State of Delaware
DEPARTMENT OF
NATURAL RESOURCES &
ENVIRONMENTAL CONTROL
David Small, Secretary

Delaware's 2016 305(b) Groundwater-Quality Assessment Based on Public-Well Data: Results of Sampling, October 1, 2013 through September 30, 2015

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Groundwater-Quality Highlights

Groundwater quality in Delaware was assessed based on raw-water data collected during a two-year time period (October 1, 2013 through September 30, 2015) from public water-supply (PWS) wells. The water-quality database consisted of almost 30,000 analyses. Five aquifer types were recognized for reporting purposes: (1) unconfined, (2) confined, (3) semi-confined, (4) fractured-rock, and (5) karst. Unconfined, confined, and semi-confined aquifers occur in the mid-Atlantic Coastal Plain Physiographic Province, which comprises most (~96%) of Delaware's land-surface area. Fractured-rock and karst aquifers occur in the Piedmont Physiographic Province in the remaining northernmost portion of the state. There are 1,174 active PWS wells and a large majority (90%) of these wells produce from Coastal-Plain aquifers; 5% produce from Piedmont aquifers; and aquifer designations for the remainder are either not known or not yet established. Well depths range from 22 to 957 ft below land surface (bls) with a median well depth of 145 ft bls. Highlights from the groundwater-quality assessment follow*:

- **Based on nitrate data, almost half of the wells evaluated are susceptible to human influence.** Nitrate concentrations exceeded 0.4 mg/L, a threshold indicative of human impacts, in 43.5% of the samples.
- **The unconfined aquifer is the most susceptible to human influence.** This aquifer had the highest median nitrate concentration (4.70 mg/L), the largest fraction of concentrations exceeding 0.4 mg/L (91.3%), and the smallest fraction of non-detectable concentrations (7.2%).
- **Nitrate concentrations exceeded the drinking-water standard in <5% of all samples.** Concentrations exceeded the Primary Maximum Contaminant Level (PMCL) of 10 mg/L for drinking water in 4.5% of the samples. Areally, PMCL exceedances were limited to unconfined wells located in Sussex County.
- **Overall, nitrate concentrations decrease with depth.** Trends in nitrate concentrations with respect to sample depth indicate that overall the vertical extent of human influence was primarily limited to depths of ~350 ft below land surface and shallower. At depths greater than 350 ft, nitrate was not detected above the quantitation limit. The deepest nitrate detection was associated with a fractured-rock well. (Wells in Piedmont aquifers typically have very long open intervals that may allow contaminants to enter at shallower depths.) Nitrate detections in Coastal-Plain wells were primarily limited to depths of 240 ft and shallower.
- **Organic compounds were frequently undetectable.** Organic compounds were not detected in 93.4% of the analyses. Almost three-quarters (71.4%) of the detections were found at concentrations less than 1 µg/L. Chloroform, a disinfection byproduct, was the most-frequently detected organic compound.
- **Organic compounds rarely exceeded drinking-water standards.** Specifically, organic compounds exceeded PMCLs in 0.5% of the analyses. The following analytes were found above the PMCL: tetrachloroethylene (PCE) and Bis(2-chloroethyl) ether (BCEE).
- **Some organic compounds have depth trends similar to nitrate.** Specifically, concentrations of methyl tert-butyl ether (MTBE), PCE, and trichloroethylene (TCE) with respect to sample depth indicate that the vertical extent of human impact in the Coastal-Plain aquifers is limited to depths of ~150 ft bls. Data for Piedmont aquifers were limited in this assessment, but in past assessments, organic compounds were detected at greater depths in fractured-rock and karst aquifers, the wells in which typically have very long open intervals that may allow contaminants to enter at shallower depths.
- **Trace elements were frequently undetectable.** Trace elements were not detected in 72% of the analyses. More than half (53%) of the detections were found at concentrations less than 0.1 mg/L and all detections (100%) were found at concentrations less than 1 mg/L. Chromium, nickel, and barium were the top three most-frequently detected trace elements.

- **Arsenic data were too limited in this assessment for meaningful analysis; based on previous assessments, arsenic detections were primarily limited to confined wells in glauconitic aquifers.** Based on the 2014 assessment (Kasper, 2014), arsenic was one of the top five most frequently detected trace elements. Detections of arsenic were primarily limited to confined wells that produce from the Rancocas, Mt. Laurel, or Piney Point aquifers, which are associated with glauconitic geologic formations. A USGS study targeting the Rancocas aquifer and completed during the reporting period (Denver, 2016) found that 15 (41.7%) of 36 wells had arsenic concentrations in excess of the PMCL (10 µg/L).
- **Radionuclide data were very limited in this assessment.** Available radionuclide data were limited to the following parameters with the number of analyses indicated in parentheses: uranium-238 (14), radium-226 (3), radium-228 (3), and gross alpha particle activity (3). All uranium-238 results were ND and thus below the 0.03 mg/L PMCL. All of radium-226 and radium-228 combined results were below the 5 pCi/L PMCL. All gross alpha particle activities were below the 15 pCi/L PMCL. A USGS study targeting the Rancocas aquifer and completed during the reporting period (Denver, 2016) found that 14 (44.4%) of 36 wells had radon concentrations above the lower proposed MCL (300 pCi/L); none of the radon concentrations exceeded the proposed alternative MCL of 4,000 pCi/L.

Other groundwater-quality findings:

- **Overall, groundwater is predominantly soft or moderately hard.** Specifically, most of the results (84.5%) met either of these criteria. There were no hardness data for karst wells; based on previous assessments, this aquifer type routinely had the most elevated hardness values.
- **Groundwater was acidic in about half of the overall samples.** Specifically, pH values were less than the lower limit of the Secondary Maximum Contaminant Level (SMCL) range (6.5-8.5 standard pH units) in 52.6% of the samples. Unconfined and semi-confined wells had the largest fractions of pH values below the SMCL range (88.6 and 80.0%, respectively); in contrast, confined wells had pH values that were predominantly within the SMCL range (76.3%). There were limited pH data for fractured-rock and karst wells; based on previous assessments, karst wells had the highest median pH and the largest fraction of samples within the SMCL range.
- **Iron was elevated in almost one third of the samples.** Iron exceeded the SMCL (0.3 mg/L) in 31.2% of the samples. Elevated iron was detected at virtually all depths. Relative to other Coastal-Plain aquifer types, semi-confined wells had the largest fraction of concentrations greater than the SMCL (46.2%).
- **Groundwater is generally dilute overall based on total dissolved solids (TDS) data.** Specifically, the median TDS concentration was 146 mg/L. All TDS concentrations were below the 500 mg/L SMCL. There were no TDS data for karst wells; based on previous assessments, this aquifer type typically had the highest median TDS concentration.
- **Chloride concentrations rarely exceeded the drinking-water standard.** Chloride concentrations exceeded the SMCL (250 mg/L) in less than 1% of the samples. The most elevated chloride concentration (282 mg/L) was associated with an unconfined well sample.
- **Sodium concentrations were above the health advisory level in about one quarter of the samples.** Sodium concentrations exceeded the Health Advisory (HA) of 20 mg/L in 23.3% of the samples. Sodium concentrations above the HA were found at virtually all depths. Confined wells had the largest fraction of sodium concentrations above the HA (29.5%).

*Note: Because only raw or apparently raw groundwater-quality data were evaluated, the results may not be representative of finished or treated water delivered to consumers. Therefore, an exceedance of a drinking-water standard does not necessarily indicate that a public water-supply system is not in compliance.

Introduction

Per Section 106(e) of the Federal Water Pollution Control Act (FWPCA; as amended through P.L. 107-303, November 27, 2002), more commonly known as the Clean Water Act, States are required to collect, compile, and analyze water-quality data and report results to the U.S. Environmental Protection (U.S. EPA) on a biennial basis. Because reporting requirements are outlined in Section 305(b) of the FWPCA, these reports are commonly referred to as "305(b) reports." Although the FWPCA focuses primarily on the quality of navigable [surface] waters, Section 106(e) states that groundwater quality must be reported "…to the extent practicable." Guidelines to this end have consequently been developed (U.S. EPA, 1997).

Inter-Departmental policy for Delaware has improved the Department of Natural Resources and Environmental Control's (DNREC's) ability to assess statewide groundwater quality (DNREC, 2007). The referenced policy requires that all groundwater samples collected in Delaware be identified by well permit number or "DNREC ID." The DNREC ID is the only statewide numbering system unique to well permits issued in Delaware and, therefore, the primary means to obtain well-construction information (DNREC, 2007). Well-construction information, in conjunction with geographic data and hydrogeologic mapping, allows for determinations of aquifer or aquifer type, basic data that are critical to any groundwater-quality investigation.

Efforts by the Department of Health and Social Services (DHSS) have been underway to identify water-quality data for public wells by DNREC ID. Electronic water-quality data are stored in the DHSS's Safe Drinking Water Information System (SDWIS). DNREC's Source Water Assessment and Protection Program (SWAPP) maintains a database (hereafter the "SWAPP database") that contains DNREC IDs, well-construction details, geographic coordinates, and hydrogeologic data for public water-supply wells in Delaware. This 305(b) groundwater-quality assessment is based on information stored in the SDWIS and the SWAPP database; supplemental groundwater-quality data were provided by Tidewater Utilities, Inc. (TUI). Methodologies for data acquisition and analysis are similar to those employed in DNREC's 2008, 2010, 2012, and 2014 305(b) groundwater-quality assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012).

Purpose and scope

This report serves as "Part IV: Groundwater Assessment" of Delaware's overall 2016 305(b) report (DNREC, 2016). The primary purpose of this report is to summarize and report raw or apparently raw groundwater-quality data collected from public water-supply wells in Delaware during the timeframe spanning October 1, 2013 through September 30, 2015. Per U.S. EPA (1997) guidance, data are evaluated with respect to hydrogeologic setting and water-quality criteria where possible. The scope of this report is limited to available data obtained from two primary sources: the DHSS's SDWIS and the DNREC's SWAPP database. For this assessment, these databases were supplemented with data collected during the reporting period by Tidewater Utilities, Inc.

Acknowledgements

Philippe Maitre of the DHSS is gratefully acknowledged for developing SDWIS queries to generate raw (or apparently raw) groundwater-quality data for public water-supply wells. Douglas Rambo of the DNREC assisted with the acquisition of up-to-date SWAPP data.

Tidewater Utilities, Inc. is acknowledged for providing supplemental groundwater-monitoring data, which greatly improved the DNREC's reporting capabilities. John Barndt, P.G. of the DNREC reviewed the draft report and provided helpful comments for its improvement. Funding for this project is from a U.S. EPA grant pursuant to Section 106 of the Clean Water Act.

General hydrogeology

Delaware covers ~2,010 mi^2 and is comprised of two Physiographic Provinces: the Piedmont and the Atlantic Coastal Plain. The Piedmont covers ~82 mi^2 in northern Delaware (Figure 1) and is comprised of meta-sedimentary, meta-igneous, and igneous rocks (Plank et al., 2000). Areally, metamorphic rocks (mostly gneiss) are dominant based on 1-36,000-scale mapping of bedrock geology in Delaware's Piedmont (Schenck et al., 2000). Bedrock ages range from Precambrian to Silurian, although diabase dikes of Mesozoic age have been identified (Plank et al., 2000; Schenck et al., 2000).

Two main hydrogeologic units have been recognized in Delaware's Piedmont (after Werkheiser, 1995): non-carbonate and carbonate aquifers. Werkheiser (1995) used the term "non-carbonate aquifer" to describe the hydrologic unit occurring predominantly in fractured gneiss. For the purpose of this reporting, however, "fractured-rock aquifer" is used so as to avoid confusion with other non-carbonate aquifers occurring in Coastal-Plain sediments (Table 1). This aquifer-type designation is generally consistent with the SWAPP database. The Cockeysville aquifer, which occurs in the Cockeysville Marble, is the only carbonate aquifer in Delaware. Although the outcrop of the Cockeysville Marble is relatively small (~2.2 mi^2), the Cockeysville aquifer is a major source of public and domestic water supply in northern Delaware (Talley, 1995; Werkheiser, 1995). In this report the term "karst aquifer" is used in lieu of carbonate or Cockeysville aquifer (Table 1). This aquifer-type designation is consistent with the SWAPP database.

The remaining 1,928 mi^2 (96%) of Delaware's land-surface area is underlain by Mid-Atlantic Coastal Plain sediments that onlap crystalline basement rocks (i.e., bedrock). These seaward-dipping and -thickening sediments range in age from Triassic to Holocene (Table 1). Depositional environments vary, but most sediments were laid down in marine, estuarine, and fluvial environments. Overall, 13 major and several minor aquifers are recognized in the Coastal Plain of Delaware (Table 1). Minor, unnamed aquifers occur mostly in Miocene-age sediments (Table 1) and hence the name "minor-Miocene aquifers" has been used to designate these hydrologic units.

For the purpose of this reporting, Coastal-Plain aquifers are subdivided into three main aquifer types: unconfined, semi-confined, and confined. These aquifer-type designations are consistent with the SWAPP database. The unconfined aquifer, also called the Columbia aquifer, occurs predominantly in Pleistocene- to Pliocene-age sediments that comprise Delaware's surficial geologic framework (Table 1). (The term "unconfined aquifer" is used in this report in lieu of "Columbia aquifer" because, as indicated in Table 1, the Columbia aquifer may be confined in some locations.) In areas where confined aquifers subcrop, however, the unconfined aquifer can be in direct hydraulic connection with older geologic units. The semi-confined and confined aquifers predominantly occur in sediments of Miocene age or older. In general, with reference to Table 1, Miocene aquifers are used for potable water supply in Kent County and Sussex County; Eocene and Paleocene aquifers are used in southern New Castle County and Kent County; and Cretaceous aquifers are used in New Castle County.

Table 1. Hydrostratigraphic units in Delaware. [Modified after the Delaware Geological Survey, http://www.dgs.udel.edu/delaware-geology/coastal-plain-hydrostratigraphic-chart, accessed August 25, 2016.]

AGE	GEOLOGIC UNITS	HYDROLOGIC UNITS
Holocene	various informal deposits	Unassigned
Pleistocene	Delaware Bay Group	Columbia aquifer
	Nanticoke River Group	
	Assawoman Bay Group	
	unassigned	Confining beds / minor, poor aquifer
	Columbia Fm.	Columbia aquifer
Pliocene	Beaverdam Fm.	
Miocene	Bethany Fm.	Pocomoke aquifer and confining beds
	Cat Hill Fm.	Manokin aquifer and confining beds
	St. Marys Fm.	Confining beds / minor, poor aquifer
	Choptank Fm.	unnamed aquifers and confining beds
		Milford aquifer
	Calvert Fm.	Confining beds
		Frederica aquifer
		Confining beds
		Federalsburg aquifer
		Confining beds
		Cheswold aquifer
		Confining beds
Oligocene	glauconitic unit	unassigned
Eocene	glauconitic unit	
	Piney Point Fm.	Piney Point aquifer and confining beds
	Shark River Fm.	Confining beds
	Deal Fm.	
	Manasquan Fm.	Rancocas aquifer and confining beds
Paleocene	Vincentown Fm.	
	Hornerstown Fm.	Confining beds
Cretaceous	Navesink Fm.	
	Mount Laurel Fm.	Mount Laurel aquifer
	Marshalltown Fm.	Confining beds
	Englishtown Fm.	Englishtown aquifer
	Merchantville Fm.	Confining beds
	Magothy Fm.	Magothy aquifer
	Potomac Fm.	Potomac aquifer system and confining beds
Triassic and Jurassic	Post-rift unconformity rocks (of Jurassic age) and rift-basin rocks (inferred)	unassigned
Paleozoic to Precambrian	Various Fms. (bedrock)	Fractured-rock aquifer
		Cockeysville (karst) aquifer

Methods of investigation

Groundwater quality in Delaware was assessed based on pre-existing information stored in two separate databases: the DHSS's SDWIS and the DNREC's SWAPP database. DHSS staff developed queries to extract SDWIS records of raw or apparently raw groundwater-quality data collected from public water-supply systems during the reporting period (October 1, 2014 through September 30, 2015). Data resulting from these queries (26,389 analyses) were provided to DNREC in December 2015 in a Microsoft Office Access 2007 ("Access") database. For the 2016 assessment, supplemental groundwater-quality data for 90 public wells (1,875 analyses) were obtained from a private water utility, Tidewater Utilities, Inc. Combined, the data sources contained 28,264 water-quality analyses. Records obtained from the SWAPP database were current as of March 21, 2016. The records included well details such as DNREC ID, depth, geographic coordinates, geologic formation, aquifer, and aquifer type.

Access was used to link and extract data from SDWIS and the SWAPP database. For wells with more than one analysis of a given analyte, results were averaged. Analytes not detected above laboratory quantitation limits ("nondetects") were treated as zeros in all calculations. Results were evaluated with respect to Primary Maximum Contaminant Levels (PMCLs), Secondary Maximum Contaminant Levels (SMCLs), and Health Advisories (HAs) for public water-supply systems (DHSS, 2015; U.S. EPA, 2012). Hardness data were evaluated with respect to the scale of Love (1962). Because only raw or apparently raw groundwater-quality data were evaluated, the results may not be representative of finished or treated water delivered to consumers. Therefore, an exceedance of a drinking-water standard does not necessarily indicate that a public water-supply system is not in compliance (see also Ferrari, 2001, p. 5).

Where possible, data were evaluated with respect to aquifer type (i.e., unconfined, confined, semi-confined, fractured-rock, or karst). Data were, however, generally insufficient in quantity for meaningful analyses of groundwater quality in specific aquifers (Table 1). Some data also were evaluated with respect to sample depth, which was taken to be the bottom of a well's screened interval. Evaluation of trends (e.g., concentration vs. depth) in this assessment are qualitative and not statistically derived. Environmental Systems Research Institute's (ESRI's) ArcMap, a geographic information system (GIS), was used for the spatial analysis of groundwater data. Tabulated statistics (e.g., Table 2) are the result Microsoft Office Excel 2010 ("Excel") calculations. Golden Software, Inc.'s Grapher version 11 ("Grapher") was used to construct percentile diagrams. Values plot as outliers on percentile diagrams (e.g., Figure 4) if either of the following criteria are met:

$$\text{Value} < QL - 1.5 \times IQR \quad \text{or} \quad \text{Value} > QU + 1.5 \times IQR$$

Where:

IQR is the interquartile range (i.e., the difference between the 75^{th} and 25^{th} percentiles)
QL is the lower quartile or 25^{th} percentile (i.e, the bottom of the box in Figure 4)
QU is the upper quartile or 75^{th} percentile (i.e., the top of the box in Figure 4)

Differences between tabulated statistics (e.g., Table 2) and corresponding percentile diagrams (e.g., Figure 4) are the result of differences in the computational methods of Excel and Grapher.

