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Occurrence and Distribution of Mercury in the Surficial Aquifer, Long Neck Peninsula, Sussex County, Delaware, 2003–04

Scientific Investigations Report 2006-5011

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

Cover. U.S. Geological Survey satellite photograph of the Pot Nets Bayside community, Long Neck Peninsula, Sussex County, Delaware.

Occurrence and Distribution of Mercury in the Surficial Aquifer, Long Neck Peninsula, Sussex County, Delaware, 2003–04

By Michael T. Koterba[1], A. Scott Andres[2], Joseph Vrabel[1], Dianna M. Crilley[1], Zoltan Szabo[1], John F. DeWild[1], George R. Aiken[1], and Betzaida Reyes-Padro[1]

[1] U.S. Geological Survey
[2] Delaware Geological Survey

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Conversion Factors, and Vertical Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Flow rate	
gallon per minute (gal/min)	3.785	liter per minute (L/min)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram

Temperature in degrees Celsius ($^{\circ}C$) can be converted to degrees Fahrenheit ($^{\circ}F$) as follows:

$$^{\circ}F = (1.8 \times {}^{\circ}C) + 32$$

Vertical datum: In this report, vertical coordinate information is referenced to the North American Datum of 1983 (NAD83).

Altitude, as used in this report, refers to distance above or below sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 $^{\circ}C$).

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

Concentrations of chemical constituents in sediment are given in micrograms per kilogram (µg/kg), or as a percentage by weight, in percent (%).

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By Michael T. Koterba, A. Scott Andres, Joseph Vrabel, Dianna M. Crilley, Zoltan Szabo, John F. DeWild, George R. Aiken, and Betzaida Reyes-Padro

Abstract

In January 2001, mercury (Hg) was detected (500 nanograms per liter, ng/L, or greater) in the distribution system of the Long Neck Water Company (LNWC), Pot Nets, Delaware. By April 2001, two LNWC production wells had been taken off-line because discharge concentrations of total mercury (HgT) either had exceeded or approached the Federal limit of 2,000 ng/L. From October 2003 through January 2005, the U.S. Geological Survey, Delaware Geological Survey, and Delaware Department of Natural Resources and Environmental Control conducted a cooperative study to (a) determine if the Hg contamination was widespread, (b) identify possible forms of Hg in ground water, and (c) examine Hg occurrence in relation to (geo)chemical conditions and characteristics of ground water and sediment in the surficial aquifer on the Long Neck Peninsula, Sussex County, Delaware.

An initial water-quality survey conducted with samples from 22 production wells revealed that concentrations of HgT in ground water in the surficial aquifer ranged from 0.11 to 1,820 ng/L. Shallow ground water (less than 120 feet below land surface) throughout most of the peninsula, including that which contained elevated concentrations of HgT (exceeding 100 ng/L), appeared to be affected by human activities. All samples contained volatile organic compounds (VOCs) and elevated nitrate-nitrogen (NO_3-N, exceeding 0.4 milligrams per liter, mg/L). Most (16 of 22) samples had elevated specific conductance (SC, in excess of 100 microsiemens per centimeter at 25 degrees Celsius). Elevated concentrations of HgT, however, only occurred in five production wells in the Pot Nets Bayside and Lakeside communities.

The vertical distribution of HgT in shallow ground water (less than 80 feet below land surface) was determined with samples collected at 5 to 6 vertical-nest short-screened (2–5-foot length) monitoring wells installed near Bayside and Lakeside production wells with the highest HgT concentrations (exceeding 1,000 ng/L). Elevated concentrations of HgT (100–6,380 ng/L) occurred in the shallow aquifer near each well at different depths.

Chemical analyses of selected soil, fill, and aquifer sediment samples, obtained during the installation of nested wells, indicated that little HgT occurred in soil or fill at either site (40 micrograms per kilogram, µg/kg, or less). No HgT was detected (less than 20 µg/kg) in aquifer sediment samples. These low HgT concentrations imply that neither the soil, fill, nor aquifer sediment was a likely source of the elevated Hg in ground water.

Given Hg occurrence appeared to be a ground-water transport phenomenon, the forms of Hg in transport were investigated. Differences in HgT concentrations between raw and filtered (0.1- and (or) 0.4-absolute micrometer pore size) samples from nested wells were random in sign and similar in magnitude to the variability in measuring HgT attributed to field and laboratory methods (± 5–10 percent, for HgT concentrations exceeding 100 ng/L). Thus, Hg transport likely occurred in a dissolved or fine-colloidal nonparticulate phase.

Methyl mercury (HgMe) only was detected at low concentrations (0.06 ng/L or less) in nested-well samples with low to moderate concentrations of HgT (less than 366 ng/L). Whether HgMe occurred at similar concentrations in samples with high HgT concentrations was unresolved due to a sample-matrix interference problem.

Potential complex forms of Hg were investigated in relation to the occurrence of selected ligands (organic carbon, sulfide, and chloride concentrations) and geochemical conditions (for example, pH and dissolved oxygen concentrations). Only dissolved organic carbon (DOC) appeared directly related to Hg occurrence. Elevated concentrations of HgT and DOC co-occurred in ground water at both Pot Nets sites. The average concentration of DOC was about four times greater in samples from the Pot Nets wells with the highest HgT concentrations (exceeding 1,000 ng/L) than in most Pot Nets or peninsula samples with low HgT concentrations (less than or equal to 20 ng/L).

The relation between Hg and DOC does not appear to be coincidental. Nested-well samples with elevated concentrations of HgT and DOC generally had a higher specific ultraviolet absorption at 280 nanometers than samples with low concentrations of DOC and HgT. The highest acid-neutralization capacities (ANCs) occurred in ground-water samples with the highest concentrations of DOC and HgT at both sites, and DOC and ANC were positively correlated (r^2=0.90). In addition, the fraction of hydrophobic carbon, measured for samples with the highest concentrations of HgT at each site, equaled or exceeded by several fold the total DOC found in samples with low concentrations of HgT at each site. These findings indicated the possible presence of humic aromatic and aliphatic carbon compounds in the hydrophobic carbon fraction. Other studies in different locations, but with similar hydro-chemical conditions, have shown such carbon fractions can strongly interact with simple chemical forms of Hg –ionic (HgII), sulfide (HgS), or methyl (HgMe).

Shallow ground water at each Pot Nets site appeared affected by human activities. Detectable VOCs, and elevated SC, NO_3^--N, and (or) magnesium occurred at all sampled depths, including those depths that corresponded to elevated concentrations of HgT. In addition, the apparent dates of recharge and ages of ground water, estimated from sample concentrations of chlorofluorocarbon compounds (CFCs), indicated that ground water with elevated concentrations of HgT at both Pot Nets sites was similar in relation to apparent recharge dates and ages (circa 1970 to 1985, or 20–35 years). Ground-water samples with low concentrations of HgT, which were obtained from nested wells screened at deeper and shallower depths than the wells with high concentrations, of HgT, had apparent recharge dates that corresponded to times before and after this period, respectively.

The elevated concentration of Hg in ground water near the Pot Nets wells appears to be of local, anthropogenic, and relatively recent origin, and possibly from a single source. High concentrations of HgT (exceeding 1,000 ng/L) first occurred at the Lakeside production well just 2 months after high concentrations led to the shutdown of the Bayside well. Elevated concentrations of HgT only have been found in shallow ground water in the vicinity of these two Pot Nets production wells. No measurable Hg occurred in the aquifer sediment at either production-well site. Ground water with elevated concentrations of HgT appeared relatively young and similar in apparent age at both sites. In addition, its quality at all sampled depths at both sites reflected chemical indicators of recent human activities typically associated with residential, or agricultural followed by residential, development.

The occurrence of elevated Hg at both Pot Nets community sites in ground water that also appeared affected by residential and (or) agricultural development also has been widely observed in similar settings and coastal aquifers in New Jersey. It is not possible, however, to determine from the limited historical data on Hg in the shallow aquifer, and this single study, whether or not there could be a potentially more widespread but scattered pattern of Hg occurrence in the shallow surficial aquifer in Delaware.

Introduction

This study focused on shallow ground water on the Long Neck Peninsula, Sussex County, Delaware (fig.1). In January 2001, mercury (Hg) was detected at selected points in the distribution system of the Long Neck Water Company (LNWC), Pot Nets, Delaware (detection level 500 nanograms per liter, ng/L, Department of Natural Resources and Environmental Control, 2002). In February 2001, a Hg concentration of 3,000 ng/L at LNWC production well Pi31-01 in the Pot Nets Bayside (hereafter, Bayside) community (fig. 1) exceeded the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) of 2,000 ng/L (U.S. Environmental Protection Agency, 2002)[1], and this well was taken off-line. Shortly thereafter, in April 2001, elevated concentrations of Hg occurred at a second LNWC production well, Ph35-25, in the nearby Pot Nets Lakeside (hereafter, Lakeside) community (fig. 1). The Hg concentration eventually increased to 1,900 ng/L, and in August 2001, this well was taken off-line.

Subsequent preliminary studies were conducted in relation to each contaminated well by the Delaware Department of Natural Resources and Environmental Control, (DNREC) (2002) and McCrone, Inc. and the LNWC (James Mooney, Operations Manager, LNWC, written commun., 2004). In part, the DNREC study defined wellhead protection areas for LNWC wells at Pot Nets Bayside and Lakeside, and found the following:

(a) Production wells and the aquifer in the Pot Nets community areas appeared vulnerable to surficial contamination;
(b) Source-water protection areas for the Pot Nets Bayside and Lakeside communities did not overlap; and
(c) Hg contamination was not from well construction or pump materials.

McCrone, Inc. and the LNWC (James Mooney, Operations Manager, LNWC, written commun., 2004) found the following:

(a) Elevated Hg concentrations persisted in production wells (for example, Pi31-01 or Ph35-25) that are pumped routinely (daily); and
(b) No Hg was detected in shallow ground water (less than 40 feet, ft, below land surface) at Bayside (Pi31-01) site.

[1] Hereafter, references to Federal drinking-water standards or the U.S. Environmental Protection Agency Maximum Contaminant Levels relate to this reference, which will not be parenthetically cited.

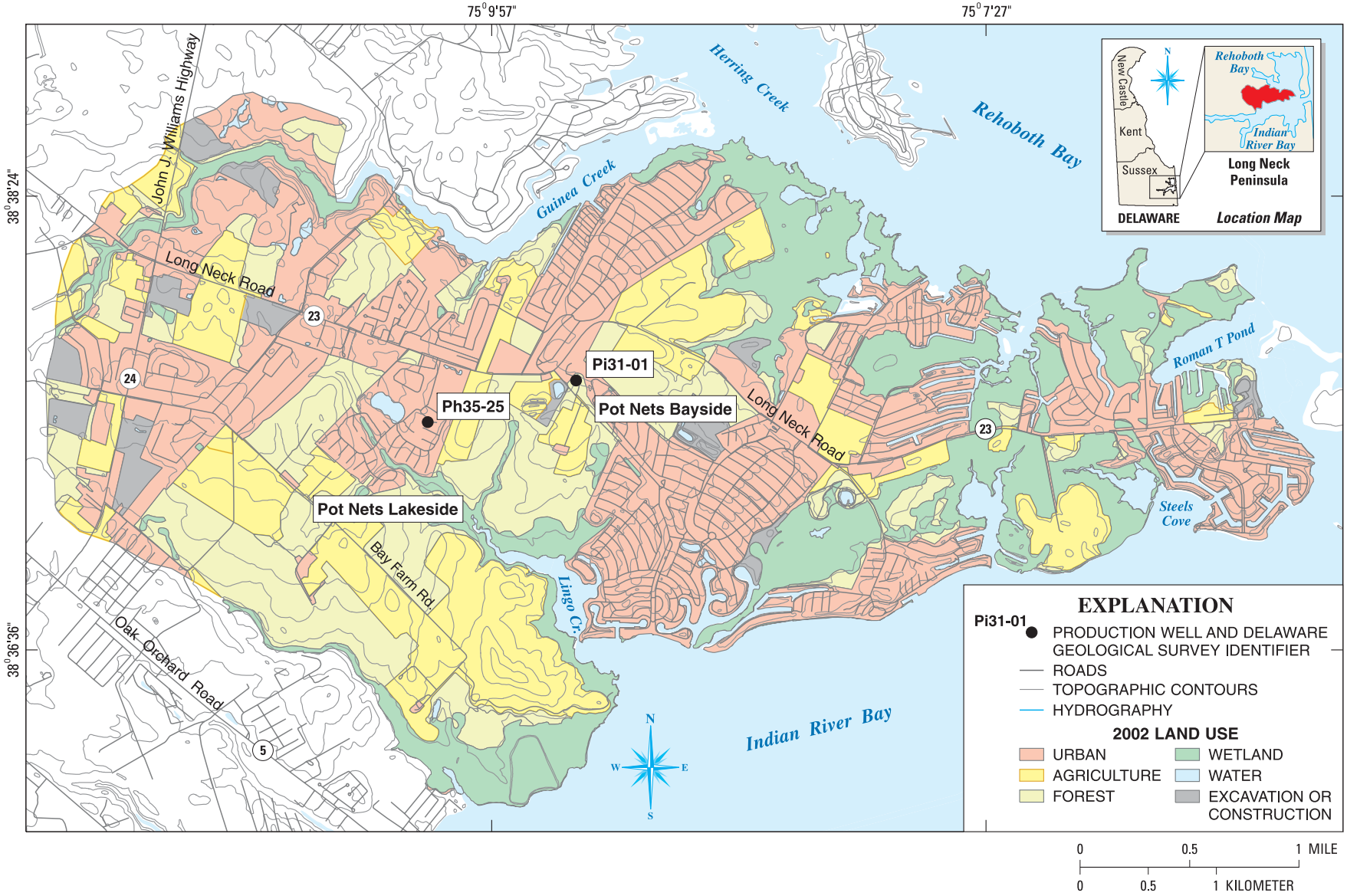

Figure 1. Location and land use and cover of the Long Neck Peninsula, Sussex County, Delaware (modified from land-use coverage from the Delaware Office of State Planning Coordination, 2002).

Independent of these studies, there also has been no documented release of Hg on the Long Neck Peninsula that could indicate a potential recent and local Hg source (Department of Natural Resources and Environmental Control, Toxic Release Inventory Database, Delaware, 1995–2003).

Before the occurrence of elevated concentrations of Hg in Pot Nets production wells, mercury had not been measured above the USEPA MCL in any Delaware public production well since the mid–1980s (Blair Venables, Hydrologist, DNREC, written commun., 2001). Historically, mercury has not been reported for the surficial aquifer in Delaware, but (pre–1989) data were compiled for the confined aquifers of the Delmarva Peninsula, and although the number of analyses were limited, mercury was detected (detection limit 100 ng/L) in 31 of 45 well samples, with a maximum concentration of 1,200 ng/L (Hamilton and others, 1989, Table 11, p. 64). Historical data, however, could be positively biased. Recent (post–1989) ground-water-quality assessments that included Delaware also have not included data on Hg (Hamilton and others, 1993; Ferrari, 2002; Denver and others, 2004). Thus, readily available knowledge of the distribution of Hg in shallow ground water is lacking for Delaware, including the Long Neck Peninsula.

The lack of detectable total mercury concentrations in ground water (HgT_{gw}) in the surficial aquifer of Delaware is in sharp contrast to shallow ground water in a similar coastal aquifer setting in New Jersey. Beginning in the 1990s, a series of studies of the unconfined and extensive (7,770 square kilometers, km^2) Kirkwood-Cohansey Aquifer (KCA) led to the following conclusions: (a) background concentrations for HgT_{gw} were 10 ng/L or less; (b) Hg contamination was widespread, but locally and regionally heterogeneous; and (c) the highest concentrations (2,000 ng/L–72,000 ng/L) of Hg reflected samples collected from hundreds of domestic production wells located chiefly in residential areas developed on, or adjacent to and downgradient from, agricultural lands (Murphy and others, 1994; Barringer and Macleod, 2001; Barringer and others, 2005).

The contrast in Hg occurrence and distribution in shallow ground water given the similar types of surficial aquifers, coastal settings, and patterns in development in Delaware and New Jersey raised several questions. Did elevated Hg concentrations occur elsewhere in the surficial aquifer on the Long Neck Peninsula? Did the high concentrations of HgT_{gw} at the two Pot Nets production wells reflect a pattern of anthropogenic ground-water contamination on the Long Neck Peninsula similar to that found in New Jersey? How was mercury likely transported, and was it from a single native or anthropogenic source or multiple sources?

In October 2004, the U.S. Geological Survey (USGS), Delaware Geological Survey (DGS), and DNREC entered into a cooperative agreement to determine if the extent (occurrence and geographic distribution) of Hg contamination in shallow ground water possibly was more widespread than just the Pot Nets Lakeside and Bayside community sites near the two production wells that were taken off-line. To address whether Hg in the vicinity of the two contaminated Pot Nets production wells likely was from an anthropogenic source or sources, the vertical distribution of Hg in ground water and sediment were characterized, chemical or physical form(s) of mercury in sediment and ground water were identified, and other ground-water quality, geochemical, or aquifer characteristics were determined and evaluated in relation to the occurrence or transport of Hg in ground water. Results from all of the above also were used to aid in the identification of possible source(s) of Hg contamination.

Purpose and Scope

The purpose of this report is to provide descriptions of the occurrence and distribution (geographical and vertical) of total Hg, other selected forms of Hg, and their relation to other determined ground-water physical or chemical characteristics or conditions in the shallow surficial aquifer, on the Long Neck Peninsula, Sussex County, Delaware. These descriptions were derived from the analyses of ground water and surficial-sediment data, which were obtained in relation to sequential studies, as follows:

(a) The occurrence and geographical distribution of Hg, its possible forms, and the relations between Hg and other selected ground-water-quality constituents are described on the basis of data and samples obtained in November and December, 2003 from 22 production wells (13 public and 9 private wells), geographically distributed throughout the study area, and screened in the surficial aquifer.

(b) The occurrence and vertical distribution of Hg in the surficial aquifer, its possible forms in ground water, and relations between Hg and other selected surficial-sediment or ground-water characteristics are described on the basis of surficial-sediment and ground-water data and samples obtained in the vicinity of the Bayside (Pi31-01) and Lakeside (Ph35-25) production wells as part of a second study, which consisted of three phases:

Phase 1: Determine the short-term (approximately 24-hour) variability in the bulk and selected chemical and physical characteristics of production-well discharge, and given a suitable period of stability in these properties in production-well discharge, determine if bulk physical and chemical properties of shallow ground water in the vicinity of each pumping production well differ with depth.

Phase 2: Determine the occurrence and vertical distribution of Hg and other selected chemical and physical characteristics in the surficial sediment in the vicinity of each production well. (Total mercury concentrations in sediment hereafter are referred to as HgT_{sed}).

Phase 3: Determine the occurrence and vertical distribution of total Hg in ground water, selected physical and chemical forms of Hg, and their relation to other water-quality characteristics and conditions, including geochemical characteristics, with depth in the vicinity of each production well. Given the results from Phases 2 and 3, identify possible forms of Hg in transport and probable source(s) of elevated Hg. (Total mercury concentrations in ground water hereafter are referred to as HgT_{gw}).

For (a) above, concentrations of HgT_{gw} in samples obtained from 22 production wells distributed throughout the Long Neck Peninsula and screened in the shallow surficial aquifer were used to describe the spatial occurrence and distribution of total mercury in raw water ($HgT_{gw\text{-}raw}$) in the surficial aquifer. Data used to identify and describe the possible forms of Hg, and ground-water characteristics or geochemical conditions that possibly related to the occurrence and distribution of HgT_{gw}, included the following: concentrations of total mercury and methyl mercury in filtered samples (0.4-micrometer (µm) absolute pore size encapsulated nylon pleated filter), hereafter referred to as $HgT_{gw\text{-}f0.4\ and}$ $HgMe_{gw\text{-}f0.4}$, respectively, bulk properties (pH, specific conductance (SC), and concentrations of dissolved organic carbon (DOC) and dissolved oxygen (DO), and concentrations of major ions, selected nutrients (nitrogen and carbon), trace elements, and volatile organic compounds (VOCs).

For (b) Phase 1 above, concentrations of HgT_{gw}, bulk properties, major ions, nutrients, and selected trace elements from samples collected at different times during a 26-hour period in February 2004 at the Bayside production-well (Pi31-01) site were used to describe short-term variations in the bulk chemistry of well discharge. Bulk-chemistry data obtained at about 1-ft depth intervals in two nearby monitoring wells, and water-quality samples similar to those above but obtained at different depths from one monitoring well, were used to provide a preliminary description of changes in ground-water chemistry with depth in the shallow aquifer. At the Lakeside site, data obtained from the production well (Ph35-25) and a nearby monitoring well, before and during pumping of the production well, were limited to bulk properties. Knowledge of temporal variations (or lack thereof) in the bulk chemistry of production-well discharge through time, and changes in the chemistry in monitoring well discharge with depth, were used to develop the sampling approach, and to identify screen depths for the new vertically nested monitoring wells, respectively, at each production-well site.

For (b) Phase 2 above, concentrations of HgT_{sed}, total sulfur, and carbon (total, organic, and inorganic), and trace elements were obtained from soil, apparent fill, and aquifer sediment samples collected during installation of vertical nests of monitoring wells in June and July 2004. These data were used to describe the vertical distribution of Hg and its relation to other chemical constituents in sediment in the aquifer near each contaminated production well.

For (b) Phase 3 above, concentrations of $HgT_{gw\text{-}raw}$, $HgT_{gw\text{-}f0.4}$, and additional filtered samples for total mercury to better assess Hg occurrence in the particulate phase (0.1-µm absolute pore size nylon pleated filter, hereafter referred to as $HgT_{gw\text{-}f0.1}$), as well as data on bulk properties, major ions, nutrients (carbon, sulfur, and nitrogen), selected trace elements, VOCs, chlorofluorocarbon compounds (CFC-11, -12, and -113), and dissolved gases (methane, carbon dioxide, nitrogen, oxygen, and argon) were obtained from ground-water samples collected from production and nested monitoring wells during an approximately 30-hour period at each Pot Nets site in September 2004. These data were used to describe the vertical distribution of HgT_{gw} in the surficial aquifer at selected depths, to compare Hg concentrations in ground water (HgT_{gw}) and sediment (HgT_{sed}), to describe different possible forms of Hg in ground water (for example, by comparing $HgT_{gw\text{-}raw}$ to $HgT_{gw\text{-}f0.4}$, $HgT_{gw\text{-}f0.1}$, and $HgMe_{gw\text{-}f0.4}$), and to relate Hg occurrence to that of other ground-water contaminants, constituents, or geochemical conditions, and the apparent recharge dates and ages of ground water at different depths. Collectively, these data were used to help identify possible sources of Hg contamination.

Description of Study Area

The Long Neck Peninsula is a small (about 9.9-square-mile) coastal area in Sussex County, Delaware (fig. 1). The year-round resident population of the peninsula is less than 10,000, but increases to between 20,000 and 30,000 during the summer months—Memorial Day through Labor Day (U.S. Census Bureau, 2000).

The Long Neck Peninsula is a low-lying area (elevation less than 25 ft) with topography that is relatively flat and gently rolling with small streams (fig. 1). Residential and commercial development is concentrated along the main thoroughfares—the John Williams Highway (State Road (SR) 24) and Long Neck Road (SR 23), with SR 23 generally following the topographic divide from west to east along the peninsula.

As of 2002, about 40 percent of the Long Neck Peninsula could be classified as urban (chiefly residential and light commercial) with about 3 percent of the land area in transition, mainly toward urban use (table 1). Before the development of summer and retirement communities that began in the early 1960s, predominant land uses were agriculture, forest, and wetland (U.S. Geological Survey, 1954); as of 2002, however, each of these land uses comprised less than about 20 percent of the total land area.

Table 1. Land use and cover for the Long Neck Peninsula, Sussex County, Delaware, 2002

[Modified from 2002 coverage, Delaware Office of State Planning Coordination, Projection UT Zone 18 NAD 83—see figure 1]

Use category	Area (square miles)	Area (percent)
Urban	3.85	38.8
Agricultural	1.84	18.5
Forest	1.87	18.9
Wetland	1.94	19.6
Water	0.10	1.1
Transitional	0.31	3.1
Total	9.91	100

Hydrogeology

The Long Neck Peninsula lies within the Atlantic Coastal Plain Physiographic Province, and is underlain by a wedge of mainly unconsolidated sediment that extends throughout the Delmarva Peninsula. Cushing and others (1973) described this wedge as a series of confined aquifers and associated confining beds overlain by a surficial aquifer that generally is unconfined.

The aquifer on the Long Neck Peninsula on the basis of the formations described can be referred to as the surficial aquifer. The major near-surface geologic units for this aquifer on the peninsula are from oldest to youngest as follows (Andres, 2005)[2]: (a) the Bethany Formation of Miocene to Pliocene age (Andres, 2004), (b) the Beaverdam Formation of Pliocene age (Groot and Jordan, 1990), and (c) the Lynch Heights and Scotts Corners Formations of Quaternary age (Ramsey, 1993, 1997). In the Bayside and Lakeside areas (figs. 2a and 2b), fine-grained beds of the Bethany Formation, which commonly form the base of the aquifer, were apparently not penetrated by nested-well boreholes of up to 80 ft in depth, but Andres (1987) and Talley (1987) found the depth to the base of the aquifer can exceed 100 ft. The Lynch Heights and Scotts Corners Formations are relatively thin (less than 15-ft-thick) deposits that overlie the Beaverdam Formation. The Lynch Heights Formation is the surficial unit at land-surface elevations above 15 ft.

The coarsest aquifer sediment, chiefly well-sorted sand and gravel, and the most permeable part of the aquifer occur in the lower part of the Beaverdam Formation (fig. 2b). Drillers for production wells on the peninsula often seek this part of the aquifer, and production wells used in this study were screened in this part of the aquifer. Above this interval, sediments of the upper Beaverdam Formation tend to fine upward, and grade into interbedded sand, silty sand, and sandy silt and clay, which in turn are overlain by the Lynch Heights and Scotts Corners Formations.

Depending on surficial materials, the surficial aquifer could be unconfined, semi-confined, or confined. Surficial materials comprised mainly of sand and gravel can function as aquifers; however, materials comprised of silts and clays can function as semi-confining or confining units.

Andres (1991a, 2004) and Andres and others (2002) mapped surficial materials (within 20 ft of the land surface) in relation to their potential to transmit water into the surficial aquifer (fig. 3). Recharge potential for surficial sediments ranged from poor to excellent, with poor-to-fair potentials in the vicinity of the Lakeside (Ph35-25) and Bayside (Pi31-01) production wells. Samples and geophysical logs collected during and after drilling of nested wells at these sites confirmed the presence of silts and clays, but their thickness was highly variable over short distances. Overall, the heterogeneity in recharge potential throughout the study area (fig. 3), which also was confirmed by drilling conducted during nested-well installations at the Bayside and Lakeside sites, indicated that shallow ground-water-flow patterns could be complex.

Surface materials of generally undocumented origin, hereafter designated as fill, also can overlie surficial formations in or near areas of urban development on the Long Neck Peninsula. Historical topographic maps (U.S. Geological Survey, 1954) indicate sources of fill include borrow pits in or near the Lakeside and Bayside Communities. Andres (1987) and Talley and Andres (1987) also identified several abandoned borrow pits that likely were sources for fill. Most of these pits currently (2005) are covered by residential developments and related infrastructure.

Fill materials were identified during drilling of nested wells at both Pot Nets community sites (Appendix B, figs. B1 and B2). At the Bayside production-well (Pi31-01) site, which is largely covered by a secondary mixed hardwood forest (fig. 4a), from 0.5 to l.5 ft of apparent fill overlies the original forest soil (organic and mineral horizons). At the Lakeside production-well (Ph35-25) site, a mainly grassy area between a landscaped swimming pool complex and residential area (fig. 4b), about 2 ft of new soil and surface fill appears to overlie aquifer sediment. The surficial fill at both Pot Nets sites likely reflects cut-and-fill operations during development construction (James Mooney, Operations Manager, LNWC, written commun., 2004). Given no chemical analysis for Hg had been conducted on soil, fill, or aquifer sediment in either community before this study, it needed to be determined whether the fill was from local sources or was Hg-contaminated material brought in from other areas.

2. The stratigraphic nomenclature used is that of the Delaware Geological Survey. It includes formation nomenclature, for example, Beaverdam, Bethany, Scotts Corners, and Lynch Heights Formations different than that used by the U.S. Geological Survey. Use of the terms upper and lower Beaverdam Formations are informal stratigraphic units.

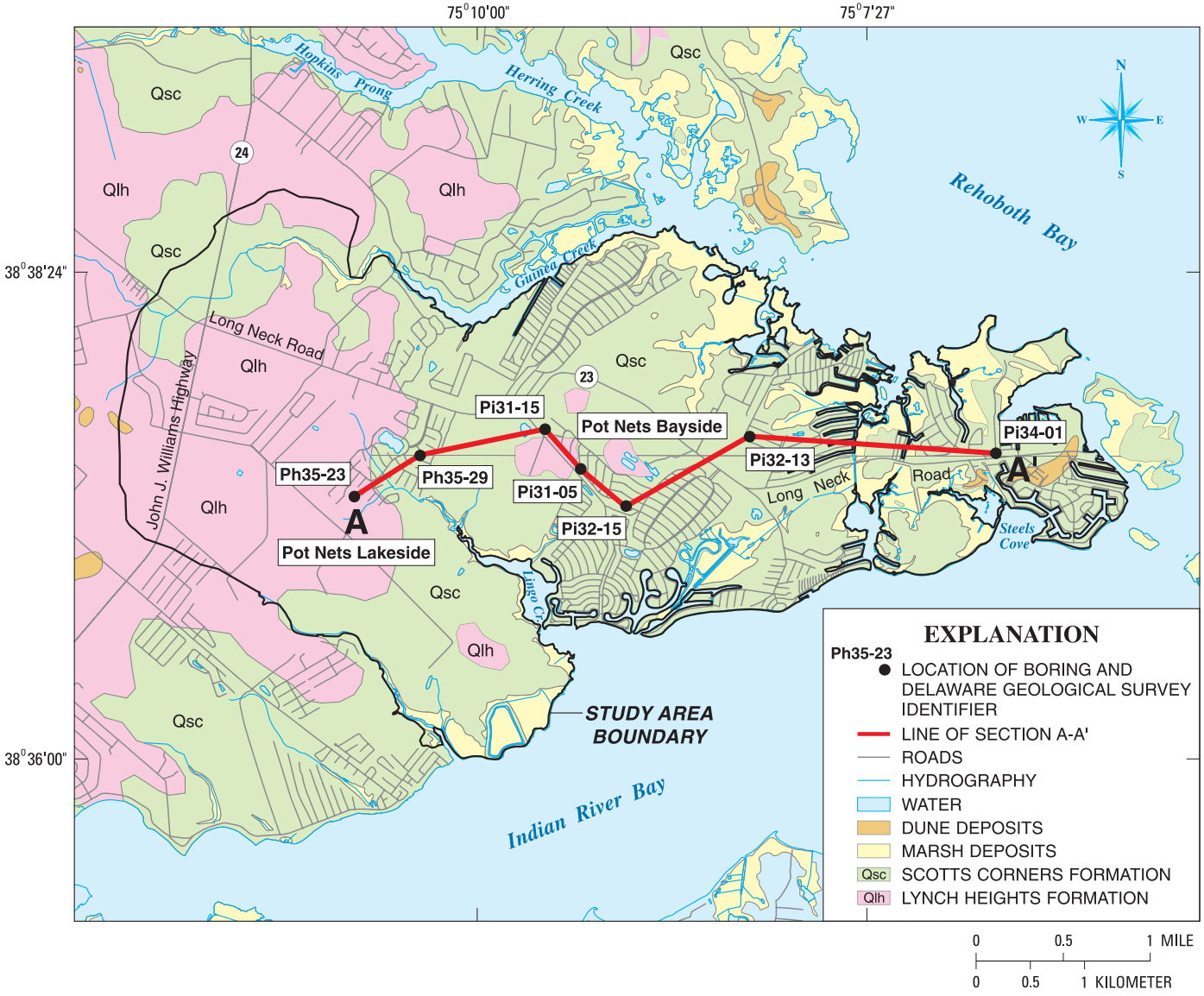

Figure 2a. Surficial geology and line of section A-A' in the vicinity of Pot Nets Lakeside and Bayside communities, Long Neck Peninsula, Sussex County, Delaware (modified from Andres, 2005).

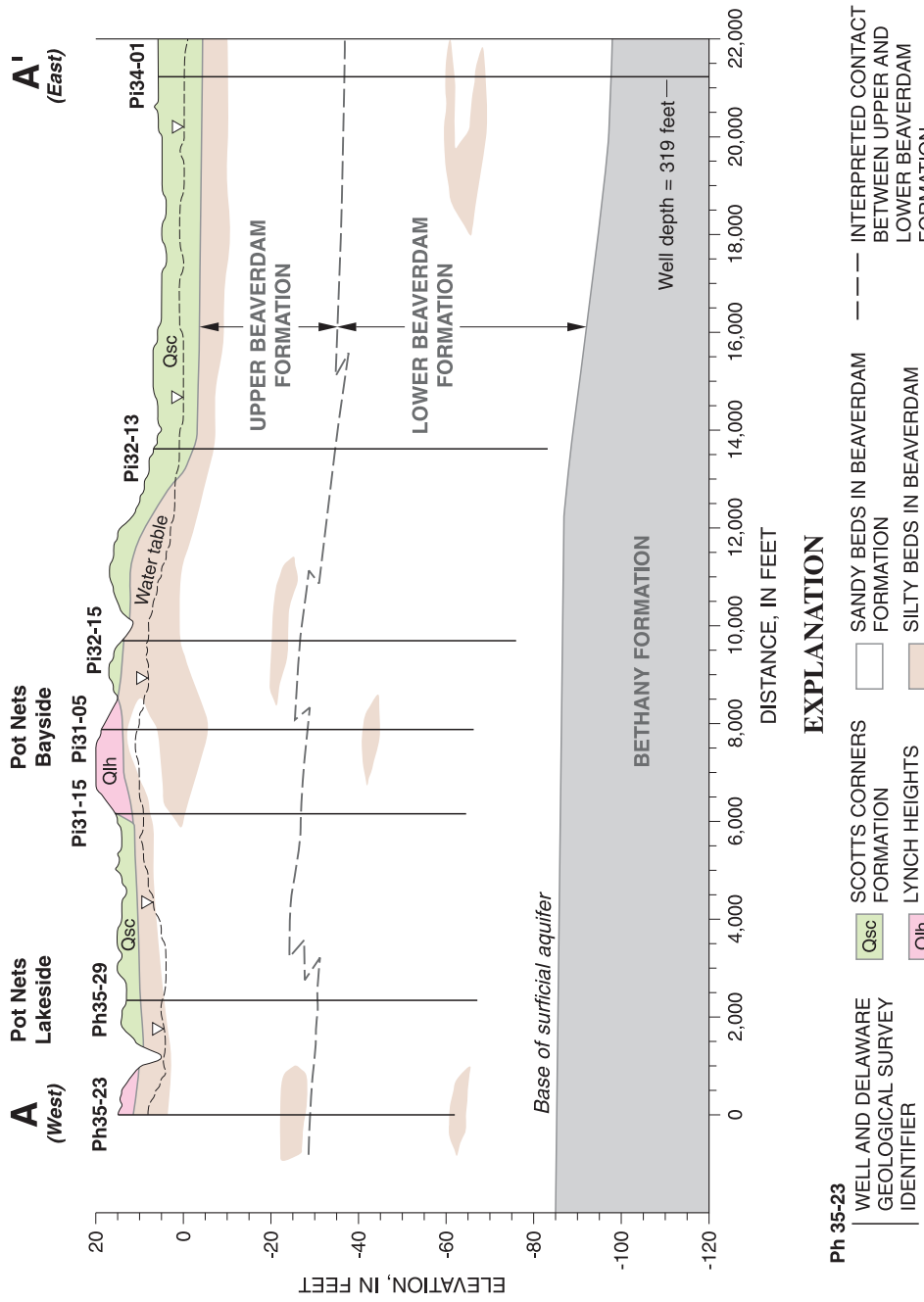

Figure 2b. Geologic cross section A-A' through Pot Nets Lakeside and Bayside communities, Long Neck Peninsula, Sussex County, Delaware (modified from Andres, 2005).

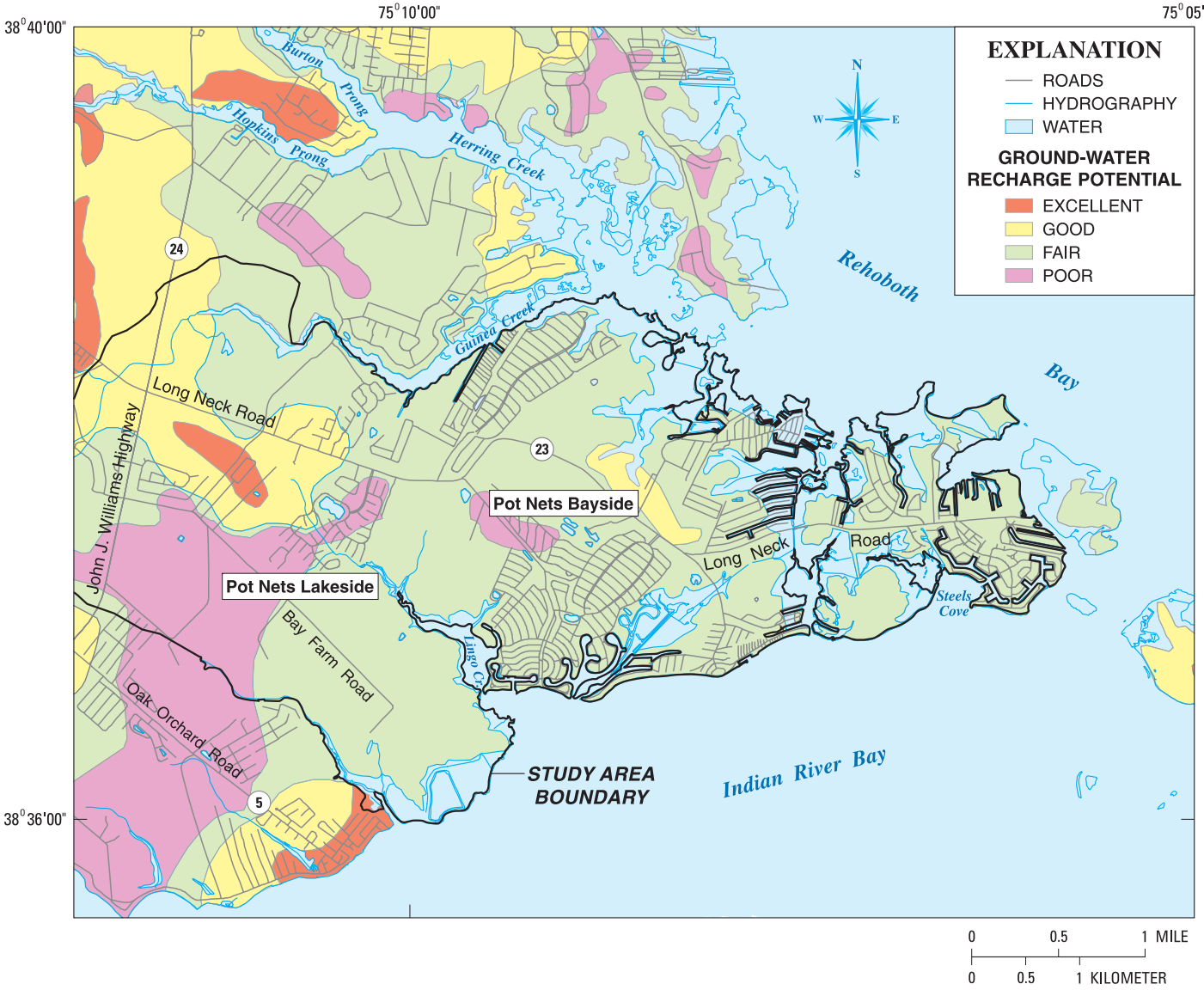

Figure 3. Relative recharge potential, showing the ability of the upper 20 feet of the surficial material to transmit recharge to the surficial aquifer, Long Neck Peninsula, Sussex County, Delaware (modified from Andres, 2004, and Andres and others, 2002).

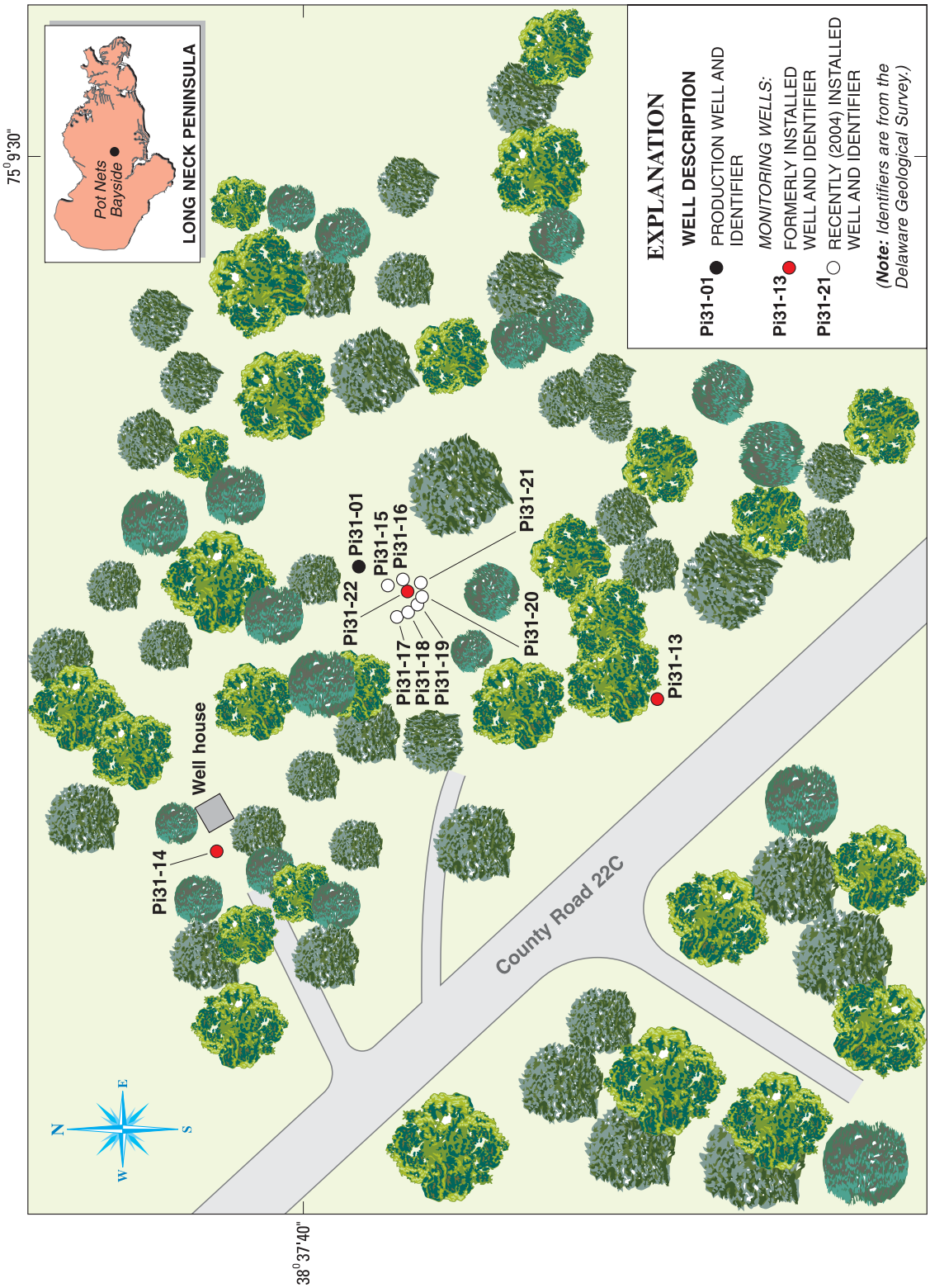

Figure 4a. Location of the Pot Nets Bayside production well (Pi31-01) and either formerly (Pi31-13, 14, and 22) or recently (2004) installed (Pi31-15, 16, 17, 18, 19, 20, and 21) monitoring wells.

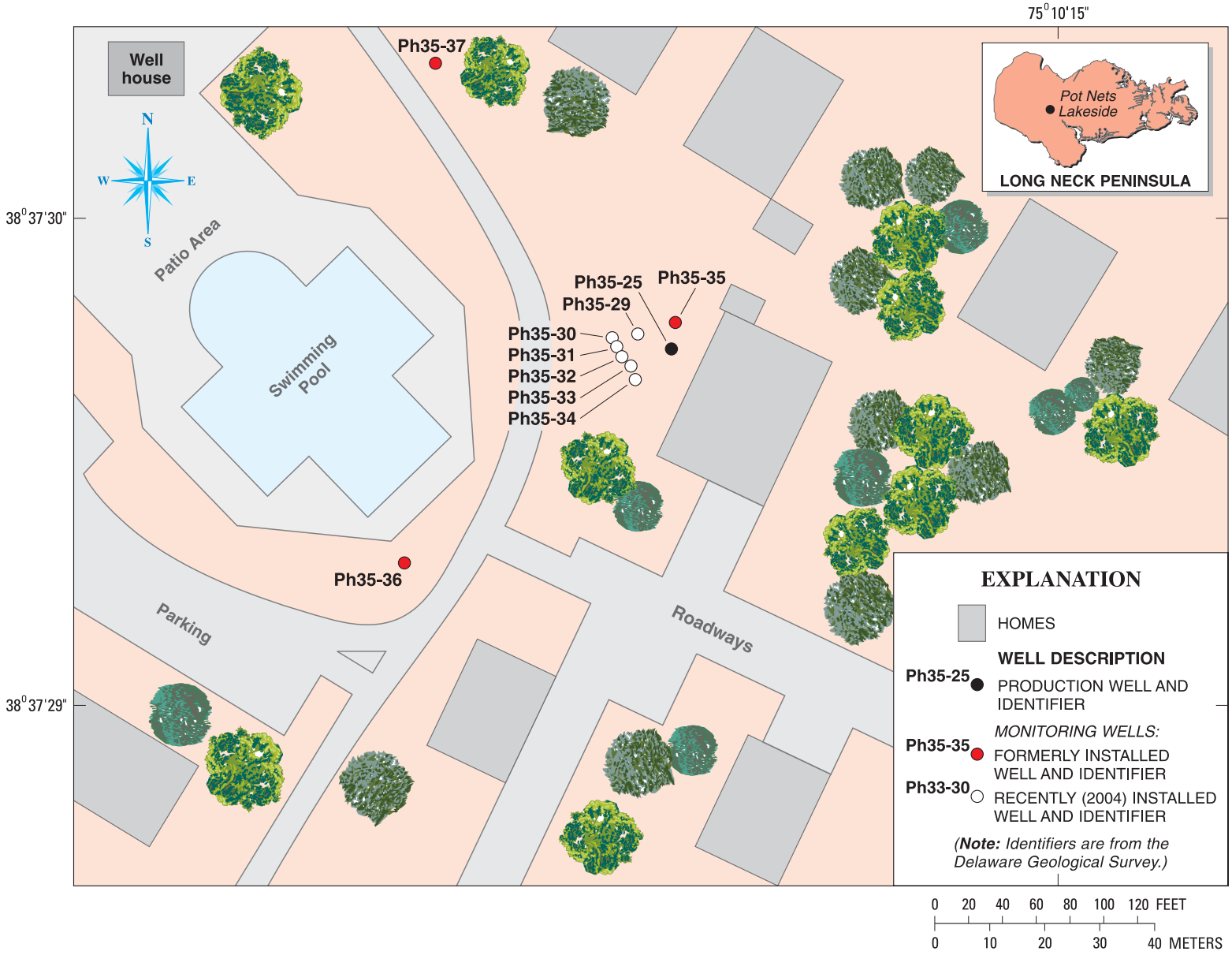

Figure 4b. Location of the Pot Nets Lakeside production well (Ph35-25) and either formerly (Ph35-35, 36, and 37) or recently (2004) installed (Ph35-29, 30, 31, 32, 33, and 34) monitoring wells.

All documented water supplies for Sussex County utilize ground water (Wheeler, 2003). Supply-well locations and depths (Blair Venables, Hydrologist, DNREC, written commun., 2004) indicate that most Long Neck Peninsula wells withdraw water from the surficial aquifer. Records also indicate that most residences along SR23 and SR24 on the western end of the peninsula (fig. 1) are served by private production wells, whereas the bulk of the water for the large (post–1960) developments on the peninsula chiefly is supplied by commercial (public) production wells. The LNWC operates 10 public wells in the Bayside (8) and Lakeside (2) communities. These wells withdraw water from the surficial aquifer for most major residential areas at and east of Lakeside (James Mooney, Operations Manager, LNWC, written commun., 2004).

The surficial aquifer throughout much of the State of Delaware is unconfined and vulnerable to contamination by human activities. Agricultural and residential-commercial developments, via septic systems and leachate from applications of fertilizer, lime, and manure, have been considered the causes of elevated concentrations of nitrate-nitrogen or NO_3^--N (0.4 milligrams per liter or more, or mg/L) in shallow ground water beneath or downgradient of these areas throughout the Delmarva Peninsula, with the highest concentrations (greater than 3 mg/L) of NO_3^--N having been found near or beneath agricultural areas (Shedlock and others, 1999; Hamilton and others, 1989). At least 20 percent of the samples from wells used in these studies exceeded the USEPA MCL for NO_3^--N (10 mg/L). Concentrations of NO_3^--N also have increased since the late 1980s at moderate depths in well-oxygenated parts of the surficial aquifer, but have remained low (less than 1 mg/L) in poorly oxygenated ground water (Denver and others, 2004). Low concentrations of herbicides (less than 1 microgram per liter, or µg/L), below Federal drinking-water standards, and used mainly on corn and soybean crops (for example, triazines, alachlor, and metolachlor), have occurred in shallow ground water near agricultural fields, as well as in nontidal streams during base-flow conditions (Koterba and others, 1993; Denver and others, 2004). Agricultural and residential land uses also have been associated with elevated concentrations of calcium, magnesium, sodium and (or) chloride attributed to liming, road salt, and septic effluent (Shedlock and others, 1999). Local studies of the surficial aquifer in eastern Sussex County, including parts of the Long Neck Peninsula, also have found elevated concentrations of dissolved solids, selected ions, and NO_3^--N associated with residential and agricultural land uses (Denver, 1986, 1989; Andres, 1991b; Delaware Department of Natural Resources and Environmental Control, 2002).

Persistent elevated concentrations of Hg in the surficial aquifer on the Delmarva Peninsula have not been reported (Delaware Department of Natural Resources and Environmental Control, 2002). Mercury, however, has not been part of regional or local ground-water-quality studies on the Delmarva Peninsula, or in Delaware or Sussex County, including Long Neck Peninsula (Hamilton and others, 1993; Ferrari, 2002; Denver and others, 2004).

North of Delaware, and assuming background concentrations of 10 ng/L or less, mercury has been found at elevated concentrations in the surficial KCA in the Atlantic Coastal Plain of southern New Jersey (Murphy and others, 1994; Barringer and others, 2005). Concentrations of Hg in filtered samples (0.45-µm capsule) in excess of the USEPA MCL (2,000 ng/L) occurred in samples from hundreds of private production wells in at least 70 residential areas that draw their water from the KCA (Barringer and others, 1997). The spatial distribution of Hg-contaminated ground water has been described as highly irregular, and extensive contamination plumes of Hg-contaminated ground water have not been found (Barringer and others, 2005). There also has been no clear evidence of point sources. Mercury concentrations near or exceeding the USEPA MCL mainly have occurred in samples from either private wells in residential and mixed residential and agricultural land-use areas, or from monitoring wells in residential areas. These mercury-contaminated wells have been associated with areas where ground-water quality also appeared to have been affected by agricultural and (or) residential development; the documented effects have included elevated concentrations of NO_3^--N, other selected ions, pesticides, and VOCs (Stackelberg and others, 1997, 2000; Barringer and others, 2005). These effects appeared similar to those noted earlier for agricultural and residential land uses on the surficial aquifer of the Delmarva Peninsula, including Delaware. Given the similarity in coastal settings, land-use patterns, and related types of contamination in the surficial aquifers in portions of Delaware and New Jersey, and the widespread and elevated concentrations of Hg in the KCA in New Jersey, the appearance of high concentrations of HgT_{gw} in the LNWC Bayside Pi31-01 and Lakeside Ph35-25 wells raised the possibility of widespread Hg contamination in the surficial aquifer on the Long Neck Peninsula.

Data Collection and Data Quality

This study included three major data-collection activities: (a) a source-water-quality survey, which involved sampling at production wells geographically distributed throughout the Long Neck Peninsula; (b) a preliminary time- and depth-series study to aid in the design of vertically nested monitoring wells, which mainly involved repeated water-quality data collection and sampling at the Bayside production well (Pi31-01) and at two nearby monitoring wells; and (c) a vertical distribution study that required the collection of soil, fill, and aquifer-sediment samples during the installation of vertical nests of monitoring wells near each Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production well sites, and the subsequent collection of water-quality data and samples at each production and monitoring well at these two sites. Methods of data collection relevant to

these activities—including (a) the selection and installation of production and monitoring wells, respectively, and (b) the collection, processing, and chemical analyses of soil, fill, and aquifer-sediment samples and ground-water samples—are described below. The quality of the data collected and whether it bears on the interpretation of the data also are discussed.

Well Selection and Installation

Production wells for sampling were identified that provide a broad geographic distribution of ground-water samples for Hg and other water-quality constituents in that part of the surficial aquifer commonly used to obtain drinking-water supplies. Boreholes also were drilled and nests of short-screened monitoring wells installed to characterize the vertical distribution of Hg and relate this distribution to other chemical constituents in sediment and ground water in areas of known Hg contamination.

Selection of Long Neck Peninsula Production Wells

Production wells initially were selected with the assistance of DNREC and DGS from State well-completion records, and on the basis of the following guidelines:

(a) The well was to be located within the study area (fig. 1), and recently, if not currently, in use;
(b) The well was to be constructed of relatively inert materials—preferably polyvinyl chloride (PVC) casing and screen with screw rather than glued joints, and have a sampling spigot close to the wellhead and before any treatment or storage tanks;
(c) Well discharge was to be generated by a submersible positive displacement pump to reduce the potential for volatile constituent losses—for example, CFCs, VOCs, or dissolved gases; and
(d) Drilling notes were to indicate that the well likely was screened in the surficial aquifer in the Beaverdam Formation, which would imply that all or most of the screen interval occurred within 40–100 ft below land surface.

About 100 production wells were initially identified in the study area. Most of the identified wells occurred on commercial and residential properties, either along one of the two main thoroughfares (fig. 1, SR23 and SR24) or on secondary roads just off these thoroughfares. To enhance geographical coverage of the aquifer, the main thoroughfares and major secondary roads were subdivided into roughly equidistant segments, and each candidate well was assigned by proximity to one road segment. Data from DNREC drilling records for wells assigned to a given segment were evaluated with the above guidelines. Wells that met the guidelines were considered candidate wells for sampling for that segment. One well was randomly selected from among the candidate wells for that segment. The owner of that well was contacted during an onsite visit to verify that the well was operational and could be sampled, and to obtain written permission to collect water-quality data and samples. The above process was repeated for each segment until wells were obtained for each segment or no candidate wells remained for a segment.

Geographical coverage was sparse along some road segments. Permission could not be obtained to sample wells located along the southeastern two-thirds of Bay Farm Road (fig. 1), which eliminated a large area of mixed forest and agricultural use from the study area. Permission denials also reduced the number of candidate wells in the central part of the Peninsula along SR23. Therefore, all 10 LNWC production wells were included to provide coverage of the aquifer in the area of known Hg contamination.

Maximizing geographical coverage required the modification of some plumbing systems to include wells that otherwise would have been unsuitable for sampling. Four selected wells (Appendix A, Table A1, footnote a) each were fitted with a hose bib on a PVC compression coupling that was installed between the wellhead and either treatment or storage tanks and multiple distribution lines. Before installation, the bib and coupling were cleaned—initially soaked for 24 hours in a 0.1 percent by volume phosphate-free detergent solution, flushed with clean tap water for at least several days, and flushed with deionized, low-mercury, active-carbon filtered (DACF) water[3] for at least 24 hours. Each cleaned hose bib and coupling was double-bagged in sealable polypropylene bags, and shipped to and installed by a contract plumber, who was trained to reduce equipment contamination during its installation. Installation occurred about 2 weeks before sampling in order to initially and repeatedly condition the bib and coupling with well water.

With the modifications in guidelines and plumbing, a total of 22 production wells, geographically distributed throughout the study area (fig. 5), were selected for sampling. Owner, construction, and depth information for these wells (Appendix A, table A1), chiefly compiled from DNREC well-completion reports, indicated:

Nine wells supplied private homes or businesses, one of which solely was used for residential irrigation (Ph34-24). Thirteen wells were public-supply wells.

(a) Most (18) wells were constructed of threaded PVC; four wells were made of steel. Each well had a smooth or hose-threaded brass bib located between the wellhead and any tanks and major distribution lines.[4]

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[3] DACF water has a specific conductance of less than 1 microsiemen per centimeter at 25 degrees Celsius, and a total mercury concentration of less than 1 nanogram per liter.

[4] Except for four wells, all wells have brass hose bibs that were installed during initial well construction, and presumably for sample collection on the main distribution line between the wellhead and storage or treatment tanks. Consistent with the above, similar hose bibs were installed on the main distribution line of each of the remaining four wells.

