In cooperation with the Pennsylvania Department of Health and the Pennsylvania Department of Environmental Protection

Reconnaissance of Arsenic Concentrations in Ground Water From Bedrock and Unconsolidated Aquifers in Eight Northern-Tier Counties of Pennsylvania

Open-File Report 2006–1376

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

Reconnaissance of Arsenic Concentrations in Ground Water From Bedrock and Unconsolidated Aquifers in Eight Northern-Tier Counties of Pennsylvania

By Dennis J. Low and Daniel G. Galeone

In cooperation with the Pennsylvania Department of Health and the
Pennsylvania Department of Environmental Protection

Open-File Report 2006-1376

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: *http://www.usgs.gov/pubprod*
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: *http://www.usgs.gov*
Telephone: 1-888-ASK-USGS

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

Although this report is in the public domain, permission must be secured from the individual copyright owners to reproduce any copyrighted material contained within this report.

Suggested citation:
Low, D.J., and Galeone, D.G., 2007, Reconnaissance of arsenic concentrations in ground water from bedrock and unconsolidated aquifers in eight northern-tier counties of Pennsylvania: U.S. Geological Survey Open-File Report 2006-1376, 35 p.

Contents

Abstract 1
Introduction 2
Purpose and Scope 2
Previous Work 4
Description of Study Area 4
Geohydrology 4
Bedrock Aquifers 7
Unconsolidated Aquifers 7
Water Use 8
Methods of Study 8
Sampling Design 8
Well and Spring Owner Participation and Sampling 8
Targeted Sampling 8
Laboratory Procedures and Quality Control 9
Arsenic Concentrations in Ground Water 11
Reconnaissance of Total-Arsenic Concentrations 11
Relation of Total Arsenic To Geology 13
Relation of Total Arsenic to Iron Staining and Hydrogen Sulfide 15
Redox Conditions and Concentrations of Arsenic Species 15
Summary 17
Acknowledgments 18
References Cited 18
Appendix 1 - U.S. Geological Survey Homeowner Questionnaire 21
Appendix 2 - Records of selected wells and springs, northern-tier counties, Pennsylvania 25

Figures

1-5. Maps showing:
1. Location of the eight counties that comprise the study area, northern-tier counties of Pennsylvania 3
2. The generalized bedrock geology of the study area, northern-tier counties of Pennsylvania 5
3. The extent of the Wisconsin ice sheet and major valley fill deposits in the study area, northern-tier counties of Pennsylvania 6
4. The location of sampled sites and ranges of total-arsenic concentrations, northern-tier counties of Pennsylvania 12
5. The location of sampled sites and ranges of total-arsenic concentrations in Tioga County 14

6. Graph showing distribution of total-arsenic concentration and well depth by geologic units, northern-tier counties of Pennsylvania 15

Tables

1. Generalized geologic column and dominant rock type(s), northern-tier counties of Pennsylvania ...7
2. Results of quality control for analyses of total-arsenic concentration, Pennsylvania Department of Environmental Protection Laboratory..... 10
3. Results of quality control for analyses of dissolved arsenic and arsenic species, U.S. Geological Survey National Water Quality Laboratory..... 11
4. Number of well and spring samples collected for total-arsenic analysis and water use, northern-tier counties of Pennsylvania..... 13
5. Well depths and well-owner observations on the presence (or absence) of iron staining and (or) hydrogen-sulfide odor for wells containing water with total-arsenic concentrations of 4 µg /L or greater, northern-tier counties of Pennsylvania..... 16
6. Dissolved arsenic and arsenic species concentrations and field-water-quality measurements for wells that contain water with dissolved arsenic concentrations greater than 10 µg /L, northern-tier counties of Pennsylvania 17

Conversion Factors, Datums, and Abbreviations

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)

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

$$°F=(1.8\times°C)+32$$

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 National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) and the North American Datum of 1927 (NAD 27).

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

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

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

Other abbreviations:

mL, milliliter
µL, microliter
mv, millivolts

Reconnaissance of Arsenic Concentrations in Ground Water From Bedrock and Unconsolidated Aquifers in Eight Northern-Tier Counties of Pennsylvania

By Dennis J. Low and Daniel G. Galeone

Abstract

Samples of ground water for analysis of total-arsenic concentrations were collected in eight counties–Potter, Tioga, Bradford, Susquehanna, Wayne, Pike, Sullivan, and Wyoming–and from eight bedrock formations (bedrock aquifers) and overlying glacial aquifers in the north-central and northeastern parts of Pennsylvania in July 2005 and from March through June 2006. The samples were collected from a total of 143 domestic wells, 2 stock wells, 4 non-community wells, 2 community water-system wells, and 3 domestic springs by well or spring owners using sampling kits provided by the U.S. Geological Survey (USGS). An additional 15 domestic wells were sampled by the USGS for analysis of total arsenic. These 15 samples were collected using the same methods and sampling kits provided to the homeowners.

Samples were analyzed for total arsenic by the Pennsylvania Department of Environmental Protection Laboratory using a minimum reporting level of 4.0 µg/L (micrograms per liter). Arsenic was detected in water from 18 domestic wells in four counties–Bradford (3 wells), Sullivan (1 well), Tioga (13 wells), and Wayne (1 well). The median concentration of total arsenic was less than 4.0 µg/L, and the maximum concentration was 188 µg/L. Water from 10 wells had concentrations of total arsenic greater than the U.S. Environmental Protection Agency Maximum Contaminant Level of 10 µg/L.

Detectable concentrations of total arsenic were measured in water from wells that ranged in depth from 29 to 400 feet, and that were completed in three aquifers–Lock Haven Formation, Catskill Formation, and unconsolidated glacial sediments; no springs had detectable concentrations of total arsenic. Water samples representing the Lock Haven Formation were collected from 60 wells; water from 12 of these wells had detectable concentrations of total arsenic. Water samples representing the Catskill Formation were collected from 57 wells; water from 4 wells had detectable concentrations of total arsenic. Water samples representing the unconsolidated glacial sediments were collected from 17 wells; 2 wells had water with detectable concentrations of total arsenic.

Contingency tables tested for significant differences in total arsenic between aquifers, topographic settings, and well depths. Concentrations of total arsenic were significantly greater (95-percent confidence level) in the Lock Haven Formation than in the other bedrock units. Concentrations of total arsenic also varied significantly by topographic setting. Wells completed in the Lock Haven Formation and located in valleys had significantly greater concentrations of total arsenic than similar wells located on hilltops or slopes. Concentrations of total arsenic did not vary significantly by topographic setting in the Catskill Formation. Concentrations of total arsenic did not vary significantly by well depth for any aquifer.

Iron staining, hydrogen-sulfide odor, or both were common complaints of well owners. Iron staining was a complaint of 44 well owners. Hydrogen-sulfide odor was a complaint of 35 well owners. Fourteen well owners complained of both iron staining and hydrogen sulfide. No correlation to the presence of arsenic in the wells sampled was found with iron staining, hydrogen-sulfide odor, or both.

Water from 8 of the 10 wells that contained concentrations of total arsenic greater than 10 µg/L were sampled by USGS personnel for the determination of concentrations of dissolved arsenic (minimum reporting level 0.3 µg/L) and arsenic species {arsenite [As (III)], arsenate [As (V)], monomethylarsonate (MMA), and dimethylarsinate (DMA)} at the USGS National Water Quality Laboratory. Analytical results from these samples showed a median concentration of 38.7 µg/L dissolved arsenic in water and a maximum of 178 µg/L. As (III) was the most common arsenic species present in the water for seven of the eight wells and was found in water characteristic of reducing environments [pH 8.2 to 9.1, dissolved oxygen 0.06 to 0.29 milligrams per liter (mg/L), and oxidation reduction potential -63 to -203 millivolts (mv)]. As (V) was the dominant arsenic species in water characteristic of an oxidizing environment (pH 4.8, dissolved oxygen 2.15 mg/L, oxidation reduction potential 265 mv). The arsenic species MMA and DMA were detected in the water from two wells. The arsenic species MMA was detected at an estimated concentration of 0.9 µg/L in water from one well; the concentration was less than 1.2 µg/L in water from seven wells. The arsenic species DMA was detected at concentrations of 1.0 and 1.5 µg/L in water from two wells; the concentration was less than 0.6 µg/L in water from six wells. Both wells that contained detectable concentrations of MMA and

DMA produced water that was characteristic of reducing environments.

Introduction

Almost 1 million households (19.8 percent) or 2.2 million people in Pennsylvania obtain their drinking water from privately owned drilled or dug wells (U.S. Census Bureau, 1990; Hutson and others, 2000). This water is not regularly tested for contaminants.

Long-term ingestion of arsenic in drinking water can increase the risk of skin, lung, bladder, kidney, liver, and prostate cancer, as well as several non-cancerous ailments including cardiovascular disease, diabetes, and neurological dysfunction (National Research Council, 1999, 2001; Twarakavi and Kaluarachchi, 2006). In recognition of the health risks associated with arsenic, the U.S. Environmental Protection Agency (USEPA) decreased the Maximum Contaminant Level (MCL) from 50 to 10 µg/L (U.S. Environmental Protection Agency, 2001).

In the northern-tier counties–Potter, Tioga, Bradford, Susquehanna, Wayne, Pike, Sullivan, and Wyoming–of Pennsylvania, elevated concentrations of arsenic (> 10 µg/L) have been reported in public and private water-supply wells that obtain water from glacial and bedrock aquifers (Taylor and others, 1983; Taylor, 1984; Taylor and Werkheiser, 1984; Williams and others, 1998). The distribution of arsenic in sampled wells appears random and unpredictable even over relatively short distances (less than 1 mi). This is also the case in southwestern Ohio (Thomas and others, 2005), Michigan (Kolker and others, 2003), New Hampshire (Ayotte and others, 1999, 2003), and many parts of the world (Smedley, 2003). It is not clear which combination(s) of hydrologic, geologic, and geochemical factors and (or) well-construction characteristics are responsible for elevated concentrations of arsenic in ground water.

Arsenic occurs naturally in the bedrock and unconsolidated aquifers in many areas of the United States. According to Welch and others (1988), arsenic concentrations are particularly elevated in marine shales. Ryker (2003) notes arsenic concentrations can vary over time and can be influenced by local pumping effects. Hem (1985) stresses the importance of the mineralogy of the aquifer and the geochemistry of the ground water passing through the aquifer. Although the parent source of arsenic in aquifers is rarely determined, arsenean pyrite [$Fe(S,As)_2$], arsenopyrite (FeAsS), and (or) other unspecified sulfide minerals are often proposed (Foster, 2003). Hydrous metal oxides (for example: iron, aluminum, and manganese) and clay minerals commonly occur as coatings on other minerals and are important sources or sinks for arsenic (Smedley and Kinniburgh, 2001; Foster, 2003). Organic matter, wood preservatives, swine and poultry feed or pharmaceuticals, glass production, pesticides, and waste-disposal sites can also be sources of arsenic.

Arsenate (H_3AsO_4) and arsenite (H_3AsO_3) are the most common and stable forms of arsenic in ground water (Stollenwerk, 2003). Arsenate has an oxidation state of +5 [As (V)] and is the predominant form of arsenic in oxic waters. Arsenite has an oxidation state of +3 [As (III)] and is the predominant form of arsenic in reducing waters. Of the two, As (III) has been considered to be more toxic (U.S. Environmental Protection Agency, 1976) and more mobile. However, recent work suggests that most ingested As (V) can be reduced to As (III) (National Research Council, 1999). Both can adsorb and desorb from mineral surfaces and form protonated oxyanions in aqueous solutions that are pH dependent (Stollenwerk, 2003, p. 69).

The extent of arsenic adsorption and desorption is largely controlled by pH (Stollenwerk, 2003, p. 99-100). Although As (V) and As (III) adsorb over a wide pH range, As (V) is adsorbed much stronger at lower pH values; As (III) adsorption increases with higher pH and peaks at about pH 8 or 9.

In order to better evaluate the distribution of arsenic in Pennsylvania ground water, the U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Health (PaDOH) and the Pennsylvania Department of Environmental Protection (PaDEP), began a study in 2005 to relate concentrations of arsenic to major aquifers. The eight-county northern-tier area of Pennsylvania (fig. 1) was selected as an area to examine on the basis of (1) previous work that identified elevated concentrations of arsenic in the unconsolidated and consolidated bedrock aquifers, and (2) the identification of elevated concentrations of arsenic in adjacent states with similar hydrology and geology.

Purpose and Scope

This report describes the occurrence and distribution of arsenic in ground water used for water supply (primarily domestic) across eight northern-tier counties of Pennsylvania–Potter, Tioga, Bradford, Susquehanna, Wayne, Pike, Sullivan, and Wyoming–and compares the occurrence of arsenic in ground water among eight bedrock formations (bedrock aquifers) and the unconsolidated aquifers.

The report is based on results of analyses of 166 well and 3 spring samples collected from July 2005 to June 2006 by well or spring owners and the USGS. This report presents data for total and dissolved arsenic and arsenic species, field-water-quality data, and well construction and associated site data. The report describes methods used for obtaining the water samples and the quality control used to evaluate sample and laboratory bias and variability, as well as potential sample contamination. Geologic, esthetic, and (or) well characteristics (for example well depth) are analyzed to evaluate their relation to concentrations of total arsenic.

