/2013	1400	--	5.3	4,300	0.849	<0.0569	-62.1	-9.54
6/5/2013	1330	--	5.6	4,740	0.769	<0.0569	-60.8	-9.14
6/26/2013	1230	7.32	5.7	4,100	--	--	-59.1	-9.07
USGS site name PI-592								
7/26/2012	1000	--	3.8	2,780	0.241	<0.0569	-61.8	-9.43
6/25/2013	1100	4.93	3.9	2,800	--	--	-61.7	-9.29
USGS site name PI-593								
7/18/2012	1500	--	--	J0.452	<0.0615	<0.0569	-63.9	-9.66
9/12/2012	1200	--	--	J0.316	<0.0615	<0.0569	-62.8	-9.61
10/17/2012	1430	--	--	J0.359	<0.0615	<0.0569	-62.9	-9.61
11/15/2012	1400	--	--	J0.388	<0.0615	<0.0569	-63.4	-9.55
12/12/2012	0700	--	--	0.549	<0.0615	<0.0569	-63.3	-9.55
1/9/2013	1130	--	--	J0.461	<0.0615	<0.0569	-62.0	-9.46
2/12/2013	1000	--	--	J0.382	<0.0615	<0.0569	-63.1	-9.93
3/12/2013	0930	--	--	J0.414	<0.0615	<0.0569	-63.0	-9.64
4/4/2013	1150	--	--	1.76	<0.0615	J0.0751	-63.9	-9.69
4/4/2013	1405	--	--	0.822	<0.0615	<0.0569	-66.0	-10.06
5/9/2013	1100	--	--	J0.427	<0.0615	<0.0569	-63.8	-9.69
6/4/2013	1000	--	--	J0.462	<0.0615	<0.0569	-63.6	-9.68
6/25/2013	1100		--	<0.22	--	--	-63.5	-9.56
USGS site name PI-599								
7/24/2012	1230	--	0.011	15.7	<0.0615	<0.0569	-58.2	-8.86
6/25/2013	1430	0.0181	0.014	10.0	--	--	-56.5	-8.87
USGS site name PI-600								
7/24/2012	1100	--	--	<0.211	<0.0615	<0.0569	-65.5	-9.57
9/11/2012	1300	--	--	0.865	<0.0615	<0.0569	-63.0	-9.52
10/17/2012	1100	--	--	<0.211	<0.0615	<0.0569	-63.3	-9.52
11/14/2012	1400	--	--	0.264	<0.0615	<0.0569	-63.6	-9.47
12/13/2012	1100	--	--	<0.211	<0.0615	<0.0569	-63.7	-9.50
1/9/2013	1400	--	--	0.262	<0.0615	<0.0569	-63.6	-9.45
2/12/2013	1400	--	--	<0.211	<0.0615	<0.0569	-63.2	-9.63
3/12/2013	1200	--	--	<0.211	<0.0615	<0.0569	-65.6	-9.65
4/2/2013	1500	--	--	<0.211	<0.0615	<0.0569	-64.3	-9.49
5/7/2013	1300	--	--	0.229	<0.0615	<0.0569	-63.3	-9.59
6/4/2013	1300	--	--	<0.211	<0.0615	<0.0569	--	--
6/25/2013	1400	<0.0001	--	<0.220	--	--	-63.2	-9.57

Table 17. Results of laboratory analysis for dissolved gases and for isotopic composition of methane, dissolved inorganic carbon, and water in water samples collected from 20 wells in Pike County, Pennsylvania, summer 2012.

[Analyses performed by Isotech Laboratories, Inc.; dissolved gas anaysis reported in mole percent of gas in headspace which is approximately equal to volume percent. Shaded rows identify sequential replicate samples; USGS, U.S. Geological Survey; DIC, dissolved inorganic carbon; %, mole percent; ‰, per mil; cc/L, cubic centimeters per liter; mg/L, milligrams per liter; na, not analyzed; nd, not detected; --, no data; Isotopic composition of hydrogen is relative to Vienna Standard Mean Ocean Water (VSMOW). Isotopic composition of carbon is relative to Vienna Pee Dee Belemnite (VPDB). Isotopic composition of oxygen is relative to VSMOW, except for carbon dioxide which is relative to VPDB; He, helium; H_2, hydrogen; Ar, argon; O_2, oxygen; CO_2, carbon dioxide; N_2, nitrogen; CO, carbon monoxide; C1, methane; C2, ethane; C6+, higher chain hydrocarbons; DIC, dissolved inorganic carbon]

USGS site name	Date	Sample time	He, in %	H_2, in %	Ar, in %	O_2, in %	CO_2, in %	N_2, in %	CO, in %	C1, in %	C2, in %	[1]C6+, in %	δ^{13}C1, in ‰	δD_{C1}, in ‰	$\delta^{13}C_{DIC}$, in ‰	Dissolved CH_4, in cc/L	Dissolved CH_4, in mg/L	δD_{H2O}, in ‰	$\delta^{18}O_{H2O}$, in ‰
PI-524	7/25/2012	0900	na	nd	1.27	3.77	0.15	74.36	nd	20.45	0.0022	nd	-64.55	-216.9	--	8.9	5.9	-58.6	-9.06
PI-524	7/25/2012	0901	na	nd	1.18	3.77	0.16	74.49	nd	20.40	0.0022	nd	-64.52	-219.9	--	8.5	5.7	-58.5	-9.04
PI-524	9/11/2012	1000	na	nd	1.28	2.00	0.14	76.90	nd	19.68	0.0022	nd	-64.63	-221.2	-10.2	7.6	5.0	-58.8	-9.06
PI-524	10/6/2012	1330	na	nd	1.31	2.61	0.16	75.95	nd	19.97	0.0023	nd	-64.63	-218.9	--	8.1	5.4	-60.0	-9.23
PI-524	11/14/2012	1130	na	nd	1.23	1.79	0.12	77.79	nd	19.07	0.0021	nd	-64.70	-225.0	-10.3	7.5	5.0	-59.2	-9.13
PI-524	12/12/2012	1130	na	nd	1.30	0.83	0.14	76.7	nd	21.03	0.0023	nd	-64.65	-221.7	-10.3	8.7	5.8	-59.7	-9.14
PI-524	12/12/2012	1131	na	nd	1.30	0.98	0.15	76.55	nd	21.02	0.0023	nd	-64.62	-223.9	-10.2	7.8	5.2	-59.2	-9.22
PI-524	1/8/2013	1300	na	nd	1.22	4.16	0.12	75.95	nd	18.55	0.0019	0.0002	-64.68	-219.5	-10.5	7.5	5.0	-60.2	-9.23
PI-524	2/13/2013	1200	na	nd	1.23	3.04	0.12	76.45	nd	19.16	0.0022	nd	-64.74	-223.0	-10.2	7.9	5.2	-58.7	-9.09
PI-524	3/13/2013	1300	na	nd	1.24	2.07	0.12	77.47	nd	19.1	0.002	nd	-64.82	-223.6	-10.4	7.6	5.1	-58.5	-9.1
PI-524	4/3/2013	1500	na	nd	1.26	2.17	0.12	76.8	nd	19.65	0.0022	nd	-64.75	-223.0	-10.1	7.7	5.1	-58.6	-9.14
PI-524	5/8/2013	1400	na	nd	1.30	2.86	0.16	75.5	nd	20.18	0.0022	nd	-64.66	-226.0	--	8.0	5.3	-62.1	-9.54
PI-524	6/5/2013	1330	na	nd	1.29	1.52	0.16	76.33	nd	20.7	0.0024	nd	-64.65	-223.2	--	8.5	5.6	-60.8	-9.14
PI-524	6/26/2013	1220	na	nd	1.29	0.61	0.16	76.24	nd	21.7	0.0024	nd	-64.63	-223.9	-10.1	8.6	5.7	-59.1	-9.07
PI-592	7/26/2012	1000	na	nd	1.30	4.31	0.074	78.47	nd	15.84	0.0013	0.0003	-64.41	-201.8	--	5.7	3.8	-61.8	-9.43
PI-592	6/25/2013	1100	na	nd	1.39	0.73	0.077	80.79	nd	17.01	0.0015	nd	-64.52	-204.5	-16.3	5.8	3.9	-61.7	-9.29
PI-599	7/24/2012	1230	na	nd	1.36	5.17	0.66	92.75	nd	0.0570	nd	0.0006	--	--	--	0.016	0.011	-58.2	-8.86
PI-599	6/25/2013	1430	na	nd	1.69	0.84	0.90	96.50	nd	0.0699	nd	nd	--	--	-14.3	0.021	0.014	-56.5	-8.87

[1]Most higher chain hydrocarbon gases were not detected and are not tabulated; these include C_2H_4, C_3, C_3H_6, iC_4, nC_4, iC_5, nC_5.

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Barometric pressure, in mmHg	Temperature, air, in °C	Depth to water level, in ft bls	Dissolved oxygen, water, unfiltered, in mg/L	Dissolved oxygen, water, unfiltered, in % of saturation	pH, water, unfiltered, field, in standard units	pH, water, unfiltered, laboratory, in standard units	Specific conductance, water, unfiltered, laboratory, in µS/cm	Specific conductance, water, unfiltered, in µS/cm	Temperature, water, in °C	Dissolved solids dried at 180 °C, water, filtered, in mg/L	Hardness, water, in mg/L as $CaCO_3$
Parameter code:			00025	00020	72019	00300	00301	00400	00403	90095	00095	00010	70300	00900
Environmental replicates														
PI-524	7/26/2012	0900	743	21	--	M	0	8.3	8.3	298	296	11.4	165	60.7
PI-524	7/26/2012	0901	743	21	--	M	0	8.3	8.3	302	296	11.4	177	61.1
PI-524	12/12/2012	1130	756	-2	55.22	M	0	8.2	8.3	299	300	10.7	176	61.9
PI-524	12/12/2012	1131	756	-2	--	M	0	8.2	8.3	296	300	10.7	164	61.9
PI-558	7/25/2012	1000	770	30	16.13	5.9	54	6.5	6.9	108	111	11.6	67	42.9
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--	--	--
PI-593	4/4/2013	1150	743	0	41.5	0	0	7.8	8.1	176	168	10.5	113	71.6
PI-593	4/4/2013	[1]1405	--	--	41.87	0	--	7.7	8.2	175	166	10.4	97	71.1
Equipment blanks														
PI-600	5/6/2013	1429	--	--	--	--	--	--	E 6.7	E 6.4	1	--	<20	--
Laboratory	9/13/2013	1015	--	--	--	--	--	5.9	--	--	2	--	--	--

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.—Continued

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Calcium, water, filtered, in mg/L	Magnesium, water, filtered, in mg/L	Potassium, water, filtered, in mg/L	Sodium fraction of cations, water, in % in equivalents of major cations	Sodium, water, filtered, in mg/L	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, in mg/L as $CaCO_3$	Bromide, water, filtered, in mg/L	Chloride, water, filtered, in mg/L	Fluoride, water, filtered, in mg/L	Silica, water, filtered, in mg/L as SiO_2	Sulfate, water, filtered, in mg/L	Ammonia, water, filtered, in mg/L as N
Parameter code:			00915	00925	00935	00932	00930	90410	71870	00940	00950	00955	00945	00608
Environmental replicates														
PI-524	7/26/2012	0900	14.9	5.57	0.27	61	42.8	123	0.180	23.7	0.20	9.36	0.76	0.064
PI-524	7/26/2012	0901	15.0	5.55	0.27	61	43.6	--	0.190	23.6	0.20	9.29	0.87	--
PI-524	12/12/2012	1130	15.4	5.54	0.22	59	40.0	122	0.159	22.0	0.19	9.56	0.82	0.059
PI-524	12/12/2012	1131	15.4	5.52	0.21	59	40.4	122	0.154	21.7	0.18	9.49	0.86	0.058
PI-558	7/25/2012	1000	13.2	2.35	0.40	19	4.55	33.5	0.021	3.29	0.05	9.17	14.4	<0.010
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--	--	<0.010
PI-593	4/4/2013	1150	22.5	3.60	0.81	19	7.68	67.9	0.014	9.85	0.10	10.6	8.80	<0.010
PI-593	4/4/2013	[1]1405	22.3	3.57	0.79	19	7.55	67.8	0.016	9.16	0.11	9.81	8.78	<0.010
Equipment blanks														
PI-600	5/6/2013	1429	<0.022	<0.011	<0.03	--	n0.06	<4	<0.01	<0.06	<0.01	0.11	<0.09	<0.01
Laboratory	9/13/2013	1015	--	--	--	--	<0.06	<4	--	--	--	n0.018	--	--