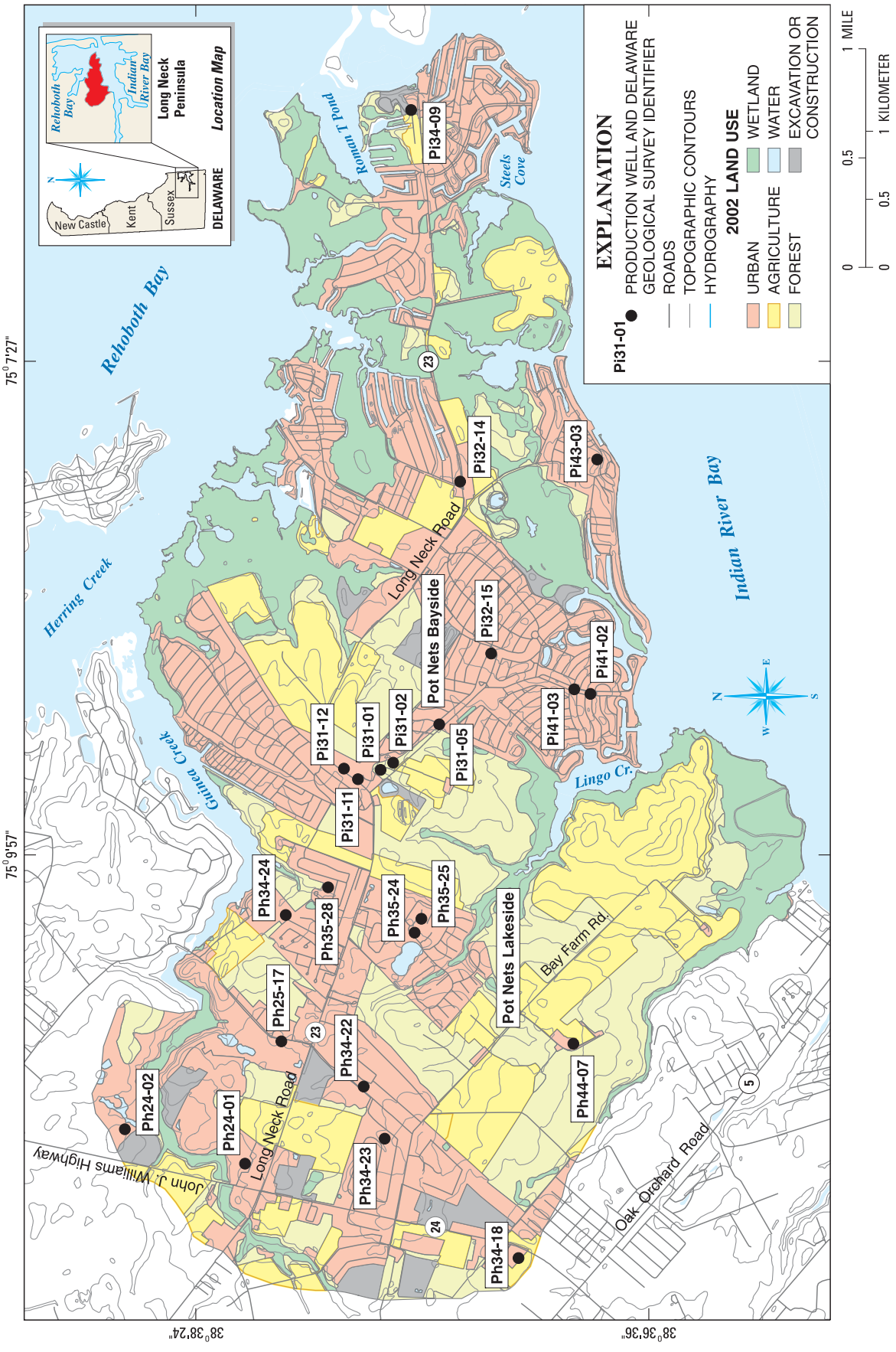

Figure 5. Locations of production wells used in the source-water quality survey of the shallow surficial aquifer, Long Neck Peninsula, Sussex County, Delaware (Land use and cover modified from the Delaware Office of State Planning Coordination, 2002).

(b) Except for well Ph34-23, all wells had submersible positive displacement pumps. Well Ph34-23 was a shallow well with a surface suction pump.
(c) Wells were screened in the surficial aquifer and Beaverdam Formation. For private wells, the depth from land surface to the top of the screened interval averaged 55 ft and ranged from 30 to 73 ft. Screen length ranged from 5 to 10 ft with a median and mode of 10 ft. Public wells generally were deeper and had longer screens than private wells. Depth from the land surface to the top of the screened interval averaged 67 ft and ranged from 42 to 98 ft. Screen length ranged from 6 to 40 ft with a median and mode of 15 ft.

Installation of Pot Nets Bayside and Lakeside Monitoring Wells

During previous studies (James Mooney, Operations Manager, LNWC, written commun., 2004), three monitoring wells were installed in the vicinity of each of the contaminated Pot Nets production wells (figs. 4a and 4b). Well-completion records from DNREC indicated the screened intervals (12 to 15 ft) of these monitoring wells were similar in length and depth to the screened interval of the nearby production well at each site (Appendix A1, table A1, Pi31-01 and Ph35-25). Water-quality and geophysical data, obtained with a submersible multi-parameter sonde and gamma and resistivity tools in selected monitoring wells near each pumping production well, indicated potential differences in ground-water bulk chemistry or lithologic materials with depth (Appendix D; Andres, 2005). The differences observed in bulk chemical properties and geophysical logs were of sufficient magnitude to warrant the installation of vertical nests of monitoring wells with short screens at each production-well site.

In late June and early July 2004, the DGS and USGS installed vertical nests of wells that consisted of one long-screen (70-ft length) and five or six short-screen (2-to-5 ft length) monitoring wells in the vicinity of each contaminated production well (figs. 4a and 4b). Summary well construction and depth characteristics of the installed monitoring wells for each vertical well nest are provided (Appendix A, table A2).

Borehole drilling for monitoring wells was conducted with a DGS truck-mounted drill rig with an 8-in. (inch) hollow-stem auger (Andres, 2005). During drilling, expelled cuttings were placed on polypropylene sheets. After well installation was complete, all residual cuttings were removed from the site. Between boreholes, auger flights and other wetted drilling equipment were cleaned with a power washer and water obtained from well Ph31-12 (fig. 5), which drew water from formations similar to those being drilled but had low concentrations of HgT_{gw}.[5]

Vertical-nest boreholes at each site were placed along an arc about 15 to 25 ft from the production well with adjacent boreholes separated by about 5 ft (figs. 4a and 4b). The use of an arc pattern, the distance of the arc from the production well, and distance between adjacent boreholes along the arc were chosen to ensure all monitoring wells were within the zone of influence of the pumping production well, and located about the same distance from the production well, but with sufficient space between adjacent borehole locations to reduce potential effects of drilling or installation of one monitoring well on ground-water flow or quality in the vicinity of adjacent installed monitoring wells (Appendix D). The arc compass bearing in relation to the production well (figs. 4a and 4b) was chosen to lie in the general direction of the formerly installed long-screen monitoring well(s) that had most consistently yielded samples with the highest Hg concentrations as determined from previous studies (Delaware Department of Natural Resources and Environmental Control, 2002; James Mooney, Operations Manager, LNWC, written commun., 2004). Well depth, and screen depth and length for each well, were selected to intercept ground water traveling toward the pumping production well from parts of the aquifer where it appeared ground-water chemistry and possibly Hg concentrations differed given previously observed differences in the bulk properties of ground water and in the characteristics of aquifer sediment with depth (Appendix D).

Monitoring wells were constructed with 10-ft lengths of 2-in. nominal-outside diameter (OD) schedule 40 PVC casing with screw-thread joints and O-ring seals, and 0.01-in. or 0.02-in. slotted 2 to 5 ft schedule 40 PVC screen. Well components were assembled on clean polypropylene sheets placed onsite; the assembler wore powderless nitrile gloves. After placing the casing and screen in the borehole, the annular space was backfilled in the order listed with commercially produced clean commercial fine gravel to a depth about 1 ft above the screened interval, about 1 to 2 ft of clean filter sand, and at least 2 ft of bentonite pellets. Water from LNWC well Ph31-12 was added as necessary to reduce sediment heaving in the borehole. Except for the infrequent collapse of sediments around the borehole, remaining annular space was backfilled with a combination of commercial bentonite, fine-to-medium sand, and gravel to the depth of the water table, and then granular bentonite, from the water table to land surface.

Wells were developed within several days of installation. Development involved surging while simultaneously withdrawing water from the well with a 1.75-in. OD PVC perforated tube coupled to 1-in OD polypropylene tubing that was attached to a portable centrifical pump. Development was terminated at each well after about 45 to 60 minutes of pumping at which point discharge was clear, and measured bulk chemical properties (pH, temperature, DO, and SC) were relatively stable compared to initial readings. Final discharge rates differed with well depth and lithologic material.

[5] Historically (2000–2004), total mercury was not detected in this well water, given detection limits that ranged from 0.1 to 0.5 microgram per liter (James Mooney, Operations Manager, LNWC, written commun., 2004) . Data from this study indicated the total mercury concentration in this well water was about 1.5 nanograms per liter (Appendix A, table A6).

The lowest discharge (about 0.5 gallons per minute) occurred at the shallowest well at each site, which was screened in fine-silty sand with discontinuous clay lenses (Appendix B). The highest discharge (about 8 gallons per minute) at each site occurred at the deepest well, which was screened in medium-to-coarse sand (Appendix B).

To complete installation, each well casing was cut to within several inches of land surface, the top of the fresh-cut casing permanently notched to establish a measuring point to water level, and the casing sealed with a lockable cap. The assigned State well permit tag was attached to the exposed casing, and a bolted steel cover was installed over the well. The final well elevation was obtained from a laser-level survey privately contracted by the LNWC, which used an established USGS benchmark for reference. Surveys were repeated until the difference in elevation at each well was less than 0.02 ft for two sequential surveys of all wells at a site.

Well development was repeated several weeks after installation to enhance the flow of ground water through the well screen, and to remove any fines introduced during final stage of well installation. Surging first was performed along the entire length of the wetted casing with a 1.75-in. OD solid cylinder of schedule 80 PVC fitted to 0.75-in. OD schedule 40 PVC tubing. This surging immediately was followed by simultaneous surging and water withdrawal with the previously described PVC development tool and dedicated polypropylene tubing. This entire process was repeated, and the well then pumped until discharge was clear. Well depth was re-measured and compared to the depth taken during installation to verify that no fines remained at the bottom of the well.

After development was completed at each well, reused down-hole development tools were cleaned with a 0.5 percent by volume phosphate-free detergent and water (well Pi31-12) solution, and then rinsed with well Pi31-12 water to remove detergent. All used polypropylene discharge tubing was replaced with new tubing for each well.

Field Data and Sample Collection

Field data and samples for ground water (Appendix A) and sediment (Appendix B) as well as selected quality-assurance measures (Appendix C) were obtained for each major study objective at different geographical scales as follows:

(a) A peninsula-wide source-water-quality survey of Hg and other water-quality characteristics in the shallow surficial aquifer, which involved the collection of bulk chemical and physical property data and water samples from 22 (9 private and 13 public) production wells during November and December 2003 (fig. 5), and

(b) A local Pot Nets Bayside-Lakeside community vertical distribution study of Hg in ground water and sediment which required:

  (1) A preliminary study to aid in the design and installation of, as well as development of a data and sample-collection procedure for, vertically nested monitoring wells, which was conducted in February 2004. This study involved the collection of bulk property (chemical and physical) data and water samples from Bayside production well Pi31-01 and nearby monitoring wells Pi31-13 and Pi31-17 (fig. 4a), and the collection of data from the Lakeside production-well site at monitoring well Ph35-35 (fig. 4b).

  (2) A sediment and water-quality study at the Bayside and Lakeside production-well sites (figs. 4a and 4b), with sediment data and sample collection conducted in late June to early July 2004 from boreholes made during the installation of vertical-nest monitoring wells; and with ground-water data and sample collection at each of these wells and the nearby pumping production well at each site in September 2004.

Ground-Water Data and Water Samples

Detailed descriptions of activities antecedent to sampling—including antecedent production-well pumping, equipment cleaning and set-up, and well discharge and sampling rates, are provided (Appendix D). Except for filter pore sizes, collection of ground-water data and samples (table 2), whether from production or monitoring wells, followed USGS National Field Manual (NFM) protocols (Wilde and Radtke, 2003) modified for low-flow trace element and Hg sampling (Lewis and Brigham, 2004; Ivahnenko and others, 1996, 2001; Olson and DeWild, 1999). For this study, encapsulated nylon pleated filters with absolute pore sizes of either 0.4 µm or 0.1 µm were used. Dissolved-gas (DG) and CFC samples were collected in accordance with USGS CFC-DG Laboratory protocols *(http//water.usgs.gov/lab/cfc/sampling/newmethod.htm)*.

Sampling at each well was started with continuous-flow discharge measurements of bulk properties—pH, SC, DO, turbidity, temperature, and oxidation-reduction potential—monitored to assess chemical stability of well discharge. Except for turbidity, stability was considered achieved when a measured bulk property was relatively constant for three successive readings taken at 3- to-10 minute intervals (Wilde and Radtke, 2003).

Turbidity is a key parameter for trace-element sampling (Gibs and others, 2000). Achievement of low turbidity values (less than 1 Nephelometric Turbidity Unit, or NTU) was emphasized. Once low turbidity and stability in other bulk properties were achieved, which typically took an hour or more at each well, bulk-property data were collected (table 2 and Appendix A, tables A3, A9, A10, and A11) and sampling was initiated.

Data and sample collection differed depending upon the sampling activity (tables 2 and 3). In relation to the buffering capacity of ground water (Rounds and Wilde, 2001), and for the source-water-quality survey and the local preliminary time- and depth-series study, alkalinity (ALK) data were

Table 2. Types of wells and ground-water data and samples collected by the U.S. Geological Survey from production and monitoring wells, Long Neck Peninsula, Sussex County, Delaware, 2003–04

[X, sample collected; --, no sample collected; raw, unfiltered water; 0.4-µm filt. or 0.1-µm filt., filtrate water from a 0.4- or 0.1-micrometer (µm) absolute pore size pleated and encapsulated nylon filter; 0.45-µm filt., filtrate from a 25-millimeter-diameter, 0.45-µm nominal pore size, glass-fiber plate filter; bulk properties include temperature, pH, oxidation-reduction potential, dissolved-oxygen concentration, specific conductance at 25 degrees Celsius, turbidity, and either acid-neutralization capacity (ANC) or alkalinity (ALK), as determined by field titrations of raw or 0.4-µm filt. samples, respectively.]

Sample type	Data and sample collection for		
	Source-water-quality survey	Preliminary time- and depth-series studies	Vertical profile distribution studies
	Types of wells		
	Peninsula public or private production wells	Bayside production and monitoring wells	Bayside–Lakeside production and monitoring wells
	Types of data and samples collected		
Mercury, total, raw	X	X	X
Mercury, total, 0.4-µm filt.	X	X	X
Mercury, total, 0.1-µm filt.	--	--	X
Mercury, methyl, 0.4-µm filt.	X [a]	--	X
Bulk properties, raw	X	X	X
Major ions, 0.4-µm filt.	X	X	X
Nitrogen, raw and 0.45-µm filt.	X	X	X
Carbon, raw and 0.45-µm filt.	X	X	X
Trace elements, 0.4-µm filt.	X	X	--
VOCs, raw	X	--	X
Chlorofluorocarbon compounds, raw	--	--	X
Dissolved gases, raw	X	--	X
Oxygen-deuterium isotopes, raw	--	X	--
Hydrogen-sulfide species, raw	--	--	X
Ultraviolet absorbance, at 254 and 280 nanometers, raw	--	--	X
Dissolved organic carbon fractions, 0.45-µm filt.	--	--	X [a]

[a] Fourteen of 22 wells were selected for methyl mercury sampling, with an emphasis on wells located in the vicinity of areas with known mercury contamination in ground water; a monitoring well with elevated mercury at each Pot Nets community site was selected for fractionated-carbon sampling.

Table 3. U.S. Geological Survey laboratories and sample type, handling, and delivery

Laboratory	Sample type, handling, and delivery
National Water Quality Laboratory, Water Resources Division, Denver, Colorado	**Ground water:** Major ions, selected nutrients (nitrate-nitrite nitrogen, nitrite nitrogen, dissolved organic carbon (DOC) and particulate inorganic and organic carbon), volatile organic compounds (VOCs), and DOC ultraviolet absorbance at 254 and 280 nanometers. Except for major ions and trace elements, samples were chilled to less than 5 degrees Celsius (5 °C) without freezing. Samples were shipped overnight from the field during the week samples were collected.
Mercury Research Laboratory, Middleton, Wisconsin	**Ground water:** Total mercury in raw and 0.4-micrometer (µm) absolute pore size filter samples from each production and monitoring well, total mercury in 0.1-µm absolute pore size filter samples from monitoring wells near well Pi31-01, and methyl mercury in selected 0.4-µm filtered samples from all production and selected monitoring wells at both sites. Samples acidified and chilled to less than 5 °C, and shipped overnight within 2 weeks of collection. (The laboratory also provided analyses of selected split samples spiked with either methyl mercury, or methyl mercury and VOCs.)
Chlorofluorocarbon and Isotope Laboratory, Reston, Virginia	**Ground water:** Chlorofluorocarbons and dissolved gases from samples collected at selected production and monitoring wells. Samples were hand-delivered to the laboratory within a week of collection.
National Research Program, Boulder, Colorado	**Ground water:** Fractionation of dissolved organic carbon into neutral and reactive-carbon fractions from samples collected at two monitoring wells with high mercury (greater than 1,000 nanograms per liter). Four-liter 0.4-µm absolute pore size filtered samples chilled to about 5 °C, and shipped overnight within 10 days of collection.
National Water Quality Laboratory, Geologic Division, Denver, Colorado	**Sediment:** Total mercury, selected trace elements, total sulfur, and particulate organic and inorganic carbon. Samples were chilled to less than 5 °C without freezing until and after processing. Selected processed samples were shipped on dry ice overnight within 3 weeks of collection.

obtained from filtered samples (0.4-µm absolute pore size nylon pleated filter in nylon capsule, hereafter 0.4-µm capsule) with the Gran titration method. For the vertical distribution study, ANC, rather than ALK, data were obtained in a similar fashion, with raw, rather than filtered, water samples in order to reduce total sampling times at each Pot Nets production-well site while the production well was pumping. Given no evidence of a particulate buffering phase, bicarbonate concentrations were computed directly from either ANC or ALK (Appendix A, tables A3, A9, A10, and A11). Hydrogen sulfide also was determined with raw-water samples (table 2, and Appendix A, table A11) within 10–15 minutes of sample collection with the methylene blue method (American Public Health Association, 1981) and color spectrophotometer (Carmody and others, 1998).

Except for CFC and DG samples (see below), all raw and filtered samples were collected in a portable sample chamber that was designed and cleaned between uses in accordance with USGS NFM protocols (Wilde and Radtke, 2003). Most filtered samples (table 2) were collected from a 0.4-µm capsule that was inserted directly into the sample feed line. For the vertical distribution study, additional filtered samples for mercury ($HgT_{gw\text{-}f0.1}$) were obtained from Bayside wells with a nylon encapsulated 0.1-µm absolute pore size nylon pleated filter (hereafter 0.1-µm capsule) to better assess potential particulate phases of Hg in known areas of Hg ground-water contamination.

Raw-water samples for nitrogen (total particulate) and carbon (total, inorganic, and organic particulate) were collected and chilled to 5 degrees Celsius (or °C) or less (tables 2 and 3). Each raw-water sample was suction-filtered through a baked, 25-millimeter (or mm)-diameter, 0.45-µm glass-fiber, plate filter, and the filter and filtrate chilled until analyzed.

Four raw-water samples for the fractionation of DOC (table 3) were collected sequentially in 1-liter amber baked glass bottles from one nested monitoring well at each site. Each 1-liter sample was suction filtered as described above,

the filtrates combined in a 4-liter baked amber glass bottle, and the composite sample was chilled until analyzed.

Sampling for CFCs and DGs (table 2) required split-flow sampling, with an additional sampling line (refrigerant-grade copper tubing) dedicated to the collection of these samples (Appendix D). Due to waste overflow, sampling for CFCs and DGs was conducted in a clean area with drainage, either inside or outside the well house.

All samples were physically or chemically preserved as soon as possible during or after collection in accordance with the USGS NFM (Wilde and Radtke, 2003). Samples were delivered or sent to select USGS Laboratories for analysis (table 3).

Documentation of all laboratory analytical methods, including methods for Hg, is provided (Appendix A, tables A18 and A19). Laboratory analytical methods for Hg and the separation of DOC into fractional components are briefly described below.

All Hg analyses of water samples were performed at the USGS Mercury Research Laboratory (MRL), Middleton, Wisconsin. Analysis of total Hg in raw or filtered samples (table 3) involved three major steps: (a) oxidation of Hg species to reactive mercury (Hg(II), (b) reduction of Hg(II) to elemental mercury (Hg^o), and (c) quantification of Hg^o by cold vapor atomic fluorescence spectroscopy—CVAF (Olson and DeWild, 1999). The analysis of $HgMe_{gw\text{-}f0.4}$ required sample distillation to reduce interferences, aqueous-phase ethylation of Hg species in the distillate, separation of ethylated species by gas chromatography, and quantification as methy-ethyl mercury by CVAF (DeWild and others, 2002). Analysis of $HgMe_{gw\text{-}f0.4}$ samples for the peninsula source-water-quality survey revealed a matrix-interference problem—CVAF detector quenching for samples with high HgT_{gw} concentrations (greater than 1,000 ng/L). Subsequent quantification for the vertical distribution study (table 3) utilized inductively coupled plasma-mass spectroscopy—ICPMS.

The fractionation procedure of Aiken and others (1992) isolates and quantifies carbon fractions (table 4—hydrophobic and hydrophilic) linked to the complexation and transport of inorganic (Hg(II), methylated (HgMe), or sulfide (HgS, colloidal) mercury (Ravichandran and others, 1998, 1999; Haitzer and others, 2002, 2003; Qian and others, 2002; Aiken and others, 2003; Waples and others, 2005). To obtain these fractions for ground water, a large volume of total sample often must be collected, filtered, and chilled in the field. Sampling at each Pot Nets site had to be completed within a 30-hour period (Appendix D), which limited fractionation sampling to one sample from each site, and total sample volumes to 4 liters. The USGS National Research Program in Boulder, Colorado analyzed the samples (table 3). The analysis required passing an acidified (pH 2) filtrate sequentially through two resin columns, which were back eluted with sodium hydroxide (pH 13) to obtain the reactive organic fractions (table 4). The concentration of each fraction was obtained by DOC analysis.

Soil, Fill, and Aquifer-Sediment Data and Samples

Surficial soil and fill samples were collected at each production-well site with a hand-screwed steel post auger at 0.5-ft depth intervals to a total depth of about 2–3 ft, below which sediment were operationally defined as aquifer sediment. Subsamples of selected auger material—(relic) soil O, A, B, and upper C horizons and apparent fill)—were identified on site, and individually double-bagged in re-sealable polypropylene bags and chilled (to about 5 °C). Aquifer sediment cores were collected during drilling with 2-ft-long, 2-in.-OD, steel split-barrel samplers equipped with cleaned[6] transparent acetate barrel liners. At each site and first borehole, continuous cores were obtained during drilling from the land surface to the water table, and thereafter at roughly 5-ft intervals. Additional cores were obtained at subsequent boreholes at selected and final depths.

Between uses, each core sampler was scrubbed with a plastic bristle brush and a 0.5 percent by volume phosphate-free detergent and (well Ph31-12) water solution, rinsed with this water to remove detergent, and rinsed several times with DACF water. A new cleaned liner then was installed, and the sampler reassembled.

As each core sampler was retrieved, the acetate liner was removed and sealed with cleaned polypropylene caps and placed on a polyethylene sheet. Core depth, orientation, and useable portion were recorded on the side of the liner and on field forms, which also were used to note sediment composition. Each capped liner was placed in a waxed core box that was enclosed in nested polypropylene bags and chilled on ice.

Individual soil or fill samples and aquifer-sediment cores were transported to the laboratory and refrigerated at about 5 °C. Cores remained chilled until processed, at which time the core was inspected to obtain final data for lithologic descriptions, and subdivided to provide subsamples for laboratory analysis (Appendix B, figs. B1 and B2, and tables B1 through B10). Sample processing was conducted at the Patuxent Wildlife Research Center, Laurel, Maryland, in the laboratory on a clean dedicated polyethylene sheet, and with nonmetallic equipment—cleaned plastic spatulas and tweezers, glass bowls, and polyfluorocarbon subsample containers. Between processing samples, reused equipment was washed in a 0.2 percent by volume phosphate-free detergent and tap water solution, rinsed with tap water to remove detergent, and rinsed several times with DACF water.

Processing of individual sediment cores generally took about 20–30 minutes. It began with the initial visual and textural identification and documentation (Appendix B, tables B1 through B10) of lithologic characteristics (relative gravel, sand, silt, and clay content), relative sand size

[6] For sediment collection, cleaned implies equipment soaked for at least 24 hours in a 10 percent by volume solution of hydrochloric acid and deionized activated-carbon filtered water, rinsed at least three times with this water, double-bagged in polypropylene bags, and chilled (5 degrees Celsius or lower) until used.

Table 4. Dissolved organic carbon fractions obtained from dual-column resin extractions (modified from Ravichandran and others, 1998)

Column type	Back-elution solution	Organic fraction	Comments
Amberlite, XAD8, acrylic ester	0.1 Normal sodium hydroxide	**Hydrophobic (fulvic) acids**	Can contain long-chain (5 to 9 carbon) carboxylic acids, one- and two-ring aromatic carboxylic acids or phenols, and aquatic humic substances
	→		
	Methyl cyanide solution[a]	Hydrophobic organic neutrals	
Eluent			
↓			
Amberlite, XAD4, styrene, divinylbenzene	0.1 Normal sodium hydroxide	**Hydrophilic acids**	Can contain short-chain (5 or less carbon) aliphatic acids, and polyfunctional organic acids
	→		
	Methyl cyanide solution[a]	Hydrophilic organic neutrals	
↓			
Eluent from both columns		Low molecular weight hydrophilic compounds	

[a]Can also be estimated by difference rather than extraction for samples with low dissolved organic carbon.

(coarse, medium, or fine), and color (Munsell Color, 1990). Extraneous materials, including woody debris (for example, sticks and roots) or large pebbles and stones were removed with tweezers. Bottom (1-in.) core-end segments and sediment that appeared mixed during drilling or coring also were described but discarded. Useable parts of each core that visually and texturally were different in lithologic composition were identified, separated from other materials with a dedicated thin-bladed plastic spatula, and trimmed to remove and discard thin (0.25-in.) sections from each end. If sediment of similar composition appeared as a continuum in two or three depth-sequential cores, then subsections were taken from individual cores and combined into a composite sample.

Each lithologic sample was transferred to a dedicated glass bowl, where it was homogenized by hand with a dedicated spatula until uniform in appearance. From 40–80 grams wet weight of the homogenized sample was transferred into an acid-rinsed tared 500-milliliter (or mL) polyethylene sediment container, and the container re-weighed to determine the wet weight of the sample. Another 20–40 grams of homogenized sample was transferred to an acid-rinsed 80-mL polyethylene container for archival. Sample containers were refrigerated at about 5 °C.

Lithologic samples were selected for chemical analyses after processing all samples, and reviewing lithologic data and sample-depth location. Selected samples included soil (various horizons), fill, and clay materials near the land surface, and different lithologic materials at depths corresponding to locations above, within, and below the screened interval of each contaminated production well (Appendix B, table B11). Samples in 500-mL polyethylene containers were shipped on dry ice within 3 weeks of their collection for sediment chemical analysis to the USGS NWQL, Geologic Division, Denver, Colorado (table 3).

Documentation of laboratory analytical methods for sediment analysis is provided (Appendix B, table B12). In brief, sediment analyses included total sulfur, and organic, inorganic, and total carbon on sediment dried (96 hours at 23 °C) to constant weight in a convection oven, and lightly ground to a uniform texture with mortar and pestle. Analyses for HgT_{sed} and selected trace elements (TEs) were conducted on digested [7] dried-and-ground sediment. Total mercury in the digestion solution was quantified by cold-vapor atomic absorption spectrometry.

Composite lithologic profiles were prepared by the USGS and DGS from core descriptions obtained from each site (Appendix B, figs. B1 and B2, and tables B1 through B10). These profiles reflected soil, fill, and aquifer sediment from the Beaverdam, Lynch Heights, and Scotts Corners Formations in the vicinity of each contaminated production well, as described earlier in this report (see *Introduction, Hydrogeology*).

[7] For total mercury: Nitric acid-sodium dichromate, 2 hours at 110 degrees Celsius; for trace elements: Hydrochloric-Nitric-Perchloric-Hydrofluoric acids, 3 hours at 110-150 degrees Celsius.

Data Quality

Data provided by USGS laboratories from sample analyses (table 3) underwent routine systematic reviews by the laboratories, and were externally reviewed by project staff. Data-quality issues that resulted from these reviews were addressed in discussions between USGS laboratory and project staff. Data obtained through direct measurements or analyses of samples in the field were quality-assured in accordance with the USGS NFM Protocols (Wilde and Radtke, 2003). Additional measures, including the collection of blank, replicate, and spiked samples, were used to assess the quality of selected data.

Quality-assurance reviews indicated that most data obtained from sampling activities (table 1) were interpretable for the purposes of this study without reservation. The following describes limitations in the quality of selected data for Hg, major ions (bicarbonate), ALK, ANC, and the apparent recharge dates (ages) of ground water.

Mercury

Quality-control (QC) samples (blanks and duplicate ground-water samples) were collected in the field during sampling to help evaluate the potential bias and variability in HgT_{gw} concentrations in raw or filtered ground-water samples because of field and laboratory equipment or methods. Additional QC samples (ground-water samples spiked with different chemical forms of Hg and other constituents) were prepared and analyzed by the USGS MRL, Middleton, Wisconsin, to evaluate $HgMe_{gw\text{-}f0.4}$ analytical methods.

To determine if ambient conditions and (or) field and laboratory methods or equipment led to sample contamination, source-water and field blanks were obtained during major sampling activities (table 5). Concentrations of $HgT_{gw\text{-}raw}$ in NWQL source water for field blanks ranged from 0.03–0.05 ng/L or near the average 0.04 ng/L MRL daily detection level for mercury. Except for a field blank obtained during the vertical distribution study, HgT_{gw} concentrations in raw or filtered field blanks were low—less than 0.35 ng/L, and no measurable $HgMe_{gw\text{-}f0.4}$ (0.04 ng/L or more) was found in field blanks (table 5).

The magnitude of HgT_{gw} in field blanks could have reflected ambient site or antecedent sampling-equipment conditions. Concentrations of HgT_{gw} (in raw and filtered samples) were highest in those field blanks processed after sampling at wells with high HgT_{gw} concentrations (table 5, footnote a), and generally were similar in magnitude to the low concentrations of HgT_{gw} found in some ground-water samples (Appendix A, tables A6 and A14). Barringer and others (2005) also found higher Hg concentrations in blanks obtained at monitoring-well sites compared to production-well sites. This bias could have resulted from the additional equipment (for example, portable submersible pump) and (or) additional field activity associated with the collection of samples at monitoring wells.

Table 5. Mercury concentrations in field and source-water blanks and corresponding ground-water samples for major sampling activities on Long Neck Peninsula, Sussex County, Delaware, 2003–04

[DGS, Delaware Geological Survey; µm, micrometer, absolute pore size of nylon-encapsulated nylon pleated filter; ng/L, nanograms per liter; Min, minimum; Max, maximum; <, less than; ---, no value; n/a, not applicable]

Blank sample type	Ground-water sampling activity	DGS well-site identifier	Date	Time	Blank concentration			Ground-water concentration, range [a]					
					Total mercury, unfiltered (ng/L)	Total mercury, 0.4-µm filtered (ng/L)	Methyl mercury, 0.4-µm filtered (ng/L)	Total mercury, unfiltered (ng/L)		Total mercury, 0.4-µm filtered (ng/L)		Methyl mercury, 0.4-µm filtered (ng/L)	
								Min	Max	Min	Max	Min	Max
Field	Peninsula survey	Ph24-01	11/25/2003	1600	0.12	0.12	< 0.04	0.11	1,820	0.09	1,790	< 0.04	< 0.04
		Pi31-12	12/17/2003	1009	---	0.09	< 0.04						
Field	Time-depth series	Pi31-01	02/12/2004	1030	0.32	0.23	---	1,140	1,560	1,260	1,550	---	---
Field	Vertical well nest	Ph35-25	09/16/2004	0930	1.62	2.37	< 0.04	0.89	6,380	1.07	6,100	<0.04	0.06
Source water	For all of above	Ph35-25	04/23/2004	1035	0.05	0.03	< 0.04	n/a	n/a	n/a	n/a	n/a	n/a

[a] Range is for ground-water samples from all wells at which samples were collected for that activity. Total mercury concentrations found in raw well water sampled just before field blank was collected were as follows: Ph24-01 (0.18 ng/L), Ph31-12 (1.49 ng/L), Ph31-01 (1,830 ng/L), and Ph35-25 (1,000 ng/L).

Table 6. Mercury concentrations in sequentially collected ground-water samples at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production wells, Sussex County, Delaware, 2003–04

[DGS, Delaware Geological Survey; µm, micrometer, absolute pore size of nylon-encapsulated nylon pleated filter; ng/L, nanograms per liter; <, less than; ---, no value]

Sample designation	DGS well site identifier	Date	Time	Total mercury, unfiltered (ng/L)	Total mercury, 0.4-µm filtered (ng/L)	Methyl mercury, 0.4-µm filtered (ng/L)
Primary	Pi31-01	12/10/2003	1230	1,820	1,790	< 0.04
Duplicate	Pi31-01	12/10/2003	1345	1,940	1,920	---
Primary	Ph35-25	02/12/2004	1425	---	---	< 0.04
Duplicate	Ph35-25	02/12/2004	1426	---	---	< 0.04

For the purposes of this study, background concentrations in ground water—geographically for the Long Neck Peninsula or vertically at the local Bayside and Lakeside sites—were described conservatively as being 10 ng/L or less. This concentration was 5 to 10 times greater than the actual concentrations in field blanks (table 5) and some ground-water samples (Appendix A, tables A6 and A14), and thus, could be higher than the actual HgT_{gw}, concentrations in ground water unaffected by human activity.

Data obtained from sequentially collected samples of ground water from a given well, hereafter referred to as duplicate samples, provided an indication of the variability in HgT_{gw} measurements as a result of field and laboratory methods—the repeated field processing, handling, and shipping, and laboratory processing and analysis of samples (table 6). The relative difference between duplicate-sample concentrations for HgT_{gw} in raw (or filtered) samples collected at a given well was about 6–7 percent, and was similar to the variation in duplicate-sample Hg concentrations reported by others (Barringer and others, 2005) for similar data-collection and analytical methods. It also was relatively small in magnitude compared to the variability in HgT_{gw} concentrations found in ground water (table 5), which span several orders of magnitude.

For the purposes of this study, relative differences in elevated HgT concentrations of about 6–7 percent or less between ground-water samples collected at the same well at different times, or at different wells, were considered similar in magnitude. Such small relative differences fall within the variability in measurement in HgT_{gw} concentrations attributable to field and laboratory methods.

Laboratory recoveries of total Hg from reference and internal standards, or raw or filtered ground-water samples spiked with Hg by the USGS MRL, fell within the acceptable ranges. Data-quality concerns, however, arose in relation to HgT_{gw} concentrations in survey samples from two production wells, and for methyl mercury in all production- or monitoring-well samples with HgT_{gw} concentrations in excess of 366 ng/L, and are described below.

Sampling protocols were adopted to help ensure the quality of data collected (see *Field Data and Sample Collection*). These protocols were not met, however, during the sampling at two production wells for the peninsula source-water-quality survey (Ph24-02 and Pi32-14). Despite attempts to obtain a low turbidity before sampling, discharge from well Ph24-02 (fig. 5) had the highest turbidity recorded (2.6 NTU) during sampling. The pumping rate for this production well was inadvertently set by the operator to about 500 gallons per minute (or gpm), instead of the requested 150–200 gpm (Appendix D). Small visible solids (angular flakes) were observed in discharge, and appeared to be scale or corrosion deposits from the well casing or screen. The higher-than-requested flow rate was discovered after sampling was completed.

Well Ph32-14, located just east of Pot Nets Bayside (fig. 5), was the only well in this area for which permission was obtained to sample. The well hose bib, however, was difficult to access, and located in close proximity to several distribution lines and storage tanks of different age and composition. Permission to install a new spigot closer to the wellhead was denied, so the bib was cleaned. The bib, or backflow from distribution lines or storage tanks, could have been a low-level source of contamination.

Measurable concentrations of HgT_{gw} in raw and filtered samples for wells Ph24-02 and Ph32-14 were qualified to reflect that sampling protocols were violated (Appendix A, table A6, footnote a). The qualification notes that these violations could have led to a small positive bias in data for HgT_{gw} and (or) other TEs.

Table 7. Methyl mercury concentrations and recoveries from background and spiked filtered ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25), Sussex County, Delaware, 2003–04

[DGS, Delaware Geological Survey; µm, micrometer absolute pore size filter; ng/L, nanograms per liter; spiking procedures and calculations are described in DeWild and others (2002); recovery is the ratio of the difference between measured concentrations in the spiked and unspiked samples divided by the theoretical concentration of the spiked sample, expressed in percent (%); volatile organic compounds in the spike solution (and theoretical spiked sample concentration in micrograms per liter) are as follows: Tetrachloroethylene (0.042), Trichloroethylene (0.42), 1,1,1-Trichloroethane (0.042), 1,1-Dichloroethane (0.042), Diethyl ether (0.016), Trichloromethane (0.8), and Benzene (0.008)]

DGS well identifier	Mercury, total, 0.4-µm filtered water (ng/L)	Mercury, methyl, 0.4-µm filtered water (ng/L)	Mercury, methyl, 0.4-µm filtered, methyl mercury spiked water (ng/L)	Spiked sample recovery (%)	Mercury, methyl, 0.4-µm filtered, methyl mercury and VOC-spiked water (ng/L)	Spiked sample recovery (%)
			Bayside			
Pi31-19	366	0.017	0.937	101	1.104	108
Pi31-20	2.46	0.004	1.043	106	1.082	106
Pi31-21	234	0.062	0.759	85	1.065	98
			Lakeside			
Ph35-30	1.72	0.003	0.887	94	1.031	104
Ph35-31	1.07	0.007	0.866	90	0.957	95
Ph35-34	1.52	0.015	0.997	106	1.106	100

In addition to the minor data-quality problems described for HgT_{gw}, a problem also was encountered in the quantification recovery of $HgMe_{gw\text{-}f0.4}$ in selected samples. Detector quenching occurred during the analysis of survey production-well samples with the standard CVAF method (DeWild and others, 2002). Use of different detection instrumentation (ICPMS) eliminated this problem, but revealed an underlying sample-matrix problem. No HgMe could be recovered from either background or spiked survey samples (chiefly wells Pi31-01 and Ph35-25) that had elevated concentrations of HgT_{gw} (greater than 1,000 ng/L).

Several VOCs (polychlorinated alkenes, tetra- and trichloroethylene, and several possible degradation products) found in samples from Bayside and Lakeside production wells were evaluated as potential sources of the matrix interference. A filtered sample for $HgMe_{gw\text{-}f0.4}$ was obtained from each monitoring well at the Bayside and Lakeside sites during the vertical-distribution study, and split into three subsamples. One subsample was used to obtain background $HgMe_{gw\text{-}f0.4}$ concentrations, a second subsample was spiked with HgMe, and a third subsample was spiked with HgMe and selected VOCs.

Analytical results indicated that the selected VOCs did not inhibit spiked HgMe recovery with the ICPMS methods in ground-water samples that contained up to 366 ng/L of HgT_{gw} (table 7). Recoveries also were near 100 percent for samples spiked with only HgMe. A similar study to assess the recovery of HgMe from samples that contained HgT_{gw} in excess of 366 ng/L was not performed because of funding limitations.

Implications for the interpretation of the methyl mercury data obtained for this study were as follows:

(a) All $HgMe_{gw\text{-}f0.4}$ concentration data were provided (Appendix A, tables A6 and A14), but selected data were qualified;

(b) Acceptable recoveries of HgMe from spiked $HgMe_{gw\text{-}f0.4}$ samples with low to moderate HgT_{gw} concentrations (366 ng/L or less) were deemed applicable to all ground-water samples with similar concentrations of HgT_{gw} (Appendix A, tables A6 and A14, methyl mercury data), and the $HgMe_{gw\text{-}f0.4}$ concentration data were considered suitable for interpretation; and

(c) For the source-water-quality survey, and ground-water samples with HgT_{gw} concentrations that exceeded 366 ng/L, the $HgMe_{gw\text{-}f0.4}$ data, which reflected concentrations that all were less than

0.04 ng/L, were considered uncertain and qualified as such (Appendix A, table A6, footnote b). For the vertical-distribution study, and ground-water samples with HgT_{gw} concentrations that exceeded 366 ng/L, no data were obtained for either background concentrations or recoveries of HgMe.

In relation to (c) above, there could have been no measurable HgMe in either simple forms, such as methyl mercuric chloride or hydroxide (CH_3HgCl or CH_3HgOH), or weakly to moderately bound HgMe in complex forms, in samples with concentrations of HgT_{gw} concentrations in excess of 366 n/L. It also could be that HgMe was present, but was not measurable. For example, Qian and others (2002) found that virtually all HgMe added in simple neutral forms to water that contained elevated concentrations of natural DOC appeared tightly bound to humic-carbon reduced sulfur groups. Little if any measurable HgMe was found in solution. Samples that contained elevated concentrations of HgT_{gw} in this study also possibly contained similar humic groups (see *Mercury in the Surficial Aquifer, Pot Nets Bayside and Lakeside, Mercury in Ground Water, Forms of Mercury*). Thus, if HgMe in ground-water samples from the Bayside and Lakeside sites with high concentrations of HgT_{gw} also was tightly bound, and the simple forms of HgMe added during spiking underwent similar complexation, then little to no $HgMe_{gw\text{-}f0.4}$ possibly was recoverable in these samples. Another plausible explanation was that simple-neutral or weakly complexed forms of HgMe could have been present, but were immeasurable because of a chemical interference that simply prevented the ethylation of HgMe species—a required step in analysis (see *Field Data Collection and Sample Collection, Ground-Water Data and Water Samples*). Thus, studies of HgMe recovery were deemed necessary to determine if HgMe was present and adequately recoverable from all samples with measurable HgT_{gw} concentrations.

Major Ions, Alkalinity, Acid-Neutralization Capacity, and Bicarbonate

The USGS NWQL used routine quality-assurance-and-control (QAC) samples and procedures for all non-Hg constituents (including major ions and nutrients, TEs, and VOCs), and found no analytical problems with individual data. In addition, project field blanks contained no measurable constituents except for trace amounts of several major ions—for example, calcium, sodium, and chloride concentrations at less than tenths of a milligram per liter. Additional QAC procedures used by the USGS NWQL and project, however, identified analytical anomalies for selected data that warranted discussion.

Given the principle of electroneutrality, the theoretical difference between the sum of the cationic and anionic constituent concentrations, expressed in milliequivalents per liter (meq/L), in a water sample is zero. Random errors in analytical measurements, however, can result in a computed balance that is near, but seldom, zero. In relation to the above, cation and anion concentrations and sums (in meq/L), were calculated for each ground-water sample (Appendix C, tables C1 through C3). The relative difference between cation and anion sums, expressed in percent, and hereafter referred to as the balance error, also was calculated for each sample, and compared to the theoretical value (zero), as well as with the balance errors of other samples, to help identify measurement biases or analytical omissions (the inadvertent exclusion of a major ionic constituent).

The balance error was small (about 10 percent or less) and positive for most individual samples, and averaged less than 5 percent for all samples for the peninsula source-water-quality survey and local vertical-distribution studies (Appendix C, Table C4). The magnitude of these balance errors was attributed to small biases in measurement of one or more major ions. Only balance errors for samples from two production wells (Ph34-23 and Pi31-01), and one monitoring well (Pi31-13) warrant further discussion.

For production well Ph34-23, the balance error was –32.5 percent, and contrary in sign, and notably greater in magnitude, than the balance errors for other peninsula survey production-well samples (Appendix C, table C4). The negative difference indicated that measured anionic concentrations exceeded measured cationic concentrations. Other than an unusually high nitrate-plus-nitrite nitrogen concentration (Appendix A, table A5, 12.3 mg/L), this sample exhibited no distinguishing chemical characteristics. The USGS NWQL confirmed that the concentration value was valid, but that the analysis required sample dilution, which likely increased the imprecision, and possibly contributed to the bias, in measurement. No further action was taken to confirm this result, as resampling was not an option. The uncertainty and possible bias in the measurement of nitrate-plus-nitrite-nitrogen was documented (Appendix A, table A5, footnote a).

As part of the preliminary design study, three time-series samples were collected from production well Pi31-01 after at least 2 hours of pumping, and all three samples had high balance errors (Appendix C, table C4, Bayside time-series sampling, Pi31-01, 11–14 percent). These errors were two to three times greater than the balance error for the sample collected immediately after pumping began at this well (4.7 percent). Also, the three depth-series samples collected from monitoring well Pi31-13 after 24–26 hours of pumping at well Pi31-01 had high balance errors (28–32 percent). These balance errors were two to three times greater than the balance errors described above for the three time-series samples obtained at the nearby production well (Pi31-01) before and after sampling at well Pi31-13.

The potential source of the relatively large positive balance errors for selected samples from wells Pi31-01 and Pi31-13 was investigated but remains unknown. A review of USGS NWQL analytical control data taken during the analysis of the Pi31-01 and Pi31-13 samples indicated no major bias in measurement for individual major ions. Thus, major-ion data obtained from the USGS NWQL were deemed suit-

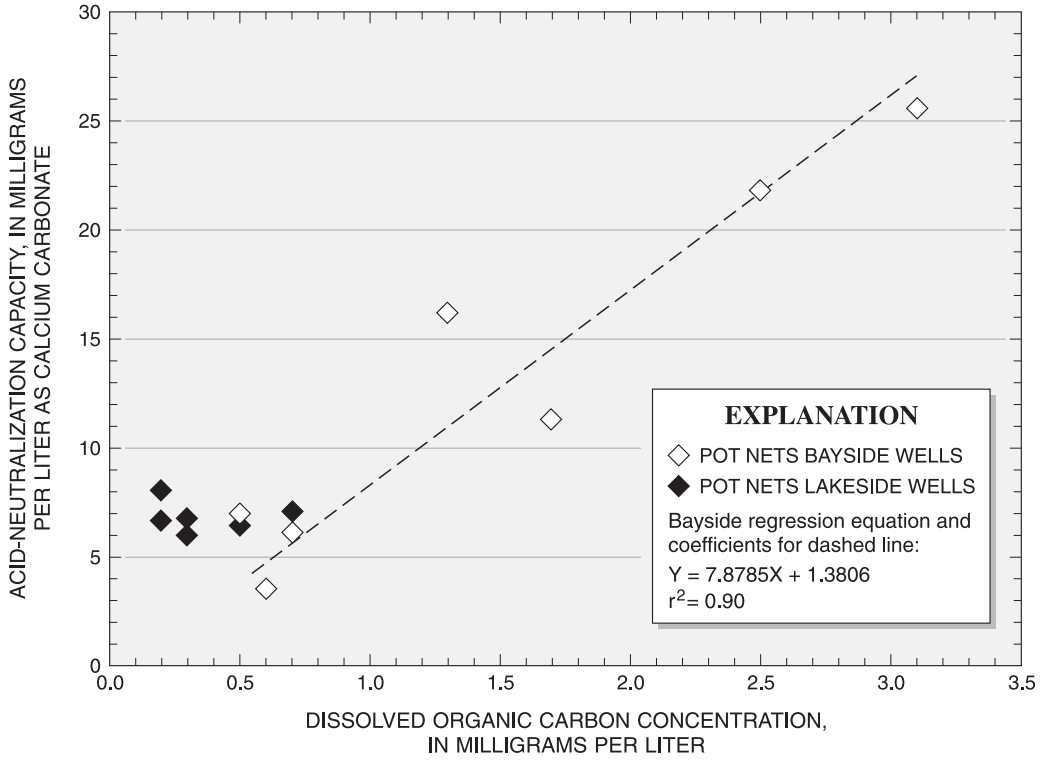

Figure 6. Dissolved organic carbon and acid-neutralization capacity for ground-water samples from monitoring wells at the Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware.

able for interpretation.

Given bicarbonate concentrations were derived from field ALK and ANC data (see *Field Data and Sample Collection*), and were relevant in the calculated equivalent balances (Appendix C), data for this ion, as well as ALK and ANC, were reviewed by the project staff.[8] For the peninsula source-water-quality survey, and the local preliminary time- and depth-series study, the ALK and bicarbonate data were obtained from titrations of 0.40-µm capsule-filtered samples. For the local vertical-distribution study, ANC and bicarbonate data were derived from titrations of raw water. Regardless of whether samples were filtered or unfiltered, however, it appeared unlikely that titration results, including estimated bicarbonate concentrations, were influenced by sample type. There was no evidence of particulate matter in ground-water samples. Turbidity of raw water (well discharge) also was low (0.7 NTU or less) at the time of sample collection for most (41of 42) samples (Appendix A, tables A3, A9, A10, and A11), including the samples with large balance errors. There was no measurable particulate (in)organic carbon in any sample (Appendix A, tables A5, A9, A10, and A13). Thus, field titrations of raw or filtered samples were considered equivalent means to estimate bicarbonate.

Bicarbonate data were generated from the Gran titration method in accordance with USGS NFM protocols (Rounds and Wilde, 2001). An initial review of bicarbonate data revealed titration end-point anomalies—the theoretically calculated and actual bicarbonate endpoints differed for some ground-water samples. The problem initially was assumed to reflect difficulties in the titration of weakly buffered samples given the low ALK (ANC) values of 26 mg/L or less as calcium carbonate (Appendix A, tables A3, A9, A10, and A11). Subsequent analysis, however, revealed that DOC was positively correlated with ANC ($r^2 = 0.90$), and that the Bayside samples with elevated $HgT_{gw\text{-}f0.4}$ also likely contained elevated amounts of DOC (fig. 6). The DOC concentration seldom exceeded 0.4 mg/L in ground water, except for samples from the Pot Nets Bayside and Lakeside community wells that generally contained elevated concentrations of $HgT_{gw\text{-}f0.4}$, DOC, ANC, and bicarbonate (fig. 6 and Appendix A).

The positive correlation between DOC and ANC indicated that organic ligands could presumably chemically buffer changes in sample pH during titrations. This would be the first reported instance of DOC compounds at elevated levels acting as buffering agents in shallow residential area

[8] No titration yielded measurable carbonate (estimated reporting level is 1 milligram per liter).

ground water on the Delmarva Peninsula. Hem (1985) notes that DOC can contain organic compounds that are important contributors to the buffering capacity. Kharaka and others (1986) describe acetate, succinate, and oxalate compounds in DOC as possible contributors.

Assuming organic ligands were present and acted as conjugate bases to buffer ground water, these compounds could account in part for the net positive bias in balance errors noted above for selected samples from wells Pi31-01 and Pi31-13. If a DOC of 1 mg/L reflected acetate with a single negative charge (Kharaka and others, 1986), this would equate to 0.083 meq/L, which could be considered a relevant contribution to the anionic balance (Appendix C). Samples for DOC, however, were not collected during the preliminary study. Thus, it was not possible to estimate the possible DOC contribution, nor the concomitant bicarbonate reduction to the anionic balance, for samples with large anionic deficits.

Given the results of the review of the bicarbonate, ALK, and ANC titrations, the following data qualifications were adopted for this report:

(a) Bicarbonate concentrations derived from titrations with end-point anomalies were qualified as estimated values (Appendix A, tables A3, A9, A10 and A11—Bicarbonate, E-prefix code), and

(b) Titration end-point anomalies for wells with elevated DOC concentrations (exceeding 0.4 mg/L) and HgT_{gw} concentrations (exceeding 100 mg/L) were assumed to reflect DOC contributing to the buffering capacity of these samples. The ALK or ANC and bicarbonate data for these wells were qualified to indicate that the DOC could be a contributing factor (Appendix A, tables A6, A9, A10, and A11—ALK or ANC, and Bicarbonate, footnoted), which for bicarbonate, implied that computed concentration values likely were positively biased.

Chlorofluorocarbon Apparent Recharge Dates and Ages of Ground Water

Sampling at the Bayside (Pi31-01) and Lakeside (Ph35-25) production wells and vertically nested monitoring wells included DGs and CFCs (Appendix A, tables A16 and A17). These data were used to determine the apparent recharge dates (ages) of ground water (*http://water.usgs.gov/lab/chlorofluorocarbons/background/,—accessed December 21, 2005*). The quality of recharge date (age) data was judged by (a) consistency between duplicate-sample dates (ages) for a given CFC compound (CFC-11, CFC-12, or CFC-113), and (b) consistency among dates (ages) obtained among different CFC compounds. To avoid rounding error bias, raw data were used to evaluate consistency (table 8).

Most recharge dates (ages) met both of the above consistency criteria. Duplicate-sample recharge dates for each well and CFC compound were similar or differed by at most a few years (table 8), and were within the expected range in variability attributable to analytical methods for duplicate samples (Eurybiades Busenberg, Chief Supervisor, USGS CFC Laboratory, written commun., 2004). There also was close agreement among recharge dates derived for the same well but with different CFC compounds, with the proviso that CFC-12 dates occurred slightly later in time than either CFC-11 or CFC-113 dates. Samples with reliable dates were assumed valid for interpretive use (table 8).

An apparent date of recharge (age) was considered unreliable if the sample CFC concentration either exceeded the estimated historical atmospheric concentrations for that compound, or appeared markedly younger than the apparent dates (ages) from the other CFC compounds. Several wells were identified for which the recharge dates (and ages) appeared unreliable (Table 8, data coded as " *** "). The CFC-12 dates for wells Ph35-25, Ph35-32, and Ph35-34, for example, likely reflected inclusion of a local CFC-12 source, which has been noted in ground water affected by residential-commercial development (Szabo and others, 1996; Ho and others, 1998; Plummer and others, 1998). Unreliable estimates of apparent recharge dates (ages) also can occur if ground waters recharged at different times were mixed because of ground-water pumping—a situation which is more likely to arise if long, rather than short, screened wells are used for sampling (Eurybiades Busenberg, Chief Supervisor, USGS CFC Laboratory, written commun., 2004).

Apparent dates of recharge for the Bayside production-well discharge were deemed unreliable (table 8, Pi31-01). Dates for all three CFC compounds for this production well were either modern or 1–2 decades younger than the apparent dates (ages) determined from nearby monitoring-well samples obtained from samples at depths (screened intervals) that bracket the depth (screened interval) of this production well. The manner of CFC contamination was unknown, but results could reflect samples that were exposed to air (in soil or from current atmosphere). Although similar sampling methods and equipment were used at all wells, the potential for contamination by air was greater for production than monitoring well samples. At each production well, the discharge passed from the well through about 100 ft of buried multi-joint steel pipe to a well-house brass spigot, and then through three sample-tubing connections (Appendix D). For each monitoring well, the discharge passed through only one gas-compression fitting—that which connects the submersible pump outlet and CFC-DG sampling tubing.

For the purposes of this study, only reliable raw recharge (age) data were reported (table 8, and Appendix A, table A17). For the interpretation of these data, however, raw duplicate-sample values of the apparent recharge date (age) for a given CFC compound and well (table 8) were averaged; the average date (age) rounded to the nearest whole number was used as the estimated date of apparent recharge (age). This approach allowed the variability attributable to variations in field and laboratory methods to be incorporated into data interpretation. For a given well and CFC compound, the relative difference in percent between whole-number

Table 8. Qualified raw data for apparent dates (ages) of recharge for ground-water samples from production and vertically nested monitoring wells at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey; raw data, values in tenths may or may not be significant; CFC, chlorofluorocarbon; ***, apparent date (age) estimate cannot be reliably determined because of sample exposure to atmospheric conditions at time of sampling, ground-water contamination by non-atmospheric local anthropogenic source, or the mixing of waters with different CFC and (or) dissolved gas concentrations]

DGS well identifier	Apparent recharge, date			Apparent age, years			Well type and depth (feet below land surface)
	CFC-11	CFC-12	CFC-113	CFC-11	CFC-12	CFC-113	
				Bayside			
Pi31-01	***	***	***	***	***	***	Production well (66.0)
	***	***	***	***	***	***	
Pi31-16	1974.0	1977.0	1977.0	30.7	27.7	27.7	Monitoring wells (79.5)
	1974.0	1977.0	1977.0	30.7	27.7	27.7	
Pi31-17	1978.0	1983.0	1984.0	26.7	21.7	20.7	
	1979.5	1983.5	1984.5	25.2	21.2	20.2	(65.0)
Pi31-18	1971.5	1977.5	1979.0	33.2	27.2	25.7	
	1971.0	1977.0	1978.5	33.7	27.7	26.2	(62.0)
Pi31-19	1988.5	1990.5	***	16.2	14.2	***	
	1986.5	1990.5	***	18.2	14.2	***	(55.0)
Pi31-20	1984.0	1990.0	***	20.7	14.7	***	
	1984.0	1991.0	***	20.7	13.7	***	(48.0)
Pi31-21	1985.5	***	1989.5	19.2	***	15.2	
	1985.5	***	1989.0	19.2	***	15.7	(26.0)
				Lakeside			
Ph35-25	1971.5	***	1975.0	33.2	***	29.7	Production well (73.0)
	1971.5	***	1974.0	33.2	***	30.7	
Ph35-30	1968.5	1973.5	1964.5	36.2	31.2	40.2	Monitoring wells (78.5)
	1968.5	1973.0	1965.5	36.2	31.7	39.2	
Ph35-31	1973.0	1979.0	1976.0	31.7	25.7	28.7	
	1973.0	1977.5	1973.0	31.7	27.2	31.7	(68.0)
Ph35-32	1976.5	***	1979.0	28.2	***	25.7	
	1977.0	***	1979.0	27.7	***	25.7	(60.0)
Ph35-33	1978.5	1987.5	1985.5	26.2	17.2	19.2	
	1980.0	1987.0	1985.5	24.7	17.7	19.2	(46.5)
Ph35-34	1985.5	***	1987.5	19.2	***	17.2	
	1985.0	***	1987.5	19.7	***	17.2	(24.5)

Summary statistics for the relative difference in apparent recharge dates (ages) between duplicate ground-water samples collected from vertical-nest monitoring wells at the Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware

[Relative difference is computed as the difference between recharges dates (ages) divided by their average for duplicate ground-water samples collected from a given well and for a given chlorofluorocarbon compound, expressed in percent; Min, minimum; Max, maximum]

Chlorofluorocarbon (CFC) compound	Relative difference, in percent				Number of duplicate sample pairs
	Average	Standard deviation	Range		
			Min	Max	
CFC-11	0.00	0.05	-0.08	0.10	11
CFC-12	0.02	0.05	-0.03	0.10	9
CFC-113	0.02	0.06	-0.05	0.15	8

apparent recharge dates (ages) was computed from the reliable duplicate sample data (table 8) for each well and CFC compound (see table above). This variability, which was presumed to reflect the operational variability inherent in field and laboratory methods, was relatively small in magnitude (maximum 0.15 percent), random in sign, and similar among CFC compounds. For comparative purposes, a difference in the average apparent recharge dates of 3 years, for example, for 1970 and 1973, between two different ground-water samples also yielded a relative difference equal to 0.15 percent. Hence, average apparent recharge dates (ages) among different samples computed from the same CFC compound were considered to reflect different apparent recharge dates if they differed by at least 3 years.

