science for a changing world

Prepared in cooperation with the Delaware Geological Survey and Delaware Department of Natural Resources and Environmental Control

Occurrence and Distribution of PFAS in Sampled Source Water of Public Drinking-Water Supplies in the Surficial Aquifer in Delaware, 2018; PFAS and Groundwater Age-Dating Results

Open-File Report 2021–1109

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

Cover: The well house of well Md11-04 in Harrington, Delaware. Photograph by Betzaida Reyes, U.S. Geological Survey.

Occurrence and Distribution of PFAS in Sampled Source Water of Public Drinking-Water Supplies in the Surficial Aquifer in Delaware, 2018; PFAS and Groundwater Age-Dating Results

By Betzaida Reyes

Prepared in cooperation with the Delaware Geological Survey and Delaware Department of Natural Resources and Environmental Control

Open-File Report 2021–1109

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

U.S. Geological Survey, Reston, Virginia: 2021

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

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov/.

Suggested citation:
Reyes, B., 2021, Occurrence and distribution of PFAS in sampled source water of public drinking-water supplies in the surficial aquifer in Delaware, 2018; PFAS and groundwater age-dating results: U.S. Geological Survey Open-File Report 2021–1109, 27 p., https://doi.org/10.3133/ofr20211109.

Associated data for this publication:
Reyes, B., 2021, Data in support of the occurrence and distribution of per- and polyfluoroalkyl substances in sampled source water of public drinking-water supplies in the surficial aquifer in Delaware, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9T0IA3Z.

U.S. Geological Survey, 2021, USGS water data for the Nation: U.S. Geological Survey National Water Information System database, available at, https://doi.org/10.5066/F7P55KJN.

ISSN 2331-1258 (online)

Acknowledgments

This project was funded under a cooperative agreement between the Delaware Geological Survey (DGS) and the U.S. Geological Survey (USGS), in support of the Delaware Department of Natural Resources and Environmental Control (DNREC). The author would like to thank DNREC employees for their excellent help, cooperation, and support in providing the database of public water-supply wells and assisting in the selection of replacement wells for this study. The author would also like to thank USGS employees Deborah A. Bringman and Michael S. Brownley, who provided office and field technical support for this project, as well as Meghan N. Petenbrink and Alexander M. Soroka who provided significant help with data analysis and manuscript preparation, and Irene Fisher for her per- and polyfluorinated alkyl substances expertise. In addition, thank you to all the well owners and water managers who allowed access to their property to sample the wells for this study.

Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Pressure	
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
atmosphere, standard (atm)	760	millimeters of mercury (mmHg)

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

°F = (1.8 × °C) + 32.

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

°C = (°F – 32) / 1.8.

Datum

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

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

Supplemental Information

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

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or as part per trillion (ppt).

Abbreviations

DNREC	Delaware Department of Natural Resources and Environmental Control
EPA	U.S. Environmental Protection Agency
HAL	health advisory level
HBSL	health-based screening level
MCL	maximum contaminant level
NWIS	National Water Information System
PFAS	per- and polyfluorinated alkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
ppb	parts per billion
ppt	parts per trillion
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey

Occurrence and Distribution of PFAS in Sampled Source Water of Public Drinking-Water Supplies in the Surficial Aquifer in Delaware, 2018; PFAS and Groundwater Age-Dating Results

By Betzaida Reyes

Abstract

The U.S. Geological Survey, in cooperation with the Delaware Department of Natural Resources and Environmental Control and the Delaware Geological Survey, conducted a groundwater-quality investigation to (1) describe the occurrence and distribution of PFAS, and (2) document any changes in groundwater quality in the Columbia aquifer public water-supply wells in the Delaware Coastal Plain between 2000 and 2008 and between 2008 and 2018. Thirty public water-supply wells located throughout the Columbia aquifer of the Delaware Coastal Plain were sampled from August through November 2018. Groundwater collected from the wells was analyzed for the occurrence and distribution of 18 per- and polyfluorinated alkyl substances (PFAS) as well as groundwater age. Descriptive statistical analyses were performed to assess PFAS analytical results within the well network and the combined perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) concentrations were compared to the U.S. Environmental Protection Agency's (EPA) health advisory level (HAL) for informational purposes only and not for evidence of compliance or noncompliance with Federal regulations. The EPA's HAL is a health-based reference level for public drinking water as supplied to customers and is not applied to source (raw) water. Groundwater-age data were compared for sites sampled in 2000, 2008, and 2018 to document any changes.