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.—Continued

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Nitrate plus nitrite, water, filtered, in mg/L as N	Nitrite, water, filtered, in mg/L as N	Ortho-phosphate, water, filtered, in mg/L as P	Aluminum, water, filtered, in µg/L	Barium, water, filtered, in µg/L	Beryllium, water, filtered, in µg/L	Cadmium, water, filtered, in µg/L	Chromium, water, filtered, in µg/L	Cobalt, water, filtered, in µg/L	Copper, water, filtered, in µg/L	Iron, water, filtered, in µg/L	Iron, water, unfiltered, recoverable, in µg/L
Parameter code:			00631	00613	00671	01106	01005	01010	01025	01030	01035	01040	01046	01045
Environmental replicates														
PI-524	7/26/2012	0900	<0.040	<0.001	0.027	<2.2	138	<0.006	<0.016	<0.07	0.024	<0.80	25.6	91.1
PI-524	7/26/2012	0901	--	--	--	<2.2	138	0.006	<0.016	<0.07	<0.021	<0.80	25.8	--
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	23.3	60.3
PI-524	12/12/2012	1131	<0.040	<0.001	0.026	<2.2	137	<0.006	<0.032	<0.07	0.040	<0.80	25.9	57.5
PI-558	7/25/2012	1000	0.107	<0.001	0.010	<2.2	3.51	<0.006	<0.016	0.09	0.059	38.1	15.6	14.8
PI-558	7/25/2012	1001	0.109	0.002	0.011	--	--	--	--	--	--	--	--	--
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	<4.0	<4.6
PI-593	4/4/2013	[1]1405	<0.040	<0.001	0.007	2.9	80.7	<0.006	<0.016	<0.07	<0.023	<0.80	<4.0	<4.6
Equipment blanks														
PI-600	5/6/2013	1429	<0.04	<0.001	<0.004	<2.2	<0.1	<0.006	<0.016	<0.07\	<0.023	n1.36	<4	<4.6
Laboratory	9/13/2013	1015	--	--	--	--	--	--	--	--	--	n1.10	--	--

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.—Continued

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Lead, water, filtered, in µg/L	Lead, water, unfiltered, recoverable, in µg/L	Lithium, water, filtered, in µg/L	Manganese, water, filtered, in µg/L	Manganese, water, unfiltered, recoverable, in µg/L	Molybdenum, water, filtered, in µg/L	Nickel, water, filtered, in µg/L	Silver, water, filtered,, in µg/L	Strontium, water, filtered, in µg/L	Thallium, water, filtered, in µg/L	Tungsten, water, filtered,, in µg/L	Vanadium, water, filtered, in µg/L
	Parameter code:		01049	01051	01130	01056	01055	01060	01065	01075	01080	01057	01155	01085
							Environmental replicates							
PI-524	7/26/2012	0900	0.039	0.10	106	20.2	18.9	0.324	<0.09	<0.005	502	<0.010	0.094	<0.08
PI-524	7/26/2012	0901	0.027	--	119	20.3	20.4	0.313	0.10	<0.005	493	<0.010	0.101	<0.08
PI-524	12/12/2012	1130	<0.025	0.07	143	18.0	17.6	0.367	<0.09	<0.010	495	<0.010	0.051	<0.08
PI-524	12/12/2012	1131	<0.025	0.07	140	18.5	18.2	0.388	<0.09	<0.010	499	<0.010	0.047	<0.08
PI-558	7/25/2012	1000	0.484	0.43	10.6	7.42	7.47	0.114	0.69	<0.005	76.4	<0.010	<0.010	<0.08
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--	--	--
PI-593	4/4/2013	1150	0.498	1.23	17.6	15.2	14.1	0.339	0.11	<0.005	541	<0.010	<0.010	<0.08
PI-593	4/4/2013	[1]1405	0.593	0.49	17.7	13.9	14.3	0.327	0.17	<0.005	542	<0.010	<0.010	<0.08
							Equipment blanks							
PI-600	5/6/2013	1429	0.349	0.557	<0.22	<0.16	<0.2	<0.014	<0.09	<0.005	<0.2	<0.01	<0.01	<0.08
Laboratory	9/13/2013	1015	n 0.0492	0.082	--	--	--	--	--	--	--	--	--	--

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.—Continued

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Zinc, water, filtered, in µg/L	Antimony, water, filtered, in µg/L	Arsenic, water, filtered,, in µg/L	Arsenic, water, unfiltered, in µg/L	Boron, water, filtered, in µg/L	Selenium, water, filtered, in µg/L	Gross alpha radioactivity, 30-day recount, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 30-day count, water, filtered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, unfiltered, Th-230 curve, in pCi/L	Gross alpha radioactivity, 72-hour count, water, filtered, Th-230 curve, in pCi/L	Gross beta radioactivity, 30-day recount, water, unfiltered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 30-day count, water, filtered, Cs-137 curve, in pCi/L
	Parameter code:		01090	01095	01000	01002	01020	01145	63016	62639	63014	62636	63017	62645
							Environmental replicates							
PI-524	7/26/2012	0900	<1.4	<0.027	0.26	0.35	84	<0.03	1.7	1.5	6.4	2.2	3.0	R 0.7
PI-524	7/26/2012	0901	<1.4	<0.027	0.27	--	83	<0.03	3.7	1.6	4.0	3.0	3.4	0.9
PI-524	12/12/2012	1130	<1.4	<0.027	0.26	0.32	83	<0.03	1.5	--	3.0	--	1.4	--
PI-524	12/12/2012	1131	<1.4	<0.027	0.24	<0.28	86	<0.03	2.5	--	3.6	--	0.9	--
PI-558	7/25/2012	1000	5.8	<0.027	0.08	<0.28	20	0.04	R -0.2	0.6	R -0.1	R 0.4	R 0.2	R -0.1
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--	--	--
PI-593	4/4/2013	1150	2.4	0.066	1.9	1.7	34	<0.03	1.3	--	2.7	--	2.1	--
PI-593	4/4/2013	[1]1405	3.1	0.064	1.9	2.2	34	<0.03	2.7	--	4.2	--	1.6	--
							Equipment blanks							
PI-600	5/6/2013	1429	2.76	<0.027	<0.04	<0.28	n 3.2	<0.03	--	--	--	--	--	--
Laboratory	9/13/2013	1015	n 1.83	--	--	--	<3	--	--	--	--	--	--	--

Table 18. Results of laboratory analysis of environmental replicate samples from three wells in Pike County, Pennsylvania, 2012–2013 and of equipment blanks for selected trace constituents.—Continued

[Environmental replicates collected about 1 minute apart except for sequential replicate in well PI-593 collected on April 4, 2013, about 2 hours apart; USGS, U.S. Geological Survey; <, less than; ANC, acid neutralizing capacity; mmHg, millimeters of mercury, °C, degrees Celsius; ft, feet; bls, below land surface; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; pCi/L, picocuries per liter; Th-230, thorium-230; Cs-137, cesium-137; --, no data; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; n, below the laboratory reporting level and above the long-term method detection level; Isotech, Isotech Laboratories, Inc.; TA, TestAmerica, Inc.]

USGS site name	Date	Sample time	Gross beta radioactivity, 72-hour count, water, unfiltered, Cs-137 curve, in pCi/L	Gross beta radioactivity, 72-hour count, water, filtered, Cs-137 curve, in pCi/L	Radon-222, water, unfiltered, in pCi/L	Uranium (natural), water, filtered, in µg/L	Methane, in mg/L (Isotech)	Methane, in µg/L (TA)	Ethane, in µg/L (TA)	Ethene, in µg/L (TA)	δD_{H2O}, in per mil	$\delta^{18}O_{H2O}$, in per mil
	Parameter code:		**63015**	**62642**	**82303**	**22703**	**68831**	**76994**	**82045**	**82044**	**82082**	**82085**
Environmental replicates												
PI-524	7/26/2012	0900	2.4	R 0.6	460	0.137	5.9	4,860	0.400	<0.0569	-58.6	-9.06
PI-524	7/26/2012	0901	2.5	R 0.6	--	0.138	5.7	4,190	0.370	<0.0569	-58.5	-9.04
PI-524	12/12/2012	1130	R 0.2	--	450	0.131	5.8	4,820	0.345	<0.0569	-59.7	-9.14
PI-524	12/12/2012	1131	1.8	--	470	0.157	5.2	5,090	0.299	<0.0569	-59.2	-9.22
PI-558	7/25/2012	1000	R 0.4	R -0.2	1,410	<0.004	--	--	--	--	--	--
PI-558	7/25/2012	1001	--	--	1,480	--	--	--	--	--	--	--
PI-593	4/4/2013	1150	2.5	--	1,130	0.635	--	1.78	--	0.0761	--	--
PI-593	4/4/2013	[1]1405	2.5	--	1,130	0.627	--	0.822	--	--	--	--
Equipment blanks												
PI-600	5/6/2013	1429	--	--	R 13	<0.004	--	<0.211	<0.0615	<0.0569	--	--
Laboratory	9/13/2013	1015	--	--	--	--	--	--	--	--	--	--

[1]Sequential replicate collected from well PI-593 about 2 hours after initial environmental sample.