Public wells

As of March 21, 2016, there were 1,174 active public water-supply wells in the SWAPP database. Of the active wells, 1,140 (97%) have geographic coordinates and are plotted in Figure 1A. With reference to Figure 1A, there are 240 wells (21%) in New Castle County, 313 wells (27%) in Kent County, and 587 wells (52%) in Sussex County. (Percentages in this report may not total 100% due to rounding.)

Aquifer type is known for 1,106 (94%) of the 1,174 active wells (Figure 2). Wells where aquifer type is known and geographic coordinates are available are plotted in Figures 1B thru 1F. Out of all active wells, Coastal-Plain wells account for 1,052 (90%) and Piedmont wells account for 54 (5%) (Figure 2). The large percentage of Coastal-Plain wells relative to Piedmont wells is due to both land-area differences and the fact that public-water supply in the Piedmont and New Castle County is largely from surface-water resources (Wheeler, 2003). Aquifer type for the remaining 68 active wells is either unknown (due to a lack of well-construction data) or not yet assigned (Figure 2).

Coastal-Plain wells include wells screened in unconfined, semi-confined, or confined aquifers (Figures 1B thru 1D and Figure 2). Out of the 1,174 active wells, unconfined wells account for 473 (40%), confined wells account for 521 (44%), and semi-confined wells account for 58 (5%) (Figure 2). A large majority of the unconfined wells with geographic coordinates (384 of 463 or 83%) are located in Sussex County; the remaining unconfined wells include 50 (11%) in Kent County and 29 (6%) in New Castle County (Figure 1B). Confined wells are more evenly distributed throughout the Coastal Plain of Delaware, with most of these wells situated in Kent County (Figure 1C). Specifically, out of 502 confined wells with geographic coordinates, 216 (43%) are located in Kent County, 141 (28%) are located in New Castle County, and 145 (29%) are located in Sussex County. All 57 semi-confined wells have geographic coordinates (Figure 1D); 26 (46%) are located in Kent County, 25 (44%) are located in Sussex County, and 6 (11%) are located in New Castle County.

Piedmont wells include fractured-rock and karst wells and are limited to the northernmost portion of the State (Figures 1E and 1F and Figure 2). Out of the 1,174 active wells, fractured-rock wells account for 46 (4%) and karst wells account for 8 (1%) (Figure 2). All 46 fractured-rock and 8 karst wells (Figure 2) have geographic coordinates and are plotted in Figures 1E and 1F, respectively. Karst wells coincide with the Cockeysville Marble outcrop in northern New Castle County (Figure 1F).

Well depths, taken as the bottom of the well screen, are known for 1,088 (93%) of 1,174 active wells (Figure 3). Overall, well depths range from 22 to 957 ft below land surface (bls) and are skewed (Figure 3). The median well depth is 145 ft bls and the 25th and 75th percentiles are 89 and 245 ft bls, respectively. Well depths are not known for 86 (7%) of the active wells (Figure 3).

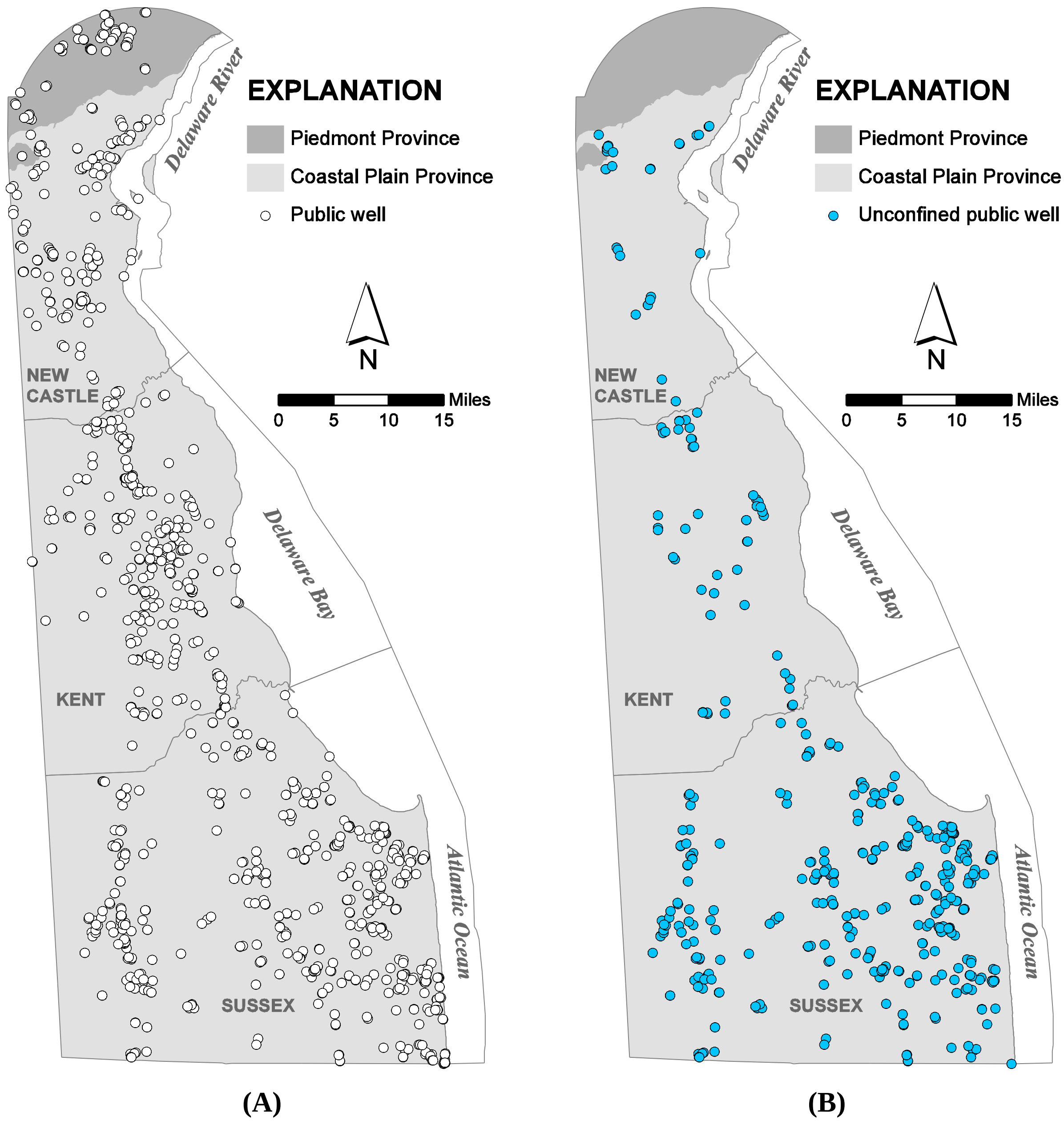
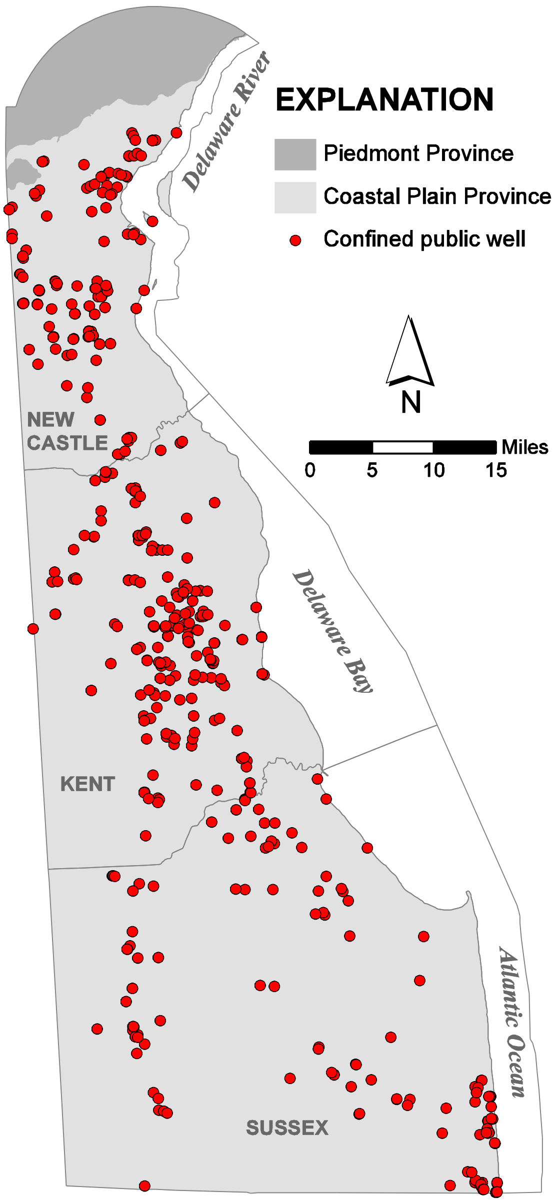
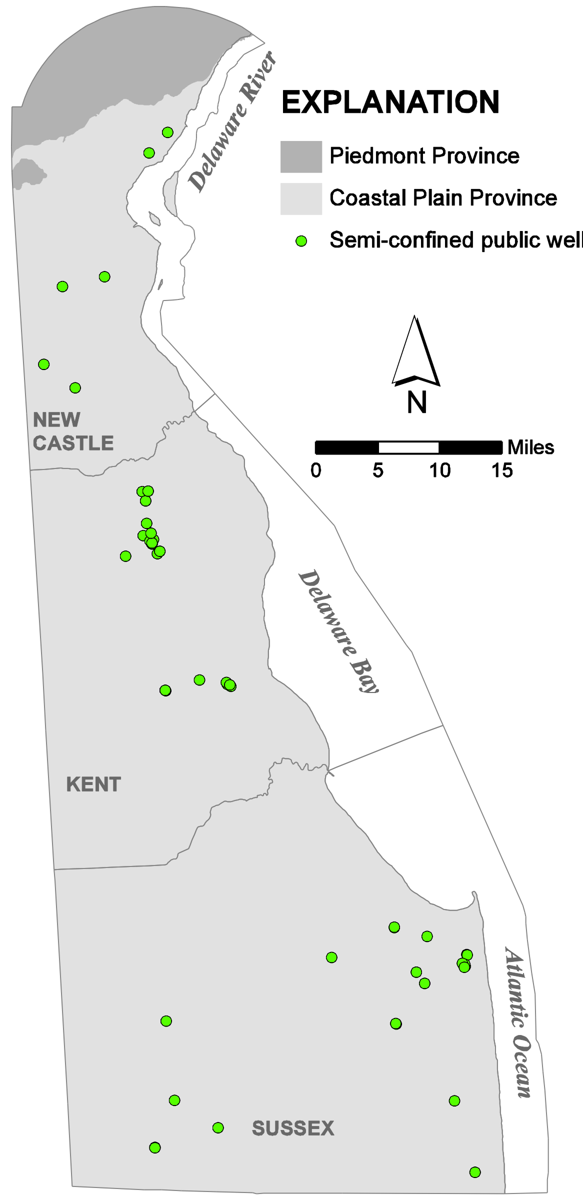


Figure 1. Maps of active public water-supply wells in Delaware – (A) all wells and (B) unconfined wells.



(C)



(D)

Figure 1. Maps of active public water-supply wells in Delaware (*cont.*) – (C) confined wells and (D) semi-confined wells.

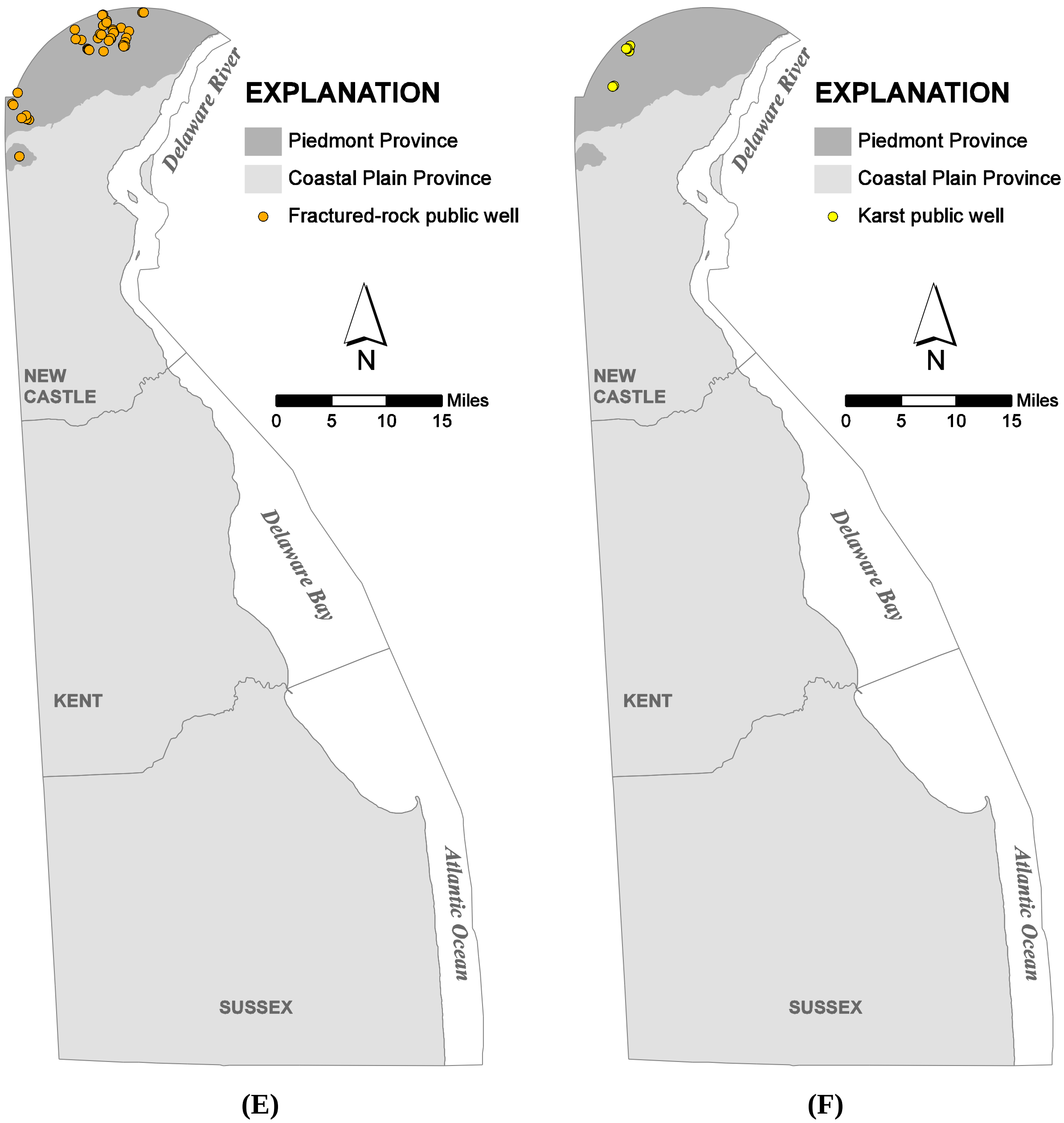


Figure 1. Maps of active public water-supply wells in Delaware (*cont.*) – (E) fractured-rock wells and (F) karst wells.

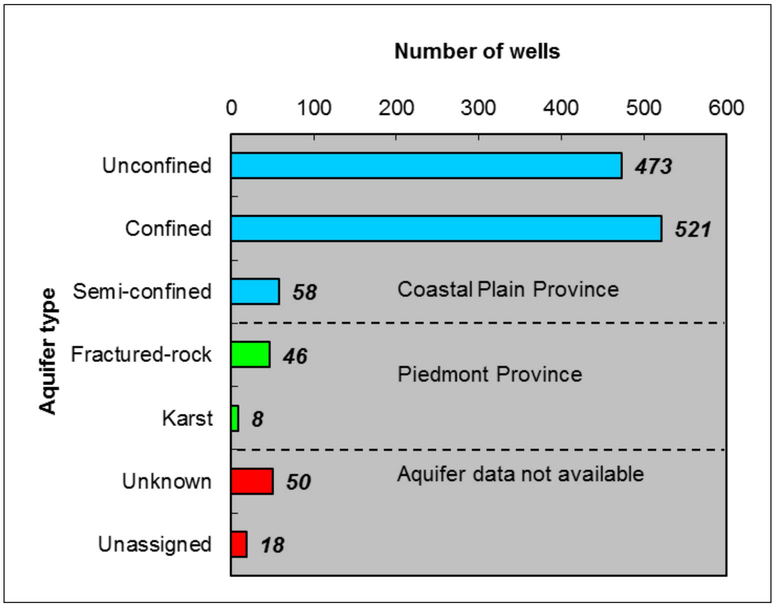


Figure 2. Histogram of active public water-supply wells by aquifer type.

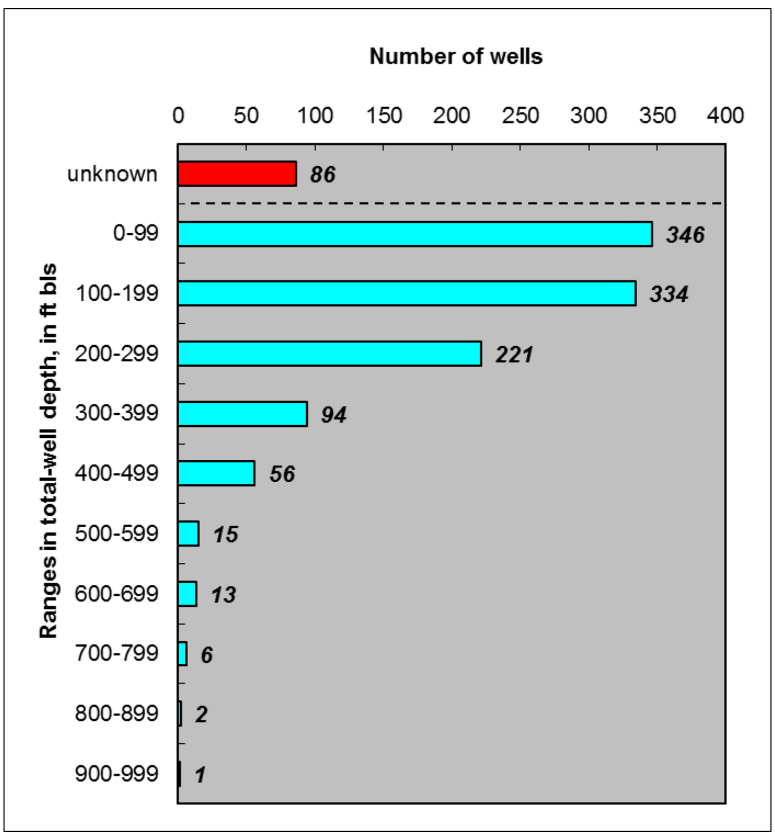


Figure 3. Histogram of active public water-supply wells by ranges in total-well depth.