All samples were analyzed for 18 PFAS using EPA Method 537 (modified). Forty-four percent of the analyzed PFAS were detected in the study well network. Sixteen of the sampled wells have one or more PFAS detections, and as many as eight different PFAS were found in a single sample. Wells with a higher number of PFAS detected (five or more) were in New Castle and Sussex Counties. The PFAS most frequently detected were PFOA, with 47 percent detection; perfluorohexanoic acid (PFHxA), with 33 percent detection; and PFOS and perfluorohexane sulfonate (PFHxS), with 27 percent detection each. PFAS concentrations were below 1,000 parts per trillion (ppt). Two wells exceeded the EPA's lifetime-drinking water health advisory level of 70 ppt for combined concentrations of PFOA and PFOS.

The average age of groundwater entering the screens of the supply wells sampled in 2018 ranged from 8.2 to 45.8 years, with a median groundwater age of 25.7 years. Groundwater age was positively correlated with well depth and negatively correlated with dissolved oxygen. Groundwater age and PFAS concentrations were negatively correlated in the Columbia aquifer. Data from the 23 resampled wells indicate a significant positive difference in the average modeled groundwater-sample-age results. The average groundwater age from samples collected in 2018 was generally 5 years older than the average groundwater age from samples collected in 2008. The same pattern was found during cycle two (2008) of this study, where the 2008 groundwater age was on average 7 years older than the samples collected in 2000. The distribution of groundwater sample ages among the 17 trend wells and during the three study cycles (2000, 2008, and 2018) indicates that sample-age medians were statistically different from zero; well-water sample-age data show a slight increase in groundwater sample age.

Introduction

Groundwater is the primary drinking water source in Delaware. Previous studies have documented the influence of human activities on the quality of this important resource through the detection of low concentrations (<1 microgram per liter [µg/L] or parts per billion [ppb]) of pesticides, volatile organic compounds, and other manmade chemicals in supply wells. These chemicals were detected in source waters of 30 Delaware public water-supply wells (fig. 1) sampled in previous monitoring studies completed in 2000 (Ferrari, 2002), 2008 (Reyes, 2010), and in this 2018 study. All 30 wells sampled are screened in the Columbia surficial aquifer (well-depth range was between 37 and 139 feet below land surface). Although concentrations of these organic compounds were generally low, all water samples had at least one compound detected, and most samples had multiple detections. These results demonstrate the influence of human activities on the quality of this important drinking water resource.

As part of the Source Water Assessment and Protection Program, which was created by Congress as part of the Safe Drinking-Water Act Amendments of 1996, State of Delaware officials have a continued interest in monitoring and in observing broad changes in the water quality of source waters since previous sampling events (2000 and 2008) detected low-level contamination in supply well samples. As part of this new sampling effort, per- and polyfluoroalkyl substances (PFAS) were included. PFAS, which are a large group of manmade chemicals that include perfluorooctanoic acid (PFOA), perfluorooctane sulfanate (PFOS), and hexafluoropropylene oxide dimer acid (HFPO-DA or Gen X), have come to the attention of researchers and risk managers because of their persistence, toxicity, and number of adverse effects in humans and laboratory animals (U.S. Environmental Protection Agency, 2018). Although there are many chemicals included in the PFAS group and the U.S. Environmental Protection Agency (EPA) has not established a maximum contaminant level (MCL) for all of them, the EPA did establish a lifetime drinking-water health advisory level (HAL) of 70 parts per trillion (ppt; or 0.07 ppb) for PFOA and PFOS in May 2016, as these have been the most extensively produced and studied PFAS (U.S. Environmental Protection Agency, 2016a). Both chemicals are potentially of concern to human health in the Coastal Plain aquifer and warrant continued study of their and other PFAS distribution in groundwater. Although combined concentrations of PFOA and PFOS were compared to the EPA's HAL, these comparisons were made for informational purposes and not for evidence of compliance or noncompliance with Federal regulations. The EPA HAL is a health-based reference level for public drinking water as supplied to customers and is not applied to source (raw) water. Groundwater-age data were collected as part of this study by averaging the laboratory sulfur hexafluoride (SF_6) ages estimated from each of two samples collected from each water-supply well and were compared for sites sampled in 2000, 2008, and 2018 to document any groundwater-age changes.

Description of Study Area

The study area falls entirely in the Delaware portion of the Atlantic Coastal Plain Physiographic Province and all wells sampled are screened in the Columbia aquifer (Benson and others, 1986; Reyes, 2010). The Columbia aquifer consists primarily of sands and gravels of fluvial and marginal marine origin and is an important drinking water resource in the Atlantic Coastal Plain of Delaware. Since the Columbia aquifer is largely unconfined, it is susceptible to contamination from spills, unmanaged wastes, and the application of agricultural chemicals on or near the land surface.

