Prepared in cooperation with the
Pennsylvania Department of Conservation and Natural Resources,
Bureau of Topographic and Geologic Survey

Baseline Groundwater Quality from 20 Domestic Wells in Sullivan County, Pennsylvania, 2012

Scientific Investigations Report 2013–5085

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

Cover. North Mountain, Laporte Township, Sullivan County, Pennsylvania. View is looking southeast from "Wright's View" across the Muncy Creek Valley.

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

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:
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., http://pubs.usgs.gov/sir/2013/5085/

Acknowledgements

The cooperation of the residents of Sullivan County who made their wells accessible for sampling is greatly appreciated. The author thanks Taylor Suskie of the Pennsylvania Geological Survey for her assistance with well location and sampling.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

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

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

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

Abbreviations

AMCL	alternate maximum contaminant levels
MCL	maximum contaminant level
PaGS	Pennsylvania Geological Survey
SMCL	secondary maximum contaminant level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
µg/L	micrograms per liter
mg/L	milligrams per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
pCi/L	picocuries per liter

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Baseline Groundwater Quality from 20 Domestic Wells in Sullivan County, Pennsylvania, 2012

By Ronald A. Sloto

Abstract

Water samples were collected from 20 domestic wells during August and September 2012 and analyzed for 47 constituents and properties, including nutrients, major ions, metals and trace elements, radioactivity, and dissolved gases, including methane and radon-222. This study, done in cooperation with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey (Pennsylvania Geological Survey), provides a groundwater-quality baseline for central and southern Sullivan County prior to drilling for natural gas in the Marcellus Shale.

The analytical results for the 20 groundwater samples collected during this study indicate that only one constituent (gross-alpha radioactivity) in one sample was found to exceed the U.S. Environmental Protection Agency (USEPA) primary drinking water maximum contaminant level (MCL). Water samples from 85 percent of the sampled wells exceeded the proposed USEPA MCL of 300 picocuries per liter (pCi/L) for radon-222; however, only two water samples (10 percent of sampled wells) exceeded the proposed USEPA alternate maximum contaminant level (AMCL) of 4,000 pCi/L for radon-222. In a few samples, the concentrations of total dissolved solids, iron, manganese, and chloride exceeded USEPA secondary maximum contaminant levels (SMCL). In addition, water samples from two wells contained methane concentrations greater than 1 milligram per liter (mg/L).

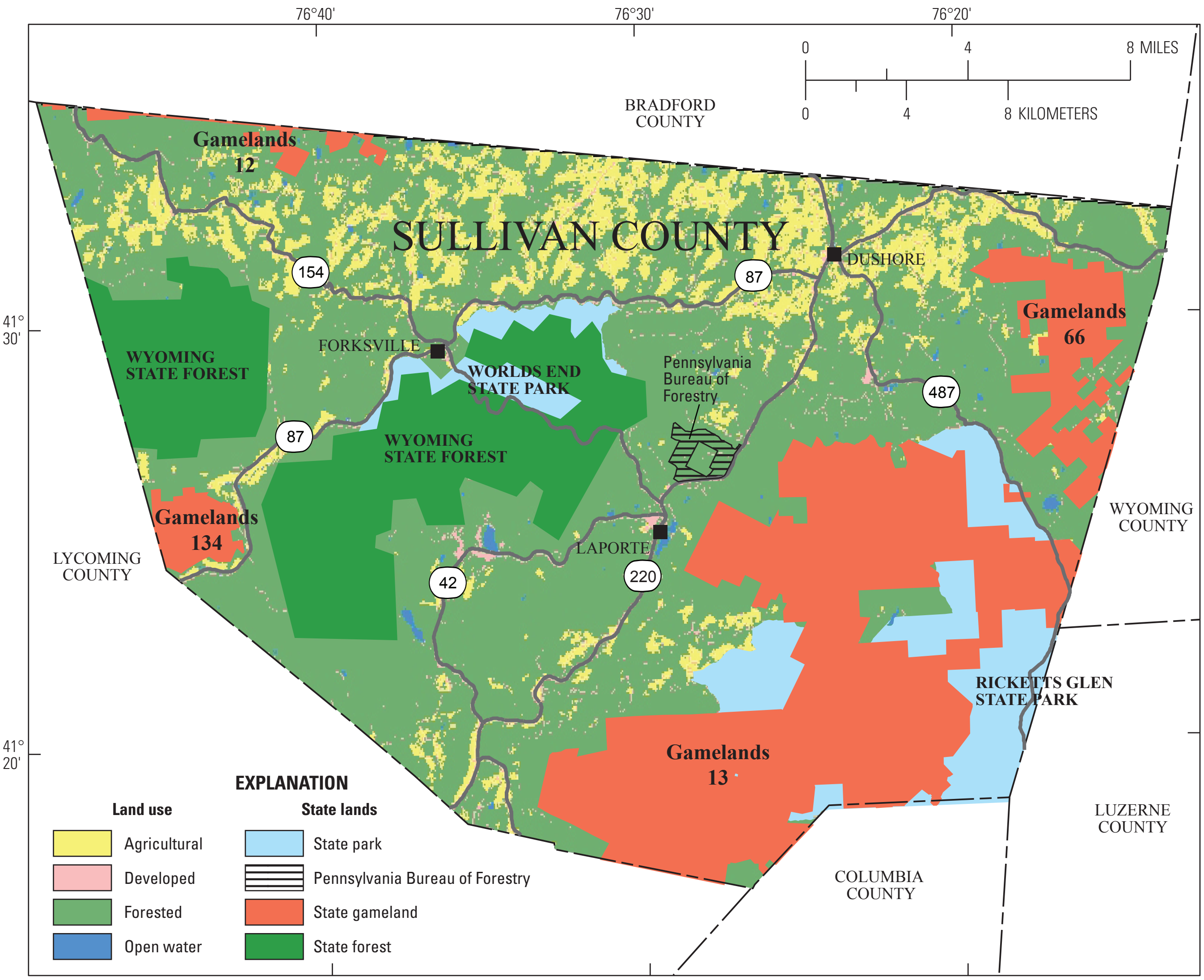
In general, most of the water-quality problems involve aesthetic considerations, such as taste or odor from elevated concentrations of total dissolved solids, iron, manganese, and chloride that develop from natural interactions of water and rock minerals in the subsurface. The total dissolved solids concentration ranged from 31 to 664 mg/L; the median was 130 mg/L. The total dissolved solids concentration in one water sample exceeded the USEPA SMCL of 500 mg/L. Chloride concentrations ranged from 0.59 to 342 mg/L; the median was 12.9 mg/L. The concentration of chloride in one water sample exceeded the USEPA SMCL of 250 mg/L. Concentrations of dissolved iron ranged from less than 3.2 to 6,590 micrograms per liter (µg/L); the median was 11.5 µg/L. The iron concentration in samples from 20 percent of the sampled wells exceeded the USEPA SMCL of 300 µg/L. Concentrations of dissolved manganese ranged from less than 0.13 to 1,710 µg/L; the median was 38.5 µg/L. The manganese concentration in samples from 35 percent of the sampled wells exceeded the USEPA SMCL of 50 µg/L.

Activities of radon-222 ranged from 169 to 15,300 picocuries per liter (pCi/L); the median was 990 pCi/L. The gross alpha-particle radioactivity ranged from below detection to 33 pCi/L; the median was 1.5 pCi/L. The gross alpha-particle radioactivity of one water sample exceeded the USEPA MCL of 15 pCi/L.

Concentrations of dissolved methane ranged from less than 0.001 to 51.1 mg/L. Methane was not detected in water samples from 13 wells, and the methane concentration was less than 0.07 mg/L in samples from five wells. The highest dissolved methane concentrations were 4.1 and 51.1 mg/L, and the pH of the water from both wells was greater than 8. Water samples from these wells were analyzed for isotopes of carbon and hydrogen in the methane. The isotopic ratio values fell in the range for a thermogenic (natural gas) source. The water samples from these two wells had the highest concentrations of arsenic, boron, bromide, chloride, fluoride, lithium, molybdenum, and sodium of the 20 wells sampled.

Introduction

Sullivan County, which is located in north central Pennsylvania (fig. 1), is underlain by the Marcellus Shale. The Marcellus Shale, which is being exploited for natural gas, lies approximately 6,000 to 9,000 feet (ft) below land surface in Sullivan County. All of the residents of Sullivan County rely on groundwater as a source of water supply. Drilling and hydraulic fracturing of horizontal natural gas wells have the potential to contaminate freshwater aquifers that provide drinking water and the base flow of streams (Kargbo and others, 2010; Kerr, 2010; U.S. Environmental Protection Agency, 2013a). Since 2006, permits have been issued for 188 Marcellus Shale gas wells (Pennsylvania Department of Environmental Protection, 2012a), and 67 natural gas wells have been drilled into the Marcellus Shale in Sullivan County. Most of



Base from U.S. Geological Survey digital data

State park boundaries from Pennsylvania Department of Conservation and Natural Resources (2011); State forest boundaries from Pennsylvania Department of Conservation and Natural Resources (2010); State gamelands boundaries from Pennsylvania Game Commission (2011); County boundary and roads from Pennsylvania Department of Transportation (2009a, 2009b); land use from LaMotte (2008)

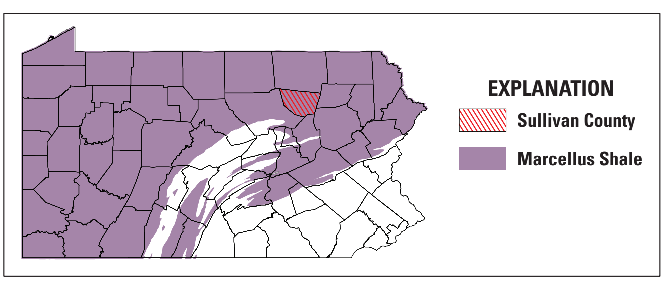


Figure 1. Land use and State lands in Sullivan County, Pennsylvania.

the wells are in the northern part of the county (Pennsylvania Department of Environmental Protection, 2012b).