Results and discussion

Results are grouped into four main categories: general chemistry, organic compounds, trace elements, and radionuclides.

General chemistry

For this assessment, general groundwater chemistry includes parameters routinely measured in public water-supply systems: Nitrate as nitrogen, total dissolved solids, chloride, sodium, iron, hardness as $CaCO_3$, and pH. Nitrate as nitrogen is the only parameter in this category with a PMCL (10 mg/L; U.S. EPA, 2012). Other parameters in this category include those that generally affect the aesthetic qualities of the water supply, such as taste, odor, color, corrosiveness, etc. Most of these parameters have SMCLs.

Nitrate as nitrogen

Overall, 992 nitrate as nitrogen (“nitrate”) analyses are in the SDWIS query provided to DNREC. Of these, 110 (11%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 91 nitrate analyses. Duplicate analyses for individual wells were averaged resulting in a total of 177 nitrate analyses where aquifer type is known (Table 2). This number translates to ~16% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, nitrate concentrations ranged from nondetectable (ND) to 14.5 mg/L with a median of ND (Table 2 and Figure 4). Nitrate was not detected above the laboratory quantitation limit in 97 (54.8%) of the 177 analyses (Table 2). Concentrations in 77 (43.5%) of the samples exceeded 0.4 mg/L (Table 2), a threshold used to distinguish between natural and human-impacted groundwater (Hamilton et al., 1993). Nitrate concentrations exceeded the PMCL (10 mg/L) in 8 (4.5%) of the 177 samples (Table 2). All of the PMCL exceedances occurred in Sussex County (Figure 5). Overall, nitrate concentrations decrease with depth and, below depths of ~180 ft bls, concentrations never exceeded the PMCL (Figure 6). Nitrate concentrations exceeded 0.4 mg/L to depths of ~350 ft bls, and this may be an indication of the vertical extent of human influence on groundwater quality. The deepest nitrate detection was associated with a fractured-rock well; wells in Piedmont aquifers typically have very long open intervals that may allow contaminants to enter at shallower depths. Nitrate detections in Coastal-Plain wells were primarily limited to depths of 240 ft and shallower.

Unconfined wells account for 69 (39%) of the 177 individual samples linked by DNREC ID (Table 2). This number translates to ~15% of the total number of active unconfined wells (473) statewide (Figure 2). Nitrate was not detected above the laboratory quantitation limit in 5 (7.2%) of the 69 samples. Concentrations in 63 (91.3%) of the 69 samples exceeded 0.4 mg/L suggesting that groundwater quality in the unconfined aquifer is largely affected by human activities. Nitrate concentrations below 0.4 mg/L may reflect natural groundwater quality or geochemical conditions that do not favor nitrification. For example, the southeastern corner of Sussex County coincides with an area where shallow groundwater is largely anoxic and nitrate concentrations are often <0.4 mg/L (Kasper and Strohmeier, 2007). The most elevated nitrate concentration (14.5 mg/L) was detected in an unconfined well (Table 2 and Figure 4). Out of the five aquifer types, unconfined wells had the highest median nitrate concentration (4.70 mg/L) and the lowest percentage of nondetects (Table 2 and Figure 4). The median nitrate concentration is in agreement with the median concentration (4.884 mg/L) from a USGS study of 30 randomly-selected unconfined public water-supply wells in Delaware (Reyes, 2010).

Moreover, the median nitrate concentration from this study is slightly lower than the median concentrations for shallow (5.4 mg/L) and intermediate (5.5 mg/L) depths in the unconfined aquifer on the Delmarva Peninsula (Denver et al., 2004). A watershed-scale study in Sussex County, Delaware, reported a higher median nitrate concentration (6.4 mg/L) for the unconfined aquifer (Kasper and Strohmeier, 2007). Land use in that watershed is and has been largely agricultural. For this assessment, nitrate exceeded the PMCL in 8 (11.6%) of the 69 unconfined aquifer samples (Table 2), all of which occurred in Sussex County (Figure 5a). This percentage of PMCL exceedances is higher than the percentage reported by Reyes (2010), who found two out of 30 public wells with nitrate above the PMCL. In contrast, other studies of shallow groundwater quality at the State scale (Pellerito et al., 2008) and watershed scale (Kasper and Strohmeier, 2007) reported higher percentages of PMCL exceedances (18 and 32%, respectively). There is no apparent trend in nitrate concentrations with depth in the unconfined aquifer (Figure 6). The most elevated concentration (14.5 mg/L) was detected at a depth of 100 ft bls. The deepest unconfined PMCL exceedance (13.1 mg/L) occurred at a depth of 180 ft bls and the shallowest PMCL exceedance (11 mg/L) occurred at a depth of 68 ft bls. Analysis of unconfined nitrate data for the last five assessments indicates no substantial changes in aggregate statistics over time (Figure 7). Specifically, median nitrate concentrations, as well as interquartile ranges, have remained fairly stable since 2008 when current reporting methodologies were put in place. Furthermore, the fractions of unconfined nitrate concentrations above 0.4 mg/L (82 to 91%) and PMCL exceedances (9 to 12%) have remained consistent over time.

Confined wells account for 94 (53.1%) of the 177 individual samples linked by DNREC ID (Table 2). This number translates to ~18% of the total number of active confined wells (521) statewide (Figure 2). Nitrate was not detected above the laboratory quantitation limit in 87 (92.6%) of the 94 samples. Concentrations in 5 (5.3%) of the 94 wells exceeded 0.4 mg/L suggesting that the groundwater quality in a small fraction of confined aquifer wells may be susceptible to human activities (Table 2). Nitrate was below the PMCL in all confined well samples (Table 2; Figure 5b). Nitrate concentrations generally decrease with depth in confined aquifers, consistent with the overall trend (Figure 6).

Semi-confined wells account for 13 (7.3%) of the 177 individual samples linked by DNREC ID (Table 2). This number translates to ~22% of the total number of active semi-confined wells (58) statewide (Figure 2). Nitrate was not detected above the laboratory quantitation limit in 5 (38.5%) of the 13 samples. Limited data suggest that semi-confined wells have an intermediate susceptibility to human impacts relative to confined and unconfined wells (Table 2). Specifically, nitrate concentrations in a large fraction of the semi-confined well samples (61.5%) exceeded 0.4 mg/L, indicating human influence on groundwater quality. Nitrate was below the PMCL in all semi-confined well samples (Table 2; Figure 5b).

Fractured-rock wells (1 sample) and karst wells (no data) are poorly represented in this assessment. For more information on the occurrence of nitrate in these aquifer types, the interested reader is referred to previous assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012).

Table 2. Statistical summary of nitrate data by aquifer type. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; ---, no data; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	177	69	94	13	1	---
Percent of total (%)	100	39.0	53.1	7.3	0.6	---
Maximum (mg/L)	14.50	14.50	9.56	3.80	0.60	---
75th percentile (mg/L)	3.50	6.91	ND	1.88	0.60	---
50th percentile (mg/L)	ND	4.70	ND	1.24	0.60	---
25th percentile (mg/L)	ND	2.18	ND	ND	0.60	---
Minimum (mg/L)	ND	ND	ND	ND	0.60	---
Number not detected (#ND)	97	5	87	5	0	---
Percent not detected (%ND)	54.8	7.2	92.6	38.5	0.0	---
Number > 0.4 mg/L (#)	77	63	5	8	1	---
Percent > 0.4 mg/L (%)	43.5	91.3	5.3	61.5	100.0	---
Number > 10 mg/L PMCL (#)	8	8	0	0	0	---
Percent > 10 mg/L PMCL (%)	4.5	11.6	0.0	0.0	0.0	---

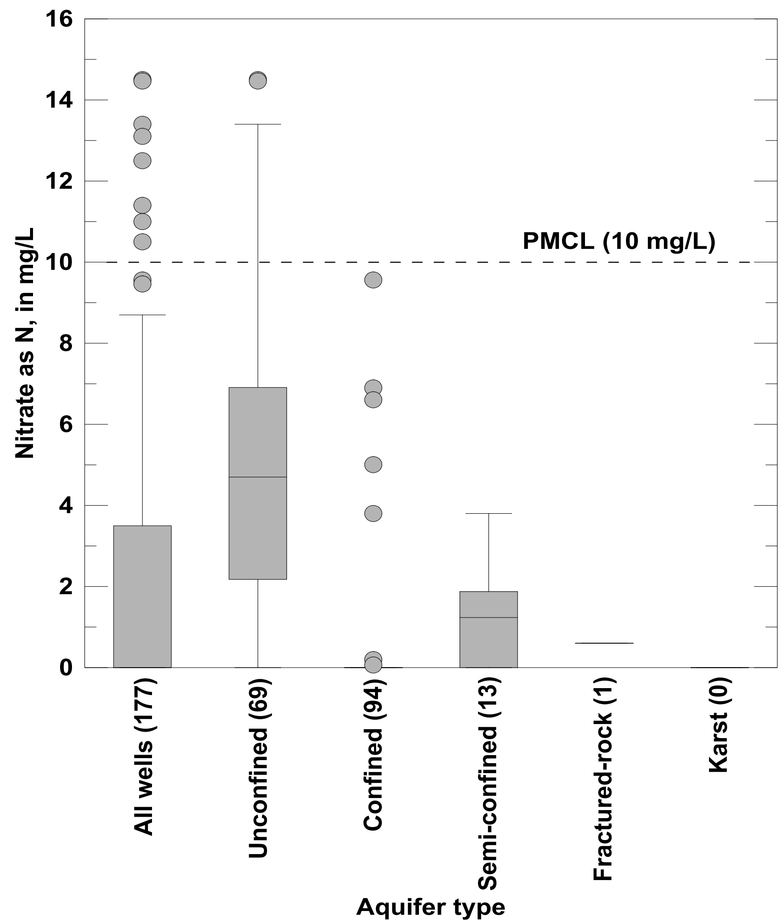


Figure 4. Percentile diagrams of nitrate data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples per aquifer type; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

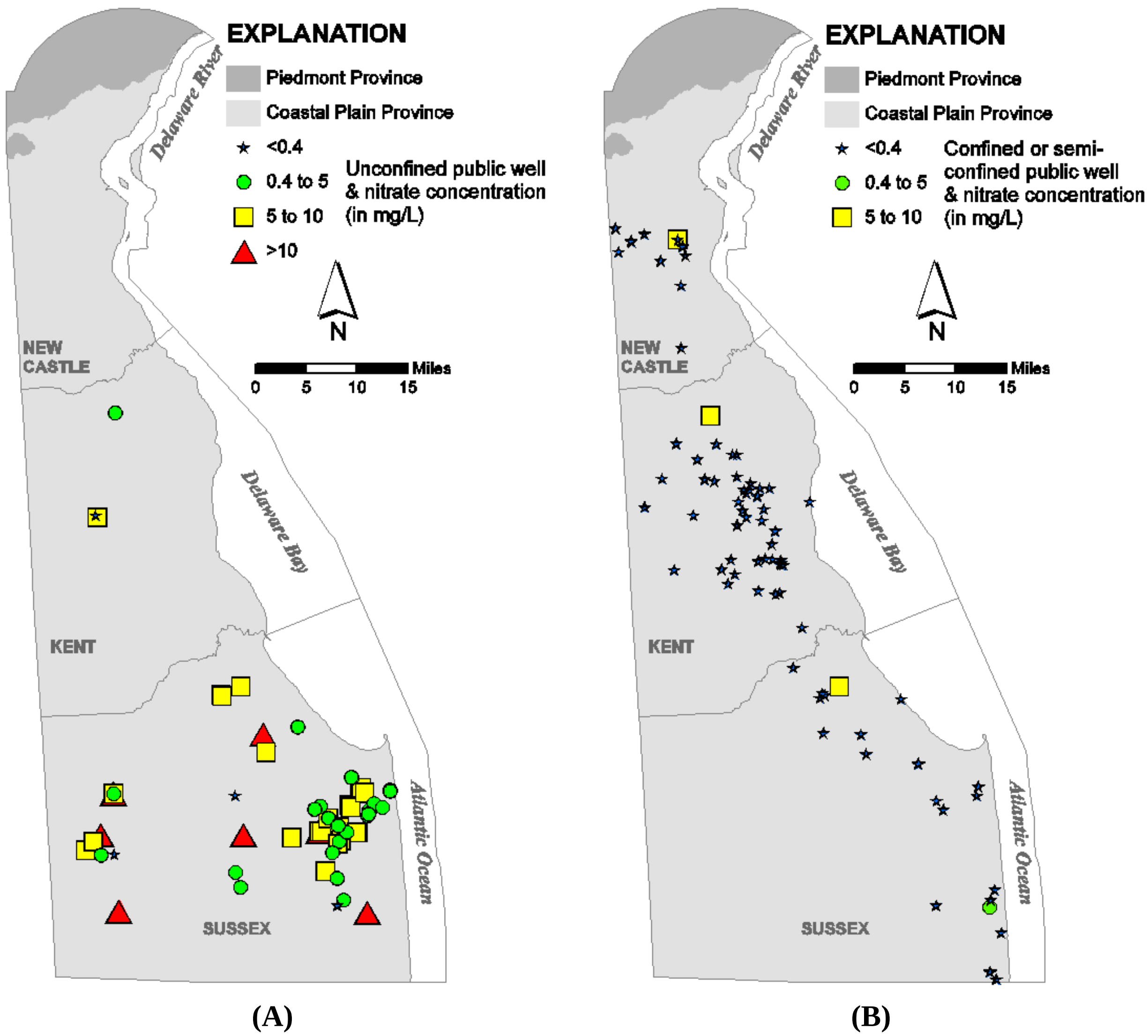


Figure 5. Maps showing nitrate concentration ranges in (A) unconfined and (B) confined/semi-confined public water-supply wells.

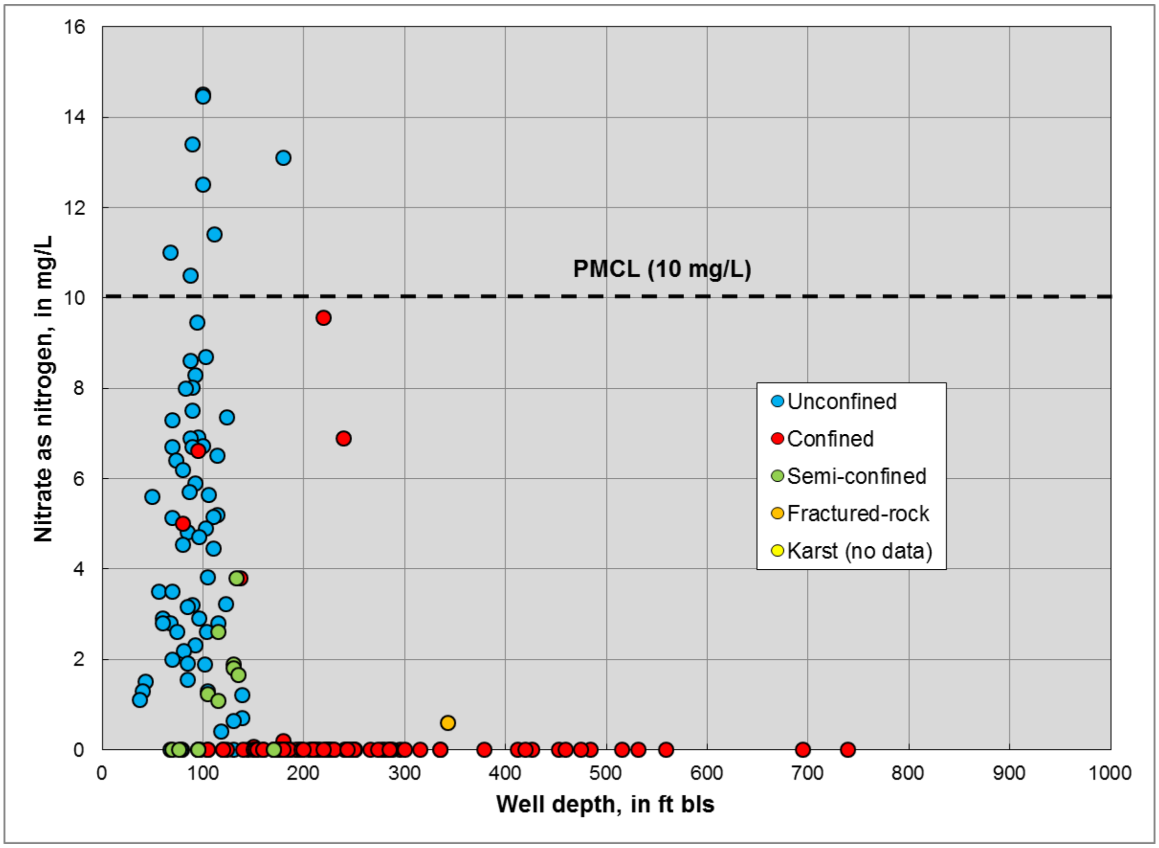


Figure 6. Scatter plot of nitrate versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

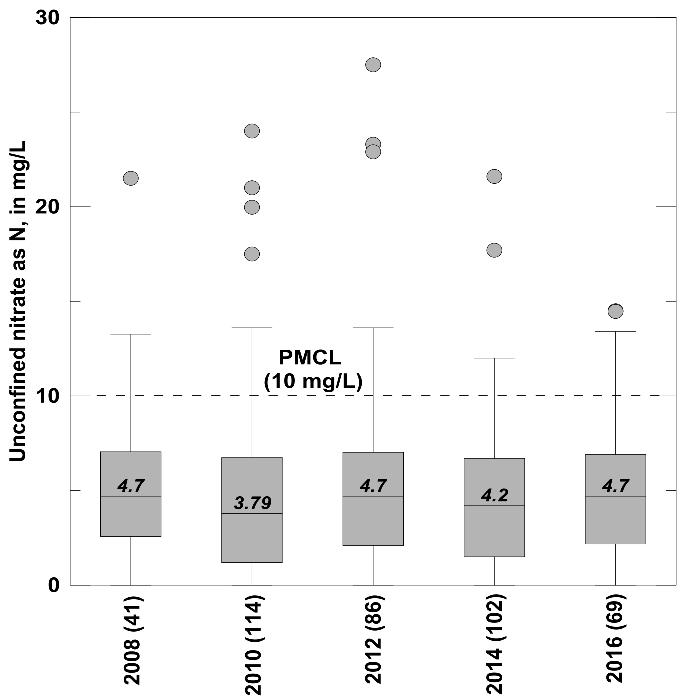


Figure 7. Percentile diagrams of unconfined nitrate data for current and past assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012). [mg/L, milligrams per liter; circles, outliers; (#), number of samples per reporting period; bold, italicized numbers on diagrams denote median concentrations; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Total dissolved solids

Overall, 45 total dissolved solids (TDS) analyses are in the SDWIS query provided to DNREC. Of these, 26 (58%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 96 TDS analyses. Duplicate analyses for individual wells were averaged resulting in a total of 102 TDS analyses where aquifer type is known (Table 3). This number translates to ~9.2% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, TDS concentrations ranged from 35 to 440 mg/L with a median value of 146 mg/L (Table 3 and Figure 8). All TDS concentrations were below the SMCL (500 mg/L; Table 3).