Mercury in the Surficial Aquifer

The conditions and characteristics of ground-water quality in the surficial aquifer mainly were determined from samples collected from production wells as part of the source-water-quality survey for the Long Neck Peninsula, and from vertically nested monitoring wells near each contaminated production well as part of the local vertical-distribution study in the Bayside and Lakeside communities. Results for each of these studies are described below.

Long Neck Peninsula

Concentrations of $HgT_{gw\text{-}raw}$ ranged from 0.11 to 1,820 ng/L for the 22 Peninsula survey production wells (Appendix A, table A6). The wide range in concentrations indicated differences occurred in the geographical distribution of Hg in the used portion of the surficial aquifer at depths of 30 to 120 ft below land surface. Throughout most of the peninsula, the concentrations for $HgT_{gw\text{-}raw}$ appeared low, 10 ng/L or less (fig. 7), and similar to background concentrations described for production wells in similar coastal aquifer settings (KCA) in New Jersey (Barringer and others, 2005; Murphy and others, 1994) and ground water elsewhere (Krabbenhoft and Babiarz, 1992). Slightly elevated concentrations of $HgT_{gw\text{-}raw}$ occurred in two production wells that were located in relatively diverse locations (fig. 7, Ph24-02, 13.9 ng/L and Pi32-14, 20.6 ng/L), and reflected low-level ground-water contamination or sampling artifacts (see *Data Quality, Mercury*). Truly elevated concentrations of $HgT_{gw\text{-}raw}$ (greater than 100 ng/L) chiefly occurred in the vicinity of the Bayside and Lakeside Communities (fig. 8), and were highest at wells Pi31-01 and Ph35-25, which had known histories of elevated Hg (Department of Natural Resources and Environmental Control, 2002).

The limited spatial extent of elevated concentrations of $HgT_{gw\text{-}raw}$ in the surficial aquifer implied that the source (origin) of the Hg likely occurred in the vicinity of the Bayside and Lakeside communities. The heterogeneous pattern to the spatial occurrence of elevated concentrations of $HgT_{gw\text{-}raw}$ in peninsula ground water also was similar to geographic patterns in the occurrence of Hg that have been observed in ground water in the other similar coastal aquifer settings (KCA) in New Jersey (Barringer and others, 2005).

Forms of Mercury

Other studies have found that Hg in similar coastal settings and aquifers could exist in particulate (filter) and dissolved (filtrate) forms (Barringer and MacLeod, 2001; Barringer and Szabo, 2001). Mercury in shallow ground water in the surficial aquifer on the Long Neck Peninsula, however, mainly occurred in a dissolved or fine-colloidal,

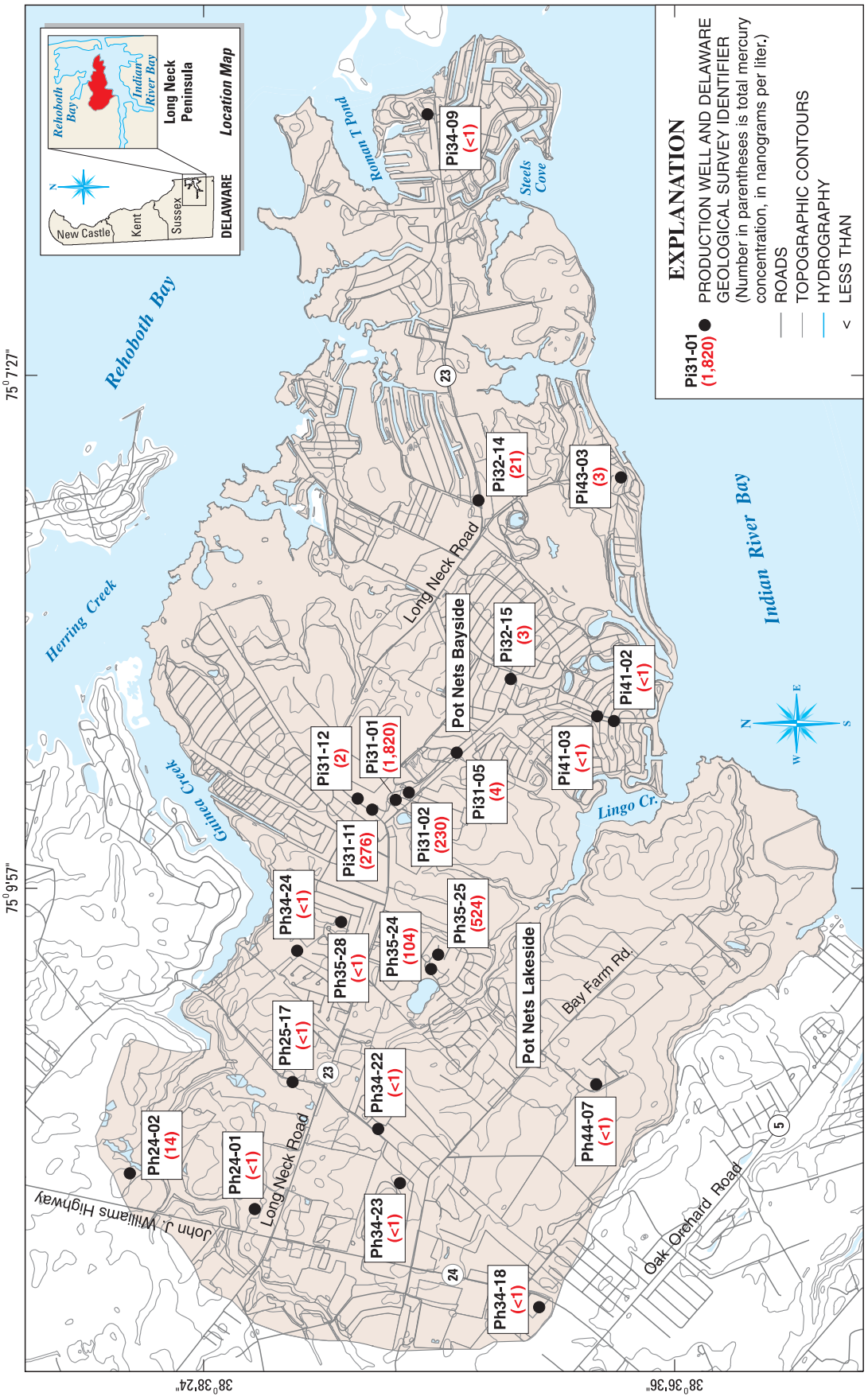

Figure 7. Total mercury concentrations in ground-water samples from production wells in the surficial aquifer, Long Neck Peninsula, Sussex County, Delaware, 2004.

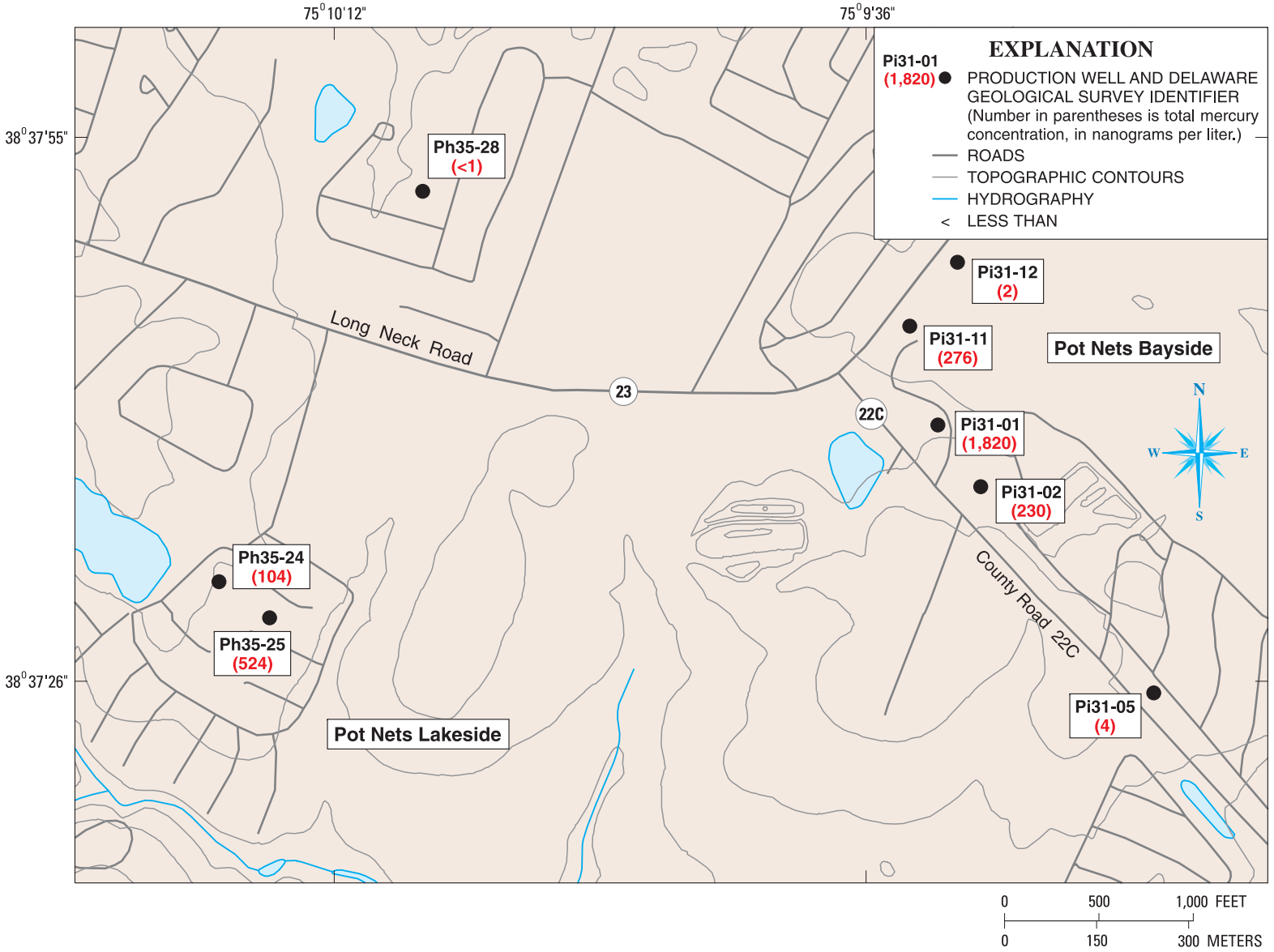

Figure 8. Total mercury concentrations in ground-water samples from production wells in the surficial aquifer near Pot Nets Bayside well (Pi31-01) and Lakeside well (Ph35-25), Long Neck Peninsula, Sussex County, Delaware, 2004.

rather than particulate, phase. The absence of a particulate-phase Hg was inferred from the similarity in $HgT_{gw\text{-}raw}$ and $HgT_{gw\text{-}f0.4\ or\ -f0.1}$ concentrations for duplicate samples of ground water from each peninsula survey production well that were either unfiltered (raw) or filtered before analysis (fig. 9). The relative differences in HgT_{gw} concentrations between raw and filtered duplicate samples with elevated HgT_{gw} (in excess of 100 ng/L) also appeared random in sign, small in magnitude (averaged 5.9 percent), and fell within the range of the relative difference in HgT_{gw} attributable to variations in Hg measurement associated with field and laboratory methods (see *Data Quality, Mercury*).

Absence of particulate Hg was further supported by turbidity and particulate-carbon data. Except for one production-well sample (Ph24-02), turbidity was low (less than 1 NTU), and, if particulates were present, their magnitude bore no relation to $HgT_{gw\text{-}raw}$ (fig. 10). There also was no measurable particulate carbon (Appendix A, table A5), a potential means of Hg transport.

Despite the elevated concentrations of HgT_{gw} found in selected production wells (fig. 8), no HgT_{gw} concentration in any production well sampled during this study exceeded the Federal standard for public drinking-water supplies (2,000 ng/L). The presence of Hg as HgMe, however, was investigated because the latter was known to readily bioaccumulate (Fitzgerald and Lamborg, 2005). No $HgMe_{gw\text{-}f0.4}$ was detected (USGS MRL detection level 0.04 ng/L) in ground-water samples from the 14 peninsula production wells selected for this analysis (table 3, and Appendix A, table A6). This result, however, only was validated for those production wells that contained less than 366 ng/L of HgT_{gw}. For production wells with HgT_{gw} in excess of 366 ng/L, the results (sample concentrations reported as less than 0.04 ng/L) for $HgMe_{gw\text{-}f0.4}$ could not be validated (see *Data Quality, Mercury*).

Relations Between Mercury and Other Chemical Constituents

Bulk chemical properties (Appendix A, table A3) indicated ground water in the used resource portion of the surficial aquifer on the Long Neck Peninsula was moderately acidic (pH ranged from 5.1–5.9), weakly buffered (ALK was less than 18 mg/L), suboxic-to-oxic (DO was between 2.9–8.5 mg/L), and was low to moderate in dissolved solids (SC ranged from 69–262 microsiemens per centimeter at 25 degrees Celsius, or µS/cm at 25°C). Major-ion data revealed that sodium and chloride generally are the dominant ions (Appendix C, table C1). Except for barium, TEs, if measurable, generally occurred at low concentrations of about 10 µg/L or less) (Appendix A, table A6). There was no measurable nitrite or particulate nitrogen; nitrate was the major form of nitrogen, and NO_3^--N concentrations ranged from 0.7–12.3 mg/L (Appendix A, table A5). There also was no measurable particulate carbon (inorganic or organic); carbon chiefly occurred as DOC (0.45-µm capsule filter) and, except for well Pi31-01 (DOC, 1.2 mg/L), at low concentrations—0.4 mg/L or less. One or more VOCs occurred in all 22 survey production wells (Appendix A, table A7); the most frequently detected VOCs were chloroform, methyl *tert*-butyl ether, and 1,1,1-trichloroethane (table 9).

Federal drinking-water standards, although promulgated for public-supply production wells, also were used as guidelines in this study to indicate concentrations of constituents that could pose a health risk to privately owned and consumed supplies. Whereas no standard was exceeded for any sample collected from peninsula production wells used for public supplies, two standards were exceeded in samples obtained from two private production wells. For well Ph34-23, the concentration of NO_3^--N was 12.3 mg/L, which exceeded the Federal standard of 10.0 mg/L. This NO_3^--N concentration, however, reflected a higher-than-normal degree of imprecision (see *Data Quality, Major Ions...*). For well Pi32-14, the concentration of tetrachloroethylene was 7.29 µg/L, and exceeded the Federal standard of 5.0 µg/L. This result was verified by re-sampling and independent analyses of samples collected by the USGS and DNREC.

There was ample evidence among production-well survey data that ground-water quality in the shallow aquifer on the Long Neck Peninsula appeared affected by human activities. Denver (1989) noted that ground water affected by agriculture and (or) septic-system drainage in eastern Sussex County had elevated dissolved solids—SC in excess of 100 µS/cm. Seventy-two percent (16 of 22) of the peninsula survey samples had SC values that exceeded 100 µS/cm (table 10). Hamilton and others (1993) concluded that concentrations of nitrate-plus-nitrite nitrogen above 0.4 mg/L reflected contamination from septic systems and (or) agricultural or residential applications of fertilizer or manure. All peninsula survey samples had NO_3^--N concentrations that exceeded 0.4 mg/L (table 10). Ferrari (2002) described VOCs in the surficial aquifer in Delaware associated with gasoline or other petroleum fossil fuels, by-products from chlorination of drinking water, agricultural applications (as pesticides or solvents), industrial uses (dry cleaning, solvents, and degreasers), or chemical manufacturing. He found all 30 production-well samples had at least 1 detectable VOC, and 93 percent (28 of 30) of the samples had at least 2 detectable VOCs. For the peninsula survey, all 22 production-well samples had at least 1 detectable VOC, and 59 percent (13 of 22) of the samples had at least 2 VOCs (table 10). He also noted that chloroform (28 of 30), tetrachloroethylene (20 of 30), methyl *tert*-butyl ether (17 of 30), and 1,1,1-trichloroethane (10 of 30) were among the most commonly detected VOCs in shallow ground water in Delaware. These VOCs also were the most commonly detected VOCs in peninsula ground water (table 9).

Elevated concentrations of HgT_{gw} occurred in ground water that also appeared affected by human activities on the basis of one or more indicators (table 10). This result was consistent with the source of Hg being of anthropogenic origin. These indicators also illustrated, however, that ground water that contained background concentrations of HgT_{gw} also was similarly affected by human activities. Thus,

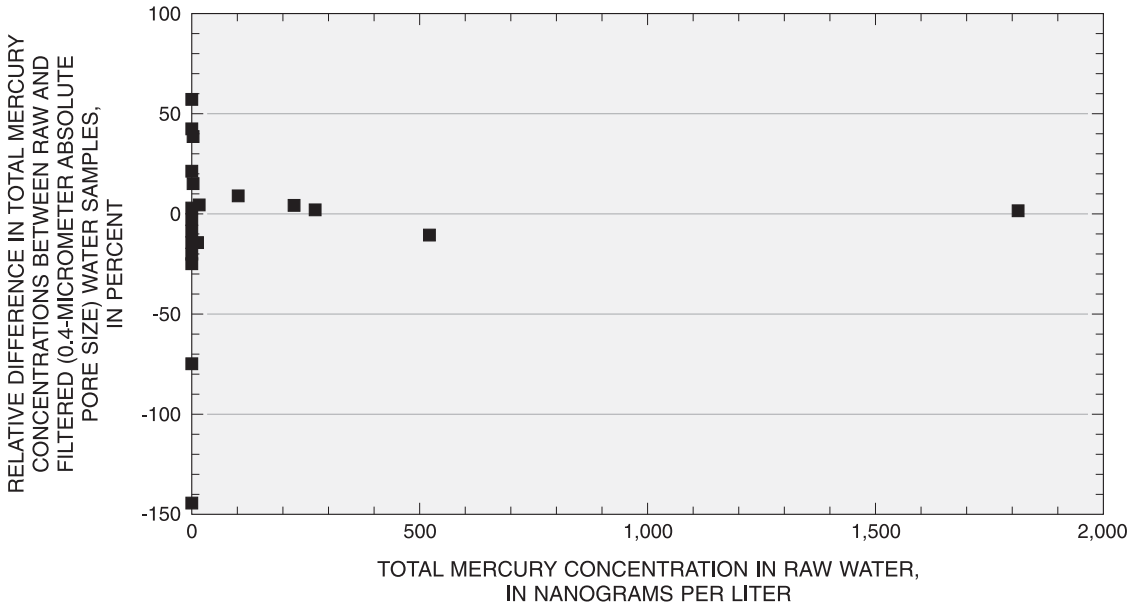

Figure 9. Relative difference in total mercury concentrations between filtered and raw water samples from production wells, Long Neck Peninsula, Sussex County, Delaware, 2004. (Relative difference is the difference between filtrate and raw-water concentrations, divided by their mean concentration, expressed in percent.)

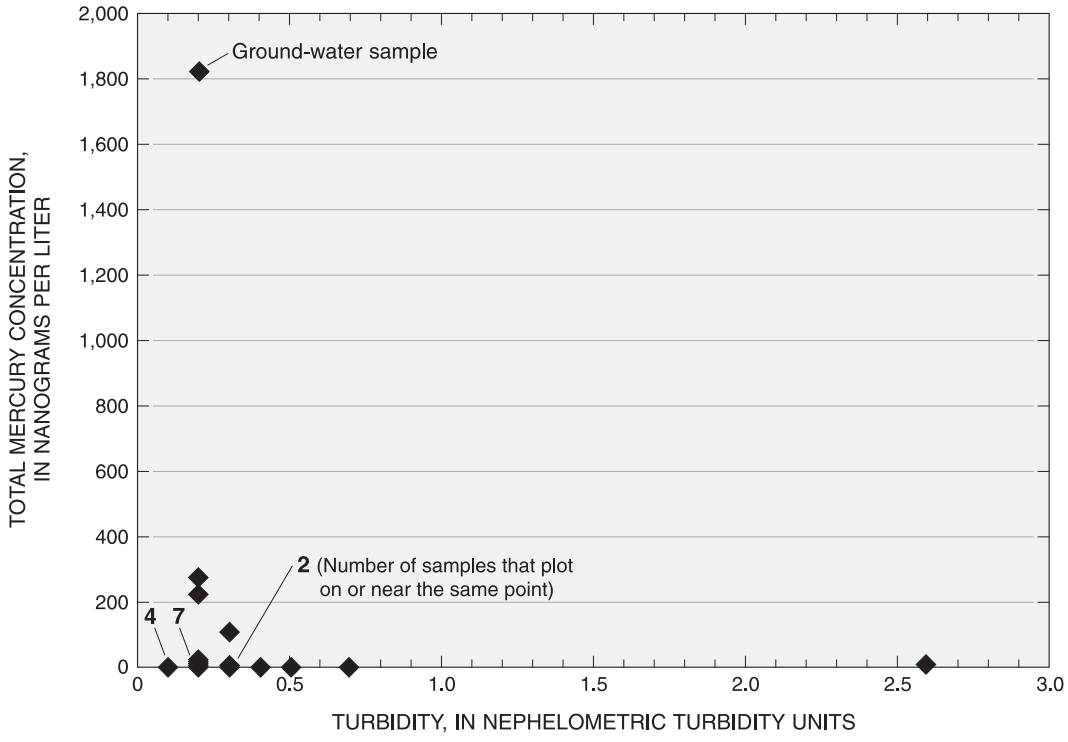

Figure 10. Turbidity and total mercury concentrations for ground-water samples from production wells, Long Neck Peninsula, Sussex County, Delaware, 2004.

Table 9. Frequently detected volatile organic compounds in ground-water samples from production wells on the Long Neck Peninsula, Sussex County, Delaware, 2003

[Relative number of detections is ratio of the number of wells for which compound was detected to the total number of wells from which samples were collected (22); relative number of detections also is expressed in percent; µg/L, micrograms per liter; **E**, laboratory estimated value]

Compound	Relative number of detections	Relative number of detections (%)	Maximum concentration (µg/L)
Chloroform	21/22	95	8.16
Methyl *tert*-butyl ether	7/22	32	5.5
1,1,1-Trichloroethane	6/22	27	**E** 0.8
Tetrachloroethylene	4/22	18	7.29
Trichloroethylene	2/22	9	0.40
1,1-Dichloroethane	2/22	9	**E** 0.6
1,4-Dichlorobenzene	2/22	9	0.12
Bromodichloromethane	2/22	9	7.17
Dibromochloromethane	2/22	9	4.9
Methyl *tert* pentyl ether	2/22	9	0.65

ground water affected by human activity appeared a necessary but insufficient condition to uniquely identify areas with elevated HgT_{gw} in the shallow aquifer on the peninsula. Other studies in similar coastal settings also have found Hg occurrence can be related to but not uniquely defined by anthropogenic indicators of ground-water contamination (Barringer and others, 2005).

Although the occurrence of elevated HgT_{gw} can be associated with ground water affected by human activities, bivariate plots and correlation analyses revealed none of the aforementioned indicators correlated with concentrations of HgT_{gw} in ground water. Neither did any other bulk property or chemical constituent measured in production-well samples. There also was no discernible difference in the major-ion chemistry among ground waters with and without elevated HgT_{gw} (fig. 11).

The only observed relations between elevated HgT_{gw} and other ground-water constituents of note were as follows:

(a) The highest concentrations of $HgT_{gw\text{-}f0.4}$ (1,790 ng/L) and DOC (1.2 mg/L) occurred at the Bayside production well Pi31-01 (Appendix A, tables A5 and A6). This DOC concentration was three to four times greater than the DOC concentration in other wells (Appendix A, table A5).

(b) Except for Ph3525 and Pi31-02, Pot Nets wells with the highest concentrations of HgT_{gw} (Appendix A, table A6), also contained tetrachloroethylene and (or) likely degradation products—such as trichloroethylene and 1,1,1-trichloroethane (Appendix A, table A7).

The lack of relations between concentrations of HgT_{gw} and other chemical parameters or constituents in peninsula shallow ground water has been observed in other Hg studies conducted in similar coastal aquifers and settings. Although Barringer and others (2005) found HgT_{gw} (filtered) concentrations that ranged from 0.1 to 100 ng/L were positively correlated with concentrations of calcium, chloride, sodium, nitrate, and DOC, no significant correlations were found at elevated HgT_{gw} concentrations (greater than 100 ng/L).

Results from this study and that by Barringer and others (2005) implied that the occurrence of elevated HgT_{gw} was only marginally related to widespread patterns in land use related to human activity. In both studies, the latter had a widespread effect on the quality of ground water, including areas where the ground water also contained elevated HgT_{gw}. Thus, the occurrence of elevated concentrations of HgT_{gw} could have reflected selected human activities that occurred only on a limited spatial scale—for example, the inadvertent loss or the inappropriate disposal of Hg in selected locations—that were embedded within a large spatial backdrop of agricultural and (or) residential land use.

Both coastal studies illustrated that the occurrence of elevated concentrations of HgT_{gw} in ground water was geographically heterogeneous—a pattern consistent with small but widely dispersed and relatively thin contaminant plumes. Therefore, the use of production wells could have been of limited value in the identification of factors that relate to the occurrence of elevated HgT_{gw}. By design, most production wells have long screened intervals and relatively high pumping rates (see *Selection of Long Neck Peninsula Production Wells* and *Appendix D*). These design characteristics are best suited for supplying water, but are not necessarily well suited for the isolation and identification of chemical characteris-

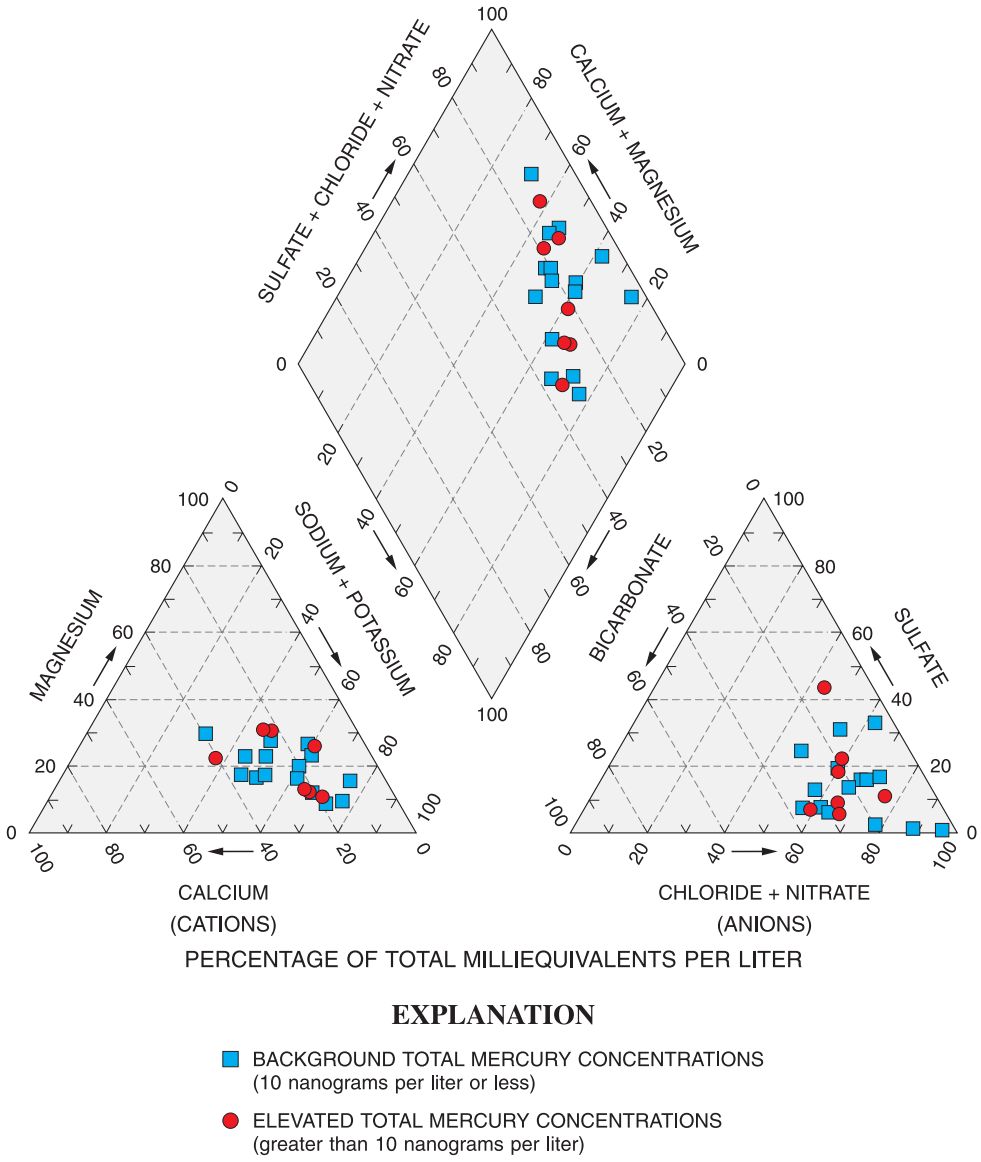

Figure 11. Concentrations of total mercury and major ions in ground-water samples from production wells, Long Neck Peninsula, Sussex County, Delaware, 2004.

Table 10. Production wells that exceeded water-quality criteria—for elevated specific conductance, nitrate-nitrogen concentrations, and detectable volatile organic compounds—and total mercury concentrations, Long Neck Peninsula, Sussex County, Delaware, 2003

[DGS, Delaware Geological Survey; >, greater than; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; VOCs, volatile organic compounds; YES, exceeds stated threshold value; NO, at or below stated threshold value; shaded data, total mercury exceeded 100 ng/L; ---, total mercury less than 100 ng/L; affected well ratio, number of wells that had indicator that exceeded the stated threshold, or had more than one detectable VOC, divided by the total number of wells]

DGS well identifier	Elevated specific conductance (>100 µS/cm at 25°C)	Elevated nitrate-nitrogen concentration (>0.4 mg/L)	Number of detectable VOCs	Number of criteria exceeded	Elevated total mercury concentration (>100 ng/L)
		Bayside Wells			
Pi31-01	YES	YES	4	3	1,820
Pi31-11	NO	YES	3	2	276
Pi31-02	YES	YES	1	2	230
Pi31-05	YES	YES	3	3	---
Pi32-15	YES	YES	2	3	---
Pi41-02	NO	YES	1	1	---
Pi41-03	NO	YES	2	2	---
Pi31-12	YES	YES	2	3	---
		Lakeside Wells			
Ph35-25	NO	YES	1	1	524
Ph35-24	YES	YES	1	2	104
		Other Wells			
Ph24-01	NO	YES	1	1	---
Ph24-02	YES	YES	4	3	---
Ph25-17	YES	YES	2	3	---
Ph34-18	YES	YES	1	2	---
Ph34-22	NO	YES	2	2	---
Ph34-23	YES	YES	1	2	---
Ph34-24	YES	YES	5	3	---
Ph35-28	YES	YES	3	3	---
Ph44-07	YES	YES	1	2	---
Pi32-14	YES	YES	4	3	---
Pi34-09	YES	YES	1	2	---
Pi43-03	YES	YES	4	3	---
Affected well ratio	16/22	22/22	13/22		5/22

tics or conditions associated with contaminant plumes of limited areal and vertical extent. In addition, the mixing of ground waters whose chemistry differs with depth in long screened intervals during the pumping of these production wells to obtain samples also could have masked chemical constituents or conditions uniquely associated with a contaminant plume that contained elevated HgT_{gw}. To address the above concerns, a vertical distribution study of Hg in the shallow aquifer was conducted with vertically nested short-screened monitoring wells in the vicinity of each of the Bayside (Pi31-01) and Lakeside (Ph35-25) production wells with the highest concentrations of HgT_{gw}.

Pot Nets Bayside and Lakeside

The vertical distribution of HgT_{gw} was characterized at selected depths in the shallow surficial aquifer at the Bayside (Pi31-01) and Lakeside (Ph35-25) production-well sites. Chemical characteristics and geochemical settings that potentially related to the occurrence, form, transport, and source of Hg also were determined for local aquifer sediment and ground water at selected depths. The characterization and assessment were conducted on the basis of analyses of soil, fill, and aquifer sediment data obtained during the installation in 2004 of the vertical nests of short-screened monitoring wells, and analyses of ground-water data obtained in the field and from samples collected from the contaminated production wells and the newly installed short-screened monitoring wells at the Pot Nets Bayside and Lakeside sites.

Mercury in Sediment

Lithologic sediment descriptions (Appendix B, figs. B1 and B2) were combined with the concentrations of HgT for selected sediment samples (HgT_{sed}, Appendix B, table B11) to illustrate the vertical (depth) profile of HgT_{sed} in the surficial sediment at each site (fig. 12). This illustration shows that slightly elevated concentrations of HgT_{sed} (40 micrograms per kilogram, µg/kg, or less) occurred only in surficial soil and fill. No measurable HgT_{sed} (reporting level 20 µg/kg) was found in aquifer sediment.

Relations Between Mercury and Other Sediment Constituents

Samples with measurable HgT_{sed} at the Bayside and Lakeside sites also were analyzed for other chemical constituents often associated with elevated Hg, including organic carbon, sulfur, and selected TEs.

Carbon: Samples of soil and fill that contained measurable HgT_{sed} also had measurable organic carbon (fig. 13). Organic carbon (OC) was the predominant form of carbon (Appendix B, table B11) and, in soil and fill, ranged from 0.18 to 1.79 percent by weight. It also was visible in surficial soil and fill, but not in the underlying sediment samples (Appendix B, tables B1 through B10). The co-occurrence of HgT_{sed} and OC in soil and fill indicated that Hg possibly was bound to OC (Barringer and others, 1997).

Sulfur and Trace Elements: Elevated sulfur in conjunction with Hg in sediment is a potential indicator of solid mercuric sulfide (Lowry and others, 2004). No measurable sulfur was found in samples (Appendix B, table B11, sulfur, less than 5 percent by weight); thus, no discernible relation was found between HgT_{sed} and sulfur in soil, fill, or sediment, and there was no evidence to support the occurrence of solid mercuric sulfide (metacinnabar) in sediment.

Several TEs were found at measurable and elevated concentrations in soil, fill, or aquifer sediment from both sites (Appendix B, table B11—for example, aluminum, iron, and titanium). These TEs, however, appeared ubiquitous, and occurred in all or most lithologic materials and neither exclusively, nor at elevated concentrations, solely in soil or fill samples that contained elevated HgT_{sed}.

occurred in all or most lithologic materials and neither exclu

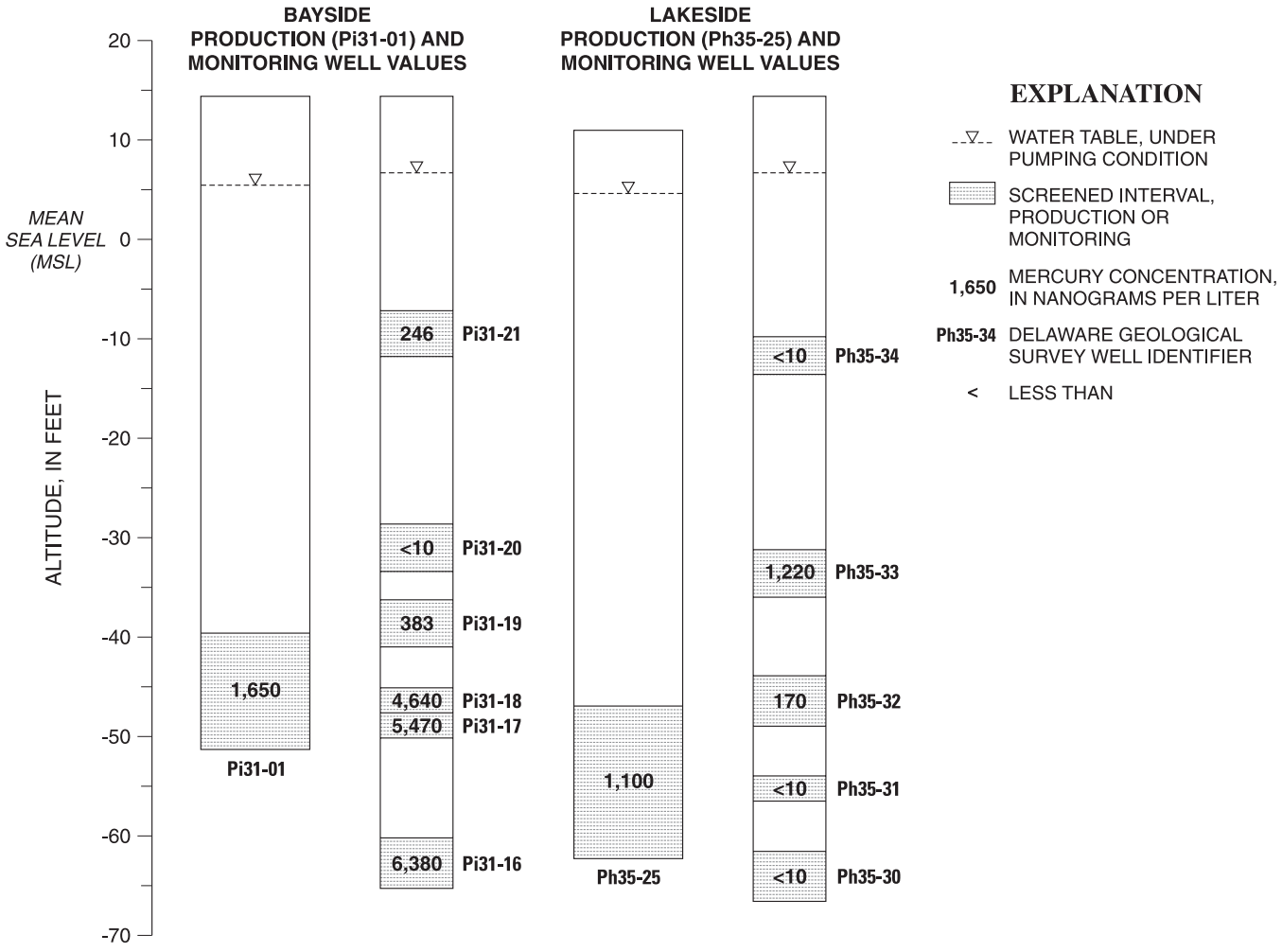

Figure 14. Depth distribution of total mercury concentrations in ground water at the Pot Nets Bayside well (Pi31-01) and Lakeside well (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2005.

other inorganic (chloride and sulfide) or organic (carbon) complexes with Hg potentially occurred in ground water at either site.

Particulate and Non-Particulate Mercury: The observed differences in HgT_{gw} between raw and filtered (0.45-µm nominal pore size filter) duplicate ground-water samples from coastal settings similar to the Long Neck Peninsula led Barringer and Szabo (2001) to report that HgT_{gw} in excess of 1,000 ng/L had a particulate component. A similar conclusion could not be drawn for shallow ground water at the Bayside and Lakeside sites for HgT_{gw} concentrations as high as 6,380 ng/L. At either site, the $HgT_{gw\text{-}raw}$ and $HgT_{gw\text{-}f0.4\ or\ -f0.1}$ concentrations generally were similar in magnitude for duplicate samples from each monitoring well (figs. 15 A and B). Also, the relative difference in HgT_{gw} concentrations (in percent) between raw and filtered samples from each well with an elevated HgT concentration (100 ng/L or more) fell within the expected range in relative difference in HgT_{gw} concentrations attributable to laboratory and field methods for the analysis of duplicate samples of the same type (± 6–7 percent, see *Data Quality, Mercury*). For the Pot Nets Bayside wells, for example, relative differences in HgT_{gw} between duplicate raw and 0.1-µm capsule-filtered samples from six monitoring wells were random in sign, ranged from -5.0 to +23.6 percent, and averaged 4.9 percent (table 11). The one high value (+23.6 percent) actually implied that the HgT_{gw} concentration was greater in the capsule-filtered than raw sample for well (Pi31-21), which appeared to indicate a higher degree of variability or measurement than normal rather than the presence of particulate mercury.

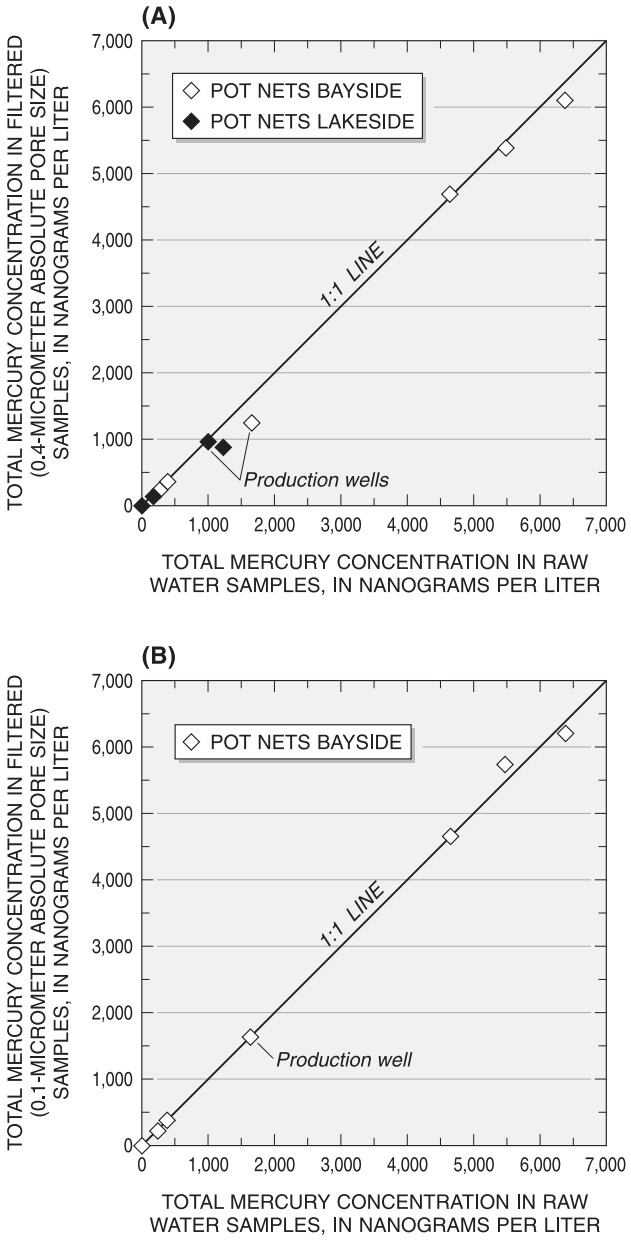

Figure 15. **(A)** Concentrations of total mercury in raw and filtered (0.4-micrometer absolute pore size) ground-water samples from the Pot Nets Bayside well (Pi31-01) and Lakeside well (Ph35-25) sites, 2005, and **(B)** concentrations of total mercury in raw and filtered (0.1-micrometer absolute pore size) ground-water samples from the Pot Nets Bayside well (Pi31-01) site, Long Neck Peninsula, Sussex County, Delaware, 2005.

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Table 11. Relative difference in total mercury concentrations between raw and filtered (0.1-micrometer absolute pore size) samples for the production and each vertically nested monitoring well at the Pot Nets Bayside (Pi31-01) site, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey; Hg, mercury; µm, micrometer; ng/L, nanograms per liter; relative difference equals difference in concentrations between raw and filtered samples divided by their average concentration, expressed in percent (%), Average, of monitoring well values only; Std Dev, standard deviation, of monitoring well values only]

DGS well identifier	Total Hg, raw water (ng/L)	Total Hg, 0.1-µm filtered (ng/L)	Relative difference (%)
		Production well	
Pi31-01	1,650	1,620	1.8
		Monitoring wells	
Pi31-16	6,380	6,220	2.5
Pi31-17	5,470	5,750	-5.0
Pi31-18	4,640	4,670	-0.6
Pi31-20	2.37	2.27	4.3
Pi31-19	383	367	4.3
Pi31-21	246	194	23.6
		Average	4.9
		Std Dev	9.8

Total particulate carbon and turbidity data also indicated that Hg transport was unlikely to occur in a particulate phase. There was no measurable particulate carbon in ground-water samples from either Pot Nets site (Appendix A, table A13). Turbidity seldom occurred at levels greater than 1 NTU (table 12), which implied that no reflective particulates occurred in ground water at either site. Moreover, samples with turbidity values above 0.2 NTU had only low to moderate amounts of HgT_{gw} (0.89–383 ng/L; table 12).

Methyl mercury: Concentrations of $HgMe_{gw\text{-}f0.4}$ were shown to be low (about 0.06 ng/L or less; table 7) in selected Bayside and Lakeside monitoring-well samples with low $HgT_{gw\text{-}raw}$ concentrations (366 ng/L or less). As such, only a fraction (less than 1 percent) of the total amount of Hg transported as HgT_{gw} would be as HgMe. This result, however, must be tempered by the fact that HgMe concentrations for samples with $HgT_{gw\text{-}raw}$ in excess of 366 ng/L remained unknown because of an apparent sample-matrix interference and a lack of data to determine and verify HgMe recoveries in samples with high $HgT_{gw\text{-}raw}$ concentrations (see *Data*

Table 12. Turbidity and total mercury concentrations in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2003

[DGS, Delaware Geological Survey; Hg, mercury; NTU, nephelometric turbidity unit; ng/L, nanograms per liter]

Site	DGS site identifier	Turbidity, raw water (NTU)	Total Hg, raw water (ng/L)
Bayside	Pi31-01	0.1	1,650
Monitoring	Pi31-16	0.2	6,380
Wells	Pi31-17	0.2	5,470
	Pi31-18	0.2	4,640
	Pi31-19	0.6	383
	Pi31-21	1.7	246
	Pi31-20	0.5	2.37
Lakeside	Ph35-25	0.1	1,000
Monitoring	Ph35-33	0.2	1,220
Wells	Ph35-32	0.4	170
	Ph35-30	0.2	1.65
	Ph35-31	0.4	0.98
	Ph35-34	0.4	0.89

Quality, Mercury).

Indirect geochemical evidence that possibly little HgMe at least was formed in ground water at either Pot Nets site was obtained from geochemical conditions at both sites. Ground water at all sampled depths at each site contained measurable DO (Appendix A, table A11), which would have inhibited *in situ* microbial reduction of sulfate to sulfide, and the primary process by which HgMe is thought to be produced (Wiener and others, 2002). Also, although no published data were found for HgMe concentrations in ground water in similar coastal settings, validated Bayside and Lakeside data (table 7) were consistent with the very low HgMe concentrations reported for oxic waters draining areas with no known Hg sources—0.8 ng/L or less (Wiener and others, 2002, p. 417).

Inorganic and Organic Complexes: What Hg complexes form or how they are transported in water depends upon the chemical conditions (for example, pH and DO), and the type and concentration of available ligands (Wiener and others, 2002). The identification and quantification of possible organomercuric compounds and their ligand precursors, and computations of chemical equilibria for these compounds, would be required to clearly address this question. For the purposes of this study, however, available research findings were combined with observed data on the general geochemical conditions and ligand availability in Pot Nets ground water, to identify (un)likely forms of Hg in transport.

Ravichandran and others (1998) have noted that absent DOC, mercury speciation is controlled mainly by pH, DO, and inorganic ligand availability—for example, ionic Hg(II) can react to form soluble hydroxides ($Hg(OH)^{-1}$ and or $Hg(OH)_2$), soluble chlorides ($HgCl^{+1}$ or $HgCl_2$), or sulfides (soluble $HgSH^{+1}$, $Hg(SH)_2$, and HgS_2^{2-}, or insoluble Hg (metacinnabar, HgS). At low pH and no DO, it has been argued that sulfide if present at even low (nanomolar) concentrations reacts with Hg to form soluble HgS (Gilmore and others, 1998; Benoit and others, 1999; Reddy and Aiken, 2001; Lowry and others, 2004). Absent sulfides and in oxic waters, theoretical equilibrium calculations have been used to indicate competition can occur—with chloride complexes likely dominating at pH 4, DOC-Hg complexes likely dominating at pH 6, and hydroxide complexes likely dominating at pH 8 (Benoit and others, 2001; Reddy and Aiken, 2001).

When present in water, DOC that contains humic substances has been shown to strongly interact with simple ionic, sulfide, or methylated forms of Hg (Ravichandran and others, 1998, 1999; Haitzer and others, 2002, 2003; Qian and others, 2002; Aiken and others 2003; Waples and others, 2005). The individual chemical structures of these DOC complexes largely have remained unknown, but the organic ligand groups that are suspected of binding Hg include reactive acids, esters, and thiols, and these reactive forms of DOC, as noted earlier (see *Field Data and Sample Collection, Ground-Water-Data and Water Samples)* have been at least been partially isolated by the fractionation of DOC (Aiken and others, 1992) into the hydrophobic acid (HPOA) or the transphilic acid (TPIA) fractions.

To identify if Hg in transport likely occurred as an inorganic or organic complex, the potential forms of Hg in Pot Nets ground water were investigated on the basis of current research findings such as those described above, and in conjunction with data obtained on the availability of selected types of ligands in ground water at the Pot Nets sites. This analysis is described below and begins with the simpler inorganic complexes that involve sulfide and chloride.

Sulfide Complexes can form rapidly in water given nanomolar or higher concentrations of hydrogen sulfide (HS^-) in the absence of DO and under circumneutral-to-acidic conditions (Paquette and Helz, 1997; Benoit and others, 1999; Aiken and others, 2003), as follows (assuming Hg initially is present as mercury dihydroxide, $Hg(OH)_2$):

$$Hg(OH)_2 + 2HS^- + 2H^+ = Hg(HS)_2 + 2H_2O \quad (1)$$

Geochemical conditions in Pot Nets ground water (table 13) appeared unfavorable to the formation of soluble mercuric di-(hydrogen sulfide), $Hg(HS)_2$. Although the pH of ground water was moderately acidic, no sulfide was detected in ground water (detection level 0.01 mg/L, or 3 micromoles per liter). Measurable DO occurred at all depths sampled, as did sulfur, but as sulfate not sulfide (table 13). Thus, if mercuric sulfide were being transported in

Table 13. Geochemical conditions related to the occurrence or formation of mercuric sulfide (metacinnabar) in ground water at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; ng/L, nanograms per liter; mg/L, milligrams per liter; wells with background shaded data have total mercury equal to or above 1,000 ng/L; <, less than]

Site	DGS well identifier	Total mercury, unfiltered (ng/L)	pH, field standard units	Dissolved oxygen (mg/L)	Hydrogen sulfide (mg/L)	Sulfate (mg/L)
Bayside	Pi31-01	1,650	5.1	4.0	< 0.01	7.9
	Pi31-16	6,380	5.3	1.7	< 0.01	2.5
	Pi31-17	5,470	5.3	1.5	< 0.01	4.0
	Pi31-18	4,640	5.2	3.1	< 0.01	4.2
	Pi31-19	383	5.2	4.9	< 0.01	6.9
	Pi31-20	2.37	5.0	5.0	< 0.01	14.4
	Pi31-21	246	5.0	5.2	< 0.01	7.2
Lakeside	Ph35-25	1,000	5.5	4.7	< 0.01	1.5
	Ph35-33	1,220	5.5	1.8	< 0.01	2.7
	Ph35-32	170	5.7	2.3	< 0.01	1.3
	Ph35-30	1.65	5.6	6.5	< 0.01	0.6
	Ph35-31	0.98	5.6	6.4	< 0.01	0.8
	Ph35-34	0.89	5.2	2.7	< 0.01	13.3

Pot Nets ground water, it likely would have been as insoluble metacinnabar, HgS (solubility coefficient equals $10^{-52.4}$, Aiken and others, 2003). No Hg, however, was found in a particulate phase in ground water at either Pot Nets site. Nor was Hg or sulfur measurable in aquifer sediments, which under the oxic ground-water conditions, would have been expected if solid metacinnabar originally occurred or was accumulating in sediments. Thus, if Hg were being transported as a sulfide species in Pot Nets ground water, it would not likely be as simply soluble $Hg(HS)_2$ or insoluble HgS, but more likely as a complexed form of sulfide (Waples and others, 2005).

Chloride Complexes that are soluble and transportable can form under circumneutral pH and oxic conditions (Benoit and others, 1999, 2001; Reddy and Aiken, 2001; Wiener and others, 2002), as follows:

$$Hg(OH)_2 + 2Cl^- + 2H^+ = HgCl_2 + 2H_2O \quad (2) \text{ or}$$

$$Hg(OH)_2 + 3Cl^- + 2H^+ = HgCl_3^- + 2H_2O \quad (3)$$

where Hg initially is assumed to be present as mercuric hydroxide ($Hg(OH)^+$) or dihydroxide ($Hg(OH)_2$).

Geochemical conditions at both Pot Nets sites appeared to support the formation of chloride complexes (equations 2 and 3). Ground water was oxic and moderately acidic with a pH range of 6 (table 14). There also was ample chloride—15–30 mg/L (0.2–0.8 millimoles). It already has been noted, however, that given oxic and moderately acidic conditions, and an absence of hydrogen sulfide, that DOC which contains appreciable HPOA and TPIA fractions would compete with chloride to form Hg complexes.

Organic Carbon Complexes can form under circumneutral pH and oxic conditions (Ravichandran and others, 1998, 1999; Benoit and others, 1999, 2001; Reddy and Aiken, 2001; Wiener and others, 2002; Haitzer and others, 2002, 2003; Aiken and others, 2003; Lowry and others, 2004; Fitzgerald and Lamborg, 2005), for example:

$$Hg(OH)^+ + \text{Fulvic acid}^{-n} = \text{HgOH-Fulvic acid}^{n-1} \quad (4) \text{ or}$$

$$Hg(OH)^+ + \text{Humic acid}^{-n} = \text{HgOH-Humic acid}^{n-1} \quad (5) \text{ or}$$

$$Hg(OH)^+ + ORS^{-n} = HgOH\text{-}ORS^{n-1} \quad (6)$$

where ORS indicates a reduced organic sulfur ligand, for example, a thiol.

Geochemical conditions at both Pot Nets sites appeared to support the formation of organic complexes (equations 4, 5, and 6). Assuming the DOC in Pot Nets ground water con-

Table 14. Geochemical conditions related to the occurrence or formation of mercuric chloride or organomercuric complex formation in ground water at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; ng/L, nanograms per liter; mg/L, milligrams per liter; <, less than; **E**, estimated by laboratory; wells with background shaded data have total mercury equal to or above 1,000 ng/L]

Site	DGS well identifier	Total mercury, unfiltered (ng/L)	pH, field standard units	Dissolved oxygen (mg/L)	Chloride (mg/L)	Dissolved organic carbon (mg/L)
Bayside	Pi31-01	1,650	5.1	4.0	21.8	1.7
	Pi31-16	6,380	5.3	1.7	15.1	1.3
	Pi31-17	5,470	5.3	1.5	20.0	2.5
	Pi31-18	4,640	5.2	3.1	23.1	3.1
	Pi31-19	383	5.2	4.9	20.4	0.5
	Pi31-21	246	5.0	5.2	30.5	0.6
	Pi31-20	2.37	5.0	5.0	18.2	0.7
Lakeside	Ph35-25	1,000	5.5	4.7	10.3	**E** 0.3
	Ph35-33	1,220	5.5	1.8	11.1	0.5
	Ph35-32	170	5.7	2.3	9.85	**E** 0.2
	Ph35-30	1.65	5.6	6.5	10.5	< 0.3
	Ph35-31	0.98	5.6	6.4	10.5	**E** 0.2
	Ph35-34	.89	5.2	2.7	17.6	0.7

tained the appropriate organic ligands, measurable DOC was found in ground water at most depths sampled at both Pot Nets sites (table 14). Pot Nets ground-water samples that had elevated concentrations of $HgT_{gw\text{-}raw}$ (1,000 ng/L or greater) also generally had elevated concentrations of DOC (in excess of 0.4 mg/L).

According to the equilibrium studies by Reddy and Aiken (2001), the pH range of Pot Nets ground water with high $HgT_{gw\text{-}raw}$ and DOC would have favored DOC over chloride complex formation. Furthermore, other researchers have shown that strong interactions occurred between DOC and Hg, if the DOC contained appreciable HPOA or TPIA, and if Hg initially occurred as a simple inorganic (Hg(II) chloride or sulfide complex or as methyl mercury (Ravichandran and others, 1999; Haitzer and others, 2002, 2003; Qian and others, 2002; Aiken and others, 2003; Waples and others, 2005). The above research also indicated that under pH and oxic conditions similar to the conditions in Pot Nets ground water, and for Hg to DOC ratios of 1,000–10,000 nanograms per milligram (or ng/mg), the DOC-Hg binding coefficients for these interactions were on the order of $10^{12–23}$, greatest at low Hg:DOC ratios, and likely related to the binding of Hg by organic thiols, or humic, fulvic, or hydrophobic acids. The Hg:DOC ratios for Pot Nets ground-water samples with high $HgT_{gw\text{-}raw}$ were 2,864 ng/mg for the Bayside site (table 14, averaged ratio for wells Pi-31-16, -17, and -18), and 2,440 ng/mg for the Lakeside site (table 14, ratio for well Ph 35-33). These ratios fell toward the lower end of the range in ratios cited by the research above, and provided further evidence that Hg transport in Pot Nets ground water could have occurred as a DOC-related complex.

Hydrophobic and Hydrophilic Acid Carbon Fractions: Although research findings and Pot Nets geochemical conditions support Hg transport as a DOC complex, the question that arose was whether the DOC in ground water at the Pot Nets site likely contained the appropriate DOC-related humic substances (HPOA and TPIA). Four parameters related to DOC composition were examined to address this question. The parameters were (a) the absorbance of ultraviolet light by DOC samples, (b) the ratio of the measured absorbance to the concentration of DOC, (c) the acid fractions (HPOA and HPIA) in DOC, and (d) ANC and its relation to DOC.