The results of this study can help water suppliers and homeowners in Pennsylvania make informed decisions about the need for testing for arsenic in ground water. This is especially important because the controls on arsenic distribution and concentration are poorly understood, and remediation methods

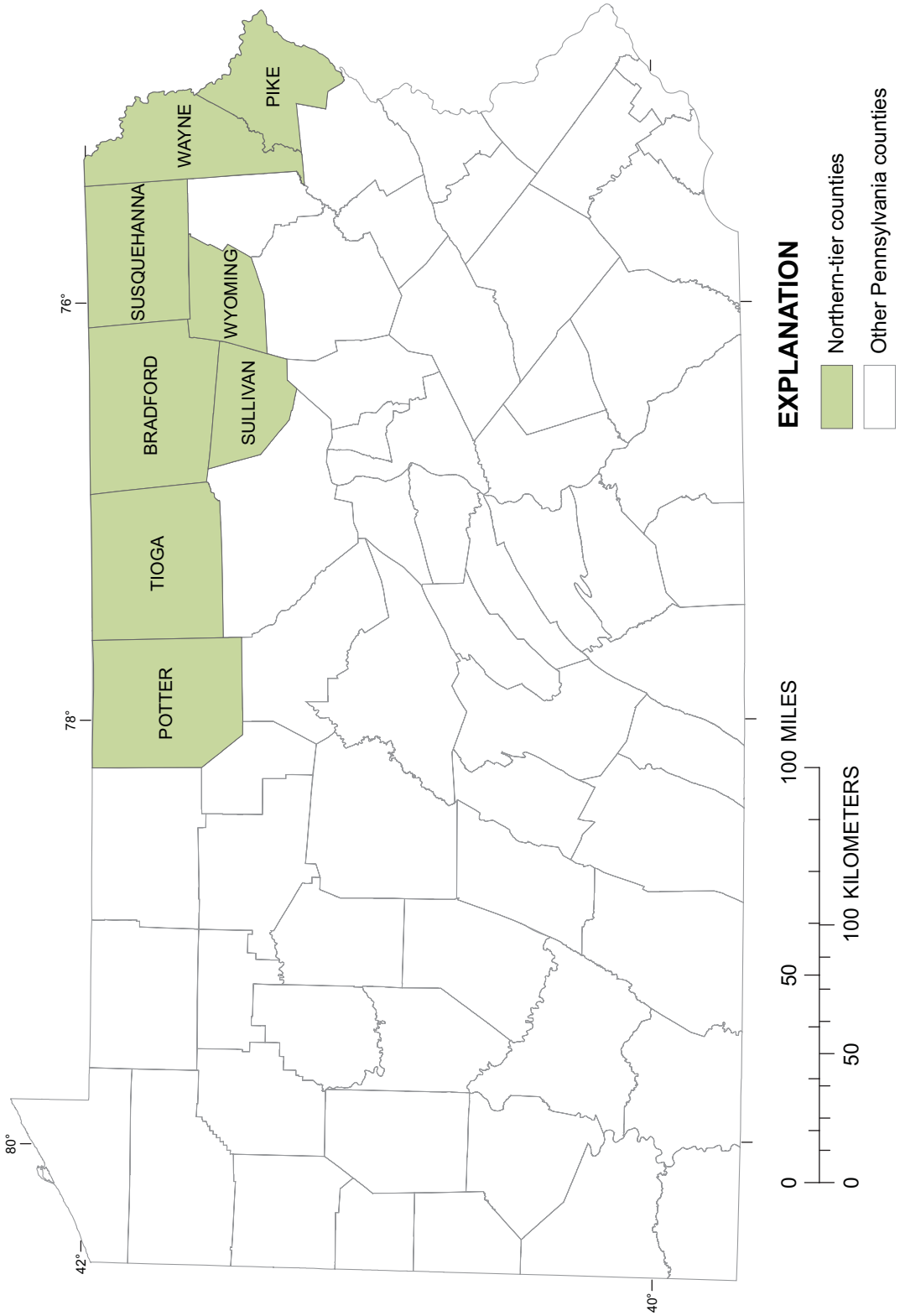

Figure 1. Location of the eight counties that comprise the study area, northern-tier counties of Pennsylvania.

for homeowners may require substantial cost and continued maintenance. This information also could be useful for the USEPA, the PaDEP, and the PaDOH in protecting human health.

Previous Work

A large amount of work regarding arsenic in ground water has been conducted by the USGS (Welch and others, 2000a, 2000b). Ohio and Illinois were extensively glaciated, resulting in thick unconsolidated aquifers and buried valleys. Water supplies are obtained in these valleys as well as in the underlying or adjacent bedrock aquifers. In northeastern Ohio, Matisoff and others (1982) investigated elevated concentrations of arsenic where a buried valley dissects a sandstone aquifer overlain by till. The authors suggested that arsenic was released from iron oxides under reducing conditions, possibly from methane gas from deep underground storage. Another possibility was that iron oxides had become unstable in a reducing environment created after a layer of surficial till restricted recharge to the aquifer. In southwestern Ohio, Thomas and others (2005) found that ground-water samples with elevated concentrations of arsenic collected from glacial deposits and carbonate bedrock had at least one common factor–iron concentrations were greater than 1,000 µg/L. Thomas and others also hypothesized that arsenic was released from iron oxides under reducing conditions (by reductive dissolution or reductive desorption).

Warner (2001) and Kelly and others (2005) investigated sand-and-gravel glacial aquifers in central Illinois and found considerable spatial variability in the arsenic concentrations, even in areas as small as 0.5 mi^2. Kelly and others (2005) also noted the solubility of arsenic was controlled by oxidation-reduction conditions. It appeared that elevated concentrations of arsenic were associated with high concentrations of iron, bicarbonate, total organic carbon, and ammonia nitrogen and low concentrations of sulfate, chloride, and manganese.

The presence of arsenic in ground water may have its origins in episodic periods of mountain building. Goldhaber and others (2003, p. 127) mention the effect of "…large-scale hydrothermal fluid migration events in the central and eastern United States … " on arsenic enrichment of pyrite in the bedrock aquifers and correlate them to the late stages of the Ouachita and Appalachian orogenies. In New England, many of the mountains consist of igneous (granite) or metamorphic (schist or gneiss) rocks enriched in minerals like pyrite. By analyzing rock lithologies and arsenic concentrations, Ayotte and others (1999, 2003) suggest that the major source of arsenic is naturally occurring and strongly correlated to the underlying geology.

Detectable concentrations of arsenic are relatively common throughout Pennsylvania; elevated concentrations also are found (Low and Chichester, 2006). Moore (1995) found elevated concentrations of arsenic in the sands along the shores of Lake Erie. Moore and Buckwalter (1996) determined that areas with a history of oil and gas drilling tended to have elevated concentrations of arsenic in the ground water. Much of this association, however, may be the result of improperly abandoned oil and gas wells. Taylor and Werkheiser (1984) found greater concentrations of arsenic in several members of the Catskill Formation than in the other units sampled. Taylor (1984), Taylor and others (1983), and Williams and others (1998) found that arsenic was more common in water from wells in glaciated valleys and shaley bedrock units than in wells completed on ridges and hilltops that penetrated bedrock units dominated by sandstone. They also reported that wells drilled in major valleys to depths much greater than 100 to 200 ft could penetrate sodium chloride or saline type water. Recent work by Mark Stephens (Pennsylvania Department of Environmental Protection, oral commun., 2006) in northeastern Tioga County indicates an association between arsenic and brine leaking from a borehole drilled to a depth below the freshwater aquifers. Mark Stephens also noted a possible association between arsenic and methane gas, and deep drilling for natural gas is more common now (2006) than in the recent past for many of the counties in the northern tier of Pennsylvania.

Description of Study Area

The study area (fig. 1) covers 5,028 mi^2 in eight counties–Potter, Tioga, Bradford, Susquehanna, Wayne, Pike, Sullivan, and Wyoming–in the north-central and northeastern parts of Pennsylvania (northern-tier counties) and lies within the Appalachian Plateaus Physiographic Province and the Ridge and Valley Physiographic Province (Berg and others, 1989). The northern-tier counties are underlain by sedimentary rocks that range in age from Silurian to Pennsylvanian (table 1). The three most extensive bedrock units are the Catskill, Lock Haven, and Huntley Mountain Formations. The remaining units individually make up less than 10 percent of the underlying bedrock (fig. 2).

Most of the bedrock formations are covered in part by unconsolidated glacial deposits (predominantly sand, gravel, and till) (fig. 3). This material ranges in thickness from a few feet on hilltops to more than 100 ft in major valley bottoms (Berg and others, 1980, fig. 1; Williams and others, 1998).

Land cover in the eight counties is diverse. Land-cover data show that forest is dominant (53-88 percent), followed by agriculture (19-32 percent) (Taylor and others, 1983; Taylor, 1984; Davis, 1989). Wetlands, urban (residential, commercial, industrial), other (barren, mines, quarries), and water represent the remaining land uses. The distribution of these land-cover types varies across the eight-county area as topography, physiography, and agricultural practices vary.

Geohydrology

The eight-county area has been broadly folded, uplifted, and repeatedly glaciated. Acceptable quantities (3 gal/min or greater for domestic wells) of ground water can be found in the bedrock aquifers and in valleys where thick unconsolidated

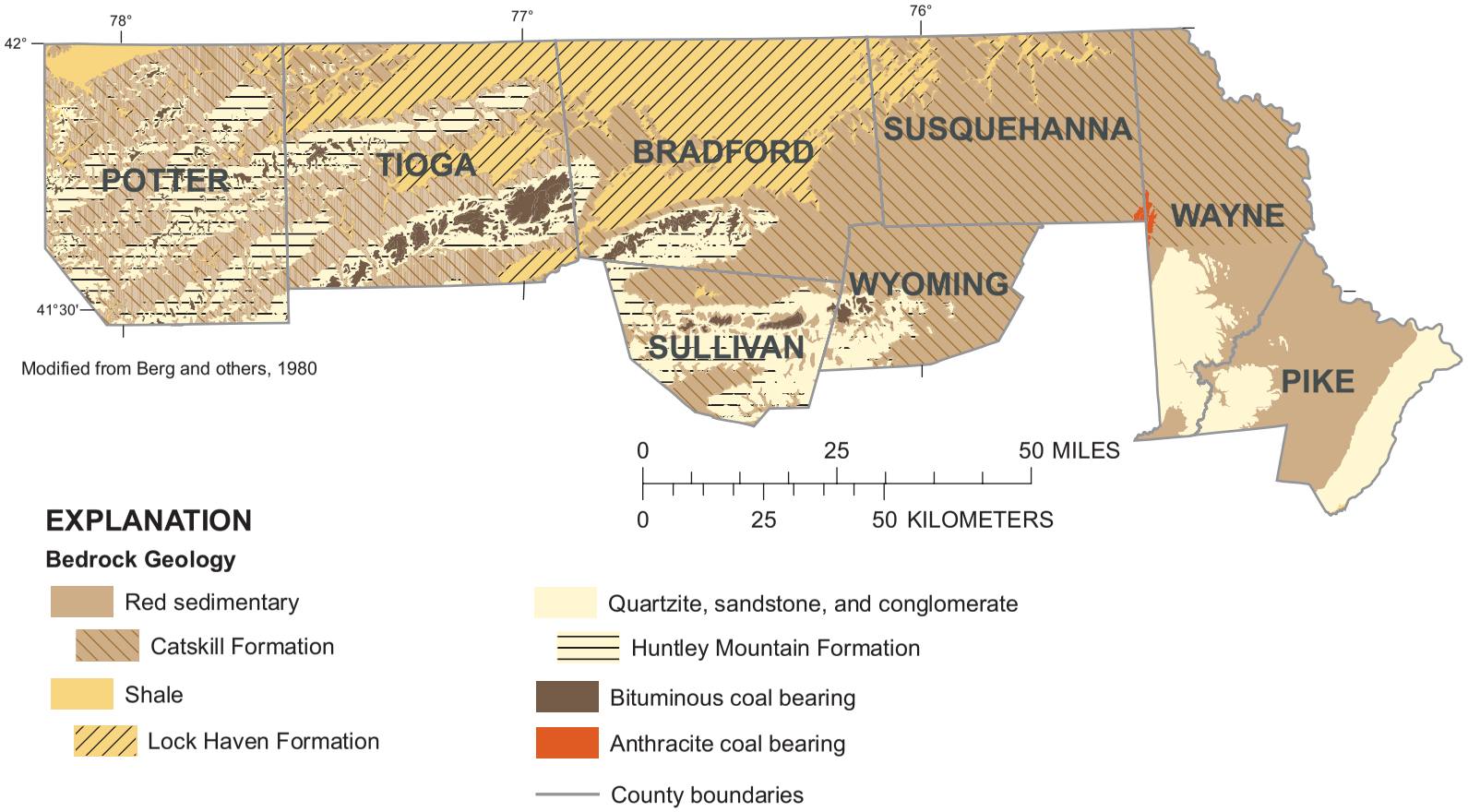

Figure 2. The generalized bedrock geology of the study area, northern-tier counties of Pennsylvania.