Agriculture is the predominant land use in Delaware with corn, soybeans, and small grains as the major crops. In 2017, approximately 37 percent of the available land area was used for farming (U.S. Department of Agriculture, 2017). Most of the agricultural activity in Delaware takes place in Kent and Sussex Counties and south of the Chesapeake and Delaware (C&D) Canal in New Castle County. The primary land uses surrounding this relatively shallow public-supply well network in the Coastal Plain of Delaware include agriculture, and low-density urban and suburban areas associated with small towns and communities (fig. 1).

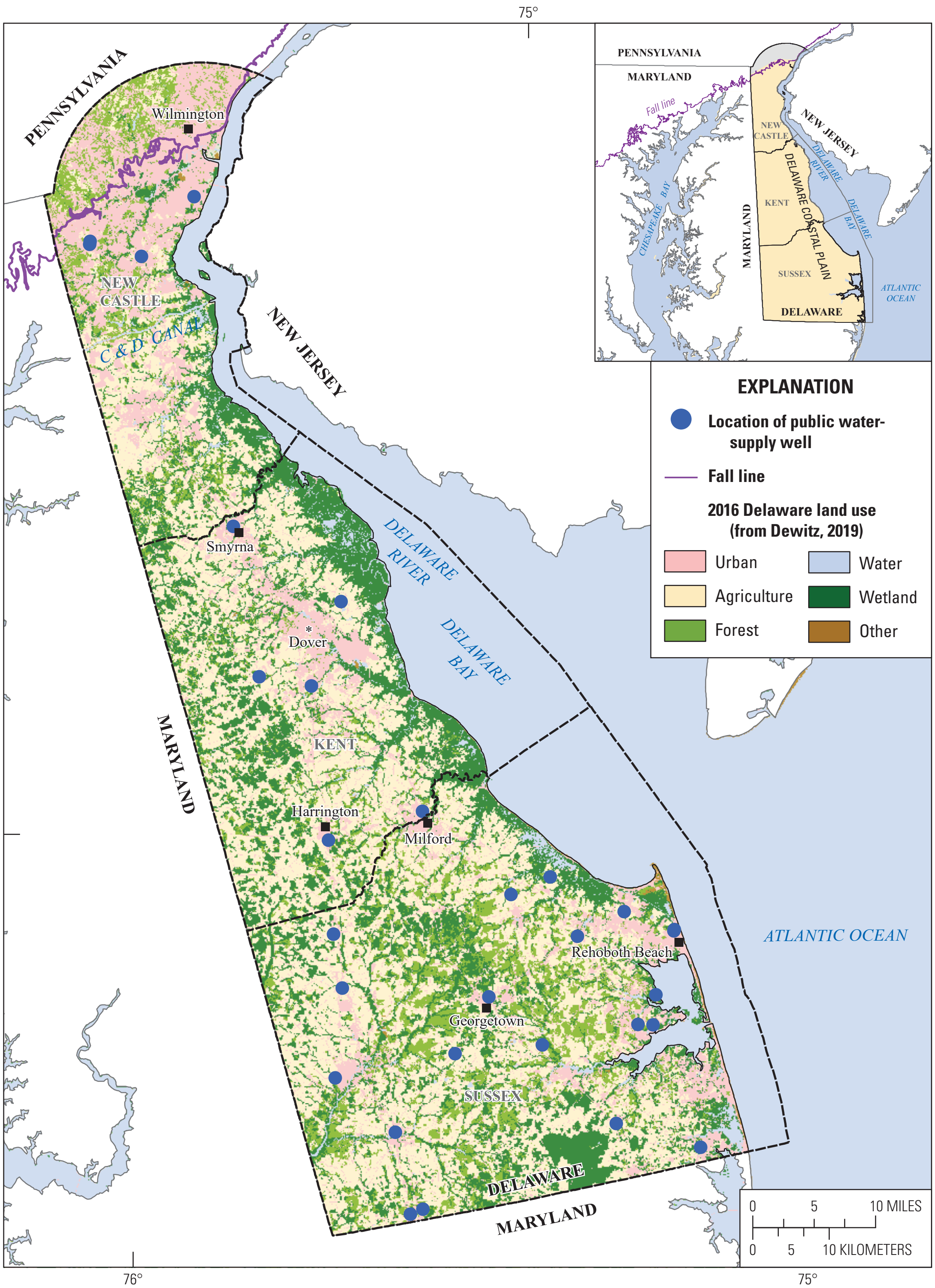
PFAS General Description

What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a large group (more than 4,000) of man-made, highly persistent chemicals that have been in use since the 1940s. PFAS are found in a wide range of consumer and industrial products such as cookware, pizza boxes, carpets, stain repellants, and firefighting foams, as well as other common products (fig. 2). PFAS are released into the air, soil, and water by PFAS manufacturing and processing facilities (such as metal plating operations), historical use in firefighting foams, and regular everyday use by consumers. Owing to their widespread use, persistence in the environment, and long half-lives, most people in the United States have been exposed to PFAS. There is evidence that because of their long half-lives and toxicity, continued exposure above threshold levels for specific PFAS may lead to adverse health effects (U.S. Environmental Protection Agency, 2016a; Agency for Toxic Substances and Disease Registry, 2018). PFOA and PFOS have been the most extensively produced and studied of these chemicals. Both chemicals are very persistent in the environment and human body, and can bioaccumulate in living organisms (U.S. Environmental Protection Agency, 2017).

There are a variety of ways in which people can be exposed to PFAS and at different levels of exposure, for instance

- Food ingestion and food packaging
- Daily exposure with commonly used items such as, but not limited to, carpets, cookware, rain gear, and so forth.
- Occupational exposure
- Drinking water



Base from U.S. Geological Survey digital data, 2016, 1:24,000 projected to
Albers Conical Equal Area, WGS 1984

Figure 1. Drinking-water wells distribution and Delaware land use.

Figure 2. Examples of products that use per- and polyfluoroalkyl substances (PFAS). Photographs from unsplash.com.

PFAS Effects on the Human Body

There is evidence that exposure to PFAS can lead to adverse health outcomes in humans or animals as they can accumulate within the body. Some studies have indicated that PFAS can cause reproductive, developmental, liver, kidney, and immunological adverse effects, as well as cancer and other health issues (U.S. Environmental Protection Agency, 2016c, 2017). The EPA established a drinking-water HAL of 70 ppt for combined concentrations of PFOA and PFOS (U.S. Environmental Protection Agency, 2016b). This HAL was established to provide information on the health risks of these chemicals and to allow for appropriate actions to protect consumers (U.S. Environmental Protection Agency, 2014). The State of Delaware adopted EPA's 2016 HAL for combined concentrations of PFOA and PFOS as screening values for hazardous substances in the Delaware Natural Resources and Environmental Control (DNREC) Remediation Section that same year (2016).