Pre-gas well drilling groundwater-quality data for water-supply wells in the northern part of Sullivan County have been collected by the natural-gas industry. However, data are not available for most of the central and southern part of the county. Without baseline data for associated water-quality constituents, it is not possible to establish a connection between gas production activities and the well-water chemistry that might be affected. This study, conducted by the U.S. Geological Survey (USGS) in cooperation with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey (Pennsylvania Geological Survey), provides a pre-gas well drilling groundwater-quality baseline for the central and southern part of Sullivan County.

Purpose and Scope

This report presents analytical data for water samples from 20 domestic wells sampled in central and southern Sullivan County in August and September 2012. The water samples were analyzed for 47 constituents, including nutrients, major ions, metals and trace elements, radioactivity, and dissolved gases, including methane and radon-222. The groundwater-quality data and summary statistics are presented for sampled constituents to provide a pre-gas well drilling baseline.

Description of Study Area

Sullivan County occupies 450 square miles (mi^2) in north central Pennsylvania (fig. 1). Land-surface elevations are highest (more than 2,500 ft above NAVD 88) in the mountains of the southeastern part of the county and lowest in the southwestern part of the county (as low as about 755 ft above NAVD 88) (U.S. Geological Survey, 2009). Average annual temperatures in Sullivan County range from about 44 to 49 degrees Fahrenheit with the warmest average annual temperatures occurring in the southwestern part of the county and the coldest average annual temperatures occurring in the mountainous areas in the northwestern, northeastern, and southeastern parts of the county (PRISM Group at Oregon State University, 2013). Average annual precipitation varies from west to east with an average of 40 inches in the western part of the county and an average of 54 inches in the eastern part of the county (PRISM Group at Oregon State University, 2013).

Population and Land Use

Sullivan County is rural with a population of 6,496 in 2010 (U.S. Census Bureau, 2013). The 2010 population is less than double the population in 1850 (Sullivan County Planning and Economic Development Office, 2010). Areas most densely populated are the boroughs of Dushore, Forksville, and Laporte (fig. 1) with 2010 populations of 746, 63, and 313, respectively. Seasonal dwellings made up 56 percent of housing units in the county in 2010 (U.S. Census Bureau, 2013).

About 87 percent of the county is forested with approximately 38 percent of forested land consisting of state parks, forests, and gamelands (fig. 1) (LaMotte, 2008). Agricultural lands are typically found in the narrow valley bottoms in the northern and south-central part of the county. Approximately 10 percent of the county is devoted to agriculture with about 5 percent of the county in cropland (Sullivan County Planning and Economic Development Office, 2010). About 3 percent of the county consists of developed land.

Physiography and Geologic Setting

Sullivan County is mostly located in the Appalachian Plateaus Physiographic Province (Sevon, 2000). The northern part of the county is in the Glaciated Low Plateau Section. This study was conducted in the central and southern parts, which are divided between the western Deep Valleys Section, and the eastern Glaciated High Plateaus Section. The Deep Valleys Section is characterized by very deep, angular valleys with some broad to narrow uplands. The Glaciated High Plateaus Section is characterized by broad to narrow, rounded to flat, elongate uplands and shallow valleys.

Sullivan County is underlain by bedrock of Pennsylvania, Mississippian, and Devonian age (figs. 2 and 3). Alluvium overlies the bedrock in the stream valleys. The geologic descriptions below for alluvium and bedrock units cropping out in Sullivan County are from Taylor and others (1983).

Alluvium

The thick, unconsolidated deposits of Quaternary age that fill the stream valleys are collectively called alluvium. Alluvium, which consists of gravel, sand, and clay, fills some valleys to depths of over 200 ft. In some areas, the alluvium has been transported relatively long distances as a result of glacial processes (outwash), and in other areas, it has been weathered from the nearby rock formations.

Allegheny and Pottsville Formations

In Sullivan County, the rocks of Pennsylvanian age are mapped as the Allegheny and Pottsville Formations, undivided. The Allegheny Formation is composed of sandstone, siltstone, thin beds of limestone, and coal. Reported thicknesses for this unit are consistently about 300 ft. The upper part of the Pottsville Formation consists mainly of sandstone, siltstone, thin beds of coal, and conglomerate. The lower part of the Pottsville Formation consists predominantly of sandstone. Thickness estimates for the Pottsville Formation range from 140 to 200 ft.

Mauch Chunk Formation

The Mauch Chunk Formation of Mississippian age generally consists of two units. The lower unit is interbedded

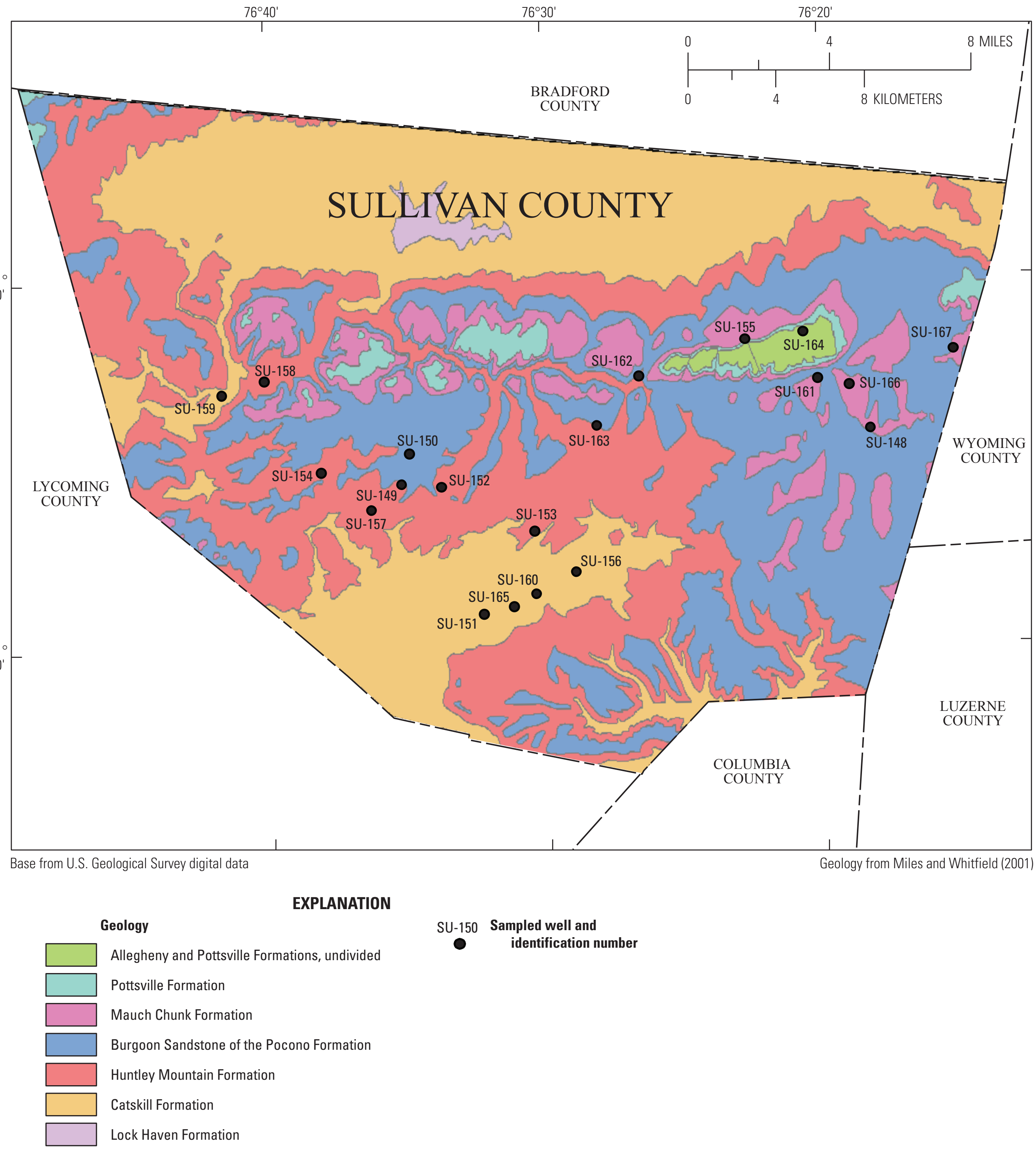


Figure 2. Geology and location of groundwater-sampling sites, Sullivan County, Pennsylvania.

SYSTEM	GEOLOGIC UNIT		LITHOLOGY
Quaternary	alluvium		Poorly sorted clay, sand, and gravel
Pennsylvanian	Allegheny and Pottsville Formations, undivided	Allegheny Formation	Sandstone, siltstone, limestone, and coal
		Pottsville Formation	Sandstone, siltstone, coal, and conglomerate
Mississippian	Mauch Chunk Formation		Sandstone, siltstone, shale, and mudstone
	Pocono Formation	Burgoon Sandstone Member	Sandstone, shale, conglomerate, and mudstone
	Huntley Mountain Formation		Sandstone, siltstone, and shale
Devonian	Catskill Formation		Sandstone, siltstone, shale, and conglomerate
	Lock Haven Formation		Sandstone, siltstone, shale, and conglomerate

Figure 3. Stratigraphic chart for Sullivan County, Pennsylvania. From Edmunds (1996).

sandstone, siltstone, shale, and mudstone. The upper unit is a light-gray calcareous quartz sandstone. The Mauch Chunk Formation is up to 300 ft thick.

Burgoon Sandstone

The Mississippian age Burgoon Sandstone Member of the Pocono Formation is informally divided into two units. The upper unit consists of light-gray, fine- to medium-grained, well-sorted, pure quartz sandstone (orthoquartzite). The lower unit consists of gray sandstone and minor interbedded gray shale, conglomerate, and mudstone. Reported thicknesses for the upper member range from 120 to 240 ft. Reported thicknesses for the lower member range from 570 to 800 ft.

Huntley Mountain Formation

The Huntley Mountain Formation of Late Devonian and Early Mississippian age consists of greenish-gray to light olive-gray sandstone and some thin beds of grayish-red siltstone or clay shale. The formation is reported to be about 600 ft thick.

Catskill Formation

The Catskill Formation of Devonian age consists of a succession of grayish-red sandstone, siltstone, and shale with some gray sandstone and conglomerate. The sandstone layers are generally fine grained and thin bedded. The thickness of the Catskill Formation varies from about 1,200 to 2,000 ft.

Lock Haven Formation

The Lock Haven Formation of Devonian age is composed predominantly of light olive gray interbedded sandstone, siltstone, shale, and a few thin beds of conglomerate near the top. No wells completed in the Lock Haven Formation were sampled.