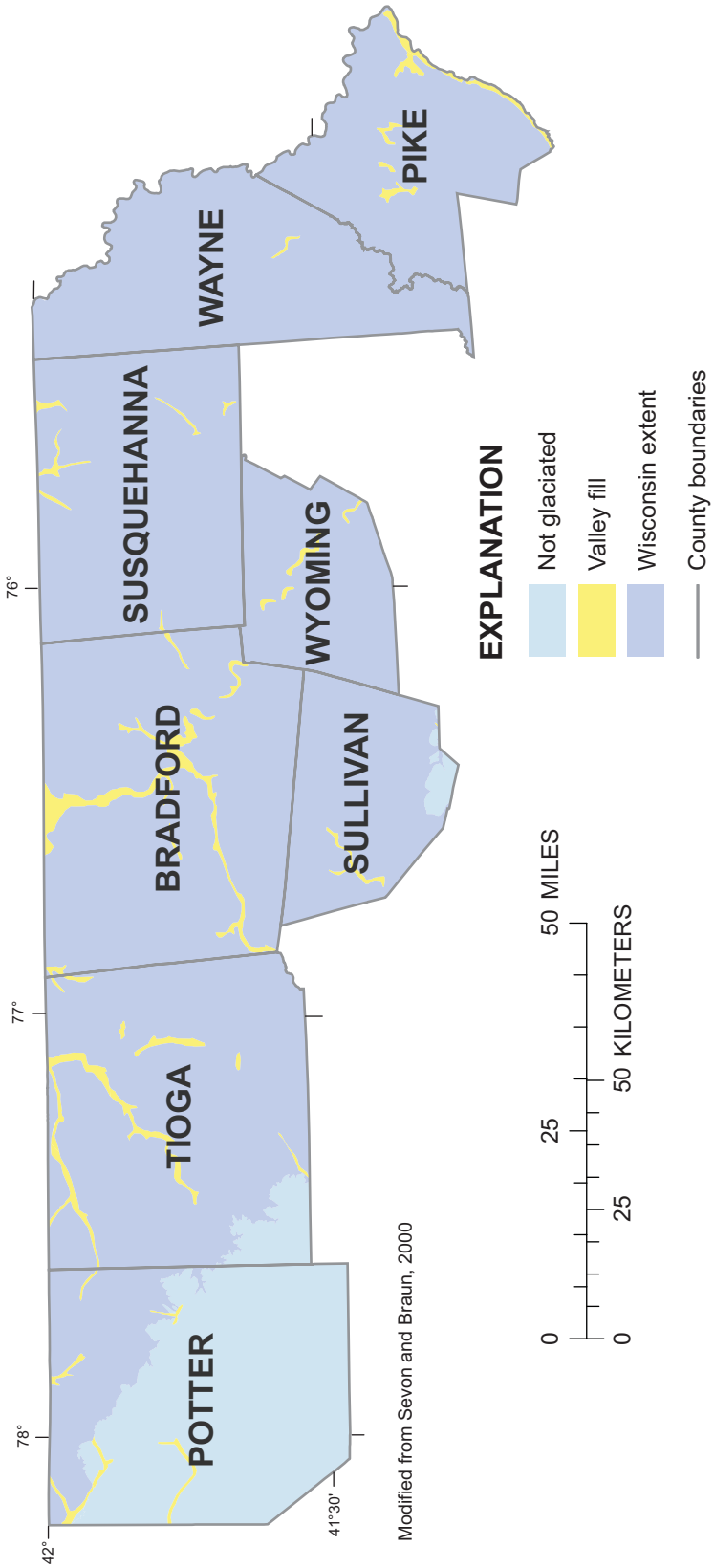

Figure 3. The extent of the Wisconsin ice sheet and major valley fill deposits in the study area, northern-tier counties of Pennsylvania.

Table 1. Generalized geologic column and dominant rock type(s), northern-tier counties in Pennsylvania.

System	Dominant rock type(s)	Group, Formation, or Member
Quaternary	Sand, gravel, till	Glacial deposits
Pennsylvanian	Anthracite coal bearing	Pottsville and Lewellyn Formations
Pennsylvanian	Bituminous coal bearing	Pottsville Formation and Allegheny Group
Mississippian and Devonian	Red sedimentary (siliciclastics)	Mauch Chunk Formation; Catskill Formation; Long Run, Walcksville, and Duncannon Members of the Catskill Formation
Mississippian and Devonian	Quartzite, sandstone, and conglomerate	Pocono and Burgoon Formations; Huntley Mountain Formation; Packerton, Poplar Gap, and Towamensing Members of the Catskill Formation; Trimmers Rock Formation; Mahantango Formation
Mississippian and Devonian	Shale	Shenango through Oswayo Formations; Chadakoin Formation; Lock Haven Formation; Marcellus Formation

sequences of sand and gravel exist (Williams and others, 1998). In certain areas, wells drilled in major valleys that exceed a depth of 100 to 200 ft may encounter brine-rich or saline water (Williams and others, 1998).

Bedrock Aquifers

The Lock Haven Formation of Devonian age underlies 1,141 mi^2 and crops out in six counties (fig. 2). The Lock Haven Formation is a marine shale comprised of light-olive-gray to gray, thin to medium, inter-bedded, very-fine grained sandstone, siltstone, and silty shale; a few conglomerate beds occur near the top. The Lock Haven Formation is moderately resistant to weathering and forms hills and ridges of moderate relief slopes (Geyer and Wilshusen, 1982).

The Lock Haven Formation is known for its brackish or saline water and the presence of hydrogen sulfide (Geyer and Wilshusen, 1982). Williams and others (1998) described 23 wells in the Lock Haven Formation that produced sodium-chloride type or saline water, including 1 well that produced brine. These waters represent areas where ground-water flow is controlled in part by low-permeability material and where sodium and chloride are dominant anions. These wells ranged in depth from 99 to 720 ft. Saline water was reported by well owners or confirmed by water-quality analysis at depths that ranged from 95 to 290 ft.

The Catskill Formation of Devonian age overlies the Lock Haven Formation. The Catskill Formation and its members cover 2,945 mi^2 in all eight counties (fig. 2). The Catskill Formation is a complex unit consisting of various amounts of gray to red shale, siltstone, sandstone, and conglomerate. Shales weather rapidly; sandstone, siltstone, and conglomerate are moderately resistant to weathering and break up into medium to large blocks. In Pike and the southern part of Wayne Counties, the Pennsylvania Topographic and Geologic Survey has divided the Catskill Formation into a series of members – Duncannon, Packerton, Poplar Gap, Towamensing, and Walcksville. Alternating or interbeds of gray to red shales, siltstones, sandstones, and, on occasion, conglomerate are common in these members (Berg and others, 1980). The Catskill Formation forms plateaus of medium relief with stable steep slopes (Geyer and Wilshusen, 1982).

Although the Catskill Formation produces water that is generally soft and acceptable for most uses, elevated concentrations of iron, manganese, and total dissolved solids are present locally. Williams and others (1998) identified 15 wells from which saline water was produced from restricted-flow zones. These wells ranged in depth from 65 to 580 ft below land surface. The top of the restricted-flow zones were encountered at depths that ranged from 65 to 400 ft.

The Huntley Mountain Formation of Mississippian and Devonian age overlies the Catskill Formation. The Huntley Mountain Formation covers 892 mi^2 in five counties (fig. 2). The Huntley Mountain Formation is made up of two sandstone sequences. The upper unit is a tan to olive, fine- to medium-grained, iron-stained, quartzitic sandstone with a conglomerate in the upper part. The lower unit is gray to tan, fine-grained, argillaceous sandstone. Both units contain interbeds of shale and mudstone. The sandstone is moderately resistant to weathering, forming flanks of steep valley walls of incised plateaus (Geyer and Wilshusen, 1982). Although the Huntley Mountain Formation yields water acceptable for most uses, the iron concentration may be high.

Unconsolidated Aquifers

Glacial and postglacial valley-fill sediments consist of till, stratified drift, alluvium, and swamp deposits. Stratified drift includes ice-contact deposits, lacustrine and deltaic deposits, and outwash. Alluvium and swamp deposits compose the postglacial material (Williams and others, 1998). Thickness of the unconsolidated aquifers ranges from a few feet in upland areas to more than 100 ft in major valleys. Water sufficient to meet domestic needs can be obtained from wells almost anywhere

there is sufficient thickness (more than 10 ft) of unconsolidated material. However, these sediments are more susceptible to surface pollution and commonly yield water that is hard and has elevated concentrations of iron and manganese.

Williams and others (1998) identified six wells (four wells in stratified drift, two wells in till) that produced saline water from restricted-flow zones. The depths of these wells ranged from 58 to 119 ft. The top of the restricted-flow zones ranged from 58 to 115 ft.

Water Use

The largest consumers of ground water in the study area are public water suppliers, mineral producers, and industry (Davis, 1989; Taylor, 1984; Taylor and others, 1983; Williams and others, 1998). Public water systems generally are confined to the larger municipalities or residential subdivisions. In 2006, approximately 161,000 people (52.9 percent) were served by private wells in the northern-tier counties (Arianne Proctor, Pennsylvania Department of Environmental Protection, written commun., 2006; U.S. Census Bureau, 2006). Much of the projected population growth will occur outside the major municipalities; hence, the use of private wells will need to increase to meet domestic requirements.

Methods of Study

Sampling Design

Arsenic is widely dispersed in the rocks and unconsolidated sediments of Pennsylvania, and areas with water containing elevated concentrations of arsenic are difficult to identify. By having homeowners collect water samples, a large geographic area could be sampled and greater efforts could be directed toward those sites that contained concentrations of total arsenic above the MCL of 10 µg/L.

The Information Office of the USGS Pennsylvania Water Science Center prepared a document describing the goals of the study and the reasons why it was important to evaluate the presence of arsenic in ground water. The document was released in March 2006 via public-service announcements through 55 radio stations and 34 daily or community newspapers and encouraged well owners to participate in the study.

Well and Spring Owner Participation and Sampling

Each well or spring owner who chose to participate in the study received an individual packet that contained (1) a letter explaining the study further and listing contacts for more information; (2) a questionnaire regarding well construction (well depth, casing length, date well drilled, and driller name); (3) a questionnaire regarding water treatment (sediment filter, water softener, reverse osmosis, or ultra-violate light), water problems (smell, taste, color, or staining), and length of use (appendix 1); (4) a 125 mL plastic sample bottle; (5) a set of directions for sampling, and (6) a postage-paid envelope to return the bottle to the USGS Pennsylvania Water Science Center.

Requests to participate began to arrive within days of the public-service announcement in March and continued into June 2006. A limit of approximately 25 samples per county initially was established to ensure that sufficient samples were collected from all eight counties. Because of the low response, an additional effort was put forth to contact well and spring owners through various county health agencies, the Pennsylvania State Agricultural Extension Agents, County Conservation Districts, the Pennsylvania Master Well Owner Network (MWON), and the PaDEP Office in Williamsport, Pa. By the end of June 2006, a total of 169 ground-water samples was delivered to the USGS Pennsylvania Water Science Center for processing and analysis. In almost all cases, the samples did not pass through any treatment system such as water softeners or filters.

Water samples that arrived at the USGS Pennsylvania Water Science Center were logged in, reviewed for completeness of the questionnaire, and acidified to a pH of less than 2 using approximately 1.5 mL of nitric acid (7.7 normality trace-metal quality). The data from the questionnaires were entered into a spreadsheet. The samples were then delivered to the PaDEP laboratory for analysis of total arsenic.

Targeted Sampling

Water samples were collected for analysis of total arsenic from 15 wells by the USGS. Five of the samples were collected in July 2005 in the vicinity of Tioga Junction, Pa., as part of another ground-water study in Tioga County, to evaluate field and laboratory methods for collecting, processing, and analyzing samples for dissolved-arsenic speciation. On June 14 and 15, 2006, the remaining 10 samples were collected for analysis of total arsenic in areas where elevated concentrations of total arsenic had already been confirmed by a previous well owner sample. USGS collection methods for samples analyzed for total arsenic were identical to the methods homeowners were requested to follow. An additional seven samples were collected by the USGS for dissolved arsenic, arsenite (As III), arsenate (As V), monomethylarsonate (MMA), and dimethylarsinate (DMA), hereafter termed arsenic species, at wells containing water with concentrations of total arsenic greater than 10 µg/L.

Procedures for collecting water for analyses of dissolved arsenic and arsenic species were more rigorous than that required for collecting samples for total arsenic. Before collection of any samples, wells were pumped at a constant discharge rate of approximately 3 gal/min for a minimum of 20 minutes. The low pumping rate and duration of pumping were based on (1) the desire not to stress the well beyond normal use; (2) daily use of the well (hence, good connection with the aquifer because the water in the borehole is constantly being replaced); and (3) the field measurements becoming stabilized after

20 minutes. Discharge water was monitored for temperature, dissolved oxygen, specific conductance, pH, and oxidation-reduction potential (to convert oxidation-reduction potential to Eh, add 200 millivolts) using a multi-parameter instrument and flow-through chamber. Once the field measurements were stable (within 5 percent of the last reading) or after pumping the well a minimum of 20 minutes, water from the discharge spigot was pumped through an acid-rinsed disposable capsule filter with pore size of 0.45 µm into sample bottles. Water to be analyzed for arsenic species and for dissolved arsenic was collected in a 10 mL amber-colored plastic bottle and a 250 mL translucent, acid-rinsed plastic bottle, respectively.

For sample preservation, water for analysis of dissolved arsenic was acidified with nitric acid (7.7 normality, trace-metal quality) to a pH of less than 2. Water for analysis of arsenic species was preserved with 100 µL ethylenediaminetetraacetic acid (EDTA) (Garbarino and others, 2002; Wilde and others, 2004). Bottles were immediately placed in an ice-filled cooler and later transferred to laboratory refrigerators. Bottles were shipped on ice via overnight delivery to the USGS National Water Quality Laboratory (NWQL) within a week of collection for analysis.

Laboratory Procedures and Quality Control

Concentrations of unfiltered (total) arsenic were determined at the PaDEP laboratory using an inductively coupled plasma-mass spectrometer (ICP/MS) and USEPA method 200.8, Revision 5.4; the minimum reporting level of the instrument was 4.0 µg/L.

Quality control (QC) at the PaDEP laboratory was maintained by utilizing 100 µg/L standards, 100 µg/L fortified blanks, 100 µg/L fortified matrix samples, and 100 and 400 µg/L calibration standards. QC of samples submitted was maintained by using 5 replicate samples, 7 metal-free samples, and 14 standard reference water samples (SRWS). SRWS are created at the NWQL to evaluate laboratory capabilities to accurately quantify analyte concentrations. SRWS contain known concentrations of selected trace metals and other analytes. The SRWS selected for this study was T-135, which contained 10 µg/L arsenic. Any contamination during sample collection and analysis was determined through analytical results from metal-free samples. Replicate samples helped to test the inherent variability of arsenic due to laboratory or sampling methodology. T-135 helped to determine inherent bias in the sampling or analytical procedures.