There were no TDS data for karst wells for this assessment; however, this aquifer type had the highest median TDS concentration based on previous assessments (Kasper, 2010; Kasper and Strohmeier, 2012). In addition, with only one sample there were limited data for fractured-rock wells (Table 3). Based on previous 305(b) assessments, TDS data for karst and fractured-rock wells were in sharp contrast, a finding that is consistent with Werkheiser (1995). Elevated TDS in karst wells has been attributed to the dissolution of carbonate rocks (Werkheiser, 1995). Based on 35 samples, unconfined wells had the lowest median TDS concentration (96 mg/L; Table 3 and Figure 8), a value that is lower than the median value of 116 mg/L reported by Ferrari (2001) and Reyes (2010). TDS concentrations for confined and semi-confined wells were higher than concentrations for unconfined wells (Table 3 and Figure 8), likely due to longer groundwater contact time with formation sediments. TDS concentrations generally increase with depth; however, there are several wells that deviate from the general trend and some of these wells are screened in the confined portion of the Potomac aquifer system (Figure 9).

Table 3. Statistical summary of total dissolved solids (TDS) data by aquifer type. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; ---, no data; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	102	35	58	8	1	---
Percent of total (%)	100	34.3	56.9	7.8	1.0	---
Maximum (mg/L)	440	202	440	236	288	---
75th percentile (mg/L)	192	126	204	198	288	---
50th percentile (mg/L)	146	96	177	102	288	---
25th percentile (mg/L)	92	71	144	75	288	---
Minimum (mg/L)	35	35	50	51	288	---
Number not detected (#ND)	0	0	0	0	0	---
Percent not detected (%ND)	0.0	0.0	0.0	0.0	0.0	---
Number > 500 mg/L SMCL (#)	0	0	0	0	0	---
Percent > 500 mg/L SMCL (%)	0.0	0.0	0.0	0.0	0.0	---

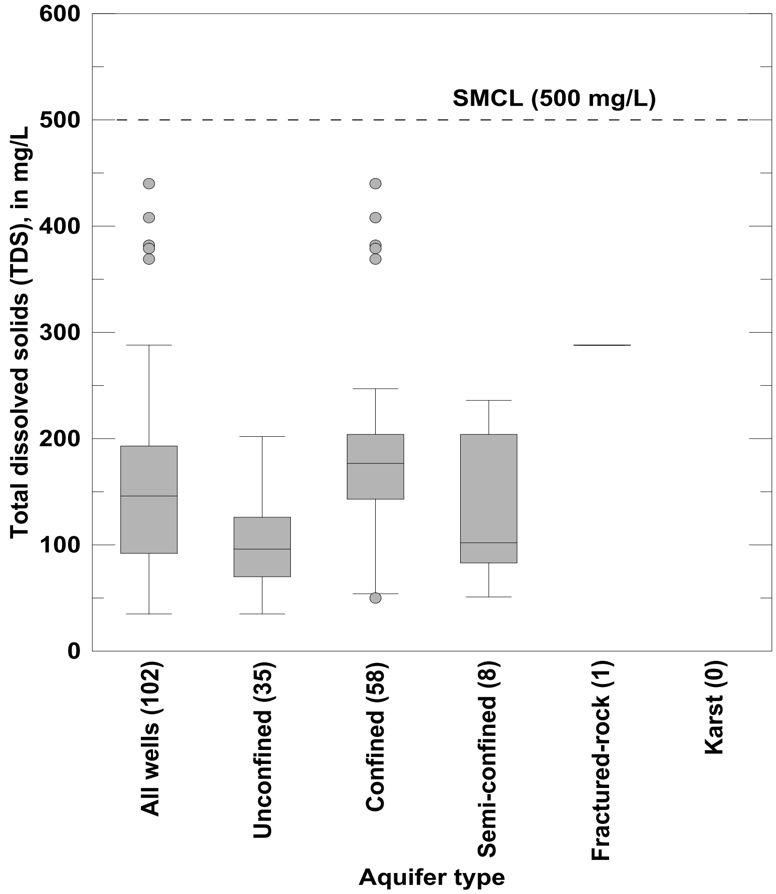


Figure 8. Percentile diagrams of total dissolved solids (TDS) data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

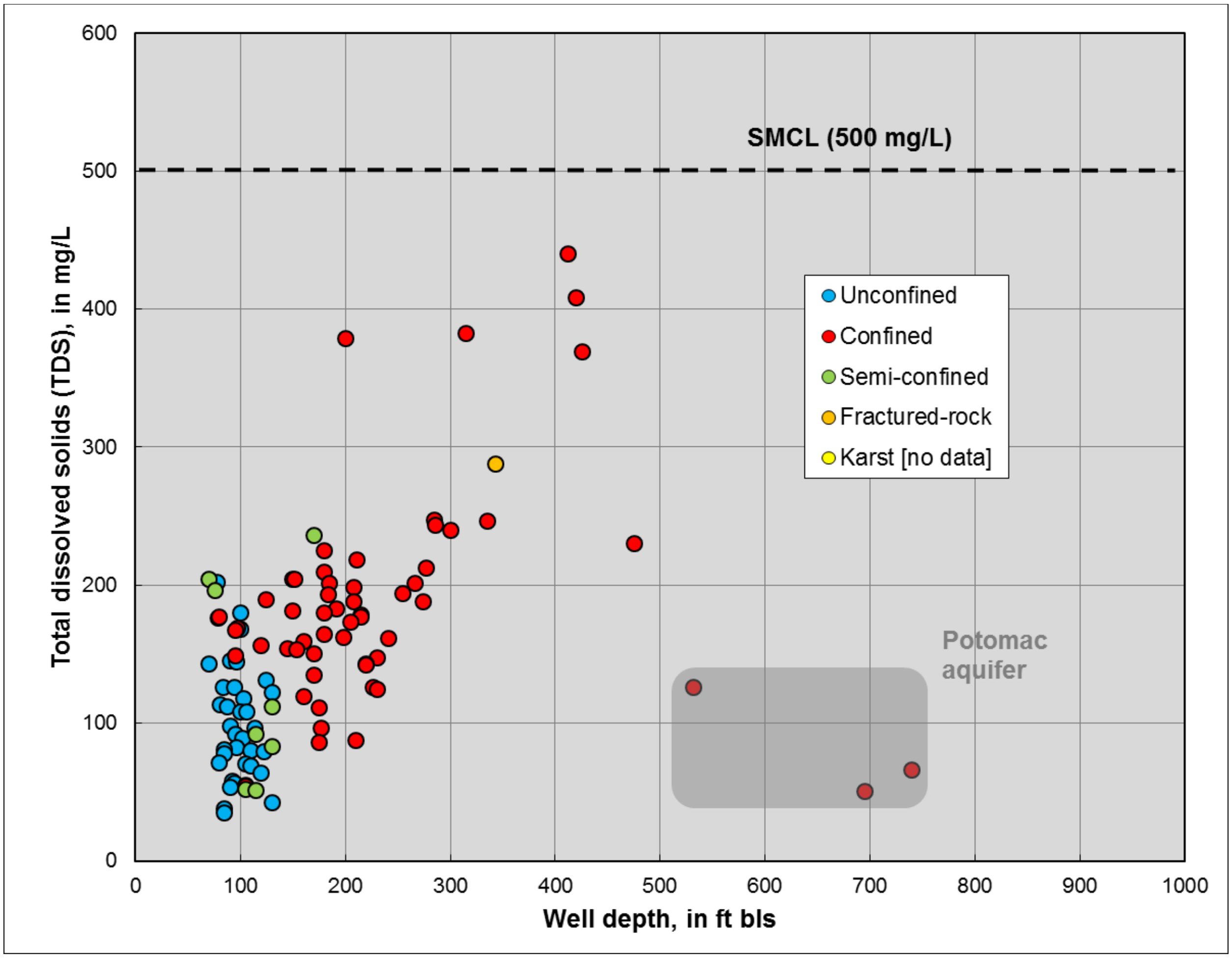


Figure 9. Scatter plot of total dissolved solids (TDS) versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Chloride

Overall, 1,006 chloride analyses are in the SDWIS query provided to DNREC. Of these, 136 (13.5%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 97 chloride analyses. Duplicate analyses for individual wells were averaged resulting in 181 chloride analyses where aquifer type is known (Table 4). This number translates to ~16.4% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, chloride concentrations ranged from 0.9 to 282 mg/L with a median value of 7.5 mg/L (Table 4 and Figure 10). Chloride concentrations exceeded the SMCL (250 mg/L) in 1 (0.6%) of the 181 analyses (Table 4).

The most elevated chloride concentration (282 mg/L) was associated with an unconfined well. Unconfined wells had the highest median chloride concentration (15 mg/L). These results may be indicative of impacts from human activities occurring at or near the land surface (e.g., road salting). The median value for the unconfined aquifer is in general agreement with, but lower than, Ferrari's (2001) median of 18.3 mg/L and Reyes' (2010) median of 18.6 mg/L.

Semi-confined and confined wells had lower median chloride concentrations (9.1 and 3.3 mg/L, respectively; Table 4 and Figure 10). Chloride concentrations generally decrease with depth; below depths of ~400 ft bls concentrations are typically <20 mg/L (Figure 11). Fractured-rock wells (1 sample) and karst wells (no data) are poorly represented in this assessment. For more information on the occurrence of chloride in these aquifer types, the interested reader is referred to previous assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012).

Table 4. Statistical summary of chloride data by aquifer type. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; ---, no data; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	181	71	96	13	1	---
Percent of total (%)	100	39.2	53.0	7.2	0.6	---
Maximum (mg/L)	282.0	282.0	58.5	24.4	54.2	---
75th percentile (mg/L)	15.0	18.3	5.6	10.3	54.2	---
50th percentile (mg/L)	7.5	15.0	3.3	9.1	54.2	---
25th percentile (mg/L)	3.2	11.7	2.4	5.5	54.2	---
Minimum (mg/L)	0.9	3.2	0.9	3.6	54.2	---
Number not detected (#ND)	0	0	0	0	0	---
Percent not detected (%ND)	0.0	0.0	0.0	0.0	0.0	---
Number > 250 mg/L SMCL (#)	1	1	0	0	0	---
Percent > 250 mg/L SMCL (%)	0.6	1.4	0.0	0.0	0.0	---

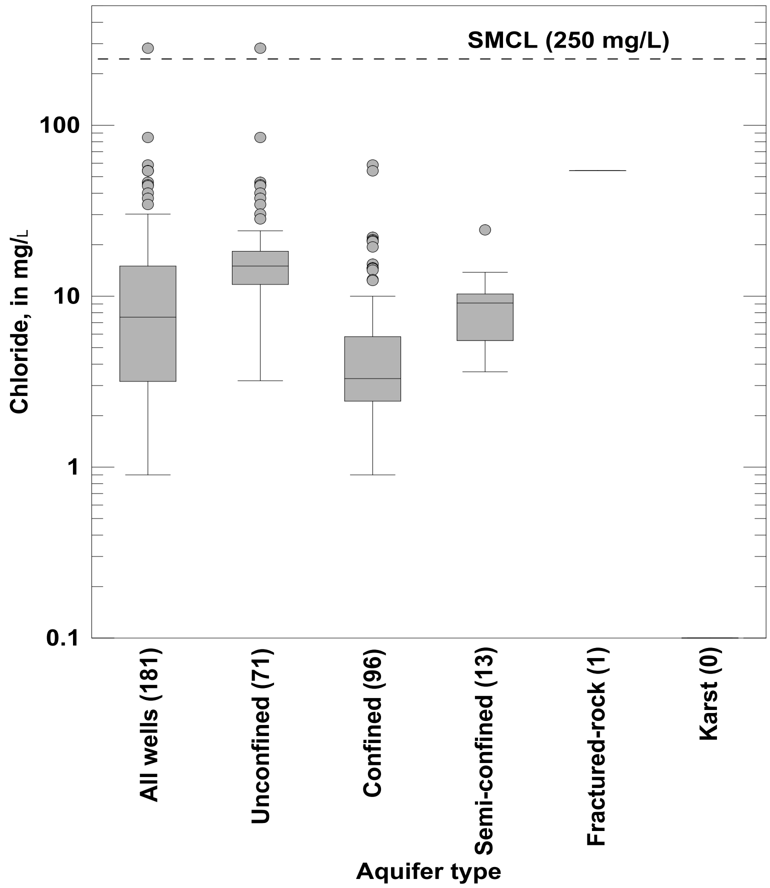


Figure 10. Percentile diagrams of chloride data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

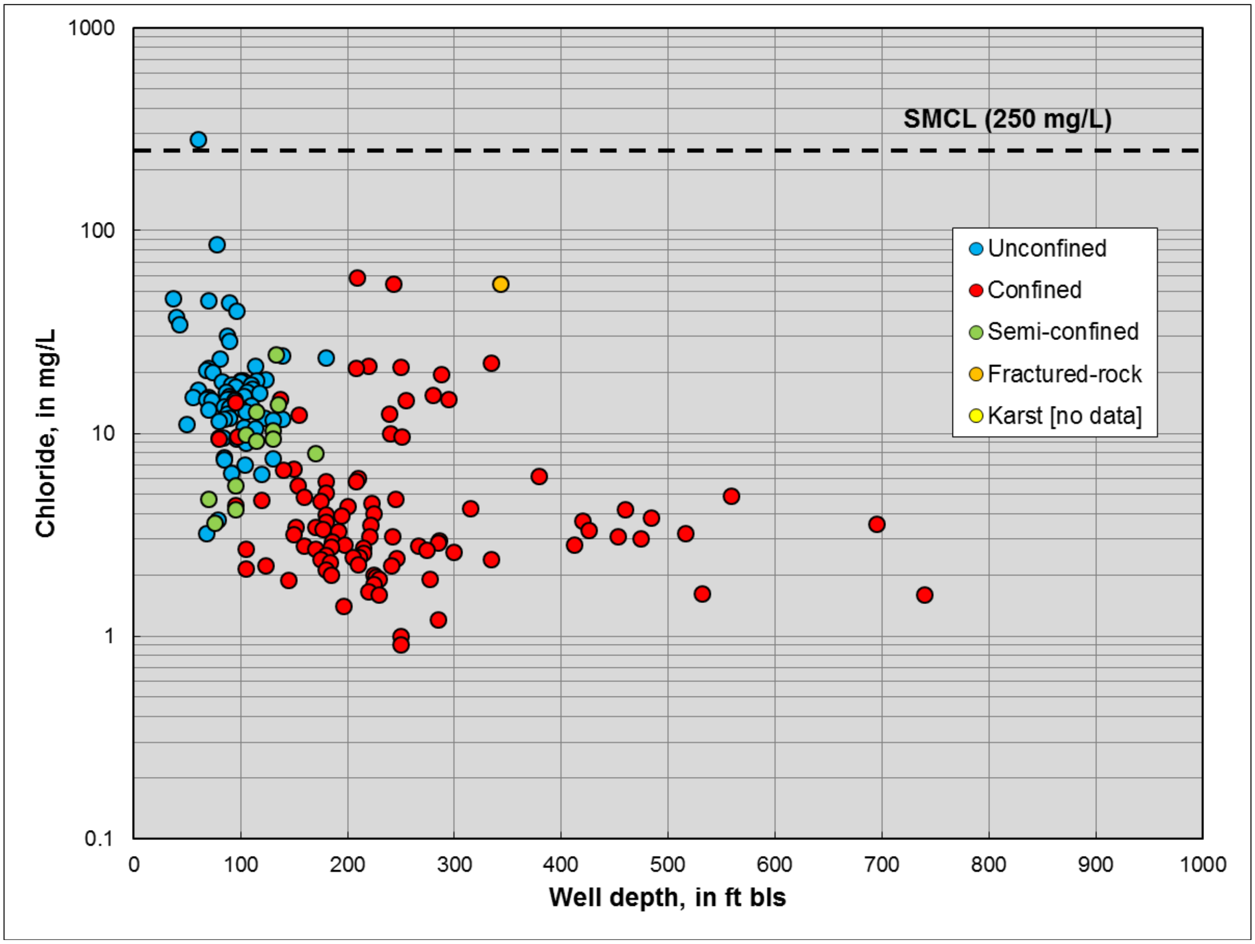


Figure 11. Scatter plot of chloride versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Sodium

Overall, 549 sodium analyses are in the SDWIS query provided to DNREC. Of these, 117 (21.3%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 97 sodium analyses. Duplicate analyses for individual wells were averaged resulting in 176 sodium analyses where aquifer type is known (Table 5). This number translates to ~15.9% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, sodium concentrations ranged from 2.8 to 158.5 mg/L with a median value of 10.9 mg/L (Table 5 and Figure 12). Sodium concentrations exceeded the Health Advisor (HA; 20 mg/L) in 41 (23.3%) of the 176 samples (Table 5).