Methods

Water samples were collected from 20 domestic wells (table 1 and fig. 2) during August and September 2012 and analyzed to characterize their physical and chemical quality. Samples were analyzed for 47 constituents and properties, including nutrients, major ions, metals and trace elements, radioactivity, and dissolved gases, including methane and radon-222. Two samples, one field blank and one replicate sample, were collected for quality assurance and quality control.

Site Selection

Selection of water wells for sampling was made by the USGS in consultation with the Pennsylvania Geological Survey (PaGS). Wells were selected from the Pennsylvania Groundwater Information System database (Pennsylvania Geological Survey, 2012). Only wells with construction data on file were considered. A field reconnaissance was conducted to locate 20 wells, obtain permission to sample, and verify that any treatment systems could be bypassed. All wells selected for sampling are private domestic wells (table 1).

Sampling and Analytical Methods

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

Sampling was done at all well sites using the following steps. (1) The existing submersible well pump was turned on and allowed to run. (2) A raw-water tap between the well and the pressure tank was opened, and the water was allowed to flush to ensure that the water was representative of the aquifer. (3) The water was analyzed with a multiprobe meter for physical properties (temperature, specific conductance, and pH) and dissolved oxygen concentration. (4) After the measurements of these physical properties stabilized, pre-rinsed sample bottles were filled according to USGS protocols (U.S. Geological Survey, variously dated). Samples were collected through a short piece of silicone tubing attached to the raw-water tap, which avoided all water-treatment systems.

The analyses for physical properties, radioactivity, and dissolved gases were done on unfiltered water samples to obtain total concentrations. Samples for dissolved concentrations of nutrients, major ions, and metals and trace elements were filtered through a pre-rinsed 0.45-micrometer cellulose capsule filter. To prevent sample degradation, nitric acid was added to the major ion and metals and trace-element samples. Samples for radon analysis were obtained through an inline septum with a gas-tight syringe to avoid atmospheric contact. Samples for gross alpha and beta radioactivity and dissolved gases were obtained through silicon tubing that was placed in bottles that were filled and stoppered while submerged in a 5-liter beaker of pumped water to avoid atmospheric contact.

The samples were stored on ice in coolers and shipped by overnight delivery to the following three laboratories: (1) the USGS National Water Quality Laboratory in Denver, Colorado, for analysis of major ions, nutrients, metals and trace elements, and radon; (2) a USGS contract laboratory in California for analysis of gross alpha and beta radioactivity; and (3) the USGS Chlorofluorocarbon Laboratory in Reston, Virginia, for analysis of methane and other dissolved gases. Descriptions of analytical methods for all constituents except the dissolved gases and isotopes are available through the U.S. Geological Survey (2012a); the methods for determination of dissolved gases in water are described by the U.S. Geological Survey (2012b). The analytical results are available through the USGS National Water Information System (U.S. Geological Survey, 2012c).

Water samples containing methane concentrations greater than 1 milligram per liter (mg/L) were shipped on ice to a contract laboratory in Illinois for hydrocarbon and isotopic analysis. The stable carbon isotopes ^{12}C and ^{13}C and the stable hydrogen isotopes ^{1}H (protium) and ^{2}H (deuterium) were determined. For the determination of carbon and hydrogen isotopic ratios for hydrocarbons in a gas mixture, individual hydrocarbons were first separated and then converted into carbon dioxide and water for mass-spectrometric analysis. The hydrocarbons were separated from the water sample by using a gas chromatograph and channeled into a combined combustion-collection unit. The combined combustion-collection unit has quartz combustion tubes filled with cupric oxide to convert the hydrocarbons into carbon dioxide and water, which are then collected and purified for isotopic analysis.

The carbon dioxide was transferred into Pyrex tubing and sealed for mass spectrometric analysis. The $^{13}C/^{12}C$ ratio was determined by a mass spectrometric analysis that compared the sample to a reference standard. The carbon isotope ratio value ($\delta^{13}C$) is reported in terms of per mil (‰) notation with respect to the Vienna Peedee Belemnite (VPDB) standard. Water samples for hydrogen isotope analysis were sealed into Pyrex tubing along with a measured quantity of zinc. Each sample tube was reacted in a heating block at 500°C for 35 minutes to generate hydrogen gas. Once the sample had been reacted, the $^{1}H/^{2}H$ ratio was determined by mass spectrometric analysis that compared the sample to a reference standard. The hydrogen isotope ratio value (δD) is reported in terms of per mil notation with respect to the Vienna Standard Mean Ocean Water (VSMOW) standard (Alan R. Langenfeld, Isotech Laboratories, Inc., written commun., 2012).

Table 1. Information on 20 wells sampled in Sullivan County, Pennsylvania, 2012.

[Well locations are shown in figure 2. --, information not available; >, greater than; R, reported]

Well-identification number	Date sampled	Well depth (feet below land surface)	Casing length (feet)	Yield (gallons per minute)	Depth to water (feet below land surface)	Geologic unit
SU-148	8/22/2012	245	20	15	--	Mauch Chunk Formation
SU-149	8/20/2012	250	50	30	>140	Burgoon Sandstone member of the Pocono Formation
SU-150	8/14/2012	440	40	10	--	Burgoon Sandstone member of the Pocono Formation
SU-151	8/15/2012	340	41	10	--	Catskill Formation
SU-152	8/15/2012	115	40	23	--	Huntley Mountain Formation
SU-153	8/15/2012	250	67	9	--	Huntley Mountain Formation
SU-154	8/14/2012	248	129	15	--	Huntley Mountain Formation
SU-155	8/23/2012	145	81	5	--	Mauch Chunk Formation
SU-156	8/16/2012	250	30	2	100 R	Catskill Formation
SU-157	8/21/2012	280	268	10	114.1	Huntley Mountain Formation
SU-158	8/22/2012	46	12	6	15 R	Huntley Mountain Formation
SU-159	8/23/2012	104	104	20	30 R	Alluvium
SU-160	8/15/2012	500	40	1.5	235.4	Catskill Formation
SU-161	9/5/2012	200	50	15	50 R	Burgoon Sandstone member of the Pocono Formation
SU-162	8/21/2012	140	60	>25	--	Huntley Mountain Formation
SU-163	8/21/2012	100	54	15	--	Burgoon Sandstone member of the Pocono Formation
SU-164	8/22/2012	300	40	30	--	Allegheny and Pottsville Formations, undivided
SU-165	8/20/2012	440	60	6	--	Catskill Formation
SU-166	8/23/2012	180	30	4	80 R	Mauch Chunk Formation
SU-167	8/27/2012	200	40	10	--	Mauch Chunk Formation

Baseline Groundwater Quality

Analytical results for the 20 groundwater samples collected during this study are provided in the following sections. The quality of the sampled groundwater was generally within U.S. Environmental Protection Agency (USEPA) standards, although in some samples, the concentrations of certain constituents exceeded drinking-water standards (U.S. Environmental Protection Agency, 2006, 2012). In general, most of the water-quality problems involve aesthetic considerations, such as taste or odor from excessive dissolved solids, iron, manganese, and chloride that develop from natural interactions of water and rock minerals in the subsurface.

The quality assurance/quality control (QA/QC) field-blank sample contained no constituent in concentrations greater than the laboratory reporting levels; this indicates that no contamination occurred through the sampling or analytical procedures.

The difference in concentration between the sample and the QA/QC replicate sample (well SU-162) ranged from 0 to 2.5 percent for major ions and nutrients. Variability was considered acceptable if the difference was less than 5 percent. The difference in concentration between the sample and the QA/QC replicate sample (well SU-162) for metals and trace elements ranged from 0.5 to 47.5 percent; the median difference was 2.2 percent. The analytes with the largest percent differences in concentrations between the sample and its replicate were low-concentration analytes where the concentrations were near the laboratory reporting level. The greatest difference (47.5 percent) was for molybdenum; the difference in concentration between the sample (0.137 µg/L) and the replicate sample (0.072 µg/L) was 0.065 µg/L. The laboratory detection limit for molybdenum was 0.014 µg/L. The range in measured molybdenum concentrations was from less than 0.014 to 3.78 µg/L.

Physical Properties

Physical properties include temperature, pH, and specific conductance. These properties are unstable and are determined in the field at the time a water sample is collected. Alkalinity and dissolved oxygen concentration also are determined in the field. Alkalinity was determined for several samples in the laboratory. Summary statistics for physical properties are given in table 2, and field values and analytical results are provided in table 3.

The USEPA has set maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) for some constituents in drinking water (table 4). MCLs generally are set because elevated concentrations of these constituents may cause adverse health effects. SMCLs generally are set for aesthetic reasons; elevated concentrations of these constituents may impart an undesirable taste or odor to water.

pH is a measurement of the activity of hydrogen ions in water. pH is expressed in logarithmic units with a pH of 7 considered neutral. Water with a pH less than 7 is acidic; water with a pH greater than 7 is basic. pH values in this study ranged from 5.0 to 8.8; the median pH was 6.8 (table 2). The pH of 10 of the 20 samples (50 percent) was outside the USEPA SMCL range of 6.5 to 8.5 (U.S. Environmental Protection Agency, 2012). Nine samples had a pH less than 6.5, and one sample had a pH greater than 8.5 (table 3).

Water samples from the Burgoon Sandstone Member of the Pocono Formation were the most acidic. The median pH of water samples from the Burgoon Sandstone Member was 5.9; from the Mauch Chunk Formation, 6.6; from the Catskill Formation, 6.9, and from the Huntley Mountain Formation, 7.0.

The alkalinity of a solution is a measure of the capacity for solutes it contains to react with and neutralize acid (Hem, 1985, p. 106). Alkalinity ranged from 6.4 to 134 mg/L as calcium carbonate; the median concentration was 62.3 mg/L (table 2). Alkalinity is related to the pH of a water sample. In general, water samples with a higher pH have a higher alkalinity.

Specific conductance is a measurement of the ability of water to conduct an electric current. Specific conductance ranged from 42 to 1,280 microsiemens per centimeter (µS/cm); the median specific conductance was 218 µS/cm (table 2). Median specific conductance values ranged from 187 µS/cm for the Catskill Formation to 248 µS/cm for the Huntley Mountain Formation. Specific conductance is related to the dissolved solids concentration of a water sample ($r^2 = 0.98$, fig. 4). The mean ratio of specific conductance to total dissolved solids was 0.63 for 20 water samples.