Appendixes 1–2

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Barometric pressure, in mmHg	Temperature, air, in °C	Depth to water level, in ft bls	Dissolved oxygen, water, unfiltered, in mg/L	Dissolved oxygen, water, unfiltered, in % of saturation	pH, water, unfiltered, field, in standard units	pH, water, unfiltered, laboratory, in standard units	Specific conductance, water, unfiltered, laboratory, in µS/cm	Specific conductance, water, unfiltered, in µS/cm	Temperature, water, in °C
	Parameter code:		00025	00020	72019	00300	00301	00400	00403	90095	00095	00010
PI-274	8/10/1982	1050	--	--	--	--	--	7.4	7.8	207	202	21.0
PI-274	7/17/2012	1600	739	34	--	0.7	6	7.7	7.8	158	151	11.8
PI-288	6/2/1982	1615	--	--	--	--	--	5.7	6.2	66	72	10.0
PI-288	9/6/2007	1200	747	25.5	49.25	10.8	94	6.0	7.8	72	70	9.2
PI-288	7/18/2012	1200	732	--	54.9	9.2	84	5.8	E 6.1	E 69	64	9.9
PI-507	7/25/2012	1230	740	24.5	--	5.4	50	6.4	6.8	219	212	10.4
PI-507	9/12/2012	0930	752	13	--	5.5	50	6.4	6.9	215	228	10.2
PI-507	10/16/2012	1000	733	7	--	5.8	54	6.7	6.9	216	207	10.2
PI-507	11/15/2012	1100	750	3	--	6.0	54	6.8	6.7	214	209	10.1
PI-507	12/12/2012	0900	749		--	6.0	54	6.8	6.8	216	203	10.0
PI-507	1/8/2013	1100	749	2	--	5.9	53	6.4	6.7	214	203	10.0
PI-507	2/13/2013	0930	737	-4	--	5.3	49	6.9	6.8	210	177	10.6
PI-507	3/13/2013	1130	737	4	--	5.2	48	6.9	6.8	210	177	10.6
PI-507	4/3/2013	1000	749		--	7.9	71	6.6	6.8	213	191	10.2
PI-507	5/8/2013	1130	743	16	--	7.8	72	6.1	7.0	218	226	10.3
PI-507	6/5/2013	1030	746	22	--	8.2	74	6.4	6.9	213	221	10.2
PI-507	6/27/2013	1130	738	24	--	6.0	55	6.3	6.9	218	208	10.4
PI-524	4/17/2006	1200	--	--	--	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	750	15	56.82	0.1	0	8.3	8.3	303	299	11.1
PI-524	1/21/2012	1131	756	-2	--	M	0	8.2	--	--	300	10.7
PI-524	7/26/2012	0900	743	21	--	M	0	8.3	8.3	298	296	11.4
PI-524	7/26/2012	0901	743	21	--	M	0	8.3	8.3	302	296	11.4
PI-524	9/11/2012	1000	755	9	--	0.1	0	8.2	8.3	297	308	11.4
PI-524	10/16/2012	1330	744	12	--	M	0	8.5	8.3	287	299	11.1
PI-524	11/14/2012	1130	761	5	--	0.1	0	8.7	8.3	293	295	10.9
PI-524	12/12/2012	1130	756	-2	55.22	M	0	8.2	8.3	299	300	10.7
PI-524	12/12/2012	1131	756	-2	--	M	0	8.2	8.3	296	300	10.7
PI-524	1/8/2013	1300	754	1	56.07	0.2	2	8.3	8.3	289	285	10.5
PI-524	2/13/2013	1200	741	2	56.2	0.7	6	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	0	8.3	8.3	300	280	10.6
PI-524	5/8/2013	1400	748	15	55.16	0.2	2	8.0	8.3	290	264	10.8
PI-524	6/5/2013	1330	753	22	42.32	0.1	1	8.1	8.4	283	294	11.4
PI-524	6/26/2013	1230	746	24	42.19	0.1	0	8.3	8.3	302	290	11.5
PI-552	8/28/2007	1600	746	25	65.88	0.3	2	7.3	7.6	215	207	11.0
PI-552	7/24/2012	1530	--	33.5	67.29	M	--	7.4	7.6	214	200	11.3
PI-553	8/29/2007	1000	735	25	124.35	0.1	1	7.2	7.6	98	95	11.5
PI-553	7/25/2012	1000	740	19	123.86	0.1	0	7.3	7.6	100	96	10.7
PI-555	8/30/2007	1000	724	25	116.92	4.6	40	6.8	7.1	149	142	9.2
PI-555	7/17/2012	1200	728	30.5	120.98	4.2	38	7.1	7.3	140	138	9.4
PI-557	9/4/2007	1700	730	25	49.8	6.0	55	6.2	6.2	195	185	10.9
PI-557	7/25/2012	1700	740	25.5	--	2.9	27	6.4	6.7	224	214	11.1
PI-558	9/5/2007	1100	761	20.5	16.42	8.6	79	6.5	6.9	93	90	11.6
PI-558	7/25/2012	1000	770	30	16.13	5.9	54	6.5	6.9	108	111	11.6
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	--	--	--	<0.2	--	8.0	8.5	357	345	11.7
PI-592	7/26/2012	1000	740	27	9.51	0.1	1	8.7	8.6	337	326	11.7
PI-592	6/25/2013	1100	755	--	6.14	0.2	2	8.6	8.6	339	325	11.4
PI-593	7/18/2012	1500	733	32	45.93	M	0	8.0	8.0	179	171	10.9
PI-593	9/12/2012	1200	752	20	--	0.1	0	7.8	8.1	178	185	10.7
PI-593	10/17/2012	1430	744	9	43.51	0.4	4	8.3	8.0	185	173	10.5
PI-593	11/15/2012	1400	751	3	42.51	0.1	0	8.3	7.9	194	187	10.3
PI-593	12/12/2012	0700	747	-3	41.61	0.1	0	8.3	7.8	589	191	10.2
PI-593	1/9/2013	1130	741	1	42.51	0.1	0	8.3	7.9	377	191	10.2
PI-593	2/12/2013	1000	731	2	41.5	0.8	7	7.6	8.1	177	157	10.2
PI-593	3/12/2013	0930	731	12	--	0.9	8	7.7	8.1	200	167	10.2
PI-593	4/4/2013	1150	743	0	41.5	0	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	2	7.8	8.1	177	179	10.4
PI-593	6/4/2013	1000	740	20	41.77	0.1	0	7.7	8.1	194	184	10.6
PI-593	6/25/2013	1100	737	28	41.81	0.1	0	7.9	8.0	186	179	10.9
PI-599	7/24/2012	1230	743	33.5	110.44	0.3	3	7.8	8.0	265	268	12.4
PI-599	6/25/2013	1430	755	--	114.18	0.2	2	7.8	8.0	266	259	11.6
PI-600	7/24/2012	1100	765	30	144.66	M	0	7.8	8.0	221	216	11.1
PI-600	9/11/2012	1300	752	16	--	0.2	2	7.9	8.0	222	216	11.0
PI-600	10/17/2012	1100	744	11	--	0.2	2	7.9	8.0	224	218	10.6
PI-600	11/14/2012	1400	760	7	142.51	0.1	1	8.2	8.1	222	217	10.6
PI-600	12/13/2012	1100	754	1	162.04	0.2	2	8.3	8.1	221	207	10.4
PI-600	1/9/2013	1400	746	0	163.36	0.1	1	7.9	8.0	226	222	10.4
PI-600	2/12/2013	1400	740	0	151.05	0.6	6	7.8	8.1	218	183	10.4
PI-600	3/12/2013	1200	738	10	149.58	0.4	4	7.8	8.0	221	190	10.4
PI-600	4/2/2013	1500	743	1	140.71	0.1	0	7.8	8.1	222	211	10.5
PI-600	5/7/2013	1300	748	20	141.13	0.5	5	7.3	8.0	220	225	10.5
PI-600	6/4/2013	1300	746	22	141.07	0.4	4	7.7	8.1	221	226	10.9
PI-600	6/25/2013	1400	744	31	141.11	0.1	1	7.8	8.0	227	220	10.7

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Dissolved solids dried at 180 °C, water, filtered, in mg/L	Dissolved solids, water, filtered, sum of constituents, in mg/L	Hardness, water, in mg/L as $CaCO_3$	Calcium, water, filtered, in mg/L	Magnesium, water, filtered, in mg/L	Potassium, water, filtered, in mg/L	Sodium adsorption ratio, water, number	Sodium fraction of cations, water, % in equivalents of major cations	Sodium, water, filtered, in mg/L
	Parameter code:		70300	70301	00900	00915	00925	00935	00931	00932	00930
PI-274	8/10/1982	1050	--	120	77.0	21.0	5.90	1.30	0.70	27	13.0
PI-274	7/17/2012	1600	95	96	61.1	16.6	4.76	0.93	0.56	26	10.1
PI-288	6/2/1982	1615	--	34	22.0	6.8	1.10	0.50	0.20	14	1.6
PI-288	9/6/2007	1200	--	E 43	23.1	7.38	1.13	0.41	0.25	20	2.71
PI-288	7/18/2012	1200	40	37	21.4	6.76	1.09	0.42	0.33	26	3.51
PI-507	7/25/2012	1230	134	121	80.3	19.6	7.53	0.71	0.58	24	12.0
PI-507	9/12/2012	0930	125	107	78.2	18.8	7.49	0.66	0.56	24	11.3
PI-507	10/16/2012	1000	117	100	77.1	18.7	7.27	0.69	0.55	24	11.2
PI-507	11/15/2012	1100	121	117	81.0	20.0	7.43	0.64	0.52	22	10.7
PI-507	12/12/2012	0900	125	E 114	78.1	19.1	7.31	0.65	0.53	23	10.7
PI-507	1/8/2013	1100	119	113	78.8	19.3	7.32	0.67	0.52	22	10.5
PI-507	2/13/2013	0930	128	119	79.2	18.7	7.79	0.67	0.55	23	11.2
PI-507	3/13/2013	1130	133	116	73.7	18.3	6.69	0.67	0.56	24	11.0
PI-507	4/3/2013	1000	123	E 117	74.9	18.6	6.83	0.67	0.53	23	10.5
PI-507	5/8/2013	1130	130	120	77.4	18.4	7.52	0.69	0.59	25	11.9
PI-507	6/5/2013	1030	119	118	76.7	18.4	7.37	0.64	0.54	23	10.8
PI-507	6/27/2013	1130	124	114	73.2	17.9	6.80	0.71	0.59	25	11.5
PI-524	4/17/2006	1200	--	--	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	--	E 165	62.1	15.5	5.69	0.25	2.20	58	39.9
PI-524	1/21/2012	1131	--	--	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	165	164	60.7	14.9	5.57	0.27	2.41	61	42.8
PI-524	7/26/2012	0901	177	164	61.1	15.0	5.55	0.27	2.44	61	43.6
PI-524	9/11/2012	1000	174	173	61.9	15.3	5.60	0.23	2.42	61	43.4
PI-524	10/16/2012	1330	161	153	59.6	14.8	5.35	0.27	2.29	60	40.4
PI-524	11/14/2012	1130	163	157	61.2	15.2	5.49	0.25	2.42	61	43.2
PI-524	12/12/2012	1130	176	147	61.9	15.4	5.54	0.22	2.22	59	40.0
PI-524	12/12/2012	1131	164	168	61.9	15.4	5.52	0.21	2.25	59	40.4
PI-524	1/8/2013	1300	174	154	60.8	15.1	5.42	0.26	2.29	60	40.9
PI-524	2/13/2013	1200	162	170	62.2	15.0	5.85	0.26	2.34	60	42.1
PI-524	3/13/2013	1300	169	166	58.2	14.8	5.02	0.24	2.37	61	41.3
PI-524	4/3/2013	1500	180	169	57.4	14.5	5.02	0.26	2.35	61	40.7
PI-524	5/8/2013	1400	169	169	61.2	15.0	5.64	0.26	2.37	60	42.3
PI-524	6/5/2013	1330	167	167	60.5	14.8	5.54	0.26	2.25	59	40.0
PI-524	6/26/2013	1230	184	170	58.5	14.6	5.23	0.26	2.51	62	43.9
PI-552	8/28/2007	1600	--	E 127	89.0	23.7	7.22	0.25	0.32	14	6.92
PI-552	7/24/2012	1530	137	133	98.5	26.5	7.74	0.24	0.32	14	7.24
PI-553	8/29/2007	1000	--	E 61	32.8	8.03	3.10	0.63	0.59	34	7.80
PI-553	7/25/2012	1000	56	62	35.6	8.61	3.37	0.61	0.57	32	7.73
PI-555	8/30/2007	1000	--	E 87	69.5	22.4	3.30	0.59	0.07	4	1.42
PI-555	7/17/2012	1200	91	78	67.6	21.5	3.25	0.64	0.07	4	1.36
PI-557	9/4/2007	1700	--	E 106	61.7	14.2	6.36	0.66	0.67	29	12.0
PI-557	7/25/2012	1700	125	127	80.8	18.6	8.32	0.74	0.71	28	14.7
PI-558	9/5/2007	1100	--	E 57	35.7	11	1.98	0.39	0.22	16	3.07
PI-558	7/25/2012	1000	67	63	42.9	13.2	2.35	0.40	0.30	19	4.55
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	193	191	19.2	4.85	1.56	0.80	6.96	88	68.8
PI-592	7/26/2012	1000	191	192	18.6	4.75	1.47	0.72	7.13	89	69.4
PI-592	6/25/2013	1100	187	196	19.0	4.88	1.50	0.68	6.76	88	66.6
PI-593	7/18/2012	1500	109	102	72.9	22.5	3.91	0.80	0.42	20	8.18
PI-593	9/12/2012	1200	105	95	70.6	21.8	3.78	0.82	0.41	19	7.85
PI-593	10/17/2012	1430	114	93	72	22.1	3.91	0.75	0.40	19	7.81
PI-593	11/15/2012	1400	116	103	82.2	25.7	4.20	0.77	0.36	16	7.37
PI-593	12/12/2012	0700	342	E 273	242	74.7	13.1	1.22	0.37	11	13.1
PI-593	1/9/2013	1130	207	183	153	47.4	8.14	1.01	0.36	13	10.3
PI-593	2/12/2013	1000	106	97	70.9	21.9	3.79	0.79	0.41	19	7.86
PI-593	3/12/2013	0930	116	110	76.5	23.9	3.90	0.81	0.39	18	7.75
PI-593	4/4/2013	1150	113	105	71.6	22.5	3.60	0.81	0.40	19	7.68
PI-593	4/4/2013	1405	97	103	71.1	22.3	3.57	0.79	0.39	19	7.55
PI-593	5/9/2013	1100	104	104	70.7	21.7	3.87	0.82	0.42	20	8.12
PI-593	6/4/2013	1000	127	110	73.6	22.6	3.99	0.79	0.41	19	8.07
PI-593	6/25/2013	1100	107	103	71.7	22.2	3.78	0.77	0.39	19	7.62
PI-599	7/24/2012	1230	154	160	109	30.9	7.56	0.42	0.79	27	18.8
PI-599	6/25/2013	1430	148	142	104	29.2	7.38	0.37	0.75	27	17.6
PI-600	7/24/2012	1100	123	128	101	27.7	7.58	0.70	0.30	13	6.85
PI-600	9/11/2012	1300	141	126	106	29.2	7.81	0.69	0.29	12	6.85
PI-600	10/17/2012	1100	131	116	101	27.2	7.71	0.70	0.29	13	6.67
PI-600	11/14/2012	1400	123	120	104	28.8	7.58	0.67	0.31	13	7.12
PI-600	12/13/2012	1100	127	120	106	29.1	7.75	0.68	0.31	13	7.28
PI-600	1/9/2013	1400	126	118	103	28.4	7.56	0.68	0.29	12	6.71
PI-600	2/12/2013	1400	136	132	101	27.6	7.66	0.65	0.30	13	6.89
PI-600	3/12/2013	1200	128	130	100	27.9	7.22	0.67	0.28	12	6.44
PI-600	4/2/2013	1500	128	E 131	96.5	26.6	7.07	0.70	0.31	14	7.01
PI-600	5/7/2013	1300	138	130	98.4	26.2	7.79	0.72	0.31	14	7.12
PI-600	6/4/2013	1300	145	133	102	27.8	7.65	0.70	0.30	13	6.94
PI-600	6/25/2013	1400	136	127	99.8	27.7	7.23	0.63	0.29	13	6.68