Median sodium concentrations were comparable amongst the various aquifer types (Table 5 and Figure 12). The median concentration for the unconfined aquifer (11.4 mg/L) was comparable to Ferrari's (2001) median of 11.7 mg/L, but lower than Reyes' (2010) median of 14.2 mg/L. Unconfined wells also had a substantial fraction of concentrations above the HA (14.9%; Table 5 and Figure 12). Sodium is a component of the human diet and poultry manure and, therefore, its presence in shallow aquifers can reflect impacts from wastewater disposal and agricultural practices (Denver, 1989). Confined wells had the lowest median sodium concentration (9.8 mg/L), but the largest fraction of concentrations above the HA (29.5%; Table 5 and Figure 12). In some instances, elevated sodium concentrations can be detected in glauconitic aquifers (e.g., the Piney Point aquifer as delineated in Figure 13) due to ion-exchange processes (Spoljaric, 1986). Relative to other Coastal-Plain aquifer types, semi-confined wells had a median sodium concentration (10.1 mg/L) comparable to confined wells, and the second-highest fraction of concentrations above the HA (23.1%; Table 5 and Figure 12). Fractured-rock wells (1 sample) and karst wells (no data) are poorly represented in this assessment. For more information on the occurrence of sodium in these aquifer types, the interested reader is referred to previous assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012). Overall, sodium concentrations exceeded the HA at virtually all depths (Figure 13).

Table 5. Statistical summary of sodium data by aquifer type. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; ---, no data; HA, health advisory for public water-supply systems (U.S. EPA, 2012).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	176	67	95	13	1	---
Percent of total (%)	100	38.1	54.0	7.4	0.6	---
Maximum (mg/L)	158.5	158.5	156.7	59.4	14.5	---
75th percentile (mg/L)	18.3	14.5	24.0	18.2	14.5	---
50th percentile (mg/L)	10.9	11.4	9.8	10.1	14.5	---
25th percentile (mg/L)	7.1	8.7	6.3	8.5	14.5	---
Minimum (mg/L)	2.8	2.9	2.8	5.5	14.5	---
Number not detected (#ND)	0	0	0	0	0	---
Percent not detected (%ND)	0.0	0.0	0.0	0.0	0.0	---
Number > 20 mg/L HA (#)	41	10	28	3	0	---
Percent > 20 mg/L HA (%)	23.3	14.9	29.5	23.1	0.0	---

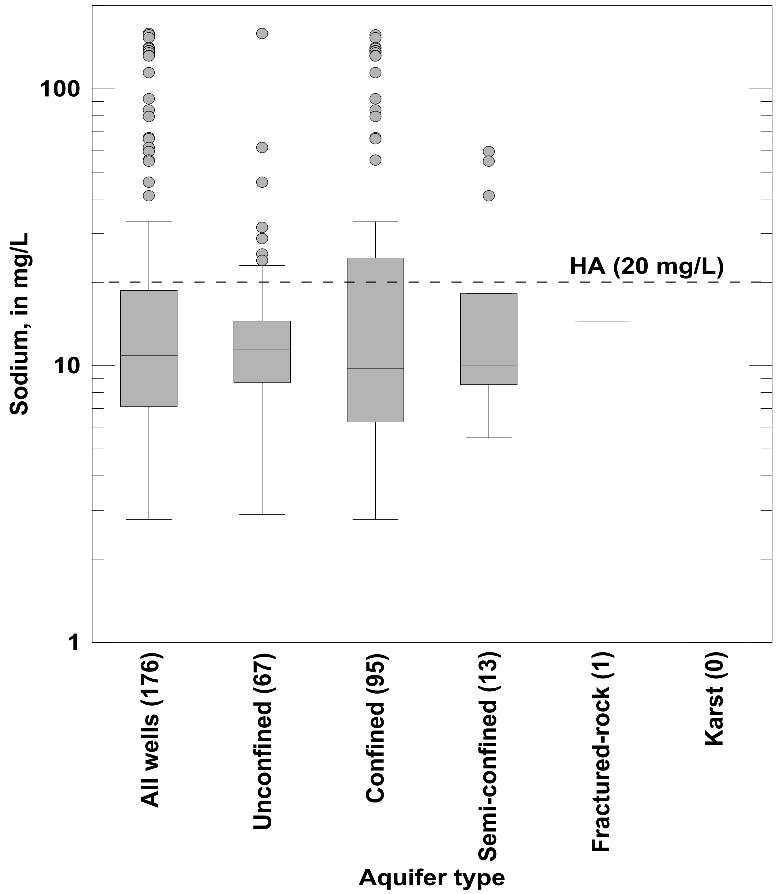


Figure 12. Percentile diagrams of sodium data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples; HA, health advisory for public water-supply systems (U.S. EPA, 2012).]

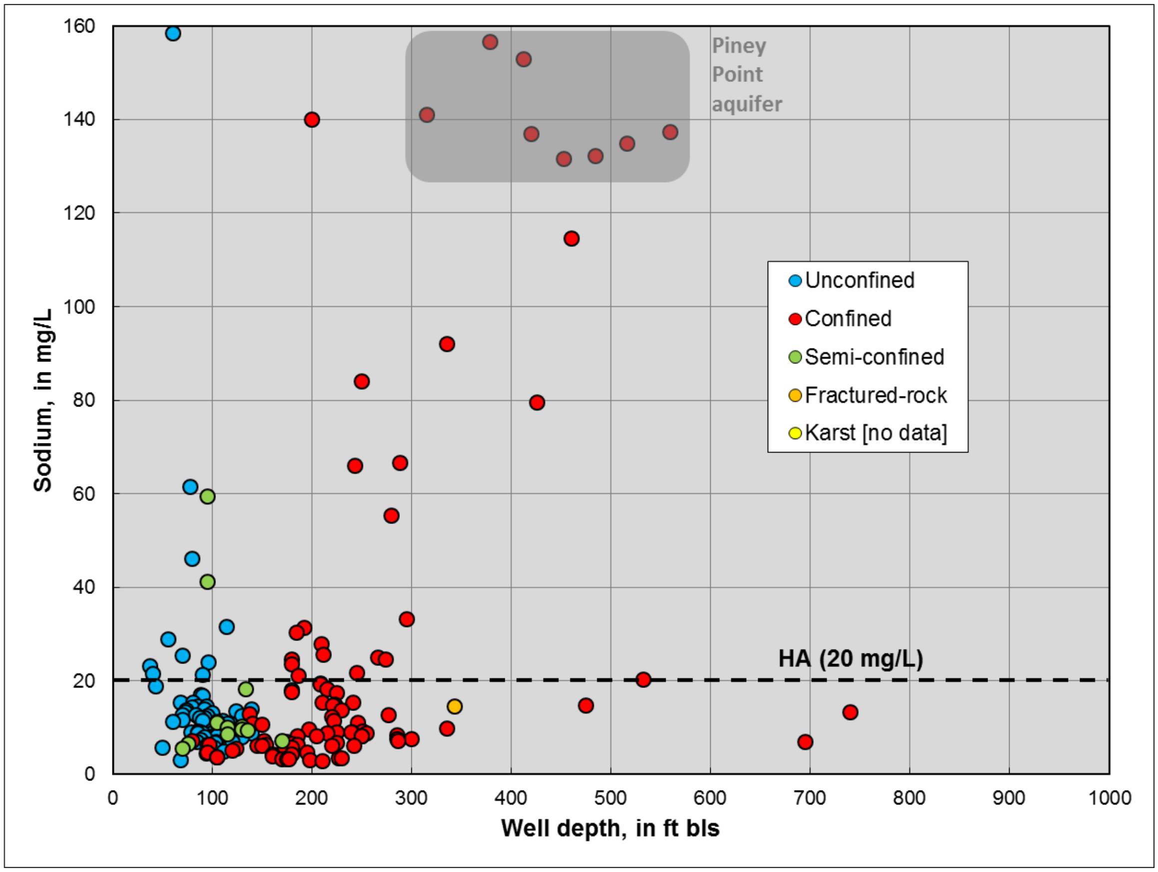


Figure 13. Scatter plot of sodium versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; HA, health advisory for public water-supply systems (U.S. EPA, 2012.]

Iron

Overall, 547 iron analyses are in the SDWIS query provided to DNREC. Of these, 115 (21.0%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 97 iron analyses. Duplicate analyses for individual wells were averaged resulting in 173 iron analyses where aquifer type is known (Table 6). This number translates to ~15.6% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, iron concentrations ranged from ND to 12.15 mg/L with a median value of 0.05 mg/L (Table 6 and Figure 14). Iron was not detected above the laboratory quantitation limit in 81 (46.8%) of the 173 analyses. Iron concentrations exceeded the SMCL (0.3 mg/L) in 54 (31.2%) of the 173 samples (Table 6).

Relative to other Coastal-Plain aquifer types, semi-confined wells had the highest median iron concentration (0.22 mg/L), the smallest fraction of ND concentrations (30.8%), and the largest fraction of concentrations above the SMCL (46.2%; Table 6 and Figure 14). Confined wells had the second-highest median iron concentration (0.12 mg/L) and the second-largest fraction of concentrations above the SMCL (28.3%); in addition, the most elevated iron concentration (12.15 mg/L) was associated with a confined well sample (Table 6 and Figure 14). Although elevated iron concentrations (up to 10.2 mg/L) were associated with unconfined wells, this aquifer type had the lowest median iron concentration (ND), the largest fraction of ND concentrations (58.5%), and the smallest fraction of concentrations above the SMCL (18.5%; Table 6 and Figure 14). The fraction of unconfined iron concentrations above the SMCL was greater than those reported by Ferrari (2001; 17%) and Reyes (2010; 13%). Fractured-rock wells (1 sample) and karst wells (no data) are poorly represented in this assessment. For more information on the occurrence of iron in these aquifer types, the interested reader is referred to previous assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012). Overall, iron exceeded the SMCL at virtually all depths (Figure 15).

Table 6. Statistical summary of iron data by aquifer type. [mg/L, milligrams per liter; ND, not detected above laboratory quantitation limit; ---, no data; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	173	65	94	13	1	---
Percent of total (%)	100	37.6	54.3	7.5	0.6	---
Maximum (mg/L)	12.15	10.20	12.15	2.86	ND	---
75th percentile (mg/L)	0.50	0.15	0.88	0.79	ND	---
50th percentile (mg/L)	0.05	ND	0.12	0.22	ND	---
25th percentile (mg/L)	ND	ND	ND	ND	ND	---
Minimum (mg/L)	ND	ND	ND	ND	ND	---
Number not detected (#ND)	81	38	38	4	1	---
Percent not detected (%ND)	46.8	58.5	40.4	30.8	100.0	---
Number > 0.3 mg/L SMCL (#)	54	12	36	6	0	---
Percent > 0.3 mg/L SMCL (%)	31.2	18.5	38.3	46.2	0.0	---

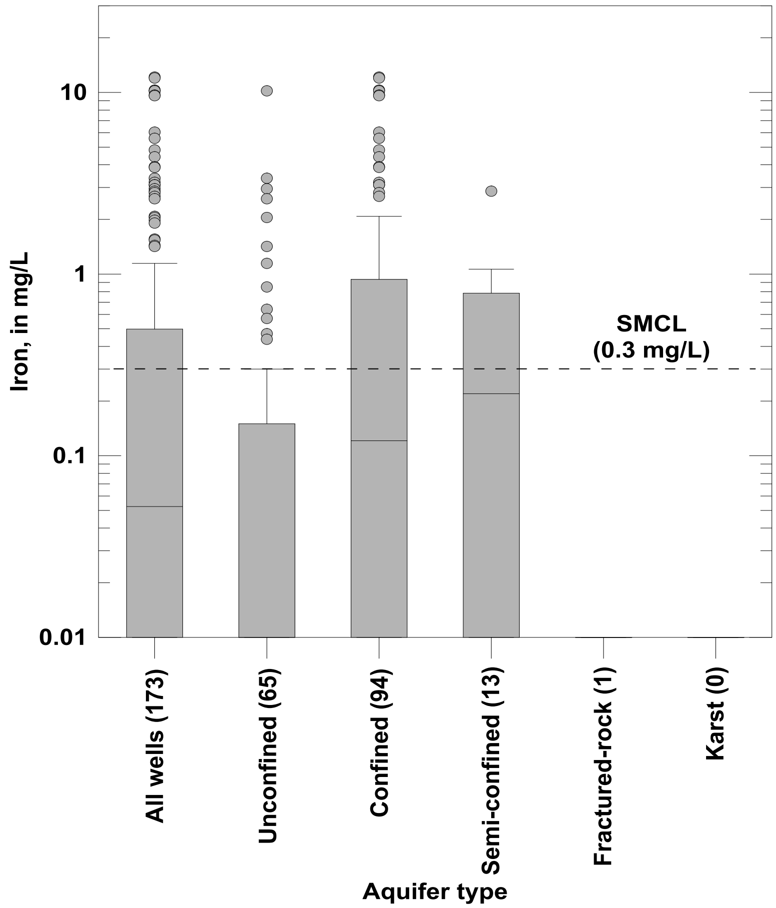


Figure 14. Percentile diagrams of iron data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012); nondetects assigned values of 0.01 mg/L to allow display on semi-logarithmic plot.]

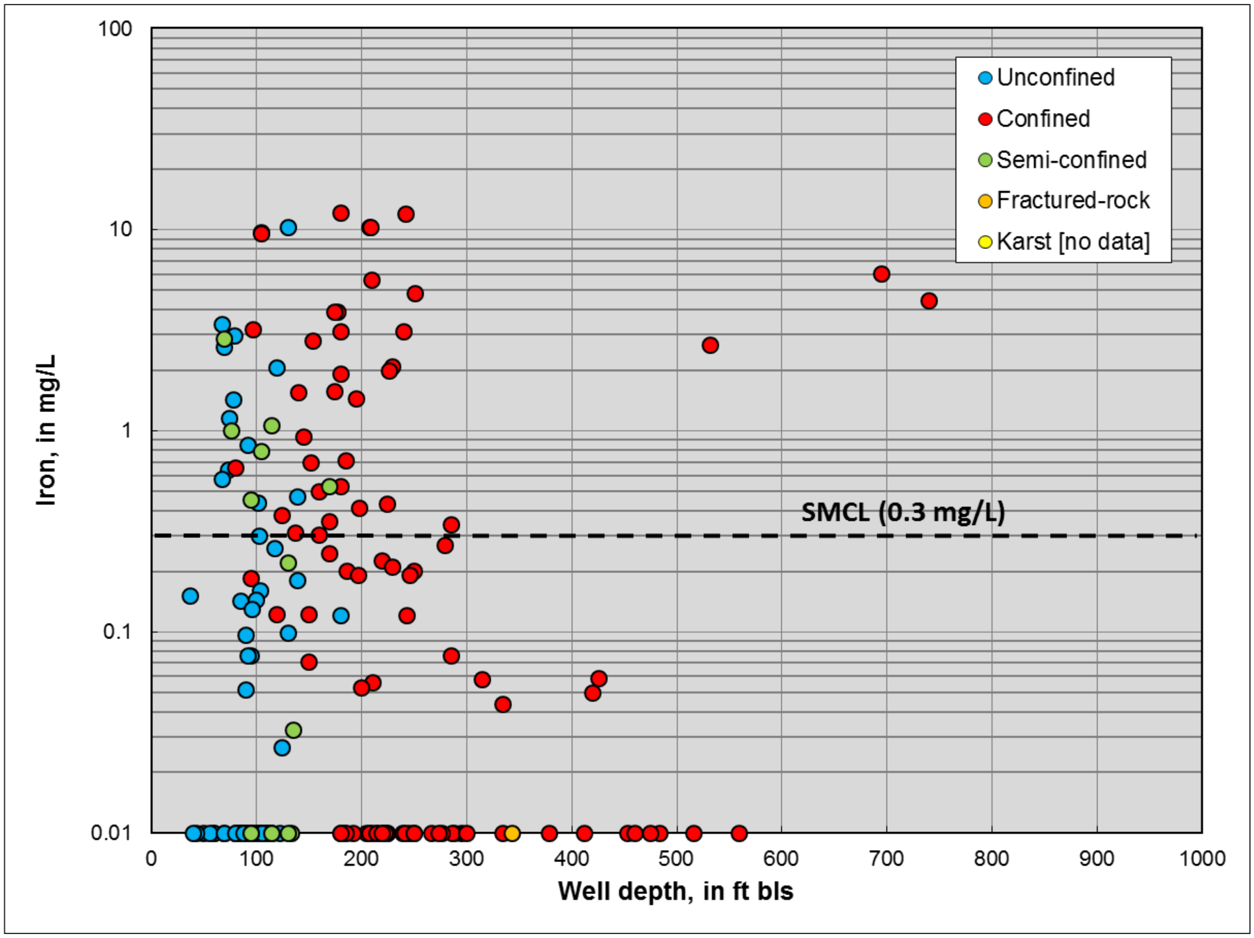


Figure 15. Scatter plot of iron versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012); nondetects assigned values of 0.01 mg/L to allow display on semi-logarithmic plot.]

Hardness as $CaCO_3$

Water hardness is affected by the amount of dissolved calcium and magnesium in the water, as well as other constituents. Overall, 47 hardness as $CaCO_3$ ("hardness") analyses are in the SDWIS query provided to DNREC. Of these, 28 (59.6%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 97 hardness analyses. Duplicate analyses for individual wells were averaged resulting in 103 hardness analyses where aquifer type is known (Table 7). This number translates to ~9.3% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, hardness concentrations ranged from ND to 178 mg/L with a median value of 52.3 mg/L (Table 7 and Figure 16). Hardness was not detected above the laboratory quantitation limit in 2 (1.9%) of the 103 analyses. With respect to the hardness scale of Love (1962), most of the analyses (87 or 84.5%) were classified as soft or moderately hard; the remaining 14.6% of the analyses were classified as hard (Table 7). None of the results were classified as very hard.

There were no hardness data for karst wells for this assessment; however, based on previous assessments, this aquifer type had the highest median hardness concentration and the largest fraction of concentrations classified as very hard (Kasper, 2010; Kasper and Strohmeier, 2012). Previously reported hardness results for karst wells were in general agreement with Werkheiser (1995), who reported that more than 75% of karst well samples could be classified as very hard. Hardness data for karst and fractured-rock wells are typically in sharp contrast (Werkheiser, 1995). Fractured-rock wells (1 sample; Table 7) are poorly represented in this assessment; for more information on the occurrence of hardness in this aquifer type, the interested reader is referred to Werkheiser (1995) or Kasper (2008). Confined wells had the highest median hardness concentration (95 mg/L) and the largest fractions classified as hard (24.1%) or moderately hard (53.4%) (Table 7 and Figure 16). Most of the semi-confined well samples were classified as soft (77.8%), with the remaining fraction of samples classified as either hard (11.1%) or moderately hard (11.1%) (Table 7 and Figure 16). Unconfined wells had the largest fraction of results classified as soft (94.3%), with the remaining fraction of the samples (5.7%) classified as moderately hard (Table 7 and Figure 16). There was no clear trend in hardness with respect to sample depth; groundwater classified as hard occurred at depths ranging from 70 to almost 500 ft bls (Figure 17). The three deepest confined well samples were classified as soft and associated with the Potomac aquifer system (Figure 17).