Dissolved oxygen concentrations ranged from 0.1 to 9.1 mg/L; the median concentration was 4.3 mg/L (table 2). Median dissolved oxygen concentrations ranged from 1.5 mg/L for the Huntley Mountain Formation to 4.7 mg/L for the Burgoon Sandstone Member.

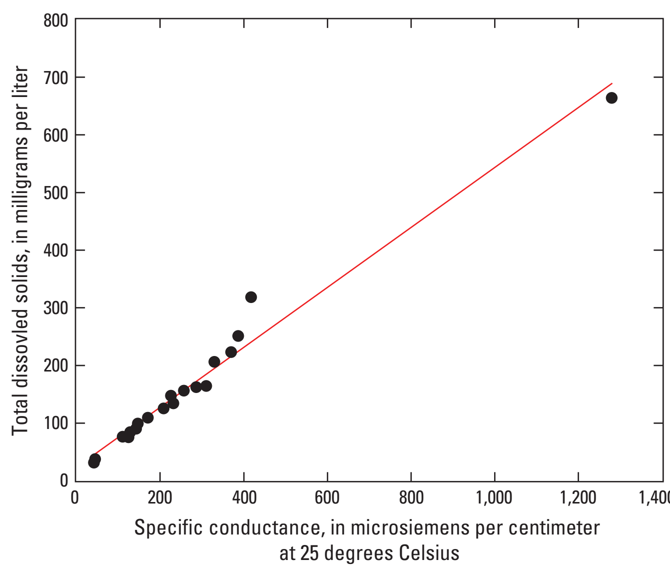


Figure 4. Relation between total dissolved solids and specific conductance for groundwater samples from wells in Sullivan County, Pennsylvania

Table 2. Summary statistics for physical properties and dissolved gas concentrations in water samples from 20 wells sampled in Sullivan County, Pennsylvania, 2012.

[Dissolved gas samples analyzed by the U.S. Geological Survey Chlorofluorocarbon Laboratory in Reston, Virginia; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; <, less than; --, unable to compute statistic]

Constituent or property	All wells			Burgoon Sandstone Member of the Pocono Formation (n=4)			Catskill Formation (n=4)			Huntley Mountain Formation (n=6)			Mauch Chunk Formation (n=4)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
pH, field (standard units)	5.0	6.8	8.8	5.0	5.9	6.2	5.7	6.9	8.4	5.8	7.0	8.8	5.6	6.6	7.1
Specific conductance, field (µS/cm)	42	218	1,280	42	215	370	125	187	1,280	45	248	418	129	227	387
Oxygen, dissolved, field (mg/L)	0.1	4.3	9.1	0.3	4.7	5.6	0.9	3.2	7.9	0.2	1.5	9.1	0.1	2.5	7.3
Temperature (degrees Celsius)	9.0	11.1	12.4	9.8	10.5	11.8	10.1	11.4	12.4	9.0	10.1	12.3	9.4	11.1	11.6
Alkalinity (mg/L as $CaCO_3$)	6.4	62.3	134	6.4	44.0	62.2	38.7	71.5	105	16.2	67.7	134	24.6	62.0	78.2
Methane, dissolved (mg/L)	<0.001	<0.001	51.1	<0.001	<0.001	0.063	<0.001	<0.001	4.1	<0.001	<0.001	51.1	<0.001	--	0.052
Carbon dioxide, dissolved (mg/L)	0.35	21.8	120	47.0	54.3	120	0.56	20.1	90.4	0.35	12.6	36.4	7.07	32.9	86.9
Nitrogen gas, dissolved (mg/L)	17.2	20.4	31.6*	18.9	20.1	23.0	17.2	20.0	22.2	17.6	20.6	22.3	18.9	20.7	24.1
Argon, dissolved (mg/L)	0.66	0.73	1.06*	0.68	0.71	0.74	0.66	0.70	0.76	0.66	0.73	0.78	0.69	0.74	0.80

*Allegheny and Pottsville Formations, undivided.

Table 3. Physical properties and dissolved gas concentrations for water samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Locations are shown in figure 2; site information is listed in table1. Dissolved gas samples analyzed by the U.S. Geological Survey Chlorofluorocarbon Laboratory in Reston, Virginia; mg/L, milligrams per liter; <, less than; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data; $CaCO_3$, calcium carbonate. **Bold** values exceed drinking-water standard]

Well-identification number	pH, field (standard units)	Specific conductance, field (µS/cm)	Oxygen, dissolved, field (mg/L)	Temperature (degrees Celsius)	Alkalinity, field, as $CaCO_3$ (mg/L)	Alkalinity, lab, as $CaCO_3$ (mg/L)	Methane, dissolved (mg/L)	Carbon dioxide, dissolved (mg/L)	Nitrogen gas, dissolved (mg/L)	Argon, dissolved (mg/L)
SU-148	6.8	143	0.3	9.4	--	78.2	0.002	19.9	21.8	0.77
SU-149	**6.2**	370	5.6	11.0	62.2	--	<0.001	53.1	18.9	0.68
SU-150	**5.8**	257	0.3	9.8	--	44.8	0.06	120	21.2	0.73
SU-151	8.4	1,280	0.9	11.2	77.3	--	4.1	0.6	22.2	0.76
SU-152	7.2	287	0.6	9.0	97.0	--	<0.001	13.2	21.7	0.74
SU-153	**6.3**	418	7.9	10.1	42.1	--	<0.001	36.4	20.6	0.73
SU-154	**8.8**	330	0.2	10.0	--	134	51.1	0.4	19.1	0.66
SU-155	**6.3**	311	0.1	11.0	--	61.7	0.05	45.9	24.1	0.80
SU-156	6.9	147	7.9	12.4	65.7	--	<0.001	18.1	17.2	0.66
SU-157	6.7	111	2.4	11.4	40.0	--	<0.001	11.9	20.6	0.73
SU-158	**5.8**	45	9.1	12.3	--	16.2	<0.001	32.4	17.6	0.67
SU-159	7.0	232	7.4	11.5	--	63.6	<0.001	6.3	20.2	0.73
SU-160	6.9	226	5.2	10.1	105	--	<0.001	22.1	19.7	0.71
SU-161	**6.0**	172	3.8	10.0	43.1	--	<0.001	47.0	23.0	0.74
SU-162	7.4	209	0.2	9.3	93.3	--	0.002	8.9	22.3	0.78
SU-163	**5.0**	42	5.5	11.8	--	6.4	<0.001	55.5	19.1	0.70
SU-164	7.0	171	5.6	11.8	--	90.4	0.002	21.5	31.6	1.06
SU-165	**5.7**	125	1.1	11.6	38.7	--	<0.001	90.4	20.3	0.70
SU-166	**5.6**	387	4.8	11.6	--	24.6	<0.001	7.1	18.9	0.72
SU-167	7.1	129	7.3	11.1	62.3	--	<0.001	86.9	19.5	0.69

Table 4. U.S. Environmental Protection Agency maximum contaminant, secondary contaminant, and action levels for constituents in drinking water.

[From U.S. Environmental Protection Agency (2012). µg/L, micrograms per liter; mg/L, milligrams per liter; pCi/L, picocuries per liter; --, no standard; N, nitrogen]

Regulated constituent	Maximum contaminant level	Action level[1]	Secondary maximum contaminant level
Aluminum	--	--	50–200 µg/L
Antimony	6 µg/L	--	--
Arsenic	10 µg/L	--	--
Barium	2 mg/L	--	--
Beryllium	4 µg/L	--	--
Cadmium	5 µg/L	--	--
Chromium, total	100 µg/L	--	--
Chloride	--	--	250 mg/L
Copper	--	--	1,000 µg/L
Fluoride	4 mg/L	--	2 mg/L
Iron	--	--	300 µg/L
Lead	--	15 µg/L	--
Manganese	--	--	50 µg/L
Nitrate as N	10 mg/L	--	--
Nitrite	1 mg/L	--	--
pH	--	--	6.5–8.5
Selenium	50 µg/L	--	--
Silver	--	--	100 µg/L
Sulfate	--	--	250 mg/L
Total dissolved solids	--	--	500 mg/L
Uranium	30 µg/L	--	--
Zinc	--	--	5 mg/L
Gross alpha radioactivity	15 pCi/L	--	--

[1]Lead is regulated by a treatment technique that requires water purveyors to control the corrosiveness of their water. If more than 10 percent of tap-water samples exceed the action level, the water purveyor must take additional steps.

Major Ions

Major ions dissolved from soil and rock make up most of the dissolved solutes in groundwater; the remainder comes mostly from constituents dissolved in precipitation. Summary statistics for major ions are given in table 5, and analytical results are provided in table 6. Major ions, in order of decreasing median concentration, were calcium, chloride, sodium, sulfate, silica, magnesium, potassium, fluoride, and bromide.

Total dissolved solids (tables 5 and 6) is a measurement of the total solutes in water. The USEPA SMCL for total dissolved solids in drinking water is 500 mg/L. The total dissolved solids concentration ranged from 31 to 664 mg/L; the median concentration was 130 mg/L. Median total dissolved solids concentrations ranged from 123 mg/L in the Catskill Formation to 144 mg/L in the Huntley Mountain Formation. The total dissolved solids concentration in water from one sample exceeded the SMCL. The elevated total dissolved solids concentration (664 mg/L) in the water sample from well SU-151 in the Catskill Formation was caused by elevated concentrations of sodium and chloride. The likely cause of the elevated sodium and chloride is connate water in the formation and a zone of restricted groundwater flow that limits flushing.

Chloride concentrations ranged from 0.59 to 342 mg/L; the median concentration was 12.9 mg/L. Median chloride concentrations ranged from 6.18 mg/L in the Catskill Formation to 39.6 mg/L in the Burgoon Sandstone Member. The concentration of chloride (342 mg/L) in the water sample from well SU-151 in the Catskill Formation (the geologic unit with the lowest median chloride concentration) exceeded the USEPA SMCL of 250 mg/L for chloride (tables 5 and 6).