Weishaar and others (2003) have noted that ultraviolet absorbance (UVA) at selected wavelengths (λs)—generally 254 nanometers (UVA_{254}) and 280 nanometers (UVA_{280})—can provide an indirect measure of humic aromatic substances associated chiefly with HPOA. They also have cautioned, however, that absorbance values for DOC can be positively biased by high concentrations of dissolved iron (500 µg/L or greater) or NO_3^--N (9 mg/L or greater), or changes in sample pH beyond the range of about 4.5–7.5 for the DOC (HPOA) samples tested. No Pot Nets ground-water

Table 15. Total mercury, dissolved organic carbon, and ultraviolet absorbance in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; ng/L, nanograms per liter; mg/L, milligrams per liter; cm, centimeter; **E**, estimated; wells with background shaded data have total mercury equal to or above 1,000 ng/L; UVA, ultraviolet absorbance; 254 or 284, wavelengths at which the absorbance was measured; nm, nanometers; <, less than]

Site	DGS well identifier	Total mercury, unfiltered (ng/L)	Dissolved organic carbon (mg/L)	UVA, 254 nm on carbon, organic dissolved (units/cm)	UVA, 280 nm on carbon, organic dissolved (units/cm)
Bayside	Pi31-01	1,650	1.7	0.019	0.011
	Pi31-16	6,380	1.3	0.015	0.010
	Pi31-17	5,470	2.5	0.032	0.019
	Pi31-18	4,640	3.1	0.039	0.023
	Pi31-19	383	0.5	0.005	<0.004
	Pi31-21	246	0.6	0.009	0.007
	Pi31-20	2.37	0.7	0.007	0.005
Lakeside	Ph35-25	1,000	**E** 0.3	0.004	<0.004
	Ph35-33	1,220	0.5	0.013	0.009
	Ph35-32	170	**E** 0.2	0.005	0.004
	Ph35-30	1.65	< 0.3	0.004	<0.004
	Ph35-31	0.98	**E** 0.2	0.004	0.004
	Ph35-34	0.89	0.7	0.011	0.008

sample contained iron or NO_3^--N concentrations that equaled or exceeded the above values, or had a pH outside of the above range (Appendix A, tables A11 through A13). Also there was no evidence of (in)organic particulates and only low turbidities in Pot Nets ground-water samples. Thus, differences in the measured UVA of 0.010 units per centimeter (or units/cm) or greater were considered to reflect possible differences in the amount or type of aromatic carbon.

Measurable UVA occurred at both λs for most DOC ground-water samples from the Pot Nets sites (table 15). For a given sample, UVA_{254} exceeded or equaled UVA_{280}. For a given λ and site, and except for well Ph35-34, monitoring wells with high concentrations of $HgT_{gw\text{-}raw}$ (1,000 ng/L or greater) had higher DOC and UVA $_{254\ or\ 280}$ values than the monitoring-well samples with low to moderate $HgT_{gw\text{-}raw}$ concentrations. For Bayside monitoring wells with high $HgT_{gw\text{-}raw}$, for example, the average DOC concentration, UVA_{254}, and UVA_{280} were 2.3 mg/L, 0.027 units/cm, and 0.016 units/cm, respectively; similar measures for wells with low to moderate $HgT_{gw\text{-}raw}$ were 0.06 mg/L, 0.007 units/cm, and 0.005 units/cm, respectively (table 15). Thus, on average, Bayside samples with high concentrations of $HgT_{gw\text{-}raw}$ had 3–4 fold greater concentrations of DOC, and exhibited a greater absorbance, than samples with low $HgT_{gw\text{-}raw}$.

To normalize absorbance for differences in DOC concentrations among samples, the ratio of UVA_{λ} to DOC commonly is used, which is defined as the specific ultraviolet absorbance (SUVA), and expressed as follows (Weishaar and others, 2003):

$$SUVA_{\lambda}\ (L/mg\text{-}m) = [(UVA_{\lambda}, units/cm) / (DOC, mg/L)] \times C, cm/m \quad (7)$$

where

λ is the absorbance wavelength in nanometers,
UVA is the ultraviolet absorbance per centimeter (cm) of light path,
DOC is the dissolved organic carbon in milligrams per liter (mg/L), and
C is a constant equal to 100 centimeters per meter (m).

Weishaar and others (2003) found that the SUVA could be a good general indicator and predictor of the aromatic carbon (HPOA fraction) contents of DOC in water.

Table 16. Total mercury, dissolved organic carbon, and specific ultraviolet absorbance (SUVA) in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; 254 or 280, wavelength at which absorbance was measured; nm, nanometers; ng/L, nanograms per liter; mg/L, milligrams per liter; L/mg-m, liter per milligram meter; <, less than; >, greater than; **E**, estimated; wells with background shaded data have total mercury equal to or above 1,000 ng/L]

Site	DGS well identifier	Total mercury, unfiltered (ng/L)	Dissolved organic carbon (mg/L)	SUVA, 254 nm on carbon, organic dissolved (L/mg-m)	SUVA, 280 nm on carbon, organic dissolved (L/mg-m)
Bayside	Pi31-01	1,650	1.7	1.11	0.65
	Pi31-16	6,380	1.3	1.15	0.80
	Pi31-17	5,470	2.5	1.28	0.76
	Pi31-18	4,640	3.1	1.26	0.74
	Pi31-19	383	0.5	1.00	< 0.80
	Pi31-21	246	0.6	1.50	1.17
	Pi31-20	2.37	0.7	1.00	0.71
Lakeside	Ph35-25	1,000	**E** 0.3	1.33	< 1.33
	Ph35-33	1,220	0.5	2.60	1.80
	Ph35-32	170	**E** 0.2	2.50	**E** 2.00
	Ph35-30	1.65	< 0.3	> 1.33	< 1.33
	Ph35-31	0.98	**E** 0.2	2.00	**E** 2.00
	Ph35-34	0.89	0.7	1.57	1.14

Measurable SUVA occurred at both λ for most ground-water samples from the Bayside and Lakeside sites (table 16). For a given Pot Nets sample, $SUVA_{254}$ equaled or exceeded $SUVA_{280}$—an indication that $SUVA_{254}$ possibly was a better indicator than $SUVA_{280}$ of aromatic or HPOA-related carbon. For a given λ and site, however, there was no correlation between $SUVA_{254}$ and $HgT_{gw\text{-}raw}$ among Bayside ground-water samples (linear regression coefficient squared, r^2, equaled 0.02); but a moderately positive correlation did occur between $SUVA_{254}$ and $HgT_{gw\text{-}raw}$ for Lakeside samples (r^2 equaled 0.47). These results indicated a possible difference in the type of aromatic or HPOA-related carbon in ground waters at these two sites.

The relation between SUVA and DOC can indicate if the absorbance differs in ground water between sites, or possibly among samples from the same site, for reasons other than the concentration of DOC (figs. 16 A and B). Except for samples from the shallowest wells at each site (figs.16 A and B, SUVA plotted points with HgT(s), samples with elevated concentrations of $HgT_{gw\text{-}raw}$ appeared to have higher $SUVA_{280}$ (fig.16A) and $SUVA_{254}$ (fig.16B) values than samples with background $HgT_{gw\text{-}raw}$ concentrations. The differences in SUVA among samples at a site appeared more pronounced at 254 nm than at 280 nm, and more apparent at the Lakeside than Bayside site. These patterns were consistent with previously described correlations between UVA and $HgT_{gw\text{-}raw}$. They also indicated that the relative proportion of aromatic or HPOA-related carbon to DOC possibly was highest in Hg-contaminated waters, and more so at the Lakeside than Bayside site.

Samples from the shallowest wells at each Pot Nets site appeared to be somewhat anomalous in relation to other samples and the patterns between concentrations of HgT_{gw} and DOC, and absordance or SUVA among those samples (see figs. 16 A and B, for example). The anomalous behavior was attributed to these samples corresponding to wells installed in heterogeneous strata of clays and silty sands that differed noticeably from sediments deep in the aquifer and where Hg contamination was most evident.

Although Weishaar and others (2003) found that SUVA could be a good indicator of the relative aromatic or HPOA-related carbon content in water, SUVA alone cannot reliably discriminate among samples if the latter differ markedly in the composition of DOC source materials. To address this concern in this study, data on DOC composition were obtained from the fractional analysis of the DOC on selected Pot Nets samples (table 17). Fractionation of the DOC in two samples—one from each Pot Nets site, and each of which

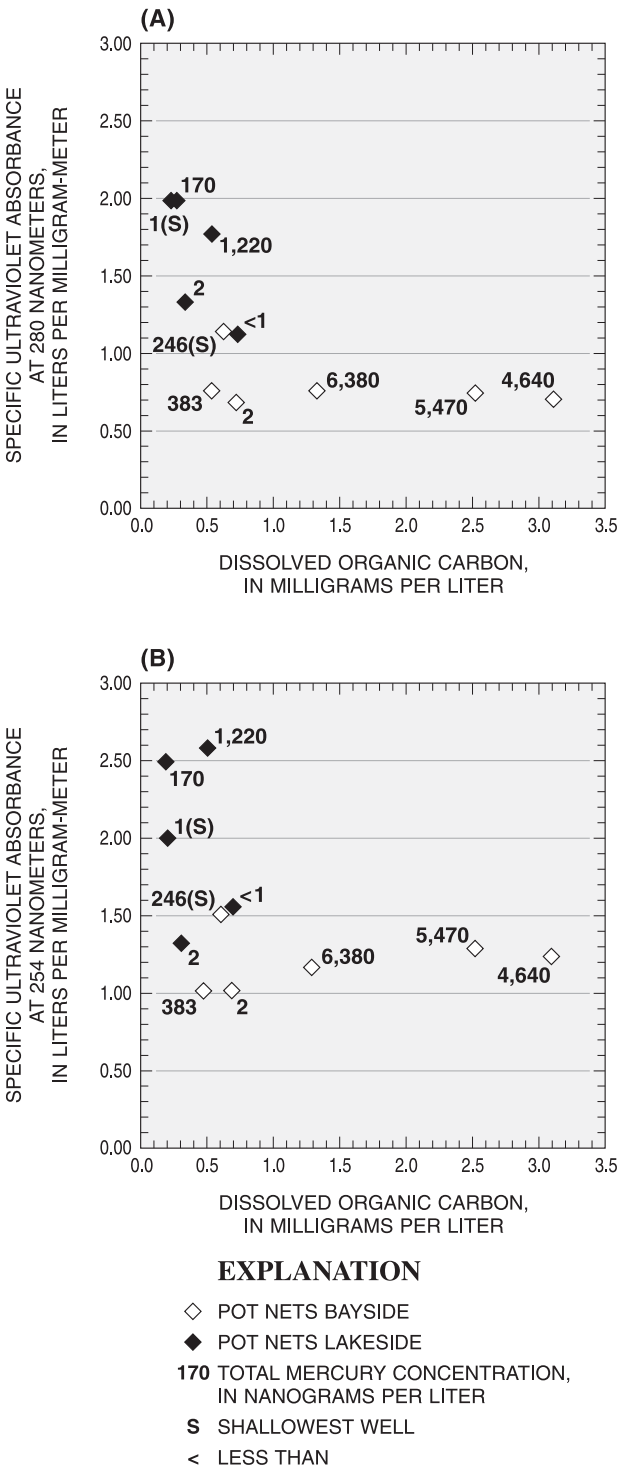

Figure 16. Dissolved organic carbon and specific ultraviolet absorbance **(A)** at 280 nanometers and **(B)** at 254 nanometers, for filtered (0.4-micrometer absolute pore size) samples from Pot Nets Bayside well (Pi31-01) and Lakeside well (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2005.

contained high $HgT_{gw\text{-}raw}$—revealed that about half (45–48 percent) of the DOC in each sample was partitioned into the HPOA fraction (table 17). Also, a notable fraction of the DOC (15 percent) in the Bayside sample also consisted of a hydrophilic acid fraction (TPIA). The Lakeside sample only had sufficient DOC to estimate the HPOA fraction.

The relative amounts of HPOA, and to a lesser extent, TPIA, in Pot Nets ground water were considered important because it is these carbon fractions that have been used in most other studies to demonstrate that DOC in aquatic environments could contain humic substances that strongly interact with Hg (Ravichandran and others, 1998, 1999; Aiken and others, 2003; Haitzer and others, 2002, 2003; Waples and others, 2005). The estimated concentrations of HPOA and TPIA found in Pot Nets samples with high concentrations $HgT_{gw\text{-}raw}$ appeared substantial. For the Bayside ground-water sample (table 17, well Pi31-17), the estimated amount of HPOA, 1.2 mg/L (=0.45 x 2.8), appeared to be about two times the total DOC found in other Bayside monitoring wells with low to moderate concentrations of $HgT_{gw\text{-}raw}$ (table 16). Also, the amount of HPOA carbon estimated for the Lakeside sample (Table 17, well Ph35-33), 0.3 mg/L (=0.48 x 0.6), about equaled the total DOC found in other Lakeside monitoring wells with low concentrations of $HgT_{gw\text{-}raw}$. In addition, except for the Bayside production well (Pi31-01), which had high concentrations of DOC and $HgT_{gw\text{-}raw}$, the amount of HPOA in the Bayside sample exceeded, and the amount in the Lakeside samples about equaled, the total DOC found in 20 of the other 21 production wells that were part of the Peninsula source-water-quality survey (Appendix A, table A5). Finally, the concentrations (in mg/L) of the HPOA and TPIA fractions found in the Bayside well Pi31-37 and HPOA fraction in the Lakeside well Ph35-33 were considerably greater than the concentrations (typically in µg/L) of these fractions found in natural or relatively uncontaminated ground waters with less than 1–2 mg/L of DOC.

The possibility that the HPOA and TPIA carbon fractions contained reduced thiol, humic, fulvic, or other hydrophobic acid groups, and therefore oxidizeable (protenatable) ligand groups, also was supported by the strong positive correlation between DOC and ANC noted previously for ground-water samples from the Bayside site (fig. 6, r^2 equals 0.90). Thus, most samples with generally high DOC also had high ANC, and included most samples with high concentrations of $HgT_{gw\text{-}raw}$ (table 18). The Bayside samples with high DOC and $HgT_{gw\text{-}raw}$ concentrations, for example, also had ANCs that were 3 to 6 times greater than the ANCs for the Bayside samples that had low-to-moderate $HgT_{gw\text{-}raw}$.

Given that bicarbonate also likely contributed to the ANC (see *Major Ions, Alkalinity, Acid-Neutralization Capacity, and Bicarbonate*) it was not possible to determine what fraction of the ANC reflected DOC or bicarbonate. It should be noted, however, that there was no apparent correlation (r^2 equals 0.01) between DOC and ALK concentrations among peninsula survey samples (data from Appendix A, table A3, excluding Bayside production well). Nor has

Table 17. Fractional components of dissolved organic carbon in selected ground-water samples with elevated total mercury concentrations from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004 [a]

[DGS, Delaware Geological Survey; HPOA, hydrophobic organic acid fraction; HPON, hydrophobic organic neutral fraction calculated by difference (**E**, estimated); HPI, low molecular weight hydrophilic compound fraction; TPIA, transphilic organic acid fraction; TPIN, transphilic organic neutral fraction, calculated by difference; ng/L, nanograms per liter; mg/L, milligrams per liter; %, percentage of dissolved organic matter in mg/L; ---, insufficient dissolved organic matter to accurately determine fraction]

DGS well identifier	Total mercury, raw water (ng/L)	Dissolved organic carbon (mg/L)	HPOA (%)	HPON (%)	HPI (%)	TPIA (%)	TPIN (%)
Bayside, Well Pi31-17	5,470	2.8	45	**E** 10	19	15	**E** 8
Lakeside, Well Ph35-33	1,220	0.6	48	--	--	--	--

[a] Total DOC concentrations of study samples are low for this type of analysis, which typically is done on surface and not ground water. Sampling time constraints at each site, however, prevented the collection and processing of more than a 4-liter filtered sample from each well.

Table 18. Total mercury and dissolved organic carbon concentrations, and acid-neutralization capacity in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; ng/L, nanograms per liter; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; **E**, estimated by laboratory; wells with background shaded data contain total mercury equal to or above 1,000 ng/L; <, less than]

Site	DGS well identifier	Total mercury, unfiltered (ng/L)	Dissolved organic carbon (mg/L)	Acid-neutralization capacity (mg/L as $CaCO_3$)
Bayside	Pi31-01	1,650	1.7	11.3
	Pi31-16	6,380	1.3	16.2
	Pi31-17	5,470	2.5	21.8
	Pi31-18	4,640	3.1	25.6
	Pi31-19	383	0.5	7.0
	Pi31-21	246	0.6	3.6
	Pi31-20	2.37	0.7	6.1
Lakeside	Ph35-25	1,000	**E** 0.3	6.8
	Ph35-33	1,220	0.5	6.5
	Ph35-32	170	**E** 0.2	8.1
	Ph35-30	1.65	< 0.3	6.0
	Ph35-31	0.98	**E** 0.2	6.7
	Ph35-34	0.89	0.7	7.1

the strong correlation between DOC and ANC at the Bayside site been observed or reported for ground waters elsewhere in other similar coastal aquifers settings in Delaware or New Jersey.

The combination of the DOC fractionation results, and relations among DOC, UVA, SUVA, and ANC collectively provided multiple lines of evidence that the transport of Hg in ground water at the Pot Nets sites could be as a DOC-related complex. High concentrations of HgT_{gw} were associated with unusually elevated concentrations of DOC. This DOC contained what appeared to be unusually high fractions of HPOA and TPIA carbon for at least one sample at the Bayside site, and a high fraction of at least HPOA for at least one sample at the Lakeside site. The DOC concentrations associated with ground water at the Pot Nets Bayside site also appeared to be highly correlated to ANC, which indicated the possible presence of protenatable DOC humic substances, which would be expected if this DOC contained humic and fulvic acids, or other reduced ligand groups that are oxidizeable. All of the above appeared consistent with studies that have identified and utilized HPOA and TPIA carbon fractions to demonstrate that strong DOC-Hg interactions (complex formation) can arise in oxic and circumneutral pH aqueous environments similar to those described for Pot Nets ground water at these two sites. Thus, it would seem most likely that the transport of Hg in ground water at the Pot Nets sites relates to similar DOC-Hg interactions and DOC complex formation.

Although the sources of DOC and Hg in ground water at the Bayside and Lakeside sites are unknown, several potential sources were identified. Wetlands lie between and to the south of the Bayside and Lakeside sites, artificial lined ponds (Bayside spray-irrigation facilities) and an artificial lake (Lakeside) occur near each community, and refilled or partially refilled borrow pits occur to the east of Bayside, between Bayside and Lakeside, and to the west of Lakeside (fig. 1). In addition, the main part of the Bayside community to the south of production well Pi31-01 historically relied on individual but now abandoned septic systems, and development of both Pot Nets communities required that trees be cut, which led to stump dumps that were buried at locations that are for the most part unknown (James Mooney, Operations Manager, LNWC, written commun., 2004).

Vertical Distribution of Mercury

Previous studies conducted at both the Bayside and Lakeside production-well sites found elevated HgT_{gw} in both production and existing monitoring wells, and, for the Bayside site, no measurable mercury (reporting level of 500 ng/L) in ground water to a depth of 40 ft from the land surface (Department of Natural Resources and Environmental Control, 2002; James Mooney, Operations Manager, LNWC, written commun., 2004). Results for the current study were derived from field data and samples collected from the vertically nested, short-screen monitoring wells at each site, while the nearby production well was pumping. They revealed that elevated concentrations of HgT_{gw} (in excess of 100 ng/L) occurred in ground water at both sites (fig. 14). At the Bayside site, elevated $HgT_{gw\text{-}raw}$ concentrations mainly occurred from 50–80 ft below land-surface datum (lsd), or 35–65 ft below mean sea level (msl), but possibly could have extended deeper into the aquifer. At the Pot Nets Lakeside site, elevated concentrations of $HgT_{gw\text{-}raw}$ were found at shallower depths than at the Bayside site—at about 45–65 ft below the lsd (30–50 ft below msl).

Distribution of Mercury in Relation to Sediment Type: To determine whether the distribution of $HgT_{gw\text{-}raw}$ concentrations in the shallow aquifer at each site reflected geological controls or unrestricted ground-water flow patterns in the vicinity of either Pot Nets production well, the vertical distributions of mercury in ground water (fig. 14) and sediment (fig. 12) were compared in the vicinity of each well. Except for the occurrence of silty sand at depth, ground water with elevated concentrations of HgT_{gw} (in excess of 100 ng/L) at depth for either site did not correspond solely to one lithologic stratum but extended across multiple strata.

Distribution of Mercury in Relation to Apparent Age of Ground Water: In the surficial unconfined aquifer, and beneath well-drained areas with high recharge potential on the Delmarva Peninsula, a simple relation often has been observed between the apparent age of ground water and depth. Ground-water age increases with depth (Dunkle and others, 1993; Reilly and others, 1994; Shedlock and others, 1999). Given no evidence of local geologic controls (above), a similar relation was anticipated for ground water in the surficial aquifer in the vicinity of the Pot Nets Bayside and Lakeside production wells.

Apparent dates of recharge determined from the analysis of CFCs in ground-water samples from vertically nested monitoring wells (table 8) indicated that ground water at the Bayside and Lakeside production-well sites generally followed the simple age-depth distribution model. At each site, and for each CFC compound, the average apparent recharge date generally occurred earlier in time with increased depth, and, hence, ground water increased in apparent age with depth (fig. 17). This finding further supported that the distribution of Hg in ground water at each Pot Nets site was governed by solute (DOC-complex) transport and local patterns in shallow ground-water flow.

The apparent recharge dates (ages) also had implications in relation to potential source(s) of the elevated Hg in local ground water. The CFC dates (ages) indicated that ground waters throughout the vertical profile at each Pot Nets site all were relatively young in origin. The oldest apparent date for recharge was 1965 (40 years in apparent age), and occurred in the deepest well at Lakeside (table 8, Well Pi35-30, for CFC-113).

Given that all ground-water samples at both Pot Nets sites had measurable CFCs, and hence, reflected relatively young ground water, there was no evidence of discharge in the vicinity of either production well from deeper and older regional ground-water flow either from the surficial aquifer, or an underlying confined aquifer. Other studies on the surfi-

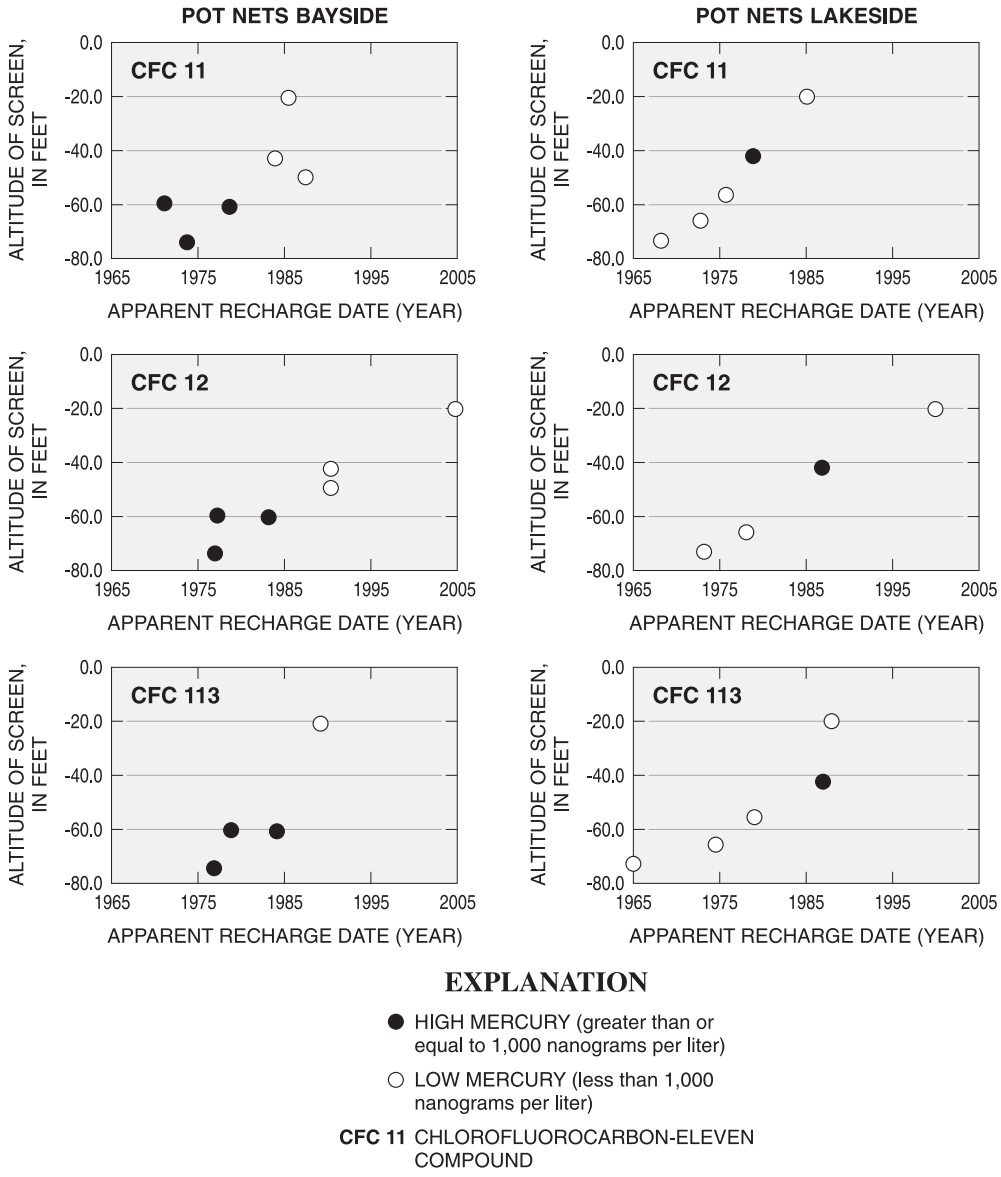

Figure 17. Apparent ages of ground water from three chlorofluorocarbon compounds, and depths from land surface to the tops of the screened intervals of monitoring wells with high or low concentrations of total mercury at the Pot Nets Bayside well (Pi31-01) and Lakeside well (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2005.

cial aquifer of the Delmarva Peninsula have shown that older ground waters of this type do not contain measurable CFCs because the origins of these waters typically reflect recharge that predates (circa 1950s) the use and atmospheric release of appreciable CFCs (Reilly and others, 1994; Dunkle and others, 1993; Shedlock and others, 1999).

The occurrence of elevated concentrations of $HgT_{gw\text{-}raw}$ (in excess of 100 ng/L) in ground waters of relatively young origins, combined with (a) the lack of measurable Hg in local aquifer sediments, and (b) the lack of elevated Hg concentrations in ground water sampled elsewhere on the Long Neck Peninsula, provided multiple lines of evidence that the source(s) of Hg contamination was (were) likely of anthropogenic and local origin(s). Whether or not there was a single common local source or multiple local sources of Hg could not be ascertained. At the Lakeside site, ground water with high concentrations of $HgT_{gw\text{-}raw}$ (greater than 1,000 ng/L) occurred in relation to a single sampled depth of about 35 ft below msl (fig.14), with apparent recharge dates that ranged between about 1979 and 1987 (fig. 17). At the Bayside site, ground water at depth with high $HgT_{gw\text{-}raw}$ concentrations occurred at depths of 45–65 ft below msl (fig. 14), which corresponded to apparent recharge dates that ranged between about 1971–1984 (fig. 17). Thus, although high concentrations of Hg occurred deeper within and over a wider range of depths in the aquifer at the Bayside site than at the Lakeside site, apparent recharge dates for ground waters with elevated HgT concentrations at both sites overlap in time, which indicated a possible common Hg source. That there could be a single source of Hg common to the contamination of ground water at both sites also is supported by the fact that elevated HgT_{gw} concentrations occurred at the Lakeside production well within just 2 months of the termination of pumping at the Bayside production well (see *Introduction*). To further investigate whether ground water with elevated Hg at the Pot Nets Bayside and Lakeside sites reflects a single common source or multiple sources, its occurrence was analyzed in relation to other chemical constituents in ground water at each site.

Relations Between Mercury and Other Ground-Water Constituents

Analysis of possible relations between elevated $HgT_{gw\text{-}raw}$ and other chemical constituents (or parameters) in Pot Nets Bayside and Lakeside ground water was conducted in a manner similar to that previously described for Hg in ground water in the surficial aquifer at the peninsula scale. This local-scale analysis, however, focused on relations between $HgT_{gw\text{-}raw}$ and indicators that reflected ground water affected by human activities at the Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, and included SC, major ions, and VOCs.

Specific Conductance and Major Ions: Denver (1989) described the chemistry of ground water that was "natural or only slightly affected by human activity," in the surficial aquifer in eastern Sussex County, Delaware, including the Long Neck Peninsula. This water had a low SC (median of 60 µS/cm) that rarely exceeded 100 µS/cm.[9] For the current study, however, the SC of ground-water samples from monitoring wells at the Bayside site ranged from 132–163 µS/cm at 25 °C (Appendix A, table A11). At the Lakeside site, SC ranged from 64–125 µS/cm at 25 °C. The SC data indicate that ground water from all sampled depths at the Bayside site, and the two depths at the Lakeside site was affected by human activity (table 19). Also, except for Lakeside well Ph35-32, the affected ground water reflects all depths at which elevated $HgT_{gw\text{-}raw}$ occurred.

Denver (1989) also described the major-ion chemistry of ground water considered to be relatively unaffected by human activities (hereafter, referred to as natural ground water) in the surficial aquifer in eastern Sussex County, Delaware. Sodium and bicarbonate were the dominant cation and anion, respectively. In addition, natural ground water contained relatively lesser amounts of other cations—calcium, magnesium, and potassium in that order, and lesser amounts of other anions—chloride, sulfate, and nitrate plus nitrite nitrogen (hereafter, nitrate), in that order, than ground water affected by agricultural and residential (septic-system effluent) activities. For the latter, Denver (1989) noted that concentrations of sodium, calcium, magnesium, and potassium were elevated above those of natural water. Nitrate also was likely to be the dominant anion, sulfates were elevated, and bicarbonate was low, the latter being presumably consumed by acids produced during nitrification of reduced forms of nitrogen—for example, ammonium in fertilizers, manure, or septic effluent.

A comparison of the ionic composition of natural ground water as described by Denver (1989) with ground water at the Pot Nets sites (table 20) indicated that ground water at the Bayside site, and to a lesser extent at the Lakeside site, appeared affected by human activity. Maximum, median, or minimum concentrations (milliequivalents per liter) for sodium, magnesium, chloride, and sulfate were each higher in Bayside ground water than in natural ground water. At the Lakeside site, the major-ion chemistry of ground water appeared to be less affected by human activities than ground water at the Bayside site.

As Bayside, and to a lesser extent Lakeside, ground water appeared to be affected by agricultural and (or) residential development, the ionic chemistry at each site was investigated further to determine if patterns in ionic composition could be related to Hg occurrence. Bayside ground water at most sampled depths (table 21) exhibited a consistent relative abundance among major cations, as follows:

Sodium>Magnesium>Calcium>Potassium

At the Lakeside site, relative abundance of major cations was similar among samples from the three deepest monitoring wells (table 21, Lakeside, wells Ph35-30, -31, and -32), and also similar in order to what Denver (1989) found for natural ground water.

9. Temperature at time of specific conductance measurements is not reported in publication.

Table 19. Ground-water samples with (or without) elevated specific conductance, increased relative abundance of selected cations, elevated nitrate-nitrogen concentrations, detectable volatile organic compounds, and total mercury concentrations collected from production and monitoring wells at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey, monitoring well identifiers in **bold**; >, greater than; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ng/L, nanograms per liter; Mg, magnesium ion; Ca, Calcium ion; VOCs, volatile organic compounds; YES, exceeds threshold value; NO, at or below threshold value; threshold values: for elevated specific conductance from Denver (1989), for Mg and Ca relative order derived from concentrations expressed in milliequivalents per liter, for elevated nitrate plus nitrite-nitrogen from Hamilton and others (1993); shaded data, monitoring wells with total mercury concentrations greater than 100 nanograms per liter]

DGS well identifier	Depth of well from land-surface datum (feet)	Elevated specific conductance (>100 µS/cm at 25 °C)	Order of secondary cationic abundance Mg>Ca or Ca>Mg	Elevated nitrate plus nitrite-nitrogen (>0.40 mg/L)	Number of detectable VOCs excluding chloroform	Number of indicator criteria exceeded	Total mercury concentration (ng/L)
			Bayside				
Pi31-01	66.0	YES	Mg > Ca	NO	3	3	1,650
Pi31-21	26.5	YES	Mg > Ca	NO	0	2	246
Pi31-20	48.0	YES	Mg > Ca	NO	1	3	2
Pi31-19	55.5	YES	Mg > Ca	NO	1	2	383
Pi31-18	62.0	YES	Mg > Ca	NO	4	2	4,640
Pi31-17	65.0	YES	Mg > Ca	NO	2	2	5,470
Pi31-16	80.0	YES	Mg > Ca	YES	1	4	6,380
			Lakeside				
Ph35-25	73.0	NO	Ca > Mg	NO	0	2	1,000
Ph35-34	25.0	NO	Mg > Ca	NO	2	2	1
Ph35-33	47.0	YES	Mg > Ca	NO	0	3	1,220
Ph35-32	60.0	NO	Ca > Mg	NO	0	2	170
Ph35-31	68.0	NO	Mg > Ca	YES	0	2	1
Ph35-30	79.0	YES	Mg > Ca Mg > Ca	YES	0	3	2

Sodium>Calcium>Magnesium>Potassium

For ground water associated with the two remaining Lakeside monitoring wells (Ph35-33 and -34), magnesium exceeded calcium—a pattern similar to the relative abundance of cations in ground water at Pot Nets Bayside. The occurrence of magnesium rather than calcium as the second most abundant cation in all Pot Nets Bayside and selected Lakeside ground-water samples was contrary to the relative order of major ions in natural ground water, and therefore used to indicate anthropogenic contamination (table 19).

Accurate analysis of the relative abundance of anions was not possible because of the potential positive bias in bicarbonate concentrations for Pot Nets ground water that also contained elevated concentrations of DOC (see *Data Quality, Major Ions, …, Bicarbonate*). It should be noted, however, that whereas bicarbonate was found to be the dominant anion in natural water (Denver, 1989 and table 20, this report), and even with the potential positive bias in concentrations, it was not the dominant anion in ground water at the Pot Nets sites (table 20). Either chloride or nitrate, both of which appeared to be additional indicators of ground water affected by human activities, generally dominated the anionic composition of ground water depending on the Pot Nets well selected.

In relation to samples from both Pot Nets sites, there were three discernible patterns in the relative abundance of major ions in relation to elevated concentrations of $HgT_{gw\text{-}raw}$, as follows:

(a) Except for well Ph35-32, all samples with elevated concentrations of $HgT_{gw\text{-}raw}$ had a similar relative

Table 20. Concentrations of major ions (in milliequivalents per liter) for natural or nearly natural ground-water samples and ground-water samples from monitoring wells at Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[Relative percentage for each major cation (anion) is computed as its concentration divided by the sum of the cationic (anionic) concentrations (in milliequivalents per liter), expressed in percent; data for natural or nearly natural ground water from Denver (1989); Max, maximum; Min, minimum]

	Natural or nearly natural ground water [a]			Bayside ground water			Lakeside ground water		
Ionic constituent	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**
Sodium	0.291	0.387	0.191	0.696	0.922	0.583	0.401	0.509	0.366
Calcium	0.125	0.165	0.049	0.170	0.267	0.093	0.162	0.189	0.065
Magnesium	0.049	0.115	0.018	0.270	0.407	0.211	0.106	0.413	0.051
Potassium	0.034	0.046	0.010	0.055	0.064	0.042	0.032	0.059	0.026
Bicarbonate	0.200	0.300	0.120	0.238	0.524	0.082	0.131	0.164	0.131
Chloride	0.164	0.310	0.116	0.570	0.860	0.426	0.296	0.496	0.278
Nitrate plus nitrite nitrogen	0.143	0.200	0.004	0.123	0.495	0.069	0.056	0.385	0.041
Sulfate	0.010	0.042	0.001	0.116	0.300	0.052	0.027	0.277	0.012

[a] (From Denver, 1986)

Table 21. Relative percentages of major ions (in milliequivalents per liter, expressed in percent) for ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey; monitoring-well identifier in **bold** text, with wells for each site listed from shallowest to deepest for depth measured relative to land-surface datum; ng/L, nanograms per liter; relative percentage for each major cation (anion) is computed as its concentration divided by the sum of the cationic (anionic) concentrations (in milliequivalents per liter), expressed in percent (%); bicarbonate is excluded because of possible positive bias in measured concentrations; shaded data reflect monitoring wells with total mercury concentrations in excess of 1,000 nanograms per liter]

DGS well identifier	Well depth (feet)	Total mercury concentration (ng/L)	Sodium (%)	Magnesium (%)	Calcium (%)	Potassium (%)	Chloride (%)	Nitrate (%)	Sulfate (%)
				Bayside					
Pi31-01	66.0	1,650	55.1	26.8	13.7	4.5	68.2	13.7	18.2
Pi31-21	26.5	246	50.2	32.4	14.1	3.3	77.4	9.1	13.5
Pi31-20	48.0	2.37	48.3	33.7	12.9	5.1	53.2	15.8	31.1
Pi31-19	55.5	383	65.5	20.9	8.9	4.8	66.6	16.8	16.7
Pi31-18	62.0	4,640	64.7	17.4	13.5	4.4	80.7	8.5	10.8
Pi31-17	65.0	5,470	65.9	16.7	13.0	4.4	76.6	12.1	11.3
Pi31-16	80.0	6,380	53.5	22.2	20.3	4.0	43.8	50.9	5.3

DGS well identifier	Well depth (feet)	Total mercury concentration (ng/L)	Sodium (%)	Magnesium (%)	Calcium (%)	Potassium (%)	Chloride (%)	Nitrate (%)	Sulfate (%)
				Lakeside					
Ph35-25	73.0	1,000	63.8	12.5	19.1	4.7	58.9	34.8	6.3
Ph35-34	25.0	0.89	38.2	40.3	15.8	5.7	60.9	5.1	34.0
Ph35-33	47.0	1,220	65.4	17.3	10.7	6.6	73.7	13.1	13.2
Ph35-32	60.0	170	69.7	9.6	15.9	4.9	78.8	13.6	7.7
Ph35-31	68.0	0.98	62.3	12.1	21.5	4.1	48.2	49.1	2.7
Ph35-30	79.0	1.65	60.5	13.4	22.4	3.7	42.7	55.5	1.8

order of abundance of major cations:

Sodium>Magnesium>Calcium>Potassium

Well Ph35-32, which had an intermediate $HgT_{gw\text{-}raw}$ concentration, had calcium in greater abundance than magnesium.

(b) Except for well Pi31-16, all samples with elevated concentrations of $HgT_{gw\text{-}raw}$ had chloride as the most abundant anion, which with (a) above indicates most Hg contaminated wells have sodium-chloride type waters; well Pi31-16, which is one of the most contaminated wells at the Bayside site had a sodium-nitrate type water.

(c) Samples with elevated concentrations of $HgT_{gw\text{-}raw}$ also had a relatively low abundance of sulfate (less than 14 percent).

None of the above conditions, however, were unique to ground water with elevated $HgT_{gw\text{-}raw}$ concentrations. Thus, it only could be concluded that in relation to the patterns in ionic composition, Pot Nets ground waters with elevated $HgT_{gw\text{-}raw}$ concentrations also were affected by human activities. The effects on the ionic composition also appeared to be greatest in ground water at the Bayside site (table 20), which also had the highest $HgT_{gw\text{-}raw}$ concentrations throughout the greatest portion of the shallow aquifer (fig. 14).

Volatile Organic Compounds: Trace concentrations of 10 VOC compounds were detected in 1 or more ground-water samples from the 2 production and 11 vertically nested short-screened monitoring wells at the Bayside and Lakeside sites (table 22). Most VOC detections occurred in ground-water samples from the Bayside site, and about half (10 of 19) of the Bayside detections were in the wells with elevated $HgT_{gw\text{-}raw}$ (table 23). Whereas chloroform, trichloroethylene, and tetrachloroethylene were detected previously (for example, see table 9), other VOCs were detected for the first time at both sites. Although none of these VOCs were detected in field blanks (see *Data Quality*), only the VOCs with repeated detections were summarized as indicators of ground water affected by human activities (table 19).

Combined Indicators of Ground-Water Contamination: Andres (2005) indicated that the recharge potential to the surficial aquifer at the Bayside and Lakeside sites was generally fair to good. The Department of Natural Resources and Environmental Control (2002) indicated the surficial aquifer in the Pot Nets areas was vulnerable to contamination. Combining indicators of anthropogenic contamination (table 19) provided a direct means to assess the relative effect that human activities have had on shallow ground-water quality at each site, and provided an additional means to assess indicators of human activity and the occurrence of elevated concentrations of HgT_{gw} at each site.

There was strong evidence that shallow ground water at the Bayside site has been contaminated by the recent human activity related to agricultural and (or) residential land use (table 19). Elevated SC occurred in relation to all sampled depths. Magnesium was elevated in all parts of the aquifer sampled. Nitrate was elevated in the deepest, and sulfate elevated and VOC detections were most frequent in the shallowest parts of the aquifer. None of the above indicators, however, uniquely related to the occurrence of elevated HgT_{gw}. What the indicators provided was about a 30-year history (given the apparent ground-water ages) of the susceptibility of the recharge area for this production well to contamination.

The shallow aquifer at the Pot Nets Lakeside site also appeared contaminated by recent human activities, but there were fewer contaminants in general at all depths than were found at the Bayside site (table 19). Nitrate was apparent at elevated concentrations at selected depths. Magnesium also was elevated in deep ground water.

Table 22. Volatile organic compounds detected in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[Frequency of detection is ratio of number of samples with a detection compared to total number of samples at the site; µg/L, micrograms per liter; **E**, laboratory-estimated concentration]

Site	Compound detected	Frequency of detection	Range of measurable concentrations (µg/L)
Bayside	Chloroform	7/7	0.35 to 3.53
Bayside	Benzene	4/7	**E** 0.01 to **E** 0.02
Bayside	Trichloroethylene	3/7	0.11 to 0.23
Bayside	Diethyl ether	2/7	0.2 to 0.4
Bayside	Tetrachloroethylene	1/7	**E** 0.02
Bayside	Isopropylbenzene	1/7	**E** 0.03
Bayside	4-Isopropyl-1-Methylbenzene	1/7	**E** 0.03
Lakeside	Chloroform	6/6	**E** 0.08 to 0.77
Lakeside	Toluene	1/6	1.01
Lakeside	Ethylbenzene	1/6	**E** 0.03

Table 23. Number of detectable volatile organic compounds and total mercury concentrations in ground-water samples from Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites, Long Neck Peninsula, Sussex County, Delaware, 2004

[DGS, Delaware Geological Survey; **bold** identifiers for monitoring wells; ng/L, nanograms per liter]

DGS well identifier	Number of detectable VOCs	Total mercury (ng/L)
Pi31-01	4	1,650
Pi31-16	2	6,380
Pi31-17	3	5,470
Pi31-18	5	4,640
Pi31-19	2	383
Pi31-21	1	246
Pi31-20	2	2
Ph35-25	1	1,000
Ph35-33	1	1,220
Ph35-32	1	170
Ph35-30	1	2
Ph35-31	1	1
Ph35-34	3	1

Elevated SC only occurred in intermediate parts of the shallow aquifer at this site. The only frequently detected VOC at the Lakeside site was chloroform, which occurred in all ground-water samples but one collected for this study. Elevated HgT_{gw}, concentrations only occurred at intermediate depths, which also had elevated concentrations of nitrate and (or) magnesium.

By way of comparison, the difference in the degree of contamination provided by the indicators for the two Pot Nets sites paralleled the degree to which elevated HgT_{gw} concentrations occurred in the shallow aquifer at each site. The Bayside site had multiple indicators that revealed contamination throughout most of the shallow aquifer. Ground water at this site also had the highest concentrations of HgT_{gw} throughout the greatest range in depths.

Summary and Conclusions

Until recently, mercury concentrations at or above the U.S. Environmental Protection Agency Maximum Contaminant Level of 2,000 nanograms per liter had not occurred in a public production well in Delaware since about the mid-1980s. In 2001, however, concentrations of total mercury that exceeded or approached this Federal level were found in two public production wells in the surficial aquifer in the residential communities of Pot Nets Bayside and Lakeside on the Long Neck Peninsula, Sussex County, Delaware. Also by 2001, studies conducted in similar settings and surficial coastal aquifers in New Jersey had revealed widespread but geographically heterogeneous occurrences of elevated mercury concentrations in hundreds of chiefly private production wells. The above findings combined with a lack of readily available data on mercury concentrations in shallow ground water in the surficial aquifer in Delaware were cause for concern. To address this concern, a cooperative investigation between the U.S. Geological Survey, Delaware Geological Survey, and Delaware Department of Natural Resources and Environmental Control was conducted from October 2003 through January 2005. The purpose of this study was to determine the geographical and vertical (depth) distributions, possible forms of transport, and potential sources of mercury in ground water in the shallow surficial aquifer on the Long Neck Peninsula.

A water-quality survey of the surficial aquifer on the peninsula conducted in 2003 with 22 private and public production wells revealed that shallow ground water (30–120 feet below land surface) throughout most of the peninsula contained less than 10 nanograms per liter of total mercury. Elevated concentrations (100–1,820 nanograms per liter) of mercury were found in five production wells in the communities of Pot Nets Bayside and Lakeside. This survey also revealed that the quality of shallow ground water throughout most of the peninsula appeared affected by human activities related to agricultural and (or) residential land use. Groundwater samples from all production wells contained elevated nitrate-nitrogen concentrations (0.4 milligrams per liter or greater). Most (16 of 22) production-well samples, including those with elevated mercury concentrations, had elevated concentrations of dissolved solids (specific conductance of 100 microsiemens per centimeter or greater). One or more volatile organic compounds also were detected in every production well. Bivariate plots and analyses, however, revealed no direct relation between the concentrations of total mercury and any of the above indicators of water quality or other measured chemical properties or constituents in shallow ground water.

To determine the vertical distribution of mercury in the shallow aquifer, vertical nests of 5–6 short-screen (2–5-foot) monitoring wells were installed at selected depths (between 25–80 feet below land surface) near the production well in each Pot Nets community with the highest concentration of total mercury. Chemical analyses of the soil, fill, and aquifer sediment, collected from boreholes during the installation of monitoring wells in June and July 2005, indicated that mercury was not detectable (less than 20 micrograms per kilogram) in these surficial materials at the residential Lakeside production-well site. Mercury only was found (40 micrograms per kilogram or less) in the soil and fill, but was undetectable in the underlying aquifer sediment, at the forested Bayside production-well site. Measurable mercury also

co-occurred with measurable organic carbon (0.2–1.8 percent by weight) in the surface soil and fill at this site. The low concentrations of mercury in surficial materials at both sites, however, appeared to reflect patterns also observed in coastal aquifers in New Jersey—namely, the accumulation of low levels of mercury through atmospheric deposition, followed by the redistribution of this mercury in relation to the intensity of development (construction) at each site. It also appeared unlikely that the low concentrations of mercury in surficial material were the source of the elevated mercury found in ground water at depth at each site.

Data from ground-water samples collected from the vertically nested monitoring wells in September 2005 indicated that elevated concentrations of total mercury occurred in shallow ground water at both sites, but at different depths. Mercury concentrations were highest in ground water at the Pot Nets Bayside production-well site, ranged from 2–6,400 nanograms per liter, and were 4,640–6,380 nanograms per liter at depths of about 60–80 feet below land surface. At the Pot Nets Lakeside production-well site, the mercury concentrations were between 1–1,220 nanograms per liter and highest (150–1,220 nanograms per liter) at depths of about 40–60 feet below land surface. At each site, the mercury concentration in production-well discharge was intermediate in value to the concentrations found in samples from nearby monitoring wells that were screened at depths just above, at, or below the screened interval of the production well. Thus, the discharge likely reflected the mixing and blending of ground waters with different mercury concentrations, and possibly ground-water chemistry, at different depths.

To determine if the distribution of mercury differed as a function of ground-water chemistry with depth, mercury concentrations were compared to bulk-property and other ground-water characteristics and conditions at different depths. Elevated concentrations of mercury only occurred in ground water that also appeared affected by human activities; but ground water affected by human activities did not always contain elevated concentrations of mercury. Elevated concentrations of dissolved solids (specific conductance) and nitrate-nitrogen, a greater relative abundance of magnesium in relation to calcium, and (or) detectable volatile organic compounds, for example, were found at most, if not all, sampled depths at the Pot Nets Bayside site, and at selected depths, including those that also had elevated mercury concentrations, at the Lakeside site.

Additional evidence that the source(s) of mercury responsible for the contamination of ground water was (were) likely anthropogenic in origin was found in the apparent age of ground water with depth. Derived from concentrations of up to three different chlorofluorocarbon compounds (CFC -11, -12, and -113) and selected dissolved gases at both sites, the apparent age of ground water generally increased with depth at both Pot Nets sites. Ground water at the shallowest depths at each site appeared to have been recharged after about 1985. At depths of about 80 feet, or about 10–15 feet below the bottom of the screened interval of the production well, ground water appeared to have been recharged some time after about 1965. Ground waters that contained elevated concentrations of mercury at both sites likely were recharged during about the same period of time (early 1970s to mid-1980s), and therefore appeared similar in apparent ages (about 20–35 years old as of 2005).

The likely forms in which mercury occurred in the surficial aquifer also were investigated, and results supported the hypothesis that mercury likely was transported in a dissolved or fine colloidal rather than particulate phase. Total mercury concentrations were similar in raw and filtered (0.4- or 0.1-micrometer absolute pore size) samples obtained from the same well. The relative difference in elevated mercury concentrations between duplicate ground-water samples collected from an individual well, but processed as either raw and filtered samples, appeared random in sign, and similar in magnitude (plus or minus 6–7 percent or less) to the relative differences found in mercury concentrations between similar types of duplicate samples collected from the same well. In addition, ground-water samples that contained elevated mercury had no measurable particulates that potentially could have transported mercury. There was no measurable particulate carbon (less than 0.01 milligrams per liter), for example, and turbidities were quite low (less than 1 Nephelometric Turbidity Unit).

Given mercury occurrence appeared to be a transport-related phenomenon in ground water, the possible form(s) of mercury in transport were further investigated, and ultimately centered upon organic complexes. For those ground-water samples having less than 366 nanograms per liter of total mercury, methyl mercury in samples from the peninsula survey and the local vertical distribution study occurred at only low concentrations (0.06 nanograms per liter or less), which corresponded to less than about 1 percent of the total mercury in ground water. A sample matrix interference problem was encountered, however, with samples that contained high concentrations of mercury (1,000 nanograms per liter or greater) and dissolved organic carbon (in excess of 0.7 milligrams per liter). No methyl mercury was recovered from survey samples, or from survey samples with high total mercury concentrations that were spiked in the laboratory with methyl mercury to provide a theoretical concentration of about 1 nanogram per liter.

Dissolved organic carbon was the only chemical parameter that appeared related to elevated concentrations of total mercury in the surficial aquifer. Concentrations of dissolved organic carbon averaged about 2 milligrams per liter in monitoring-well samples with high concentrations of mercury at both Pot Nets sites. This average concentration was at least 2–3 times greater than the average concentration of dissolved organic carbon for monitoring-well samples from either Pot Nets site, or for production-well samples throughout most of the peninsula, that contained background concentrations of mercury (10 nanograms per liter or less).

Fractional analyses of the dissolved organic carbon in ground-water samples from one monitoring well at each Pot Nets site with high concentrations of total mercury indicated that 46–48 percent of this carbon partitioned into the hydro-

phobic acid fraction. This type of carbon fraction has been linked to strong interactions with mercury in other aquatic environments with geochemical conditions similar to those found in the shallow ground water at both Pot Nets sites—oxic waters with circumneutral to moderately acidic pH. Fractionation results also indicated that the amount of hydrophobic carbon could be on the order of 0.3–1.2 milligrams per liter, which equaled or exceeded by several fold the total amount of dissolved organic carbon in ground-water samples with background concentrations of total mercury.

Other evidence that supported the occurrence of a reactive form of dissolved carbon involved in the transport of mercury was the high correlation (r^2=0.90) between dissolved organic carbon and acid-neutralization capacity. Also, elevated ultraviolet absorbance and specific ultraviolet absorbance occurred for most samples with elevated concentrations of dissolved organic carbon and mercury.

Although the actual source(s) of mercury contamination remained unknown, there was considerable evidence that the elevated concentrations of mercury at both Pot Nets production-well sites could be the result of a single source of anthropogenic mercury. High concentrations of mercury in the Pot Nets Lakeside production-well discharge first occurred about 2 months after the Bayside production well was taken off line. Peninsula survey results indicated that elevated concentrations of mercury only occurred in ground-water samples taken in the vicinity of the two Pot Nets production wells with the highest mercury concentrations. Also, little to no measurable mercury was found in soil, fill, or aquifer-sediment samples at either site, and no particulate mercury occurred in ground water, which reduced the likelihood of native mineral sources. There also was no evidence of any regional discharge of deep (old) ground water that possibly contained mercury at either site. Ground-water samples with elevated concentrations of mercury at the Pot Nets Bayside and Lakeside sites appeared young in age (circa 1970–1985), and were associated with elevated concentrations of one or more different indicators of contamination related to recent land use.

Despite the evidence that the elevated concentrations of mercury in ground water possibly resulted from a single relatively recent anthropogenic source, at least several different potential source areas for elevated dissolved organic carbon and possibly mercury were identified in or near the Pot Nets communities. Wetlands were identified between and to the south of both communities, artificial ponds and lakes also occurred near each production-well site, and refilled or partially refilled borrow pits have been documented to the east of the Bayside community, between the two communities, and west of the Lakeside community. In addition, it was noted that development of both communities involved the cutting of trees, and creation of buried stump dumps. Thus, knowledge of the actual form(s) of the organomercuric complex(es), and of local patterns of ground-water flow, would help reduce the number of potential source locations of elevated dissolved organic carbon and possibly mercury in the Pot Nets Bayside and Lakeside communities.

From a broader geographical perspective, the findings from this study were compared and contrasted to previous studies, chiefly in New Jersey, of elevated concentrations of mercury in ground water in similar coastal aquifer settings. This study determined that elevated concentrations of dissolved organic carbon, and, in particular, hydrophobic carbon, could have played a major role in mercury transport in ground water beneath the Pot Nets communities. The role of dissolved carbon in mercury transport has not been fully explored in similar settings and coastal aquifers in New Jersey. Results from this study and the New Jersey studies in were similar in that no direct relations were found between elevated concentrations of mercury in ground water and other measured chemical or physical parameters in aquifer sediment or ground water. Collectively, these studies also found that shallow ground water that contained elevated concentrations of mercury also appeared affected over a broader geographical extent by human activities associated with recent agricultural and residential development. In this study, however, elevated concentrations of mercury in the surficial aquifer appeared to most likely reflect mercury use or misuse on a local scale within these widespread types of development. Also given (a) the limited amount of data available on concentrations of mercury in the shallow surficial aquifer in Delaware, and (b) the limited aerial extent of the Long Neck Peninsula (about 10 square miles), it is not possible to determine whether the occurrence of elevated concentrations of mercury in the surficial aquifer beneath the Pot Nets communities reflects a single isolated incident, or indicates a potentially more geographically widespread but heterogeneous pattern of mercury occurrence in the shallow surficial aquifer in Delaware similar to the situation found to the north in the surficial coastal aquifers in New Jersey.

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Selected References

Aiken, G., Haitzer, M., Ryan, J.N., and Nagy, K., 2003, Interactions between dissolved organic matter and mercury in the Florida everglades: Journal de Physique IV, v. 107, p. 29–32.

Aiken, G.R., McKnight, D.M., Thorn, K.A., and Thurman, E.M., 1992, Isolation of hydrophilic organic acids from water using nonionic macroporous resins: Organic Geochemistry, v. 18, no. 4, p. 567–573.

American Public Health Association, 1981, Part 400, Determination of inorganic nonmetallic constituents: Method 427 C, Methylene Blue Method, *in* Standard methods for the examination of water and wastewater: American Public Health Association (15th ed.), p. 447–449.

Andres, A. Scott, 1987, Geohydrology of the Northern Coastal Area, Delaware: Delaware Geological Survey Hydrologic Map Series No. 5, Sheet 1, Basic geohydrologic data, scale 1:24,000.

Andres, A. Scott, 1991a, Methodology for mapping ground-water recharge areas in Delaware's Coastal Plain: Delaware Geological Survey Report of Investigations No. 49, 28 p.

Andres, A. Scott, 1991b, Results of the coastal Sussex County, Delaware ground-water quality survey: Delaware Geological Survey Open File Report No. 34, 18 p.

Andres, A. Scott, 2004, Ground-water recharge potential mapping in Kent and Sussex Counties, Delaware: Delaware Geological Survey Report of Investigations No. 66, 14 p.

Andres, A. Scott, 2005, Results of hydrogeologic investigations at Well Sites 6 and 10 Pot Nets: Report to Delaware Department of Natural Resources and Environmental Control: Newark, Delaware, University of Delaware, 24 p.

Andres, A. Scott, Howard, C.S., Keyser, T.A., and Wang, L.T., 2002, Ground water recharge potential maps of Kent and Sussex Counties, Delaware: Delaware Geological Survey Digital Product DP02-02, Version 1.5, ESRI E00 format.

Barringer, J.L., and MacLeod, C.L., 2001, Relation of mercury to other chemical constituents in ground water in the Kirkwood-Cohansey aquifer system, New Jersey Coastal Plain, and mechanisms for mobilization of mercury from sediments to ground water: U.S. Geological Survey Water-Resources Investigations Report 00–4230, 154 p.

Barringer, J.L., MacLeod, C.L., and Galagher, R.A., 1997, Mercury in ground water, soils, and sediments of the Kirkwood-Cohansey aquifer system in the New Jersey Coastal Plain: U.S. Geological Survey Open-File Report 95–475, 260 p.

Barringer, J.L., and Szabo, Z., 2001, Distribution of mercury in shallow ground water of the New Jersey Coastal Plain and a possible mechanism of transport *in* Proceedings of U.S. Environmental Protection Agency and U.S. Geological Survey Workshop on Fate, Transport, and Transformation of Mercury in Aquatic and Terrestrial Environments, May 8–10, 2001, West Palm Beach, Florida: U.S. Environmental Protection Agency Report EPA/625/R-02/005, p. 69–70.

Barringer, J.L., Szabo, Z., Kauffman, L.J., Barringer, T.H., Stackelberg, P.E., Ivahnenko, T., Rajagopalan, S., and Krabbenhoft, D.P., 2005, Mercury concentrations in water from an unconfined aquifer system, New Jersey coastal plain: Science of the Total Environment, v. 346, p. 169–183.

Benoit, J.M., Gilmore, C.C., Mason, R.P., and Heyes, A., 1999, Sulfide controls on mercury speciation and bioavailability of mercury: Applied Environmental Microbiology, v. 63, p. 4,267–4,271.

Benoit, J.M., Mason, R.P., Gilmour, C.C, and Aiken, G.R., 2001, Constants for mercury binding by dissolved organic matter isolates from the Florida Everglades: Geochimica et Cosmochimica Acta, v. 65, no. 24, p. 4,445–4,451.

Carmody, R.W., Plummer, L.N., Busenberg, E., and Coplen, T.B., 1998, Methods for collection of dissolved sulfate and sulfide and analysis of their isotopic composition: U.S. Geological Survey Open-File Report 97–234, 91 p.

Casagrande, A., 1948, Classification and identification of soils: Transactions of the American Society of Civil Engineers, v. 113, p. 901–992.