Study Methods

This study was developed to obtain information on the spatial occurrence and distribution of PFAS in the unconfined aquifer in the Delaware Coastal Plain. Source water samples collected for this purpose were analyzed for PFAS and gaseous SF_6 to determine groundwater ages.

Study Sampling Network

The study well network consisted of 30 drinking-water wells distributed throughout the State of Delaware and screened in the Columbia aquifer. Its purpose was to observe source groundwater quality across a network of previously sampled wells (Ferrari, 2002; Reyes, 2010), and identify and quantify the spatial and temporal changes in water quality in Delaware's Columbia aquifer public-drinking water-supply wells between 2000, 2008, and 2018. All groundwater samples were collected from the source water to supply wells prior to any filtering or treatment and are therefore representative of the available groundwater resource rather than drinking water. The network (fig. 1; table 1) of 30 wells was sampled from August to November 2018, and the samples were analyzed for 18 PFAS using the modified EPA Method 537 (U.S. Environmental Protection Agency, 2009; table 2) and groundwater age.

To the extent possible, the 2018 well network was the same as in fall of 2000 and 2008. In the event a previously sampled well was no longer in use, U.S. Geological Survey (USGS) personnel worked with DNREC personnel to identify a suitable replacement well. Replacement wells were selected based on the following DNREC established criteria: (1) well located within a 1-mile radius with similar well construction, (2) used as a public drinking-water supply, and (3) screened in the unconfined aquifer.

Sampling Collection and Analysis

Wells were sampled and analyzed for PFAS and groundwater age. Field parameters (appendix 1; table 1.1) including water temperature, specific conductance, pH, dissolved oxygen, and alkalinity were determined in the field following the protocols outlined in U.S. Geological Survey (variously dated). All groundwater samples were collected from the raw-sample tap prior to any filtering or treatment and are therefore representative of the available groundwater resource rather than drinking water. Wells were purged to remove standing water in the casing (generally three well volumes) before samples were collected. Purging continued until dissolved oxygen (±0.3 milligrams per liter [mg/L]), pH (±0.1 units), specific conductance (±3 percent), water temperature (±0.2 degrees Celsius [°C]), and turbidity (±10 percent) stabilized. Direct collection of PFAS water-quality samples from the spigot was collected into two 250-milliliter (mL) bottles or one 500-mL bottle using elbow-length gloves. Another subset of samples was collected into 1-liter bottles for dissolved gases and SF_6 analyses for groundwater age. Bottles were chilled to maintain a temperature of 4 °C during shipment to the laboratory.