Table 7. Statistical summary of hardness data by aquifer type. [mg/L, milligrams per liter; ND, not detected; ---, no data; hardness scale after Love (1962).]

Statistics	All Wells	Unconfined Wells	Confined Wells	Semi-Confined Wells	Fractured-Rock Wells	Karst Wells
Number of wells/samples (#)	103	35	58	9	1	0
Percent of total (%)	100	34.0	56.3	8.7	1.0	0.0
Maximum (mg/L)	178.0	112.0	178.0	131.0	83.9	---
75th percentile (mg/L)	102.5	38.6	118.8	21.6	83.9	---
50th percentile (mg/L)	52.3	29.2	95.0	13.6	83.9	---
25th percentile (mg/L)	24.2	14.9	75.1	6.2	83.9	---
Minimum (mg/L)	ND	ND	ND	4.2	83.9	---
Number not detected (#ND)	2	1	1	0	0	---
Percent not detected (%ND)	1.9	2.9	1.7	0.0	0.0	---
Soft; 0-60 mg/L (#)	52	33	12	7	0	---
Soft; 0-60 mg/L (%)	50.5	94.3	20.7	77.8	0.0	---
Mod. hard; 61-120 mg/L (#)	35	2	31	1	1	---
Mod. hard; 61-120 mg/L (%)	34.0	5.7	53.4	11.1	100.0	---
Hard; 121-180 mg/L (#)	15	0	14	1	0	---
Hard; 121-180 mg/L (%)	14.6	0.0	24.1	11.1	0.0	---
Very hard; >180 mg/L (#)	0	0	0	0	0	---
Very hard; >180 mg/L (%)	0.0	0.0	0.0	0.0	0.0	---

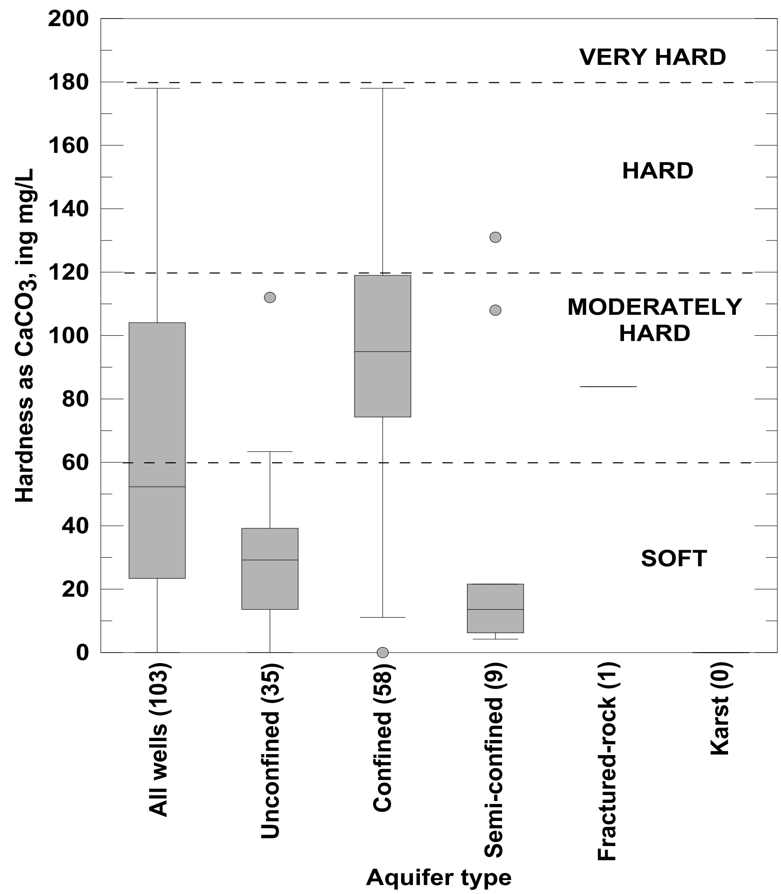


Figure 16. Percentile diagrams of hardness data by aquifer type. [mg/L, milligrams per liter; circles, outliers; (#), number of samples; hardness scale after Love (1962).]

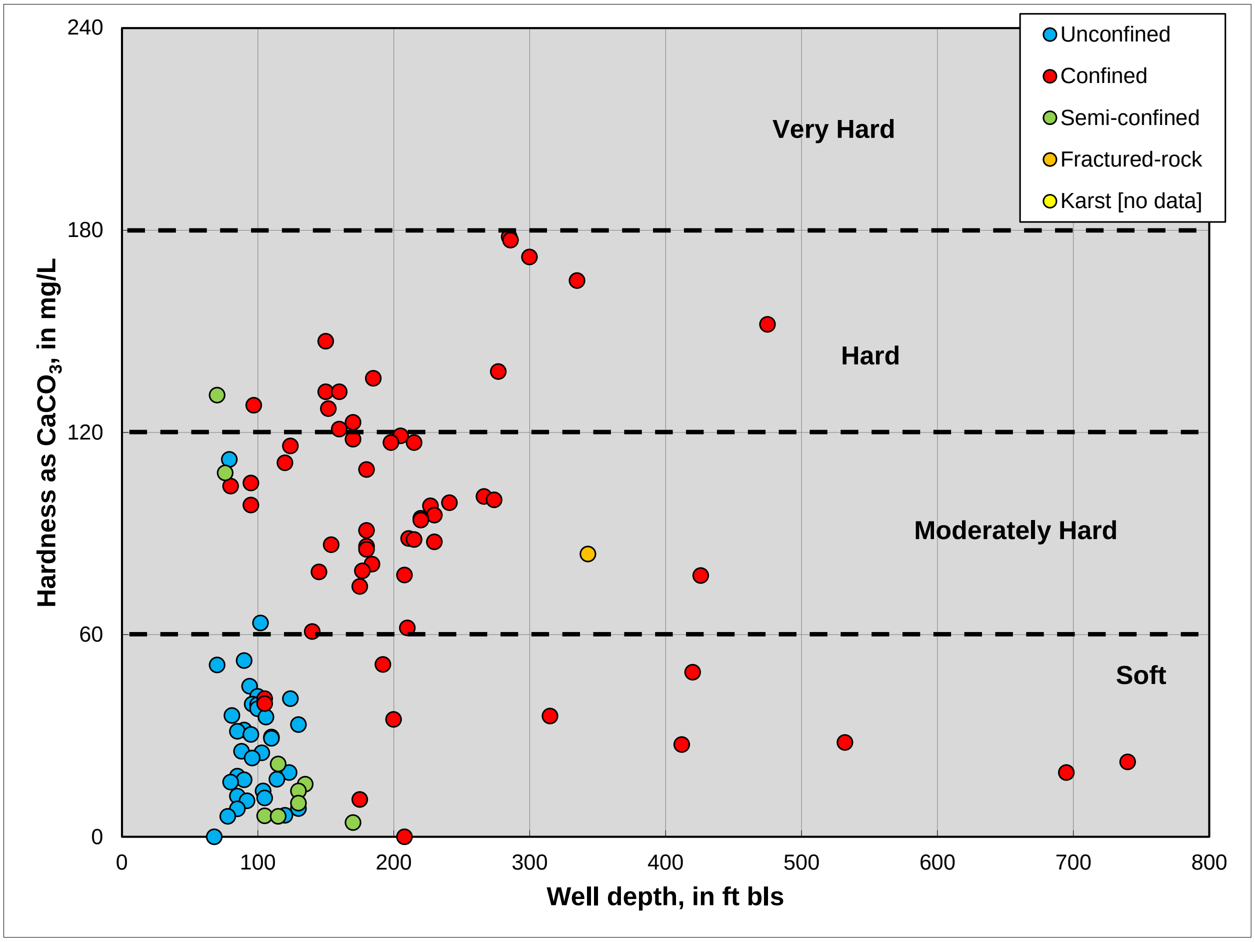


Figure 17. Scatter plot of hardness versus well depth. [mg/L, milligrams per liter; ft bls, feet below land surface; hardness scale after Love (1962).]

pH

Overall, 462 pH analyses are in the SDWIS query provided to DNREC. Of these, 40 (8.7%) could be linked by DNREC ID. Supplemental data collected by Tidewater Utilities, Inc. provided an additional 95 pH analyses. Duplicate analyses for individual wells were averaged resulting in 116 pH analyses where aquifer type is known (Table 8). This number translates to 10.5% of the total number of wells (1,106) where aquifer type is known (Figure 2). Overall, pH ranged from 4.6 to 9.1 standard units (S.U.) with a median value of 6.4 S.U. (Table 8 and Figure 18). Values of pH were below the lower limit of the SMCL range (6.5 to 8.5 S.U.) in 60 (52.6%) of the 114 samples; values were within the SMCL range in 53 (46.5%) of the 114 samples (Table 8). Only one pH value exceeded the upper limit of the SMCL range.

Confined wells had the highest median pH value (7.3 S.U.) and the largest fraction of samples within the SMCL range (76.3%; Table 8). Although there were no pH data for karst wells for this assessment, based on previous assessments, this aquifer type had the highest median pH concentration and the largest fraction of values within the SMCL range (Kasper, 2010; Kasper and Strohmeier, 2012). Calcium carbonate in the karst aquifer (due to marble) and some confined and semi-confined aquifers (due to shell material) buffers the pH of groundwater that flows through these aquifers. Unconfined and semi-confined wells had comparable median pH values (5.5 and 5.8, respectively); however, unconfined wells had the largest fraction of values below 6.5 S.U. and outside the SMCL range (88.6%; Table 8 and Figure 18). Fractured-rock wells (1 sample; Table 7) are poorly represented in this assessment. Overall, pH values below 6.5 S.U. were most prevalent at depths of ~250 ft bls and shallower (Figure 19).

Table 8. Statistical summary of pH data by aquifer type. [S.U., standard units; ---, no data; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Statistics	**All Wells**	**Unconfined Wells**	**Confined Wells**	**Semi-Confined Wells**	**Fractured-Rock Wells**	**Karst Wells**
Number of wells/samples (#)	114	44	59	10	1	0
Percent of total (%)	100.0	38.6	51.8	8.8	0.9	0.0
Maximum (S.U.)	9.1	7.4	9.1	7.6	6.6	---
75th percentile (S.U.)	7.5	5.7	8.0	6.1	6.6	---
50th percentile (S.U.)	6.4	5.5	7.3	5.8	6.6	---
25th percentile (S.U.)	5.5	5.3	6.6	5.5	6.6	---
Minimum (S.U.)	4.6	4.6	4.8	5.4	6.6	---
pH <6.5 SMCL (#)	60	39	13	8	0	---
pH <6.5 SMCL (%)	52.6	88.6	22.0	80.0	0.0	---
pH 6.5 to 8.5 (#)	53	5	45	2	1	---
pH 6.5 to 8.5 (%)	46.5	11.4	76.3	20.0	100.0	---
pH >8.5 SMCL (#)	1	0	1	0	0	---
pH >8.5 SMCL (%)	0.9	0.0	1.7	0.0	0.0	---

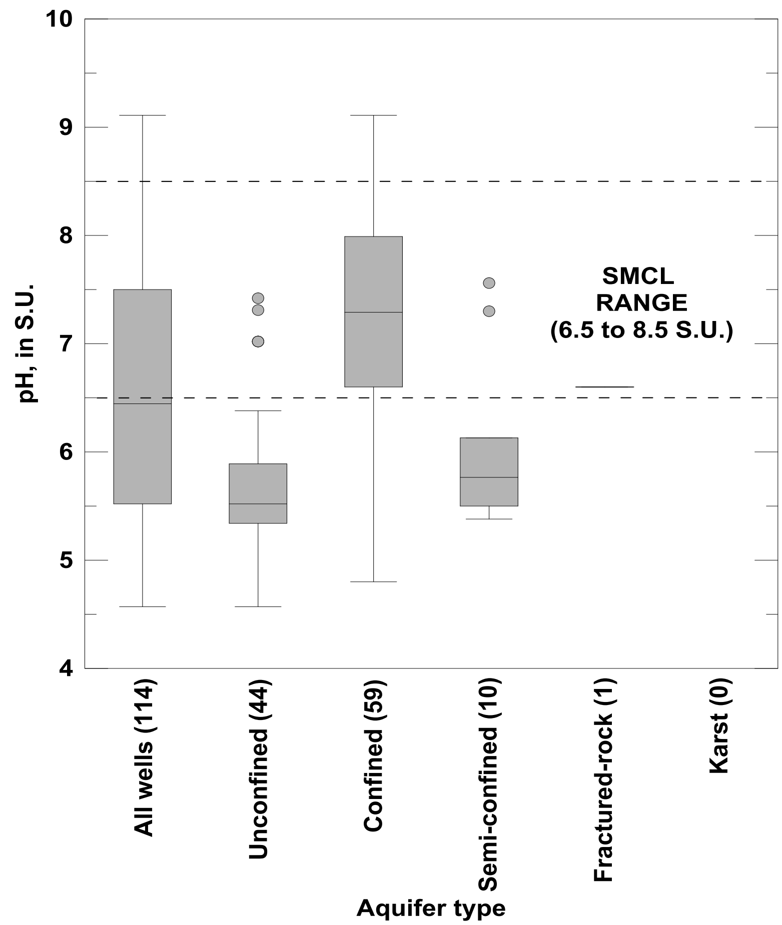


Figure 18. Percentile diagrams of pH data by aquifer type. [S.U., standard units; crosses, outliers; (#), number of samples; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

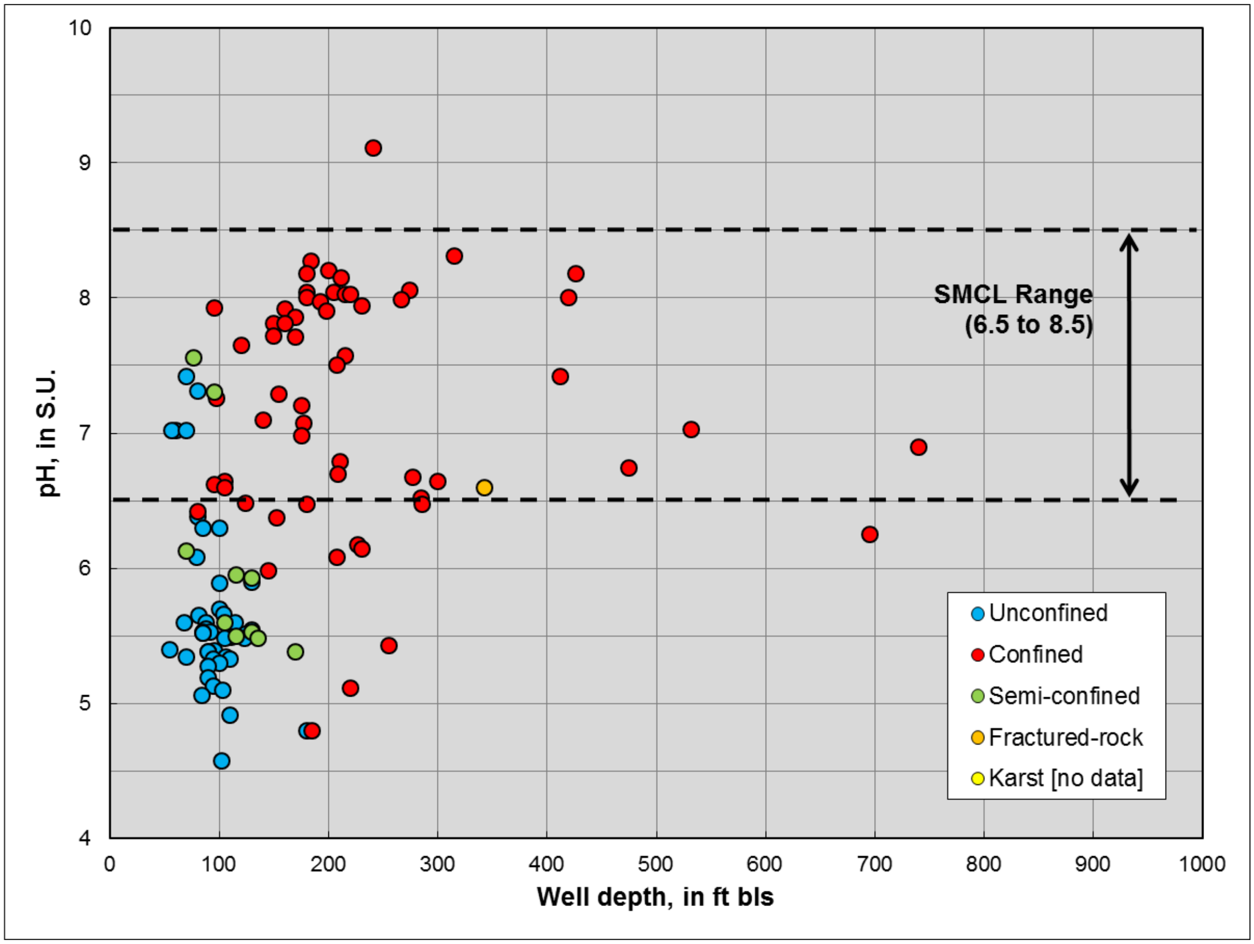


Figure 19. Scatter plot of pH versus well depth. [S.U., standard units; ft bls, feet below land surface; SMCL, secondary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

Organic compounds

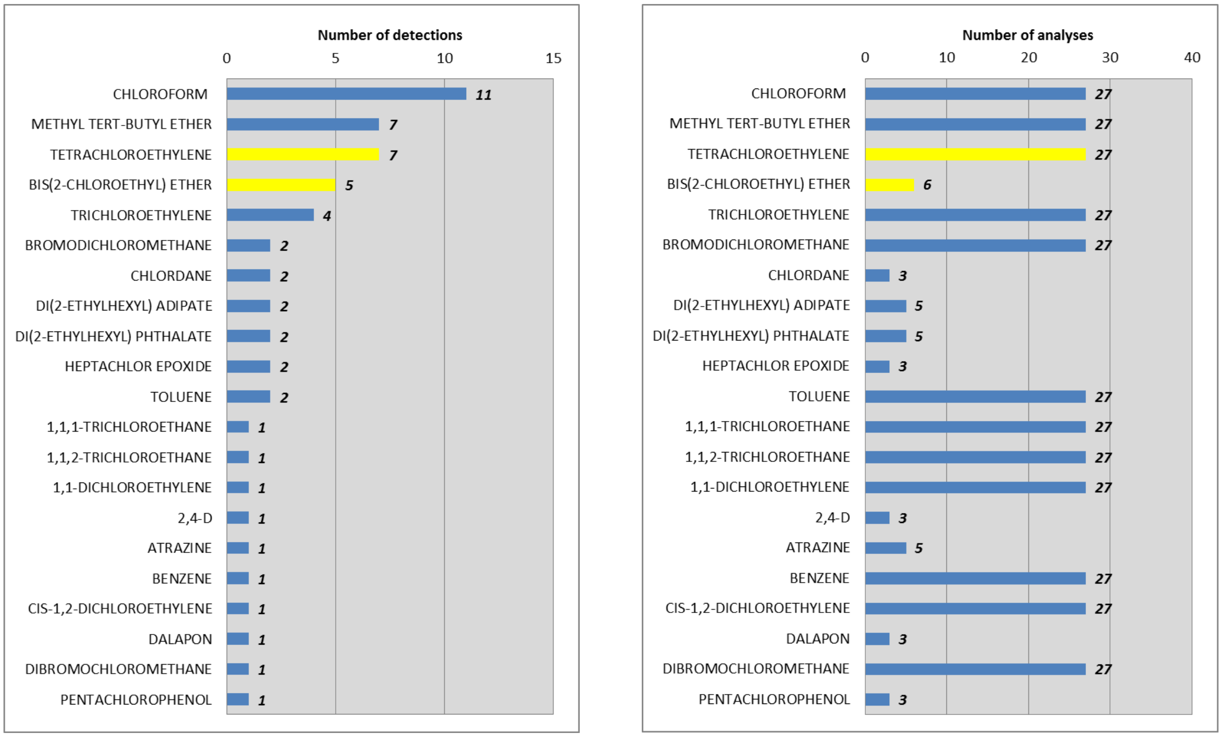
Because organic compounds (OCs) include a broad list of volatiles, semi-volatiles, and pesticides, they are treated in this report as a group of analytes rather than individual analytes. Overall, 15,440 OC analyses are in the SDWIS query provided to DNREC. Of these, 8,161 (52.9%) could be linked by DNREC ID. Duplicate analyses for individual wells were averaged resulting in 844 OC analyses. OCs were not detected in 788 (93.4%) of the 844 analyses. Out of the 51 organic compounds analyzed, 21 (41.2%) were detected (Figure 20).