Concentrations of dissolved arsenic and arsenic species were determined at the NWQL by collision reaction cell inductively coupled plasma-mass spectrometry (cICP/MS) using USGS method I-2020-5 (Garbarino and others, 2002, 2006). The method detection limit was 0.12 µg/L.

QC samples submitted to NWQL for analysis of dissolved arsenic and arsenic species were prepared according to standard USGS protocols (Wilde and others, 2004). The QC samples for dissolved arsenic consisted of one replicate sample and two SRWS. The QC samples for arsenic species consisted of one metal-free, one replicate, one SRWS, and one matrix-spike sample. Replicate samples were collected immediately after the routine samples in the field using the same collection methods and equipment.

The relative percent difference (RPD) was determined for replicate samples, for which results (for both the original and replicate sample) were greater than the reporting limit, to determine if PaDEP laboratory precision met the guidance criteria of less than or equal to 20 percent difference. The RPD calculation was as follows:

$$\text{RPD (\%)} = [S - D] / ((S + D)/2) \times 100, \qquad (1)$$

where

S is original sample result,
D is replicate sample result, and
[ ] is absolute value

To evaluate the magnitude of the variability for triplicate samples (in this case, three SWRS), a calculation of percent relative standard deviation (% RSD) was determined. The goal is for recoveries to be within +/-20 percent. The % RSD was calculated as follows:

$$\text{\% RSD} = \left(\frac{\text{standard deviation of the triplicate recovery results}}{\text{mean concentration of the triplicate recovery results}}\right) \text{X } 100. \qquad (2)$$

Percent recovery was determined for blank-spike samples (submitted only to NWQL) by dividing the measured concentration by the theoretical concentration and multiplying this product by 100. The theoretical concentration for matrix-spike samples was determined by mixing a known volume of a field sample (with a known concentration) with a known volume of a standard-reference solution. Percent recoveries under 100 percent indicate that the laboratory underestimated the theoretical concentration; a percent recovery above 100 percent indicates an overestimation.

QC samples submitted to the PaDEP laboratory are summarized in table 2. There were no detections for any metal-free samples submitted to the laboratory. Recoveries of total arsenic in SRWS exhibited a negative bias, indicating the laboratory typically did not recover all the total arsenic in the sample; however, the RPD for SRWS ranged from 0.0 to 4.2 percent, well within the acceptable limit. All replicate pairs submitted to the PaDEP laboratory had arsenic concentrations less than 4.0 µg/L; therefore, the replicate analysis did not indicate any problems with precision or variability in the laboratory methodology at the minimum detection level. The variability (% RDS) in triplicate SRWS submitted to the laboratory were well within the acceptable range of +/-20 percent (table 2).

QC samples submitted to the NWQL are summarized in table 3. No arsenic species were detected in the blank sample submitted to the NWQL. The SRWS submitted showed a slight positive bias for dissolved arsenic. The SRWS for arsenic speciation showed a slight negative bias because the mean recovery for the different arsenic species was 98 percent. The difference measured in concentrations between the one replicate pair submitted for dissolved arsenic analysis was well within the precision (+/- 20 percent) of the methods used (table 3).

Table 2. Results of quality control for analyses of total-arsenic concentration, Pennsylvania Department of Environmental Protection Laboratory.

[--, not applicable; µg/L, micrograms per liter; <, less than; RSD, relative standard deviation; RPD, relative percent difference; SRWS, USGS-Standard Reference Water Sample T-135]

Sample type	Date	SRWS Theoretical concentrations, (µg/L)	Measured concentration, (µg/L)	RPD, in percent	RSD, in percent
		Replicate Samples			
Well Original	04/03/2006	--	< 4.0	--	--
Well Replicate	04/03/2006	--	< 4.0	0	--
Well Original	04/10/2006	--	< 4.0	--	--
Well Replicate	04/10/2006	--	< 4.0	0	--
Well Original	05/03/2006	--	< 4.0	--	--
Well Replicate	05/03/2006	--	< 4.0	0	--
Well Original	03/29/2006	--	< 4.0	--	--
Well Replicate	03/29/2006	--	< 4.0	0	--
Well Original	04/06/2006	--	< 4.0	--	--
Well Replicate	04/06/2006	--	< 4.0	0	--
		Blank Samples			
Metal Free	04/13/2006	0.0	< 4.0	--	--
Metal Free	04/13/2006	.0	< 4.0	--	--
Metal Free	04/24/2006	.0	< 4.0	--	--
Metal Free	05/10/2006	.0	< 4.0	--	--
Metal Free	05/23/2006	.0	< 4.0	--	--
Metal Free	05/23/2006	.0	< 4.0	--	--
Metal Free	06/06/2006	.0	< 4.0	--	--
		Reference Samples			
SRWS	04/18/2006	10.0	9.2	4.2	--
SRWS	05/23/2006	10.0	9.3	3.6	--
SRWS	06/24/2006	10.0	9.2	4.2	--
SRWS	04/24/2006	10.0	9.2	4.2	--
SRWS	04/20/2006	10.0	9.4	3.9	--
SRWS	06/06/2006	10.0	9.8	1.0	--
SRWS	04/18/2006	10.0	9.2	4.2	--
SRWS	06/24/2006	10.0	9.4	3.9	--
		Triplicate Samples			
SRWS triplicate	04/12/2006	10.0	10.7	3.4	7.3
SRWS triplicate	05/10/2006	10.0	10.4	2.0	7.3
SRWS triplicate	05/10/2006	10.0	10.0	.0	7.3
SRWS triplicate	05/10/2006	10.0	10.2	1.0	.4
SRWS triplicate	04/13/2006	10.0	9.8	1.0	.4
SRWS triplicate	04/13/2006	10.0	10.5	2.4	.4

Table 3. Results of quality control for analyses of dissolved arsenic and arsenic species, U.S. Geological Survey National Water Quality Laboratory.

[SRWS, USGS-Standard Reference Water Sample T-135; µg/L, micrograms per liter; --, not applicable; RPD, relative percent difference; E, estimated; <, less than]

Sample type	Theoretical concentration, (µg/L)	Measured concentration, (µg/L)	RPD, in percent	Percent recovery
Well original	--	175	--	--
Well replicate	--	178	-1.7	--
SRWS	10.0	10.3	-3.0	--
SRWS	10.0	10.2	-2.0	--
Blank				
Arsenite	.0	<.6	--	--
Arsenate	.0	<.6	--	--
Monomethylarsonate	.0	<1.2	--	--
Dimethylarsinate	.0	<.6	--	--
Blank spike				
Arsenite	21.7	21.0	--	97
Arsenate	21.7	21.1	--	97
Monomethylarsonate	21.7	22.1	--	102
Dimethylarsinate	21.7	20.6	--	95
Original				
Arsenite	--	14.1	--	--
Arsenate	--	E .6	--	--
Monomethylarsonate	--	<1.2	--	--
Dimethylarsinate	--	<.6	--	--
Matrix spike				
Arsenite	35.6	35.4	--	99
Arsenate	22.3	22.0	--	99
Monomethylarsonate	21.7	21.3	--	98
Dimethylarsinate	21.7	21.7	--	100

Arsenic Concentrations in Ground Water

Water from 158 domestic wells, 2 stock wells, 4 non-community wells, 2 community water-system wells, and 3 domestic springs in the northern-tier counties of Pennsylvania were analyzed for total arsenic (appendix 2). Detectable concentrations (4.0 µg/L or greater) of arsenic were measured in the water from 18 wells (10.8 percent) from four counties–Bradford, Sullivan, Tioga, and Wayne. Arsenic was not detected in any of the three sampled springs. Concentrations of total arsenic ranged from less than 4 µg/L to 188 µg/L; the median was less than 4.0 µg/L. Water from 10 wells (6.0 percent) sampled had concentrations of total arsenic greater than the USEPA MCL of 10 µg/L. The distribution of sampled sites and the range of total arsenic in the water from each well and spring are shown in figure 4. The number of samples collected per county varied considerably (fig. 4 and table 4).

Reconnaissance of Total-Arsenic Concentrations

Arsenic was detected in the water from three wells in Bradford County–BR-873, BR-855, and BR-854; the concentrations of total arsenic were 5.3, 39.4, and 117 µg/L, respectively. The two wells containing water with the highest concentrations of total arsenic are on slopes and are completed in the Lock Haven Formation at depths of 250 and 256 ft, respectively.

Arsenic was detected in the water of one well in Sullivan County; the concentration of total arsenic was 9.8 µg/L. This well, SU-135, is on a slope and is completed in the Catskill Formation at a depth of 400 ft.

The largest number of samples submitted was from wells in Tioga County (figs. 4 and table 4). This heightened interest is probably the result of an incident of arsenic contamination in a small community in northeast Tioga County (fig. 5). A commercial well encountered saline water at a depth of about 223 ft.

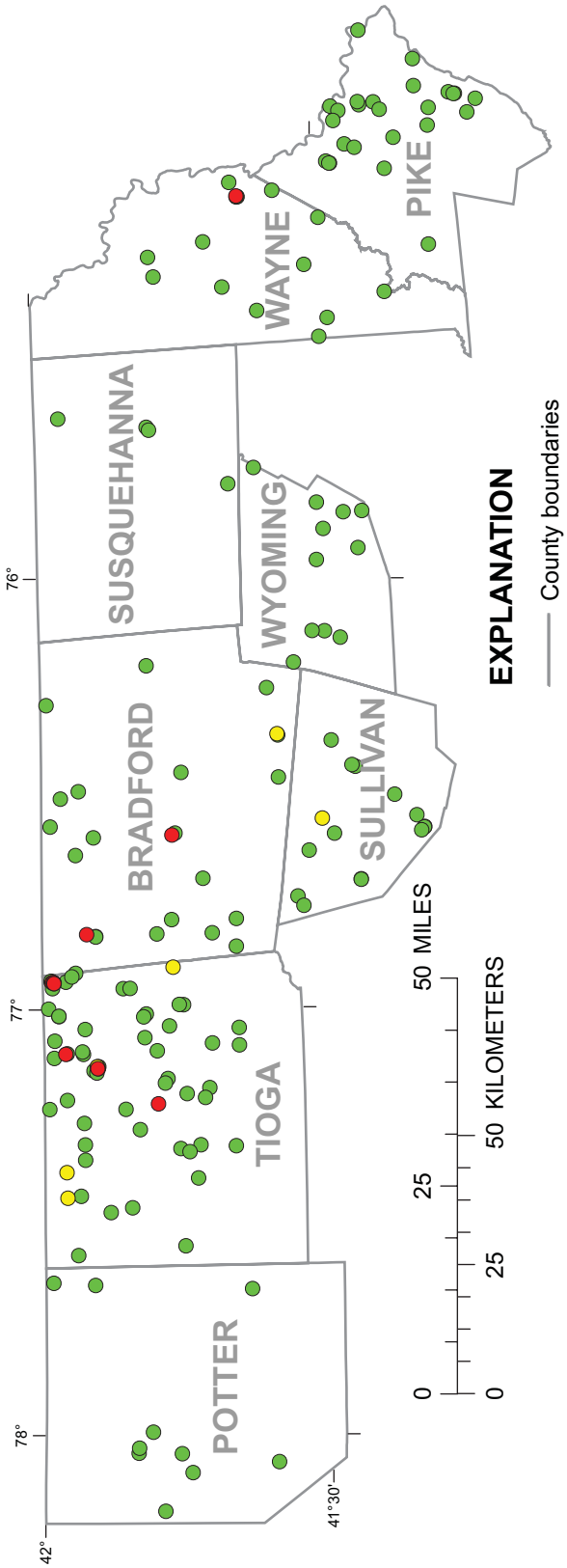

Figure 4. The location of sampled sites and ranges of total-arsenic concentrations, northern-tier counties of Pennsylvania.

Table 4. Number of well and spring samples collected for total-arsenic analysis and water use, northern-tier counties of Pennsylvania.

County	Number of well samples	Number of spring samples	Water use			
			Domestic	Non-community	Community	Stock
Bradford	22	1	21	0	0	1
Pike	25	0	22	3	0	0
Potter	10	0	10	0	0	0
Sullivan	14	1	12	1	0	1
Susquehanna	4	0	4	0	0	0
Tioga	65	1	63	0	2	0
Wayne	15	0	15	0	0	0
Wyoming	11	0	11	0	0	0

The well was abandoned because of the presence of saline water, but the well was not immediately plugged after abandonment. As a result of hydrostatic pressure, this saline water flowed upward into the shallow bedrock and unconsolidated aquifers that supplied water to nearby domestic wells. Unfortunately, the saline water was enriched in arsenic and contaminated approximately 10 wells (Mark Stephens, Pennsylvania Department of Environmental Protection, oral commun., 2006). Another possible factor for the large number of samples submitted from Tioga County is the increase in deep gas drilling in the county and concern that domestic wells may be adversely affected by this activity. The distribution of the sites in Tioga County is shown in more detail in figure 5.

Arsenic was detected in the water from 13 wells in Tioga County; the concentrations of total arsenic in these wells ranged from 4.0 to 53.8 µg/L; the median was 13.0 µg/L. Well depths in these 13 wells ranged from 29 to 175 ft; the median was 112 ft (fig. 6). Only two wells–TI-670 and TI-704–are on slopes; the remaining wells are in valleys. The concentrations of arsenic in the water of the two slope wells were 34.4 and 4.0 µg/L, respectively. Two wells–TI-576 and TI-668–are completed in the unconsolidated aquifers; the concentrations of total arsenic were 47.6 and 14.4 µg/L, respectively. One well–TI-704–is completed in the Catskill Formation. The remaining wells are completed in the Lock Haven Formation.