Cushing, E.M., Kantrowitz, I.H., and Taylor, K.R., 1973, Water resources of the Delmarva Peninsula: U.S. Geological Professional Paper 822, 58 p.

Delaware Office of State Planning Coordination, 2002, Land use and cover, Projection UTM, Zone 18 NAD 83, accessed on February 25, 2006 at *http://www.state.de.us/planning/info/lulcdata/2002_lulc.shtml*

Denver, J.M., 1986, Hydrogeology and geochemistry in the unconfined aquifer in west-central and southwestern Delaware: Delaware Geological Survey Report of Investigations No. 41, 100 p.

Denver, J.M., 1989, Effects of agricultural practices and septic system effluent on the quality of water in the unconfined aquifer in parts of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations No. 45, 66 p.

Denver, J.M., Ator, S.W., Debrewer, L.M., Ferrari, M.J., Barbaro, J.R., Hancock, T.C., Brayton, M.J., and Nardi, M.R., 2004, Water quality in the Delmarva Peninsula, Delaware, Maryland, and Virginia, 1999–2001: U.S. Geological Survey Circular 1228, 30 p.

Department of Natural Resources and Environmental Control, Toxic Release Inventory Database, Delaware, 1995–2003, accessed on February 25, 2006 at *http://www2.state.de.us/serc/reports.shtml*

Department of Natural Resources and Environmental Control, 2002, Public water supply source water assessment for Long Neck Water Company, Sussex County, Delaware: Dover, Delaware, Delaware Department of Natural Resources and Environmental Control, Division of Water Resources, Source Water Assessment Program, 38 p.

DeWild, J.F., Olson, M.L., and Olund, S.D., 2002, Determination of methyl mercury by aqueous phase ethylation, followed by gas chromatographic separation with cold vapor atomic fluorescence detection: U.S. Geological Survey Open-File Report 01–445, 14 p.

Dunkle, S.A., Plummer, L.N., Busenberg, E., Phillips, P.J., Denver, J.M., Hamilton, P.A., Michel, R.L., and Coplen, T.B., 1993, Chlorofluorocarbons (CCl_3F and CCl_2F_2) as dating tools and hydrologic tracers in shallow ground water of the Delmarva Peninsula, Atlantic Coastal Plain, United States: Water Resources Research, v. 29, no. 12, p. 3,837–3,860.

Ferrari, M.J., 2002, Occurrence and distribution of selected contaminants in public drinking-water supplies in the surficial aquifer in Delaware: U.S. Geological Survey Open-File Report 01–327, 70 p.

Fitzgerald, W.F., and Lamborg, C.H., 2005, Geochemistry of mercury in the environment, *in* Lollar, B.S., ed., Environmental geochemistry, Volume 9: Treatise on geochemistry, Holland, H.D., and Turekia, K.K. (exec. eds.): Oxford, England, Elsivier-Pergamon, p. 108–140.

Gibs, J., Szabo, Z., Ivahnenko, T., and Wilde, F.D., 2000, Change in field turbidity and trace element concentrations during well purging: Ground Water, v. 38, no. 4, p. 577–588.

Gilmore, C.C., Riedel, G.S., Ederington, M.C., Bell, J.T., Benoit, J.M., Gill, G.A., and Stordal, M.C., 1998, Methylmercury concentrations and production rates across a trophic gradient in the northern Everglades: Biogeochemistry, v. 80, p. 327–345.

Groot, J.G., and Jordan, R.R., 1990, The Pliocene and Cenozoic deposits of Delaware: Palynology, ages, and paleoenvironments: Delaware Geological Survey Report of Investigations No. 58, 41 p.

Haitzer, M., Aiken, G.R., and Ryan, J.N., 2002, Binding of mercury (II) to dissolved organic matter: The role of the mercury-to-DOM concentration ratio: Environmental Science and Technology, v. 36, no. 16, p. 3,564–3,570.

Haitzer, M., Aiken, G.R., and Ryan, J.N., 2003, Binding of mercury (II) to aquatic humic substances: Influence of pH and source of humic substances: Environmental Science and Technology, v. 37, no. 11, p. 2,436–2,441.

Hamilton, P.A., Denver, J.M., Phillips, P.J., and Shedlock, R.J., 1993, Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia—Effects of agricultural activities on, and distribution of, nitrates and other inorganic constituents in the surficial aquifer: U.S. Geological Survey Open-File Report 93–40, 87 p.

Hamilton, P.A., Shedlock, R.J., and Phillips, P.J., 1989, Ground-water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia—Analysis of available water-quality data through 1987: U.S. Geological Survey Open-File Report 89–34, 71 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, p. 105–111.

Hintelmann, H., Hempel, M., and Wilken, R.D., 1995, Observation of unusual organic mercury species in soils and sediments of industrially contaminated sites: Environmental Science and Technology, v. 29, no. 7, p. 1,845–1,850.

Hintelmann, H., Welbourn, P.M., and Evans, R.D., 1997, Measurement of complexation of methyl mercury (II) compounds by freshwater humic substances using equilibrium dialysis: Environmental Science and Technology, v. 31, no. 2, p. 489–495.

Ho, D.T., Sclosser, P., Smethie, W.M., Jr., and Simpson, H.J., 1998, Variability in atmospheric chlorofluorocarbons (CC13F) and (CC12F2) near a large urban area: Implications for groundwater dating: Environmental Science and Technology, v. 32, no. 16, p. 2,377–2,382.

Ivahnenko, T., Szabo, Z., and Gibs, J., 2001, Changes in sample collection and analytical techniques and effects on retrospective comparability of low-level concentrations of trace elements in ground water: Water Resources Research, v. 35, no. 15, p. 3,611–3,624.

Ivahnenko, T., Szabo, Z., and Hall, G.S., 1996, Use of an ultra-clean sampling technique with inductively coupled plasma-mass spectrometry to determine trace-element concentrations in water from the Kirkwood-Cohansey aquifer system, Coastal Plain, New Jersey: U.S. Geological Survey Open-File Report 96–142, 36 p.

Kharaka, Y.K., Law, L.M., Carothers, W.W., and Goerlitz, D.F., 1986, The role of organic species dissolved in formation waters in mineral digenesis, *in* Gautier, E. (ed.), Relationship of organic matter and mineral digenesis: SEPM Special Volume 3, p. 11–122.

Kolka, R.K., Grigal, D.F., Verry, E.S., and Nater, E.A., 1999, Mercury and organic carbon relationships in streams draining forested upland/peatland watersheds: Journal of Environmental Quality, v. 28, no. 4, p. 766–775.

Koterba, M.T., Banks, W.S.L., and Shedlock, R.J., 1993, Pesticides in shallow ground water in the Delmarva Peninsula: Journal of Environmental Quality, v. 22, no. 3, p. 500–518.

Krabbenhoft, D.P., and Babiarz, C.L, 1992, The role of ground water transport in aquatic mercury cycling: Water Resources Research, v. 28, no. 12, p. 3,119–3,128.

Krabbenhoft, D.P., Benoit, J.M., Babiarz, C.L., Hurley, J.P., and Andren, A.W., 1995, Mercury cycling in Allequash Creek: Air, Water, & Soil Pollution, v. 80, p. 425–433.

Lane, S.L., Flanagan, S., and Wilde, F.D., March 2003, Selection of equipment for water sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A2, accessed on February 25, 2006 at *http://pubs.water.usgs.gov/twri9A2/*

Lewis, M.E., and Brigham, M.E., 2004, Processing of water samples: Low-level mercury: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, Sec. 5.6.4B, accessed on February 25, 2006 at *http://water.usgs.gov/owq/FieldManual/chapter5/pdf/5.6.4.B_v1.0.pdf*

Lindsey, W.L., 1979, Chemical equilibria in soils: New York, John Wiley and Sons, 449 p.

Lowry, G.V., Shaw, S., Kim, C.S., Rytuba, J.J., and Brown, G.E., Jr., 2004, Macroscopic and microscopic observations of particle-facilitated mercury transport from New Idria and Sulfur Bank mercury mine tailings: Environmental Science and Technology, v. 38, no. 19, p. 5,101–5,111.

Munsell Color, 1990, Munsell soil color charts: Baltimore, Maryland, Macbeth Division, Kollmorgen Instruments Corporation, 21 p.

Murphy, E., Dooley, J., Windom, H.L., and Smith, R.G., 1994, Mercury species in potable ground water in southern New Jersey: Water, Air & Soil Pollution, v. 78, p. 61–72.

Nater, E.A., and Grigal, D.F., 1992, Regional trends in mercury distribution across the Great Lakes states, north central USA: Nature, v. 358, p. 139–141.

Olson, M.L., and DeWild, J.F., 1999, Low-level collection techniques and species-specific analytical methods for mercury in water, sediment, and biota: U.S. Geological Survey Water-Resources Investigations Report 99–4018–B, 11 p.

Paquette, K.E., and Helz, G.R., 1997, Inorganic speciation of mercury in sulfidic waters: The importance of zero-valent sulfur: Environmental Science and Technology, v. 31 p. 2,148–2,153.

Plummer, L.N., Busenberg, E., Drenkard, S., Schlosser, P., Ekwurzel, B., Weppermig, R., McConnell, J.B., and Michel, R.L., 1998, Flow of river water into a karstic limestone aquifer: 2. Dating the young fraction of groundwater mixtures in the upper Floridian aquifer near Valdosta, Georgia: Applied Geochemistry, vol. 13, no. 8, p. 1,017–1,043.

Qian, J., Skylberg, U., Frech, W., Bleam, W.F., Bloom, P.R, and Petit, P–E., 2002, Bonding of methyl mercury to reduced organic sulfur groups, in soil and stream matter as determined by X-ray absorption spectroscopy and binding affinity studies: Geochimica et Cosmochimica Acta, v. 66, p. 3,873–3,885.

Ramsey, K.W., 1993, Geology of the Milford and Mispillion River Quadrangles: Delaware Geological Survey Map Series No. 8, scale 1:24,000.

Ramsey, K.W., 1997, Geology of the Milford and Mispillion River Quadrangles: Delaware Geological Survey Report of Investigations No. 55, 40 p.

Ravichandran, M., Aiken, G.R., Reddy, M.M., and Ryan, J.N., 1998, Enhanced dissolution of Cinnabar (Hydrogen Sulfide) by dissolved organic matter isolated from the Florida Everglades: Environmental Science and Technology, v. 32, no. 21, p. 3,305–3,311.

Ravichandran, M., Aiken, G.R., Ryan, J.N., and Reddy, M.M., 1999, Inhibition of precipitation and aggregation of Metacinnabar (Mercuric Sulfide) by dissolved organic matter isolated from the Florida Everglades: Environmental Science and Technology, v. 33, no. 9, p. 1,418–1,423.

Reddy, M.M., and Aiken, G.R., 2001, Fulvic acid—sulfide ion competition for mercury ion binding in the Florida Everglades: Air, Water & Soil Pollution, v. 132, p. 89–104.

Reilly, T.E., Plummer, L.N., Phillips, P.J., and Busenberg, E., 1994, The use of simulation and multiple environmental tracers to quantify ground-water flow in a shallow aquifer: Water Resources Research, v. 30, no. 2, p. 421–433.

Rounds, S.A., and Wilde, F.D., eds., September 2001, Alkalinity and acid-neutralizing capacity (2d ed.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, sec. 6.6, accessed on December 20, 2005 at *http://pubs.water.usgs.gov/twri9A6*

Shedlock, R.J., Denver, J.M., Hayes, M.A., Hamilton, P.A., Koterba, M.T., Bachman, L.J., Phillips, P.J., and Banks, W.S.L., 1999, Water-quality assessment of the Delmarva Peninsula, Delaware, Maryland, and Virginia: Results of Investigations, 1987–91: U.S. Geological Survey Water-Supply Paper 2355–A, 41 p.

Slowey, A.J., Rytuba, J.J., and Brown, G.E., Jr., 2005, Speciation of mercury and mode of transport from placer gold mine tailings: Environmental Science and Technology, v. 39, no. 6, p. 1,547–1,554.

Stackelberg, P.E., Hopple, J.A., and Kauffman, L.J., 1997, Occurrence of nitrates, pesticides, and volatile organic compounds in the Kirkwood-Cohansey aquifer system, southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 97–4241, 8 p.

Stackelberg, P.E., Kaufman, L.J., Baehr, A.L., and Ayers, M.A., 2000, Comparison of nitrate, pesticides, and

volatile organic compounds in samples from monitoring and public-supply wells, Kirkwood-Cohansey aquifer system, southern New Jersey: U.S. Geological Survey Water-Resources Investigations Report 00-4123, 58 p.

Szabo, Z., Rice, D.E., Plummer, L.N., Busenberg, E., Drenkard, S., and Sclosser, P., 1996, Age dating of shallow groundwater with chlorofluorocarbons, tritium/helium, and flow path analysis, southern New Jersey Coastal Plain: Water Resources Research, v. 32, no. 4, p. 1,023–1,038.

Talley, J.H., 1987, Geohydrology of the Southern Coastal Area, Delaware: Delaware Geological Survey Hydrologic Map Series No. 7, Sheet 1, Basic geohydrologic data, scale 1:24,000.

Talley, J.H., and Andres, A.S., 1987, Basic hydrologic data for coastal Sussex County, Delaware: Delaware Geological Survey Special Publication No. 14, 101 p.

U.S. Census Bureau, 2000, Population Finder, accessed on December 20, 2005, at *http:// factfinder.census.gov/home/saff/main.html?_lang=en*

U.S. Environmental Protection Agency, 2002, Current drinking water standards, list of contaminants and MCLs, CPA 816-F-02-013, accessed on December 21, 2005 at *http://www.epa.gov/safewater/mcl.html#mcls*

U.S. Geological Survey, 1954, Topographic Map, 15-Minute Series, Rehoboth Beach, 1 p.

Waples, J.S., Nagy, K.L., Aiken, G.R., and Ryan, J.N., 2005, Dissolution of cinnabar (HgS) in presence of natural organic matter: Geochimica et Cosmochimica Acta, v. 69, no. 6, p. 1,575–1,588.

Weishaar, J.L., Aiken, G.R., Bergamashi, B.A., Fram, M.S., Fujii, R., and Mopper, K., 2003, Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic matter: Journal of Environmental Science, v. 37, no. 2, p. 4,702–4,708.

Wheeler, J.C., 2003, Freshwater use in Delaware, 2000: U.S. Geological Survey Fact Sheet FS 111–03, 2 p.

Wiener, J.G., Krabbenhoft, D.P., Heinz, G.M., and Scheuhammer, A.M., 2002, Ecotoxicology of Mercury, Chapter 16, *in* Hoffman, D.J., Rattner, B.A., Burton, Jr., G.A., and Cairns, Jr., J., eds., Handbook of ecotoxicology, (2d ed.): Boca Raton, Florida, CRC Press, p. 407–461.

Wilde, F.D., and Radtke, D.B., eds., 2003, Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, accessed on February 25, 2006 at *http://pubs.water.usgs.gov/twri9A6/*

Appendixes A Through D Follow

Appendix A

Data on Well Characteristics and Water Quality, and Analytical Methods Used for Water Samples for the Long Neck Peninsula Mercury Study

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Table A1. *Long Neck Peninsula production and formerly installed monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003-04 – Identification, location, and construction characteristics*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; DNREC, Delaware Department of Natural Resources and Environmental Control; S, steel; PVC, polyvinyl chloride; U, unknown; all construction data obtained from DNREC drilling records]

DGS local well number	USGS site identification number	DNREC permit number	Latitude (degrees, minutes, seconds)[b]	Longitude (degrees, minutes, seconds)[b]	Date well constructed	Casing and screen material	Depth of well (feet)	Diameter of well (inches)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Elevation of land-surface datum
Production Wells											
Ph24-01	383811075113001	99346	** ** **	** ** **	1994	PVC	115	12	75	115	U
Ph24-02	383840075112001	110577	** ** **	** ** **	1997	PVC	128	10	98	128	U
Ph25-17[a]	383803075105301	180015	** ** **	** ** **	2001	PVC	68	4	58	68	U
Ph34-18	383706075115901	110928	** ** **	** ** **	1997	PVC	80	4	70	80	U
Ph34-22	383744075110701	56455	** ** **	** ** **	1984	PVC	79	4	73	79	U
Ph34-23[a]	383738075112301	175698	** ** **	** ** **	2000	PVC	70	2	60	70	U
Ph34-24	383738075112201	177133	** ** **	** ** **	2001	PVC	70	4	60	70	U
Ph35-24	383731075102001	63103	** ** **	** ** **	1986	PVC	71	8	57	71	13.0
Ph35-25	383729075101601	63104	** ** **	** ** **	1986	PVC	73	8	58	73	10.9
Ph35-28	383752075100601	10711	** ** **	** ** **	U	U	U	U	U	U	U
Ph44-07[a]	383657075110201	107122	** ** **	** ** **	1996	PVC	65	4	55	65	U
Pi31-01	383739075093101	49714	** ** **	** ** **	1982	PVC	66	8	54	66	14.3
Pi31-02	383736075092801	49713	** ** **	** ** **	1982	PVC	70	8	55	70	17.9
Pi31-05	383725075091701	63102	** ** **	** ** **	1986	PVC	85	8	69	85	18.4
Pi31-11	383745075093301	89527	** ** **	** ** **	1993	PVC	113	8	93	113	15.8
Pi31-12	383748075093001	89528	** ** **	** ** **	1992	PVC	110	8	84	110	15.5
Pi32-14	383720075080301	56056	** ** **	** ** **	1984	PVC	53	4	48	53	U
Pi32-15	383713075085501	10653	** ** **	** ** **	1972	S	90	6	U	U	9.7
Pi34-09[a]	383733075061101	38713	** ** **	** ** **	1977	PVC	35	4	30	35	U
Pi41-02	383649075090701	10651	** ** **	** ** **	1962	S	85	6	U	U	9.6
Pi41-03	383653075090601	10652	** ** **	** ** **	1965	S	89	6	U	U	9.4
Pi43-03	383648075075601	107980	** ** **	** ** **	1996	PVC	48	2	42	48	U
Monitoring Well											
Pi31-13	383740075093303	190202	** ** **	** ** **	2002	PVC	72	4	54	72	14.35

[a] At least 2 weeks before sampling, a cleaned and conditioned brass hose bib was installed inline between the well head and all storage tanks and secondary distribution lines.

[b] Latitude and longitude data can be requested from the Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Table A2. *Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production and recently (2004) installed monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Identification, location, and construction characteristics*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; DNREC, Delaware Department of Natural Resources and Environmental Control; PVC, polyvinyl chloride. Except for elevation datum provided by the Long Neck Water Company, Sussex County, Delaware, all construction data are from well completion reports. Depths accurate to nearest 0.5 feet.]

DGS local well number	USGS site identification number	DNREC permit number	Latitude (degrees, minutes, seconds)[b]	Longitude (degrees, minutes, seconds)[b]	Date well constructed	Casing and screen material	Depth of well (feet)	Diameter of well (inches)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Elevation of land-surface datum (feet)
					Pot Nets Bayside						
Pi31-01	383739075093101	49714	** ** **	** ** **	11/2/1982	PVC	66.0	8	54.0	66.0	13.86
Pi31-15	383739075093102	201114	** ** **	** ** **	6/2/2004	PVC	80.0	2	10.0	80.0	13.90
Pi31-16	383739075093103	201115	** ** **	** ** **	6/8/2004	PVC	80.0	2	74.5	79.5	13.96
Pi31-17	383739075093104	201469	** ** **	** ** **	6/10/2004	PVC	65.0	2	61.0	65.0	13.66
Pi31-18	383739075093105	201470	** ** **	** ** **	6/10/2004	PVC	62.0	2	60.0	62.0	13.77
Pi31-19	383739075093106	201471	** ** **	** ** **	6/9/2004	PVC	55.5	2	50.0	55.0	13.63
Pi31-20	383739075093107	201472	** ** **	** ** **	6/9/2004	PVC	48.0	2	43.0	48.0	13.71
Pi31-21	383739075093108	201473	** ** **	** ** **	6/9/2004	PVC	26.5	2	21.0	26.0	13.77
					Pot Nets Lakeside						
Ph35-25	383729075101601	63104	** ** **	** ** **	4/7/1986	PVC	73.0	8	58.0	73.0	10.30
Ph35-29	383729075101602	201113	** ** **	** ** **	6/4/2004	PVC	78.5	2	8.0	78.0	10.99
Ph35-30	383729075101603	201116	** ** **	** ** **	6/14/2004	PVC	79.0	2	73.5	78.5	11.12
Ph35-31	383729075101604	201492	** ** **	** ** **	6/14/2004	PVC	68.0	2	66.0	68.0	10.94
Ph35-32	383729075101605	201493	** ** **	** ** **	6/15/2004	PVC	60.0	2	56.0	60.0	10.88
Ph35-33	383729075101606	201494	** ** **	** ** **	6/15/2004	PVC	47.0	2	42.5	46.5	10.73
Ph35-34	383729075101607	201495	** ** **	** ** **	6/15/2004	PVC	25.0	2	20.5	24.5	10.72
					Field Blank						
Ph35-25	383729075101601	63104	** ** **	** ** **	4/7/1986	PVC	73.0	8	58.0	73.0	10.30

[b] Latitude and longitude data can be requested from the Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Table A3. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Bulk properties and field parameters*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; mV, millivolts; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no data; E, estimated value]

DGS local well number	USGS site identification number	Sample date	Sample time	Oxidation-reduction potential (mV)[a]	Turbidity (NTU)	Dissolved oxygen (mg/L)	pH, field standard units
Ph24-01	383811075113001	11/25/2003	1115	274	0.1	4.4	5.9
Ph24-02	383840075112001	12/2/2003	1330	630	2.6	5.7	5.8
Ph25-17	383803075105301	12/11/2003	0945	279	0.1	6.1	5.4
Ph34-18	383706075115901	12/10/2003	0930	337	0.4	7.8	5.1
Ph34-22	383744075110701	12/4/2003	1000	279	0.2	6.0	5.7
Ph34-23	383738075112301	12/15/2003	1500	282	0.2	7.8	5.3
Ph34-24	383738075112201	12/1/2003	1330	258	0.2	2.9	5.5
Ph35-24	383731075102001	12/16/2003	1330	230	0.3	5.3	5.5
Ph35-25	383729075101601	12/17/2003	1445	198	0.2	4.1	5.7
Ph35-28	383752075100601	12/16/2003	0900	--	0.2	6.4	5.5
Ph44-07	383657075110201	12/9/2003	0915	300	0.3	8.5	5.3
Pi31-01	383739075093101	12/10/2003	1230	280	0.2	3.5	5.2
Pi31-02	383736075092801	12/9/2003	1315	256	0.2	8.0	5.4
Pi31-05	383725075091701	12/4/2003	1330	248	0.1	7.6	5.4
Pi31-11	383745075093301	12/11/2003	1315	254	0.2	3.8	5.6
Pi31-12	383748075093001	12/17/2003	1145	221	0.1	6.2	5.5
Pi32-14	383720075080301	12/8/2003	1530	267	0.2	6.6	5.6
Pi32-15	383713075085501	11/26/2003	1015	161	0.5	7.6	5.6
Pi34-09	383733075061101	12/3/2003	0945	316	0.2	4.0	5.2
Pi41-02	383649075090701	12/15/2003	1115	202	0.3	5.9	5.8
Pi41-03	383653075090601	11/26/2003	1430	--	0.7	4.0	5.7
Pi43-03	383648075075601	12/3/2003	1415	213	0.2	5.1	5.7

[a] Relative to calomel electrode.

pH, laboratory standard units	Specific conductance, field (µS/cm)	Specific conductance, laboratory (µS/cm)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	DGS local well number
6.6	98	94	14.7	9.0	E 11	Ph24-01
6.1	136	140	14.5	4.6	E 6	Ph24-02
6.0	113	119	13.3	6.9	9	Ph25-17
5.7	109	116	13.7	1.8	E 3	Ph34-18
5.8	84	87	14.1	10.8	E 13	Ph34-22
5.7	115	121	13.7	4.5	E 6	Ph34-23
6.2	145	157	14.4	12.4	E 16	Ph34-24
6.0	108	119	14.7	7.3	E 9	Ph35-24
6.1	74	77	14.7	8.0[b]	E 10[b]	Ph35-25
5.8	141	149	14.6	6.4	E 8	Ph35-28
E 6.8	241	275	13.3	3.2	E 4	Ph44-07
6.1	132	142	14.0	10.3[b]	E 13[b]	Pi31-01
5.9	134	144	13.7	4.0	5	Pi31-02
5.8	102	107	14.3	5.1	6	Pi31-05
6.0	88	93	14.0	6.7	E 9	Pi31-11
5.9	102	107	14.4	6.8	E 8	Pi31-12
6.0	256	255	15.4	17.6	E 20	Pi32-14
6.6	117	123	14.6	6.4	E 8	Pi32-15
6.2	107	111	14.0	1.5	E 2	Pi34-09
6.0	73	75	13.9	6.9	E 9	Pi41-02
6.7	69	70	14.1	7.2	E 9	Pi41-03
6.2	262	281	13.8	11.6	E 14	Pi43-03

[b] Dissolved organic carbon possibly contributes to Alkalinity and positive bias in Bicarbonate.

Table A4. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Major ions*

[DGS, Delaware Geological Survey; mg/L, milligrams per liter; <, less than]

DGS local well number	Sample date	Sample time	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as SiO_2 (mg/L)	Sulfate, as SO_4^{2-} (mg/L)	Dissolved residue (mg/L)
Ph24-01	11/25/2003	1115	5.69	1.62	1.25	9.30	0.04	10.8	<0.2	23.1	7.5	73
Ph24-02	12/2/2003	1330	8.88	2.98	1.58	9.38	<0.02	12.1	<0.2	19.4	16.1	98
Ph25-17	12/11/2003	0945	3.79	2.26	1.79	12.8	0.05	20.6	<0.2	16.7	6.6	73
Ph34-18	12/10/2003	0930	6.28	2.86	3.27	5.63	0.04	14.1	<0.2	12.2	0.3	74
Ph34-22	12/4/2003	1000	3.07	1.08	1.36	11.3	0.06	11.7	<0.2	21.3	2.1	68
Ph34-23	12/15/2003	1500	5.08	2.63	2.04	10.7	0.06	13.5	<0.2	18.5	0.6	86
Ph34-24	12/1/2003	1330	5.64	2.50	2.30	17.6	0.07	19.5	<0.2	17.2	2.6	104
Ph35-24	12/16/2003	1330	4.01	1.45	1.54	13.5	0.07	12.6	<0.2	19.8	1.5	76
Ph35-25	12/17/2003	1445	2.31	0.81	1.18	10.0	0.13	9.83	<0.2	18.8	1.6	65
Ph35-28	12/16/2003	0900	7.68	3.27	2.04	12.0	0.04	16.9	<0.2	20.2	13.1	97
Ph44-07	12/9/2003	0915	3.65	3.67	2.89	33.2	0.06	66.1	<0.2	11.6	0.8	131
Pi31-01	12/10/2003	1230	2.92	3.46	2.14	15.2	0.31	21.0	<0.2	16.0	8.7	81
Pi31-02	12/9/2003	1315	4.77	4.01	2.12	11.8	0.06	16.5	<0.2	17.5	3.2	96
Pi31-05	12/4/2003	1330	2.37	2.61	2.11	10.9	0.05	15.3	<0.2	17.0	4.8	66
Pi31-11	12/11/2003	1315	3.11	1.10	1.46	11.1	0.05	12.7	<0.2	19.9	2.4	77
Pi31-12	12/17/2003	1145	4.97	1.73	1.76	9.83	0.05	14.1	<0.2	19.8	4.0	76
Pi32-14	12/8/2003	1530	10.7	8.31	2.55	23.1	0.10	36.5	<0.2	21.2	18.6	169
Pi32-15	11/26/2003	1015	4.87	3.19	1.93	10.6	0.05	13.0	<0.2	18.6	5.7	80
Pi34-09	12/3/2003	0945	2.36	2.16	4.01	10.8	0.07	14.9	<0.2	8.50	10.6	70
Pi41-02	12/15/2003	1115	1.68	0.70	1.24	10.4	0.05	10.1	<0.2	20.3	1.7	62
Pi41-03	11/26/2003	1430	2.18	0.62	1.35	9.52	0.04	9.77	<0.2	23.1	3.0	56
Pi43-03	12/3/2003	1415	13.4	3.91	16.3	19.5	0.16	49.1	<0.2	14.2	15.7	159

Table A5. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Nutrients*

[DGS, Delaware Geological Survey; mg/L, milligrams per liter; <, less than; E, estimated value]

DGS local well number	Sample date	Sample time	Nitrogen, total particulate (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Carbon, total particulate (mg/L)	Carbon, inorganic, particulate (mg/L)	Carbon, organic particulate (mg/L)	Carbon, organic dissolved (mg/L)
Ph24-01	11/25/2003	1115	<0.02	<0.008	1.89	<0.1	<0.1	<0.1	E 0.3
Ph24-02	12/2/2003	1330	<0.02	<0.008	4.83	<0.1	<0.1	<0.1	E 0.3
Ph25-17	12/11/2003	0945	<0.02	<0.008	0.73	<0.1	<0.1	<0.1	0.4
Ph34-18	12/10/2003	0930	<0.02	<0.008	5.74	<0.1	<0.1	<0.1	E 0.3
Ph34-22	12/4/2003	1000	<0.02	<0.008	1.32	<0.1	<0.1	<0.1	E 0.3
Ph34-23	12/15/2003	1500	<0.02	<0.008	12.3[a]	<0.1	<0.1	<0.1	E 0.3
Ph34-24	12/1/2003	1330	<0.02	<0.008	5.32	<0.1	<0.1	<0.1	0.4
Ph35-24	12/16/2003	1330	<0.02	<0.008	5.25	<0.1	<0.1	<0.1	E 0.3
Ph35-25	12/17/2003	1445	<0.02	<0.008	2.07	<0.1	<0.1	<0.1	E 0.3
Ph35-28	12/16/2003	0900	<0.02	<0.008	4.13	<0.1	<0.1	<0.1	0.4
Ph44-07	12/9/2003	0915	<0.02	<0.008	0.49	<0.1	<0.1	<0.1	E 0.3
Pi31-01	12/10/2003	1230	<0.02	<0.008	1.52	<0.1	<0.1	<0.1	E 1.2
Pi31-02	12/9/2003	1315	<0.02	<0.008	6.55	<0.1	<0.1	<0.1	0.4
Pi31-05	12/4/2003	1330	<0.02	<0.008	2.58	<0.1	<0.1	<0.1	0.4
Pi31-11	12/11/2003	1315	<0.02	<0.008	2.14	<0.1	<0.1	<0.1	E 0.3
Pi31-12	12/17/2003	1145	<0.02	<0.008	3.07	<0.1	<0.1	<0.1	E 0.3
Pi32-14	12/8/2003	1530	<0.02	<0.008	7.45	<0.1	<0.1	<0.1	0.4
Pi32-15	11/26/2003	1015	<0.02	<0.008	4.75	<0.1	<0.1	<0.1	E 0.3
Pi34-09	12/3/2003	0945	<0.02	<0.008	2.52	<0.1	<0.1	<0.1	0.3
Pi41-02	12/15/2003	1115	<0.02	<0.008	1.90	<0.1	<0.1	<0.1	<0.3
Pi41-03	11/26/2003	1430	<0.02	<0.008	0.91	<0.1	<0.1	<0.1	<0.3
Pi43-03	12/3/2003	1415	<0.02	E 0.005	3.68	<0.1	<0.1	<0.1	0.4

[a] Increased uncertainty in value due to sample dilution required for analysis.

Table A6. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Mercury and other trace elements*

[DGS, Delaware Geological Survey; ng/L, nanograms per liter; µg/L, micrograms per liter; <, less than; --, no data; E, estimated value; M, presence of material verified but not quantified. In some cases, a filtered constituent could be higher in value than its unfiltered counterpart, which reflects differences in the reporting accuracy of the methods used. Filtered mercury samples from a 0.4-micrometer absolute pore size filter]

DGS local well number	Sample date	Sample time	Total mercury, unfiltered (ng/L)	Total mercury, filtered (ng/L)	Methyl-mercury, filtered (ng/L)	Arsenic (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)
Ph24-01	11/25/2003	1115	0.18	0.19	<0.04	<2	51	11	0.05
Ph24-02	12/2/2003	1330	13.9[a]	16.1[a]	--	<2	53	8	0.05
Ph25-17	12/11/2003	0945	0.14	0.18	--	<2	68	11	E 0.03
Ph34-18	12/10/2003	0930	0.64	0.74	--	<2	182	9	0.12
Ph34-22	12/4/2003	1000	0.11	0.24	--	<2	48	10	0.04
Ph34-23	12/15/2003	1500	0.11	0.09	<0.04	<2	59	8	0.05
Ph34-24	12/1/2003	1330	0.16	1.01	<0.04	<2	98	9	0.04
Ph35-24	12/16/2003	1330	104	95.7	<0.04	<2	68	8	E 0.03
Ph35-25	12/17/2003	1445	524	579	<0.04[b]	<2	35	E 8	E 0.02
Ph35-28	12/16/2003	0900	0.57	0.58	<0.04	<2	86	9	0.07
Ph44-07	12/9/2003	0915	0.63	0.65	--	<2	299	14	0.11
Pi31-01	12/10/2003	1230	1,820	1,790	<0.04[b]	<2	101	11	0.07
Pi31-02	12/9/2003	1315	230	222	<0.04	<2	75	11	0.08
Pi31-05	12/4/2003	1330	4.30	2.89	--	<2	71	13	0.05
Pi31-11	12/11/2003	1315	276	273	--	<2	31	9	E 0.03
Pi31-12	12/17/2003	1145	---	1.49	<0.04	<2	40	10	0.04
Pi32-14	12/8/2003	1530	20.6[a]	19.7[a]	<0.04	<2	131	16	0.16
Pi32-15	11/26/2003	1015	2.89	2.85	<0.04	<2	54	13	0.05
Pi34-09	12/3/2003	0945	0.58	0.38	<0.04	<2	120	19	E 0.03
Pi41-02	12/15/2003	1115	0.30	0.17	<0.04	<2	31	9	E 0.02
Pi41-03	11/26/2003	1430	0.14	0.17	--	<2	24	12	<0.04
Pi43-03	12/3/2003	1415	2.78	2.42	<0.04	<2	190	30	0.12

[a] Sampling protocols violated; values possibly positively biased--see text for further discussion.

[b] Values uncertain due to sample matrix interference, possibly elevated dissolved organic carbon.

Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Zinc (µg/L)	DGS local well number
0.9	5.1	E 4	3.45	.8	<0.4	1.06	0.5	4	Ph24-01
8.1	21.3	E 3	6.71	.9	<0.4	4.38	0.7	33	Ph24-02
E 0.7	2.0	<6	0.76	2.4	<0.4	0.33	0.7	3	Ph25-17
<0.8	4.3	<6	1.54	6.9	<0.4	1.60	<0.4	12	Ph34-18
E 0.7	7.3	<6	1.15	.9	<0.4	0.45	E 0.2	3	Ph34-22
<0.8	1.6	<6	0.09	2.8	<0.4	0.23	<0.4	M	Ph34-23
E 0.7	1.8	<6	0.68	1.2	<0.4	0.70	E 0.2	14	Ph34-24
<0.8	2.6	7	1.55	3.0	<0.4	0.47	<0.4	6	Ph35-24
E 0.5	2.2	E 5	0.43	9.4	<0.4	0.31	<0.4	4	Ph35-25
0.9	1.6	11	0.42	3.5	<0.4	1.25	0.8	8	Ph35-28
<0.8	3.0	<6	0.30	11.6	<0.4	1.09	E 0.3	16	Ph44-07
<0.8	3.7	10	0.99	51.8	<0.4	0.65	0.6	14	Pi31-01
0.8	1.8	E 5	4.77	6.1	<0.4	0.88	0.5	36	Pi31-02
E 0.7	7.4	60	4.92	5.9	<0.4	1.30	0.7	313	Pi31-05
E 0.6	1.7	<6	0.45	E 0.7	<0.4	0.68	<0.4	4	Pi31-11
<0.8	2.9	E 5	0.96	1.9	<0.4	1.20	0.5	5	Pi31-12
3.9	2.2	<6	1.27	22.3	<0.4	1.34	0.7	9	Pi32-14
1.5	3.1	14	0.26	3.9	<0.4	0.75	1.0	19	Pi32-15
<0.8	1.3	<6	0.51	9.0	<0.4	0.32	E 0.2	5	Pi34-09
E 0.7	201	34	0.64	1.2	<0.4	0.45	<0.4	17	Pi41-02
E 0.8	2.1	44	1.36	1.4	<0.4	0.50	E 0.3	4	Pi41-03
<0.8	47.9	197	0.50	7.1	<0.4	1.21	1.1	120	Pi43-03

Table A7. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds*

[DGS, Delaware Geological Survey; µg/L, micrograms per liter; <, less than; bold value denotes detection or measurable concentration; E, estimated value. Concentrations are not corrected for surrogate recoveries.]

DGS local well number	Sample date	Sample time	1,1,1,2-Tetrachloroethane (µg/L)	1,1,1-Trichloroethane (µg/L)	1,1,2,2-Tetrachloroethane (µg/L)	1,1,2-Trichloroethane (µg/L)
Ph24-01	11/25/2003	1115	<0.03	<0.03	<0.16	<0.06
Ph24-02	12/2/2003	1330	<0.03	<0.03	<0.16	<0.06
Ph25-17	12/11/2003	0945	<0.03	<0.03	<0.16	<0.06
Ph34-18	12/10/2003	0930	<0.03	<0.03	<0.16	<0.06
Ph34-22	12/4/2003	1000	<0.03	<0.03	<0.16	<0.06
Ph34-23	12/15/2003	1500	<0.03	<0.03	<0.16	<0.06
Ph34-24	12/1/2003	1330	<0.03	**E 0.08**	<0.16	<0.06
Ph35-24	12/16/2003	1330	<0.03	<0.03	<0.16	<0.06
Ph35-25	12/17/2003	1445	<0.03	<0.03	<0.16	<0.06
Ph35-28	12/16/2003	0900	<0.03	**E 0.04**	<0.16	<0.06
Ph44-07	12/9/2003	0915	<0.03	<0.03	<0.16	<0.06
Pi31-01	12/10/2003	1230	<0.03	**E 0.01**	<0.16	<0.06
Pi31-02	12/9/2003	1315	<0.03	<0.03	<0.16	<0.06
Pi31-05	12/4/2003	1330	<0.03	<0.03	<0.16	<0.06
Pi31-11	12/11/2003	1315	<0.03	**E 0.02**	<0.16	<0.06
Pi31-12	12/17/2003	1145	<0.03	<0.03	<0.16	<0.06
Pi32-14	12/8/2003	1530	<0.03	**E 0.01**	<0.16	<0.06
Pi32-15	11/26/2003	1015	<0.03	**E 0.05**	<0.16	<0.06
Pi34-09	12/3/2003	0945	<0.03	<0.03	<0.16	<0.06
Pi41-02	12/15/2003	1115	<0.03	<0.03	<0.16	<0.06
Pi41-03	11/26/2003	1430	<0.03	<0.03	<0.16	<0.06
Pi43-03	12/3/2003	1415	<0.03	<0.03	<0.16	<0.06

1,1-Dichloroethane (µg/L)	1,1-Dichloroethylene (µg/L)	1,1-Dichloropropene (µg/L)	1,2,3,4-Tetramethylbenzene (µg/L)	1,2,3,5-Tetramethylbenzene (µg/L)	1,2,3-Trichlorobenzene (µg/L)	DGS local well number
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph24-01
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph24-02
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph25-17
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph34-18
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph34-22
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph34-23
E 0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph34-24
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph35-24
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph35-25
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph35-28
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Ph44-07
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi31-01
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi31-02
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi31-05
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi31-11
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi31-12
E 0.06	<0.02	<0.03	<0.1	<0.1	<0.3	Pi32-14
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi32-15
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi34-09
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi41-02
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi41-03
<0.04	<0.02	<0.03	<0.1	<0.1	<0.3	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	1,2,3-Trichloropropane (µg/L)	1,2,3-Trimethylbenzene (µg/L)	1,2,4-Trichlorobenzene (µg/L)	1,2,4-Trimethylbenzene (µg/L)	1,2-Dibromo-3-chloropropane (µg/L)
Ph24-01	11/25/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph24-02	12/2/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph25-17	12/11/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph34-18	12/10/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph34-22	12/4/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph34-23	12/15/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph34-24	12/1/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph35-24	12/16/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph35-25	12/17/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph35-28	12/16/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Ph44-07	12/9/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi31-01	12/10/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi31-02	12/9/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi31-05	12/4/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi31-11	12/11/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi31-12	12/17/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi32-14	12/8/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi32-15	11/26/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi34-09	12/3/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi41-02	12/15/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi41-03	11/26/2003	<0.18	<0.1	<0.1	<0.06	<0.5
Pi43-03	12/3/2003	<0.18	<0.1	<0.1	<0.06	<0.5

1,2-Dibromoethane (µg/L)	1,2-Dichlorobenzene (µg/L)	1,2-Dichloroethane (µg/L)	1,2-Dichloroethane-d4, recovery surrogate (percent)	1,2-Dichloropropane (µg/L)	DGS local well number
<0.04	<0.05	<0.1	135	<0.03	Ph24-01
<0.04	<0.05	<0.1	141	<0.03	Ph24-02
<0.04	<0.05	<0.1	137	<0.03	Ph25-17
<0.04	<0.05	<0.1	135	<0.03	Ph34-18
<0.04	<0.05	<0.1	107	<0.03	Ph34-22
<0.04	<0.05	<0.1	111	<0.03	Ph34-23
<0.04	<0.05	<0.1	142	<0.03	Ph34-24
<0.04	<0.05	<0.1	106	<0.03	Ph35-24
<0.04	<0.05	<0.1	110	<0.03	Ph35-25
<0.04	<0.05	<0.1	108	<0.03	Ph35-28
<0.04	<0.05	<0.1	129	<0.03	Ph44-07
<0.04	<0.05	<0.1	134	<0.03	Pi31-01
<0.04	<0.05	<0.1	130	<0.03	Pi31-02
<0.04	<0.05	<0.1	105	<0.03	Pi31-05
<0.04	<0.05	<0.1	134	<0.03	Pi31-11
<0.04	<0.05	<0.1	107	<0.03	Pi31-12
<0.04	<0.05	<0.1	128	<0.03	Pi32-14
<0.04	<0.05	<0.1	138	<0.03	Pi32-15
<0.04	<0.05	<0.1	144	<0.03	Pi34-09
<0.04	<0.05	<0.1	112	<0.03	Pi41-02
<0.04	<0.05	<0.1	138	<0.03	Pi41-03
<0.04	<0.05	<0.1	129	<0.03	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	1,3,5-Trimethylbenzene (µg/L)	1,3-Dichlorobenzene (µg/L)	1,3-Dichloropropane (µg/L)	1,4-Dichlorobenzene (µg/L)
Ph24-01	11/25/2003	<0.04	<0.03	<0.1	<0.03
Ph24-02	12/2/2003	<0.04	<0.03	<0.1	<0.03
Ph25-17	12/11/2003	<0.04	<0.03	<0.1	**E 0.05**
Ph34-18	12/10/2003	<0.04	<0.03	<0.1	<0.03
Ph34-22	12/4/2003	<0.04	<0.03	<0.1	<0.03
Ph34-23	12/15/2003	<0.04	<0.03	<0.1	<0.03
Ph34-24	12/1/2003	<0.04	<0.03	<0.1	<0.03
Ph35-24	12/16/2003	<0.04	<0.03	<0.1	<0.03
Ph35-25	12/17/2003	<0.04	<0.03	<0.1	<0.03
Ph35-28	12/16/2003	<0.04	<0.03	<0.1	<0.03
Ph44-07	12/9/2003	<0.04	<0.03	<0.1	<0.03
Pi31-01	12/10/2003	<0.04	<0.03	<0.1	<0.03
Pi31-02	12/9/2003	<0.04	<0.03	<0.1	<0.03
Pi31-05	12/4/2003	<0.04	<0.03	<0.1	**0.12**
Pi31-11	12/11/2003	<0.04	<0.03	<0.1	<0.03
Pi31-12	12/17/2003	<0.04	<0.03	<0.1	<0.03
Pi32-14	12/8/2003	<0.04	<0.03	<0.1	<0.03
Pi32-15	11/26/2003	<0.04	<0.03	<0.1	<0.03
Pi34-09	12/3/2003	<0.04	<0.03	<0.1	<0.03
Pi41-02	12/15/2003	<0.04	<0.03	<0.1	<0.03
Pi41-03	11/26/2003	<0.04	<0.03	<0.1	<0.03
Pi43-03	12/3/2003	<0.04	<0.03	<0.1	<0.03

1,4-Bromofluorobenzene, recovery surrogate (percent)	2,2-Dichloropropane (µg/L)	2-Chlorotoluene (µg/L)	*o*-Ethyl toluene (µg/L)	3-Chloropropene (µg/L)	4-Chlorotoluene (µg/L)	DGS local well number
89.5	<0.05	<0.04	<0.06	<0.50	<0.05	Ph24-01
91.7	<0.05	<0.04	<0.06	<0.50	<0.05	Ph24-02
71.4	<0.05	<0.04	<0.06	<0.50	<0.05	Ph25-17
74.1	<0.05	<0.04	<0.06	<0.50	<0.05	Ph34-18
82.7	<0.05	<0.04	<0.06	<0.50	<0.05	Ph34-22
84.4	<0.05	<0.04	<0.06	<0.50	<0.05	Ph34-23
84.3	<0.05	<0.04	<0.06	<0.50	<0.05	Ph34-24
81.0	<0.05	<0.04	<0.06	<0.50	<0.05	Ph35-24
74.7	<0.05	<0.04	<0.06	<0.50	<0.05	Ph35-25
84.5	<0.05	<0.04	<0.06	<0.50	<0.05	Ph35-28
73.4	<0.05	<0.04	<0.06	<0.50	<0.05	Ph44-07
71.5	<0.05	<0.04	<0.06	<0.50	<0.05	Pi31-01
73.3	<0.05	<0.04	<0.06	<0.50	<0.05	Pi31-02
85.3	<0.05	<0.04	<0.06	<0.50	<0.05	Pi31-05
72.4	<0.05	<0.04	<0.06	<0.50	<0.05	Pi31-11
84.9	<0.05	<0.04	<0.06	<0.50	<0.05	Pi31-12
78.1	<0.05	<0.04	<0.06	<0.50	<0.05	Pi32-14
85.2	<0.05	<0.04	<0.06	<0.50	<0.05	Pi32-15
84.8	<0.05	<0.04	<0.06	<0.50	<0.05	Pi34-09
77.0	<0.05	<0.04	<0.06	<0.50	<0.05	Pi41-02
87.4	<0.05	<0.04	<0.06	<0.50	<0.05	Pi41-03
78.1	<0.05	<0.04	<0.06	<0.50	<0.05	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	4-Isopropyl-1-methylbenzene (µg/L)	Acetone (µg/L)	Acrylonitrile (µg/L)	Benzene (µg/L)	Bromobenzene (µg/L)	Bromochloromethane (µg/L)
Ph24-01	11/25/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph24-02	12/2/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph25-17	12/11/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph34-18	12/10/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph34-22	12/4/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph34-23	12/15/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph34-24	12/1/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph35-24	12/16/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph35-25	12/17/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph35-28	12/16/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Ph44-07	12/9/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi31-01	12/10/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi31-02	12/9/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi31-05	12/4/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi31-11	12/11/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi31-12	12/17/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi32-14	12/8/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi32-15	11/26/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi34-09	12/3/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi41-02	12/15/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi41-03	11/26/2003	<0.08	<6	<1	<0.02	<0.03	<0.12
Pi43-03	12/3/2003	<0.08	<6	<1	<0.02	<0.03	<0.12

Bromodichloromethane (µg/L)	Bromoethene (µg/L)	Bromomethane (µg/L)	Carbon disulfide (µg/L)	Chlorobenzene (µg/L)	Chloroethane (µg/L)	DGS local well number
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph24-01
7.17	<0.1	<0.3	<0.04	<0.03	<0.1	Ph24-02
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph25-17
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph34-18
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph34-22
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph34-23
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph34-24
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph35-24
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph35-25
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph35-28
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Ph44-07
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi31-01
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi31-02
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi31-05
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi31-11
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi31-12
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi32-14
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi32-15
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi34-09
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi41-02
<0.03	<0.1	<0.3	<0.04	<0.03	<0.1	Pi41-03
0.31	<0.1	<0.3	<0.04	<0.03	<0.1	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	Chloromethane (µg/L)	*cis*-1,2-Dichloroethylene (µg/L)	*cis*-1,3-Dichloropropene (µg/L)	Dibromochloromethane (µg/L)
Ph24-01	11/25/2003	<0.2	<0.02	<0.05	<0.1
Ph24-02	12/2/2003	<0.2	<0.02	<0.05	**4.9**
Ph25-17	12/11/2003	<0.2	<0.02	<0.05	<0.1
Ph34-18	12/10/2003	<0.2	<0.02	<0.05	<0.1
Ph34-22	12/4/2003	<0.2	<0.02	<0.05	<0.1
Ph34-23	12/15/2003	<0.2	<0.02	<0.05	<0.1
Ph34-24	12/1/2003	<0.2	<0.02	<0.05	<0.1
Ph35-24	12/16/2003	<0.2	<0.02	<0.05	<0.1
Ph35-25	12/17/2003	<0.2	<0.02	<0.05	<0.1
Ph35-28	12/16/2003	<0.2	<0.02	<0.05	<0.1
Ph44-07	12/9/2003	<0.2	<0.02	<0.05	<0.1
Pi31-01	12/10/2003	<0.2	<0.02	<0.05	<0.1
Pi31-02	12/9/2003	<0.2	<0.02	<0.05	<0.1
Pi31-05	12/4/2003	<0.2	<0.02	<0.05	<0.1
Pi31-11	12/11/2003	<0.2	<0.02	<0.05	<0.1
Pi31-12	12/17/2003	<0.2	<0.02	<0.05	<0.1
Pi32-14	12/8/2003	<0.2	<0.02	<0.05	<0.1
Pi32-15	11/26/2003	<0.2	<0.02	<0.05	<0.1
Pi34-09	12/3/2003	<0.2	<0.02	<0.05	<0.1
Pi41-02	12/15/2003	<0.2	<0.02	<0.05	<0.1
Pi41-03	11/26/2003	<0.2	<0.02	<0.05	<0.1
Pi43-03	12/3/2003	<0.2	<0.02	<0.05	**E 0.1**

Dibromomethane (µg/L)	Dichloromethane (µg/L)	Diethyl ether (µg/L)	Diisopropyl ether (µg/L)	Ethyl methacrylate (µg/L)	2-Butanone (µg/L)	DGS local well number
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph24-01
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph24-02
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph25-17
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph34-18
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph34-22
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph34-23
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph34-24
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph35-24
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph35-25
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph35-28
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Ph44-07
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi31-01
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi31-02
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi31-05
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi31-11
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi31-12
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi32-14
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi32-15
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi34-09
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi41-02
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi41-03
<0.05	<0.1	<0.1	<0.10	<0.2	<4.0	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	Ethylbenzene (µg/L)	Hexachlorobutadiene (µg/L)	Hexachloroethane (µg/L)	Methyl iodide (µg/L)	4-Methyl-2-pentanone (µg/L)
Ph24-01	11/25/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph24-02	12/2/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph25-17	12/11/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph34-18	12/10/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph34-22	12/4/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph34-23	12/15/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph34-24	12/1/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph35-24	12/16/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph35-25	12/17/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph35-28	12/16/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Ph44-07	12/9/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi31-01	12/10/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi31-02	12/9/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi31-05	12/4/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi31-11	12/11/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi31-12	12/17/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi32-14	12/8/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi32-15	11/26/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi34-09	12/3/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi41-02	12/15/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi41-03	11/26/2003	<0.03	<0.1	<0.1	<0.35	<0.4
Pi43-03	12/3/2003	<0.03	<0.1	<0.1	<0.35	<0.4

Isopropylbenzene (µg/L)	Methyl acrylonitrile (µg/L)	Methyl acrylate (µg/L)	Methyl methacrylate (µg/L)	Methyl *tert*-pentyl ether (µg/L)	DGS local well number
<0.04	<0.8	<2.0	<0.3	<0.08	Ph24-01
<0.04	<0.8	<2.0	<0.3	<0.08	Ph24-02
<0.04	<0.8	<2.0	<0.3	<0.08	Ph25-17
<0.04	<0.8	<2.0	<0.3	<0.08	Ph34-18
<0.04	<0.8	<2.0	<0.3	<0.08	Ph34-22
<0.04	<0.8	<2.0	<0.3	<0.08	Ph34-23
<0.04	<0.8	<2.0	<0.3	<0.08	Ph34-24
<0.04	<0.8	<2.0	<0.3	<0.08	Ph35-24
<0.04	<0.8	<2.0	<0.3	<0.08	Ph35-25
<0.04	<0.8	<2.0	<0.3	<0.08	Ph35-28
<0.04	<0.8	<2.0	<0.3	<0.08	Ph44-07
<0.04	<0.8	<2.0	<0.3	<0.08	Pi31-01
<0.04	<0.8	<2.0	<0.3	<0.08	Pi31-02
<0.04	<0.8	<2.0	<0.3	**E 0.05**	Pi31-05
<0.04	<0.8	<2.0	<0.3	<0.08	Pi31-11
<0.04	<0.8	<2.0	<0.3	<0.08	Pi31-12
<0.04	<0.8	<2.0	<0.3	<0.08	Pi32-14
<0.04	<0.8	<2.0	<0.3	<0.08	Pi32-15
<0.04	<0.8	<2.0	<0.3	<0.08	Pi34-09
<0.04	<0.8	<2.0	<0.3	<0.08	Pi41-02
<0.04	<0.8	<2.0	<0.3	<0.08	Pi41-03
<0.04	<0.8	<2.0	<0.3	**0.65**	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	*m*- and *p*-Xylene (µg/L)	Naphthalene (µg/L)	2-Hexanone (µg/L)	Butylbenzene (µg/L)	*n*-Propylbenzene (µg/L)
Ph24-01	11/25/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph24-02	12/2/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph25-17	12/11/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph34-18	12/10/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph34-22	12/4/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph34-23	12/15/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph34-24	12/1/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph35-24	12/16/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph35-25	12/17/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph35-28	12/16/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Ph44-07	12/9/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi31-01	12/10/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi31-02	12/9/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi31-05	12/4/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi31-11	12/11/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi31-12	12/17/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi32-14	12/8/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi32-15	11/26/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi34-09	12/3/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi41-02	12/15/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi41-03	11/26/2003	<0.06	<0.5	<0.7	<0.1	<0.04
Pi43-03	12/3/2003	<0.06	<0.5	<0.7	<0.1	<0.04

o-Xylene (µg/L)	*sec*-Butylbenzene (µg/L)	Styrene (µg/L)	Ethyl *tert*-butyl ether (µg/L)	Methyl *tert*-Butyl ether (µg/L)	*tert*-Butylbenzene (µg/L)	Tetrachloroethylene (µg/L)	DGS local well number
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph24-01
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph24-02
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph25-17
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph34-18
<0.04	<0.06	<0.04	<0.05	**0.2**	<0.06	<0.06	Ph34-22
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph34-23
<0.04	<0.06	<0.04	<0.05	**0.6**	<0.06	**0.10**	Ph34-24
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph35-24
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph35-25
<0.04	<0.06	<0.04	<0.05	**0.4**	<0.06	<0.06	Ph35-28
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Ph44-07
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	**E 0.07**	Pi31-01
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Pi31-02
<0.04	<0.06	<0.04	<0.05	**0.3**	<0.06	<0.06	Pi31-05
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Pi31-11
<0.04	<0.06	<0.04	<0.05	**E 0.1**	<0.06	<0.06	Pi31-12
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	**7.29**	Pi32-14
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Pi32-15
<0.04	<0.06	<0.04	<0.05	**0.3**	<0.06	<0.06	Pi34-09
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	<0.06	Pi41-02
<0.04	<0.06	<0.04	<0.05	<0.2	<0.06	**E 0.02**	Pi41-03
<0.04	<0.06	<0.04	<0.05	**5.5**	<0.06	<0.06	Pi43-03

Table A7. *Ground-water-quality data for supply wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Volatile and semi-volatile organic compounds – Continued*

DGS local well number	Sample date	Tetrachloromethane (µg/L)	Tetrahydrofuran (µg/L)	Toluene (µg/L)	Toluene-d8, recovery surrogate (percent)	*trans*-1,2-Dichloroethylene (µg/L)
Ph24-01	11/25/2003	<0.06	<2	<0.05	102	<0.03
Ph24-02	12/2/2003	<0.06	<2	<0.05	104	<0.03
Ph25-17	12/11/2003	<0.06	<2	<0.05	94.1	<0.03
Ph34-18	12/10/2003	<0.06	<2	<0.05	95.0	<0.03
Ph34-22	12/4/2003	<0.06	<2	<0.05	90.8	<0.03
Ph34-23	12/15/2003	<0.06	<2	<0.05	97.3	<0.03
Ph34-24	12/1/2003	<0.06	<2	<0.05	102	<0.03
Ph35-24	12/16/2003	<0.06	<2	<0.05	94.8	<0.03
Ph35-25	12/17/2003	<0.06	<2	<0.05	94.4	<0.03
Ph35-28	12/16/2003	<0.06	<2	<0.05	96.9	<0.03
Ph44-07	12/9/2003	<0.06	<2	<0.05	93.8	<0.03
Pi31-01	12/10/2003	<0.06	<2	<0.05	97.6	<0.03
Pi31-02	12/9/2003	<0.06	<2	<0.05	94.3	<0.03
Pi31-05	12/4/2003	<0.06	<2	<0.05	90.2	<0.03
Pi31-11	12/11/2003	<0.06	<2	<0.05	94.7	<0.03
Pi31-12	12/17/2003	<0.06	<2	<0.05	99.4	<0.03
Pi32-14	12/8/2003	<0.06	<2	<0.05	94.6	<0.03
Pi32-15	11/26/2003	<0.06	<2	<0.05	101	<0.03
Pi34-09	12/3/2003	<0.06	<2	<0.05	101	<0.03
Pi41-02	12/15/2003	<0.06	<2	<0.05	97.7	<0.03
Pi41-03	11/26/2003	<0.06	<2	<0.05	101	<0.03
Pi43-03	12/3/2003	<0.06	<2	<0.05	91.8	<0.03

***trans*-1,3-Dichloropropene (µg/L)**	***trans*-1,4-Dichloro-2-butene (µg/L)**	**Bromoform (µg/L)**	**Trichloroethylene (µg/L)**	**Chloroform (µg/L)**	**Vinyl chloride (µg/L)**	**DGS local well number**
<0.09	<0.7	<0.10	<0.04	**E 0.08**	<0.1	Ph24-01
<0.09	<0.7	**1.95**	<0.04	**8.18**	<0.1	Ph24-02
<0.09	<0.7	<0.10	<0.04	**0.46**	<0.1	Ph25-17
<0.09	<0.7	<0.10	<0.04	**0.13**	<0.1	Ph34-18
<0.09	<0.7	<0.10	<0.04	**0.11**	<0.1	Ph34-22
<0.09	<0.7	<0.10	<0.04	**E 0.06**	<0.1	Ph34-23
<0.09	<0.7	<0.10	<0.04	**0.31**	<0.1	Ph34-24
<0.09	<0.7	<0.10	<0.04	**0.34**	<0.1	Ph35-24
<0.09	<0.7	<0.10	<0.04	**0.34**	<0.1	Ph35-25
<0.09	<0.7	<0.10	<0.04	**0.65**	<0.1	Ph35-28
<0.09	<0.7	<0.10	<0.04	**2.15**	<0.1	Ph44-07
<0.09	<0.7	<0.10	**0.40**	**1.71**	<0.1	Pi31-01
<0.09	<0.7	<0.10	<0.04	**0.82**	<0.1	Pi31-02
<0.09	<0.7	<0.10	<0.04	**3.17**	<0.1	Pi31-05
<0.09	<0.7	<0.10	**E 0.08**	**1.52**	<0.1	Pi31-11
<0.09	<0.7	<0.10	<0.04	**0.98**	<0.1	Pi31-12
<0.09	<0.7	<0.10	<0.04	**E 0.02**	<0.1	Pi32-14
<0.09	<0.7	<0.10	<0.04	**1.16**	<0.1	Pi32-15
<0.09	<0.7	<0.10	<0.04	<0.02	<0.1	Pi34-09
<0.09	<0.7	<0.10	<0.04	**1.10**	<0.1	Pi41-02
<0.09	<0.7	<0.10	<0.04	**0.81**	<0.1	Pi41-03
<0.09	<0.7	<0.10	<0.04	**0.64**	<0.1	Pi43-03

Table A8. *Ground-water-quality data for Long Neck Peninsula production wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2003 – Dissolved gases*

[DGS, Delaware Geological Survey; mg/L, milligrams per liter; atm., atmospheres]

DGS local well number	Sample date	Sample time	Concentration (mg/L)					Partial pressures at field temperatures (atm.)				
			Argon (Ar)	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrogen (N_2)	Oxygen (O_2)	Argon (Ar)	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrogen (N_2)	Oxygen (O_2)
Ph24-01	11/25/2003	1115	0.7124	40.107	0.0000	20.885	0.072	0.0106	0.0199	0.0000	0.9700	0.0015
Ph24-02	12/2/2003	1330	0.6873	20.875	0.0000	20.939	5.353	0.0102	0.0103	0.0000	0.9689	0.1083
Ph25-17	12/11/2003	0945	0.6842	83.673	0.0000	19.512	2.128	0.0099	0.0398	0.0000	0.8826	0.0420
Ph34-18	12/10/2003	0930	0.7150	42.979	0.0000	20.406	5.778	0.0104	0.0207	0.0000	0.9301	0.1149
Ph34-22	12/4/2003	1000	0.7142	59.171	0.0000	20.294	2.809	0.0105	0.0289	0.0000	0.9320	0.0563
Ph34-23	12/15/2003	1500	0.6816	74.011	0.0000	19.584	5.091	0.0099	0.0356	0.0000	0.8926	0.1013
Ph34-24	12/1/2003	1330	0.6758	112.255	0.0000	20.083	0.113	0.0100	0.0553	0.0000	0.9275	0.0023
Ph35-24	12/16/2003	1330	0.6995	50.950	0.0000	19.977	2.917	0.0104	0.0253	0.0000	0.9278	0.0592
Ph35-25	12/17/2003	1445	0.6817	38.860	0.0000	19.537	1.932	0.0101	0.0193	0.0000	0.9074	0.0392
Ph35-28	12/16/2003	0900	0.6752	51.470	0.0000	19.190	4.207	0.0100	0.0255	0.0000	0.8896	0.0853
Ph44-07	12/9/2003	0915	0.7178	45.743	0.0000	20.419	5.454	0.0103	0.0217	0.0000	0.9236	0.1076
Pi31-01	12/10/2003	1230	0.6222	169.425	0.0000	18.512	0.634	0.0091	0.0826	0.0000	0.8502	0.0127
Pi31-02	12/9/2003	1315	0.6708	52.779	0.0000	18.891	6.493	0.0097	0.0254	0.0000	0.8610	0.1291
Pi31-05	12/4/2003	1330	0.6695	64.116	0.0000	18.768	3.079	0.0098	0.0315	0.0000	0.8652	0.0620
Pi31-11	12/11/2003	1315	0.7111	49.279	0.0000	20.489	1.078	0.0104	0.0240	0.0000	0.9392	0.0216
Pi31-12	12/17/2003	1145	0.6907	41.300	0.0000	19.636	3.955	0.0102	0.0203	0.0000	0.9069	0.0798
Pi32-14	12/8/2003	1530	0.6916	86.200	0.0000	20.366	0.126	0.0104	0.0438	0.0000	0.9582	0.0026
Pi32-15	11/26/2003	1015	0.6708	45.181	0.0000	18.923	3.280	0.0099	0.0225	0.0000	0.8789	0.0666
Pi34-09	12/3/2003	0945	0.6474	20.669	0.0000	17.864	1.458	0.0095	0.0101	0.0000	0.8204	0.0292
Pi41-02	12/15/2003	1115	0.6984	33.722	0.0000	19.803	3.744	0.0102	0.0163	0.0000	0.9060	0.0748
Pi41-03	11/26/2003	1430	0.6977	37.238	0.0000	19.851	0.555	0.0102	0.0182	0.0000	0.9117	0.0111
Pi43-03	12/3/2003	1415	0.6616	58.434	0.0000	18.672	3.674	0.0096	0.0282	0.0000	0.8527	0.0732

Table A9. *Ground-water-quality data for Pot Nets Bayside production well Pi31-01 sampled in Sussex County, Delaware, by the U.S. Geological Survey on February 11-12, 2004 — Time-series data*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; mV, millivolts; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; ng/L, nanograms per liter; <, less than; E, estimated value per mil; M, presence of material verified but not quantified. A filtered constituent could be higher in value than its unfiltered counterpart, and reflects differences in the reporting accuracy of the methods used. Filtered samples used a 0.40-micrometer absolute pore size filter.]