Of the 56 OC detections, almost three-quarters (40 or 71.4%) were found at concentrations less than 1 µg/L. The top five most-frequently detected OCs are summarized as follows: Chloroform, a disinfection byproduct; methyl tert-butyl ether (MTBE), a gasoline oxygenate; tetrachloroethylene (PCE), a solvent; bis(2-chloroethyl) ether (BCEE), a solvent; and trichloroethylene (TCE), a solvent (Figure 20). These findings are generally consistent with studies by Ferrari (2001) and Reyes (2010) involving water-quality data for 30 unconfined public water-supply wells in Delaware, as well as previous 305(b) groundwater-quality assessments

(Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012). These results are also consistent with nationwide VOC data collected by the USGS (Zogorski et al., 2006).

PMCLs were exceeded in 4 (0.5%) of the 844 analyses. The following analytes were found above the PMCL: PCE (3 exceedances) and BCEE (1 exceedance). Aquifer type was established for all four of the samples with PMCL exceedances. Of these, the three TCE exceedances were associated with unconfined wells and the single BCEE exceedance was associated with a confined well. The confined well sample with elevated BCEE is completed in the Potomac aquifer system, an extremely heterogeneous fluvial system used most extensively for water supply in the northern, most populated portion of Delaware (McKenna et al., 2004). These findings, although limited, further illustrate the susceptibility of the unconfined aquifer and the Potomac aquifer system to contamination.

MTBE, TCE, and PCE are within the top five most frequently detected OCs (Figure 20), consistent with the findings of Ferrari (2001), Reyes (2010), and previous 305(b) groundwater-quality assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012). Well depths were established for 27 MTBE, 27 TCE, and 27 PCE analyses, and scatter plots of these parameters versus well depth are shown in Figure 21. Although OC data for this assessment were somewhat limited, MTBE, TCE, and PCE detections were limited to depths of ~150 ft bls, which is generally consistent with Kasper (2008, 2010, 2014) and Kasper and Strohmeier (2012). Overall, these findings are consistent with trends of nitrate versus well depth (Figure 5), and appear to provide another indication of the vertical extent of human impact on groundwater quality in Delaware.



(A) **(B)**

Figure 20. Frequency distributions of organic compound (A) detections and (B) analyses. [Bars highlighted yellow indicate one or more concentration above the PMCL or primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

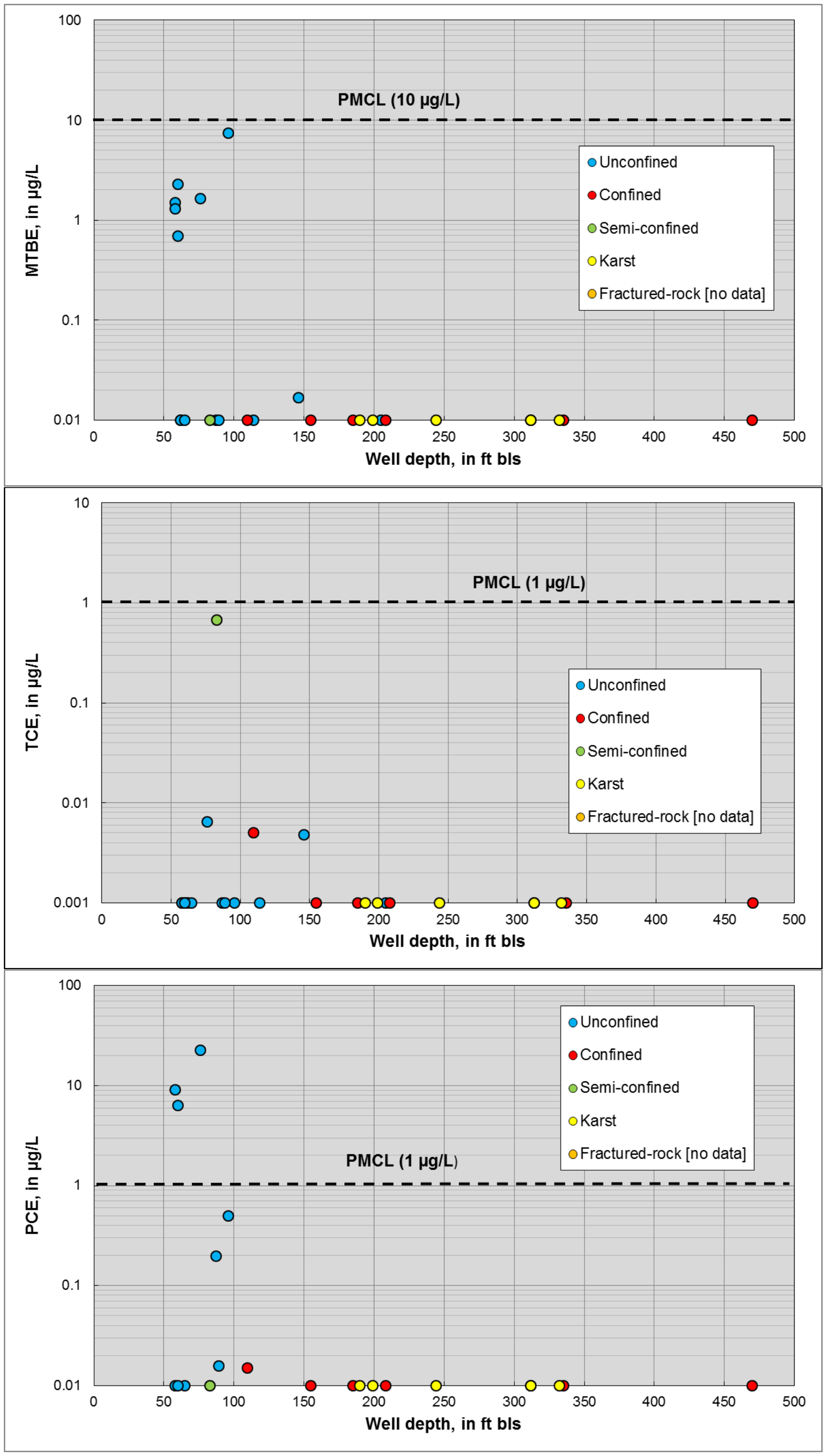


Figure 21. Scatter plots of methyl tert-butyl ether (MTBE), trichloroethylene (TCE), and tetrachloroethylene (PCE) versus well depth. [µg/L, micrograms per liter; ft bls, feet below land surface; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012); nondetectable concentrations (zeros) assigned values of 0.01 or 0.001 µg/L to allow display on semi-logarithmic plots.]

Trace elements

For this assessment, trace elements are limited to the following analytes with PMCLs (DHSS, 2015; U.S. EPA, 2012): antimony (0.006 mg/L), arsenic (0.010 mg/L), barium (2 mg/L), beryllium (0.004 mg/L), cadmium (0.005 mg/L), chromium (0.1 mg/L), cyanide (0.2 mg/L), fluoride (2 mg/L), lead (0.015 mg/L*), mercury (0.002 mg/L), nickel (0.1 mg/L), selenium (0.05 mg/L), and thallium (0.002 mg/L). (*Action level for Treatment Technique (TT; U.S. EPA, 2012).) Overall, 1,848 trace-element analyses are in the SDWIS query provided to DNREC. Of these, 468 (25.3%) could be linked by DNREC ID. Duplicate analyses for individual wells were averaged resulting in 282 trace-element analyses. Trace elements were not detected in 203 (72%) of the 282 analyses.

Although trace element data for this assessment were limited, based on available data, detectable concentrations were less than 0.1 mg/L in 42 (53%) of the 79 detections and less than 1 mg/L in all 79 (100%) of the detections. Chromium, nickel, and barium were the three most-frequently detected trace elements (Figure 22). (Although fluoride had the largest number of detections (33), it also had the largest number of analyses (114) and it was detected in a relatively smaller fraction (30%) of analyses (Figure 22).) Chromium was detected in 13 (86.7%) of the 15 analyses, nickel was detected in 13 (86.7%) of the 15 analyses, and barium was detected in 12 (80.0%) of the 15 analyses (Figure 22). Lead, arsenic, and beryllium were also detected in some groundwater samples (Figure 22). PMCLs or action levels were not exceeded in any of the 282 analyses.

The fate, transport, and remediation of arsenic in Delaware soil have been evaluated (DNREC, 2005; Sparks et al., 2007). Published data on arsenic in Delaware's groundwater are generally lacking, however, and limited to the surficial aquifer system (see, for e.g., Denver et al., 2004) and, more recently, the Rancocas aquifer (Denver, 2016). Sources of arsenic in groundwater on the Delmarva Peninsula include, but are not limited to, poultry manure applied to agricultural fields, pesticides and fertilizers, abandoned tanneries, lumber treated with chromium copper arsenate, and glauconitic sediments deposited in marine environments (Denver et al., 2004; DNREC, 2005). A recent study of arsenic in groundwater in the Coastal-Plain aquifers of Maryland (Drummond and Bolton, 2010) found that arsenic concentrations in excess of the PMCL were primarily limited to the Piney Point and Aquia aquifers. (Note that the Aquia aquifer of Maryland is analogous to the Rancocas aquifer of Delaware; see Table 1.) Arsenic in these aquifers is apparently due to naturally-occurring sources, which may include calcareous shell material and cement, glauconite grains, phosphate pellets, goethite pellets, and iron oxyhydroxide coatings on mineral grains (Drummond and Bolton, 2010).

In this assessment, arsenic data were limited to only 17 analyses and a single detection (Figure 22). Based on the previous assessment (Kasper, 2014), arsenic was detected in 23 (42.6%) of 54 analyses and what follows is an excerpt from that assessment.

> *Overall, concentrations ranged from nondetectable to 0.0093 mg/L, which is slightly below the PMCL (0.010 mg/L). Aquifer type was established for 46 (85%) of the 54 arsenic analyses. Of these 46 analyses, 15 were associated with unconfined wells, 2 were associated with a semi-confined wells, 28 were associated with confined wells, and one was associated with a fractured-rock well; no data were associated with karst wells. Although arsenic concentrations never exceeded the PMCL, the most-elevated detections were associated with confined wells with depths ranging from ~250 to 500 ft bls (Figure 22* [Figure 23,

this report]*). All of these confined wells produce from either the Rancocas, Mt. Laurel, or Piney Point aquifers, which are associated with glauconitic geologic formations (Ramsey, 2005, 2007). These findings are consistent with Drummond and Bolton (2010). Arsenic was detected at very low concentrations in six of the 15 unconfined well samples as well as the single fractured-rock well sample. Arsenic was ND in the two semi-confined well samples.*

In 2015, the USGS evaluated the occurrence and distribution of arsenic and radon in Delaware's Rancocas aquifer, which is an important source of drinking water in southern New Castle County and northwestern Kent County (Denver, 2016). Arsenic was detected in 34 (94.4%) of the 36 samples and concentrations ranged from about 0.11 to 27 µg/L. Arsenic exceeded the PMCL (0.010 mg/L) in 15 (41.7%) of the 36 samples. The most elevated arsenic concentrations were detected in the southern portion of the study area in a southwest-northeast trending band that coincides with geologic strike (Figure 24). This spatial pattern of arsenic concentrations in Delaware's Rancocas aquifer is an extension of previous work by the Maryland Geological Survey (Drummon and Bolton, 2010; Figure 24).

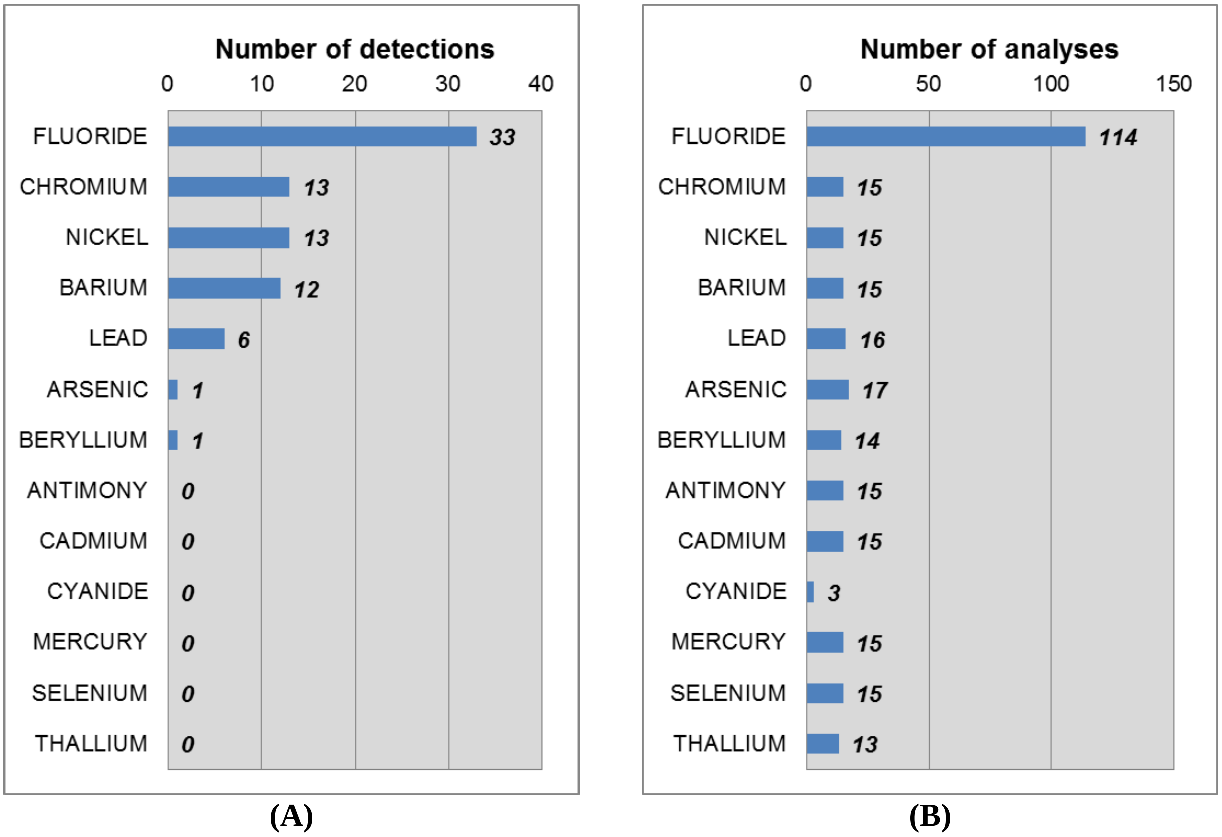


Figure 22. Frequency distributions of trace element (A) detections and (B) analyses. [Bars highlighted yellow indicate one or more concentration above the PMCL or primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

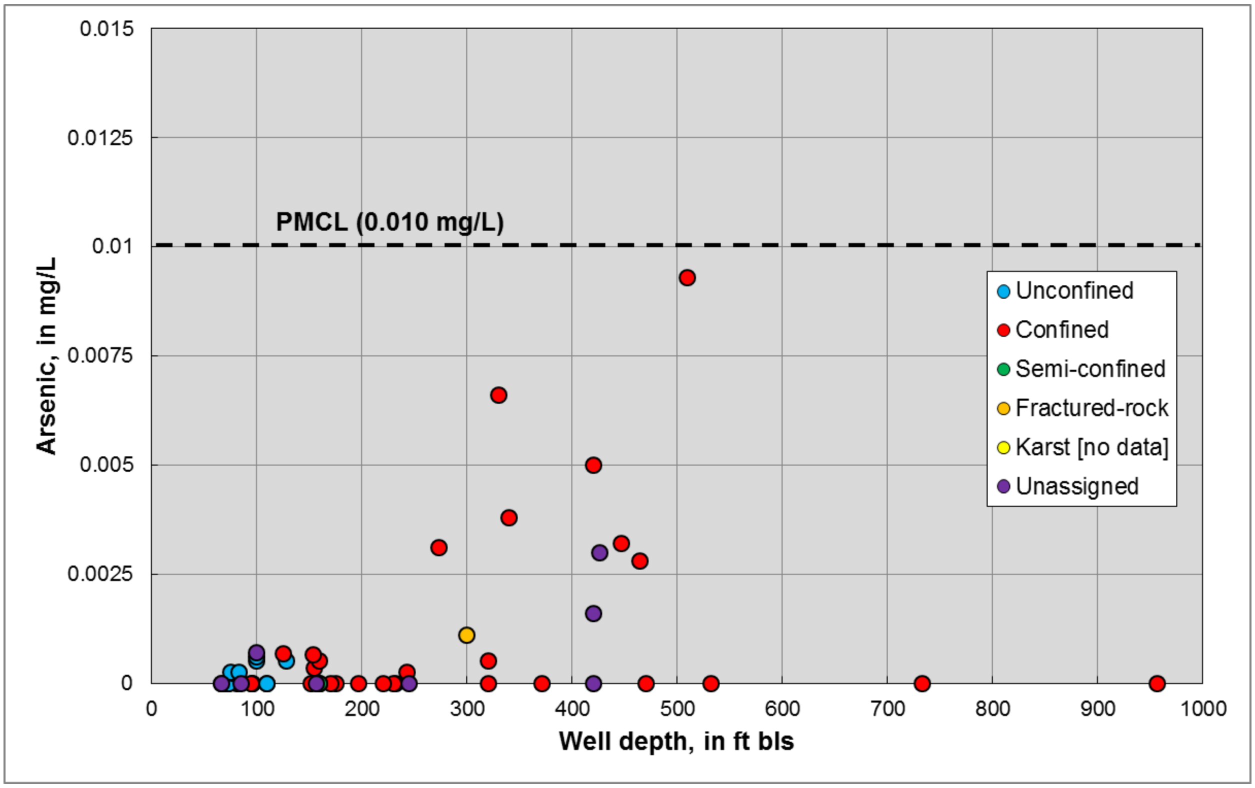


Figure 23. Scatter plot of arsenic versus well depth from Delaware's 2014 305(b) groundwater-quality assessment based on public-well data (Kasper, 2014). [mg/L, milligrams per liter; ft bls, feet below land surface; PMCL, primary maximum contaminant level for public water-supply systems (DHSS, 2015; U.S. EPA, 2012).]