Total arsenic was detected in the water from one well in Wayne County; the arsenic concentration was 188 µg/L, the highest measured. This well, WN-135, is on a slope and is completed in the Catskill Formation at a depth of 340 ft. As a result of the elevated concentration of total arsenic, two wells within 0.5 mi and downslope of WN-135 were sampled. Arsenic was not detected in these two wells at the reporting limit of 4.0 µg/L.

Figure 6 shows the distribution of total arsenic to well depth. Two of the three deepest wells (WN-135 and BR-854) contain water with the highest concentrations of arsenic. This suggests that concentrations of arsenic increase with well depth. However, contingency tables did not support such an interpretation.

Relation of Total Arsenic to Geology

The presence of arsenic in ground water of the northern-tier counties is strongly related to bedrock geology. Arsenic was detected with greater frequency in the water of wells completed in the Lock Haven Formation than in the water of wells completed in other formations that underlie the study area.

The Lock Haven Formation was represented by 60 wells. Water from 12 of the 60 wells (20 percent) had detectable concentrations of arsenic. Where detected in the water of sampled wells, total-arsenic concentrations ranged from 4.5 to 117 µg/L; the median was 14.2 µg/L.

The Catskill Formation was represented by 57 wells. Water from 4 of the 57 wells (7 percent) contained detectable concentrations of arsenic. The measured concentration of total arsenic in water from the Catskill Formation were 4.0, 5.3, 9.8, and 188 µg/L.

The unconsolidated aquifers were represented by 17 wells. Water from 2 of the 17 wells (12 percent) contained detectable concentrations of arsenic. The measured concentrations of total arsenic in water from the unconsolidated aquifers were 14.4 and 47.6 µg/L.

Contingency tables were generated to evaluate the presence of total arsenic in the bedrock and unconsolidated aquifers. Total arsenic was found, at the 95-percent confidence level, with statistically greater frequency (chi-square of 0.0020) in the Lock Haven Formation than in the other bedrock aquifers. Total arsenic in the Lock Haven Formation also was found with statistically greater frequency if the well was located in a valley, as compared to a slope (chi-square of 0.0038) or a hilltop (chi-square of 0.0171). Although total arsenic also was found in water samples from wells in the unconsolidated aquifers and the Catskill Formation, the frequency of detections was not statistically significant. The frequency of total arsenic did not vary significantly by well depth for any aquifer.

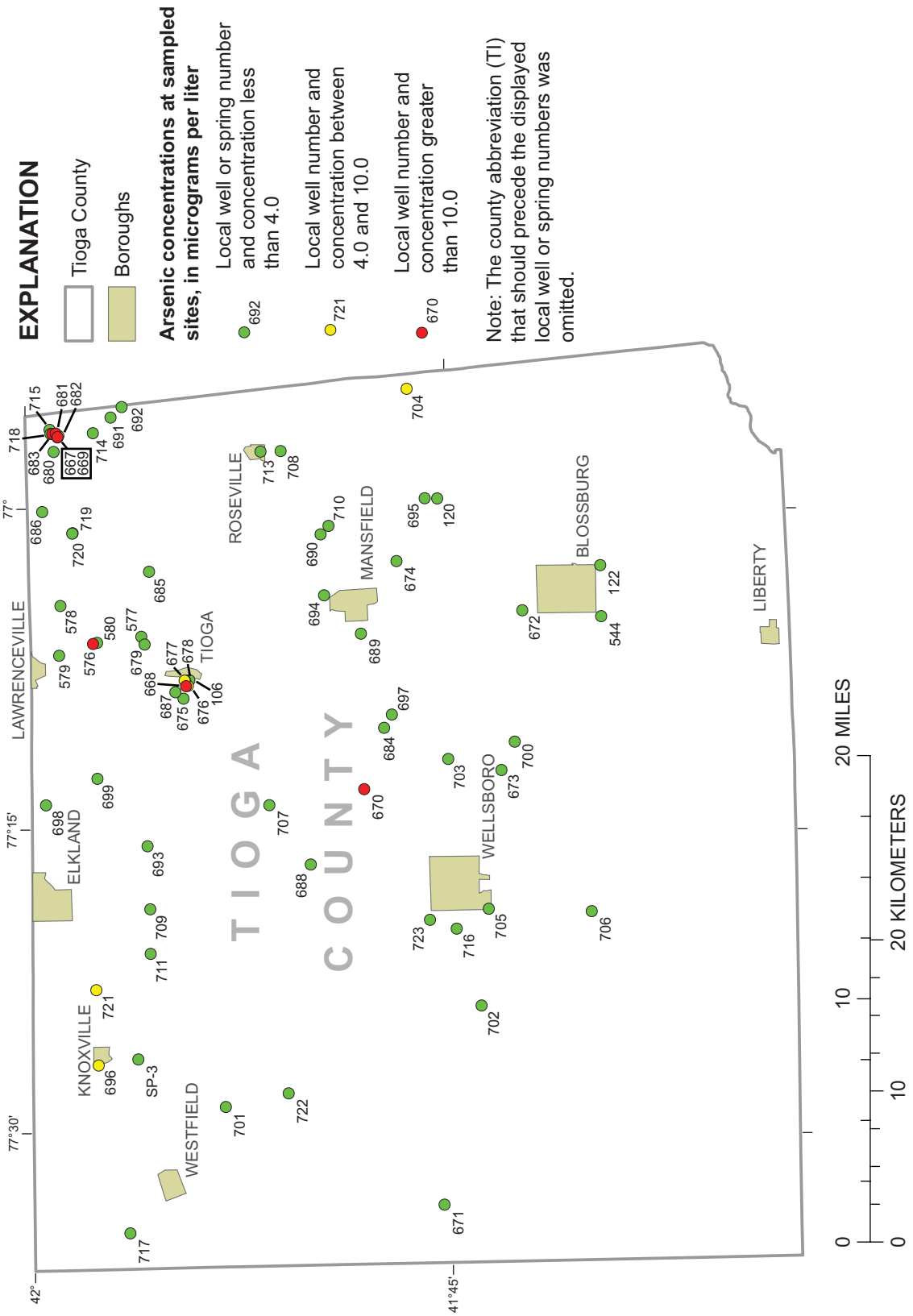

Figure 5. The location of sampled sites and ranges of total-arsenic concentrations in Tioga County.

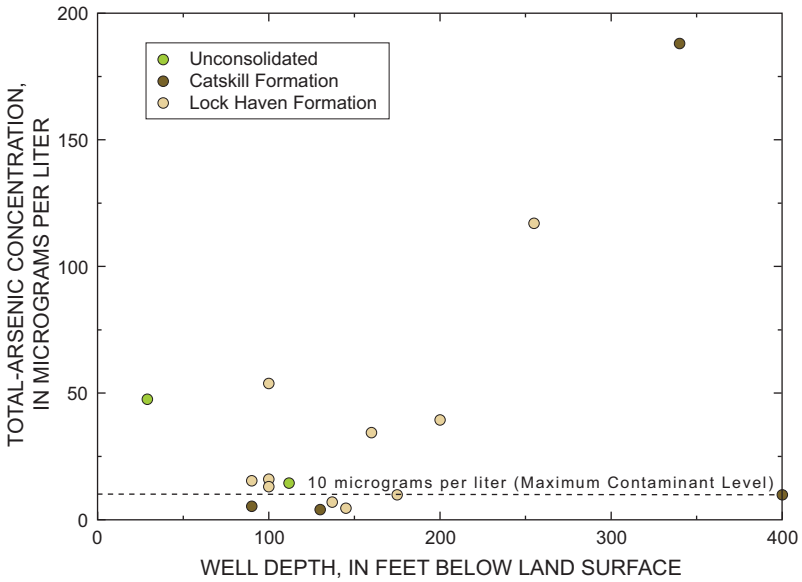

Figure 6. Distribution of total-arsenic concentration and well depth by geologic units, northern-tier counties of Pennsylvania.

Relation of Total Arsenic to Iron Staining and Hydrogen Sulfide

Trace to objectionable amounts of iron and hydrogen sulfide have been associated with the presence of arsenic (Mueller and others, 2001; Warner, 2001; Kelly and others, 2005; Thomas and others, 2005). A quantitative measurement of iron and hydrogen sulfide was beyond the scope of this study. Instead, a questionnaire (appendix 1) was used to obtain qualitative observations from the owner of the well or spring on the presence or absence of iron staining and (or) hydrogen-sulfide odor. All well and spring owners were requested to note "yes" if their drinking water had an objectionable stain or odor problem. Out of 169 samples, 44 well owners (26 percent) complained of iron staining, 35 well owners (21 percent) complained of hydrogen-sulfide odor, and 14 well owners (8 percent) complained of both. These observations are presented for only those wells with detectable concentrations of total arsenic in table 5. Contingency tables did not indicate a statistical correlation between the presence or absence of iron staining and (or) hydrogen-sulfide odor to the existence of arsenic in these wells.

Redox Conditions and Concentrations of Arsenic Species

The distribution of arsenic species in ground water is controlled by various geochemical conditions, in particular the reducing and oxidizing (redox) environment. On the basis of samples collected in Germany, Tretner and others (2006) concluded that distribution of arsenic species is affected by three factors – (1) input species of arsenic, (2) availability of reaction partners during soil and ground-water passage, and (3) the redox conditions in the ground-water environment. Mueller and others (2001) noted that As (III) correlated well with concentrations of dissolved oxygen that reflect strongly reducing conditions (< 0.1 mg/L). As (V) was associated with oxidizing conditions (dissolved oxygen > 8 mg/L).

The organic or methylated forms of arsenic, MMA and DMA, are not common in natural waters (table 6). These organic forms of arsenic are normally present in highly reducing environments where a source of carbon is present (Beth O'Shea, Dickinson College, written commun., 2006). Davis and others (1994) studied a highly reducing ground-water environment down gradient of a historical tannery in Massachusetts. Conditions were so reducing that dissolved organic carbon levels were extremely high (> 100 mg/L) from hide breakdown, leading to reduction of As (V) to As (III) and subsequent methylation by biosynthesis to MMA and DMA.

The field measurements made by USGS personnel during sampling for determinations of dissolved arsenic and arsenic species are listed in table 6. Water from all eight wells, except WN-210, was from the Lock Haven Formation or the unconsolidated aquifers. On the basis of the high pH and low dissolved oxygen and oxidation-reduction potential, water from the Lock Haven Formation and unconsolidated aquifers is the product of a reducing environment. It is in this type of environment that elevated concentrations of As (III) are expected. Well WN-210 is completed in the Catskill Formation and produces water from an oxidizing environment that is characterized by low pH, and relatively high dissolved oxygen and oxidation-reduction potential. In this type of environment, As (V) is expected to be

Table 5. Well depths and well-owner observations on the presence (or absence) of iron staining and (or) hydrogen-sulfide odor for wells containing water with total-arsenic concentrations of 4 µg/L or greater, northern-tier counties of Pennsylvania.

[Analyses for total arsenic concentration by Pennsylvania Department of Environmental Protection Laboratory; well depth, feet below land surface; µg/L, micrograms per liter; --, no data; 112ALVM, unconsolidated aquifers; 341CSKL, Catskill Formation; 341LKHV, Lock Haven Formation]

U.S. Geological Survey well number	Geologic unit	Total arsenic concentration (µg/L)	Well depth (feet)	Iron staining	Hydrogen-sulfide odor	Iron staining and hydrogen-sulfide odor
TI-576	112ALVM	47.6	29	No	No	No
TI-668	112ALVM	14.4	112	No	No	No
BR-873	341CSKL	5.3	90	No	Yes	No
SU-135	341CSKL	9.8	400	No	No	No
TI-704	341CSKL	4.0	130	No	No	No
WN-210	341CSKL	188	340	Yes	No	No
BR-854	341LKHV	117	255	No	No	No
BR-855	341LKHV	39.4	200	Yes	Yes	Yes
TI-667	341LKHV	16.0	100	No	No	No
TI-669	341LKHV	53.8	100	No	No	No
TI-670	341LKHV	34.4	160	Yes	No	No
TI-676	341LKHV	5.1	--	No	No	No
TI-677	341LKHV	6.9	137	No	No	No
TI-681	341LKHV	15.4	90	Yes	Yes	Yes
TI-682	341LKHV	9.0	--	Yes	Yes	Yes
TI-683	341LKHV	13.3	100	No	Yes	No
TI-696	341LKHV	4.5	145	Yes	No	No
TI-721	341LKHV	9.8	175	Yes	No	No

Table 6. Dissolved arsenic and arsenic species concentrations and field-water-quality measurements for wells that contain water with dissolved arsenic concentrations greater than 10 µg/L, northern-tier counties of Pennsylvania.

[Arsenic analyses by U.S. Geological Survey, National Water Quality Laboratory. As (III), arsenite; As (V), arsenate; MMA, monomethylarsenate; DMA, dimethylarsenite; µS/cm, microsiemens per centimeter at 25 degrees Celsius;<, less than; E, estimated; mg/L, milligrams per liter; °C, degrees Celsius; mv, millivolts; µg/L, micrograms per liter; 112ALVM, unconsolidated aquifers; 341CSKL, Catskill Formation; 341LKHV, Lock Haven Formation]

U.S. Geological Survey well number	Aquifer	Dissolved arsenic (µg/L)	As (III) (µg/L)	As (V) (µg/L)	MMA (µg/L)	DMA (µg/L)
BR-854	341LKHV	176	144.0	37.9	<1.2	<0.6
BR-855	341LKHV	40.1	38.7	1.6	<1.2	1.0
TI-576	112ALVM	47.6	37.3	6.7	E .9	1.5
TI-667	341LKHV	17.1	16.9	E .8	<1.2	<.6
TI-668	112ALVM	14.5	14.1	E .6	<1.2	<.6
TI-669	341LKHV	56.8	55.8	.8	<1.2	<.6
TI-670	341LKHV	35.5	28.2	7.9	<1.2	<.6
WN-210	341CSKL	27.6	1.8	33.2	<1.2	<.6

U.S. Geological Survey well number	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Temperature (°C)	Oxidation reduction potential (mv)	Sulfur odor
BR-854	461	8.5	0.18	10.6	-99	No
BR-855	564	9.1	.29	10.0	-131	Yes
TI-576	244	8.2	.19	11.9	-203	Yes
TI-667	404	8.8	.18	11.4	-160	No
TI-668	332	8.5	.06	11.1	-70	Yes
TI-669	452	8.5	.16	11.4	-63	No
TI-670	632	8.6	.19	12.0	-128	No
WN-210	181	4.8	2.15	10.6	265	No

the dominant arsenic species. The results in the northern-tier counties on arsenic speciation support the conclusion of Tretner and others (2006) that As (III) is the dominant species in strongly reducing environments (< 0.1 mg/L dissolved oxygen) and As (V) is the dominant species in oxidizing environments (> 8 mg/L dissolved oxygen).