Sample time	Oxidation-reduction potential (mV)[a]	Turbidity (NTU)	Dissolved oxygen (mg/L)	pH, field standard units	pH, laboratory standard units	Specific conductance, field (µS/cm)
1530	322	0.3	3.7	5.3	5.6	134
1615	347	0.2	3.7	5.3	E 5.9	138
1830	355	0.2	3.7	5.3	5.5	138
1730	345	0.2	3.7	5.4	5.5	138

Sample time	Sodium (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as SiO_2 (mg/L)	Sulfate, as SO_4^{2-} (mg/L)
1530	15.2	0.29	20.8	<0.2	15.0	8.0
1615	15.3	0.33	20.7	<0.2	15.0	8.7
1830	15.2	0.32	21.1	<0.2	15.0	7.9
1730	15.7	0.30	21.1	<0.2	14.9	7.8

Sample time	Total mercury, unfiltered (ng/L)	Total mercury, filtered (ng/L)	Barium, filtered (µg/L)	Barium, unfiltered (µg/L)	Iron, filtered (µg/L)	Iron, unfiltered (µg/L)
1530	1,140	1,260	102	92	15	70
1615	1,460	1,450	103	92	11	M
1830	1,510	1,500	103	91	8	M
1730	1,410	1,500	102	92	8	M

[a] Relative to calomel electrode.

Specific conductance, laboratory (µS/cm)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3^-)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sample time
136	13.9	12.5[b]	E 16[b]	3.13	3.70	2.29	1530
137	13.9	13.5[b]	E 17[b]	3.17	3.74	2.21	1615
136	13.9	12.3[b]	E 16[b]	3.13	3.69	2.26	1830
135	13.9	13.3[b]	E 16[b]	3.26	3.82	2.26	1730

Dissolved residue (mg/L)	Nitrogen, total particulate (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Carbon, total particulate (mg/L)	Carbon, inorganic particulate (mg/L)	Carbon, organic particulate (mg/L)	Sample time
94	<0.02	<0.008	1.52	<0.1	<0.1	<0.1	1530
88	<0.02	<0.008	1.53	<0.1	<0.1	<0.1	1615
94	<0.02	<0.008	1.54	<0.1	<0.1	<0.1	1830
91	<0.02	<0.008	1.55	<0.1	<0.1	<0.1	1730

Lead, filtered (µg/L)	Lead, unfiltered (µg/L)	Manganese, filtered (µg/L)	Manganese, unfiltered (µg/L)	H-2/H-1 (ratio, per mil)	O-18/O-16 (ratio, per mil)		Sample time
0.59	0.88	53.4	55.5	-34.20	-6.00		1530
0.48	0.47	52.5	54.2	-33.50	-5.94		1615
0.33	0.29	52.1	53.2	-33.80	-5.97		1830
1.10	0.60	52.2	53.2	-34.50	-6.01		1730

[b] Dissolved organic carbon possibly contributes to Alkalinity and positive bias in Bicarbonate.

Table A10. *Ground-water-quality data for Pot Nets Bayside monitoring well Pi31-13 sampled in Sussex County, Delaware, by the U.S. Geological Survey on February 12, 2004 — Depth-series data*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; MLSD, mean land-surface datum; mV, millivolts; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter; ng/L, nanograms per liter; <, less than; E, estimated value; M, presence of material verified but not quantified. A filtered constituent could be higher in value than its unfiltered counterpart, and reflects differences in reporting accuracy of the methods used. Filtered samples used a 0.40-micrometer absolute pore size filter.]

Depth below MLSD (feet)	Oxidation-reduction potential (mV)[a]	Turbidity (NTU)	Dissolved oxygen (mg/L)	pH, field standard units	pH, laboratory standard units	Specific conductance, field (µS/cm)
56.7	463	0.3	0.2	5.4	5.5	189
62.7	481	0.2	0.1	5.4	5.5	188
71.7	486	0.3	0.1	5.4	5.4	188

Depth below MLSD (feet)	Sodium (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica, as SiO_2 (mg/L)	Sulfate, as SO_4^{2-} (mg/L)
56.7	23.1	0.91	25.2	<0.2	18.7	3.0
62.7	22.8	0.96	25.7	<0.2	18.5	3.0
71.7	23.2	0.86	26.0	<0.2	18.5	3.1

Depth below MLSD (feet)	Total mercury, filtered (ng/L)	Total mercury, unfiltered (ng/L)	Barium, filtered (µg/L)	Barium, unfiltered (µg/L)	Iron, filtered (µg/L)	Iron, unfiltered (µg/L)
56.7	1,550	1,560	120	109	13	10
62.7	1,490	1,530	122	110	7	M
71.7	1,520	1,470	122	110	E 6	M

[a] Relative to calomel electrode.

Specific conductance, laboratory (µS/cm)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3^-)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Depth below MLSD (feet)
186	13.3	18.0[b]	E 22[b]	6.53	4.48	2.81	56.7
188	13.1	18.8[b]	E 22[b]	6.29	4.35	2.73	62.7
188	13.2	18.0[b]	E 22[b]	6.34	4.39	2.72	71.7

Dissolved residue (mg/L)	Nitrogen, total particulate (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Carbon, total particulate (mg/L)	Carbon, inorganic particulate (mg/L)	Carbon, organic particulate (mg/L)	Depth below MLSD (feet)
132	<0.02	<0.008	2.12	<0.1	<0.1	<0.1	56.7
126	<0.02	<0.008	2.05	<0.1	<0.1	<0.1	62.7
132	<0.02	<0.008	1.90	<0.1	<0.1	<0.1	71.7

Lead, filtered (µg/L)	Lead, unfiltered (µg/L)	Manganese, filtered (µg/L)	Manganese, unfiltered (µg/L)	H-2/H-1 (ratio, per mil)	O-18/O-16 (ratio, per mil)		Depth below MLSD (feet)
0.84	0.68	174	176	-30.20	-5.48		56.7
0.14	0.11	183	186	-32.10	-5.48		62.7
0.35	0.42	187	184	-32.70	-5.51		71.7

[b] Dissolved organic carbon possibly contributes to Alkalinity and positive bias in Bicarbonate.

Table A11. *Ground-water-quality data for Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Bulk properties and field parameters*

[DGS, Delaware Geological Survey; mV, millivolts; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; ANC, acid-neutralizing capacity, by Gran method; <, less than; E, estimated value determined from field measurement]

DGS local well number	Sample date	Sample time	Oxidation-reduction potential (mV)[a]	Turbidity (NTU)	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)
Pot Nets Bayside						
Pi31-01	9/13/2004	1000	246	0.1	4.0	40
Pi31-16	9/14/2004	1610	243	0.2	1.7	17
Pi31-17	9/14/2004	1330	197	0.2	1.5	15
Pi31-18	9/14/2004	1140	194	0.2	3.1	E 31
Pi31-19	9/14/2004	1000	238	0.6	4.9	49
Pi31-20	9/13/2004	1740	280	0.5	5.0	E 50
Pi31-21	9/13/2004	1910	274	1.7	5.2	51
Pot Nets Lakeside						
Ph35-25	9/15/2004	1300	221	0.1	4.7	48
Ph35-30	9/16/2004	1400	228	0.2	6.5	73
Ph35-31	9/16/2004	1200	234	0.4	6.4	70
Ph35-32	9/15/2004	1945	220	0.4	2.3	24
Ph35-33	9/15/2004	1730	203	0.2	1.8	20
Ph35-34	9/15/2004	1445	188	0.4	2.7	28

pH, field standard units	pH, laboratory standard units	Specific conductance, field (µS/cm)	Specific conductance, laboratory (µS/cm)	Water temperature (°C)	ANC (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Sulfide species (mg/L)
Pot Nets Bayside							
5.1	5.6	147	139	15.0	11.3[b]	E 14[b]	<0.01
5.3	5.7	161	152	17.4	16.2[b]	E 20[b]	<0.01
5.3	5.7	148	137	15.7	21.8[b]	E 27[b]	<0.01
5.2	5.6	163	154	16.0	25.6[b]	E 32[b]	<0.01
5.2	5.6	132	122	15.3	7.0[b]	9[b]	<0.01
5.0	5.5	146	138	15.1	6.1	8	<0.01
5.0	5.4	156	146	14.5	3.6	5	<0.01
Pot Nets Lakeside							
5.5	6.0	81	80	15.7	6.8	E 9	<0.01
5.6	5.9	105	100	20.8	6.0	E 8	<0.01
5.6	6.0	97	92	19.1	6.7	E 8	<0.01
5.7	6.1	64	64	16.7	8.1[b]	E 10[b]	<0.01
5.5	5.9	73	71	21.0	6.5[b]	E 8[b]	<0.01
5.2	5.6	125	119	17.8	7.1	E 9	<0.01

[a] Relative to calomel electrode.
[b] Dissolved organic carbon possibly contributes to ANC and positive bias in Bicarbonate.

Table A12. *Ground-water-quality data for Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Major ions and trace elements*

[DGS, Delaware Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value determined by laboratory]

DGS local well number	Sample date	Sample time	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Bromide (mg/L)
			Pot Nets Bayside				
Pi31-01	9/13/2004	1000	3.25	3.86	2.09	15.0	0.28
Pi31-16	9/14/2004	1610	5.35	3.56	2.07	16.2	0.31
Pi31-17	9/14/2004	1330	3.31	2.57	2.19	19.2	0.51
Pi31-18	9/14/2004	1140	3.86	3.01	2.48	21.2	0.66
Pi31-19	9/14/2004	1000	1.87	2.66	1.95	15.8	0.11
Pi31-20	9/13/2004	1740	3.12	4.94	2.40	13.4	0.07
Pi31-21	9/13/2004	1910	3.49	4.85	1.61	14.2	0.06
			Pot Nets Lakeside				
Ph35-25	9/15/2004	1300	2.54	1.01	1.21	9.75	0.14
Ph35-30	9/16/2004	1400	3.78	1.37	1.23	11.7	0.06
Ph35-31	9/16/2004	1200	3.40	1.16	1.25	11.3	0.06
Ph35-32	9/15/2004	1945	1.67	0.614	1.00	8.42	0.11
Ph35-33	9/15/2004	1730	1.31	1.29	1.59	9.22	0.29
Ph35-34	9/15/2004	1445	3.25	5.02	2.29	9.01	0.03
			Field Blank				
Ph35-25	9/16/2004	0930	0.033	< 0.008	< 0.16	0.10	< 0.016

Chloride (mg/L)	Fluoride (mg/L)	Silica, as SiO_2 (mg/L)	Sulfate, as SIO_4^{2-} (mg/L)	Dissolved residue (mg/L)	Iron (µg/L)	Manganese (µg/L)
			Pot Nets Bayside			
21.8	< 0.2	15.2	7.9	89	7	55.1
15.1	< 0.2	18.2	2.5	99	10	18.8
20.0	< 0.2	16.7	4.0	88	24	97.0
23.1	< 0.2	17.4	4.2	100	50	252
20.4	< 0.2	15.5	6.9	82	<6	9.9
18.2	< 0.17	15.5	14.4	89	8.8	39.7
30.5	< 0.2	15.5	7.2	87	13	35.7
			Pot Nets Lakeside			
10.3	< 0.2	18.3	1.5	67	<6	11.2
10.5	< 0.2	21.1	0.6	85	<6	1.4
10.5	< 0.2	19.6	0.8	76	<6	E 0.5
9.85	< 0.17	17.0	1.3	53	E 5.2	12.0
11.1	< 0.2	12.3	2.7	49	9	23.2
17.6	< 0.2	11.4	13.3	72	269	19.3
			Field Blank			
< 0.20	< 0.17	0.05	E 0.11	<10	E 3.2	< 0.8

Table A13. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Nutrients*

[DGS, Delaware Geological Survey; mg/L, milligrams per liter; UVA, ultraviolet absorbance; nm, wavelength in nanometers; L/mg cm, liters per milligram centimeter; <, less than; E, estimated value determined by laboratory; --, no data]

DGS local well number	Sample date	Sample time	Nitrogen, total particulate (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Carbon, total particulate (mg/L)	Carbon, inorganic, particulate (mg/L)	Carbon, organic particulate (mg/L)	Carbon, organic dissolved (mg/L)	UVA, 254 nm on carbon, organic dissolved (L/mg cm)	UVA, 280 nm on carbon, organic dissolved (L/mg cm)
Pot Nets Bayside											
Pi31-01	9/13/2004	1000	<0.02	<0.008	1.74	<0.1	<0.1	<0.1	1.7	0.019	0.011
Pi31-16	9/14/2004	1610	<0.02	<0.008	6.93	<0.1	<0.1	<0.1	1.3	0.015	0.010
Pi31-17	9/14/2004	1330	<0.02	<0.008	1.24	<0.1	<0.1	<0.1	2.5	0.032	0.019
Pi31-18	9/14/2004	1140	<0.02	0.013	0.96	<0.1	<0.1	<0.1	3.1	0.039	0.023
Pi31-19	9/14/2004	1000	<0.02	<0.008	2.03	<0.1	<0.1	<0.1	0.5	0.005	<0.004
Pi31-20	9/13/2004	1740	<0.02	<0.008	2.13	<0.1	<0.1	<0.1	0.7	0.007	0.005
Pi31-21	9/13/2004	1910	<0.02	<0.008	1.42	<0.1	<0.1	<0.1	0.6	0.009	0.007
Pot Nets Lakeside											
Ph35-25	9/15/2004	1300	<0.02	<0.008	2.40	<0.1	<0.1	<0.1	E 0.3	0.004	<0.004
Ph35-30	9/16/2004	1400	<0.02	<0.008	5.39	<0.1	<0.1	<0.1	<0.3	0.004	<0.004
Ph35-31	9/16/2004	1200	<0.02	<0.008	4.22	<0.1	<0.1	<0.1	E 0.2	0.004	0.004
Ph35-32	9/15/2004	1945	<0.02	<0.008	0.67	<0.1	<0.1	<0.1	E 0.2	0.005	0.004
Ph35-33	9/15/2004	1730	<0.02	<0.008	0.78	<0.1	<0.1	<0.1	0.5	0.013	0.009
Ph35-34	9/15/2004	1445	<0.02	<0.008	0.58	<0.1	<0.1	<0.1	0.7	0.011	0.008
Field Blank											
Ph35-25	9/16/2004	0930	--	<0.008	<0.06	--	--	--	<0.3	--	--

Table A14. *Ground-water-quality data for Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Mercury*

[DGS, Delaware Geological Survey; ng/L, nanograms per liter; VOC, volatile organic compound; --, no data. For total mercury samples, data are reported in relation to laboratory daily detection levels, which varied between 0.01-0.04 ng/L for the days during which analyses were conducted. All data for methyl mercury, which were analyzed on 1 day, are reported in relation to a daily detection level of 0.004 ng/L, and in accordance with laboratory spiking-recovery procedures and calculations described in DeWild and others, 2002]

DGS local well number	Sample date	Sample time	Total mercury, unfiltered (ng/L)	Total mercury, 0.4-micrometer filtered (ng/L)	Total mercury, 0.1-micrometer filtered (ng/L)	Methyl-mercury, 0.4-micrometer filtered (ng/L)	Methyl mercury, 0.4-micrometer filtered, methyl-mercury spiked[a] (ng/L)	Recovery (percent)	Methyl mercury, 0.4-micrometer filtered, methyl-mercury and VOC spiked[a,b] (ng/L)	Recovery (percent)
Pot Nets Bayside										
Pi31-01	9/13/2004	1000	1,650	1,240	1,620	--	--	--	--	--
Pi31-16	9/14/2004	1610	6,380	6,100	6,220	--	--	--	--	--
Pi31-17	9/14/2004	1330	5,470	5,400	5,750	--	--	--	--	--
Pi31-18	9/14/2004	1140	4,640	4,680	4,670	--	--	--	--	--
Pi31-19	9/14/2004	1000	383	366	367	<0.04	0.937	101	1.104	108
Pi31-20	9/13/2004	1740	2.37	2.46	2.27	<0.04	1.043	106	1.082	106
Pi31-21	9/13/2004	1910	246	234	194	0.062	0.759	85	1.065	98
Pot Nets Lakeside										
Ph35-25	9/15/2004	1300	1,000	976	--	--	--	--	--	--
Ph35-30	9/16/2004	1400	1.65	1.72	--	<0.04	0.887	94	1.031	104
Ph35-31	9/16/2004	1200	0.98	1.07	--	<0.04	0.866	90	0.957	95
Ph35-32	9/15/2004	1945	170	189	--	--	--	--	--	--
Ph35-33	9/15/2004	1730	1,220	885	--	--	--	--	--	--
Ph35-34	9/15/2004	1445	0.89	1.52	--	<0.04	0.997	106	1.106	100
Field Blank										
Ph35-25	9/16/2004	0930	1.62	2.37	--	--	--	--	--	--

[a] Samples were spiked to provide theoretical methyl mercury concentration of 1 nanogram per liter.

[b] Samples were spiked with VOCs to provide theoretical concentrations similar to the VOC concentrations previously found in one or more water samples. Resultant VOC compounds and theoretical concentrations: Tetrachloroethylene (0.042 µg/L, or micrograms per liter), Trichloroethylene (0.42 µg/L), 1,1,1-Trichloroethane (0.8 µg/L), 1,1-Dichloroethane (0.042 µg/L), Diethylether (0.016 µg/L), and Benzene (0.008 µg/L).

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (PH35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds*

[DGS, Delaware Geological Survey; µg/L, micrograms per liter; <, less than; E, estimated value determined by laboratory; values in bold indicate compound either detected or found at measurable concentration; concentrations are not corrected for surrogate recoveries]

DGS local well number	Sample date	Sample time	1,1,1,2-Tetrachloroethane (µg/L)	1,1,1-Trichloroethane (µg/L)	1,1,2,2-Tetrachloroethane (µg/L)	1,1,2-Trichloroethane (µg/L)	1,1-Dichloroethane (µg/L)	1,1-Dichloroethylene (µg/L)
Pot Nets Bayside								
Pi31-01	9/13/2004	1000	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-16	9/14/2004	1610	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-17	9/14/2004	1330	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-18	9/14/2004	1140	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-19	9/14/2004	1000	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-20	9/13/2004	1740	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pi31-21	9/13/2004	1910	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Pot Nets Lakeside								
Ph35-25	9/15/2004	1300	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Ph35-30	9/16/2004	1400	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Ph35-31	9/16/2004	1200	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Ph35-32	9/15/2004	1945	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Ph35-33	9/15/2004	1730	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Ph35-34	9/15/2004	1445	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02
Field Blank								
Ph35-25	9/16/2004	0930	<0.03	<0.03	<0.16	<0.06	<0.04	<0.02

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	1,1-Dichloropropene (µg/L)	1,2,3,4-Tetramethyl-benzene (µg/L)	1,2,3,5-Tetramethyl-benzene (µg/L)	1,2,3-Trichlorobenzene (µg/L)	1,2,3-Trichloropropane (µg/L)	1,2,3-Trimethyl-benzene (µg/L)	1,2,4-Trichloro-benzene (µg/L)	1,2,4-Trimethyl-benzene (µg/L)
Pot Nets Bayside										
Pi31-01	9/13/2004	1000	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-16	9/14/2004	1610	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-17	9/14/2004	1330	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-18	9/14/2004	1140	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-19	9/14/2004	1000	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-20	9/13/2004	1740	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pi31-21	9/13/2004	1910	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Pot Nets Lakeside										
Ph35-25	9/15/2004	1300	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Ph35-30	9/16/2004	1400	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Ph35-31	9/16/2004	1200	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Ph35-32	9/15/2004	1945	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Ph35-33	9/15/2004	1730	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Ph35-34	9/15/2004	1445	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06
Field Blank										
Ph35-25	9/16/2004	0930	<0.03	<0.1	<0.1	<0.3	<0.18	<0.1	<0.1	<0.06

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	1,2-Dibromo-3-chloropropane (µg/L)	1,2-Dibromoethane (µg/L)	1,2-Dichlorobenzene (µg/L)	1,2-Dichloroethane (µg/L)	1,2-Dichloroethane-d4, recovery surrogate (percent)	1,2-Dichloropropane (µg/L)
Pot Nets Bayside								
Pi31-01	9/13/2004	1000	<0.5	<0.04	<0.05	<0.1	117	<0.03
Pi31-16	9/14/2004	1610	<0.5	<0.04	<0.05	<0.1	114	<0.03
Pi31-17	9/14/2004	1330	<0.5	<0.04	<0.05	<0.1	116	<0.03
Pi31-18	9/14/2004	1140	<0.5	<0.04	<0.05	<0.1	116	<0.03
Pi31-19	9/14/2004	1000	<0.5	<0.04	<0.05	<0.1	118	<0.03
Pi31-20	9/13/2004	1740	<0.5	<0.04	<0.05	<0.1	118	<0.03
Pi31-21	9/13/2004	1910	<0.5	<0.04	<0.05	<0.1	115	<0.03
Pot Nets Lakeside								
Ph35-25	9/15/2004	1300	<0.5	<0.04	<0.05	<0.1	119	<0.03
Ph35-30	9/16/2004	1400	<0.5	<0.04	<0.05	<0.1	116	<0.03
Ph35-31	9/16/2004	1200	<0.5	<0.04	<0.05	<0.1	118	<0.03
Ph35-32	9/15/2004	1945	<0.5	<0.04	<0.05	<0.1	120	<0.03
Ph35-33	9/15/2004	1730	<0.5	<0.04	<0.05	<0.1	122	<0.03
Ph35-34	9/15/2004	1445	<0.5	<0.04	<0.05	<0.1	119	<0.03
Field Blank								
Ph35-25	9/16/2004	0930	<0.5	<0.04	<0.05	<0.1	111	<0.03

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	1,3,5-Trimethylbenzene (µg/L)	1,3-Dichlorobenzene (µg/L)	1,3-Dichloropropane (µg/L)	1,4-Dichlorobenzene (µg/L)	1,4-Bromofluorobenzene, recovery surrogate (percent)	2,2-Dichloropropane (µg/L)
Pot Nets Bayside								
Pi31-01	9/13/2004	1000	<0.04	<0.03	<0.1	<0.03	74.7	<0.05
Pi31-16	9/14/2004	1610	<0.04	<0.03	<0.1	<0.03	73.3	<0.05
Pi31-17	9/14/2004	1330	<0.04	<0.03	<0.1	<0.03	73.9	<0.05
Pi31-18	9/14/2004	1140	<0.04	<0.03	<0.1	<0.03	73.0	<0.05
Pi31-19	9/14/2004	1000	<0.04	<0.03	<0.1	<0.03	72.0	<0.05
Pi31-20	9/13/2004	1740	<0.04	<0.03	<0.1	<0.03	72.0	<0.05
Pi31-21	9/13/2004	1910	<0.04	<0.03	<0.1	<0.03	72.6	<0.05
Pot Nets Lakeside								
Ph35-25	9/15/2004	1300	<0.04	<0.03	<0.1	<0.03	70.6	<0.05
Ph35-30	9/16/2004	1400	<0.04	<0.03	<0.1	<0.03	70.8	<0.05
Ph35-31	9/16/2004	1200	<0.04	<0.03	<0.1	<0.03	71.3	<0.05
Ph35-32	9/15/2004	1945	<0.04	<0.03	<0.1	<0.03	70.9	<0.05
Ph35-33	9/15/2004	1730	<0.04	<0.03	<0.1	<0.03	71.5	<0.05
Ph35-34	9/15/2004	1445	<0.04	<0.03	<0.1	<0.03	71.8	<0.05
Field Blank								
Ph35-25	9/16/2004	0930	<0.04	<0.03	<0.1	<0.03	74.0	<0.05

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	2-Chlorotoluene (µg/L)	*o*-Ethyl toluene (µg/L)	3-Chloropropene (µg/L)	4-Chlorotoluene (µg/L)	4-Isopropyl-1-methylbenzene (µg/L)	Acetone (µg/L)	Acrylonitrile (µg/L)
Pot Nets Bayside									
Pi31-01	9/13/2004	1000	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pi31-16	9/14/2004	1610	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pi31-17	9/14/2004	1330	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pi31-18	9/14/2004	1140	<0.04	<0.06	<0.50	<0.05	**E 0.03**	<6	<1
Pi31-19	9/14/2004	1000	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pi31-20	9/13/2004	1740	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pi31-21	9/13/2004	1910	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Pot Nets Lakeside									
Ph35-25	9/15/2004	1300	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Ph35-30	9/16/2004	1400	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Ph35-31	9/16/2004	1200	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Ph35-32	9/15/2004	1945	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Ph35-33	9/15/2004	1730	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Ph35-34	9/15/2004	1445	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1
Field Blank									
Ph35-25	9/16/2004	0930	<0.04	<0.06	<0.50	<0.05	<0.08	<6	<1

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Benzene (µg/L)	Bromobenzene (µg/L)	Bromochloro-methane (µg/L)	Bromodichloro-methane (µg/L)	Bromoethene (µg/L)	Bromomethane (µg/L)	Carbon disulfide (µg/L)
Pot Nets Bayside									
Pi31-01	9/13/2004	1000	**E 0.01**	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-16	9/14/2004	1610	**E 0.02**	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-17	9/14/2004	1330	**E 0.01**	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-18	9/14/2004	1140	**E 0.02**	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-19	9/14/2004	1000	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-20	9/13/2004	1740	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pi31-21	9/13/2004	1910	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Pot Nets Lakeside									
Ph35-25	9/15/2004	1300	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Ph35-30	9/16/2004	1400	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Ph35-31	9/16/2004	1200	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Ph35-32	9/15/2004	1945	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Ph35-33	9/15/2004	1730	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Ph35-34	9/15/2004	1445	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04
Field Blank									
Ph35-25	9/16/2004	0930	<0.02	<0.03	<0.12	<0.03	<0.1	<0.3	<0.04

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Chlorobenzene (µg/L)	Chloroethane (µg/L)	Chloromethane (µg/L)	*cis*-1,2-Dichloro-ethylene (µg/L)	*cis*-1,3-Dichloro-propene (µg/L)	Dibromochloro-methane (µg/L)	Dibromomethane (µg/L)
Pot Nets Bayside									
Pi31-01	9/13/2004	1000	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-16	9/14/2004	1610	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-17	9/14/2004	1330	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-18	9/14/2004	1140	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-19	9/14/2004	1000	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-20	9/13/2004	1740	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pi31-21	9/13/2004	1910	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Pot Nets Lakeside									
Ph35-25	9/15/2004	1300	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Ph35-30	9/16/2004	1400	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Ph35-31	9/16/2004	1200	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Ph35-32	9/15/2004	1945	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Ph35-33	9/15/2004	1730	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Ph35-34	9/15/2004	1445	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05
Field Blank									
Ph35-25	9/16/2004	0930	<0.03	<0.1	<0.2	<0.02	<0.05	<0.1	<0.05

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Dichloromethane (µg/L)	Diethyl ether (µg/L)	Diisopropyl ether (µg/L)	Ethyl methacrylate (µg/L)	2-Butanone (µg/L)	Ethylbenzene (µg/L)	Hexachloro-butadiene (µg/L)	Hexachloro-ethane (µg/L)
Pot Nets Bayside										
Pi31-01	9/13/2004	1000	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-16	9/14/2004	1610	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-17	9/14/2004	1330	<0.1	**0.2**	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-18	9/14/2004	1140	<0.1	**0.4**	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-19	9/14/2004	1000	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-20	9/13/2004	1740	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pi31-21	9/13/2004	1910	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Pot Nets Lakeside										
Ph35-25	9/15/2004	1300	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Ph35-30	9/16/2004	1400	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Ph35-31	9/16/2004	1200	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Ph35-32	9/15/2004	1945	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Ph35-33	9/15/2004	1730	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1
Ph35-34	9/15/2004	1445	<0.1	<0.1	<0.10	<0.2	<4.0	**E 0.03**	<0.1	<0.1
Field Blank										
Ph35-25	9/16/2004	0930	<0.1	<0.1	<0.10	<0.2	<4.0	<0.03	<0.1	<0.1

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Methyl iodide (µg/L)	4-Methyl-2-pentanone (µg/L)	Isopropylbenzene (µg/L)	Methyl acrylonitrile (µg/L)	Methyl acrylate (µg/L)	Methyl methacrylate (µg/L)	Methyl *tert*-Pentyl ether (µg/L)	*m*- and *p*-Xylene (µg/L)	Naphthalene (µg/L)
Pot Nets Bayside											
Pi31-01	9/13/2004	1000	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-16	9/14/2004	1610	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-17	9/14/2004	1330	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-18	9/14/2004	1140	<0.35	<0.4	**E 0.01**	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-19	9/14/2004	1000	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-20	9/13/2004	1740	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pi31-21	9/13/2004	1910	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Pot Nets Lakeside											
Ph35-25	9/15/2004	1300	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Ph35-30	9/16/2004	1400	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Ph35-31	9/16/2004	1200	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Ph35-32	9/15/2004	1945	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Ph35-33	9/15/2004	1730	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Ph35-34	9/15/2004	1445	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5
Field Blank											
Ph35-25	9/16/2004	0930	<0.35	<0.4	<0.04	<0.8	<2.0	<0.3	<0.08	<0.06	<0.5

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	2-Hexanone (µg/L)	Butylbenzene (µg/L)	*n*-Propylbenzene (µg/L)	*o*-Xylene (µg/L)	*sec*-Butylbenzene (µg/L)	Styrene (µg/L)	Ethyl *tert*-Butyl ether (µg/L)	Methyl *tert*-Butyl ether (µg/L)	*tert*-Butylbenzene (µg/L)
Pot Nets Bayside											
Pi31-01	9/13/2004	1000	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-16	9/14/2004	1610	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-17	9/14/2004	1330	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-18	9/14/2004	1140	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-19	9/14/2004	1000	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-20	9/13/2004	1740	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pi31-21	9/13/2004	1910	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Pot Nets Lakeside											
Ph35-25	9/15/2004	1300	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Ph35-30	9/16/2004	1400	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Ph35-31	9/16/2004	1200	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Ph35-32	9/15/2004	1945	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Ph35-33	9/15/2004	1730	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Ph35-34	9/15/2004	1445	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06
Field Blank											
Ph35-25	9/16/2004	0930	<0.7	<0.1	<0.04	<0.04	<0.06	<0.04	<0.05	<0.2	<0.06

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Tetrachloro-ethylene (µg/L)	Tetrachloro-methane (µg/L)	Tetrahydro-furan (µg/L)	Toluene (µg/L)	Toluene-d8, recovery surrogate (percent)	*trans*-1,2-Dichloro-ethylene (µg/L)	*trans*-1,3-Dichloro-propene (µg/L)	*trans*-1,4-Dichloro-2-butene (µg/L)	Bromoform (µg/L)	Trichloro-ethylene (µg/L)
Pot Nets Bayside												
Pi31-01	9/13/2004	1000	**E 0.02**	<0.06	<2	<0.05	99.8	<0.03	<0.09	<0.7	<0.10	**0.23**
Pi31-16	9/14/2004	1610	<0.06	<0.06	<2	<0.05	98.1	<0.03	<0.09	<0.7	<0.10	<0.04
Pi31-17	9/14/2004	1330	<0.06	<0.06	<2	<0.05	99.1	<0.03	<0.09	<0.7	<0.10	<0.04
Pi31-18	9/14/2004	1140	<0.06	<0.06	<2	<0.05	98.1	<0.03	<0.09	<0.7	<0.10	<0.04
Pi31-19	9/14/2004	1000	<0.06	<0.06	<2	<0.05	98.1	<0.03	<0.09	<0.7	<0.10	**0.11**
Pi31-20	9/13/2004	1740	<0.06	<0.06	<2	<0.05	99.2	<0.03	<0.09	<0.7	<0.10	**0.22**
Pi31-21	9/13/2004	1910	<0.06	<0.06	<2	<0.05	98.3	<0.03	<0.09	<0.7	<0.10	<0.04
Pot Nets Lakeside												
Ph35-25	9/15/2004	1300	<0.06	<0.06	<2	<0.05	99.2	<0.03	<0.09	<0.7	<0.10	<0.04
Ph35-30	9/16/2004	1400	<0.06	<0.06	<2	<0.05	100	<0.03	<0.09	<0.7	<0.10	<0.04
Ph35-31	9/16/2004	1200	<0.06	<0.06	<2	<0.05	99.3	<0.03	<0.09	<0.7	<0.10	<0.04
Ph35-32	9/15/2004	1945	<0.06	<0.06	<2	<0.05	100	<0.03	<0.09	<0.7	<0.10	<0.04
Ph35-33	9/15/2004	1730	<0.06	<0.06	<2	<0.05	99.2	<0.03	<0.09	<0.7	<0.10	<0.04
Ph35-34	9/15/2004	1445	<0.06	<0.06	<2	**1.01**	98.3	<0.03	<0.09	<0.7	<0.10	<0.04
Field Blank												
Ph35-25	9/16/2004	0930	<0.06	<0.06	<2	<0.05	96.3	<0.03	<0.09	<0.7	<0.10	<0.04

Table A15. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Volatile and semi-volatile organic compounds - Continued*

DGS local well number	Sample date	Sample time	Chloroform (µg/L)	Vinyl chloride (µg/L)
		Pot Nets Bayside		
Pi31-01	9/13/2004	1000	**0.91**	<0.1
Pi31-16	9/14/2004	1610	**0.44**	<0.1
Pi31-17	9/14/2004	1330	**0.37**	<0.1
Pi31-18	9/14/2004	1140	**0.35**	<0.1
Pi31-19	9/14/2004	1000	**0.51**	<0.1
Pi31-20	9/13/2004	1740	**2.18**	<0.1
Pi31-21	9/13/2004	1910	**3.53**	<0.1
		Pot Nets Lakeside		
Ph35-25	9/15/2004	1300	**0.31**	<0.1
Ph35-30	9/16/2004	1400	**0.20**	<0.1
Ph35-31	9/16/2004	1200	**0.77**	<0.1
Ph35-32	9/15/2004	1945	**0.50**	<0.1
Ph35-33	9/15/2004	1730	**E 0.08**	<0.1
Ph35-34	9/15/2004	1445	**0.38**	<0.1
		Field Blank		
Ph35-25	9/16/2004	0930	<0.02	<0.1

Table A16. *Ground-water-quality data for Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Dissolved gases*

[DGS, Delaware Geological Survey; °C, degrees Celsius; mg/L, milligrams per liter; atm., atmospheres; --, no data]

DGS local well number	Sample date	Sample time	Air temperature (°C)	Recharge elevation (feet)	Concentration (mg/L)[a]					Partial pressures at field temperatures (atm.)[a]				
					Methane	Carbon dioxide	Nitrogen	Oxygen	Argon	Methane	Carbon dioxide	Nitrogen	Oxygen	Argon
					CH_4	CO_2	N_2	O_2	Ar	CH_4	CO_2	N_2	O_2	Ar
Pot Nets Bayside														
Pi31-01	9/13/2004	1009	22.3	13.9	0.000	174.407	18.905	2.702	0.6622	0.000000	0.108348	0.9972	0.0633	0.01134
		1025	22.3	13.9	0.000	173.322	19.295	2.556	0.6693	0.000000	0.108038	1.0197	0.0600	0.01149
Pi31-16	9/14/2004	1618	22.0	14.0	0.005	170.950	18.461	0.667	0.6414	0.000231	0.105661	0.9710	0.0156	0.01095
		1627	22.0	14.0	0.004	169.033	18.961	0.837	0.6486	0.000174	0.104477	0.9974	0.0195	0.01107
Pi31-17	9/14/2004	1334	21.0	13.7	0.001	222.760	19.759	1.058	0.6634	0.000040	0.133817	1.0231	0.0243	0.01112
		1344	21.0	13.7	0.000	222.248	19.253	1.087	0.6570	0.000012	0.133509	0.9969	0.0249	0.01101
Pi31-18	9/14/2004	1147	20.0	13.8	0.000	275.070	19.792	0.086	0.6537	0.000018	0.160531	1.0084	0.0019	0.01076
		1156	20.0	13.8	0.000	273.737	20.838	0.114	0.6686	0.000018	0.159753	1.0617	0.0026	0.01100
Pi31-19	9/14/2004	1009	20.0	13.6	0.000	120.189	19.245	3.930	0.6757	0.000000	0.070142	0.9805	0.0885	0.01112
		1016	20.0	13.6	0.000	119.302	18.859	4.100	0.6674	0.000000	0.069624	0.9608	0.0923	0.01098
Pi31-20	9/13/2004	1840	23.5	13.7	0.002	159.554	19.961	3.826	0.7011	0.000072	0.102843	1.0742	0.0917	0.01229
		1840	23.5	13.7	0.002	158.934	19.689	3.814	0.6973	0.000093	0.102443	1.0596	0.0914	0.01222
Pi31-21	9/13/2004	1916	22.0	13.8	0.000	119.041	20.414	3.858	0.7169	0.000000	0.073577	1.0738	0.0901	0.01224
		1923	22.0	13.8	0.000	120.062	20.207	4.375	0.7158	0.000000	0.074208	1.0629	0.1022	0.01222
Pot Nets Lakeside														
Ph35-25	9/15/2004	1309	21.0	10.9	0.001	42.475	19.238	3.606	0.6822	0.000021	0.025516	0.9961	0.0827	0.01144
		1316	21.0	10.9	0.001	42.238	19.281	3.591	0.6869	0.000041	0.025373	0.9983	0.0824	0.01152
Ph35-30	9/16/2004	1410	20.5	11.1	0.000	39.944	19.751	5.625	0.6949	0.000000	0.023652	1.0145	0.1279	0.01154
		1410	20.5	11.1	--	--	--	--	--	--	--	--	--	--
Ph35-31	9/16/2004	1205	20.5	10.9	0.000	40.487	20.216	5.554	0.7130	0.000009	0.023974	1.0384	0.1262	0.01184
		1215	20.5	10.9	0.000	41.049	20.300	5.140	0.7143	0.000009	0.024307	1.0427	0.1168	0.01186
Ph35-32	9/15/2004	2033	20.0	10.9	0.001	38.715	19.785	1.379	0.7022	0.000026	0.022594	1.0080	0.0311	0.01156
		2037	20.0	10.9	0.001	38.561	19.213	1.261	0.6906	0.000029	0.022504	0.9789	0.0284	0.01136
Ph35-33	9/15/2004	1744	21.0	10.7	0.001	50.915	16.388	1.690	0.5908	0.000044	0.030586	0.8485	0.0388	0.00990
		1752	21.0	10.7	0.000	51.775	16.473	1.805	0.5954	0.000020	0.031103	0.8530	0.0414	0.00998
Ph35-34	9/15/2004	1510	21.0	10.7	0.000	115.075	21.893	1.679	0.7689	0.000000	0.069128	1.1336	0.0385	0.01289
		1520	21.0	10.7	0.000	115.425	21.842	1.602	0.7648	0.000000	0.069339	1.1309	0.0367	0.01282

[a] Determined by U.S. Geological Survey Laboratory, Reston, Virginia.

Table A17. *Ground-water-quality data for Pots Net Bayside (Pi31-01) and Lakeside (Ph35-25) production and monitoring wells sampled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Chlorofluorocarbons*[a]

[DGS, Delaware Geological Survey; cm^3/kg, cubic centimeters per kilogram; °C, degrees Celsius; CFC, Chlorofluorocarbon; pmol/kg, picomoles per kilogram; pg/kg, picograms per kilogram; Modern, apparent age estimated to be more recent than 2001; --, apparent age estimate not available due to excessive CFC concentration]

DGS local well number	Sample date	Sample time	Excess air (cm^3/kg)	Recharge temperature (°C)	Recharge elevation (feet)	Concentration[a]			Concentration[a]			Apparent date of recharge (excess air corrected)[a]		
						CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	CFC-11 (pg/kg)	CFC-12 (pg/kg)	CFC-113 (pg/kg)	CFC-11 (year)	CFC-12 (year)	CFC-113 (year)
Pot Nets Bayside														
Pi31-01	9/13/2004	1000	2.5	14.3	13.9	3.82	2.51	0.48	524.65	303.03	89.07	1987	Modern	--
		1020	2.5	14.3	13.9	3.87	2.48	0.47	531.53	299.34	87.19	1987	2001	Modern
Pi31-16	9/13/2004	1650	2.7	16.2	14.0	1.59	1.13	0.07	218.69	136.12	13.18	1974	1977	1977
		1621	2.7	16.2	14.0	1.57	1.11	0.07	216.27	134.10	13.63	1974	1977	1977
Pi31-17	9/14/2004	1330	3.5	15.9	13.7	2.41	1.55	0.18	331.27	187.60	34.59	1978	1983	1984
		1339	3.5	15.9	13.7	2.52	1.60	0.20	346.38	193.43	36.70	1980	1984	1985
Pi31-18	9/14/2004	1143	3.1	15.4	3.8	1.17	1.18	0.10	160.46	143.01	18.67	1972	1978	1979
		1151	3.1	15.4	13.8	1.14	1.17	0.09	155.97	141.66	17.22	1971	1977	1979
Pi31-19	9/14/2004	1013	2.2	13.5	13.6	4.43	2.34	0.50	608.57	283.43	93.02	1989	1991	--
		1005	2.2	13.5	13.6	4.06	2.35	0.49	557.24	284.19	92.15	1987	1991	--
Pi31-20	9/13/2004	0822	2.4	11.8	13.7	3.91	2.50	0.62	537.33	302.47	115.68	1984	1990	--
		1835	2.4	11.8	13.7	3.86	2.56	0.61	529.77	309.25	115.23	1984	1991	--
Pi31-21	9/13/2004	1920	2.5	10.9	13.8	4.36	3.04	0.44	598.71	367.41	83.31	1986	--	1990
		1929	2.5	10.9	13.8	4.39	3.00	0.44	602.47	363.29	81.77	1986	Modern	1989
Pot Nets Lakeside														
Ph35-25	9/15/2004	1313	2.0	12.4	10.9	1.39	4.33	0.07	191.12	523.52	12.31	1972	--	1975
		1323	2.0	12.4	10.9	1.38	4.29	0.06	189.08	518.20	10.72	1972	--	1974
Ph35-30	9/16/2004	1415	2.4	12.2	11.1	0.93	0.97	0.02	127.26	117.77	3.01	1969	1974	1965
		1425	2.4	12.2	11.1	0.93	0.94	0.02	127.69	113.38	3.31	1969	1973	1966
Ph35-31	9/16/2004	1200	2.5	11.0	10.9	1.81	1.57	0.08	248.11	190.03	15.80	1973	1979	1976
		1210	2.5	11.0	10.9	1.79	1.45	0.06	245.99	174.85	10.45	1973	1978	1973
Ph35-32	9/15/2004	2043	2.0	11.5	10.9	2.71	28.98	0.12	371.87	3,504.17	22.09	1977	--	1979
		2047	2.0	11.5	10.9	2.83	29.55	0.12	388.73	3,573.25	23.26	1977	--	1979
Ph35-33	9/15/2004	1747	0.9	18.0	10.7	2.19	1.74	0.20	300.20	210.21	37.12	1979	1988	1986
		1755	0.9	18.0	10.7	2.34	1.69	0.20	321.06	204.87	37.05	1980	1987	1986
Ph35-34	9/15/2004	1505	3.0	8.3	10.7	5.09	3.31	0.43	698.84	400.22	80.72	1986	2001	1988
		1525	3.0	8.3	10.7	5.01	3.29	0.42	688.20	397.29	79.32	1985	1999	1988

[a] Excess air, concentration data, and apparent recharge dates provided by U.S. Geological Survey Laboratory, Reston, Virginia.

Table A18. *Constituents and methods for bulk properties, carbon, nutrients, major ions, trace elements, stable isotopes, and trace gases for water samples collected from selected production and monitoring wells sampled by the U.S. Geological Survey, 2003-04*

[CAS, Chemical Abstracts Service; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ng/L, nanograms per liter; --, not applicable or unavailable; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity unit; ASF, automated-segmented flow; ICP, inductively coupled plasma; MS, mass spectrometry; AA, atomic absorption; GC, gas chromatography; AF, Cold Vapor Atomic Fluorescence]

Constituent	CAS number	Sample type	Reporting Level	Reporting Units	Method of analysis
Mercury					
Total Mercury	--	Filtered[o]	0.01-0.09	ng/L	GC/AF[k,l]
Total Mercury	--	Whole (raw)	0.01-0.09	ng/L	GC/AF[k,l]
Methyl mercury	--	Filtered[o]	0.003-0.04	ng/L	GC/AF[k,l]
Bulk Properties					
Oxidation-reduction potential	--	Whole (raw)	1	millivolt	Field, probe[a]
Turbidity	--	Whole (raw)	0.1	NTU	Field, probe[a]
Dissolved oxygen	--	Whole (raw)	0.1	mg/L	Field, probe[a]
pH	--	Whole (raw)	0.1	Standard units	Field, probe[a]
Specific conductance	--	Whole (raw)	0.1	µS/cm	Field, probe[a]
Temperature	--	Whole (raw)	0.1	°C	Field, probe[a]
Buffering capacity (alkalinity or acid-neutralization capacity), as calcium carbonate, $CaCO_3$	--	Whole (raw)	0.1	mg/L	Field[a], (titration, commonly incremental, with Gran method)
Bicarbonate, as HCO_3^-	--	Whole (raw)	0.1	mg/L	Field[a] (see buffering capacity)
Carbonate, as CO_3^{2-}	--	Whole (raw)	0.1	mg/L	Field[a] (see buffering capacity)
Sulfide	--	Whole (raw)	0.001	mg/L	Field, probe[q]
UV Absorbance, 254 nm	--	Whole (raw)	0.004	units/cm	Lab[r]
UV Absorbance, 280 nm	--	Whole (raw)	0.004	units/cm	Lab[r]
Nutrients					
Carbon, total particulate	--	Filtered[o]	0.12	mg/L	High temperature combustion, thermal conductivity[b]
Carbon, organic particulate	--	Filtered[o]	0.12	mg/L	High temperature combustion, thermal conductivity[b]
Carbon, organic dissolved	--	Filtered[o]	0.33	mg/L	High temperature combustion, thermal conductivity[b]
Carbon, inorganic particulate	--	Filtered[o]	0.12	mg/L	High temperature combustion, thermal conductivity[b]
Nitrogen, total particulate	17778-88-0	Filtered[o]	0.022	mg/L	High temperature combustion, thermal conductivity[b]
Nitrite (as nitrogen)	14797-65-0	Filtered[o]	0.008	mg/L	ASF, colorimetry, diazo complex[c]
Nitrite plus nitrate (as nitrogen)	--	Filtered[o]	0.060	mg/L	ASF, colorimetry, cadmium reduction, diazo complex[c]

Table 18. *Constituents and methods for bulk properties, carbon, nutrients, major ions, trace elements, stable isotopes, and trace gases for water samples collected from selected water-supply and monitoring wells sampled by the U.S. Geological Survey, 2003-04 – Continued*

Major Ions and Trace Elements					
Bromide	24959-67-9	Filtered[o]	0.016	mg/L	ASF, colorimetry, fluorescein[d]
Chloride	16887-00-6	Filtered[o]	0.02	mg/L	ICP[d]
Fluoride	16984-48-8	Filtered[o]	0.17	mg/L	ASF, ion-selective electrode[d]
Sulfate	14808-79-8	Filtered[o]	0.18	mg/L	ICP[d] (blank bias corrected)
Silica	7631-86-9	Filtered[o]	0.04	mg/L	ICP[b,c]
Calcium	7440-70-2	Filtered[o]	0.010	mg/L	ICP[c]
Magnesium	7439-95-4	Filtered[o]	0.008	mg/L	ICP[c]
Sodium	7440-23-5	Filtered[o]	0.10	mg/L	ICP[c]
Potassium	7440-09-7	Filtered[o]	0.16	mg/L	AA Flame[d]
Arsenic	7440-38-2	Filtered[o]	1.9	µg/L	ICP/MS[g,h]
Barium	7440-39-3	(Un)filtered[o]	0.2	µg/L	ICP/MS[c,e]
Boron	7440-42-8	Filtered[o]	8	µg/L	ICP/MS[g,h]
Cadmium	7440-43-9	Filtered[o]	0.04	µg/L	ICP/MS[c,e]
Chromium	7440-47-3	Filtered[o]	0.8	µg/L	ICP/MS[c,e,i]
Copper	7440-50-8	Filtered[o]	0.4	µg/L	ICP/MS[c,e]
Iron	7439-89-6	(Un)filtered[o]	6.4	µg/L	ICP[c]
Lead	7439-92-1	(Un)filtered[o]	0.08	µg/L	(ICP), ICP/MS[c,e]
Manganese	7439-96-5	(Un)filtered[o]	0.8	µg/L	(ICP), ICP/MS[c,e]
Molybdenum	7439-98-7	Filtered[o]	0.4	µg/L	ICP/MS[c,e,j]
Nickel	7440-02-0	Filtered[o]	0.06	µg/L	ICP/MS[c,e]
Selenium	7782-49-2	Filtered[o]	0.4	µg/L	ICP/MS[g,h]
Zinc	7440-66-6	Filtered[o]	0.6	µg/L	ICP/MS[c,e]
Stable Isotopes and Trace Gases					
Oxygen-Deuterium, ratio	--	Whole (raw)	--	per mil[p]	MS[m]
Oxygen^{16}-Oxygen^{18}, ratio	--	Whole (raw)	--	per mil[p]	MS[m]
Chlorofluorocarbons	--	Whole (raw)	0.038	µg/L	GC[n]
Dissolved gases (Argon, Carbon dioxide, Methane, Nitrogen, and Oxygen)	--	Whole (raw)	--	mg/L and atmospheres	GC[n]

Note: Footnotes appear on following pages.

[a] U.S. Geological Survey, 1997 to present, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, 2 v., variously paged. [Also available online at URL http://water.usgs.gov/owq/FieldManual. Chapters originally were published from 1997-1999; updates and revisions are ongoing and are summarized at URL http://water.usgs.gov/owq/FieldManual/mastererrata.html]

[b] Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of dissolved organic carbon by UV-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92-480, 12 p.

[c] Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

[d] Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

[e] Faires, L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of metals in water by inductively-coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.

[f] Struzeski, T.M., DeGiacomo, W.J., and Zayhowski, E.J., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of dissolved aluminum and boron in water by inductively coupled plasma-atomic absorption spectroscopy: U.S. Geological Survey Open-File Report 96-149, 17 p.

[g] Jones, S.R, and Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of arsenic and selenium by graphite furnace-atomic absorption spectrophotometry: U.S. Geological Survey Open-File Report 98-639, 39 p.

[h] Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of dissolved arsenic, boron, lithium, selenium, strontium, thallium, and vanadium using inductively-coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 99-093, 31 p.

[i] McLain, Betty, 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of chromium in water by graphite furnace atomic absorption spectrophotometry: U.S. Geological Survey Open-File Report 93-449, 16 p.

[j] Jones, S.R., and McLain, B.J., 1997, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of molybdenum in water by graphite furnace atomic absorption spectrophotometry: U.S. Geological Survey Open-File Report 97-198, 32 p.

[k] DeWild, J.F., Olson, M.L., and Olund, S.D., 2002, Determination of methyl mercury by aqueous phase ethylation, followed by gas chromatographic separation with cold vapor atomic fluorescence detection: U.S. Geological Survey Open-File Report 01-445, 14 p.

[l] Olson, M.L., and DeWild, J.F., 1999, Low-level collection techniques and species-specific analytical methods for mercury in water, sediment, and biota: U.S. Geological Survey Water-Resources Investigations Report 99-4018b, 11 p.

[m] Coplen, T.B., Wildman, J.D. and Chen, J., 1991, Improvements in the gaseous hydrogen-water equilibration technique for hydrogen isotope ratio analysis: Analytical Chemistry, vol. 63, p. 910-912.

[n] Busenburg, E., Plummer, L.N., Bartholomay, R.C. and Wayland, J.E., Chlorofluorocarbons, sulfur hexafluoride, and dissolved permanent gases in ground water from selected sites in and near the Idaho National Engineering and Environmental Laboratory, Idaho, 1994-97: U.S. Geological Survey Open-File Report 98-274, 74 p.