Nutrients

Nutrients include nitrogen and phosphorus species. Nitrogen is found in water principally as nitrate (NO_3), nitrite (NO_2), and ammonia (NH_4). The presence of nutrients generally is an indicator of an anthropogenic source(s) of nitrogen, which in groundwater might include fertilizers, storm runoff, animal wastes, and effluent from septic systems. Summary statistics for nutrients are given in table 7, and analytical results are provided in table 8. Concentrations of nutrients in samples from the 20 wells were low. Nitrite, ammonia, and orthophosphorus were present in concentrations less than 0.3 mg/L. Median concentrations of ammonia (less than 0.01 mg/L) and nitrite (less than 0.001 mg/L) were below the laboratory detection limit.

Nitrate is the most prevalent nitrogen species in groundwater (table 7). Because concentrations of nitrite are so low, nitrate plus nitrite concentrations represent nitrate concentrations. The concentration of nitrate as nitrogen ranged from less than 0.04 to 1.95 mg/L; the median concentration was 0.245 mg/L. All nitrate concentrations were well below the USEPA MCL of 10 mg/L.

Metals and Trace Elements

Metals and other trace elements typically are present in concentrations less than 1 mg/L in natural waters (Hem, 1985). Most of the metals and trace elements in natural groundwater are leached from the soil or dissolved from the underlying bedrock in minute quantities by circulating groundwater. Some are present in precipitation.

Summary statistics for metals and trace elements are listed in table 9, and analytical results are provided in table 10. The USEPA has established MCLs and SMCLs for some of these constituents in drinking water (table 4). Of these constituents, only iron and manganese concentrations exceeded the USEPA water-quality standards (table 9).

Elevated concentrations of iron may cause the water to be a yellowish or orange color. Elevated concentrations of iron and manganese in water may impart a bitter taste and stain laundry and plumbing fixtures. Concentrations of dissolved iron in water from the 20 sampled wells ranged from less than 3.2 to 6,590 µg/L; the median concentration was 11.5 µg/L (table 9). Median dissolved iron concentrations ranged from 4.82 µg/L for the Huntley Mountain Formation to 154 µg/L for the Mauch Chunk Formation. Water samples from 4 of the 20 sampled wells (20 percent) exceeded the USEPA SMCL of 300 µg/L. Sources of iron in well water include minerals in the bedrock, corrosion of iron well casings, and bacterial activity.

Concentrations of dissolved manganese in water from the 20 sampled wells ranged from less than 0.13 to 1,710 µg/L; the median concentration was 38.5 µg/L (table 9). Median manganese concentrations ranged from 4.37 µg/L for the Catskill Formation to 336 µg/L for the Mauch Chunk Formation. Water samples from 7 of the 20 sampled wells (35 percent) exceeded the USEPA SMCL of 50 µg/L. Three of the four water samples (75 percent) from the Mauch Chunk Formation exceeded the USEPA SMCL for manganese.

Radionuclides

Analyses for radioactivity and radionuclides included gross alpha radioactivity, gross beta radioactivity, and dissolved radon-222 (radon gas). Uranium, a radioactive element, also was analyzed. Although radionuclides are naturally present in the groundwater of Sullivan County, they may present a health problem if activities are elevated (see U.S. Environmental protection Agency, 2013b). Summary statistics for radioactive constituents are given in table 11, and analytical results are provided in table 12. The USEPA has established or proposed MCLs for some of these constituents in drinking water (table 4).

Radioactivity is the release of energy and energetic particles by changes in the structure of certain unstable elements as they break down to form more stable arrangements. Radioactive energy is released as (1) alpha radiation consisting of positively charged helium nuclei, (2) beta radiation consisting of electrons or positrons, and (3) gamma radiation consisting of electromagnetic waves.

The most commonly used unit for radioactivity in water is picocuries per liter (pCi/L). One Curie is the activity of 1 gram of radium, which is equal to 3.7×10^{10} atomic disintegrations per second. Activity refers to the number of particles emitted by a radionuclide. The rate of decay is proportional to the number of atoms present and inversely proportional to half-life. The half-life is the amount of time it takes for a radioactive element to decay to one half its original quantity.

Naturally occurring radioactivity in groundwater is produced primarily by the radioactive decay of uranium-238 and thorium-232. These isotopes disintegrate in steps, forming a series of radioactive nuclide “daughter” products, mostly short lived, until a stable lead isotope is produced. The uranium-238 decay series produces the greatest amount of radioactivity in natural ground water (Hem, 1985, p. 147). Uranium-238 has a half-life of 4.5×10^9 years. Its daughter products include radium-226 (half-life of 1,620 years) and radon-222 (half-life of 3.8 days). Radon-222, a decay product of radium-226, is a colorless, odorless, chemically inert, alpha-particle-emitting gas, which is soluble in water. The end product of the decay series is the stable isotope lead-206.

Activities of radon-222 in water from the 20 sampled wells ranged from 169 to 15,300 pCi/L; the median activity was 990 pCi/L (table 11). Median radon-222 activities ranged from 680 pCi/L in the Mauch Chunk Formation to 1,390 pCi/L in the Catskill Formation. The USEPA does not currently regulate radon-222 in drinking water. However, under the framework specified by the 1999 Notice for the Proposed Radon in Drinking Water Rule (Federal Register, 1999), the USEPA proposed an alternative maximum contaminant level (AMCL) of 4,000 pCi/L for radon-222 for community water systems that use groundwater for all or some of the supply in states with an enhanced indoor radon program. For states without an enhanced indoor air program, the USEPA proposed an MCL of 300 pCi/L for radon-222. Water samples from 17 of the 20 wells sampled (85 percent) exceeded the proposed USEPA MCL of 300 pCi/L; however, only two water samples (10 percent of sampled wells) exceeded the proposed USEPA AMCL of 4,000 pCi/L for radon-222. All four of the water samples from the Catskill Formation exceeded the proposed USEPA MCL.

The gross alpha-particle radioactivity in water from the 20 sampled wells ranged from less than the detection limit to 33 pCi/L; the median activity was 1.5 pCi/L (table 11). The USEPA has established an MCL of 15 pCi/L for gross alpha-particle activity (table 4). One water sample exceeded the USEPA MCL.

The concentration of uranium ranged from less than 0.004 to 6.35 µg/L; the median concentration was 0.152 µg/L. No water samples exceeded the USEPA MCL of 30 µg/L for uranium.

Dissolved Gases

Dissolved gases analyzed are methane, carbon dioxide, nitrogen, argon, oxygen, and radon-222. Radon-222 was discussed in the “Radionuclides” section, and oxygen was discussed in the “Physical Properties” section. Summary statistics for the other dissolved gases are given in table 2, and analytical results are provided in table 3.

Concentrations of dissolved methane ranged from less than 0.001 to 51.1 mg/L (table 2). Methane was not detected in water samples from 13 of the wells (table 3). The dissolved methane concentrations in water from two wells, SU-151 (Catskill Formation) and SU-154 (Huntley Mountain Formation) were 4.1 and 51.1 mg/L, respectively. A dissolved methane concentration greater than 28 mg/L indicates that potentially explosive or flammable quantities of the gas are being produced (Eltschlager and others, 2001, p. 40). A very strong odor of hydrogen sulfide was noted during the sampling of well SU-154. Water from these 2 wells were the only samples from the 20 wells sampled with a pH greater than 8.

Samples of water from wells SU-151 and SU-154 were also analyzed for the hydrocarbon gases ethane, ethylene, propane, iso-butane, and N-butane and for the hydrocarbon liquids iso-pentane, N-pentane, and hexane. Ethane concentrations of 0.002 and 0.02 mg/L were measured in the water samples from wells SU-151 and SU-154, respectively. The other hydrocarbons were not detected.

Samples of water from wells SU-151 and SU-154 were analyzed for isotopes of carbon and hydrogen in the methane. The $\delta^{13}C$ values were -48.65 and -42. 37 per mil, and the δD values were -170.2 and -226.6 per mil for wells SU-151 and SU-154, respectively. These values fall within the range for a thermogenic natural gas source, rather than a microbial (biogenic) gas source (fig. 5). The water sample from well SU-151 had the highest concentrations of arsenic, bromide, chloride, lithium, molybdenum, and sodium; the second highest concentrations of barium, boron, and strontium; and the third highest concentrations of fluoride of the 20 wells sampled. The water sample from well SU-154 had the highest concentrations of boron and fluoride; the second highest concentration of bromide and sodium; and the third highest concentration of arsenic, lithium, molybdenum, and strontium of the 20 wells sampled.

Table 5. Summary statistics for concentrations of major ions in water samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[All constituent conentrations are in milligrams per liter; --, no water-quality standard; n, number of samples; <, less than]

Dissolved constituent	All wells					Burgoon Sandstone Member of the Pocono Formation (n=4)			Catskill Formation (n=4)			Huntley Mountain Formation (n=6)			Mauch Chunk Formation (n=4)		
	Minimum	Median	Maximum	Secondary maximum contaminant level[1]	Number of samples exceeding standard	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
CATIONS																	
Calcium	2.64	25.4	41.9	--	--	2.64	24.4	37.1	14.4	21.5	28.6	6.17	20.8	41.9	23.0	26.6	37.3
Magnesium	1.07	2.73	9.66	--	--	1.26	4.27	5.85	1.11	1.66	2.42	1.07	3.31	9.66	2.67	3.43	5.75
Potassium	0.44	0.90	4.47	--	--	0.53	2.46	3.14	0.55	1.09	4.47	0.44	0.71	0.96	0.77	1.06	1.90
Sodium	0.42	8.08	236	--	--	2.26	4.07	27.8	4.51	18.0	236	1.13	12.3	66.4	0.42	4.12	40.6
ANIONS																	
Bromide	[2]0.018	0.026	2.68	--	--	0.020	0.030	0.043	0.019	0.024	2.68	0.019	0.029	0.26	0.019	0.029	0.047
Chloride	0.59	12.9	342	250	1	5.0	24.6	72.5	0.98	6.18	342.0	0.59	17.2	94	0.66	23.4	81.5
Fluoride	<0.04	0.06	0.45	2	0	<0.04	0.04	0.08	<0.04	0.14	0.23	<0.04	0.06	0.45	<0.04	0.06	0.08
Sulfate	0.68	6.96	26.1	250	0	3.29	8.28	14.9	1.79	9.01	13.2	0.68	4.16	12.4	2.09	6.86	26.1
OTHERS																	
Silica	4.54	6.20	8.12	--	--	4.54	6.23	7.17	6.29	6.56	8.12	5.21	5.89	6.79	5.86	6.64	7.30
Total dissolved solids	31	130	664	500	1	31	128	223	75	123	664	37	144	318	84	127	251

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

[2]Allegheny and Pottsville Formations, undivided.