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	ANC, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, in mg/L as $CaCO_3$	ANC, water, unfiltered, inflection-point titration method, field, in mg/L as $CaCO_3$	Bromide, water, filtered, in mg/L	Chloride, water, filtered, in mg/L	Fluoride, water, filtered, in mg/L	Silica, water, filtered, in mg/L as SiO_2	Sulfate, water, filtered, in mg/L	Ammonia, water, filtered, in mg/L as N
Parameter code:			90410	00419	71870	00940	00950	00955	00945	00608
PI-274	8/10/1982	1050	104	--	--	0.40	0.20	10.0	5.00	<0.010
PI-274	7/17/2012	1600	82.8	82	0.017	0.65	0.14	9.40	3.22	0.012
PI-288	6/2/1982	1615	12.0	--	--	3.50	<0.10	4.00	9.00	<0.010
PI-288	9/6/2007	1200	--	21	--	4.44	<0.10	4.80	6.74	E 0.010
PI-288	7/18/2012	1200	15.5	11	0.018	5.42	<0.04	4.42	6.69	<0.010
PI-507	7/25/2012	1230	52.1	52	0.026	26.4	0.04	9.07	11.6	<0.010
PI-507	9/12/2012	0930	51.2	--	0.023	26.1	<0.04	9.38	11.2	<0.010
PI-507	10/16/2012	1000	51.0	--	0.026	25.9	<0.04	9.32	11.5	<0.010
PI-507	11/15/2012	1100	51.2	--	0.025	26.0	<0.04	9.73	11.3	<0.010
PI-507	12/12/2012	0900	52.4	--	E 0.025	25.0	0.04	9.29	11.6	<0.010
PI-507	1/8/2013	1100	52.9	--	0.022	24.8	0.05	9.52	11.8	<0.010
PI-507	2/13/2013	0930	53.0	--	0.021	25.3	<0.04	9.13	11.7	<0.010
PI-507	3/13/2013	1130	51.1	--	0.024	25.6	<0.04	8.19	11.6	<0.010
PI-507	4/3/2013	1000	51.0	--	0.024	26.4	E 0.04	9.14	11.6	<0.010
PI-507	5/8/2013	1130	50.6	--	0.020	27.5	0.04	9.52	11.5	<0.010
PI-507	6/5/2013	1030	48.9	--	0.022	28.1	0.05	9.45	11.1	<0.010
PI-507	6/27/2013	1130	49.7	--	0.026	28.3	0.04	8.70	10.9	<0.010
PI-524	4/17/2006	1200	--	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	--	114	--	24.4	0.21	10.1	0.36	0.059
PI-524	1/21/2012	1131	--	86	--	--	--	--	--	--
PI-524	7/26/2012	0900	123	109	0.180	23.7	0.20	9.36	0.76	0.064
PI-524	7/26/2012	0901	--	107	0.190	23.6	0.20	9.29	0.87	--
PI-524	9/11/2012	1000	122	124	0.169	21.7	0.17	9.59	0.93	0.062
PI-524	10/16/2012	1330	121	--	0.182	21.6	0.17	9.44	0.94	0.082
PI-524	11/14/2012	1130	121	--	0.162	22.4	0.19	9.53	0.81	0.059
PI-524	12/12/2012	1130	122	--	0.159	22.0	0.19	9.56	0.82	0.059
PI-524	12/12/2012	1131	122	--	0.154	21.7	0.18	9.49	0.86	0.058
PI-524	1/8/2013	1300	121	--	0.182	21.9	0.20	9.43	0.93	0.058
PI-524	2/13/2013	1200	122	--	0.168	22.0	0.19	9.39	0.96	0.079
PI-524	3/13/2013	1300	120	--	0.172	21.1	0.17	9.20	1.06	0.059
PI-524	4/3/2013	1500	123	--	0.172	23.2	--	9.32	1.07	0.059
PI-524	5/8/2013	1400	120	--	0.161	20.7	0.20	9.85	1.16	0.058
PI-524	6/5/2013	1330	120	--	0.176	22.2	0.22	9.68	1.04	0.063
PI-524	6/26/2013	1230	123	117	0.191	23.7	0.20	9.67	0.94	0.064
PI-552	8/28/2007	1600	--	89	--	2.62	0.13	16.9	15.7	E 0.016
PI-552	7/24/2012	1530	89.4	88	0.017	3.37	0.13	16.4	17.1	0.039
PI-553	8/29/2007	1000	--	50	--	0.53	0.11	9.10	1.07	<0.020
PI-553	7/25/2012	1000	52.8	52	0.014	0.47	0.12	8.69	0.96	<0.010
PI-555	8/30/2007	1000	--	71	--	0.90	E 0.06	6.50	7.61	<0.020
PI-555	7/17/2012	1200	64.2	56	0.014	0.89	0.07	6.11	8.06	<0.010
PI-557	9/4/2007	1700	--	35	--	21.9	E 0.07	10.3	10.6	<0.020
PI-557	7/25/2012	1700	63.1	61	0.047	20.9	0.11	10.4	9.63	<0.010
PI-558	9/5/2007	1100	--	24	--	1.56	E 0.06	9.60	14.9	<0.020
PI-558	7/25/2012	1000	33.5	25	0.021	3.29	0.05	9.17	14.4	<0.010
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	<0.010
PI-592	8/17/2011	1200	--	--	0.380	39.0	0.54	7.11	0.12	0.060
PI-592	7/26/2012	1000	118	116	0.353	36.6	0.53	6.72	0.38	0.057
PI-592	6/25/2013	1100	118	124	0.341	37.7	0.53	6.83	0.36	0.060
PI-593	7/18/2012	1500	67.5	62	0.021	9.8	0.11	9.43	9.30	<0.010
PI-593	9/12/2012	1200	67	--	0.018	11.8	0.08	9.35	8.85	<0.010
PI-593	10/17/2012	1430	67.1	--	0.021	11.0	0.07	9.71	9.18	<0.010
PI-593	11/15/2012	1400	66.8	--	0.020	13.8	0.07	10.2	8.63	<0.010
PI-593	12/12/2012	0700	66.7	--	E 0.049	136	0.07	10.3	9.87	<0.010
PI-593	1/9/2013	1130	67.1	--	0.035	62.8	0.08	10.3	9.43	<0.010
PI-593	2/12/2013	1000	67.4	--	0.015	10.0	0.09	9.79	8.74	<0.010
PI-593	3/12/2013	0930	67.4	--	0.020	14.1	0.11	10.2	8.62	<0.010
PI-593	4/4/2013	1150	67.9	--	0.014	9.85	0.10	10.6	8.80	<0.010
PI-593	4/4/2013	1405	67.8	--	0.016	9.16	0.11	9.81	8.78	<0.010
PI-593	5/9/2013	1100	67.2	--	0.015	9.21	0.10	10.6	9.02	<0.010
PI-593	6/4/2013	1000	67.8	--	0.017	13.6	0.09	10.6	9.11	<0.010
PI-593	6/25/2013	1100	66.9	65	0.015	9.79	0.10	9.81	8.89	<0.010
PI-599	7/24/2012	1230	143	142	0.017	0.67	0.15	11.2	3.59	0.058
PI-599	6/25/2013	1430	142	--	0.013	0.73	0.15	11.0	3.13	0.060
PI-600	7/24/2012	1100	100	94	0.015	5.20	0.05	11.5	11.3	<0.010
PI-600	9/11/2012	1300	99.4	--	0.017	5.31	0.05	12.0	11.4	<0.010
PI-600	10/17/2012	1100	98.4	--	0.016	5.61	0.06	11.6	11.4	<0.010
PI-600	11/14/2012	1400	100	--	0.018	5.25	0.06	12.0	11.2	<0.010
PI-600	12/13/2012	1100	100	--	<0.010	5.12	0.07	12.2	11.3	<0.010
PI-600	1/9/2013	1400	99.9	--	<0.050	5.19	0.06	12.4	11.3	<0.010
PI-600	2/12/2013	1400	101	--	0.013	4.88	0.05	11.7	10.8	<0.010
PI-600	3/12/2013	1200	98.7	--	0.014	5.38	0.07	12.0	10.7	<0.010
PI-600	4/2/2013	1500	100	--	<0.010	5.13	E 0.07	12.1	10.9	<0.010
PI-600	5/7/2013	1300	96.3	--	0.016	5.61	0.06	12.9	10.8	<0.010
PI-600	6/4/2013	1300	98.5	--	<0.010	6.81	0.06	12.4	11.2	<0.010
PI-600	6/25/2013	1400	101	94	0.014	5.03	0.06	11.6	10.9	<0.010