Summary

In July 2005 and from March through June 2006, the USGS, in cooperation with the Pennsylvania Department of Health and the Pennsylvania Department of Environmental Protection, measured concentrations of total arsenic in water samples from 166 wells and 3 springs in 8 counties in the northern tier of Pennsylvania. The median arsenic concentration was less than 4.0 µg/L, and the maximum was 188 µg/L. Detectable levels of total arsenic were measured in the water from 18 wells (11 percent), and 10 of the wells (6 percent) sampled contained water with concentrations of arsenic greater than the U.S. Environmental Protection Agency Maximum Contaminant Level of 10 µg/L; none of the water samples from the springs contained detectable levels of arsenic. The greatest number of wells (12 of 60 wells or 20 percent) producing water with detectable concentrations of arsenic were completed in the Lock Haven Formation. In the unconsolidated aquifers, 2 of 17 wells (12 percent) produced water with detectable concentrations of arsenic. In the Catskill Formation, 4 of 57 wells (7 percent) produced water with detectable concentrations of arsenic. Contingency tables for the three units containing detectable concentrations of arsenic indicate that arsenic is found with significantly greater frequency in the Lock Haven Formation than in the unconsolidated aquifers and the Catskill Formation. Topographic setting also significantly affected the frequency of total arsenic in the Lock Haven Formation, but not in the Catskill Formation. There was no significant difference in the frequency or concentration of total arsenic and well depth.

Previous studies in similar hydrogeologic environments have associated iron and sulfur with the presence of arsenic.

Although a quantitative analysis was beyond the scope of this project, a qualitative comparison was completed using homeowner response to the presence of iron and (or) hydrogen-sulfide odor. On the basis of the 18 wells producing water with detectable concentrations of arsenic and homeowner responses, objectionable quantities of iron, hydrogen-sulfide odor, and (or) both were found in 7 (39 percent), 5 (28 percent), and 3 (17 percent) of the wells, respectively. There was, however, no statistical correlation between iron staining and (or) hydrogen-sulfide odor and the presence of arsenic in these wells.

Dissolved arsenic, arsenic species, and related field-water-quality constituents were analyzed in water from one well in July 2005 and from seven wells in June 2006 that produced water with elevated arsenic concentrations (greater than 10 µg/L). Field measurements of pH, dissolved oxygen, and oxidation-reduction potential indicated that seven of the eight wells produced water that represented reducing environments; these wells were completed in the Lock Haven Formation or the unconsolidated aquifers. In such an environment, As (III) was the dominant arsenic species. The remaining well, completed in the Catskill Formation, produced water that represented an oxidizing environment; in this water, As (V) was the dominant arsenic species. The arsenic species MMA and DMA are not commonly detected in natural waters but were found in the water from two wells. The arsenic species MMA was detected at an estimated concentration of 0.9 µg/L in water from one well; the concentration was less than 1.2 µg/L in water from seven wells. The arsenic species DMA was detected at concentrations of 1.0 and 1.5 µg/L in water from two wells; the concentration was less than 0.6 µg/L in water from six wells. Both wells that contained detectable concentrations of MMA and DMA produced water that was characteristic of reducing environments.

Acknowledgments

The authors thank David Marchetto and Patricia Miller of the PaDOH and PaDEP, respectively, who provided a great deal of assistance in developing the project and providing input to USGS personnel as the project was being implemented. The authors also would like to acknowledge the assistance of Dennis Neuin of the PaDEP Laboratory for his work in analyzing the total-arsenic samples and the USGS National Water Quality Laboratory for assistance with arsenic speciation. We also extend thanks to our USGS colleagues Ronald Sloto, Joseph Ayotte, Kevin Breen, and Kim Otto for their detailed reviews of this report and suggestions regarding content and organization.

References Cited

Ayotte, J.D., Montgomery, D.L., Flanagan, S.M., and Robinson, K.W., 2003, Arsenic in groundwater in eastern New England—Occurrence, controls, and human health implications: Environmental Science & Technology, v. 37, no. 10, p. 2075-2083.

Ayotte, J.D., Nielsen, M.G., Robinson, G.R., Jr., and Moore, R.B., 1999, Relation of arsenic, iron, and manganese in ground water to aquifer type, bedrock lithogeochemistry, and land use in New England Coastal Basins: U.S. Geological Survey Water-Resources Investigations Report 99-4162, 61 p.

Berg, T.M., Barnes, J.H., Sevon, W.D., Skema, V.W., Wilshusen, J.P., and Yannacci, D.W., 1989, Physiographic provinces of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 13 (color), scale 1:2,000,000, 8.5 x 11.

Berg, T.M., Edmunds, W.E., Geyer, A.R., Glover, A.D., Hoskins, D.M., MacLachlan, D.B., Root, S.I., Sevon, W.D., and Socolow, A.A., comps., 1980, Geologic map of Pennsylvania: Pennsylvania Geologic Survey, 4th ser.; Map 1, scale 1:250,000, 3 sheets.

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

David, Andy, Kempton, J.H., Nicholson, Andrew, and Yare, Bruce, 1994, Groundwater transport of arsenic and chromium at a historical tannery, Woburn, Massachusetts, U.S.A.: Applied Geochemistry, v. 9, p. 569-582.

Foster, A.L., 2003, Spectroscopic investigations of arsenic species in solid phases, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 2, p. 27-65.

Garbarino, J.R., Bednar, A.J., and Burkhardt, M.R., 2002, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Arsenic speciation in natural-water samples using laboratory and field methods: U.S. Geological Survey Water-Resources Investigations Report 02-4144, 40 p.

Garbarino, J.R., Kanagy, L.K., and Cree, M.E., 2006, Determination of elements in natural-water, biota, sediment and soil samples using collision/reaction cell inductively coupled plasma-mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, sec. B, chap. 1, 87 p.

Geyer, A.R., and Wilshusen, J.P., 1982, Engineering characteristics of the rocks of Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Environmental Geology Report 1, 300 p.

Goldhaber, M.B., Lee, R.C., Hatch, J.R., Pashin, J.C., and Treworgy, J., 2003, Role of large-scale fluid-flow in subsurface arsenic enrichment, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water - Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 5, p. 127-164.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2000, Estimated use of water in the United States in 2000: U.S. Geological Survey Circular 1268, 46 p.

Kelly, W.R., Holm, T.R., Wilson, S.D., and Roadcap, G.S., 2005, Arsenic in glacial aquifers—Sources and geochemical controls: Ground Water, v. 43, no. 4, p. 500-510.

Kolker, Allan, Haack, S.K., Cannon, W.F., Westjohn, D.B., Kim, M.-J., Nriagu, Jerome, and Wooddruff, L.G., 2003, Arsenic in southeastern Michigan, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 10, p. 281-294.

Low, D.J., and Chichester, D.C., 2006, Ground-water quality data in Pennsylvania – A compilation of computerized [Electronic] databases, 1979-2004: U.S. Geological Survey Data Series 150 (*http://pubs.usgs.gov/ds/ds150).*

Matisoff, G., Khourey, K.J., Hall, J.F., and Strain, W.H., 1982, The nature and source of arsenic in northeastern Ohio ground water: Ground Water, v. 20, no. 4, p. 446-456.

Moore, M.E., 1995, Ground-water quality and flow at Presque Isle State Park, Erie County, Pennsylvania with emphasis on impacts from on-site sewage effluent disposal: Pennsylvania Geological Survey, 4th ser., Open-File Report 95-1, 67 p.

Moore, M.E., and Buckwalter, T.F., 1996, Ground-water resources data for Warren County, Pennsylvania: U.S. Geological Survey Open-File Report 94-87, 94 p.

Mueller, Seth, Verplank, Philip, and Goldfarb, Rich, 2001, Ground-water studies in Fairbanks, Alaska—A better understanding of some of the United States' highest natural arsenic concentrations: U.S. Geological Survey Fact Sheet FS-111-01, 2 p.

National Research Council, 1999, Arsenic in drinking water: Washington, D.C., National Academy Press, 273 p.

National Research Council, 2001, Arsenic in drinking water 2001 update: National Academy Press, Washington, D.C., 244 p.

Ryker, S.J., 2003, Arsenic in ground water used for drinking water in the United States, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 6, p. 165-178.

Sevon, W.D., and Braun, D.D., 2000, Glacial deposits of Pennsylvania: Pennsylvania Topographic and Geologic Survey, 4th ser., Map 59, 1 p.

Smedley, P.L., 2003, Arsenic in groundwater—South and east Asia, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 7, p. 179-209.

Smedley, P.L., and Kinniburgh, D.G., 2001, Source and behaviour of arsenic in natural waters, U.N. Synthesis Report on Arsenic in Drinking Water: Geneva, World Health Organization, p. 1-61.

Stollenwerk, K.G., 2003, Geochemical processes controlling transport of arsenic in groundwater—A review of adsorption, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 3, p. 67-100.

Taylor, L.E., 1984, Groundwater resources of the Upper Susquehanna River Basin, Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Water Resource Report 58, 136 p.

Taylor, L.E., and Werkheiser, W.H., 1984, Groundwater resources of the Lower Susquehanna River Basin, Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Water Resource Report 57, 143 p.

Taylor, L.E., Werkheiser, W.H., and Kriz, M.L., 1983, Groundwater resources of the West Branch Susquehanna River Basin, Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Water Resource Report 56, 130 p.

Thomas, M.A., Schumann, T.L., and Pletsch, B.A., 2005, Arsenic in ground water in selected parts of southwestern Ohio, 2002-2003: U.S. Geological Survey Scientific Investigations Report 2005-5138, 30 p.

Tretner, A., Kofod, M., Scholz, C., and Isenbeck-Schroter, M., 2006, Influence of the geochemical conditions and the input species on the species distribution of As in groundwater: Institute of Environmental Geochemistry, Heidelberg, Germany, accessed September 6, 2006, at *http://www.rzuser.uni-heidelberg.de/~i02/atretner/abstract.pdf.*

Twarakavi, N.K.C., and Kaluarachchi, J.J., 2006, Arsenic in the shallow ground waters of conterminous United States—Assessment, health risks, and costs for MCL compliance: Journal of the American Water Resources Association, v. 42, no. 2, p. 275-294.

U.S. Census Bureau, 1990, Housing characteristics: Pennsylvania, accessed September 1, 2006, at *http://factfinder.census.gov/servlet/QTTable?_bm=n&_lang=en&gr_name=DEC_1990_STF3_DP5&ds_name=DEC_1990_STF3_&geo_id=04000US42*.

U.S. Census Bureau, 2006, Quick facts: accessed October 12, 2006, at *http://quickfacts.census.gov/qfd/states/42*.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: U.S. Government Printing Office, 256 p.

U.S. Environmental Protection Agency, 2001, Drinking water standard for arsenic: Office of Water, EPA 815-F-00-015, accessed May 11, 2005, at *http://www.epa.gov/safewater/ars/ars_rule_factsheet.html*.

Warner, K.L., 2001, Arsenic in glacial drift aquifers and the implication for drinking water—Lower Illinois River Basin: Ground Water, v. 39, no. 3, p. 433-442.

Welch, A.H., Lico, M.S., and Hughes, J.L., 1988, Arsenic in ground water of the western United States: Ground Water, v. 26, no. 3, p. 333-347.

Welch, A.H., Watkins, S.A., Helsel, D.R., and Focazio, M.J., 2000a, Arsenic in ground water resources of the United States: U.S. Geological Survey, Fact Sheet FS-063-00, 4 p.

Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B., 2000b, Arsenic in ground water of the United States—Occurrence and geochemistry: Ground Water, v. 38, no. 4, p. 589-604.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 2004, Processing of water samples (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, Section 5.6.4.A, "Arsenic speciation" accessed June 2005, at *http://water.usgs.gov/owq/FieldManual/chapter5/pdf/5.6.4.A_v. 1.1.Pdf.*

Williams, J.H., Taylor, L.E., and Low, D.J., 1998, Hydrogeology and groundwater quality of the glaciated valleys of Bradford, Tioga, and Potter Counties, Pennsylvania: Pennsylvania Geologic Survey, 4th ser., Water Resource Report 68, 89 p.

Appendix 1 - U.S. Geological Survey Homeowner Questionnaire

STUDY PARTICIPATION INFORMATION

Name (Please Print)

Street Address

Mailing Address, if different

City, State, Zip Code

Telephone Number (day) Telephone Number (evening) Email

COMMON QUESTIONS

Why was my well chosen?

Your well is one of 200 wells that were randomly selected from a database of thousands in the study area.

What will this cost me?