Table 6. Concentrations of major ions in water samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Well locations are shown in figure 2; site information is listed in table1.All concentrations are in milligrams per liter; °C, degrees Celsius; <, less than; **Bold** values exceed drinking-water standard (U.S. Environmental Protection Agency, 2012)]

Well-identification number	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved	Potassium, dissolved	Bromide, dissolved	Chloride, dissolved	Fluoride, dissolved	Silica, dissolved	Sulfate, dissolved	Dissolved solids dried at 180°C
SU-148	25.2	3.98	1.15	0.90	0.02	1.75	0.08	6.1	2.09	90
SU-149	37.1	5.76	27.8	1.82	0.043	72.5	0.08	5.39	10.3	223
SU-150	25.5	5.85	2.87	3.14	0.033	39.3	0.06	7.06	6.25	156
SU-151	14.4	1.11	236	1.6	2.68	**342**	0.22	6.76	1.79	**664**
SU-152	40.8	5.21	9.07	0.96	0.02	19.1	0.07	5.21	12.4	162
SU-153	41.9	9.66	21.8	0.9	0.037	94	<0.04	5.79	7.36	318
SU-154	13.1	1.64	66.4	0.60	0.261	34.1	0.45	6.79	0.68	206
SU-155	37.3	5.75	7.08	1.21	0.047	45.1	0.06	7.18	9.8	164
SU-156	28.6	2.42	4.51	0.55	0.019	0.98	<0.04	8.12	7.91	99
SU-157	15.6	3.95	1.17	0.60	0.021	10.6	0.05	5.76	0.96	76
SU-158	6.17	1.07	1.13	0.44	0.019	0.59	0.05	6.35	6.55	37
SU-159	29.3	2.39	13.5	0.61	0.197	25.6	0.05	6.03	11.1	134
SU-160	27.1	1.82	31.3	0.58	0.025	5.51	0.23	6.29	13.2	147
SU-161	23.2	2.78	5.27	3.1	0.027	9.88	<0.04	7.17	14.9	100
SU-162	25.9	2.67	15.5	0.81	0.133	15.3	0.08	5.98	1.77	125
SU-162 replicate	26.1	2.66	15.4	0.79	0.136	15.2	0.08	5.97	1.75	125
SU-163	2.64	1.26	2.26	0.53	0.02	5.00	0.02	4.54	3.29	31
SU-164	19.2	6.19	9.28	1.43	0.018	0.76	0.14	6.1	4.52	109
SU-165	15.8	1.49	4.77	4.47	0.023	6.85	0.06	6.36	10.1	75
SU-166	27.9	2.87	40.6	1.9	0.039	81.5	0.05	7.3	26.1	251
SU-167	23.0	2.67	0.42	0.77	0.019	0.66	<0.04	5.86	3.91	84

Table 7. Summary statistics for concentrations of nutrients in water samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[All constituents are in milligrams per liter; n, number of samples; N, nitrogen; P, phosphorus; <, less than; NS, unable to compute statistic; --, no water-quality standard]

Dissolved constituent	All wells			Maximum contaminant level[1]	Burgoon Sandstone Member of the Pocono Formation (n=4)			Catskill Formation (n=4)			Huntley Mountain Formation (n=6)			Mauch Chunk Formation (n=4)		
	Minimum	Median	Maximum		Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Ammonia, dissolved (as N)	<0.01	<0.01	0.241	--	<0.01	NS	0.241	<0.01	<0.01	0.127	<0.01	<0.01	0.124	<0.01	NS	0.081
Nitrate plus nitrite, dissolved (as N)	<0.04	0.245	1.95	--	<0.04	1.02	1.29	0.172	0.961	1.80	<0.04	0.196	1.07	<0.04	NS	1.95
Nitrate, dissolved (as N)	<0.04	0.245	1.95	10	<0.04	1.02	1.29	0.172	0.958	1.80	<0.04	0.196	1.07	<0.04	NS	1.95
Nitrite, dissolved (as N)	<0.001	<0.001	0.005	1	<0.001	<0.001	0.001	<0.001	<0.001	0.005	<0.001	NS	0.001	<0.001	<0.001	0.002
Orthophosphate, dissolved (as P)	<0.004	NS	0.045	--	<0.004	<0.004	0.012	0.005	0.012	0.018	<0.004	NS	0.045	<0.004	NS	0.017

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

Table 8. Concentrations of nutrients in water samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Well locations are shown in figure 2; site information is listed in table1. mg/L, milligrams per liter; N, nitrogen; P, phosphorus; <, less than]

Well-identification number	Ammonia, dissolved (mg/L as N)	Nitrate plus nitrite, dissolved (mg/L as N)	Nitrate, dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Orthophosphate, dissolved (mg/L as P)
SU-148	0.075	<0.04	< 0.04	<0.001	<0.004
SU-149	0.014	0.256	0.256	<0.001	<0.004
SU-150	0.241	<0.04	< 0.039	0.001	<0.004
SU-151	0.127	0.332	0.327	0.005	0.005
SU-152	<0.01	0.159	0.158	0.001	<0.004
SU-153	<0.01	1.07	1.07	0.001	0.005
SU-154	0.124	<0.04	< 0.039	0.001	0.045
SU-155	0.081	<0.04	< 0.038	0.002	<0.012
SU-156	<0.01	1.8	1.8	<0.001	0.018
SU-157	<0.01	0.622	0.622	<0.001	<0.004
SU-158	<0.01	0.233	0.233	<0.001	0.015
SU-159	<0.01	0.415	0.415	<0.001	<0.004
SU-160	<0.01	0.172	0.172	<0.001	0.011
SU-161	<0.01	1.29	1.29	<0.001	0.012
SU-162	0.055	<0.04	<0.04	<0.001	<0.004
SU-162 replicate	0.056	< 0.04	<0.04	<0.001	<0.004
SU-163	<0.01	0.741	0.741	<0.001	<0.004
SU-164	0.229	<0.04	<0.04	<0.001	<0.004
SU-165	<0.01	1.59	1.59	<0.001	0.012
SU-166	<0.01	1.95	1.95	<0.001	0.017
SU-167	<0.01	0.234	0.234	<0.001	0.006

Table 9. Summary statistics for concentrations of metals and trace elements in samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[All concentrations are in micrograms per liter; water-quality standards from U.S. Environmental Protection Agency (2012); n, number of samples; --, no standard; <, less than; NS, could not compute statistic]

Dissolved constituent	All wells			Water-quality standard[1]			Number of samples exceeding standard	Percentage of samples exceeding standard	Burgoon Sandstone Member of the Pocono Formation (n=4)		
	Minimum	Median	Maximum	Maximum contaminant level	Action level[2]	Secondary maximum contaminant level			Minimum	Median	Maximum
Aluminum	<2.2	<2.2	26.3	--	--	50–200	0	0	<2.2	<2.2	18.5
Antimony	<0.027	<0.027	0.294	6	--	--	0	0	<0.027	NS	0.251
Arsenic	<0.03	0.30	8.85	10	--	--	0	0	<0.03	0.093	0.67
Barium	5.89	140	1,050	2,000	--	--	0	0	24	159	1,050
Beryllium	<0.006	0.010	0.125	4	--	--	0	0	0.01	0.034	0.125
Boron	4	20	153	--	--	--	--	--	7	22	91
Cadmium	<0.016	<0.016	0.112	5	--	--	0	0	0.021	NS	0.072
Chromium	<0.07	<0.07	0.3	100	--	--	0	0	<0.07	<0.07	0.1
Cobalt	<0.021	0.062	8.04	--	--	--	--	--	0.052	0.16	0.47
Copper	<0.80	4.2	130	--	--	1,000	0	0	<0.80	14.2	70.6
Iron	<3.2	11.5	6,590	--	--	300	4	20	<3.20	115	6,590
Lead	<0.025	0.364	7.36	--	15	--	0	0	<0.025	0.813	2.48
Lithium	0.48	5.73	457	--	--	--	--	--	1.29	6.59	41.5
Manganese	<0.13	38.5	1,710	--	--	50	7	35	40.1	42.6	1,710
Molybdenum	<0.014	0.126	3.78	--	--	--	--	--	<0.014	NS	0.124
Nickel	<0.09	0.42	4.3	--	--	--	--	--	0.42	1.3	4.3
Selenium	<0.03	0.08	0.95	50	--	--	0	0	<0.03	0.14	0.95
Silver	<0.005	<0.005	0.11	--	--	100	0	0	<0.005	<0.005	0.006
Strontium	13.4	221	2,450	--	--	--	--	--	647	1,048	1,180
Zinc	<1.4	9.2	44.4	--	--	5,000	0	0	10.2	24.7	25.5

Table 9. Summary statistics for concentrations of metals and trace elements in samples from 20 wells, Sullivan County, Pennsylvania, 2012.—Continued

[All concentrations are in micrograms per liter; water-quality standards from U.S. Environmental Protection Agency (2012); n, number of samples; --, no standard; <, less than; NS, could not compute statistic]

Dissolved constituent	Catskill Formation (n=4)			Huntley Mountain Formation (n=6)			Mauch Chunk Formation (n=4)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Aluminum	<2.2	4.06	26.3	<2.2	<2.2	5.12	<2.2	<2.2	14.2
Antimony	0.043	0.084	0.131	<0.027	<0.027	0.294	<0.027	<0.027	0.092
Arsenic	0.217	3.47	8.85	<0.03	0.258	4.97	0.096	0.934	2.54
Barium	81	140	415	5.89	167	304	88	170	354
Beryllium	0.008	0.010	0.057	<0.006	0.007	0.017	<0.006	0.014	0.775
Boron	9	43	150	5	25	153	4	16	43
Cadmium	<0.016	NS	0.031	<0.016	<0.016	<0.016	<0.016	0.030	0.112
Chromium	<0.07	0.1	0.3	<0.07	NS	0.1	<0.07	<0.07	0.2
Cobalt	0.063	0.065	0.076	<0.021	0.024	0.037	<0.021	1.21	8.04
Copper	4.7	22.0	130	<0.80	<0.80	21.2	1.9	8.6	70.2
Iron	<3.20	7.58	84.8	<3.20	4.82	523	<3.20	154	6,100
Lead	0.198	0.714	2.42	<0.025	0.143	1.44	0.172	0.277	7.36
Lithium	0.48	15.5	457	0.55	3.91	38.5	1.91	6.38	19.4
Manganese	0.34	4.37	69.3	0.161	14.5	316	<0.13	336	765
Molybdenum	0.044	1.16	3.78	<0.014	0.096	1.15	<0.014	0.107	0.335
Nickel	0.20	0.30	1.2	<0.09	0.18	1.4	0.21	2.4	3.9
Selenium	0.06	0.26	0.53	<0.03	NS	0.15	<0.03	NS	0.55
Silver	<0.005	NS	0.11	<0.005	<0.005	0.007	<0.005	<0.005	0.007
Strontium	45.2	82.5	2,380	13.4	173	1,210	121	212	2,450
Zinc	6.6	8.3	24.9	<1.4	4.2	13.3	2.4	11.2	44.4

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

[2] Lead is regulated by a treatment technique that requires water purveyors to control the corrosiveness of their water. If more than 10 percent of tap-water samples exceed the action level, the water purveyor must take additional steps.