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Nitrate plus nitrite, water, filtered, in mg/L as N	Nitrite, water, filtered, in mg/L as N	Ortho-phosphate, water, filtered, in mg/L	Ortho-phosphate, water, filtered, in mg/L as P	Aluminum, water, filtered, in µg/L	Barium, water, filtered, in µg/L	Beryllium, water, filtered, in µg/L	Cadmium, water, filtered, in µg/L	Chromium, water, filtered, in µg/L
	Parameter code:		00631	00613	00660	00671	01106	01005	01010	01025	01030
PI-274	8/10/1982	1050	<0.100	<0.010	0.120	0.04	--	--	--	<1	M
PI-274	7/17/2012	1600	0.055	0.001	0.092	0.03	2.8	143	<0.006	<0.016	<0.07
PI-288	6/2/1982	1615	0.550	<0.010	0.030	0.01	--	--	--	--	--
PI-288	9/6/2007	1200	0.560	E 0.001	0.049	0.016	E 1.4	--	--	0.079	0.14
PI-288	7/18/2012	1200	0.518	<0.001	0.069	0.023	<2.2	14.2	0.016	0.08	0.14
PI-507	7/25/2012	1230	0.503	<0.001	0.034	0.011	<2.2	47.4	<0.006	0.043	0.18
PI-507	9/12/2012	0930	0.516	<0.001	0.032	0.01	<2.2	48.8	<0.006	<0.016	<0.07
PI-507	10/16/2012	1000	0.553	0.010	0.032	0.01	<2.2	49.0	<0.006	0.018	0.08
PI-507	11/15/2012	1100	0.533	<0.001	0.032	0.01	<2.2	46.2	<0.006	<0.016	<0.07
PI-507	12/12/2012	0900	0.570	<0.001	0.034	0.011	<2.2	48.2	<0.006	0.054	<0.07
PI-507	1/8/2013	1100	0.573	<0.001	0.037	0.012	<2.2	47.5	<0.006	0.039	<0.07
PI-507	2/13/2013	0930	0.560	<0.001	0.031	0.01	<2.2	48.6	<0.006	0.028	<0.07
PI-507	3/13/2013	1130	0.530	<0.001	0.033	0.011	<2.2	48.3	<0.006	0.026	<0.07
PI-507	4/3/2013	1000	0.531	<0.001	0.034	0.011	<2.2	52.0	<0.006	<0.016	<0.07
PI-507	5/8/2013	1130	0.538	<0.001	0.032	0.011	<2.2	47.6	<0.006	0.027	<0.07
PI-507	6/5/2013	1030	0.566	<0.001	0.031	0.01	<2.2	48.0	<0.006	<0.016	<0.07
PI-507	6/27/2013	1130	0.574	<0.001	0.031	0.01	<2.2	47.4	<0.006	<0.016	<0.07
PI-524	4/17/2006	1200	--	--	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	<0.040	E 0.001	0.062	0.02	E 1.2	--	--	<0.040	<0.12
PI-524	1/21/2012	1131	--	--	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	<0.040	<0.001	0.081	0.027	<2.2	138	<0.006	<0.016	<0.07
PI-524	7/26/2012	0901	--	--	--	--	<2.2	138	0.006	<0.016	<0.07
PI-524	9/11/2012	1000	<0.040	<0.001	0.079	0.026	<2.2	132	<0.006	<0.016	<0.07
PI-524	10/16/2012	1330	<0.040	<0.001	0.075	0.024	<2.2	129	<0.006	<0.016	<0.07
PI-524	11/14/2012	1130	<0.040	<0.001	0.078	0.026	<2.2	135	0.008	<0.016	0.27
PI-524	12/12/2012	1130	<0.040	<0.001	0.079	0.026	<2.2	136	<0.006	<0.032	<0.07
PI-524	12/12/2012	1131	<0.040	<0.001	0.080	0.026	<2.2	137	<0.006	<0.032	<0.07
PI-524	1/8/2013	1300	<0.040	<0.001	0.085	0.028	<4.4	133	<0.006	<0.016	<0.07
PI-524	2/13/2013	1200	<0.040	<0.001	0.077	0.025	<2.2	134	0.007	<0.016	<0.07
PI-524	3/13/2013	1300	<0.040	<0.001	0.078	0.025	<2.2	135	0.007	<0.016	<0.07
PI-524	4/3/2013	1500	<0.040	<0.001	0.081	0.026	<2.2	138	0.009	<0.016	<0.07
PI-524	5/8/2013	1400	<0.040	<0.001	0.079	0.026	<2.2	127	0.006	<0.016	<0.07
PI-524	6/5/2013	1330	<0.040	<0.001	0.078	0.025	<2.2	131	<0.006	<0.016	<0.07
PI-524	6/26/2013	1230	<0.040	<0.001	0.084	0.027	<2.2	133	0.007	<0.016	<0.07
PI-552	8/28/2007	1600	<0.060	<0.002	0.035	0.011	<1.6	--	--	<0.040	<0.12
PI-552	7/24/2012	1530	<0.040	<0.001	0.023	0.007	<2.2	11.9	0.009	<0.016	<0.07
PI-553	8/29/2007	1000	<0.060	<0.002	0.060	0.02	<1.6	--	--	<0.040	<0.12
PI-553	7/25/2012	1000	<0.040	<0.001	0.058	0.019	<2.2	57.7	<0.006	<0.016	0.11
PI-555	8/30/2007	1000	0.360	<0.002	0.064	0.021	<1.6	--	--	<0.040	<0.12
PI-555	7/17/2012	1200	0.428	<0.001	0.078	0.025	<2.2	70.9	<0.006	<0.016	<0.07
PI-557	9/4/2007	1700	2.00	<0.002	0.090	0.029	E 1.1	--	--	<0.040	<0.12
PI-557	7/25/2012	1700	1.45	<0.001	0.120	0.039	<2.2	63.2	<0.006	<0.016	0.26
PI-558	9/5/2007	1100	E 0.04	E 0.001	0.054	0.018	<1.6	--	--	<0.040	E 0.07
PI-558	7/25/2012	1000	0.107	<0.001	0.031	0.01	<2.2	3.51	<0.006	<0.016	0.09
PI-558	7/25/2012	1001	0.109	0.002	0.032	0.011	--	--	--	--	--
PI-592	8/17/2011	1200	<0.020	<0.001	0.539	0.176	<1.7	327	<0.006	<0.016	<0.06
PI-592	7/26/2012	1000	<0.040	<0.001	0.542	0.177	<2.2	318	<0.006	<0.016	<0.07
PI-592	6/25/2013	1100	<0.040	<0.001	0.567	0.185	<2.2	312	0.007	<0.016	<0.07
PI-593	7/18/2012	1500	<0.040	<0.001	0.019	0.006	<2.2	73.5	<0.006	<0.016	<0.07
PI-593	9/12/2012	1200	<0.040	<0.001	0.018	0.006	<2.2	76.2	<0.006	<0.016	<0.07
PI-593	10/17/2012	1430	<0.040	<0.001	0.020	0.007	<2.2	74.3	<0.006	<0.016	<0.07
PI-593	11/15/2012	1400	<0.040	<0.001	0.018	0.006	<2.2	74.2	<0.006	<0.016	<0.07
PI-593	12/12/2012	0700	<0.040	<0.001	0.019	0.006	<2.2	191	<0.006	<0.016	<0.07
PI-593	1/9/2013	1130	0.072	<0.001	0.018	0.006	<2.2	126	<0.006	<0.016	<0.07
PI-593	2/12/2013	1000	<0.040	<0.001	0.018	0.006	<2.2	75.1	<0.006	<0.016	<0.07
PI-593	3/12/2013	0930	<0.040	<0.001	0.016	0.005	<2.2	75.5	<0.006	<0.016	<0.07
PI-593	4/4/2013	1150	<0.040	<0.001	0.020	0.007	<2.2	80.8	<0.006	<0.016	<0.07
PI-593	4/4/2013	1405	<0.040	<0.001	0.020	0.007	2.9	80.7	<0.006	<0.016	<0.07
PI-593	5/9/2013	1100	<0.040	<0.001	0.023	0.007	<2.2	72.5	<0.006	<0.016	<0.07
PI-593	6/4/2013	1000	<0.040	<0.001	0.018	0.006	<2.2	74.1	<0.006	<0.016	<0.07
PI-593	6/25/2013	1100	<0.040	<0.001	0.017	0.006	<2.2	71.1	<0.006	<0.016	<0.07
PI-599	7/24/2012	1230	<0.040	<0.001	<0.012	<0.004	<2.2	12.4	<0.006	0.044	<0.07
PI-599	6/25/2013	1430	<0.040	<0.001	0.015	0.005	<2.2	12.2	<0.006	<0.016	<0.07
PI-600	7/24/2012	1100	<0.040	<0.001	0.016	0.005	<2.2	162	<0.006	<0.016	<0.07
PI-600	9/11/2012	1300	<0.040	<0.001	0.016	0.005	<2.2	158	<0.006	<0.016	<0.07
PI-600	10/17/2012	1100	<0.040	0.003	0.017	0.005	<2.2	157	<0.006	<0.016	0.10
PI-600	11/14/2012	1400	<0.040	<0.001	0.016	0.005	<2.2	166	<0.006	<0.016	<0.07
PI-600	12/13/2012	1100	<0.040	<0.001	0.021	0.007	<2.2	165	<0.006	<0.016	<0.07
PI-600	1/9/2013	1400	<0.040	<0.001	0.018	0.006	<2.2	161	<0.006	<0.016	<0.07
PI-600	2/12/2013	1400	<0.040	<0.001	0.015	0.005	<2.2	165	<0.006	<0.016	<0.07
PI-600	3/12/2013	1200	<0.040	0.002	0.015	0.005	<2.2	159	<0.006	<0.016	<0.07
PI-600	4/2/2013	1500	<0.040	<0.001	0.019	0.006	<2.2	168	<0.006	<0.016	<0.07
PI-600	5/7/2013	1300	0.054	<0.001	0.017	0.006	<2.2	144	<0.006	<0.016	<0.07
PI-600	6/4/2013	1300	<0.040	<0.001	0.017	0.005	<2.2	149	<0.006	<0.016	<0.07
PI-600	6/25/2013	1400	<0.040	<0.001	0.015	0.005	<2.2	159	<0.006	<0.016	<0.07

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Cobalt, water, filtered, in µg/L	Copper, water, filtered, in µg/L	Iron, water, filtered, in µg/L	Iron, water, unfiltered, recoverable, in µg/L	Lead, water, filtered, in µg/L	Lead, water, unfiltered, recoverable, in µg/L	Lithium, water, filtered, in µg/L
	Parameter code:		01035	01040	01046	01045	01049	01051	01130
PI-274	8/10/1982	1050	--	40	<3	--	M	--	--
PI-274	7/17/2012	1600	0.182	<0.80	<3.2	<4.6	0.361	0.48	61.2
PI-288	6/2/1982	1615	--	--	M	--	--	--	--
PI-288	9/6/2007	1200	--	72.2	23.4	--	1.6	--	--
PI-288	7/18/2012	1200	0.034	14.3	6.2	4.9	2.15	1.96	1.25
PI-507	7/25/2012	1230	0.079	2.6	3.3	<4.6	0.554	0.35	11.6
PI-507	9/12/2012	0930	<0.021	<0.80	<3.2	8.2	0.328	0.24	11.6
PI-507	10/16/2012	1000	0.054	1.3	<4.0	<4.6	0.284	0.22	10.9
PI-507	11/15/2012	1100	0.026	1.3	<4.0	<4.6	0.428	0.37	12.5
PI-507	12/12/2012	0900	0.063	1.0	7.0	21.7	0.353	0.29	12.1
PI-507	1/8/2013	1100	0.061	1.2	<4.0	<4.6	0.302	0.28	11.7
PI-507	2/13/2013	0930	0.072	0.92	5.2	4.7	0.212	0.21	12.5
PI-507	3/13/2013	1130	0.046	<0.80	<4.0	<4.6	0.596	0.56	11.5
PI-507	4/3/2013	1000	0.269	<0.80	4.1	25.8	0.411	0.35	12.3
PI-507	5/8/2013	1130	0.055	<0.80	<4.0	6.8	0.258	0.23	11.6
PI-507	6/5/2013	1030	0.058	<0.80	4.1	<4.6	0.240	0.20	11.2
PI-507	6/27/2013	1130	0.027	<0.80	<4.0	<4.6	0.249	0.24	11.2
PI-524	4/17/2006	1200	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	--	<1.0	32.4	--	<0.080	--	--
PI-524	1/21/2012	1131	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	0.024	<0.80	25.6	91.1	0.039	0.10	106
PI-524	7/26/2012	0901	<0.021	<0.80	25.8	--	0.027	--	119
PI-524	9/11/2012	1000	0.054	<0.80	27.6	59.7	0.027	0.15	128
PI-524	10/16/2012	1330	<0.023	<0.80	28.5	50.8	<0.025	0.06	73.1
PI-524	11/14/2012	1130	<0.023	<0.80	27.3	41.6	0.031	0.27	103
PI-524	12/12/2012	1130	<0.023	<0.80	23.3	60.3	<0.025	0.07	143
PI-524	12/12/2012	1131	0.040	<0.80	25.9	57.5	<0.025	0.07	140
PI-524	1/8/2013	1300	0.040	<0.80	29.0	75.2	0.031	0.11	130
PI-524	2/13/2013	1200	0.029	<0.80	37.6	53.1	0.083	0.18	0.93
PI-524	3/13/2013	1300	0.084	<0.80	26.5	67.7	0.096	0.32	127
PI-524	4/3/2013	1500	0.027	<0.80	23.3	73.0	<0.025	0.06	138
PI-524	5/8/2013	1400	0.031	<0.80	39.1	92.4	0.031	0.22	121
PI-524	6/5/2013	1330	0.058	<0.80	33.6	77.2	0.028	0.09	120
PI-524	6/26/2013	1230	<0.023	<0.80	22.3	45.4	<0.025	0.05	130
PI-552	8/28/2007	1600	--	<0.40	67.1	--	E 0.090	--	--
PI-552	7/24/2012	1530	0.093	<0.80	52.4	68.6	0.211	0.38	9.34
PI-553	8/29/2007	1000	--	10.8	14.2	1,060	E 0.087	0.34	--
PI-553	7/25/2012	1000	0.105	1.7	4.8	1,310	0.81	3.67	6.29
PI-555	8/30/2007	1000	--	5.3	<6.0	--	<0.120	--	--
PI-555	7/17/2012	1200	<0.021	<0.80	<3.2	8	<0.025	0.29	7.47
PI-557	9/4/2007	1700	--	17.1	<6.0	--	2.23	--	--
PI-557	7/25/2012	1700	0.059	4.8	4.1	112	0.604	0.86	6.86
PI-558	9/5/2007	1100	--	25.7	E 3.8	--	0.892	--	--
PI-558	7/25/2012	1000	0.059	38.1	15.6	14.8	0.484	0.43	10.6
PI-558	7/25/2012	1001	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	0.301	<0.50	83.1	--	0.239	--	7.39
PI-592	7/26/2012	1000	<0.021	<0.80	75.7	94.1	0.320	0.39	248
PI-592	6/25/2013	1100	<0.023	<0.80	84.7	84.6	0.343	0.41	278
PI-593	7/18/2012	1500	0.030	<0.80	<3.2	5.5	0.540	0.76	15.6
PI-593	9/12/2012	1200	<0.021	<0.80	<3.2	<4.6	0.453	0.39	16.5
PI-593	10/17/2012	1430	<0.023	0.9	<4.0	<4.6	0.284	0.26	14.8
PI-593	11/15/2012	1400	<0.023	1.0	<4.0	<4.6	0.431	0.50	19.2
PI-593	12/12/2012	0700	0.182	1.8	22.4	35.9	0.616	3.24	21.1
PI-593	1/9/2013	1130	0.070	<0.80	8.8	<4.6	1.00	1.24	19.0
PI-593	2/12/2013	1000	0.040	1.7	<4.0	<4.6	0.15	0.19	18.1
PI-593	3/12/2013	0930	0.044	1.6	4.2	<4.6	0.756	0.91	16.6
PI-593	4/4/2013	1150	0.036	<0.80	<4.0	<4.6	0.498	1.23	17.6
PI-593	4/4/2013	1405	<0.023	<0.80	<4.0	<4.6	0.593	0.49	17.7
PI-593	5/9/2013	1100	0.296	<0.80	<4.0	<4.6	0.373	0.43	16.7
PI-593	6/4/2013	1000	0.032	1.1	4.9	<4.6	0.344	0.32	15.8
PI-593	6/25/2013	1100	<0.023	0.88	<4.0	<4.6	0.208	0.27	15.9
PI-599	7/24/2012	1230	0.064	<0.80	696	746	0.487	0.70	11.0
PI-599	6/25/2013	1430	0.156	<0.80	804	945	0.157	0.36	11.5
PI-600	7/24/2012	1100	0.081	16.5	6	<4.6	1.28	0.86	12.9
PI-600	9/11/2012	1300	<0.021	19.9	<3.2	8.2	0.433	0.33	12.1
PI-600	10/17/2012	1100	<0.023	27.6	<4.0	57.5	0.342	0.24	10.4
PI-600	11/14/2012	1400	<0.023	15.9	<4.0	<4.6	0.68	0.49	12.4
PI-600	12/13/2012	1100	0.087	14.9	<4.0	10.2	0.293	0.32	13.1
PI-600	1/9/2013	1400	0.042	16.5	<4.0	<4.6	0.335	0.33	12.9
PI-600	2/12/2013	1400	0.060	13.1	<4.0	<4.6	0.209	0.20	13.8
PI-600	3/12/2013	1200	0.050	1.4	<4.0	9	1.30	1.13	12.6
PI-600	4/2/2013	1500	<0.023	14.1	4.3	8.8	0.496	0.46	12.3
PI-600	5/7/2013	1300	0.122	2.6	<4.0	<4.6	0.59	1.30	11.3
PI-600	6/4/2013	1300	0.058	27.2	<4.0	<4.6	0.405	0.31	11.1
PI-600	6/25/2013	1400	<0.023	0.94	<4.0	4.6	0.368	0.47	12.1