Nothing. In fact, you will receive important information about the arsenic concentration in your drinking water. For more information on arsenic in drinking water contact:

Geisinger Health System – Steve Browning (570) 214-9727, srbrowning@geisinger.edu

PA Department of Environmental Protection Regional Offices –
http://www.depweb.state.pa.us/dep/cwp/view.asp?a=3&q=461282

Northeast – (570) 826-2511 Northwest (815) 332-6945 Northcentral (570) 327-3636
Southeast - (484) 250-5900 Southwest (412) 442-4000 Southcentral (717) 705-4700
(Please ask for your Drinking Water Program staff when calling)

PA Department of Health – Cynthia Goodman (717) 787-1708, cygoodman@state.pa.us

U.S. Environmental Protection Agency – *http://www.epa.gov/safewater/arsenic/index.html*

U.S. Geological Survey –
Dennis Low, USGS (717) 730-6959, djlow@usgs.gov
Curtis Schreffler (717) 730-6913, clschref@usgs.gov

From where is the sample collected?

Sample should be collected from a faucet or spigot that does not receive treated water (if you have a water treatment system). If you can not collect untreated water by using a by-pass valve in your plumbing we still would like a water sample from your well. Please just describe the treatment system on a separate sheet of paper.

How will the information be used?

These data will be summarized by town, township, county, geologic information, and other broad groups of variables. No individual information will be published. You will receive a copy of the report which summarizes the findings of this study in addition to your individual well water analysis results.

SAMPLE COLLECTION (filled in by well owner)

1. Collect a sample from a faucet or outside spigot that does not receive treated or filtered water (check one):
Kitchen _____ Bathroom _____ Outside spigot _____

Spigot before pressure tank _____ Spigot after pressure tank _____

Other _____ Please explain _____

If you are unable to collect an untreated water sample, please be sure to describe your treatment system below.

2. Allow the cold water to run for 2-3 minutes to clear the pipes. Reduce flow to a gentle stream.

3. Fill sample bottle with well water to just below the neck of the bottle. Make sure that the cap is securely tightened.

4. Place the filled sample bottle in the mailer and place all paper work in the plastic, sealable envelope.

WELL INFORMATION (filled in by well owner)

1. Do you use your well water as drinking water? YES __ NO__ Cooking? YES__ NO__

2. Do you have any problems with your well water (odor/staining/amount)?
YES__ NO__Please describe _____

3. Do you have a treatment/filter system for your well water? YES__ NO__

4. What type of treatment do you use? (softener, reverse osmosis systems, green sand/birm filters, permanganate/potassium, ion exchange)

Other _____

5. Is your treatment system designed for (circle any that apply): pH adjustment, Iron, Manganese, Arsenic, Radon, Sediment removal, other? _____

6. Have you ever had your well tested for arsenic? YES_____ NO _____
When _____ What was the concentration _____

7. How deep is your well?_____

8. How many feet of casing does the well have?_____

9. Have you ever stopped drinking water from this well? YES_____ NO_____
If yes, why? (bacteria, nitrate, arsenic, other)_____

10. How long have you been using the current well?_____

11. How long have you been drinking well water at your current location?_____

Please sign and date this page.

USGS Arsenic Project
215 Limekiln Road
New Cumberland, PA 17070

Homeowner name _____, Date_____

Received by _____, Date _____

Appendix 2 - Records of selected wells and springs, northern-tier counties, Pennsylvania

Well or spring location: The number that is assigned by the U.S. Geological Survey to identify the well or spring (SP). It is prefixed by the two-letter abbreviation of the county. The latitude and longitude of wells and springs are in degrees, minutes, and seconds as determined from topographic maps based upon site visits, tax parcel maps, and (or) conversations or location maps provided by well owners. Horizontal datum is the North American Datum of 1927 (NAD27).

Aquifer: 112ALVM, alluvium; 337HNLM, Huntley Mountain Formation; 341CSKL, Catskill Formation; 341LKHV, Lock Haven Formation; 341LNGR, Long Run Member of Catskill Formation; 341TMRK, Trimmers Rock Formation; 341TMSG, Towamensing Member of Catskill Formation; 341PGPK, Poplar Gap and Packerton Members of Catskill Formation, undivided; 344MNNG, Mahantango Formation.

Depth of well: Depth of drilled well, in feet below land surface, as reported on driller's log or well owner response.

Casing length: Feet of casing used to complete well, as reported on driller's log or well owner response.

Topographic setting: S, slope; H, hilltop; V, valley; W, upland draw.

Reported yield: Gallons per minute, as reported on driller's log or well owner response.

Year drilled: Year of well construction as reported by driller's log or well owner.

Sample collector : Owner – well or spring owner; USGS – U.S. Geological Survey.

Total arsenic: Concentration of total arsenic in micrograms per liter.

<, less than

E. coli, *Escherichia coli*

–, no information

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.

USGS identification number	Latitude	Longitude	Aquifer	Depth of well (feet)	Casing length (feet)	Topography	Reported yield (gal/min)
BRADFORD COUNTY							
BR SP-5	414309	764208	341LKHV	–	–	S	–
BR-336	414559	763546	341LKHV	151	96	S	–
BR-854	415524	764948	341LKHV	255	82	S	20
BR-855	414619	763602	341LKHV	200	143	S	–
BR-856	415904	763439	341LKHV	125	30	V	–
BR-857	413608	761540	341CSKL	132	32	S	–
BR-858	414214	764945	112ALVM	40	40	V	–
BR-859	415603	762945	341LKHV	150	20.5	S	–
BR-860	415627	763842	341LKHV	167	–	S	–
BR-861	413942	764749	112ALVM	15	15	V	–
BR-862	414756	761054	341LKHV	110	–	V	–
BR-863	413945	765141	341CSKL	132	–	V	–
BR-864	414515	762718	341LKHV	158	20	H	–
BR-865	414629	764751	341CSKL	–	–	V	–
BR-866	413503	762218	341CSKL	95	95	H	–
BR-867	415915	761737	341LKHV	140	20.5	H	15
BR-868	414803	764949	341CSKL	400	20	S	–
BR-869	415427	765005	341LKHV	130	20	S	–
BR-870	415427	765008	341LKHV	130	30	S	–
BR-871	415433	763615	341LKHV	150	90	H	–
BR-872	415757	763045	112ALVM	245	216	V	–
BR-873	413508	762207	341CSKL	90	–	V	–
BR-874	413504	762809	341CSKL	140	–	H	–
PIKE COUNTY							
PI-523	411709	745207	341LNGR	400	60	S	–
PI-524	411849	745339	341TMRK	380	182	V	–
PI-525	411235	745434	344MNNG	140	20	S	–
PI-526	412218	750345	341LNGR	250	200	S	–
PI-527	412456	745426	341LNGR	175	–	H	–
PI-528	411445	745346	341TMRK	420	380	S	–
PI-529	412317	745433	341LNGR	120	40	V	–
PI-530	412439	744432	341TMRK	220	38	V	–
PI-531	412628	750016	341LNGR	20	–	H	–
PI-532	412812	750244	341LNGR	230	–	V	–
PI-533	411330	745624	341TMSG	–	–	S	–
PI-534	411738	745601	341LNGR	–	–	S	–
PI-535	412526	750046	341LNGR	125	–	S	–
PI-536	412827	750234	341LNGR	–	–	S	–
PI-537	411523	745332	344MNNG	85	20	W	–
PI-538	412119	745934	341LNGR	–	–	S	–
PI-539	411452	745347	344MNNG	180	180	S	–

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

Driller	Year drilled	Owner comment	Date sampled for total arsenic (mo/yr)	Sample collecter	Remark	Total arsenic (µg/L)
–	–	None	Apr-06	Owner	<	4.0
Cummings	1980	None	Apr-06	Owner	<	4.0
Havens	1986	None	Jun-06	Owner	–	117.0
Karp	1992	Hard water, iron, smell	Apr-06	Owner	–	39.4
Vanderhoof	1968	Iron staining, smell	Apr-06	Owner	<	4.0
Cummings	1997	Yellow slime	Apr-06	Owner	<	4.0
–	1970	None	May-06	Owner	<	4.0
Vanderhoof	1990	Iron staining	Apr-06	Owner	<	4.0
–	1992	Iron staining	Apr-06	Owner	<	4.0
–	1890	Hard water	Apr-06	Owner	<	4.0
–	1998	Iron, smell	Apr-06	Owner	<	4.0
Troutmen	1966	None	Apr-06	Owner	<	4.0
Cummings	1972	Smell	May-06	Owner	<	4.0
Havens	1985	None	May-06	Owner	<	4.0
Cummings	2004	Brackish	Mar-06	Owner	<	4.0
Vanderhoof	1991	None	Apr-06	Owner	<	4.0
–	1998	Cloudy	Apr-06	Owner	<	4.0
Vanderhoof	1945	None	Apr-06	Owner	<	4.0
Havens	1963	Smell	Apr-06	Owner	<	4.0
Vanderhoof	1973	Iron staining	Apr-06	Owner	<	4.0
Vanderhoof	1985	Gasoline	Apr-06	Owner	<	4.0
–	1955	Smell	Mar-06	Owner	–	5.3
Cummings	1995	Staining and *E. coli*	May-06	Owner	<	4.0
Greening	1980	None	Mar-06	Owner	<	4.0
–	2005	Smell	Apr-06	Owner	<	4.0
Steeler	1983	Smell	Mar-06	Owner	<	4.0
Greening	1980	Rusty water	Mar-06	Owner	<	4.0
Weber	1994	Blue stains	Mar-06	Owner	<	4.0
–	1980	Smell	Mar-06	Owner	<	4.0
Greening	1971	Iron and manganese	Apr-06	Owner	<	4.0
Aqua Find Co.	2005	Smell	May-06	Owner	<	4.0
–	2002	Copper staining	Apr-06	Owner	<	4.0
Fritz Bros.	1978	Sediment	Apr-06	Owner	<	4.0
–	1972	Iron staining	Apr-06	Owner	<	4.0
Weber	2003	None	Apr-06	Owner	<	4.0
Shields	1945	None	Apr-06	Owner	<	4.0
Fritz Bros.	1964	Iron staining	Apr-06	Owner	<	4.0
–	1968	Smell	Apr-06	Owner	<	4.0
–	1987	Rust	Apr-06	Owner	<	4.0
–	1976	None	Apr-06	Owner	<	4.0

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

USGS identification number	Latitude	Longitude	Aquifer	Depth of well (feet)	Casing length (feet)	Topography	Reported yield (gal/min)
PI-540	412749	745456	341LNGR	250	230	S	–
PI-541	412700	745534	341LNGR	–	–	V	–
PI-542	412449	745453	341LNGR	–	–	S	–
PI-543	412734	745657	341LNGR	200	–	H	–
PI-544	411732	745536	341LNGR	300	43	S	–
PI-545	411759	751434	341PGPK	–	–	H	–
PI-546	412240	745537	341LNGR	150	–	W	–
PI-547	412739	750654	341LNGR	180	121	S	100
POTTER COUNTY							
PO-291	413821	773930	341CSKL	425	16	H	9
PO-292	413533	780338	341CSKL	68	42	V	15
PO-293	414436	780510	341CSKL	60	20	V	–
PO-294	414845	775932	341CSKL	140	68	V	–
PO-295	415015	780228	341CSKL	300	35	W	–
PO-286	415447	773857	341CSKL	300	–	W	–
PO-287	415909	773839	341LKHV	190	–	S	–
PO-288	415025	780358	341LKHV	90	–	W	–
PO-289	414543	780233	341CSKL	100	50	V	–
PO-290	414726	781036	341LKHV	120	110	S	–
SUSQUEHANNA COUNTY							
SQ-449	413942	754706	341CSKL	160	60	S	–
SQ-450	414807	753856	341CSKL	–	–	S	–
SQ-451	414752	753921	341CSKL	–	–	V	–
SQ-452	415720	753728	341CSKL	280	–	S	–
SULLIVAN COUNTY							
SU SP-3	412721	762636	112ALVM	–	–	V	–
SU-134	412928	762308	337HNLM	323	41	H	–
SU-135	413032	763400	341CSKL	400	30	S	–
SU-136	412917	763607	112ALVM	20	20	V	–
SU-137	411950	763524	112ALVM	43	43	V	–
SU-138	412038	763345	112ALVM	55	55	V	–
SU-139	411951	763527	112ALVM	45	45	V	–
SU-140	412009	763551	341CSKL	175	20	H	–
SU-141	412700	762652	337HNLM	–	–	S	–
SU-142	413236	764606	337HNLM	233	93	S	–
SU-143	412633	764231	112ALVM	95	95	V	–
SU-144	413158	763825	341CSKL	300	21	S	–
SU-145	412633	764236	112ALVM	65	65	V	–
SU-146	412255	763050	341CSKL	150	10	H	–
SU-147	413313	764447	341CSKL	80	–	V	–
TIOGA COUNTY							
TI SP-3	415613	772627	341CSKL	–	–	S	–
TI-106	415417	770819	112ALVM	25	25	V	–
TI-120	414521	765945	341CSKL	97	–	S	–