[o] Particulate nitrogen and carbon and dissolved carbon species: glass-fiber plate filter, 25-millimeter diameter with 0.45-micrometer nominal pore size; all other filtered species: nylon capsule and encapsulated, fluted, 0.4-micrometer nominal pore size membrane, pretreated with 7-day acid soak (50% (V:V) HCl:Deionized activated carbon filtered water), prerinsed 1 liter of DAC water, double-bagged, refrigerated until used, and prerinsed with 250 milliliters of raw water before filtered sample collected.

[p] Reporting level is determined as parts per thousand (per mill) difference from Vienna Standard Mean Ocean Water (VSMOW) reference water. The 2-sigma standard deviation of the analyses is 0.2 per mill.

[q] American Public Health Association (APHA), 1981, Part 400, Determination of inorganic nonmetallic constituents: Method 427 C, Methylene Blue Method, *in* Standard methods for the examination of water and wastewater: American Public Health Association, 15th ed., p. 447-449. Procedure is equivalent to U.S. Environmental Protection Agency Method 376.2 and Standard Method 4500-S2-D for wastewater.

[r] American Public Health Association, 1995, Ultra-violet absorbing organic constituents, *in* Standard methods for the examination of water and wastewater, 19th ed., p. 5-60 to 5-62.

Table A19. *Constituents and analytical methods for volatile and semi-volatile organic compounds for water samples collected from selected production and monitoring wells sampled by the U.S. Geological Survey, 2003-04*

[CAS, Chemical Abstracts Service; IUPAC, International Union of Pure and Applied Chemistry; µg/L, micrograms per liter; GC, gas chromatography; MS, mass spectrometry; --, unavailable data. Volatile organic compounds are grouped by chemical structure, starting with simpler hydrocarbons and ending with more complex, more highly substituted hydrocarbons.]

Constituent/ common name	CAS number	Chemical name (IUPAC name, except where noted)	Sample type	Reporting Level	Reporting Units	Method of analysis
Benzene	71-43-2	Benzene	Whole (raw)	0.021	µg/L	GC/MS[a]
Toluene	108-88-3	Methylbenzene	Whole (raw)	0.05	µg/L	GC/MS[a]
Ethylbenzene	100-41-4	Ethylbenzene	Whole (raw)	0.030	µg/L	GC/MS[a]
Styrene	100-42-5	Ethenylbenzene	Whole (raw)	0.042	µg/L	GC/MS[a]
Isopropylbenzene	98-82-8	(1-Methylethyl)benzene	Whole (raw)	0.038	µg/L	GC/MS[a]
n-Propylbenzene	103-65-1	*n*-Propylbenzene	Whole (raw)	0.042	µg/L	GC/MS[a]
1,2,4-Trimethylbenzene	95-63-6	1,2,4-Trimethylbenzene	Whole (raw)	0.056	µg/L	GC/MS[a]
1,3,5-Trimethylbenzene	108-67-8	1,3,5-Trimethylbenzene	Whole (raw)	0.044	µg/L	GC/MS[a]
Butylbenzene	104-51-8	*n*-Butylbenzene	Whole (raw)	0.12	µg/L	GC/MS[a]
sec-Butylbenzene	135-98-8	(1-Methylpropyl)benzene	Whole (raw)	0.06	µg/L	GC/MS[a]
tert-Butylbenzene	98-06-6	(1,1-Dimethylethyl)benzene	Whole (raw)	0.06	µg/L	GC/MS[a]
4-Isopropyl-1-methylbenzene	99-87-6	1-Isopropyl-4-methylbenzene	Whole (raw)	0.08	µg/L	GC/MS[a]
Naphthalene	91-20-3	Naphthalene	Whole (raw)	0.52	µg/L	GC/MS[a]
Bromomethane	74-83-9	Bromomethane	Whole (raw)	0.26	µg/L	GC/MS[a]
Dibromomethane	74-95-3	Dibromomethane	Whole (raw)	0.050	µg/L	GC/MS[a]
Bromoform	75-25-2	Tribromomethane	Whole (raw)	0.10	µg/L	GC/MS[a]
Dibromochloromethane	124-48-1	Dibromochloromethane	Whole (raw)	0.10	µg/L	GC/MS[a]
Bromochloromethane	74-97-5	Bromochloromethane	Whole (raw)	0.12	µg/L	GC/MS[a]
Chloromethane	74-87-3	Chloromethane	Whole (raw)	0.17	µg/L	GC/MS[a]

Table 19. *Constituents and analytical methods for volatile and semi-volatile organic compounds for water samples collected from selected water-supply and monitoring wells sampled by the U.S. Geological Survey, 2003-04 – Continued*

Dichloromethane	75-09-2	Dichloromethane	Whole (raw)	0.06	µg/L	GC/MS[a]
Chloroform	67-66-3	Trichloromethane	Whole (raw)	0.024	µg/L	GC/MS[a]
Tetrachloromethane	56-23-5	Tetrachloromethane	Whole (raw)	0.06	µg/L	GC/MS[a]
Dichlorodifluoromethane	75-71-8	Dichlorodifluoromethane	Whole (raw)	0.18	µg/L	GC/MS[a]
Trichlorofluoromethane	75-69-4	Trichlorofluoromethane	Whole (raw)	0.16	µg/L	GC/MS[a]
1,1,2-Trichlorotrifluoroethane	76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane	Whole (raw)	0.038	µg/L	GC/MS[a]
1,2-Dibromoethane	106-93-4	1,2-Dibromoethane	Whole (raw)	0.036	µg/L	GC/MS[a]
Chloroethane	75-00-3	Chloroethane	Whole (raw)	0.12	µg/L	GC/MS[a]
1,1-Dichloroethane	75-34-3	1,1-Dichloroethane	Whole (raw)	0.035	µg/L	GC/MS[a]
1,2-Dichloroethane	107-06-2	1,2-Dichloroethane	Whole (raw)	0.13	µg/L	GC/MS[a]
1,1,1-Trichloroethane	71-55-6	1,1,1-Trichloroethane	Whole (raw)	0.032	µg/L	GC/MS[a]
1,1,2-Trichloroethane	79-00-5	1,1,2-Trichloroethane	Whole (raw)	0.064	µg/L	GC/MS[a]
1,1,1,2-Tetrachloroethane	630-20-6	1,1,1,2-Tetrachloroethane	Whole (raw)	0.030	µg/L	GC/MS[a]
1,1,2,2-Tetrachloroethane	79-34-5	1,1,2,2-Tetrachloroethane	Whole (raw)	0.16	µg/L	GC/MS[a]
Bromoethene	593-60-2	Bromoethene	Whole (raw)	0.10	µg/L	GC/MS[a]
Vinyl chloride	75-01-4	Chloroethene	Whole (raw)	0.06	µg/L	GC/MS[a]
1,1-Dichloroethylene	75-35-4	1,1-Dichloroethene	Whole (raw)	0.024	µg/L	GC/MS[a]
cis-1,2-Dichloroethylene	156-59-2	*cis*-1,2-Dichloroethene	Whole (raw)	0.024	µg/L	GC/MS[a]
trans-1,2-Dichloroethylene	156-60-5	*trans*-1,2-Dichloroethene	Whole (raw)	0.032	µg/L	GC/MS[a]
Trichloroethylene	79-01-6	Trichloroethene	Whole (raw)	0.038	µg/L	GC/MS[a]
Tetrachloroethylene	127-18-4	Tetrachloroethene	Whole (raw)	0.06	µg/L	GC/MS[a]
Bromobenzene	108-86-1	Bromobenzene	Whole (raw)	0.028	µg/L	GC/MS[a]
Chlorobenzene	108-90-7	Chlorobenzene	Whole (raw)	0.028	µg/L	GC/MS[a]

Table 19. *Constituents and analytical methods for volatile and semi-volatile organic compounds for water samples collected from selected water-supply and monitoring wells sampled by the U.S. Geological Survey, 2003-04 – Continued*

1,2-Dichlorobenzene	95-50-1	1,2-Dichlorobenzene	Whole (raw)	0.048	µg/L	GC/MS[a]
1,3-Dichlorobenzene	541-73-1	1,3-Dichlorobenzene	Whole (raw)	0.03	µg/L	GC/MS[a]
1,4-Dichlorobenzene	106-46-7	1,4-Dichlorobenzene	Whole (raw)	0.034	µg/L	GC/MS[a]
1,2,3-Trichlorobenzene	87-61-6	1,2,3-Trichlorobenzene	Whole (raw)	0.27	µg/L	GC/MS[a]
1,2,4-Trichlorobenzene	120-82-1	1,2,4-Trichlorobenzene	Whole (raw)	0.12	µg/L	GC/MS[a]
2-Chlorotoluene	95-49-8	1-Chloro-2-methylbenzene	Whole (raw)	0.04	µg/L	GC/MS[a]
4-Chlorotoluene	106-43-4	1-Chloro-4-methylbenzene	Whole (raw)	0.05	µg/L	GC/MS[a]
1,2-Dibromo-3-chloro-propane	96-12-8	1,2-Dibromo-3-chloropropane	Whole (raw)	0.51	µg/L	GC/MS[a]
1,2,3-Trichloropropane	96-18-4	1,2,3-Trichloropropane	Whole (raw)	0.18	µg/L	GC/MS[a]
1,2-Dichloropropane	78-87-5	1,2-Dichloropropane	Whole (raw)	0.029	µg/L	GC/MS[a]
1,3-Dichloropropane	142-28-9	1,3-Dichloropropane	Whole (raw)	0.06	µg/L	GC/MS[a]
2,2-Dichloropropane	594-20-7	2,2-Dichloropropane	Whole (raw)	0.05	µg/L	GC/MS[a]
1,1-Dichloropropene	563-58-6	1,1-Dichloropropene	Whole (raw)	0.026	µg/L	GC/MS[a]
cis-1,3-Dichloropropene	10061-01-5	*cis*-1,3-Dichloropropene	Whole (raw)	0.05	µg/L	GC/MS[a]
trans-1,3-Dichloropropene	10061-02-6	*trans*-1,3-Dichloropropene	Whole (raw)	0.09	µg/L	GC/MS[a]
Hexachlorobutadiene	87-68-3	1,1,2,3,4,4-Hexachloro-1,3-butadiene	Whole (raw)	0.14	µg/L	GC/MS[a]
Methyl *tert*Butyl ether	1634-04-4	2-Methoxy-2-methylpropane	Whole (raw)	0.17	µg/L	GC/MS[a]
1,2,3,4-Tetramethylbenzene	488-23-3	1,2,3,4-Tetramethylbenzene	Whole (raw)	0.14	µg/L	GC/MS[a]
1,2,3,5-Tetramethylbenzene	527-53-7	1,2,3,5-Tetramethylbenzene	Whole (raw)	0.14	µg/L	GC/MS[a]
2-Butanone	78-93-3	2-Butanone	Whole (raw)	4	µg/L	GC/MS[a]
trans-1,4-Dichloro-2-butene	110-57-6	*trans*-1,4-Dichloro-2-butene	Whole (raw)	0.70	µg/L	GC/MS[a]
2-Hexanone	591-78-6	2-Hexanone	Whole (raw)	0.7	µg/L	GC/MS[a]
4-Methyl-2-pentanone	108-10-1	4-Methyl-2-pentanone	Whole (raw)	0.37	µg/L	GC/MS[a]

Table 19. *Constituents and analytical methods for volatile and semi-volatile organic compounds for water samples collected from selected water-supply and monitoring wells sampled by the U.S. Geological Survey, 2003-04 – Continued*

Acetone	67-64-1	2-Propanone	Whole (raw)	6	µg/L	GC/MS[a]
Acrylonitrile	107-13-1	2-Propenenitrile	Whole (raw)	1.2	µg/L	GC/MS[a]
1,2,3-Trimethylbenzene	526-73-8	1,2,3-Trimethylbenzene	Whole (raw)	0.06	µg/L	GC/MS[a]
1,4-Bromofluorobenzene, surrogate	460-00-4	--	Whole (raw)	0.1	percent	GC/MS[a]
Carbon disulfide	75-15-0	Carbon disulfide	Whole (raw)	0.038	µg/L	GC/MS[a]
1,2-Dichloroethane-4df, surrogate	17060-07-0	--	Whole (raw)	0.1	percent	GC/MS[a]
Hexachloroethane	67-72-1	Hexachloroethane	Whole (raw)	0.14	µg/L	GC/MS[a]
Diethyl ether	60-29-7	Diethyl ether	Whole (raw)	0.08	µg/L	GC/MS[a]
Ethyl *tert*-butyl ether	637-92-3	2-Ethoxy-2-methylpropane	Whole (raw)	0.05	µg/L	GC/MS[a]
Tetrahydrofuran	109-99-9	1,4-Epoxybutane	Whole (raw)	2.2	µg/L	GC/MS[a]
Diisopropyl ether	108-20-3	Diisopropyl ether	Whole (raw)	0.10	µg/L	GC/MS[a]
Ethyl methacrylate	97-63-2	Ethyl 2-methyl-2-propenoate	Whole (raw)	0.18	µg/L	GC/MS[a]
Methyl methacrylate	80-62-6	Methyl 2-methyl-2-propenoate	Whole (raw)	0.35	µg/L	GC/MS[a]
Methyl acrylonitrile	126-98-7	2-Methyl-2-propenitrile	Whole (raw)	0.76	µg/L	GC/MS[a]
Bromodichloromethane	75-27-4	Bromodichloromethane	Whole (raw)	0.028	µg/L	GC/MS[a]
Methyl acrylate	96-33-3	Methyl-2-propenoate	Whole (raw)	2	µg/L	GC/MS[a]
Methyl iodide	74-88-4	Iodomethane	Whole (raw)	0.35	µg/L	GC/MS[a]
o-Xylene	95-47-6	1,2-Dimethylbenzene	Whole (raw)	0.038	µg/L	GC/MS[a]
m- and *p*-Xylene	--	--	Whole (raw)	0.06	µg/L	GC/MS[a]
3-Chloropropene	107-05-1	3-Chloro-1-propene	Whole (raw)	0.5	µg/L	GC/MS[a]
tert-Pentyl methyl ether	994-05-8	2-Methoxy-2-methylbutane	Whole (raw)	0.08	µg/L	GC/MS[a]
o-Ethyl toluene	611-14-3	1-Ethyl-2-methylbenzene	Whole (raw)	0.06	µg/L	GC/MS[a]
Toluene-d8, surrogate	2037-26-5	Toluene-d8	Whole (raw)	0.1	percent	GC/MS[a]

[a] Connor, B.F., Rose, D.L., Noriega, M.C., Murtagh, L.K., and Abney, S.R., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of 86 volatile organic compounds in water by gas chromatography/mass spectroscopy, including detections less than reporting limits: U.S. Geological Survey Open-File Report 97-829, 86 p.

Appendix B

Data on Borehole Characteristics, Soil, Fill, and Aquifer Sediment, and Analytical Methods Used for Sediment Samples for the Long Neck Peninsula Mercury Study

Figure

B1. Composite lithologic profile for Bayside site at production well (Delaware Geological Survey) Pi31-01..... B1

B2. Composite lithologic profile for Lakeside site at production well (Delaware Geological Survey) Ph35-25..... B2

Table

B1. Acronyms and abbreviations used in core sample descriptions..... B3

B2. Description of core samples taken from well Pi31-15 (6A) Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B4

B3. Description of core samples taken from well Pi31-20 (6F) Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B6

B4. Description of core samples taken from well Pi31-19 (6E), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B6

B5. Description of core samples taken from well Pi31-18 (6D), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B7

B6. Description of core samples taken from well Pi31-17 (6C), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B7

B7. Description of core samples taken from well Pi31-16 (6B), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B8

B8. Description of core samples taken from test hole near well Pi31-16 (6Ba), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B8

B9. Description of core samples taken from test hole near well Pi31-01 (6T), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B9

B10. Description of core samples taken from well Ph35-29 (10A), Sussex County, Delaware, by the U.S. Geological Survey, 2004..... B10

B11. Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004.. B12

B12. Constituents and analytical methods for major and trace elements, carbon, and sulfur in sediments analyzed by the U.S. Geological Survey, 2004 .....B19

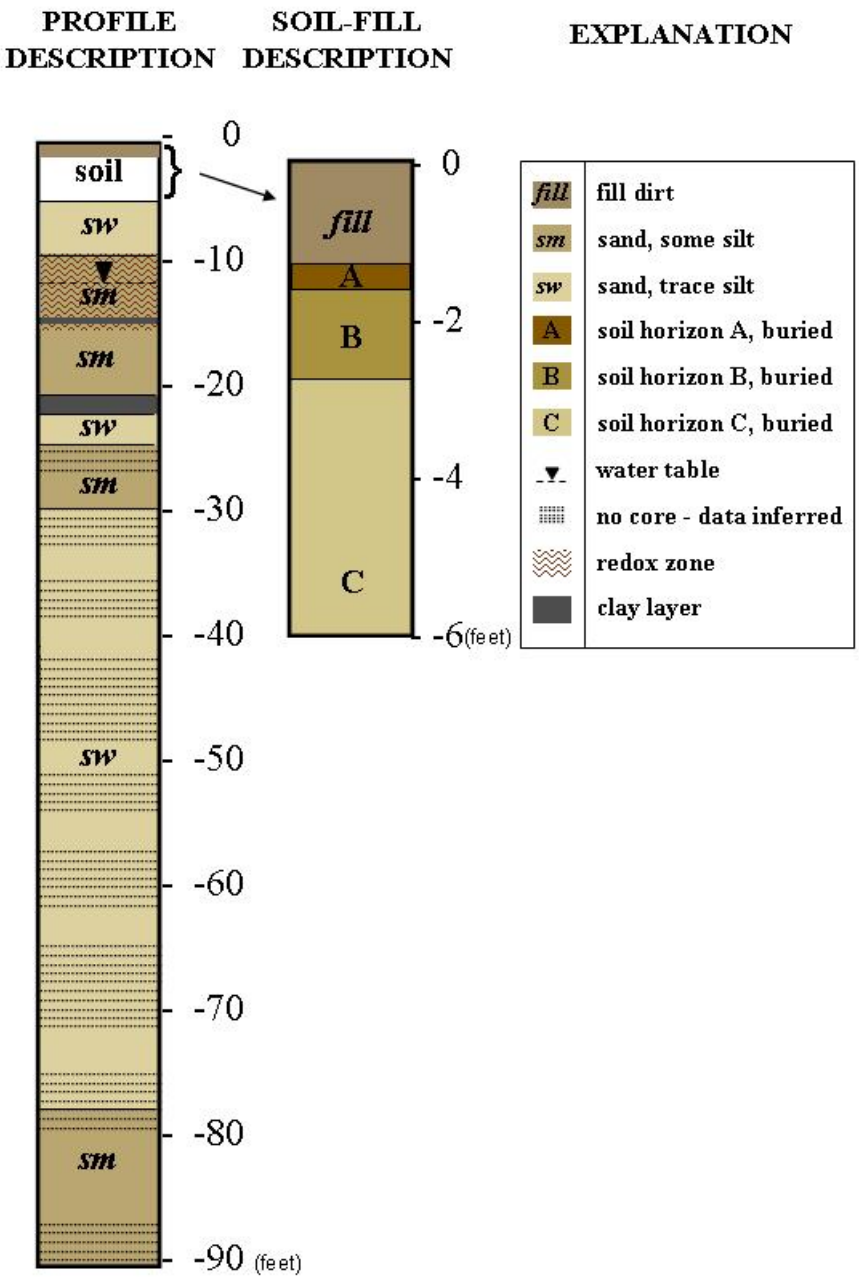

Figure B1. Composite lithologic profile at Bayside site near production well (Delaware Geological Survey) Pi31-01. (Compiled from data described in tables B2 through B9)

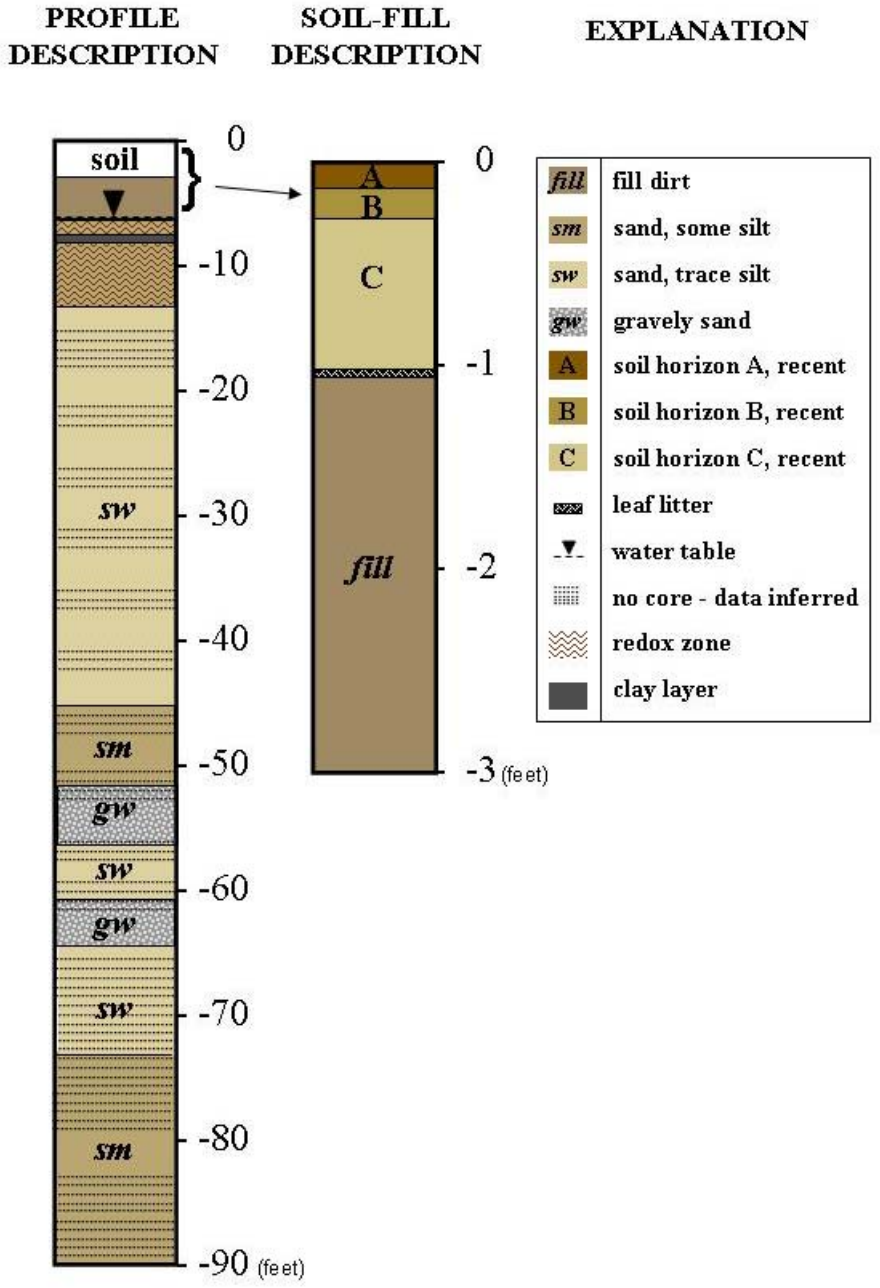

Figure B2. Composite lithologic profile at Lakeside site at production well (Delaware Geological Survey) Ph35-25. (Compiled from data described in table B10.)

Table B1. *Acronyms and abbreviations used in core sample descriptions*
[USCS, Unified Soil Classification System (Casagrande, 1948)]

USCS code	Full name
CH	Inorganic clays of high plasticity, fat clays
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays
GW	Well-graded gravels, gravel-sand mixtures, little or no fines
OL	Organic silts and organic silty clays of low plasticity
SC	Clayey sands, sand-clay mixtures
SM	Silty sands, sand-silt mixtures
SW	Well-graded sands, gravelly sands, little or no fines

Table B2. *Description of core samples taken from well Pi31-15 (6A), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-2	39	6A-1	OL	Organic, trace coarse sand; very dark grayish brown (10 YR 3/2), abundant roots
2-4	43	6A-2	SW	Sand, medium-coarse; olive brown (2.5 Y 5/4); abundant roots
		6A-3	SW	Sand, medium-coarse; dark yellowish brown (10 YR 4.5/4)
4-6	39	6A-4	SW	Sand, medium-coarse; yellowish brown (10 YR 5/6), rare gravel (0.5-inch), abundant roots
		6A-5	SW	Sand, fine-medium, organic fragments; trace clay; light yellowish brown (10 YR 6/4)
6-8	57	6A-6	SW	Sand, medium-fine, light yellowish brown (2.5 Y 6/3), trace coarse sand and pebbles
		6A-7	SW	Sand, medium-fine, trace silt; light yellowish brown (2.5 Y 6/3), quartz, opaque heavy mineral laminae
8-10	52	6A-8	SW	Sand, medium-fine, very pale brown (10 YR 8/3), quartz, trace feldspar, iron staining, very small root fragments
10-12	60	6A-9	SM	Sand, medium, slightly silty, pale yellow (2.5 Y 7/3), quartz, rare feldspar, opaque heavy minerals and thin red sand laminae, trace organic
12-14	45	6A-10	SM	Sand, medium, slightly silty, light gray (5 Y 7/1), quartz, rare feldspar, trace glauconite, pebble bed at base
14-16	92	6A-11	SM	Sand, fine-medium, slightly silty, pale yellow (2.5 Y 7/3), quartz, rare feldspar
		6A-12	SM	Sand, medium, slightly silty; light gray (5 Y 7/1), quartz, rare feldspar, opaque heavy mineral laminae

Table B2. *Description of core samples taken from well Pi31-15 (6A), Sussex County, Delaware, by the U.S. Geological Survey, 2004 – Continued*

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
16-18	90	6A-13	SC	Sand, medium-fine, slightly silty; pale yellow (2.5 Y 7/4), quartz , iron staining, 1.5-inch stiff clay clast
18-20	63	6A-17	SM	Sand, fine-medium, slightly silty, light gray (2.5 Y 7/2) to pale yellow (2.5 Y 7/3), quartz, trace feldspar, opaque heavy mineral laminae common
20-22	71	6A-16	SC	Sand, fine-very fine, slightly silty, pale yellow (2.5 Y 7/3) red sand laminae common, opaque heavy mineral laminae rare, 0.5-inch stiff clay clast
		6A-14	CH	Clay, soft, trace mica quartz and opaque heavy minerals; light gray (5 Y 7/2), red clay staining, 2-inch bed
		6A-15	SC	Sand, fine-clayey, yellow (10 YR 7/8), red mineral staining
		6A-19	SW	Sand, medium-fine, pale yellow (5 Y 8/3), quartz, rare feldspar and heavy opaque minerals, trace silt
22-24	79	6A-18	SW	Sand, medium-fine, brown-yellow (10 YR 6/8), quartz and some feldspar, heavy iron stained, trace silt
		6A-20	SM	Sand, fine-very fine, white (grayish) (5 Y 8/1), slightly silty, opaque heavy mineral laminae rare, quartz, rare feldspar
24-26				No core collected
26-28	35	6A-21	SM	Sand, very fine-fine, slightly silty (2.5 Y 8/1); white (grayish), mottled with sand, fine-medium; pale yellow (2.5 Y 7/3), iron staining
28-30	46			
30-33				No core collected
33-35	82	6A-22	SW	Sand, medium-fine, light gray (10 YR 7/1), quartz, trace feldspar, glauconite and opaque heavy mineral
35-38				No core collected
38-40	93	6A-23	SW	Sand, medium-fine, light gray (10 YR 7/1), quartz, trace feldspar, glauconite and opaque heavy mineral
40				Coring terminated

Table B3. *Description of core samples taken from well Pi31-20 (6F), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-48.5				No core collected
48.5-50.5	35	6F-1	SW	Sand, fine-medium, trace silt, pale yellow (2.5 Y 7/2), quartz, trace feldspar and opaque heavy minerals, pebble bed at base
50.5				Coring terminated

Table B4. *Description of core samples taken from well Pi31-19 (6E), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-55.3				No core collected
55.3-57.3	37	6E-1	SW	Sand, very fine-fine, trace silt; pale yellow (2.5 Y 7/2), quartz, glauconite common, opaque heavy mineral laminae
57.3				Coring terminated

Table B5. *Description of core samples taken from well Pi31-18 (6D), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-62				No core collected
62-64	27	6D-1	SW	Sand, fine; pale yellow (2.5 Y 7/2), quartz, trace glauconite and opaque heavy minerals
64				Coring terminated

Table B6. *Description of core samples taken from well Pi31-17 (6C), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-72				No core collected
72-74	49	6C-1	SW	Sand, medium-coarse, trace silt; pale yellow (2.5 Y 7/2), quartz, trace feldspar and glauconite, opaque heavy mineral laminae, thin pebble beds
74				Coring terminated

Table B7. *Description of core samples taken from well Pi31-16 (6B), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-82				No core collected
80-82	34	6B-1	SM	Sand, fine-very fine, trace silt; pale yellow (2.5 Y 7/2), quartz, trace feldspar, glauconite common, opaque heavy mineral laminae
82				Coring terminated

Table B8. *Description of core samples taken from test hole near well Pi31-16 (6Ba), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-82				No core collected
80-82	34	6Ba-1	SM	Sand, very fine-fine, trace silt; pale yellow (2.5 Y 7/2), quartz, trace feldspar, glauconite common, opaque heavy mineral laminae
84-86	67			
86				Coring terminated

Table B9. *Description of core samples taken from test hole near well Pi31-01 (6T), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Core identification number	USCS code	Lithologic description
0-0.5	58	6T-6	SM	Organic material, trace fine sand; olive brown (2.5 Y 4/3) roots, leaves, moss, pine needles, and pebbles common
0.5-1.5	34	6T-1	SM	Sand, fine-medium; light olive brown (2.5 Y 5/6), dry, very fine roots common, pebbles rare
		6T-3 6T-5	SM	Sand, fine-medium; yellowish brown (10 YR 5/6), dry
		6T-4	SM	Sand, fine-medium; yellowish brown (10 YR 5/4), dry
		6T-2	SM	Sand, fine-medium; very dark grayish brown (2.5 Y 3/2), dry, organic layer (buried A horizon)
1.5				Coring terminated

Table B10. *Description of core samples taken from well Ph35-29 (10A), Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[Core sample depth refers to the bottom of the specified interval in feet below land surface (depths are approximated based on the amount of core recovered from each interval); ft, feet; bls, below land-surface datum; USCS code letter symbols and lithologic descriptions are from the Unified Soil Classification System (Casagrande, 1948); alphanumeric codes enclosed in parentheses refer to color designations as specified in the Munsell Soil Color Charts (Munsell Color, 1990)]

Core sample depth (ft bls)	Percent recovery	Sub-sample identification number	USCS code	Lithologic description
0-2	61	10A-1	SM	Sand, silty, abundant organic fragments, coarse sand; dark grayish brown (2.5 Y 4/2); roots common, few pebbles
		10A-2	SM	Sand, medium-fine, slightly silty, trace coarse sand; dark grayish brown (2.5 Y 4/4), roots common
		10A-3	SM	Sand, silty, abundant organic fragments, coarse sand; olive brown (2.5 Y 4/2); leaf litter layer at base
		10A-4	SM	Sand medium-silty; brown (10 YR 5/3), roots common
2-4	51			
		10A-5	SM	Sand, medium-fine, slightly silty, trace coarse sand; light yellowish brown (10 YR 6/4) to brownish yellow (10 YR 6/6)
4-6	51			
		10A-6	SM	Sand, medium-fine, silty sand, laminae of red sand; light yellowish brown (10 YR 6/5) with red mottling
6-8	53			
		10A-7	SM	Sand, slightly silty; light gray (10 YR 7/2), thin red sand laminae, very pale brown homogenized (10 YR 7/4), opaque heavy mineral lamina
8-10	91		SM	
		10A-8	SM	Sand, pale yellow (2.5 Y 7/3) opaque heavy mineral bed, thin red lamina
		10A-9	CL	Sand, slightly clayey; white (2.5 Y 8/2), medium stiff clay clast (0.5 inches)
10-12	80	10A-10	SM	Sand, slightly silty; light gray (10 YR 7/2), thin red lamina
12-14	92	10A-11	SW	Sand, medium-fine; light gray (2.5 Y 7/2) with pale yellow mottling
		10A-12	SW	Sand, medium-fine; brownish yellow (10 YR 6/8)
		10A-13		Sand, medium-fine; light gray (2.5 Y 7/2) with pale yellow mottling, opaque heavy mineral bed, predominantly quartz and milky quartz
14-16	93			

Table B10. *Description of core samples taken from well Ph35-29 (10A), Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

Core sample depth (ft bls)	Percent recovery	Sub-sample identification number	USCS code	Lithologic description
16-19				No core collected
19-21	84	10A-14	SW	Sand, white to very pale yellow (5 Y 8/2); opaque heavy mineral lamina
21-24				No core collected
24-26	47	10A-15	SW	Sand, white to very pale yellow (5 Y 8/2); opaque heavy mineral lamina
26-29				No core collected
29-31	100	10A-16	SW	Sand, medium-fine; yellow (2.5 Y 7/6) with light gray (5 Y 7/2) silty sand lamina
		10A-17	SW	Sand, medium-fine; light gray (5 Y 7/2), opaque heavy mineral
31-34.5				No core collected
34.5-36.5	63	10A-18	SW	Sand, medium-fine; light gray (5 Y 7/2), opaque heavy mineral lamina and pebble beds
36.5-39				No core collected
39-41	50	10A-19	SW	Sand, medium, light gray (2.5 Y 7/2) alternating lamina of red coarse sand and pebbles
41-44				No core collected
44-46	63	10A-19	SM	Sand, medium, slightly silty; light gray (5 Y 7/2)
49-51	44	10A-20	GW	Sand, very coarse
51-54				No core collected
54-56	28	10A-21	SW	Sand, medium, slightly silty; pale yellow (2.5 Y 7/2)
56-59				No core collected
59-60	81	10A-22	GW	Sand, very coarse
60-64				No core collected
64-66	54	10A-23	GW	Sand, very coarse
66-70				No core collected
70-80				No core collected
80-82	53	10A-24	SW	Sand, medium, slightly silty, light gray (10 YR 7/2)
82				Coring terminated

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004*

[DGS, Delaware Geological Survey; USGS, U.S. Geological Survey; USCS, Unified Soil Classification System (Casagrande, 1948); LSD, land-surface datum; µg/kg, micrograms per kilogram; µg/g, micrograms per gram; <, less than]

DGS local well number	USGS site identification number	Core identification number	USCS sediment identification code	Sample date	Sample time	Depth interval of core subsample (feet below LSD)	Mercury (µg/kg)	Aluminum (µg/g)
			Pot Nets Bayside					
test hole	test hole	6T-2	SM	6/1/2004	1200	1.3 - 1.5	40	50,200
test hole	test hole	6T-3	SM	6/1/2004	1201	0.7 - 1.0	20	71,200
test hole	test hole	6T-5	SM	6/1/2004	1202	0.7 - 1.0	< 20	68,700
Pi31-15	383739075093102	6A-1	OL	6/1/2004	1300	0.0 - 0.4	30	39,800
Pi31-15	383739075093102	6A-2	SW	6/1/2004	1301	0.4 - 2.5	20	54,900
Pi31-15	383739075093102	6A-3	SW	6/1/2004	1302	2.5 - 2.9	30	81,800
Pi31-15	383739075093102	6A-8	SW	6/1/2004	1306	8.0 - 8.3	< 20	60,400
Pi31-15	383739075093102	6A-9	SM	6/1/2004	1307	8.7 - 11.2	< 20	57,800
Pi31-15	383739075093102	6A-13	SC	6/1/2004	1311	15.5 - 18.0	< 20	64,500
Pi31-15	383739075093102	6A-14	CH	6/1/2004	1315	21.4 - 21.5	< 20	103,000
Pi31-15	383739075093102	6A-20	SM	6/1/2004	1316	22.8 - 23.4	< 20	80,700
Pi31-15	383739075093102	6A-22	SW	6/1/2004	1324	33.6 - 40.0	< 20	52,900
Pi31-15	383739075093102	6A-23	SW	6/1/2004	1327	33.6 - 40.0	< 20	51,100
Pi31-20	383739075093107	6F-1	SW	6/1/2004	1334	48.3 - 51.4	< 20	33,800
Pi31-19	383739075093106	6E-1	SW	6/1/2004	1339	56.0 - 58.6	< 20	28,900
Pi31-18	383739075093105	6D-1	SW	6/1/2004	1344	62.3 - 62.9	< 20	18,100
Pi31-19	383739075093106	6C-1	SW	6/1/2004	1351	72.3 - 73.4	< 20	46,700
Pi31-16	383739075093103	6B-1	SM	6/1/2004	1357	80.7 - 81.3	< 20	31,700
test hole	test hole	6Ba-1	SM	6/1/2004	1359	82.7 - 85.4	< 20	41,000
			Pot Nets Lakeside					
Pi35-29	383729075101602	10A-1	SM	6/3/2004	1300	0.0 - 0.4	< 20	30,700
Pi35-29	383729075101602	10A-4	SM	6/3/2004	1301	0.8 - 1.1	< 20	45,700
Pi35-29	383729075101602	10A-5	SM	6/3/2004	1303	3.1 - 3.1	20	58,900
Pi35-29	383729075101602	10A-7	SM	6/3/2004	1305	6.9 - 6.5	< 20	50,300
Pi35-29	383729075101602	10A-9	CL	6/3/2004	1306	9.3 - 10.0	< 20	79,300
Pi35-29	383729075101602	10A-13	SW	6/3/2004	1310	13.3 - 13.9	< 20	59,900
Pi35-29	383729075101602	10A-14	SW	6/3/2004	1314	19.3 - 20.7	< 20	71,300
Pi35-29	383729075101602	10A-17	SW	6/3/2004	1321	30.0 - 31.0	< 20	66,000
Pi35-29	383729075101602	10A-19	SW	6/3/2004	1328	39.3 - 40.3	< 20	42,000
Pi35-29	383729075101602	10A-20	GW	6/3/2004	1331	44.8 - 45.8	< 20	76,500
Pi35-29	383729075101602	10A-21	SW	6/3/2004	1338	54.7 - 55.3	< 20	18,000
Pi35-29	383729075101602	10A-22	GW	6/3/2004	1344	59.3 - 60.1	< 20	39,300
Pi35-29	383729075101602	10A-23	GW	6/3/2004	1357	80.4 - 81.1	< 20	45,200

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

DGS local well number	Core identification number	USCS sediment identification code	Antimony (µg/g)	Arsenic (µg/g)	Barium (µg/g)	Beryllium (µg/g)	Bismuth (µg/g)	Cadmium (µg/g)	Calcium (µg/g)
			Pot Nets Bayside						
test hole	6Ta-2	SM	0.26	0.9	804	0.67	0.01	0.06	1,720
test hole	6Ta-3	SM	0.1	1	819	0.72	< 0.005	0.01	1,670
test hole	6Ta-5	SM	0.1	2	805	0.71	0.04	0.01	1,460
Pi31-15	6A-1	OL	0.1	0.5	713	0.63	< 0.005	0.05	1,940
Pi31-15	6A-2	SW	0.1	0.7	776	0.71	< 0.005	0.01	1,610
Pi31-15	6A-3	SW	0.2	3.8	773	1.1	0.07	0.02	1,200
Pi31-15	6A-8	SW	0.06	< 0.1	854	0.36	< 0.005	0.006	1,520
Pi31-15	6A-9	SM	0.04	< 0.1	877	0.43	< 0.005	0.006	1,620
Pi31-15	6A-13	SC	0.04	< 0.1	881	0.65	< 0.005	0.009	1,960
Pi31-15	6A-14	CH	0.2	1	718	2.8	0.09	0.06	1,650
Pi31-15	6A-20	SM	0.03	< 0.1	1,130	0.94	< 0.005	0.02	4,290
Pi31-15	6A-22	SW	0.02	< 0.1	1,070	0.79	< 0.005	0.01	3,430
Pi31-15	6A-23	SW	0.02	< 0.1	1,080	0.71	0.005	0.01	3,170
Pi31-20	6F-1	SW	0.04	< 0.1	689	0.46	0.006	0.007	1,760
Pi31-19	6E-1	SW	0.04	0.2	636	0.32	0.007	0.006	1,440
Pi31-18	6D-1	SW	0.03	0.1	469	0.22	0.005	0.005	700
Pi31-19	6C-1	SW	0.06	0.4	729	0.94	0.02	0.02	2,880
Pi31-16	6B-1	SM	0.04	< 0.1	632	0.59	< 0.005	0.007	1,510
test hole	6Ba-1	SM	0.06	< 0.1	688	0.72	< 0.005	0.02	3,000
			Pot Nets Lakeside						
Pi35-29	10A-1	SM	0.1	1	522	0.51	0.03	0.03	1,420
Pi35-29	10A-4	SM	0.09	0.8	721	0.52	0.02	0.01	1,270
Pi35-29	10A-5	SM	0.09	1	696	0.56	0.03	0.007	942
Pi35-29	10A-7	SM	0.07	0.5	698	0.3	0.009	0.008	1,060
Pi35-29	10A-9	CL	0.05	0.3	927	0.59	0.01	0.007	1,330
Pi35-29	10A-13	SW	0.05	0.2	1,010	0.42	0.008	0.009	1,290
Pi35-29	10A-14	SW	0.05	0.4	1,010	0.5	0.006	0.01	1,750
Pi35-29	10A-17	SW	0.04	0.5	1,080	0.64	0.009	0.008	2,050
Pi35-29	10A-19	SW	0.08	1	725	0.45	0.005	0.007	1,230
Pi35-29	10A-20	GW	0.07	0.7	925	0.99	0.02	0.02	2,560
Pi35-29	10A-21	SW	0.05	0.5	552	0.29	0.01	0.005	1,070
Pi35-29	10A-22	GW	0.03	< 0.1	755	0.56	< 0.005	0.007	2,350
Pi35-29	10A-23	GW	0.05	0.4	728	0.85	0.006	0.01	2,890

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

DGS local well number	Core identification number	USCS sediment identification code	Cerium (µg/g)	Cesium (µg/g)	Chromium (µg/g)	Cobalt (µg/g)	Copper (µg/g)	Gallium (µg/g)	Iron (µg/g)
			Pot Nets Bayside						
test hole	6Ta-2	SM	49.2	0.92	15.0	2.8	5.2	9.6	8,700
test hole	6Ta-3	SM	38.9	0.87	20.4	3.7	5.1	13	11,000
test hole	6Ta-5	SM	37.5	0.87	19.4	3.4	4.9	12	10,000
Pi31-15	6A-1	OL	50.6	0.78	15.2	2.6	5.7	7.7	9,100
Pi31-15	6A-2	SW	56.0	0.93	18.6	3.6	5.1	11	10,000
Pi31-15	6A-3	SW	49.1	1.4	29.5	5.1	6.8	15	14,000
Pi31-15	6A-8	SW	14.1	0.34	10.8	1.1	2.2	10	2,700
Pi31-15	6A-9	SM	17.7	0.31	9.2	1	3.6	9.9	2,400
Pi31-15	6A-13	SC	38.3	0.42	13.6	1.9	2.6	12	4,400
Pi31-15	6A-14	CH	152	3.6	131	10	11.3	22	29,000
Pi31-15	6A-20	SM	25.5	0.3	14.8	2	3.4	14	6,600
Pi31-15	6A-22	SW	19.1	0.28	8.5	1.1	2.2	9.3	4,600
Pi31-15	6A-23	SW	17.5	0.28	7.9	1.1	2.3	8.8	4,300
Pi31-20	6F-1	SW	14.4	0.28	8.7	0.56	1.2	5.2	1,400
Pi31-19	6E-1	SW	11.1	0.29	7.3	1.2	1.4	5.1	1,400
Pi31-18	6D-1	SW	8.5	0.18	4.6	0.4	1.1	3.1	940
Pi31-19	6C-1	SW	16.3	0.38	18.8	1.2	5.4	8.9	4,100
Pi31-16	6B-1	SM	6.8	0.24	8.5	0.47	0.84	5.2	1,100
test hole	6Ba-1	SM	18.2	0.32	18.2	1.2	3.7	7.7	4,600
			Pot Nets Lakeside						
Pi35-29	10A-1	SM	29.9	0.72	12.6	1.7	4.4	5.6	6,900
Pi35-29	10A-4	SM	36.5	0.8	15.8	2.2	3.6	7.8	6,400
Pi35-29	10A-5	SM	23.9	0.66	18.9	2.6	3.9	9.9	7,500
Pi35-29	10A-7	SM	13.6	0.39	13.2	1.8	3.8	8.2	6,200
Pi35-29	10A-9	CL	22.1	0.42	20.4	1.8	3.2	13	3,800
Pi35-29	10A-13	SW	12.8	0.29	14.7	1.6	3.0	11	4,400
Pi35-29	10A-14	SW	41.5	0.3	13.9	2	4.3	12	5,100
Pi35-29	10A-17	SW	33.6	0.33	12.7	1.8	3.2	13	3,900
Pi35-29	10A-19	SW	21.3	0.3	10.2	1.2	1.8	7.0	2,600
Pi35-29	10A-20	GW	48.9	0.36	26.5	2.7	3.3	13	4,600
Pi35-29	10A-21	SW	8.5	0.21	4.6	0.36	1.1	3.4	1,400
Pi35-29	10A-22	GW	13.2	0.29	9	1.3	1.5	6.3	1,600
Pi35-29	10A-23	GW	12.9	0.36	14.6	1.1	2.3	7.6	4,600

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004*

DGS local well number	Core identification number	USCS sediment identification code	Lanthanum (µg/g)	Lead (µg/g)	Lithium (µg/g)	Magnesium (µg/g)	Manganese (µg/g)	Molybdenum (µg/g)
			Pot Nets Bayside					
test hole	6Ta-2	SM	23.7	19.8	10.1	939	243	0.39
test hole	6Ta-3	SM	21.7	13.4	11.8	1,120	180	0.47
test hole	6Ta-5	SM	20.0	13.2	12.1	1,070	162	0.47
Pi31-15	6A-1	OL	22.6	14.9	8.2	912	261	0.40
Pi31-15	6A-2	SW	33.0	13.2	10.6	1,090	194	0.42
Pi31-15	6A-3	SW	23.8	15.0	17.6	1,630	138	0.84
Pi31-15	6A-8	SW	5.7	11.0	5.7	344	28.1	0.10
Pi31-15	6A-9	SM	9.6	11.0	5.4	278	34.6	< 0.1
Pi31-15	6A-13	SC	20.7	11.8	6.3	473	62	0.20
Pi31-15	6A-14	CH	78.3	17.2	20.4	4,520	289	0.86
Pi31-15	6A-20	SM	9.9	14.0	6.5	494	136	0.20
Pi31-15	6A-22	SW	9.4	12.0	4.2	358	114	0.10
Pi31-15	6A-23	SW	8.5	12.3	4.6	374	106	0.10
Pi31-20	6F-1	SW	8.4	8.5	4.5	213	27.3	0.10
Pi31-19	6E-1	SW	6.4	8.3	4.6	171	20.3	< 0.1
Pi31-18	6D-1	SW	5.4	6.9	3.6	112	17.3	0.20
Pi31-19	6C-1	SW	8.7	10.4	5.7	533	70.8	0.20
Pi31-16	6B-1	SM	4.1	7.4	4.7	236	14.2	< 0.1
test hole	6Ba-1	SM	9.8	9.5	5.3	459	87.9	0.10
			Pot Nets Lakeside					
Pi35-29	10A-1	SM	14.7	11.4	7.8	904	161	0.35
Pi35-29	10A-4	SM	19.0	11.6	9.2	860	127	0.29
Pi35-29	10A-5	SM	13.8	12.5	9.0	691	120	0.38
Pi35-29	10A-7	SM	7.4	11.3	6.1	329	137	0.33
Pi35-29	10A-9	CL	12.2	13.5	7.0	513	64.3	0.20
Pi35-29	10A-13	SW	5.5	13.9	5.7	263	117	0.31
Pi35-29	10A-14	SW	17.6	14.2	6.3	350	125	0.23
Pi35-29	10A-17	SW	21.9	14.5	6.9	320	75.3	0.20
Pi35-29	10A-19	SW	11.2	10.0	5.2	277	32.4	0.21
Pi35-29	10A-20	GW	18.3	12.8	7.6	551	92.8	0.29
Pi35-29	10A-21	SW	6.1	7.4	3.8	125	30.3	0.23
Pi35-29	10A-22	GW	7.6	9.3	4.7	269	38.4	< 0.1
Pi35-29	10A-23	GW	7.5	9.3	5.1	445	92.6	0.20

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

DGS local well number	Core identification number	USCS sediment identification code	Nickel (µg/g)	Niobium (µg/g)	Phosphorus (µg/g)	Potassium (µg/g)	Rubidium (µg/g)	Scandium (µg/g)	Selenium (µg/g)
				Pot Nets Bayside					
test hole	6Ta-2	SM	7.8	8.7	150	22,300	60.6	3.4	0.6
test hole	6Ta-3	SM	10.1	9.1	110	24,400	63.5	5.8	0.5
test hole	6Ta-5	SM	9.2	12	99	21,900	60.5	5.0	< 0.2
Pi31-15	6A-1	OL	6.2	7.4	220	19,100	52.7	3.4	0.4
Pi31-15	6A-2	SW	8.8	10	100	22,100	61.6	4.5	0.3
Pi31-15	6A-3	SW	14.6	12	130	20,400	64.2	6.2	0.5
Pi31-15	6A-8	SW	5.8	< 2	51	26,200	57.1	3.2	< 0.2
Pi31-15	6A-9	SM	6.0	< 2	53	25,800	58.6	2.6	0.2
Pi31-15	6A-13	SC	7.3	3.4	67	24,700	57.3	5.0	< 0.2
Pi31-15	6A-14	CH	19.3	28	160	25,400	114	21	0.8
Pi31-15	6A-20	SM	8.5	9.7	65	30,200	64.7	5.5	< 0.2
Pi31-15	6A-22	SW	4.0	4.0	42	29,500	63.4	3.0	< 0.2
Pi31-15	6A-23	SW	3.8	7.4	37	26,900	61.1	2.7	< 0.2
Pi31-20	6F-1	SW	2.2	1.9	35	18,800	43.5	1.1	< 0.2
Pi31-19	6E-1	SW	1.8	< 2	22	18,200	43.7	1.2	< 0.2
Pi31-18	6D-1	SW	1.1	< 2	26	12,800	30.2	0.7	< 0.2
Pi31-19	6C-1	SW	4.4	5.9	42	19,800	48.2	3.6	< 0.2
Pi31-16	6B-1	SM	2.1	< 2	34	16,500	38.9	1.1	< 0.2
test hole	6Ba-1	SM	3.6	2.6	38	19,500	45.6	3.1	< 0.2
				Pot Nets Lakeside					
Pi35-29	10A-1	SM	4.3	6.6	200	14,000	39.6	2.5	< 0.2
Pi35-29	10A-4	SM	5.9	8.3	72	19,900	53.8	3.3	< 0.2
Pi35-29	10A-5	SM	6.8	8.6	85	19,400	50.6	4.4	< 0.2
Pi35-29	10A-7	SM	4.5	20	62	19,100	46.1	3.9	< 0.2
Pi35-29	10A-9	CL	5.5	8.8	56	24,200	57.1	6.6	< 0.2
Pi35-29	10A-13	SW	4.8	9.5	43	25,600	59.0	5.0	< 0.2
Pi35-29	10A-14	SW	5.4	13	69	26,000	58.2	5.5	0.3
Pi35-29	10A-17	SW	5.4	6.4	57	26,300	62.6	4.7	0.2
Pi35-29	10A-19	SW	5.0	3.1	74	19,900	46.6	2.6	< 0.2
Pi35-29	10A-20	GW	14.3	13	80	23,100	54.0	6.9	0.3
Pi35-29	10A-21	SW	1.0	2.2	28	14,300	34.5	0.9	< 0.2
Pi35-29	10A-22	GW	2.4	2.4	32	20,400	48.1	1.5	< 0.2
Pi35-29	10A-23	GW	3.3	7.2	51	19,400	45.6	2.7	< 0.2

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

DGS local well number	Core identification number	USCS sediment identification code	Silver (µg/g)	Sodium (µg/g)	Strontium (µg/g)	Tantalum (µg/g)	Thallium (µg/g)	Thorium (µg/g)	Titanium (µg/g)
				Pot Nets Bayside					
test hole	6Ta-2	SM	<3	4,610	135	0.43	0.3	2.5	5,100
test hole	6Ta-3	SM	<3	4,880	139	0.75	0.3	3.3	5,300
test hole	6Ta-5	SM	<3	4,670	133	0.72	0.3	3.8	4,900
Pi31-15	6A-1	OL	<3	4,080	126	0.64	0.3	3.6	5,900
Pi31-15	6A-2	SW	<3	4,340	132	0.74	0.3	4.1	5,400
Pi31-15	6A-3	SW	<3	3,760	116	0.78	0.4	4.0	4,100
Pi31-15	6A-8	SW	<3	4,850	150	0.20	0.2	1.1	1,100
Pi31-15	6A-9	SM	<3	4,960	156	0.29	0.3	1.0	1,200
Pi31-15	6A-13	SC	<3	5,720	158	0.36	0.3	1.5	2,100
Pi31-15	6A-14	CH	<3	3,670	134	2.30	1.0	8.9	10,000
Pi31-15	6A-20	SM	<3	11,200	245	0.75	0.3	1.5	4,600
Pi31-15	6A-22	SW	<3	9,390	220	0.32	0.3	1.0	3,400
Pi31-15	6A-23	SW	<3	9,340	217	0.35	0.3	1.3	3,300
Pi31-20	6F-1	SW	<3	5,640	136	< 0.2	0.2	0.83	890
Pi31-19	6E-1	SW	<3	4,480	126	< 0.2	0.2	0.82	690
Pi31-18	6D-1	SW	<3	2,290	81.3	< 0.2	0.2	0.55	600
Pi31-19	6C-1	SW	<3	7,500	168	0.30	0.3	1.4	2,700
Pi31-16	6B-1	SM	<3	4,720	124	< 0.2	0.2	0.69	530
test hole	6Ba-1	SM	<3	7,200	161	0.31	0.2	2.1	3,300
				Pot Nets Lakeside					
Pi35-29	10A-1	SM	<3	3,120	85.8	0.37	0.2	2.3	4,100
Pi35-29	10A-4	SM	<3	3,780	115	0.42	0.3	2.4	3,900
Pi35-29	10A-5	SM	<3	3,180	108	0.50	0.3	2.8	3,800
Pi35-29	10A-7	SM	<3	3,430	115	0.99	0.2	1.6	5,200
Pi35-29	10A-9	CL	<3	4,370	152	0.57	0.3	1.7	2,400
Pi35-29	10A-13	SW	<3	4,210	162	0.44	0.3	1.4	4,000
Pi35-29	10A-14	SW	<3	5,740	171	0.76	0.3	2.0	4,500
Pi35-29	10A-17	SW	<3	6,100	187	0.33	0.3	1.4	2,700
Pi35-29	10A-19	SW	<3	3,920	127	0.20	0.3	1.1	1,100
Pi35-29	10A-20	GW	<3	6,990	170	0.63	0.3	2.1	3,800
Pi35-29	10A-21	SW	<3	2,910	106	< 0.2	0.2	0.56	1,000
Pi35-29	10A-22	GW	<3	7,060	160	< 0.2	0.3	0.62	940
Pi35-29	10A-23	GW	<3	8,250	165	0.36	0.2	1.2	3,600

Table B11. *Chemical analyses of sediment samples collected from monitoring wells drilled in Sussex County, Delaware, by the U.S. Geological Survey, 2004 - Continued*

DGS local well number	Core identification number	USCS sediment identification code	Organic carbon as carbon (percent by weight)	Inorganic carbon as carbon (percent by weight)	Sulfur (percent by weight)
			Pot Nets Bayside		
test hole	6Ta-2	SM	1.79	0.01	<0.05
test hole	6Ta-3	SM	0.19	<0.01	<0.05
test hole	6Ta-5	SM	0.18	<0.01	<0.05
Pi31-15	6A-1	OL	1.35	0.01	<0.05
Pi31-15	6A-2	SW	0.29	<0.01	<0.05
Pi31-15	6A-3	SW	0.18	<0.01	<0.05
Pi31-15	6A-8	SW	<0.05	<0.01	<0.05
Pi31-15	6A-9	SM	<0.05	<0.01	<0.05
Pi31-15	6A-13	SC	<0.05	<0.01	<0.05
Pi31-15	6A-14	CH	0.06	<0.01	<0.05
Pi31-15	6A-20	SM	<0.05	<0.01	<0.05
Pi31-15	6A-22	SW	<0.05	<0.01	<0.05
Pi31-15	6A-23	SW	<0.05	<0.01	<0.05
Pi31-20	6F-1	SW	<0.05	<0.01	<0.05
Pi31-19	6E-1	SW	<0.05	<0.01	<0.05
Pi31-18	6D-1	SW	<0.05	<0.01	<0.05
Pi31-19	6C-1	SW	0.05	<0.01	<0.05
Pi31-16	6B-1	SM	<0.05	<0.01	<0.05
test hole	6Ba-1	SM	<0.05	<0.01	<0.05
			Pot Nets Lakeside		
Pi35-29	10A-1	SM	0.54	0.01	<0.05
Pi35-29	10A-4	SM	0.20	<0.01	<0.05
Pi35-29	10A-5	SM	0.09	<0.01	<0.05
Pi35-29	10A-7	SM	0.06	<0.01	<0.05
Pi35-29	10A-9	CL	<0.05	<0.01	<0.05
Pi35-29	10A-13	SW	<0.05	<0.01	<0.05
Pi35-29	10A-14	SW	<0.05	<0.01	<0.05
Pi35-29	10A-17	SW	<0.05	<0.01	<0.05
Pi35-29	10A-19	SW	<0.05	<0.01	<0.05
Pi35-29	10A-20	GW	<0.05	<0.01	<0.05
Pi35-29	10A-21	SW	<0.05	<0.01	<0.05
Pi35-29	10A-22	GW	<0.05	<0.01	<0.05
Pi35-29	10A-23	GW	<0.05	<0.01	<0.05

Table B12. *Constituents and analytical methods for major and trace elements, carbon, and sulfur in sediment samples analyzed by the U.S. Geological Survey, 2004*

[CAS, Chemical Abstracts Service; µg/kg, micrograms per kilogram; µg/g, micrograms per gram; AA, atomic absorption; AF, Cold Vapor Atomic Fluorescence; ICP, inductively-coupled plasma; MS, mass spectrometry; HTC/TC, high temperature combustion, thermal conductivity; pct, percent by weight; HTC/I, high temperature combustion, infrared, sample sieved to less than 63-micrometer pore diameter; --, not available]

Constituent	CAS number	Sample type	Reporting Level	Reporting Units	Method of analysis
Major and Trace Elements					
Mercury	7439-97-6	Composite[a]	20	µg/kg	AA/AF[b]
Aluminum	7429-90-5	Composite[a]	8	µg/g	ICP/MS[b]
Antimony	7440-36-0	Composite[a]	0.02	µg/g	ICP/MS[b]
Arsenic	7440-38-2	Composite[a]	0.1	µg/g	ICP/MS[b]
Barium	7440-39-3	Composite[a]	0.5	µg/g	ICP/MS[b]
Beryllium	7440-41-7	Composite[a]	0.001	µg/g	ICP/MS[b]
Bismuth	7440-69-9	Composite[a]	0.005	µg/g	ICP/MS[b]
Cadmium	7440-43-9	Composite[a]	0.003	µg/g	ICP/MS[b]
Calcium	7440-70-2	Composite[a]	0.02	µg/g	ICP/MS[b]
Cerium	7440-45-1	Composite[a]	0.5	µg/g	ICP/MS[b]
Cesium	7440-46-2	Composite[a]	0.003	µg/g	ICP/MS[b]
Chromium	7440-47-3	Composite[a]	0.2	µg/g	ICP/MS[b]
Cobalt	7440-48-4	Composite[a]	0.1	µg/g	ICP/MS[b]
Copper	7440-50-8	Composite[a]	0.5	µg/g	ICP/MS[b]
Gallium	7440-55-3	Composite[a]	0.006	µg/g	ICP/MS[b]
Iron	7439-89-6	Composite[a]	50	µg/g	ICP/MS[b]
Lanthanum	7439-91-0	Composite[a]	0.3	µg/g	ICP/MS[b]
Lead	7439-92-1	Composite[a]	0.2	µg/g	ICP/MS[b]
Lithium	7439-93-2	Composite[a]	0.2	µg/g	ICP/MS[b]
Magnesium	7439-95-4	Composite[a]	0.0003	µg/g	ICP/MS[b]
Manganese	7439-96-5	Composite[a]	0.2	µg/g	ICP/MS[b]
Molybdenum	7439-98-7	Composite[a]	0.1	µg/g	ICP/MS[b]
Nickel	7440-02-0	Composite[a]	1	µg/g	ICP/MS[b]

Table B12. *Constituents and analytical methods for major and trace elements, carbon, and in sediment samples analyzed by the U.S. Geological Survey, 2004 - Continued*

Constituent	CAS number	Sample type	Reporting Level	Reporting Units	Method of analysis
Niobium	7440-03-1	Composite[a]	2	µg/g	ICP/MS[b]
Phosphorus	7723-14-0	Composite[a]	0.008	µg/g	ICP/MS[b]
Potassium	7440-097	Composite[a]	0.02	µg/g	ICP/MS[b]
Rubidium	7440-17-7	Composite[a]	0.00004	µg/g	ICP/MS[b]
Scandium	7440-20-2	Composite[a]	0.3	µg/g	ICP/MS[b]
Silver	7440-22-4	Composite[a]	3	µg/g	ICP/MS[b]
Sodium	7440-23-5	Composite[a]	0.006	µg/g	ICP/MS[b]
Strontium	7440-24-6	Composite[a]	0.05	µg/g	ICP/MS[b]
Tantalum	7440-25-7	Composite[a]	0.2	µg/g	ICP/MS[b]
Thallium	7440-28-0	Composite[a]	0.003	µg/g	ICP/MS[b]
Thorium	7440-29-1	Composite[a]	0.03	µg/g	ICP/MS[b]
Titanium	7440-32-6	Composite[a]	0.04	µg/g	ICP/MS[b]
Uranium	7440-61-1	Composite[a]	0.02	µg/g	ICP/MS[b]
Vanadium	7440-62-2	Composite[a]	0.4	µg/g	ICP/MS[b]
Yttrium	7440-65-5	Composite[a]	0.3	µg/g	ICP/MS[b]
Zinc	7440-66-6	Composite[a]	5	µg/g	ICP/MS[b]
Carbon and Sulfur					
Total carbon as carbon	--	Composite[a]	0.01	pct	HTC/TC[b]
Organic carbon as carbon	--	Composite[a]	0.01	pct	HTC/TC[b]
Carbonate as carbon	--	Composite[a]	0.01	pct	HTC/TC[b]
Sulfur	7704-34-9	Composite[a]	0.05	pct	HTC/I[b]

[a] Sample preparation: Arbogast, B.F., ed., 1990, Quality assurance manual for the branch of geochemistry, Appendix B: Analytical Methods: U.S. Geological Survey Open-File Report 90-668, p. 21-30.