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Manganese, water, filtered, in µg/L	Manganese, water, unfiltered, recoverable, in µg/L	Mercury, water, filtered, in µg/L	Molybdenum, water, filtered, in µg/L	Nickel, water, filtered, in µg/L	Silver, water, filtered, in µg/L	Strontium, water, filtered, in µg/L	Thallium, water, filtered, in µg/L	Tungsten, water, filtered, in µg/L
	Parameter code:		01056	01055	71890	01060	01065	01075	01080	01057	01155
PI-274	8/10/1982	1050	70	--	<0.10	--	<1	--	--	--	--
PI-274	7/17/2012	1600	33.6	33.1	--	0.481	0.62	<0.005	60.1	<0.010	0.038
PI-288	6/2/1982	1615	M	--	--	--	--	--	--	--	--
PI-288	9/6/2007	1200	0.65	--	<0.010	<0.120	0.71	--	--	--	--
PI-288	7/18/2012	1200	0.30	0.49	--	<0.014	0.46	<0.005	13.9	<0.010	<0.010
PI-507	7/25/2012	1230	0.19	0.20	--	0.020	0.17	<0.005	330	<0.010	<0.010
PI-507	9/12/2012	0930	<0.16	<0.20	--	0.017	0.14	<0.005	343	<0.010	<0.010
PI-507	10/16/2012	1000	<0.16	<0.20	--	0.017	0.14	<0.005	345	<0.010	<0.010
PI-507	11/15/2012	1100	<0.16	<0.20	--	0.015	0.17	<0.005	344	<0.010	<0.010
PI-507	12/12/2012	0900	<0.16	0.26	--	<0.014	0.25	<0.005	342	<0.010	<0.010
PI-507	1/8/2013	1100	0.22	<0.20	--	0.018	0.25	<0.005	334	<0.010	<0.010
PI-507	2/13/2013	0930	0.21	<0.20	--	0.020	0.25	<0.005	350	<0.010	<0.010
PI-507	3/13/2013	1130	<0.16	<0.20	--	0.021	0.17	<0.005	345	<0.010	<0.010
PI-507	4/3/2013	1000	0.42	<0.20	--	<0.014	0.23	<0.005	337	<0.010	<0.010
PI-507	5/8/2013	1130	<0.16	<0.20	--	0.017	0.18	<0.005	345	<0.010	<0.010
PI-507	6/5/2013	1030	<0.16	<0.20	--	0.015	0.26	<0.005	339	<0.010	<0.010
PI-507	6/27/2013	1130	<0.16	<0.20	--	0.015	0.17	<0.005	333	<0.010	<0.010
PI-524	4/17/2006	1200	--	--	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	20.5	--	<0.010	0.333	<0.20	--	--	--	--
PI-524	1/21/2012	1131	--	--	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	20.2	18.9	--	0.324	<0.09	<0.005	502	<0.010	0.094
PI-524	7/26/2012	0901	20.3	20.4	--	0.313	0.1	<0.005	493	<0.010	0.101
PI-524	9/11/2012	1000	19.5	19.3	--	0.397	<0.09	<0.005	478	<0.010	0.053
PI-524	10/16/2012	1330	19.7	19.2	--	0.416	<0.09	<0.005	466	<0.010	0.047
PI-524	11/14/2012	1130	19.2	18.2	--	0.414	<0.09	<0.005	470	<0.010	0.059
PI-524	12/12/2012	1130	18.0	17.6	--	0.367	<0.09	<0.010	495	<0.010	0.051
PI-524	12/12/2012	1131	18.5	18.2	--	0.388	<0.09	<0.010	499	<0.010	0.047
PI-524	1/8/2013	1300	19.5	19.9	--	0.373	0.12	<0.005	466	<0.010	0.052
PI-524	2/13/2013	1200	16.1	19.2	--	0.429	<0.09	<0.005	484	<0.010	0.049
PI-524	3/13/2013	1300	19.6	20.6	--	0.413	0.12	<0.005	482	<0.010	0.048
PI-524	4/3/2013	1500	18.3	18.6	--	0.427	<0.09	<0.005	479	<0.010	0.051
PI-524	5/8/2013	1400	21.7	20.4	--	0.435	0.10	<0.005	460	<0.010	0.045
PI-524	6/5/2013	1330	19.3	19.9	--	0.408	0.19	<0.005	462	<0.010	0.051
PI-524	6/26/2013	1230	18.5	17.9	--	0.374	0.13	<0.005	472	<0.010	0.052
PI-552	8/28/2007	1600	292	--	<0.010	0.39	0.09	--	--	--	--
PI-552	7/24/2012	1530	464	495	--	0.503	0.10	<0.005	376	<0.010	<0.010
PI-553	8/29/2007	1000	215	234	<0.010	E 0.106	0.13	--	--	--	--
PI-553	7/25/2012	1000	170	191	--	0.074	<0.09	<0.005	202	<0.010	<0.010
PI-555	8/30/2007	1000	3.97	--	<0.010	<0.120	0.15	--	--	--	--
PI-555	7/17/2012	1200	0.74	8.34	--	3.45	<0.09	<0.005	429	<0.010	0.01
PI-557	9/4/2007	1700	0.94	--	<0.010	0.235	2.7	--	--	--	--
PI-557	7/25/2012	1700	0.99	2.02	--	0.754	0.45	<0.005	99.3	<0.010	<0.010
PI-558	9/5/2007	1100	1.70	--	<0.010	<0.120	0.72	--	--	--	--
PI-558	7/25/2012	1000	7.42	7.47	--	0.114	0.69	<0.005	76.4	<0.010	<0.010
PI-558	7/25/2012	1001	--	--	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	95.1	--	--	0.582	<0.09	<0.005	375	<0.010	--
PI-592	7/26/2012	1000	89.2	85.9	--	0.535	<0.09	<0.005	362	<0.010	0.386
PI-592	6/25/2013	1100	85.3	83.6	--	0.663	<0.09	<0.005	349	<0.010	0.193
PI-593	7/18/2012	1500	16.2	15.7	--	0.322	<0.09	<0.005	544	<0.010	<0.010
PI-593	9/12/2012	1200	15.3	16.1	--	0.334	0.12	<0.005	531	<0.010	<0.010
PI-593	10/17/2012	1430	14.9	15.8	--	0.337	0.10	<0.005	536	<0.010	<0.010
PI-593	11/15/2012	1400	17.6	18.6	--	0.323	0.13	<0.005	566	<0.010	<0.010
PI-593	12/12/2012	0700	56.5	58.5	--	0.231	0.39	<0.005	991	<0.010	<0.010
PI-593	1/9/2013	1130	48.1	39.7	--	0.276	0.28	<0.005	739	<0.010	<0.010
PI-593	2/12/2013	1000	15.2	14.6	--	0.337	0.14	<0.005	548	<0.010	<0.010
PI-593	3/12/2013	0930	19.2	18.3	--	0.330	0.17	<0.005	527	<0.010	<0.010
PI-593	4/4/2013	1150	15.2	14.1	--	0.339	0.11	<0.005	541	<0.010	<0.010
PI-593	4/4/2013	1405	13.9	14.3	--	0.327	0.17	<0.005	542	<0.010	<0.010
PI-593	5/9/2013	1100	14.4	13.4	--	0.325	0.12	<0.005	533	0.012	<0.010
PI-593	6/4/2013	1000	15.6	15.7	--	0.305	0.13	<0.005	536	<0.010	<0.010
PI-593	6/25/2013	1100	13.9	13.8	--	0.313	0.10	<0.005	514	<0.010	<0.010
PI-599	7/24/2012	1230	274	262	--	1.28	0.22	<0.005	354	<0.010	<0.010
PI-599	6/25/2013	1430	259	255	--	1.16	0.16	<0.005	344	<0.010	0.012
PI-600	7/24/2012	1100	0.42	0.40	--	0.351	0.15	<0.005	716	<0.010	<0.010
PI-600	9/11/2012	1300	0.23	0.64	--	0.346	0.28	<0.005	697	<0.010	<0.010
PI-600	10/17/2012	1100	0.50	1.49	--	0.326	0.38	<0.005	666	<0.010	<0.010
PI-600	11/14/2012	1400	0.17	0.65	--	0.352	0.21	<0.005	733	<0.010	<0.010
PI-600	12/13/2012	1100	0.36	0.47	--	0.369	0.19	<0.005	755	<0.010	<0.010
PI-600	1/9/2013	1400	0.18	0.39	--	0.351	0.27	<0.005	748	<0.010	<0.010
PI-600	2/12/2013	1400	0.22	0.67	--	0.410	0.26	<0.005	766	<0.010	<0.010
PI-600	3/12/2013	1200	0.46	0.71	--	0.370	0.15	<0.005	700	<0.010	<0.010
PI-600	4/2/2013	1500	0.48	0.49	--	0.401	0.17	<0.005	777	<0.010	<0.010
PI-600	5/7/2013	1300	0.87	0.61	--	0.325	0.27	0.007	594	<0.010	<0.010
PI-600	6/4/2013	1300	0.42	0.92	--	0.342	0.78	<0.005	637	<0.010	<0.010
PI-600	6/25/2013	1400	0.19	0.41	--	0.368	0.18	<0.005	716	<0.010	<0.010