Table 10. Concentrations of metals and trace elements in samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Well locations are shown in figure 2; site information is listed in table 1. All concentrations are in micrograms per liter; <, less than; **bold** values exceed drinking-water standard]

Well-identification number	Aluminum, dissolved	Antimony, dissolved	Arsenic, dissolved	Barium, dissolved	Beryllium, dissolved	Boron, dissolved	Cadmium, dissolved	Chromium, dissolved	Cobalt, dissolved	Copper, dissolved
SU-148	<2.2	0.092	2.5	246	0.020	21	0.026	<0.07	8.04	1.9
SU-149	<2.2	0.251	0.11	288	0.018	91	<0.016	<0.07	0.052	6.4
SU-150	<2.2	<0.027	0.67	1,050	0.050	28	<0.016	<0.07	0.467	<0.80
SU-151	2.4	0.043	8.9	415	0.011	150	0.031	<0.07	0.064	4.7
SU-152	<2.2	0.294	0.36	286	<0.006	82	<0.016	<0.07	0.021	<0.80
SU-153	<2.2	<0.027	0.16	65.4	0.017	5	<0.016	0.08	0.037	3.7
SU-154	5.1	<0.027	5.0	304	0.007	153	<0.016	0.1	<0.021	<0.80
SU-155	<2.2	<0.027	1.7	354	0.009	11	0.033	<0.07	2.36	13.7
SU-156	<2.2	0.095	1.8	121	0.008	9	<0.016	0.10	0.076	39.3
SU-157	<2.2	<0.027	<0.03	5.89	<0.006	6	<0.016	<0.07	0.029	<0.80
SU-158	3.7	<0.027	0.14	8.79	0.007	5	<0.016	0.11	0.024	21.2
SU-159	<2.2	0.049	0.24	74.2	<0.006	11	<0.016	<0.07	0.03	1.3
SU-160	5.72	0.074	5.1	81	0.010	66	<0.016	0.1	0.063	4.7
SU-161	<2.2	0.031	0.08	24	0.01	15	0.021	0.08	0.217	70.6
SU-162	<2.2	<0.027	0.37	268	0.010	45	<0.016	<0.07	0.024	<0.80
SU-162 replicate	< 2.2	<0.027	0.39	271	0.008	44	<0.016	<0.07	<0 .021	<0.80
SU-163	18.5	<0.027	<0.03	29	0.125	7	0.072	<0.07	0.095	22
SU-164	<2.2	<0.027	1.3	317	0.014	40	<0.016	<0.07	0.979	<0.80
SU-165	26.3	0.131	0.22	159	0.057	19	0.028	0.3	0.065	130
SU-166	14.2	<0.027	0.10	94	0.078	43	0.112	0.15	0.062	70.2
SU-167	<2.2	<0.027	0.22	88.2	<0.006	4	<0.016	<0.07	<0.021	3.5

Table 10. Concentrations of metals and trace elements in samples from 20 wells, Sullivan County, Pennsylvania, 2012.—Continued

[Well locations are shown in figure 2; site information is listed in table1. All concentrations are in micrograms per liter; <, less than; **bold** values exceed drinking-water standard]

Well-identification number	Iron, dissolved	Lead, dissolved	Lithium, dissolved	Manganese, dissolved	Molybdenum, dissolved	Nickel, dissolved	Selenium, dissolved	Silver, dissolved	Strontium, dissolved	Zinc, dissolved
SU-148	292	0.352	8.89	**598**	0.335	1.8	<0.03	<0.005	265	8.2
SU-149	<3.2	<0.025	11.6	43.5	0.124	1.4	0.03	0.01	2,450	25.1
SU-150	**6,590**	0.375	41.5	**1,710**	<0.014	0.42	<0.03	<0.005	1,150	10.2
SU-151	9.4	0.198	457	**69.3**	3.78	0.38	0.22	0.11	945	6.6
SU-152	<3.2	0.218	6.01	0.16	0.274	0.18	<0.03	0.01	2,380	4.0
SU-153	4.2	0.647	1.8	0.44	0.024	0.41	0.10	<0.005	177	4.5
SU-154	27.7	0.038	38.5	36.8	1.15	<0.09	<0.03	<0.005	1,210	<1.4
SU-155	**6,100**	0.172	19.4	**765**	0.065	2.9	<0.03	<0.005	168	44.4
SU-156	<3.2	0.695	4.12	0.40	0.62	0.2	0.31	<0.005	159	8.1
SU-157	4.7	<0.025	0.55	28.6	0.056	0.13	0.15	<0.005	73.4	<1.4
SU-158	5.0	1.44	0.56	0.37	<0.014	1.4	0.05	<0.005	17.5	13.3
SU-159	10	0.15	5.45	1.06	0.128	0.17	0.15	<0.005	265	9.9
SU-160	5.8	0.733	26.8	0.34	1.7	0.22	0.53	<0.005	265	8.5
SU-161	13	1.25	1.29	40.1	0.055	1.2	0.95	<0.005	45.2	24.3
SU-162	**523**	0.068	20.2	**316**	0.137	0.17	<0.03	<0.005	1,180	10.8
SU-162 replicate	**520**	0.044	20.1	**311**	0.072	0.13	<0.03	<0.005	1,200	10.4
SU-163	217	2.48	1.57	41.6	<0.014	4.3	0.24	<0.005	13.4	25.5
SU-164	**1,790**	0.782	21.2	**233**	0.268	0.73	<0.03	<0.005	647	4.2
SU-165	84.8	2.42	0.48	8.34	0.044	1.2	0.06	0.01	50	24.9
SU-166	15.8	7.36	3.87	**73**	<0.014	3.9	0.55	0.01	91.6	14.2
SU-167	<3.2	0.201	1.91	<0.130	0.148	0.21	0.41	<0.005	121	2.4

Table 11. Summary statistics for concentrations and activities of radioactive constituents in samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Gross alpha and beta radioactivity analyses by Eberline Corporation of Redmond, California; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no standard; n, number of samples; R, not detected, result below sample specific critical level; <, less than; NS, unable to compute statistic]

Constituent	All wells			Water-quality standard				Burgoon Sandstone Member of the Pocono Formation (n=4)		
	Minimum activity or concentration	Median activity or concentration	Maximum activity or concentration	Maximum contaminant level[1]	Proposed maximum contaminant level[2]	Number of samples exceeding standard	Percentage of samples exceeding standard	Minimum activity or concentration	Median activity or concentration	Maximum activity or concentration
Gross alpha radioactivity, total (pCi/L)	R	1.5	33	15	--	1	5	R	1.8	33
Gross beta radioactivity, total (pCi/L)	R	2	21	--	--	--	--	1.1	2.8	21
Radon-222, dissolved (pCi/L)	[3]169	990	15,300	--	300	17	85	178	1,080	1,630
Uranium, dissolved (µg/L)	<0.004	0.152	6.35	30	--	0	0	<0.004	0.087	0.465

Constituent	Catskill Formation (n=4)			Huntley Mountain Formation (n=6)			Mauch Chunk Formation (n=4)		
	Minimum activity or concentration	Median activity or concentration	Maximum activity or concentration	Minimum activity or concentration	Median activity or concentration	Maximum activity or concentration	Minimum activity or concentration	Median activity or concentration	Maximum activity or concentration
Gross alpha radioactivity, total (pCi/L)	2.2	3.2	9.1	R	NS	2.8	R	NS	4.2
Gross beta radioactivity, total (pCi/L)	2.2	3.6	4.9	R	1.2	4.0	0.9	1.7	5.7
Radon-222, dissolved (pCi/L)	410	1,390	1,500	490	990	4,700	280	680	15,300
Uranium, dissolved (µg/L)	0.229	2.04	6.35	<0.004	0.060	1.58	0.005	0.346	1.82

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

[2]From Federal Register (1999).

[3]Allegheny and Pottsville Formations, undivided.

Table 12. Concentrations and activities of radioactive constituents in samples from 20 wells, Sullivan County, Pennsylvania, 2012.