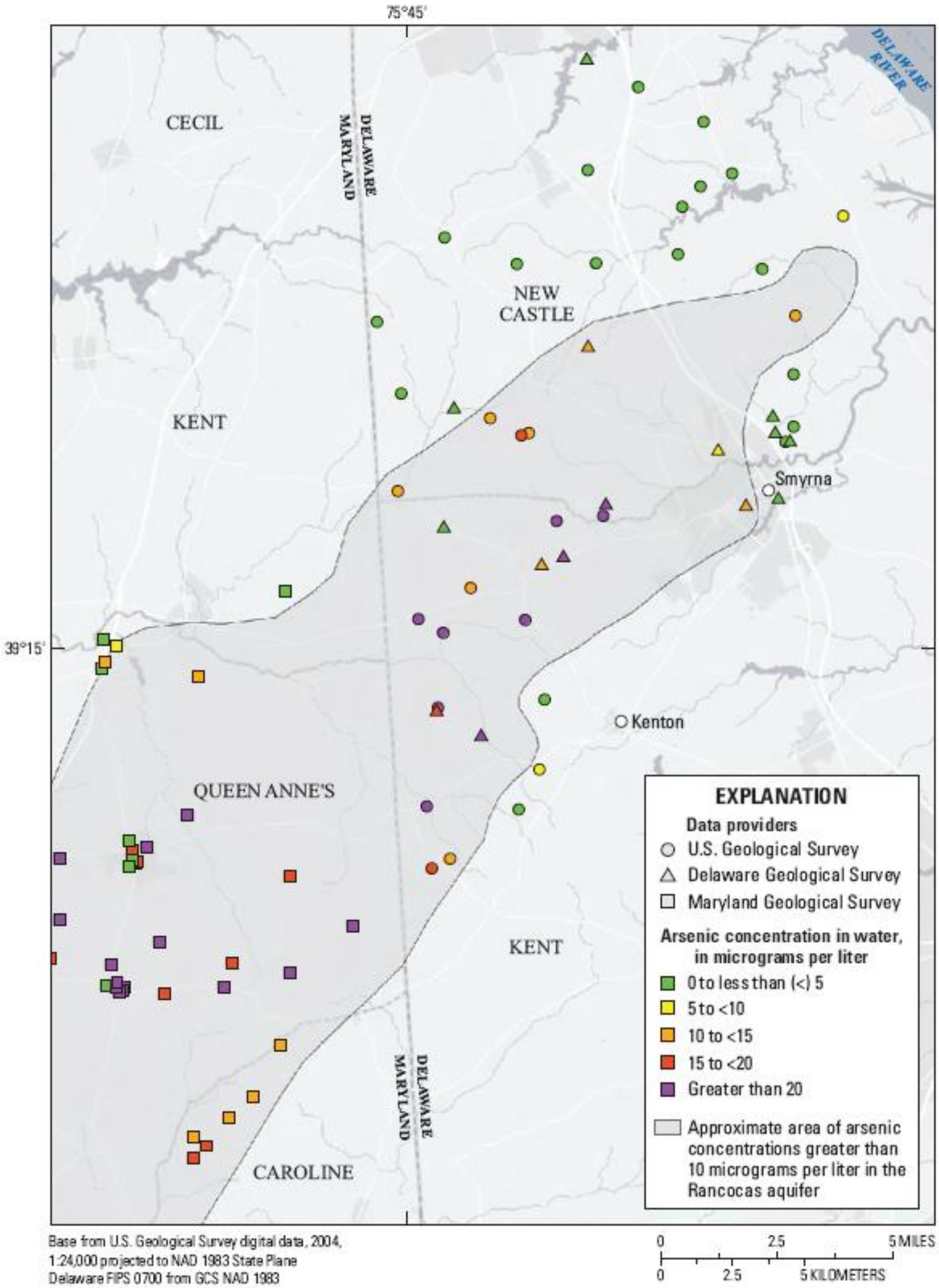


Figure 24. Map showing the distribution of arsenic in the Rancocas aquifer of Delaware and the corresponding Aquia aquifer in adjacent parts of Maryland. [Modified after Figure 5 of Denver (2016).]

Radionuclides

Radionuclides include the following parameters and their associated PMCLs (DHSS, 2015; U.S. EPA, 2012): beta particle and photon activity (4 millirems per year (mrem/yr)); gross alpha particle activity (15 picocuries per liter (pCi/L)); radium-226 and radium-228 combined (5 pCi/L); and uranium (0.03 mg/L). For radon, which is a gas derived from the radioactive decay of radium, there is a proposed PMCL of 300 pCi/L as well as a proposed alternative MCL or AMCL of 4,000 pCi/L (U.S. EPA, 1999). The higher AMCL would apply to multi-media mitigation (MMM) programs that also address radon in indoor air; the lower PMCL would apply if a MMM program is not in place (U.S. EPA, 1999).

For this 305(b) groundwater assessment, radionuclide data are limited to the following parameters: uranium-238, radium-226, radium-228, and gross alpha particle activity. Overall, 167 radionuclide analyses are in the SDWIS query provided to DNREC. Of these, 38 (22.8%) could be linked by DNREC ID. Duplicate analyses for individual wells were averaged resulting in 23 radionuclide analyses, which are summarized as follows: uranium-238 (14 analyses), radium-226 (3 analyses), radium-228 (3 analyses), and gross alpha particle activity (3 analyses). Uranium-238 was ND in all of the analyses. Individually, none of the radium-226 or radium-228 activities exceeded the 5 pCi/L PMCL; in addition, none of the three radium-226 and radium-228 combined results exceeded the PMCL. Gross alpha particle activity was below the 15 pCi/L PMCL in each of the three analyses.

As previously noted, in 2015, the USGS evaluated the occurrence and distribution of arsenic and radon in Delaware's Rancocas aquifer, which is an important source of drinking water in southern New Castle County and northwestern Kent County (Denver, 2016). Radon was detected in all 36 of the groundwater samples and concentrations ranged from 85 to 1,870 pCi/L. Radon concentrations in 16 (44.4%) of the 36 well samples were above the lower proposed MCL of 300 pCi/L. Most of these samples were located in a similar part of the aquifer as the region of elevated arsenic depicted in Figure 24. None of the radon concentrations exceeded the proposed alternative MCL of 4,000 pCi/L.

For more information on radionuclides in Delaware groundwater, the reader is referred to Bachman and Ferrari (1995) and Ferrari (2001). Studies in the Coastal-Plain regions of Maryland (Bolton, 2000) and New Jersey (Szabo and dePaul, 1998; Szabo et al., 2004; dePaul and Szabo, 2007) also have been conducted.

Summary and conclusions

The Department of Natural Resources and Environmental Control (DNREC) assessed groundwater quality in Delaware based on data collected during a two-year time period (October 1, 2013 through September 30, 2015) from public water-supply wells. The results of this assessment serve as "Part IV: Groundwater Assessment" of Delaware's overall 2016 305(b) report (DNREC, 2016). Water-quality data were obtained from the Department of Health and Social Services (DHSS) Safe Drinking Water Information System (SDWIS). SDWIS queries developed by DHSS staff provide data (26,389 analyses) indicative of raw or apparently raw groundwater quality. Supplemental groundwater-quality data for 90 public wells (1,875 analyses) were obtained from a private water utility, Tidewater Utilities, Inc. Water-quality data were linked with the DNREC's Source Water Assessment and Protection Program (SWAPP) database, which contains public-well records such as DNREC ID, depth, geographic coordinates, geologic formation, aquifer, and aquifer type. Per U.S. EPA (1997) guidance, data were evaluated with respect to hydrogeologic setting where possible and drinking-water standards or criteria where applicable (DHSS, 2015; U.S. EPA, 1999, 2012; Love, 1962).

Five aquifer types were recognized in this assessment: unconfined, confined, semi-confined, fractured-rock, and karst aquifers. Unconfined, confined, and semi-confined aquifers occur in the mid-Atlantic Coastal Plain Physiographic Province, which comprises most (~96%) of Delaware's land-surface area. Fractured-rock and karst aquifers occur in the Piedmont Physiographic Province in the northernmost portion of the state. As of March 21, 2016, there were 1,174 active public water-supply wells in Delaware and aquifer type has been established for 1,106 (94%) of these wells. Most of the wells (90%) produce from Coastal-Plain aquifers while a much smaller percentage of the wells (5%) produce from Piedmont aquifers. General statistics on aquifer type for the 1,174 active wells follow: unconfined wells (473 or 40%), confined wells (521 or 44%), semi-confined wells (58 or 5%), fractured-rock wells (46 or 4%), and karst wells (8 or 1%). Fractured-rock and karst aquifers are poorly represented in this assessment due to limited groundwater-quality data. Aquifer type is not known or has not yet been established for the remaining 68 or 6% of the wells. (Percentages may not total 100% due to rounding.) Well depths range from 22 to 957 ft below land surface (bls) with a median well depth of 145 ft bls.

Overall, groundwater is predominantly soft to moderately hard based on the hardness scale of Love (1962). Specifically, most of the results (84.5%) meet either of these criteria. With respect to Coastal-Plain aquifers, fractions of hardness results classified as soft or moderately hard are summarized as follows: unconfined wells (100%), confined wells (74.1%), and semi-confined wells (88.9%). Hardness data for Piedmont aquifers (fractured-rock and karst wells) are limited in this assessment. Based on previous assessments, karst wells had the highest median hardness concentration and the largest fraction of concentrations classified as very hard (Kasper, 2010; Kasper and Strohmeier, 2012). Groundwater is partially acidic overall, with pH values less than the lower limit of the Secondary Maximum Contaminant Level (SMCL) range (6.5 to 8.5 S.U.) in 52.6% of the samples; pH values were within the SMCL range in 46.5% of the samples. Unconfined and semi-confined wells had the largest fractions of pH values below the SMCL range (88.6 and 80.0%, respectively); in contrast, confined wells had pH values that were predominantly within the SMCL range (76.3%). Data for pH in Piedmont aquifers (fractured-rock and karst wells) are limited in this assessment. Based on previous assessments, karst wells had the highest median pH concentration and the largest fraction of values within the SMCL range (Kasper, 2010; Kasper and Strohmeier, 2012). Overall, iron exceeded the 0.3 mg/L SMCL in a considerable fraction of the samples (31.2%) and was found above the SMCL at virtually all depths. Relative to other Coastal-Plain aquifer types, semi-confined wells had the largest fraction of iron concentrations greater than the SMCL (46.2%). Groundwater is generally dilute overall with a median total dissolved solids (TDS) concentration of 146 mg/L. TDS concentrations were below the 500 mg/L SMCL in all of the samples. Although there were no TDS data for karst wells for this assessment, based on previous assessments, this aquifer type had the highest median TDS concentration (Kasper, 2010; Kasper and Strohmeier, 2012). TDS concentrations generally increase with depth, with some exceptions. Chloride concentrations exceeded the SMCL (250 mg/L) in a small fraction (0.6%) of the samples. The most elevated chloride concentration (282 mg/L) was associated with an unconfined well sample. Overall, sodium concentrations exceeded the 20 mg/L Health Advisory or HA in a considerable fraction of the samples (23.3%) and at virtually all depths. Confined wells had the largest fraction of concentrations above the HA (29.5%).

Nitrate data were used as a proxy of the extent of human influence on groundwater quality. Overall, nitrate concentrations exceeded the Primary Maximum Contaminant Level (PMCL; 10 mg/L) in 4.5% of the analyses. A large fraction of the wells (43.5%) had nitrate concentrations greater than 0.4 mg/L, a threshold indicative of anthropogenic impacts (Hamilton et al., 1993). Of the aquifer types evaluated, the unconfined aquifer, which is primarily represented in this assessment by wells in Sussex County, is the most susceptible to human impacts; it had the highest median nitrate concentration (4.7 mg/L) and the largest fraction of concentrations greater than 0.4 mg/L (91.3%). The unconfined aquifer also had the most elevated nitrate concentration (14.5 mg/L) and the largest (and only) fraction of concentrations above the 10 mg/L Primary Maximum Contaminant Level or PMCL (11.6%). The semi-confined aquifer had an intermediate median nitrate concentration (1.24 mg/L) with 61.5% of the concentrations greater than 0.4 mg/L. Confined aquifers had the lowest median nitrate concentration (nondetectable) and the smallest fraction of concentrations greater than 0.4 mg/L (5.3%). Confined aquifers also had the largest fraction of nondetectable nitrate concentrations (92.6%). Regardless of aquifer type, the vertical extent of human influence was primarily limited to depths ~350 ft below land surface (bls) and shallower; at greater depths nitrate was not detected above the quantitation limit. In Coastal-Plain wells, nitrate detections were primarily limited to depths of 240 ft and shallower. Fractured-rock and karst aquifers are poorly represented in this assessment; based on past assessments, the deepest nitrate detections were often associated with Piedmont wells with extremely long open intervals, which may allow nitrate to enter the wells at shallower depths. Areally, PMCL exceedances were limited to unconfined wells located in Sussex County.

Organic compounds (OCs) were not frequently detected and, when detected, rarely exceeded PMCLs. Specifically, OCs were not detected in 788 (93.4%) of 844 analyses. Of the 56 OC detections, almost three-quarters (40 or 71.4%) were found at concentrations less than 1 µg/L. Chloroform, a disinfection byproduct, was the most-frequently detected OC. PMCLs were exceeded in a very small fraction (4 or 0.5%) of the 844 analyses. The following analytes were found above the PMCL: tetrachloroethylene (PCE; 3 exceedances) and bis(2-chloroethyl) ether (BCEE; 1 exceedance). The three PMCL exceedances for PCE were associated with unconfined wells and the single BCEE exceedance was associated with a confined well in the Potomac aquifer system. Methyl tert-butyl ether (MTBE), PCE, and trichloroethylene (TCE) were among the top-five most-frequently detected OCs. Based on limited data for unconfined, semi-confined, confined, and karst wells, concentrations of MTBE, TCE, and PCE with respect to sample depth indicate that the vertical extent of human impact is limited to depths of ~150 ft bls and shallower; at greater depths these contaminants were not detected. As previously noted, similar trends in nitrate with respect to sample depth were identified. Many of the OC results are in agreement with Ferrari (2001), Reyes (2010), previous 305(b) groundwater-quality assessments (Kasper, 2008, 2010, 2014; Kasper and Strohmeier, 2012), and nationwide results (Zogorski et al., 2006).

Similar to OCs, trace elements were not frequently detected. Specifically, trace elements were not detected in 203 (72%) of 282 analyses. Of the 79 trace-element detections, 42 (53%) were found at concentrations less than 0.1 mg/L and all 79 (100%) were found at concentrations less than 1 mg/L. Chromium, nickel, and barium were the top three most-frequently detected trace elements. PMCLs or action levels were not exceeded in any of the 282 analyses. Although arsenic data were limited for this assessment, based on the 2014 assessment (Kasper, 2014), it was one of the top five most frequently detected trace elements. The most elevated arsenic detections in the 2014 assessment were primarily limited to confined wells with depths ranging from ~250 to 500 ft bls, and all of these confined wells produce from either the Rancocas, Mt. Laurel, or Piney Point aquifers, which are associated with glauconitic geologic formations (Ramsey, 2005, 2007). This finding is consistent with Drummond and Bolton (2010) and previous 305(b) groundwater-quality assessments (Kasper, 2008, 2010; Kasper and Strohmeier, 2012). A USGS study targeting the Rancocas aquifer in Delaware and completed during the reporting period found arsenic above the PMCL (0.010 mg/L) in 15 (41.7%) of the 36 samples (Denver, 2016).

Radionuclide data were very limited in this assessment and available data were limited to the following parameters: uranium-238, radium-226, radium-228, and gross alpha particle activity. Uranium-238 was ND in all of the analyses (n = 14). None of the three radium-226 and radium-228 combined results exceeded the 5 pCi/L PMCL. Gross alpha particle activity was below the 15 pCi/L PMCL in each of the three analyses. A USGS study targeting the Rancocas aquifer in Delaware and completed during the reporting period found radon above the proposed PMCL (300 pCi/L) in 16 (44.4%) of the 36 well samples; none of the radon concentrations exceeded the proposed alternative MCL of 4,000 pCi/L (Denver, 2016; U.S. EPA, 1999).

This 305(b) groundwater-quality assessment is the DNREC's fifth attempt to report raw or apparently raw groundwater data with respect to hydrogeologic setting on a statewide basis. The results of this assessment represent a subset of the total number of active public water-supply wells in Delaware and, therefore, should be viewed in that context. Provided that water-quality data in SDWIS continue to be identified by DNREC ID, future 305(b) groundwater-quality assessments should provide a more complete picture of groundwater quality in Delaware.

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