[b] Arbogast, B.F., 1996, Analytical methods for the Mineral Resource Surveys Program: U.S. Geological Survey Open-File Report 96-525, 248 p.

Appendix C

Data on Cation and Anion Balances for Individual Water-Quality Samples Used for the Long Neck Peninsula Mercury Study

Table

C1. Major cation and anion concentrations and sums for ground-water samples from Long Neck Peninsula source-water assessment sampling at production wells, in milliequivalents per liter..... C1

C2. Major cation and anion concentrations and sums for ground-water samples from time and depth series sampling, at Pot Nets Bayside production (Pi31-01) and monitoring well (Pi31-13), respectively, in milliequivalents per liter..... C2

C3. Major cation and anion concentrations and sums for ground-water samples from sampling at Pot Nets Bayside and Lakeside production and vertical-nest monitoring wells, in milliequivalents per liter..... C3

C4. Cation and anion equivalence sums, differences, and errors for major-ion concentrations in ground-water samples for the Long Neck Peninsula..... C4

Table C1. *Major cation and anion concentrations and sums for ground-water samples from Long Neck Peninsula source-water assessment sampling at production wells*

[meq/L, milliequivalents per liter. Bicarbonate data likely are positively biased for selected wells because of dissolved organic carbon; *see* ***Major ions, Alkalinity, Acid-Neutralization Capacity, and Bicarbonate*** *section of report*]

Well identifier	Calcium (meq/L)	Magnesium (meq/L)	Potassium (meq/L)	Sodium (meq/L)	Bicarbonate (meq/L)	Chloride (meq/L)	Sulfate (meq/L)	Nitrate (meq/L)	Bromide (meq/L)	Sum of cations (meq/L)	Sum of anions (meq/L)
Ph24-01	0.284	0.133	0.032	0.405	0.180	0.305	0.156	0.135	0.001	0.854	0.777
Ph24-02	0.443	0.245	0.040	0.408	0.098	0.341	0.335	0.345	0.000	1.137	1.120
Ph25-17	0.189	0.186	0.046	0.557	0.148	0.581	0.137	0.052	0.001	0.978	0.919
Ph34-18	0.313	0.235	0.084	0.245	0.049	0.398	0.006	0.410	0.001	0.877	0.864
Ph34-22	0.153	0.089	0.035	0.492	0.213	0.330	0.044	0.094	0.001	0.768	0.682
Ph34-23	0.253	0.216	0.052	0.465	0.098	0.381	0.012	0.879	0.001	0.988	1.371
Ph34-24	0.281	0.206	0.059	0.766	0.262	0.550	0.054	0.380	0.001	1.312	1.247
Ph35-24	0.200	0.119	0.039	0.587	0.148	0.355	0.031	0.375	0.001	0.946	0.910
Ph35-25	0.115	0.067	0.030	0.435	0.164	0.277	0.033	0.148	0.002	0.647	0.624
Ph35-28	0.383	0.269	0.052	0.522	0.131	0.477	0.273	0.295	0.001	1.227	1.176
Ph44-07	0.182	0.302	0.074	1.444	0.066	1.865	0.017	0.035	0.001	2.002	1.983
Pi31-01	0.146	0.285	0.055	0.661	0.213	0.592	0.181	0.109	0.004	1.146	1.099
Pi31-02	0.238	0.330	0.054	0.513	0.082	0.465	0.067	0.468	0.001	1.136	1.083
Pi31-05	0.118	0.215	0.054	0.474	0.098	0.432	0.100	0.184	0.001	0.861	0.815
Pi31-11	0.155	0.091	0.037	0.483	0.148	0.358	0.050	0.153	0.001	0.766	0.709
Pi31-12	0.248	0.142	0.045	0.428	0.131	0.398	0.083	0.219	0.001	0.863	0.832
Pi32-14	0.534	0.684	0.065	1.005	0.328	1.030	0.387	0.532	0.001	2.288	2.278
Pi32-15	0.243	0.263	0.049	0.461	0.131	0.367	0.119	0.339	0.001	1.016	0.957
Pi34-09	0.118	0.178	0.103	0.470	0.033	0.420	0.221	0.180	0.001	0.868	0.855
Pi41-02	0.084	0.057	0.032	0.452	0.148	0.285	0.035	0.136	0.001	0.625	0.604
Pi41-03	0.109	0.051	0.035	0.414	0.148	0.276	0.062	0.065	0.001	0.609	0.551
Pi43-03	0.669	0.322	0.417	0.848	0.229	1.385	0.327	0.263	0.002	2.256	2.206

Table C2. *Major cation and anion concentrations and sums for ground-water samples from time and depth series sampling at Pot Nets Bayside production (Pi31-01) and monitoring well (Pi31-13), respectively, in milliequivalents per liter*

[ft, feet; meq/L, milliequivalents per liter. Bicarbonate data likely are positively biased because of dissolved organic carbon; *see* ***Major ions, Alkalinity, Acid-Neutralization Capacity, and Bicarbonate*** *section of report*]

Well identifier	Date and time or Depth (ft)	Calcium (meq/L)	Magnesium (meq/L)	Potassium (meq/L)	Sodium (meq/L)	Bicarbonate (meq/L)	Chloride (meq/L)	Sulfate (meq/L)	Nitrate (meq/L)	Bromide (meq/L)	Sum of cations (meq/L)	Sum of anions (meq/L)
Pi31-01	02/12/2004 1530	0.156	0.304	0.059	0.661	0.262	0.587	0.164	0.109	0.004	1.180	1.126
Pi31-01	02/12/2004 1615	0.158	0.308	0.057	0.666	0.279	0.584	0.052	0.109	0.004	1.188	1.028
Pi31-01	02/12/2004 1830	0.156	0.304	0.058	0.661	0.262	0.595	0.083	0.110	0.004	1.179	1.055
Pi31-01	02/13/2004 1730	0.163	0.314	0.058	0.683	0.262	0.595	0.087	0.111	0.004	1.218	1.059
Pi31-13	56.7	0.326	0.369	0.072	1.005	0.361	0.711	0.062	0.151	0.011	1.771	1.297
Pi31-13	62.7	0.314	0.358	0.070	0.992	0.361	0.725	0.062	0.146	0.012	1.733	1.307
Pi31-13	71.7	0.316	0.361	0.070	1.009	0.361	0.733	0.065	0.136	0.011	1.756	1.305

Table C3. *Major cation and anion concentrations and sums for ground-water samples from sampling at Pot Nets Bayside and Lakeside production and vertical-nest monitoring wells*

[meq/L, milliequivalents per liter. Bicarbonate data likely are positively biased because of dissolved organic carbon; *see* ***Major ions, Alkalinity, Acid-Neutralization Capacity, and Bicarbonate*** *section of report*]

Well identifier	Calcium (meq/L)	Magnesium (meq/L)	Potassium (meq/L)	Sodium (meq/L)	Bicarbonate (meq/L)	Chloride (meq/L)	Sulfate (meq/L)	Nitrate (meq/L)	Bromide (meq/L)	Sum of cations (meq/L)	Sum of anions (meq/L)
					Bayside						
Pi31-01	0.162	0.318	0.053	0.653	0.229	0.615	0.164	0.124	0.004	1.186	1.137
Pi31-16	0.267	0.293	0.053	0.705	0.328	0.426	0.052	0.495	0.004	1.318	1.305
Pi31-17	0.165	0.211	0.056	0.835	0.443	0.564	0.083	0.089	0.006	1.268	1.185
Pi31-18	0.193	0.248	0.063	0.922	0.524	0.652	0.087	0.069	0.008	1.426	1.340
Pi31-19	0.093	0.219	0.050	0.687	0.148	0.575	0.144	0.145	0.001	1.049	1.013
Pi31-20	0.156	0.407	0.061	0.583	0.131	0.513	0.300	0.152	0.001	1.206	1.097
Pi31-21	0.174	0.399	0.041	0.618	0.082	0.860	0.150	0.101	0.001	1.232	1.194
					Lakeside						
Ph35-25	0.127	0.083	0.031	0.424	0.148	0.291	0.031	0.171	0.002	0.665	0.643
Ph35-30	0.189	0.113	0.031	0.509	0.131	0.296	0.012	0.385	0.001	0.842	0.826
Ph35-31	0.170	0.095	0.032	0.492	0.131	0.296	0.017	0.302	0.001	0.789	0.746
Ph35-32	0.083	0.051	0.026	0.366	0.164	0.278	0.027	0.048	0.001	0.526	0.518
Ph35-33	0.065	0.106	0.041	0.401	0.131	0.313	0.056	0.056	0.004	0.613	0.560
Ph35-34	0.162	0.413	0.059	0.392	0.148	0.496	0.277	0.041	0.000	1.026	0.963

Table C4. *Cation and anion equivalence sums, differences, and errors for major-ion concentrations in ground-water samples for the Long Neck Peninsula*

[DGS, Delaware Geological Survey; cation sum includes calcium, magnesium, potassium, and sodium; anionic sum includes sulfate, bicarbonate, nitrate, chloride, and bromide; balance error equals difference between cation and anion sums divided by the average of sums, in percent (%); meq/L, milliequivalents per liter; ft, feet; shaded values reflect relatively large balance errors]

Sampling activity	DGS well identifier	Cationic sum (meq/L)	Anionic sum (meq/L)	Difference (meq/L)	Balance error (%)	Average balance error (%)	Standard deviation of balance errors (%)
Peninsula source-water-quality assessment survey (Production wells)	Ph24-01	0.854	0.777	0.077	9.5		
	Ph24-02	1.137	1.120	0.017	1.5		
	Ph25-17	0.978	0.919	0.059	6.2		
	Ph34-18	0.877	0.864	0.013	1.5		
	Ph34-22	0.768	0.682	0.086	11.9		
	Ph34-23	0.988	1.371	-0.384	-32.5		
	Ph34-24	1.312	1.247	0.064	5.0		
	Ph35-24	0.946	0.910	0.036	3.9		
	Ph35-25	0.647	0.624	0.023	3.6		
	Ph35-28	1.227	1.176	0.050	4.2		
	Ph44-07	2.002	1.983	0.020	1.0		
	Pi31-01	1.146	1.099	0.047	4.2		
	Pi31-02	1.136	1.083	0.053	4.8		
	Pi31-05	0.861	0.815	0.046	5.5		
	Pi31-11	0.766	0.709	0.057	7.7		
	Pi31-12	0.863	0.832	0.031	3.6		
	Pi32-14	2.288	2.278	0.010	0.4		
	Pi32-15	1.016	0.957	0.059	6.0		
	Pi34-09	0.868	0.855	0.013	1.5		
	Pi41-02	0.625	0.604	0.021	3.4		
	Pi41-03	0.609	0.551	0.058	9.9		
	Pi43-03	2.256	2.206	0.049	2.2	3.00	8.50

Table C4. *Cation and anion equivalence sums, differences, and errors for major-ion concentrations in ground-water samples for the Long Neck Peninsula —Continued*

Sampling activity	DGS well identifier, Date and Time or Depth of sample		Cationic sum (meq/L)	Anionic sum (meq/L)	Difference (meq/L)	Balance error (%)	Average balance error (%)	Standard deviation of balance errors (%)
Bayside time-series data (Production well)	Well, Date and Time							
	Pi31-01	02/11/2004 1530	1.180	1.126	0.055	4.7		
		02/11/2004 1615	1.188	1.028	0.160	14.4		
		02/11/2004 1830	1.179	1.055	0.124	11.1		
		02/12/2004 1730	1.218	1.059	0.158	13.9	11.0	4.45
Bayside monitoring well depth-series data (Monitoring well)	Well, and Depth (ft)							
	Pi31-13	56.7	1.771	1.297	0.474	30.9		
		62.7	1.733	1.307	0.427	28.1		
		71.7	1.756	1.305	0.451	29.5	29.5	1.42
Bayside-Lakeside vertical distribution study (Production and vertical nest monitoring wells)				**Bayside**				
	Pi31-01		1.186	1.137	0.049	4.2		
	Pi31-16		1.318	1.305	0.013	1.0		
	Pi31-17		1.268	1.185	0.083	6.8		
	Pi31-19		1.049	1.013	0.036	3.5		
	Pi31-20		1.206	1.097	0.109	9.5		
	Pi31-21		1.232	1.194	0.038	3.1	4.67	3.00
				Lakeside				
	Ph35-25		0.665	0.643	0.022	3.4		
	Ph35-30		0.842	0.826	0.016	1.9		
	Ph35-31		0.789	0.746	0.042	5.5		
	Ph35-32		0.526	0.518	0.008	1.5		
	Ph35-33		0.613	0.560	0.053	9.1		
	Ph35-34		1.026	0.963	0.063	6.3	4.63	2.92

Appendix D
Antecedent Sampling Pumping Conditions, Sampling Set-Up, Preliminary Design Study, and Integrity Checks for Selected Monitoring Wells Used for the Long Neck Peninsula Mercury Study

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Figure

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D6. Depth profiles for specific conductance in the screened intervals of two monitoring wells before and after about 18-20 hours of pumping a nearby production well (Pi31-01), Pot Nets Bayside, Sussex County, Delaware..... D11

Table

D1. Relative standard errors (in percent) in total mercury concentrations from time 0 for successive time-series raw or filtered samples collected from production well Pi31-01 at Pot Nets Bayside, Sussex County, Delaware..... D6

D2. Relative standard errors (in percent) in total mercury concentrations between successive depth-series raw or filtered samples collected from monitoring well Pi31-13 at Pot Nets Bayside, Sussex County, Delaware..... D12

Production-Well Pumping Before Sampling

Production wells selected for sampling were indicated by their owners to be routinely (all private and most public), or at least occasionally (Long Neck Water Company, LNWC, wells Pi41-02, Pi41-03, Pi32-15, and Pi3105), used for water supplies. For the Bayside and Lakeside production wells Pi31-01 and Ph35-25, respectively, which were off line because of elevated mercury (Hg) concentrations, sampling at these and nearby monitoring wells was preceded by pumping each production well at 190-200 gallons per minute for at least several hours per day for at least several months in advance of sampling. This pumping regime was the same pumping regime commonly used by the LNWC to provide water for use. Routine monitoring by the LNWC indicated that the adopted pumping regime led to elevated total mercury (HgT) concentrations (500 nanograms per liter, ng/L, or more) in the discharge from each production well during sampling, and that flow field and geochemical conditions were likely similar to historical conditions of contamination.

During the November-December 2003 Peninsula survey sampling, it was not known how long pumping should be conducted to obtain chemical stability in the discharge from the contaminated Bayside or Lakeside production wells. Sampling was conducted at each production well after bulk chemistry parameters appeared stable (about an hour after pumping began). Sampling at the Bayside production well in February 2004, which was conducted over a 30-hr (hour) period, indicated stability likely occurred after about 2 hrs of pumping, and thereafter appeared to remain relatively stable for at least 30 hrs. For sampling conducted at the Bayside or Lakeside sites in September 2004, a slightly longer pumping period was required (about 36 hrs) for each production well. At each site, samples were collected from the production well after 2 hrs of pumping. Sampling at the nearby monitoring wells began after sampling at the production well, and was conducted sequentially and completed at all monitoring wells within 36 hrs.

Well Discharge and Sampling Rates and Equipment Set-Up and Cleaning

Use of turbidity as the key stability parameter was considered necessary because well pumping rates differed markedly depending on the type of well being sampled. For public production wells, pump flow rates were set by well owners to 150-200 gallons per minute (gpm). For private wells, that were forced to run continuously by opening multiple drain lines, well-discharge rates were not directly measurable, but appeared to be on the order of tens of gpm. For monitoring wells, the discharge rate of the submersible pump was controlled with a rheostat, and measured as the sample-line discharge. Regardless of well type, the rate of flow through the sample line was adjusted with either a spigot or hose bib on a production well, or with the rheostat for the submersible pump in a monitoring well, to provide a low sample-line discharge rate of 0.1 gpm or less.

The sample feed line to the sampling chamber consisted of a variable-length piece of 0.5-inch (in.) outer diameter (OD) polyfluorocarbon-lined high-density polypropylene (PCF-HDPE) tubing. The inflow end of the PCF-HDPE tubing was joined with a HDPE coupling to a short (1-ft) piece of 0.5-in. OD C-flex tubing. At a production well, the C-flex

tubing was either stretched over and clamped to a smooth brass spigot, or connected and clamped to a barbed nylon fitting with a female hose thread that screwed directly onto a brass or polyvinylchloride (PVC) hose bib. For all monitoring wells, the PCF-HDPE tubing was connected and clamped to a 316 stainless-steel barb fitted to the head of a small submersible helical-rotor pump.

Sampling for CFCs and DGs required the introduction of 0.375-in. OD refrigerant-grade copper sample tubing (http://water.usgs.gov/lab/chlorofluorocarbons/sampling/, accessed December 23, 2005). At a production well, sample flow was split at the discharge end of the C-Flex tubing with a nylon "Y" coupling. The copper tubing was connected and clamped to one upper stem, and the PCF-HDPE tubing was connected and clamped to the other upper stem of this coupling. For a monitoring well, a 316 stainless steel "Y" with machine threads attached to the submersible pump head was used to split the sample discharge into the copper and PCF-HDPE sample lines.

Precleaned sample bottles and chemical preservatives for mercury were provided by the U.S. Geological Survey (USGS) Mercury Research Laboratory (MRL), Middleton, Wisconsin. All other sample bottles and preservatives were obtained through other utilized USGS Laboratories (*table 3, body of report*).

All nonmetallic tubing, fittings, couplings, and filters were cleaned before use and were discarded after a single use. Cleaning involved soaking mercury-related sample-wetted equipment in a 10 percent by volume hydrochloric acid-DACF[1] water solution for 2 days (fittings and couplings) to 7 days (nonmetallic tubing and filters), rinsing and flushing equipment with DACF water to remove acid residue, double-bagging equipment in resealable polypropylene bags, and storing it at low temperatures (0 degrees Celsius, ^{o}C, or less) until it was taken into field. Except for tubing and the submersible pump, mercury-related sampling equipment was kept chilled (about 5 ^{o}C or less) on ice until used.

Reused sample-wetted equipment, including the small submersible pump, was cleaned on site for sampling conducted at more than one well during the day. Otherwise, it was cleaned at the end of the day. Cleaning was conducted in accordance with USGS National Field Manual protocols (Wilde, 2004), with a 0.02 percent by volume phosphate-free detergent and water solution, rinsed (flushed) with water to remove detergent, and finally rinsed with DACF water. For cleaning done in the field, the DACF water also was used in place of tap water for the detergent solution and detergent rinse.

Preliminary Study to Assess Short-Term Temporal Variations and Depth Differences in Ground-Water Chemistry for Placement and Sampling of Vertical-Nest Monitoring Wells

A preliminary study at the Pot Nets Bayside site was conducted to determine if differences in ground-water chemistry possibly occurred over short time periods (2 days or less) and with depth in the vicinity of a continuously pumping production well. A follow-up study was conducted to obtain data at the Pot Nets Bayside and Lakeside sites on the vertical distribution of Hg and other chemical or physical charactersitics in lithologic materials and ground water with depth.

[1] Deionized activated charcoal filtered water, with specific conductance less than 1 microsiemen per centimeter at 25 degrees Celsius, which contained less than 2 nanograms per liter of total mercury.

The preliminary study at the Pot Nets Bayside site was undertaken in February 2004 to determine if production-well discharge chemistry, including mercury, varied over short-time periods (2 days or less), and if ground-water chemistry possibly differed with depth in the vicinity of the contaminated Bayside production well. The chief intent of this preliminary study was to help identify where to place the vertical nests of short-screened monitoring wells at each site, the depths to consider for monitoring wells in those nests, and when to begin and end data and sample collection from production and newly installed monitoring wells at each site.

Short-Term Temporal Variations in Ground-Water Chemistry

The potential for short-term variations in the chemistry of ground water, including Hg concentrations, was evaluated with time-series data obtained at the Pot Nets Bayside production well (Pi31-01). These data (Appendix A, table A9) were collected on February 11-12, 2004, before, at the start (figs. D1 and D2, Time 0 hrs), and after about 1 hr, 2 hrs, and 25 hrs of pumping at this well.

Differences in the bulk chemical properties of well Pi31-01 discharge (pH, temperature, specific conductance (SC), dissolved-oxygen concentrations, and oxidation-reduction potential (millivolts) were obtained with a multi-parameter sonde. Drift-style variations in individual bulk properties chiefly occurred during the first hour or 2 of pumping, and thereafter were minor in magnitude (figs. D1 and D2). The pattern in variations indicated that changes in the chemical composition of discharged water were mainly discernable only during the first 1 to 2 hrs of pumping.

Data obtained from ground-water samples collected after pumping began indicate that the concentrations of HgT in either raw or filtered ground-water samples varied through time, and, as in the case of bulk properties, varied mainly between the first (Time-0) sample and subsequent samples collected at least 1 hr after pumping began. For raw-water samples, the concentration of HgT (hereafter, $HgT_{gw\text{-}raw}$) in the Time-0 sample was 1,140 ng/L, which was at least 270 ng/L less than the concentration of $HgT_{gw\text{-}raw}$ found in any subsequent sample. For filtered samples (0.4-micrometer absolute pore size filter), the concentration of HgT (hereafter, $HgT_{gw\text{-}f0.4}$) for the Time-0 sample equaled 1,260 ng/L, which was at least 190 ng/L less than the $HgT_{gw\text{-}f0.4}$ found in any subsequent ground-water samples. After the first hour of pumping, however, differences in the concentration of HgT_{gw} between either raw or filtered successive samples were random and relatively small in magnitude.

Relative differences (in percent) computed for HgT_{gw} between the first Time-0 sample and successive time-series samples for raw water ranged between 21-28 percent, and for filtered samples ranged between 14-18 percent (table D1). These differences are 2-4 times greater than the estimated plus or minus (±) 6-7 percent relative difference attributable to measurement variability due field and laboratory methods (*See Data Quality, Mercury*, main report). In contrast, relative differences in T-Hg between successive raw (or filtered) samples collected 1 or more hrs after pumping are somewhat random in sign and range from 0.0-6.8 percent (table D1). These small differences could be caused by measurement variability due to field and laboratory methods.

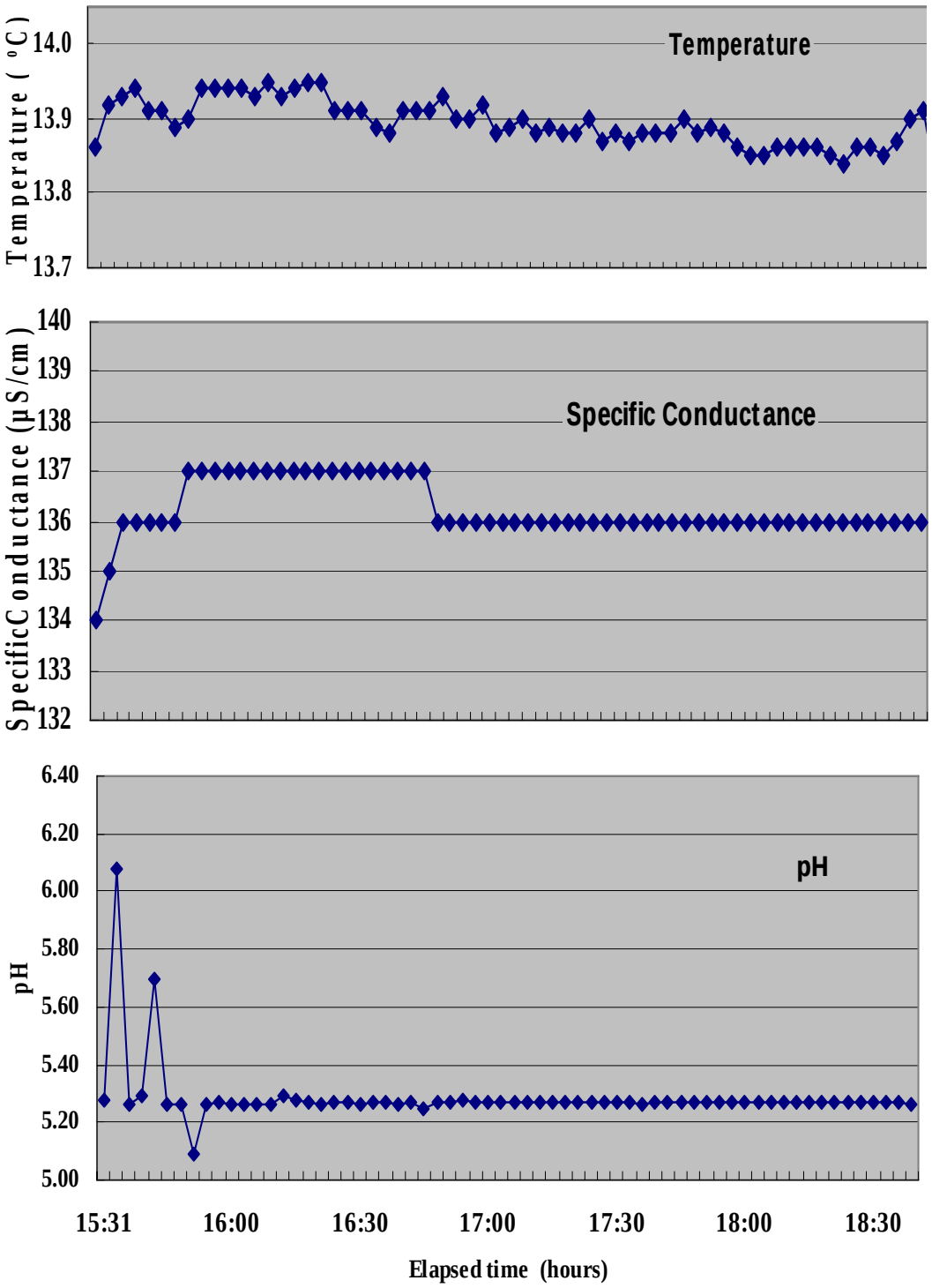

Figure D1. *Temperature, specific conductance, and pH of discharge from well Pi31-01 on February 11, 2004, at 3-minute time intervals for 3-hour period, Pot Nets Bayside, Sussex County, Delaware.*

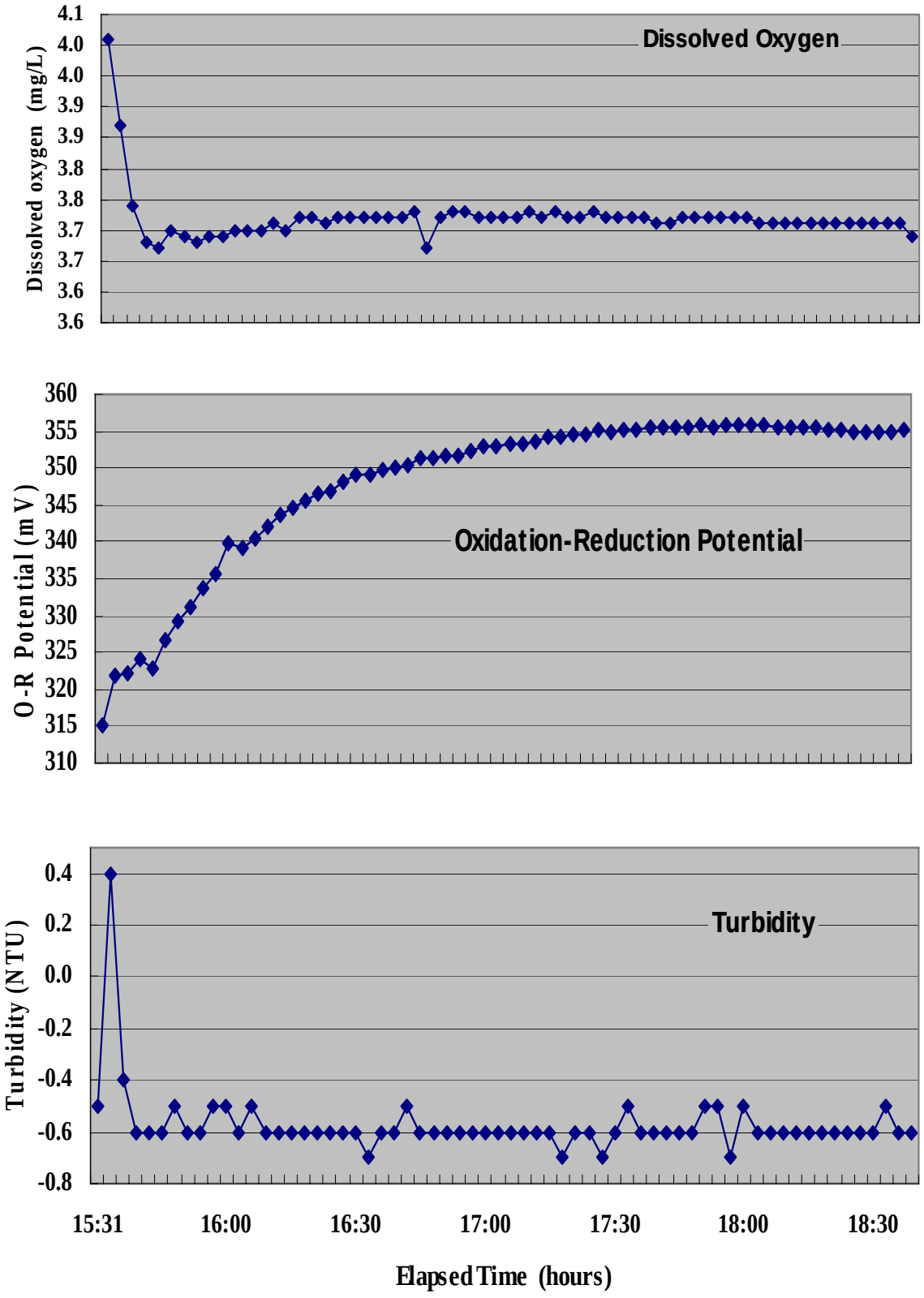

Figure D2. *Dissolved oxygen, oxidation-reduction potential, and turbidity of discharge from well Pi31-01 on February 11, 2004, at 3-minute time intervals for a 3-hour period, Pot Nets Bayside, Sussex County, Delaware.*

Table D1. *Relative standard errors (in percent) in total mercury concentrations from time 0 for successive time-series raw or filtered samples collected from production well Pi31-01 at Pot Nets Bayside, Delaware.*[a]

[HgT, total mercury, filtered, filtrate from 0.45-micrometer absolute pore size nylon filter; ---, no values]

Sample in sequence	Elapsed time from start of pumping (hours)			
	0	1	2	25
	HgT raw water			
First	---	24.6	27.9	21.2
Second	---	---	3.4	-3.5
Third	---	---	---	-6.8
	HgT filtered water			
First	---	14.0	17.4	17.4
Second	---	---	3.4	3.4
Third	---	---	---	0.0

[a] Concentration of total mercury at time 0 was 1,140 nanograms per liter for raw-water sample and 1,260 nanograms per liter for 0.4-micrometer absolute pore size filtered sample.

Comparison of other time-series data, including bulk properties, major ions, and selected trace elements (lead, iron, barium, and manganese), indicated that there was little if any variation in the chemistry of production-well discharge through time (Appendix A, table A9). The relative differences that did arise in the concentration of some individual chemical constituents generally are on the order of a few percent, which likely places them within the variability in measurement due to field and laboratory methods.

The initial changes in bulk properties and HgT_{gw} concentrations in relation to pump startup (Time-0) and after 1-2 hrs of pumping were used to guide subsequent data and sample collection at the Bayside and Lakeside community sites. For example, the minimum pumping time was set to 1-3 hrs for each production well before sample collection began. In addition, the minor variations in bulk properties and T-Hg for well discharge from 1-3 hrs to at least 25 hrs after pumping began provided a 23-24-hr time period to complete sampling for all wells at each Pot Nets site.

Differences in Ground-Water Chemistry with Depth Before and During Production Well Pumping

Potential changes in the chemistry of ground water, including Hg concentrations, with depth initially were evaluated with depth-series data (Appendix A, table A10) obtained at the Pot Nets Bayside site from two previously installed monitoring wells

(fig. 4A, Pi31-22 and Pi31-13, body of report). Depth-series data collected at each well included vertical profiles of bulk properties (temperature, pH, DO, and SC) obtained with a submersible multi-parameter sonde. Profiles were obtained at each well before and while pumping occurred at the nearby Bayside production well to determine the possible effect of pumping on the stability in ground-water chemistry with depth.

Bulk-property depth profiles obtained before pumping began at the production well indicated that notable differences occurred at only 1 depth interval—just below the solid casing, and in the first 3-5 feet of the well screen, of each monitoring well (figs. D3 through D6). The changes in bulk chemistry at this casing-screen juncture are assumed to reflect a pumping artifact—namely, a 3-5-foot mixing zone that likely is the result of the piston effect created by the daily short-term (3-5 hr) pumping of the production well, which partially draws water that had been standing in the monitoring well casing down into the screened interval where it mixes with fresh ground water. Evidence for this drawdown is the change in water levels in the monitoring wells. Water levels typically drop about 1.5 feet in monitoring well Pi31-22, and about 0.5 feet in monitoring well Pi31-13, after several hours of pumping at the production well (James Mooney, Operations Manager, LNWC, written commun., 2004). Below this 3-5-foot mixing zone, water in the screened interval of the monitoring well is assumed to be ground water. No marked changes in any bulk property were observed in ground water with depth in either monitoring well before pumping began at the production well (figs. D3 through D6).

Subsequent low-flow sampling at three different depths in monitoring well Pi31-13 confirmed little difference in water chemistry with depth. Mercury ($HgT_{gw\text{-}raw}$) occurred at high concentrations, and ranged from 1,470 to 1,560 ng/L for raw and filtered (0.4-micrometer absolute pore size) samples (Appendix A, table A10). The relative differences between $HgT_{gw\text{-}raw}$ concentrations at successively deeper depths, however, were small in magnitude, and well within the ± 6-7 percent variability $HgT_{gw\text{-}raw}$ measurement due to field and laboratory methods (table D2). Other chemical parameters and constituents, including major ions, and selected nutrients and trace elements, also differed little with depth (Appendix A, table A10).

Given that ground water in the vicinity of the production well appears chemically stratified following about 18 hrs of pumping on the basis of the profile data from well Pi31-22, the lack of chemical stratification with depth in either monitoring well before the production well pump was started, or in well Pi31-13 after pumping began, probably indicates the mixing of chemically different waters, predominately in the well casing. That this mixing did not occur in well Pi31-22 during pumping at the production well is assumed to be the result of the close proximity of this well to the production well. Well Pi31-22 lies only about 20 feet from the production well. In contrast, well Pi31-13 lies along the same radial flow line as Pi31-13 to the production well (fig.4A, *main report*), but it is about 110 feet from the production well. As a consequence, during pumping, the drawdown at well Pi31-22 was measured to be about 1.5 feet, whereas the drawdown at well Pi31-13 was determined to be about 0.5 feet. Thus, well Pi31-22 is well within the cone of depression created by the pumping production well, and thus located in ground water that is moving relatively rapidly and likely with a strong lateral flow component toward the nearby production well. This could reduce the degree of vertical mixing of ground water in the screened interval of this well.

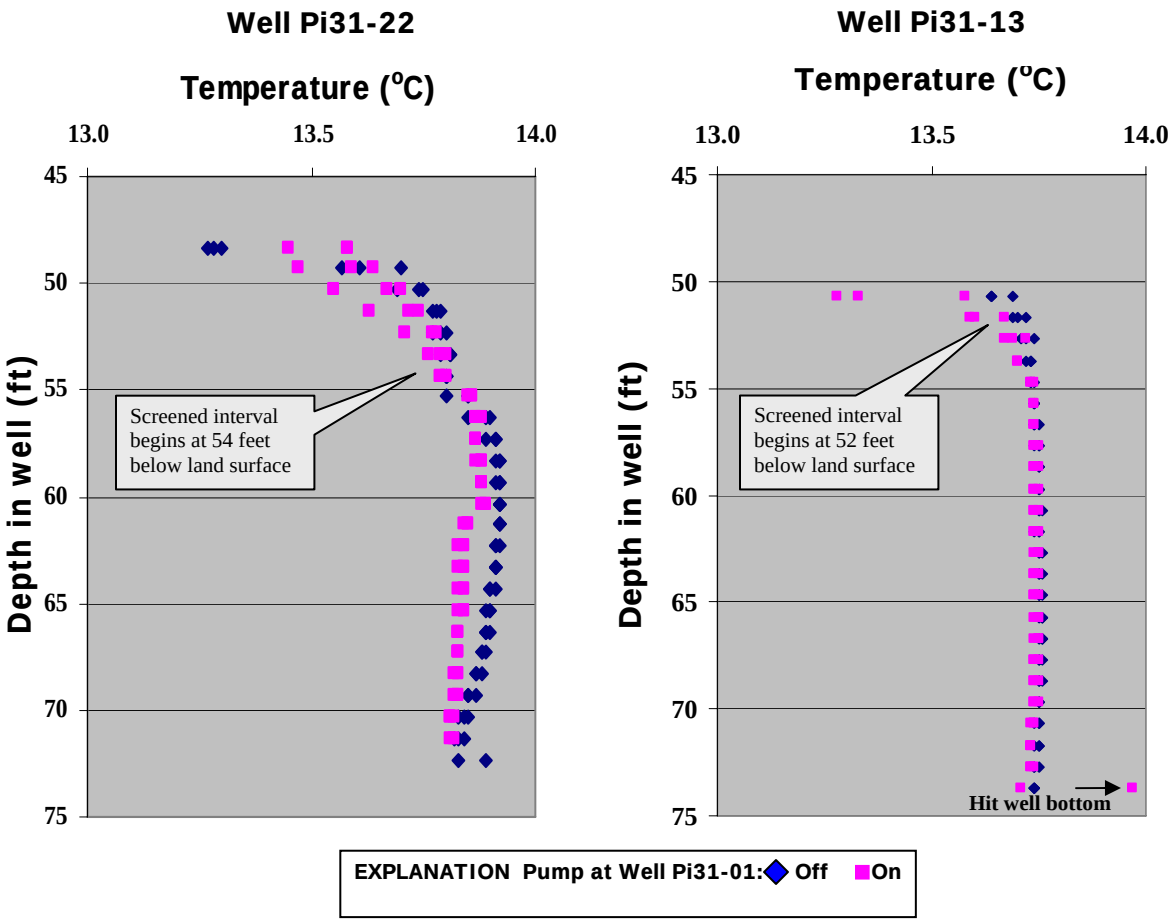

Figure D3. *Depth profiles for temperature in the screened intervals of two monitoring wells before and after about 18-20 hours of pumping a nearby production well (Pi31-01), Pot Nets Bayside, Delaware*

(Data recorded February 11, 2004 between 2.5-4.5 hours before the pumping began at well Pi31-01, and again on February 12, 2004, after 18.5-20.5 hours of pumping at well Pi31-01. Measurements were made at 1-foot depth intervals. At each interval, duplicate or triplicate measurements were recorded during a 3-minute period. Appearance of a single plotted point for a given interval and either before or after pumping began generally implies multiple identical or nearly identical values occurred for all measurements at that depth.)

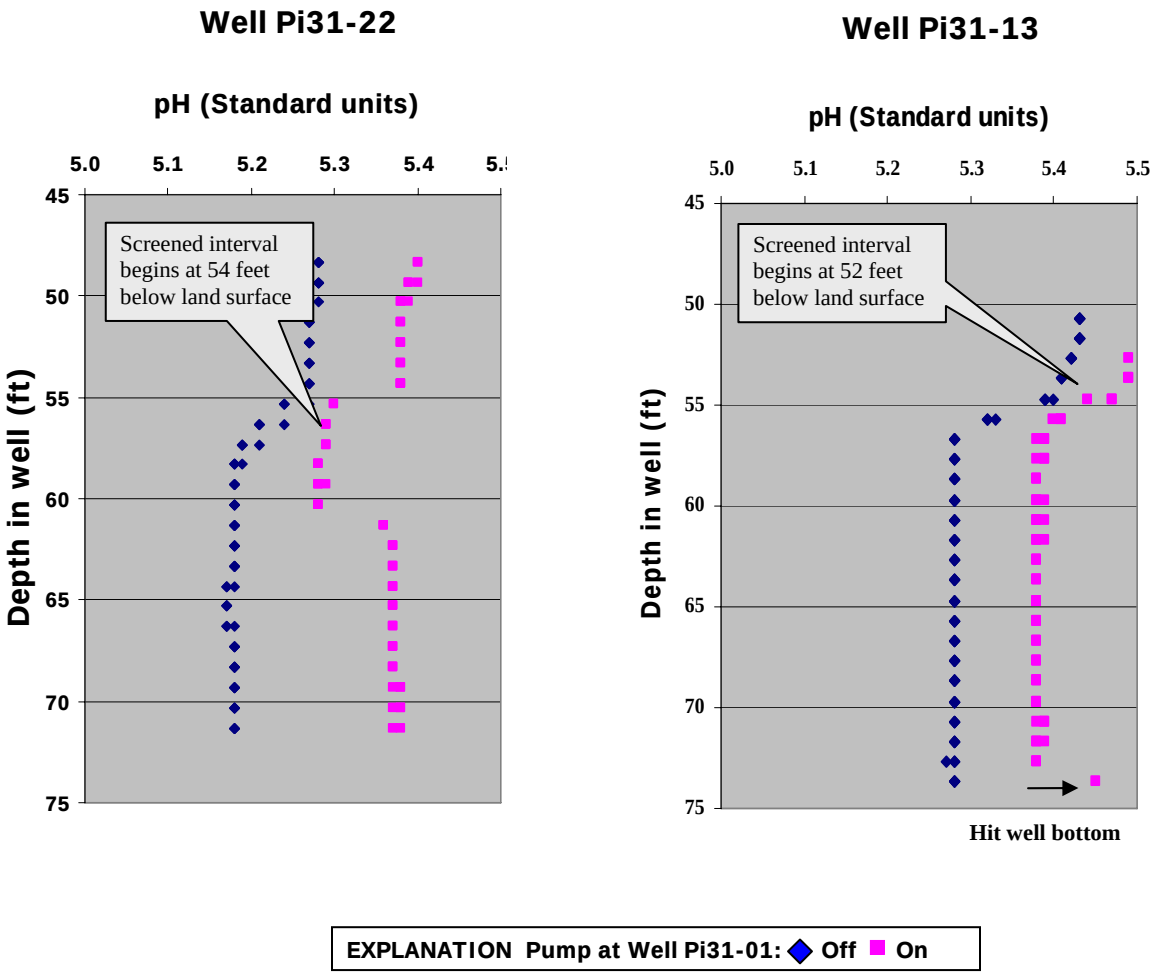

Figure D4. *Depth profiles for pH (standard units) in the screened intervals of two monitoring wells before and after about 18-20 hours of pumping a nearby production well (Pi31-01), Pot Nets Bayside, Sussex County, Delaware.*
(Data recorded February 11, 2004 between 2.5-4.5 hours before the pumping began at well Pi31-01, and again on February 12, 2004, after 18.5-20.5 hours of pumping at well Pi31-01. Measurements were made at 1-foot depth intervals. At each interval, duplicate or triplicate measurements were recorded during a 3-minute period. Appearance of a single plotted point for a given interval and either before or after pumping began generally implies multiple identical or nearly identical values occurred for all measurements at that depth.)

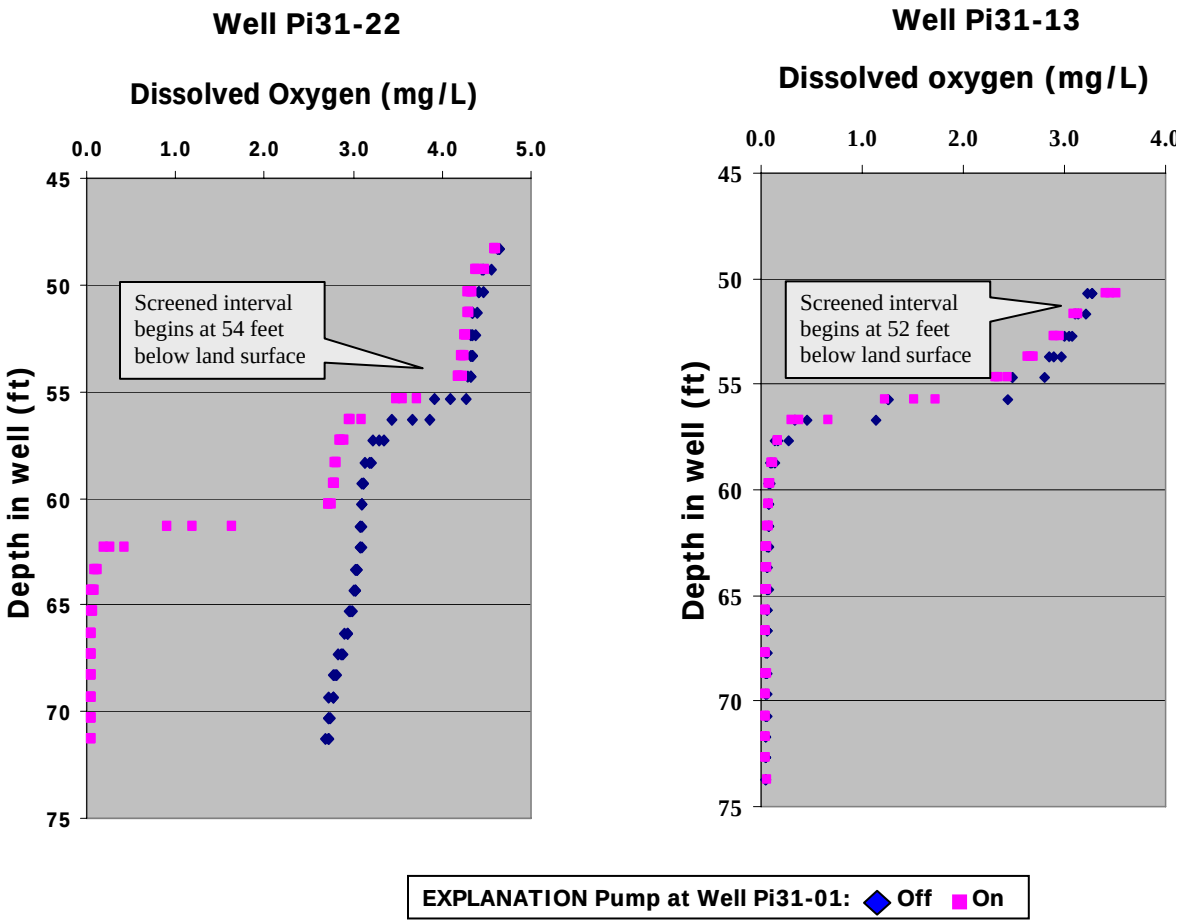

Figure D5. *Depth profiles for dissolved oxygen in the screened intervals of two monitoring wells before and after about 18-20 hours of pumping a nearby production well (Pi31-01), Pot Nets Bayside, Sussex County, Delaware.* (Data recorded February 11, 2004 between 2.5-4.5 hours before the pumping began at well Pi31-01, and again on February 12, 2004, after 18.5-20.5 hours of pumping at well Pi31-01. Measurements were made at 1-foot depth intervals. At each interval, duplicate or triplicate measurements were recorded during a 3-minute period. Appearance of a single plotted point for a given interval and either before or after pumping began generally implies multiple identical or nearly identical values occurred for all measurements at that depth.)

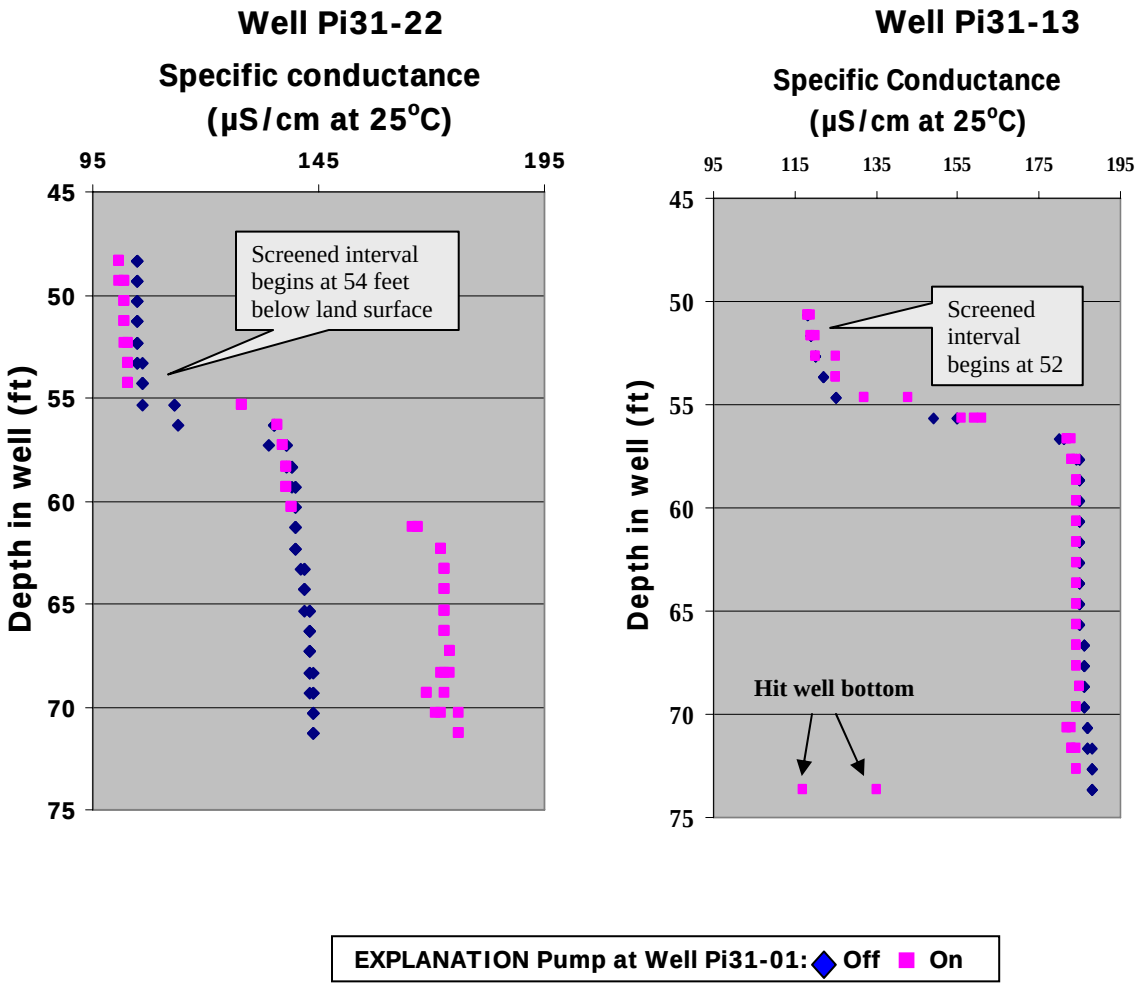

Figure D6. *Depth profiles for specific conductance in the screened intervals of two monitoring wells before and after about 18-20 hours of pumping a nearby production well (Pi31-01), Pot Nets Bayside, Sussex County, Delaware.* (Data recorded February 11, 2004 between 2.5-4.5 hours before the pumping began at well Pi31-01, and again on February 12, 2004, after 18.5-20.5 hours of pumping at well Pi31-01. Measurements were made at 1-foot depth intervals. At each interval, duplicate or triplicate measurements were recorded during a 3-minute period. Appearance of a single plotted point for a given interval and either before or after pumping began generally implies multiple identical or nearly identical values occurred for all measurements at that depth.)

Table D2. *Relative standard errors (in percent) in total mercury concentrations relative to sample at 56.7 feet for successive depth-series raw or filtered samples collected from monitoring well Pi31-13 at Pot Nets Bayside, Sussex County, Delaware.* [a]

[HgT, total mercury; filtered, filtrate from 0.45-micrometer absolute pore size nylon filter; ---, no data]

Depth of sample from land-surface datum (feet)	Depth of sample from land-surface datum (feet)		
	56.7	62.7	71.7
	HgT raw water		
56.7			
62.7	---	1.9	5.9
71.7	---	---	4.0
	HgT filtered water		
56.7	---	4.4	2.0
62.7	---	---	-2.0
71.7	---	---	---

[a] Concentration of total mercury in sample from 56.7 feet below land-surface datum was 1,550 nanograms per liter for raw-water sample and 1,560 nanograms per liter for 0.4-micrometer absolute pore size filtered sample.

Results from the depth profiling of the ground-water chemistry were used to guide the geographic placement and depths of the vertical nests of short-screened monitoring wells near each production well at the Bayside and Lakeside sites. To aid in the collection of chemically stratified ground water with depth, vertical nests of wells were placed within about 25 feet of the production well, but out beyond a formerly installed monitoring well if one existed close to the production well. This design placed the newly installed monitoring wells within the cone of depression created by the pumping production well, which appeared to reduce the mixing of chemically stratified waters in the well, and helped reduce the likelihood of sampling water that had been in contact with a formerly installed monitoring well. Depths of newly installed monitoring wells were determined in part on the basis of depth profiles taken at both sites in the formerly installed monitoring wells that were closest to the production wells. Additional profiles were obtained in June 2004 during nested well installation at formerly installed monitoring wells closest to the production well at each site. Profiles were obtained before pumping the production well and after at least several hours of pumping. Results were similar to those presented here.

Integrity Checks for Selected Monitoring Wells

Downhole video logs were obtained at all three previously installed monitoring wells in the vicinity of each contaminated production well at the Pot Nets Bayside (Pi31-01) and Lakeside (Ph35-25) sites (figs. 4A and 4B, *main report*). The logs indicated that all wells were relatively clean, free of debris, with intact casings and screened intervals. Monitoring well Pi31-22, however, did have an additional 2-foot section of PVC casing above the PVC screen compatred to what was indicated in the drilling record. This implied the depth of the casing from land surface was 54 feet

and not the 52 feet recorded in the Delaware Department of Natural Resources and Enviromental Control Well Completion Report. This anamoly was noted in the summary of well-construction characteristics (Appendix A, table A2, Well Pi31-22).

References Cited

Wilde, F.D., ed., April 2004, Cleaning of equipment for water sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A3, accessed December 23, 2005 at http://pubs.water.usgs.gov/twri9A3/

Prepared by the Maryland-Delaware-District of Columbia
Water Science Center's Publications Unit

For additional information, contact:
Director, MD-DE-DC Water Science Center
U.S. Geological Survey
8987 Yellow Brick Road
Baltimore, MD 21237

or visit our Web site at:
http://md.water.usgs.gov