[Well locations are shown in figure 2; site information is listed in table1; gross alpha and beta radioactivity analyses by Eberline Corporation of Redmond, California; µg/L, micrograms per liter; pCi/L, picocuries per liter; --, no replicate sample; R, not detected, result below sample specific critical level, value is critical level; <, less than. **Bold** values exceed drinking-water standard or proposed drinking-water standard]

Well-identification number	Gross alpha radioactivity, total (pCi/L)	Gross beta radioactivity, total (pCi/L)	Radon-222, dissolved (pCi/L)	Uranium, dissolved (µg/L)
SU-148	4.2	1.8	280	0.636
SU-149	**33**	21	**1,480**	0.16
SU-150	2.4	3.2	178	<0.004
SU-151	2.4	4.9	**1,390**	0.229
SU-152	2.8	2.9	**1,000**	1.58
SU-153	R 0.6	1.3	**2,640**	0.144
SU-154	R	1.1	**940**	0.034
SU-155	R 0.6	0.9	**670**	0.005
SU-156	3.9	2.2	**1,500**	3.44
SU-157	1.9	4	**4,700**	0.086
SU-158	R 0.1	R 0.6	**980**	<0.004
SU-159	R 0.2	R 0.3	**1,140**	0.18
SU-160	9.1	2.5	**1,390**	6.35
SU-161	1.2	2.5	**670**	0.465
SU-162	0.9	R 0.3	**490**	0.01
SU-162 replicate	--	--	--	0.009
SU-163	R	1.1	**1,630**	0.015
SU-164	0.5	1.7	169	0.005
SU-165	2.2	4.7	**410**	0.644
SU-166	R 0.5	1.5	**690**	0.056
SU-167	1.8	5.7	**15,300**	1.82

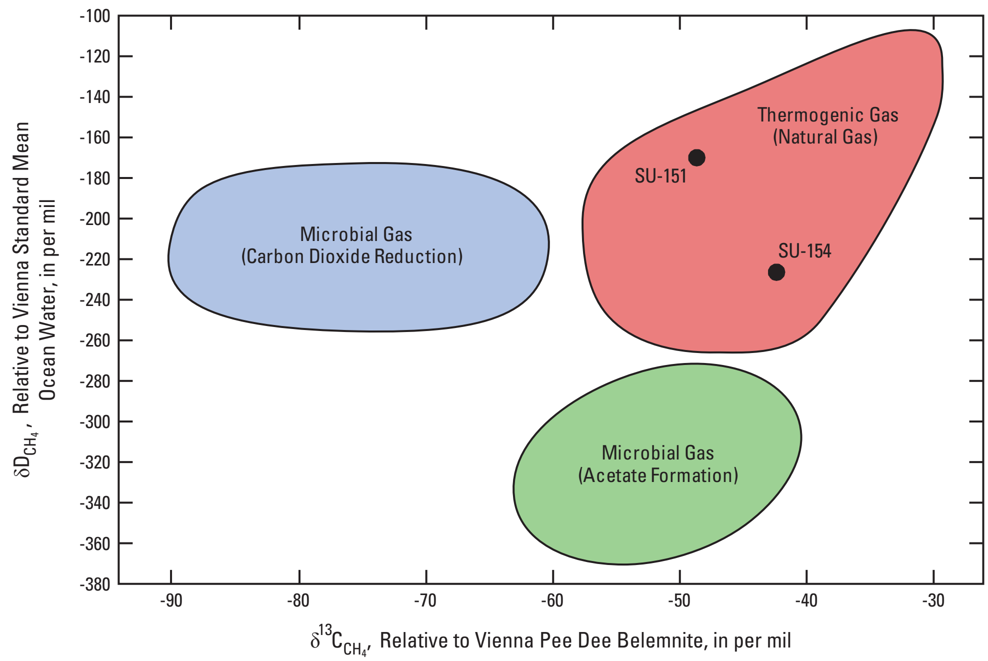


Figure 5. Stable isotopic composition of carbon and hydrogen in dissolved methane in two groundwater samples from Sullivan County, Pennsylvania. Diagram shows process end members observed in natural systems (Modified from Coleman and others, 1993, based on the dataset of Schoell, 1980). Isotope analyses were done by Isotech Laboratories, Inc., in Champaign, Illinois.

Summary

Sullivan County is underlain by the Marcellus Shale, which is being tapped as a source of natural gas. Pre-gas well drilling groundwater-quality data for water-supply wells in the northern part of Sullivan County have been collected by the natural-gas industry; however, data are not available for the rest of the county. Without baseline data for associated water-quality constituents, it is not possible to establish a connection between gas production activities and the well-water chemistry that might be affected. This study, done in cooperation with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey (Pennsylvania Geological Survey), provides a pre-gas well drilling groundwater-quality baseline for the central and southern parts of Sullivan County.

Sullivan County is underlain by surficial bedrock of Pennsylvania, Mississippian, and Devonian ages. Alluvium overlies the bedrock in the stream valleys. The major bedrock geologic formations in the county are the Pennsylvanian age Allegheny and Pottsville Formations, undivided; the Mississippian age Mauch Chunk Formation and Burgoon Sandstone Member of the Pocono Formation; and the Devonian age Catskill and Lock Haven Formations. No wells were sampled in the Lock Haven Formation.

Water samples were collected from 20 domestic wells in August and September 2012 and analyzed to characterize their physical and chemical quality. Samples were analyzed for 47 constituents and properties, including nutrients, major ions, metals and trace elements, radioactivity, and dissolved gases, including methane and radon-222. Wells were selected from the Pennsylvania Geological Survey (PaGS) Pennsylvania Groundwater Information System database. Only wells with available construction data were considered. All sampled wells are private domestic wells.

The analytical results for the 20 groundwater samples collected during this study indicate that only one constituent (gross-alpha radioactivity) in one sample was found to exceed the U.S. Environmental Protection Agency (USEPA) primary drinking water maximum contaminant level (MCL). Water samples from 85 percent of the sampled wells exceeded the proposed USEPA MCL of 300 picocuries per liter (pCi/L) for radon-222; however, only two water samples (10 percent of sampled wells) exceeded the proposed USEPA alternate maximum contaminant level (AMCL) of 4,000 pCi/L for radon-222. In a few samples, the concentrations of total dissolved solids, iron, manganese, and chloride exceeded USEPA secondary maximum contaminant levels (SMCL). In addition, water samples from two wells contained methane concentrations greater than 1 milligram per liter (mg/L). In general, most of the water-quality problems involve aesthetic considerations, such as taste or odor from elevated concentrations of total dissolved solids, iron, manganese, and chloride that develop from natural interactions of water and rock minerals in the subsurface.

pH ranged from 5.0 to 8.8 with a median value of 6.8. The pH of 50 percent of the sampled wells was outside the USEPA SMCL range of 6.5 to 8.5. Nine samples had a pH less than 6.5, and one sample had a pH greater than 8.5. The median pH of water samples ranged from 5.9 for the Burgoon Sandstone Member to 7.0 for the Huntley Mountain Formation.

The total dissolved solids concentration ranged from 31 to 664 mg/L; the median was 130 mg/L. Median total dissolved solids concentrations ranged from 123 mg/L in the Catskill Formation to 144 mg/L in the Huntley Mountain Formation. The total dissolved solids concentrations in one water sample exceeded the SMCL. The elevated total dissolved solids concentration (664 mg/L) in water from well SU-151 in the Catskill Formation was caused by elevated concentrations of sodium and chloride.

Chloride concentrations ranged from 0.5.9 to 342 mg/L; the median was 12.9 mg/L. Median chloride concentrations ranged from 6.18 mg/L in the Catskill Formation to 39.6 mg/L in the Burgoon Sandstone Member. The concentration of chloride (342 mg/L) in the water sample from well SU-151 in the Catskill Formation exceeded the USEPA SMCL of 250 mg/L for chloride.

Concentrations of nutrients were low. Nitrite, ammonia, and orthophosphorus were present in concentrations less than 0.3 mg/L. Median concentrations were less than the laboratory detection limit for ammonia and nitrite. Nitrate is the most prevalent nitrogen species in groundwater. The calculated concentration of nitrate as nitrogen ranged from less than 0.04 to 1.95 mg/L; the median concentration was 0.245 mg/L. All nitrate concentrations were well below the USEPA maximum contaminant level (MCL) of 10 mg/L.

Concentrations of dissolved iron ranged from less than 3.2 to 6,590 micrograms per liter (µg/L); the median concentration was 11.5 µg/L. Median iron concentrations ranged from 4.82 µg/L for the Huntley Mountain Formation to 154 µg/L for the Mauch Chunk Formation. Water samples from 20 percent of the sampled wells exceeded the USEPA SMCL of 300 µg/L for iron.

Concentrations of dissolved manganese ranged from less than 0.13 to 1,710 µg/L; the median concentration was 38.5 µg/L. Median manganese concentrations ranged from 4.37 µg/L for the Catskill Formation to 336 µg/L for the Mauch Chunk Formation. Water samples from 35 percent of the sampled wells exceeded the USEPA SMCL of 50 µg/L for manganese.

Activities of radon-222 ranged from 169 to 15,300 pCi/L; the median activity was 990 pCi/L. Median radon-222 activities ranged from 680 pCi/L in the Mauch Chunk Formation to 1,390 pCi/L in the Catskill Formation. Water samples from 85 percent of the sampled wells exceeded the proposed USEPA MCL of 300 pCi/L for radon-222; however, only two water samples exceeded the proposed USEPA AMCL of 4,000 pCi/L. All four of the water samples from the Catskill Formation exceeded the proposed USEPA MCL. The gross alpha-particle radioactivity ranged from less than the detection limit to 33 pCi/L; the median activity was 1.5 pCi/L. One water sample exceeded the USEPA MCL of 15 pCi/L for gross alpha-particle activity.

Concentrations of methane ranged from less than 0.001 to 51.1 mg/L. Methane was not detected in water samples from 13 of the wells. The methane concentration in water from two wells, SU-151 (Catskill Formation) and SU-154 (Huntley Mountain Formation), were 4.1 and 51.1 mg/L, respectively. Ethane concentrations of 0.002 and 0.02 mg/L were measured in the water samples from SU-151 and SU-154, respectively. A very strong odor of hydrogen sulfide was noted during the sampling of well SU-154. The pH of the water samples for both wells was greater than 8.

Samples of water from wells SU-151 and SU-154 were analyzed for isotopes of carbon and hydrogen in the methane. The values fall in the range for thermogenic natural gas, rather than microbial (biogenic) gas. The water sample from well SU-151 had the highest concentrations of arsenic, bromide, chloride, lithium, molybdenum, and sodium; the second highest concentrations of barium, boron, and strontium; and the third highest concentration of fluoride of the 20 wells sampled. The water sample from well SU-154 had the highest concentrations of boron and fluoride; the second highest concentrations of bromide and sodium; and the third highest concentrations of arsenic, lithium, molybdenum, and strontium of the 20 wells sampled.

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

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

Document prepared by the West Trenton Publishing Service Center

Sloto—**Baseline Groundwater Quality from 20 Domestic Wells in Sullivan County, Pennsylvania, 2012**—Scientific Investigations Report 2013–5085