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

Driller	Year drilled	Owner comment	Date sampled for total arsenic (mo/yr)	Sample collecter	Remark	Total arsenic (µg/L)
–	1935	Smell	Apr-06	Owner	<	4.0
–	1986	None	Apr-06	Owner	<	4.0
–	1986	None	Apr-06	Owner	<	4.0
–	1975	None	Apr-06	Owner	<	4.0
Borger	2003	Smell	Apr-06	Owner	<	4.0
–	1986	None	Apr-06	Owner	<	4.0
Weber	2002	Iron staining	Apr-06	Owner	<	4.0
Hook	2000	None	Apr-06	Owner	<	4.0
Germania	2005	None	Apr-06	Owner	<	4.0
Coudersport	1987	Iron staining, smell	Apr-06	Owner	<	4.0
–	–	None	Apr-06	Owner	<	4.0
–	1994	None	May-06	Owner	<	4.0
–	–	None	Apr-06	Owner	<	4.0
Germania	1991	Staining	Apr-06	Owner	<	4.0
–	1985	Taste, cloudy	Apr-06	Owner	<	4.0
–	1955	None	May-06	Owner	<	4.0
Kellog	1972	None	Apr-06	Owner	<	4.0
Pure Water	1978	None	Apr-06	Owner	<	4.0
Drake	1991	None	Apr-06	Owner	<	4.0
–	–	Rust	May-06	Owner	<	4.0
Drake	–	None	Mar-06	Owner	<	4.0
Treblie	2004	Smell	Apr-06	Owner	<	4.0
–	–	None	Apr-06	Owner	<	4.0
House	1999	Sediment	Apr-06	Owner	<	4.0
–	–	None	Mar-06	Owner	–	9.8
–	1950	None	Mar-06	Owner	<	4.0
–	1960	Gasoline	May-06	Owner	<	4.0
Turner	1971	None	May-06	Owner	<	4.0
Turner	1948	None	Mar-06	Owner	<	4.0
Turner	1990	None	Mar-06	Owner	<	4.0
–	–	Smell, discoloration	Mar-06	Owner	<	4.0
Cummings	–	None	Mar-06	Owner	<	4.0
–	–	Iron staining	Mar-06	Owner	<	4.0
Hess	1992	White scale	Apr-06	Owner	<	4.0
–	–	None	Mar-06	Owner	<	4.0
Hornburger	1949	None	Apr-06	Owner	<	4.0
–	–	None	Mar-06	Owner	<	4.0
–	–	Sediment	Apr-06	Owner	<	4.0
–	1930	Hard water	Jun-06	USGS	<	4.0
–	2005	Hard water	May-06	Owner	<	4.0

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

USGS identification number	Latitude	Longitude	Aquifer	Depth of well (feet)	Casing length (feet)	Topography	Reported yield (gal/min)
TI-122	413933	770301	337HNLM	177	110	V	310
TI-544	413928	770534	337HNLM	300	235	V	200
TI-576	415743	770632	112ALVM	29	29	V	–
TI-577	415559	770613	341LKHV	124	106	V	–
TI-578	415852	770442	341LKHV	145	–	V	–
TI-579	415856	770705	341LKHV	187	–	V	–
TI-580	415734	770629	341LKHV	220	142	V	–
TI-667	415854	765637	341LKHV	100	–	V	–
TI-668	415424	770836	112ALVM	112	109	V	–
TI-669	415852	765635	341LKHV	100	–	V	–
TI-670	414804	771336	341LKHV	160	–	S	–
TI-671	414518	773329	341CSKL	127	56	V	–
TI-672	414221	770508	341CSKL	225	100	S	–
TI-673	414309	771245	341CSKL	100	–	S	–
TI-674	414650	770243	341LKHV	180	180	S	–
TI-675	415430	770912	341LKHV	–	–	V	–
TI-676	415420	770835	341LKHV	–	–	V	–
TI-677	415427	770820	341LKHV	137	90	V	–
TI-678	415426	770820	112ALVM	21	21	V	–
TI-679	415552	770635	112ALVM	21	21	V	–
TI-680	415903	765719	341LKHV	–	–	V	–
TI-681	415858	765626	341LKHV	90	–	V	–
TI-682	415852	765633	341LKHV	–	–	V	–
TI-683	415905	765627	341LKHV	100	–	V	–
TI-684	414720	771041	341LKHV	180	41	S	20
TI-685	415541	770306	341LKHV	160	25	S	–
TI-686	415929	770011	341LKHV	–	–	S	–
TI-687	415447	770853	341LKHV	160	–	S	–
TI-688	415000	771711	341CSKL	165	–	V	–
TI-689	414808	770610	341LKHV	143	12	S	–
TI-690	414932	770124	341LKHV	90	90	S	–
TI-691	415700	765542	341LKHV	–	–	S	–
TI-692	415636	765512	341LKHV	265	12	H	–
TI-693	415550	771615	341LKHV	47	47	W	–
TI-694	414926	770419	341LKHV	320	11	H	–
TI-695	414548	765944	341LKHV	251	32	S	8.5
TI-696	415738	772644	341LKHV	145	–	V	–
TI-697	414703	771003	341LKHV	140	20	S	–
TI-698	415927	771415	341LKHV	220	120	S	–
TI-699	415736	771300	341LKHV	120	40	H	–
TI-700	414240	771124	341CSKL	–	–	V	–
TI-701	415306	772845	341LKHV	359	50	H	–
TI-702	414356	772359	341CSKL	140	30	H	–
TI-703	414503	771212	341LKHV	225	–	H	–

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

Driller	Year drilled	Owner comment	Date sampled for total arsenic (mo/yr)	Sample collecter	Remark	Total arsenic (µg/L)
Layne	1960	Iron and manganese	Apr-06	Owner	<	4.0
Eichleberger	1988	Smell, salty	Apr-06	Owner	<	4.0
–	–	None	Jul-05	USGS	–	47.6
–	–	None	Jul-05	USGS	<	4.0
–	–	None	Jul-05	USGS	<	4.0
–	–	None	Jul-05	USGS	<	4.0
–	–	None	Jul-05	USGS	<	4.0
–	–	None	Jun-06	USGS	–	16.0
–	1951	None	May-06	Owner	–	14.4
–	–	None	Jun-06	USGS	–	53.8
–	1971	Iron staining	May-06	Owner	–	34.4
Germania	1950	Iron staining, smell, taste	Jun-06	Owner	<	4.0
Hess	1998	None	Apr-06	Owner	<	4.0
–	1897	None	May-06	Owner	<	4.0
Cizek	1972	Smell, hard water	May-06	Owner	<	4.0
–	1990	None	Jun-06	USGS	<	4.0
–	1970	Hard water	Jun-06	USGS	–	5.1
Andrews	1970	None	Jun-06	USGS	–	6.9
Hughes	1959	None	Jun-06	USGS	<	4.0
Owner	1975	None	Jun-06	USGS	<	4.0
Bellows	2004	Iron staining, smell	Jun-06	Owner	<	4.0
Hess	1999	Iron staining, smell	May-06	Owner	–	15.4
–	1976	Iron staining, smell	May-06	Owner	–	9.0
–	1968	Smell	May-06	Owner	–	13.0
–	2001	None	Apr-06	Owner	<	4.0
–	1998	Iron staining, smell, hard water	May-06	Owner	<	4.0
–	1972	None	May-06	Owner	<	4.0
–	1963	None	Apr-06	Owner	<	4.0
–	1970	Iron staining	Apr-06	Owner	<	4.0
Andrews	1993	Color	Apr-06	Owner	<	4.0
–	1958	Smell, mineral deposits	May-06	Owner	<	4.0
Roger	1988	Smell	May-06	Owner	<	4.0
Bellows	1998	None	May-06	Owner	<	4.0
Andrews	–	None	Apr-06	Owner	<	4.0
Andrews	1997	None	May-06	Owner	<	4.0
Germania	1995	None	May-06	Owner	<	4.0
Germania	1963	Staining	May-06	Owner	–	4.5
Andrews	1982	None	May-06	Owner	<	4.0
Terwilliger	1981	None	May-06	Owner	<	4.0
Andrews	1985	Hard water	May-06	Owner	<	4.0
–	1998	Iron staining	May-06	Owner	<	4.0
Germania	1974	None	May-06	Owner	<	4.0
Cizek	1980	Iron	May-06	Owner	<	4.0
Andrews	1975	None	May-06	Owner	<	4.0

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

USGS identification number	Latitude	Longitude	Aquifer	Depth of well (feet)	Casing length (feet)	Topography	Reported yield (gal/min)
TI-704	414624	765430	341CSKL	130	19	S	–
TI-705	414339	771922	341LKHV	78	–	W	–
TI-706	413958	771931	341CSKL	–	–	H	–
TI-707	415128	771420	341CSKL	–	–	V	–
TI-708	415056	765724	341LKHV	–	–	S	–
TI-709	415545	771916	341LKHV	165	35	S	–
TI-710	414915	770100	341LKHV	300	32	S	10
TI-711	415545	772124	341LKHV	334	56	S	–
TI-713	415139	765725	112ALVM	30	30	V	–
TI-714	415738	765626	341LKHV	–	–	W	–
TI-715	415911	765615	341LKHV	–	–	S	–
TI-716	414448	772018	341CSKL	–	–	S	–
TI-717	415632	773447	341LKHV	90	30	V	–
TI-718	415909	765627	341LKHV	29	–	S	–
TI-719	415824	770113	341LKHV	86	40	V	–
TI-720	415825	770114	341LKHV	106	40	S	–
TI-721	415742	772307	341LKHV	175	–	V	–
TI-722	415051	772807	341CSKL	317	21	H	–
TI-723	414545	771952	341CSKL	300	–	H	–
WAYNE COUNTY							
WN-210	413759	750700	341CSKL	340	50	S	–
WN-211	413841	750504	341CSKL	183	42	H	–
WN-212	414656	751757	341CSKL	210	90	S	–
WN-213	412849	752419	341PGPK	80	–	S	–
WN-214	413946	751939	341CSKL	356	40	S	–
WN-215	413107	751649	341LNGR	132	–	S	–
WN-216	413412	750623	341LNGR	–	–	W	–
WN-217	414136	751316	341CSKL	–	–	S	–
WN-218	412246	752057	112ALVM	12	12	S	–
WN-219	414726	751512	341CSKL	130	–	H	–
WN-220	413611	752304	341CSKL	210	40	W	–
WN-221	412928	751021	341LNGR	280	41	S	–
WN-222	413758	750709	341CSKL	–	–	S	–
WN-223	412945	752654	341PGPK	200	–	S	–
WN-224	413752	750706	341CSKL	160	–	S	–
WYOMING COUNTY							
WY-181	412951	755341	341CSKL	200	40	S	–
WY-182	413659	754457	341CSKL	540	–	S	–
WY-183	413315	761210	341CSKL	250	–	S	–
WY-184	412956	760754	341CSKL	160	70	V	–
WY-185	413114	760750	341CSKL	198	80	V	–
WY-186	413029	755000	341CSKL	200	83	S	–
WY-187	412743	755125	341CSKL	180	80	V	–
WY-188	412545	755118	341CSKL	450	80	H	–

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

Driller	Year drilled	Owner comment	Date sampled for total arsenic (mo/yr)	Sample collecter	Remark	Total arsenic (µg/L)
Andrews	1989	None	Apr-06	Owner	–	4.0
Andrews	1978	None	May-06	Owner	<	4.0
–	1983	None	May-06	Owner	<	4.0
–	1950	Hard water	May-06	Owner	<	4.0
–	990	Smell	May-06	Owner	<	4.0
Andrews	2001	Wormy smell	Apr-06	Owner	<	4.0
Burgess	1996	None	Apr-06	Owner	<	4.0
Germania	2002	Iron staining	Apr-06	Owner	<	4.0
–	1976	None	Apr-06	Owner	<	4.0
Hess	1995	Iron and manganese	Apr-06	Owner	<	4.0
–	1986	Iron staining	Apr-06	Owner	<	4.0
–	1950	None	Apr-06	Owner	<	4.0
McLaughlin	1948	Iron staining, smell	Apr-06	Owner	<	4.0
–	1957	Iron staining, smell	Apr-06	Owner	<	4.0
Darmstadt	1993	Iron staining, smell	May-06	Owner	<	4.0
–	1984	Rusty water	May-06	Owner	<	4.0
McLaughlin	1975	Iron staining	Apr-06	Owner	–	9.8
Germania	1997	Sediment	Apr-06	Owner	<	4.0
Hess	1992	None	May-06	Owner	<	4.0
Davis	1979	Iron	Mar-06	Owner	–	188.0
Smith	1974	None	May-06	Owner	<	4.0
Tully	1994	Iron staining, smell	Mar-06	Owner	<	4.0
Fritz Bros.	1974	None	Apr-06	Owner	<	4.0
Fritz Bros.	–	None	Mar-06	Owner	<	4.0
Fritz Bros.	1998	Iron staining	Apr-06	Owner	<	4.0
–	1950	None	Apr-06	Owner	<	4.0
–	–	None	Mar-06	Owner	<	4.0
Owner	1964	Corrosion	Apr-06	Owner	<	4.0
Fritz Bros.	1993	None	Apr-06	Owner	<	4.0
Fritz Bros.	1974	None	Mar-06	Owner	<	4.0
Hook	2004	None	Mar-06	Owner	<	4.0
–	–	None	Jun-06	USGS	<	4.0
–	–	Taste	Mar-06	Owner	<	4.0
–	–	None	Jun-06	USGS	<	4.0
Cress	1960	Iron staining, taste	Mar-06	Owner	<	4.0
Cress	1977	None	Apr-06	Owner	<	4.0
Strumski	1987	Iron staining	Mar-06	Owner	<	4.0
–	1985	Iron	Apr-06	Owner	<	4.0
Cress	1974	None	May-06	Owner	<	4.0
Cress	1971	None	May-06	Owner	<	4.0
–	1945	None	May-06	Owner	<	4.0
Leib	1995	None	Apr-06	Owner	<	4.0

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

USGS identification number	Latitude	Longitude	Aquifer	Depth of well (feet)	Casing length (feet)	Topography	Reported yield (gal/min)
WY-189	412819	760852	341CSKL	75	60	V	–
WY-190	412615	755626	341CSKL	100	100	S	–
WY-191	413038	755758	341CSKL	–	–	W	–

Appendix 2. Records of selected wells and springs, northern-tier counties, Pennsylvania.—Continued

Driller	Year drilled	Owner comment	Date sampled for total arsenic (mo/yr)	Sample collecter	Remark	Total arsenic (µg/L)
Jimcon	2005	Iron	Apr-06	Owner	<	4.0
–	1988	None	May-06	Owner	<	4.0
–	1990	None	Apr-06	Owner	<	4.0