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Vanadium, water, filtered, in µg/L	Zinc, water, filtered, in µg/L	Antimony, water, filtered, in µg/L	Arsenic, water, filtered, in µg/L	Arsenic, water, unfiltered, in µg/L	Boron, water, filtered, in µg/L	Selenium, water, filtered, in µg/L
		Parameter code:	01085	01090	01095	01000	01002	01020	01145
PI-274	8/10/1982	1050	--	220	--	--	--	--	--
PI-274	7/17/2012	1600	0.51	<1.4	<0.027	1.8	1.7	19	0.49
PI-288	6/2/1982	1615	--	--	--	--	--	--	--
PI-288	9/6/2007	1200	--	73.3	--	E 0.11	--	5	0.12
PI-288	7/18/2012	1200	<0.08	27.6	<0.027	0.07	<0.28	4	0.09
PI-507	7/25/2012	1230	<0.08	292	0.032	0.32	0.36	12	0.10
PI-507	9/12/2012	0930	<0.08	70.0	<0.027	0.30	0.36	12	0.10
PI-507	10/16/2012	1000	<0.08	94.2	0.028	0.29	0.39	12	0.09
PI-507	11/15/2012	1100	<0.08	85.5	<0.027	0.31	0.36	11	0.09
PI-507	12/12/2012	0900	0.10	301	<0.027	0.31	0.30	12	0.08
PI-507	1/8/2013	1100	<0.08	294	0.031	0.30	0.37	12	0.10
PI-507	2/13/2013	0930	<0.08	175	0.029	0.31	0.32	12	0.11
PI-507	3/13/2013	1130	<0.08	109	<0.027	0.31	0.38	13	0.11
PI-507	4/3/2013	1000	<0.08	86.7	0.040	0.33	0.39	13	0.10
PI-507	5/8/2013	1130	0.10	130	0.028	0.31	0.30	12	0.12
PI-507	6/5/2013	1030	<0.08	107	0.030	0.28	0.30	11	0.11
PI-507	6/27/2013	1130	<0.08	30.8	<0.027	0.29	<0.28	10	0.09
PI-524	4/17/2006	1200	--	--	--	--	<4.0	--	--
PI-524	10/1/2007	1400	--	<4.0	--	0.29	--	77	<0.04
PI-524	1/21/2012	1131	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	<0.08	<1.4	<0.027	0.26	0.35	84	<0.03
PI-524	7/26/2012	0901	<0.08	<1.4	<0.027	0.27	--	83	<0.03
PI-524	9/11/2012	1000	<0.08	<1.4	<0.027	0.25	0.29	76	<0.03
PI-524	10/16/2012	1330	<0.08	<1.4	<0.027	0.28	0.31	76	<0.03
PI-524	11/14/2012	1130	<0.08	<1.4	<0.027	0.31	0.28	86	<0.03
PI-524	12/12/2012	1130	<0.08	<1.4	<0.027	0.26	0.32	83	<0.03
PI-524	12/12/2012	1131	<0.08	<1.4	<0.027	0.24	<0.28	86	<0.03
PI-524	1/8/2013	1300	<0.08	<1.4	<0.027	0.28	0.35	83	<0.03
PI-524	2/13/2013	1200	<0.08	<1.4	<0.027	0.31	0.28	82	<0.03
PI-524	3/13/2013	1300	<0.08	1.5	<0.054	0.28	0.32	82	<0.03
PI-524	4/3/2013	1500	<0.08	<1.4	<0.027	0.28	0.31	86	<0.03
PI-524	5/8/2013	1400	<0.08	<1.4	<0.027	0.31	0.33	76	<0.03
PI-524	6/5/2013	1330	<0.08	<1.4	<0.027	0.29	0.30	72	<0.03
PI-524	6/26/2013	1230	<0.08	<1.4	<0.027	0.27	<0.28	78	<0.03
PI-552	8/28/2007	1600	--	<6.0	--	0.34	--	8.9	<0.08
PI-552	7/24/2012	1530	<0.08	<1.4	<0.027	0.39	0.48	9.0	<0.03
PI-553	8/29/2007	1000	--	<6.0	--	0.69	0.92	5.3	<0.08
PI-553	7/25/2012	1000	<0.08	<1.4	0.057	0.69	0.95	6.0	<0.03
PI-555	8/30/2007	1000	--	<6.0	--	0.31	--	6.0	0.14
PI-555	7/17/2012	1200	<0.08	<1.4	<0.027	0.19	0.43	17	<0.03
PI-557	9/4/2007	1700	--	32.6	--	0.83	--	20	E 0.06
PI-557	7/25/2012	1700	0.08	3.4	0.040	0.67	0.64	17	0.20
PI-558	9/5/2007	1100	--	9.6	--	<0.12	--	8.7	E 0.06
PI-558	7/25/2012	1000	<0.08	5.8	<0.027	0.08	<0.28	20	0.04
PI-558	7/25/2012	1001	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	<0.08	4.1	<0.027	32.3	--	109	<0.03
PI-592	7/26/2012	1000	<0.08	1.5	<0.027	30.1	27.6	119	<0.03
PI-592	6/25/2013	1100	<0.08	<1.4	<0.027	27.9	28.4	116	0.04
PI-593	7/18/2012	1500	<0.08	<1.4	0.059	1.9	1.7	33	<0.03
PI-593	9/12/2012	1200	<0.08	4.5	0.061	2.0	1.9	31	<0.03
PI-593	10/17/2012	1430	<0.08	2.6	0.061	2.0	1.8	28	<0.03
PI-593	11/15/2012	1400	<0.08	4.8	0.063	2.0	1.8	30	<0.03
PI-593	12/12/2012	0700	0.19	5.1	0.072	1.6	1.7	27	<0.03
PI-593	1/9/2013	1130	0.11	1.8	0.073	1.8	1.5	31	<0.03
PI-593	2/12/2013	1000	<0.08	1.4	0.070	2.0	2.0	34	<0.03
PI-593	3/12/2013	0930	0.10	2.5	0.071	1.8	1.6	33	<0.03
PI-593	4/4/2013	1150	<0.08	2.4	0.066	1.9	1.7	34	<0.03
PI-593	4/4/2013	1405	<0.08	3.1	0.064	1.9	2.2	34	<0.03
PI-593	5/9/2013	1100	<0.08	2.3	0.086	1.9	1.9	30	0.04
PI-593	6/4/2013	1000	0.12	2.1	0.064	2.0	1.8	27	<0.03
PI-593	6/25/2013	1100	0.09	<1.4	0.062	1.8	1.9	28	<0.03
PI-599	7/24/2012	1230	<0.08	<1.4	<0.027	0.76	0.85	30	<0.03
PI-599	6/25/2013	1430	<0.08	3.3	<0.027	0.72	0.65	28	<0.03
PI-600	7/24/2012	1100	<0.08	<1.4	0.099	1.8	2.0	10	<0.03
PI-600	9/11/2012	1300	<0.08	4.2	0.081	1.7	1.8	9	<0.03
PI-600	10/17/2012	1100	<0.08	4.1	0.093	1.7	1.7	9	<0.03
PI-600	11/14/2012	1400	<0.08	4.5	0.084	1.8	1.7	10	<0.03
PI-600	12/13/2012	1100	<0.08	3.4	0.077	1.7	1.5	11	<0.03
PI-600	1/9/2013	1400	<0.08	3.1	0.081	1.7	1.6	10	<0.03
PI-600	2/12/2013	1400	<0.08	2.2	0.085	1.7	1.6	11	<0.03
PI-600	3/12/2013	1200	<0.08	1.7	0.093	1.8	1.9	11	0.04
PI-600	4/2/2013	1500	<0.08	1.9	0.075	1.7	1.6	11	0.05
PI-600	5/7/2013	1300	<0.08	2.3	0.09	1.5	1.7	9	0.04
PI-600	6/4/2013	1300	<0.08	3.3	0.088	1.7	1.5	8	0.05
PI-600	6/25/2013	1400	<0.08	2.4	0.068	1.5	1.6	9	<0.03

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Gross alpha radioactivity, 30 day recount, water, unfiltered, Th-230 curve, in piC/L	Gross alpha radioactivity, 30-day count, water, filtered, Th-230 curve, in piC/L	Gross alpha radioactivity, 72 hour count, water, unfiltered, Th-230 curve, in piC/L	Gross alpha radioactivity, 72-hour count, water, filtered, Th-230 curve, in piC/L	Gross alpha radioactivity, water, unfiltered, in piC/L	Gross beta radioactivity, 30 day recount, water, unfiltered, Cs-137 curve, in piC/L	Gross beta radioactivity, 30-day count, water, filtered, Cs-137 curve, in piC/L
		Parameter code:	**63016**	**62639**	**63014**	**62636**	**01519**	**63017**	**62645**
PI-274	8/10/1982	1050	--	--	--	--	--	--	--
PI-274	7/17/2012	1600	R 0.1	--	1.3	--	--	1.4	--
PI-288	6/2/1982	1615	--	--	--	--	--	--	--
PI-288	9/6/2007	1200	--	R 0.1	--	R -0.4	--	--	R 0.6
PI-288	7/18/2012	1200	R 0.3	0.5	1.0	R 0	--	R 0.1	R 0.5
PI-507	7/25/2012	1230	R 0.4	--	0.6	--	--	1.2	--
PI-507	9/12/2012	0930	R -0.2	--	0.6	--	--	1.1	--
PI-507	10/16/2012	1000	R 0.4	--	0.8	--	--	1.2	--
PI-507	11/15/2012	1100	0.4	--	7.0.	--	--	1.2	--
PI-507	12/12/2012	0900	R 0.0	--	R 0.1	--	--	R 0	--
PI-507	1/8/2013	1100	R -0.1	--	1.1	--	--	R 0.8	--
PI-507	2/13/2013	0930	R -0.3	--	R -0.3	--	--	1.2	--
PI-507	3/13/2013	1130	R -0.2	--	R -0.2	--	--	1.4	--
PI-507	4/3/2013	1000	R 0.2	--	4.9	--	--	1.1	--
PI-507	5/8/2013	1130	--	--	--	--	--	--	--
PI-507	6/5/2013	1030	--	--	--	--	--	--	--
PI-507	6/27/2013	1130	1.3	--	0.8	--	--	R 1.0	--
PI-524	4/17/2006	1200	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	--	R -0.1	--	R -1.0	--	--	R 0.9
PI-524	1/21/2012	1131	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	1.7	1.5	6.4	2.2	--	3.0	R 0.7
PI-524	7/26/2012	0901	3.7	1.6	4.0	3.0	--	3.4	0.9
PI-524	9/11/2012	1000	3	--	9.1	--	--	1.5	--
PI-524	10/16/2012	1330	2.7	--	4.4	--	--	0.9	--
PI-524	11/14/2012	1130	2.5	--	7.2	--	--	1.5	--
PI-524	12/12/2012	1130	1.5	--	3.0	--	--	1.4	--
PI-524	12/12/2012	1131	2.5	--	3.6	--	--	0.9	--
PI-524	1/8/2013	1300	--	--	--	--	--	--	--
PI-524	2/13/2013	1200	--	--	--	--	--	--	--
PI-524	3/13/2013	1300	2.1	--	2.2	--	--	2.6	--
PI-524	4/3/2013	1500	2.6	--	7.1	--	--	1.7	--
PI-524	5/8/2013	1400	--	--	--	--	--	--	--
PI-524	6/5/2013	1330	--	--	--	--	--	--	--
PI-524	6/26/2013	1230	1.4	--	1.5	--	--	1.8	--
PI-552	8/28/2007	1600	--	R -0.2	--	1	--	--	R 0.4
PI-552	7/24/2012	1530	R -0.2	R -0.4	1.2	2.3	--	1.7	R 0.1
PI-553	8/29/2007	1000	--	R -2.0	--	R 0.2	--	--	2.4
PI-553	7/25/2012	1000	R -0.1	R 0.2	0.5	0.5	--	R 0.4	R 0.3
PI-555	8/30/2007	1000	--	R 0.5	--	1.3	--	--	1.4
PI-555	7/17/2012	1200	1.1	1	0.8	1.8	--	1.2	R 0.5
PI-557	9/4/2007	1700	--	R -0.8	--	R -0.5	--	--	0.9
PI-557	7/25/2012	1700	1.5	--	1.9	--	--	1.7	--
PI-558	9/5/2007	1100	--	R -0.3	--	R -0.3	--	--	R 0.6
PI-558	7/25/2012	1000	R -0.2	0.6	R -0.1	R 0.4	--	R 0.2	R -0.1
PI-558	7/25/2012	1001	--	--	--	--	--	--	--
PI-592	8/17/2011	1200	--	--	--	--	1.4	--	--
PI-592	7/26/2012	1000	R 0.7	--	2.1	--	--	R 0.7	--
PI-592	6/25/2013	1100	R 1.2	--	2.5	--	--	2.8	--
PI-593	7/18/2012	1500	0.8	--	0.7	--	--	R 0.7	--
PI-593	9/12/2012	1200	1.6	--	1.5	--	--	1.7	--
PI-593	10/17/2012	1430	1.7	--	1.3	--	--	1.7	--
PI-593	11/15/2012	1400	0.7	--	5.3	--	--	0.9	--
PI-593	12/12/2012	0700	1.2	--	1.6	--	--	1.0	--
PI-593	1/9/2013	1130	2.3	--	1.9	--	--	1.3	--
PI-593	2/12/2013	1000	2.1	--	1.0	--	--	1.3	--
PI-593	3/12/2013	0930	1.8	--	1.3	--	--	R 0.8	--
PI-593	4/4/2013	1150	1.3	--	2.7	--	--	2.1	--
PI-593	4/4/2013	1405	2.7	--	4.2	--	--	1.6	--
PI-593	5/9/2013	1100	--	--	--	--	--	--	--
PI-593	6/4/2013	1000	--	--	--	--	--	--	--
PI-593	6/25/2013	1100	1.0	--	R -0.1	--	--	R 0.1	--
PI-599	7/24/2012	1230	R -0.4	--	0.9	--	--	R 0.3	--
PI-599	6/25/2013	1430	0.7	--	0.8	--	--	R 0.0	--
PI-600	7/24/2012	1100	1.1	--	3.3	--	--	R 0.7	--
PI-600	9/11/2012	1300	1.8	--	1.4	--	--	1.2	--
PI-600	10/17/2012	1100	2.3	--	2.3	--	--	1.1	--
PI-600	11/14/2012	1400	2.5	--	3.7	--	--	0.8	--
PI-600	12/13/2012	1100	1.0	--	2.6	--	--	R 0.2	--
PI-600	1/9/2013	1400	R 0.1	--	1.5	--	--	1.3	--
PI-600	2/12/2013	1400	1.2	--	1.2	--	--	0.9	--
PI-600	3/12/2013	1200	1.5	--	1.2	--	--	1.4	--
PI-600	4/2/2013	1500	2.7	--	3.0	--	--	1.0	--
PI-600	5/7/2013	1300	--	--	--	--	--	--	--
PI-600	6/4/2013	1300	--	--	--	--	--	--	--
PI-600	6/25/2013	1400	R 0.6	--	2.1	--	--	R 1.0	--

Appendix 1. Compilation of past and current inorganic water-quality data for wells sampled by the U.S. Geological Survey in summer 2012 and more than once from 1982 through 2013 in Pike County, Pennsylvania.—Continued

[USGS, U.S. Geological Survey; mmHg, millimeters of mercury; °C, degrees Celsius; ft bls, feet below land surface, %, percent; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, no data; <, less than; E, estimated; M, presence verified but not quantified; R, radchem non-detect, below sample-specific critical level; Th-230, thorium-230; Cs-137, cesium-137; piC/L, picocuries per liter]

USGS site name	Date	Sample start time	Gross beta radioactivity, 72 hour count, water, unfiltered, Cs-137 curve, in piC/L	Gross beta radioactivity, 72-hour count, water, filtered, Cs-137 curve, in piC/L	Gross beta radioactivity, water, unfiltered, in piC/L	Radium-226, water, filtered, radon method, in piC/L	Radon-222 2-sigma combined uncertainty, water, unfiltered, in piC/L	Radon-222, water, unfiltered, in piC/L	Uranium (natural), water, filtered, in µg/L
	Parameter code:		63015	62642	85817	09511	76002	82303	22703
PI-274	8/10/1982	1050	--	--	--	--	--	--	--
PI-274	7/17/2012	1600	R 0.3	--	--	--	--	2,000	0.055
PI-288	6/2/1982	1615	--	--	--	--	--	--	--
PI-288	9/6/2007	1200	--	R 0.4	--	--	46	2,650	0.047
PI-288	7/18/2012	1200	0.7	R 0.0	--	--	--	2,840	0.050
PI-507	7/25/2012	1230	R 0.8	--	--	--	--	1,960	0.136
PI-507	9/12/2012	0930	R 0.2	--	--	--	--	1,760	0.127
PI-507	10/16/2012	1000	R 0.2	--	--	--	--	1,840	0.118
PI-507	11/15/2012	1100	3.6	--	--	--	--	1,920	0.110
PI-507	12/12/2012	0900	R 0.5	--	--	--	--	1,900	0.119
PI-507	1/8/2013	1100	R 0.4	--	--	--	--	1,900	0.114
PI-507	2/13/2013	0930	R 0.4	--	--	--	--	1,910	0.122
PI-507	3/13/2013	1130	1.1	--	--	--	--	1,890	0.112
PI-507	4/3/2013	1000	1.6	--	--	--	--	1,890	0.120
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	2.1	--	--	0.041	--	1,880	0.097
PI-524	4/17/2006	1200	--	--	--	--	--	--	--
PI-524	10/1/2007	1400	--	0.9	--	--	23	470	0.222
PI-524	1/21/2012	1131	--	--	--	--	--	--	--
PI-524	7/26/2012	0900	2.4	R 0.6	--	--	--	460	0.137
PI-524	7/26/2012	0901	2.5	R 0.6	--	--	--	--	0.138
PI-524	9/11/2012	1000	1.6	--	--	--	--	510	0.184
PI-524	10/16/2012	1330	1.4	--	--	--	--	540	0.202
PI-524	11/14/2012	1130	2.5	--	--	--	--	480	0.184
PI-524	12/12/2012	1130	R 0.2	--	--	--	--	450	0.131
PI-524	12/12/2012	1131	1.8	--	--	--	--	470	0.157
PI-524	1/8/2013	1300	--	--	--	--	--	550	0.162
PI-524	2/13/2013	1200	--	--	--	--	--	470	0.182
PI-524	3/13/2013	1300	1.6	--	--	--	--	540	0.169
PI-524	4/3/2013	1500	2.4	--	--	--	--	500	0.146
PI-524	5/8/2013	1400	--	--	--	--	--	500	0.225
PI-524	6/5/2013	1330	--	--	--	--	--	530	0.202
PI-524	6/26/2013	1230	1.9	--	--	0.29	--	540	0.149
PI-552	8/28/2007	1600	--	R 0.5	--	--	17	150	0.210
PI-552	7/24/2012	1530	R 0.8	R 0.4	--	--	--	121	0.102
PI-553	8/29/2007	1000	--	R 0.2	--	--	21	300	E 0.038
PI-553	7/25/2012	1000	R 0.5	0.9	--	--	--	242	0.034
PI-555	8/30/2007	1000	--	0.9	--	--	45	2,430	0.332
PI-555	7/17/2012	1200	1.1	R 0.1	--	--	--	2,690	<0.004
PI-557	9/4/2007	1700	--	0.9	--	--	37	1,700	0.253
PI-557	7/25/2012	1700	1.1	--	--	--	--	2,620	0.682
PI-558	9/5/2007	1100	--	R -0.5	--	--	37	1,730	<0.040
PI-558	7/25/2012	1000	R 0.4	R -0.2	--	--	--	1,410	<0.004
PI-558	7/25/2012	1001	--	--	--	--	--	1,480	--
PI-592	8/17/2011	1200	--	--	1.3	--	--	1,210	0.014
PI-592	7/26/2012	1000	1.2	--	--	--	--	1,320	0.012
PI-592	6/25/2013	1100	3.3	--	--	0.26	--	1,350	0.013
PI-593	7/18/2012	1500	0.7	--	--	--	--	1,240	0.590
PI-593	9/12/2012	1200	1.1	--	--	--	--	1,300	0.613
PI-593	10/17/2012	1430	1.4	--	--	--	--	1,170	0.611
PI-593	11/15/2012	1400	2.6	--	--	--	--	1,400	0.600
PI-593	12/12/2012	0700	1.4	--	--	--	--	350	1.31
PI-593	1/9/2013	1130	0.8	--	--	--	--	880	0.906
PI-593	2/12/2013	1000	R 0.3	--	--	--	--	1,180	0.604
PI-593	3/12/2013	0930	1.7	--	--	--	--	1,130	0.606
PI-593	4/4/2013	1150	2.5	--	--	--	--	1,130	0.635
PI-593	4/4/2013	1405	2.5	--	--	--	--	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	2.6	--	--	0.15	--	1,290	0.547
PI-599	7/24/2012	1230	R 0.6	--	--	--	--	320	0.586
PI-599	6/25/2013	1430	2.1	--	--	0.095	--	251	0.545
PI-600	7/24/2012	1100	R 0.0	--	--	--	--	880	1.11
PI-600	9/11/2012	1300	R 1.0	--	--	--	--	860	1.11
PI-600	10/17/2012	1100	1.4	--	--	--	--	--	1.09
PI-600	11/14/2012	1400	0.7	--	--	--	--	920	1.14
PI-600	12/13/2012	1100	0.9	--	--	--	--	930	1.15
PI-600	1/9/2013	1400	0.7	--	--	--	--	1,080	1.10
PI-600	2/12/2013	1400	R 0.3	--	--	--	--	1,090	1.12
PI-600	3/12/2013	1200	0.6	--	--	--	--	1,000	1.04
PI-600	4/2/2013	1500	1.3	--	--	--	--	1,030	1.10
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	3.4	--	--	0.08	--	1,080	1.01

Appendix 2. Results of analysis for dissolved gas, chlorofluorocarbon, and sulfur hexafluoride concentrations in samples from six wells in Pike County, Pennsylvania, June 2013.

[Analyses done by U.S. Geological Survey (USGS) Chlorofluorcarbon Laboratory, Reston, Virginia. All samples collected and analyzed in duplicate, except for CFCs which were collected and analyzed in triplicate. °C, degrees Celsius; mg/L, milligrams per liter; pg/kg, picograms per kilogram; fg/kg, fentogram per kilogram; CH_4, methane; CO_2, carbon dioxide; N_2, nitrogen; O_2, oxygen; Ar, argon; CFC, chlorofluorocarbon; SF_6, sulfur hexafluoride; --, no data]

USGS site name	Date collected	Time	Field temperature, in °C	Dissolved gas concentration, in mg/L					CFCs, in pg/kg			SF_6,[1] in fg/kg
				CH_4	CO_2	N_2	O_2	Ar	CFC-11	CFC-12	CFC-113	
PI-507	06/27/13	1130	10.43	0.0005	36.4913	20.6636	5.0387	0.7293	1,609.2808	673.3542	71.1316	413.9
PI-507	06/27/13	1130	10.43	0.0006	37.0550	20.9433	5.1180	0.7370	1,564.5668	675.0886	71.6876	420.1
PI-507	06/27/13	1130	10.43	--	--	--	--	--	1,620.1352	676.9504	72.3971	--
PI-524	06/26/13	1230	11.5	7.3319	1.0432	28.9990	0.2696	0.9053	5.6960	1.7829	0.4590	78.7
PI-524	06/26/13	1230	11.5	7.3107	1.1176	28.8474	0.2530	0.9043	2.4725	1.7595	0.4531	--
PI-524	06/26/13	1230	11.5	--	--	--	--	--	--	--	--	--
PI-592	06/25/13	1100	11.39	4.9129	0.4203	26.2811	0.2487	0.8272	0.9777	0.0000	0.5955	17.4
PI-592	06/25/13	1100	11.39	4.9479	0.4607	26.2908	0.2387	0.8244	7.0666	1.9982	0.6618	15.2
PI-592	06/25/13	1100	11.39	--	--	--	--	--	5.8580	1.6615	0.8564	--
PI-593	06/25/13	1100	10.9	0.0002	1.3841	21.8441	0.3345	0.7622	2,970.1080	118.9906	10.9183	140.3
PI-593	06/25/13	1100	10.9	0.0003	1.4089	22.4465	0.3195	0.7749	2,900.5550	119.6317	11.3153	--
PI-593	06/25/13	1100	10.9	--	--	--	--	--	2,361.7125	115.5965	8.3765	--
PI-599	06/25/13	1430	11.56	0.0181	4.5824	26.7658	0.2725	0.8575	7.4428	1.9599	1.2134	15,426,834
PI-599	06/25/13	1430	11.56	0.0181	4.5663	26.8724	0.2937	0.8624	5.9462	1.6118	1.2468	--
PI-599	06/25/13	1430	11.56	--	--	--	--	--	--	--	--	--
PI-600	06/25/13	1400	10.7	0	2.3646	23.9438	0.3074	0.7964	32.8092	135.9672	0.8163	27,104,457
PI-600	06/25/13	1400	10.7	0	2.3498	24.2935	0.3162	0.7996	27.5242	29.5292	0.8089	--
PI-600	06/25/13	1400	10.7	--	--	--	--	--	31.5966	138.2385	0.4045	--

[1]Duplicate samples for SF_6 analysis from three wells (PI-524, PI-593, and PI-600) were broken in shipping and could not be analyzed; duplicate sample for SF_6 analysis from one well (PI-599) was not analyzed because of high concentrations in initial sample.

For additional information:
Director
U.S. Geological Survey
215 Limekiln Road
New Cumberland, PA 17070

http://pa.water.usgs.gov/

Document prepared by the West Trenton Publishing Service Center

Senior—**Assessment of Methane and Inorganic Constituents in Groundwater in Bedrock Aquifers, Pike County, Pa., 2012–13**—Scientific Investigations Report 2014–5117

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20145117