PFAS analyses were performed by Maxxam Analytics, a subcontract lab from RTI Laboratories, Inc., following U.S. Environmental Protection Agency Method 537 for determination of selected perfluorinated alkyl acids in drinking water by solid phase extraction and liquid chromatography/tandem mass spectrometry protocol (U.S. Environmental Protection Agency, 2009). Concentrations of gaseous SF_6 were determined at the USGS Groundwater Dating Laboratory, Chlorofluorocarbon/Dissolved Gas Laboratory in Reston, Virginia, to determine groundwater age (Plummer and Busenberg, 1999; Plummer and Friedman, 1999; Plummer and Busenberg, 2000; Busenberg and others, 2001).

Data Analysis

Descriptive statistical analyses were used to assess PFAS analytical results within the well network. Combined PFOA and PFOS concentrations were compared to the EPA's HAL. This comparison was made for informational purposes only and not for evidence of compliance or noncompliance with Federal regulations because this health-based reference level is for public drinking water as supplied to customers and is not applied to source (raw) water.

Explanatory and nonparametric statistical tests were used to characterize water chemistry differences of groundwater-age data between the three sampling events (2000, 2008, and 2018), to identify changes in groundwater quality, and to identify patterns in groundwater chemistry during the new 10-year study period (2008 to 2018). Twenty-three of the wells

Table 1. Well-construction data for sampled public water-supply wells screened in the Columbia aquifer in Delaware and modeled ages of groundwater sampled during the 2000, 2008, and 2018 sampling periods.

[USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; DNREC, Delaware Natural Resources and Environmental Control; Equip. blank, a sample collected in which blank water is processed through the equipment used for environmental sample collections. It is similar to a field blank, but done in a controlled environment such as a laboratory; Resampled, 23 public water-supply wells sampled in 2008 and 2018; Resampled, trend, 17 public water-supply wells used as trend wells, sampled in 2000, 2008, and 2018; Replacement, 7 public water-supply wells sampled only in 2018; --, no data]

USGS site identification number	DGS local well number	Sampling periods	Well description	DNREC permit number	County	Year well con-struct-ed	Casing material	Depth of well (feet)	Diameter of well (inches)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Average age in 2000 (years)	Average age in 2008 (years)	Average age in 2018 (years)
394100075334501	Cd52-40	2018	Replacement	235991	New Castle	2011	Steel	80	12	58	76	--	--	13.0
393928075440202	Db11-27	2000, 2008, 2018	Resampled, trend	10004	New Castle	1956	Steel	66	10	41	62	8.5	7.3	15.0
393916075440802	Db11-28	2000, 2008, 2018	Resampled, trend	10003	New Castle	1956	Unknown	62	10	31	62	7.0	5.8	25.0
393739075394202	Dc31-15	2000, 2008, 2018	Resampled, trend	10434	New Castle	1960	Unknown	76	17	50	70	7.5	7.6	14.0
390538075325101	DE-KE 187731	2018	Replacement	187731	Kent	2002	Plastic	55	4	48	55	--	--	14.9
383101075141001	DE-SU 56105	2018	Replacement	56105	Sussex	1984	Plastic	128	12	88	128	--	--	34.2
391747075364202	Hc34-03	2000, 2008, 2018	Resampled, trend	10068	Kent	1948	Steel	100	16	80	95	13.0	18.0	22.5
391060075282801	Ie42-03	2000, 2008, 2018	Resampled, trend	85022	Kent	1991	Steel	70	16	49	64	12.0	16.4	18.6
390703075371801	Jc33-12	2018	Replacement	102056	Kent	1994	Plastic	79	8	59	79	--	--	45.8
385522075251802	Le55-09	2000, 2008, 2018	Resampled, trend	31756	Kent	1974	Steel	91	10	71	91	18.0	23.9	37.9
385448075341801	Md11-04	2000, 2008, 2018	Resampled, trend	65911	Kent	1986	Unknown	70	10	50	70	11.0	21.7	13.2
384818075354101	Nc25-37	2000, 2008, 2018	Resampled, trend	72714	Sussex	1988	Steel	63	12	40	63	15.0	18.1	27.1
384819075190101	Ng21-03	2000, 2008, 2018	Resampled, trend	71704	Sussex	1987	Plastic	111	4	91	111	20.5	25.2	28.1
384856075151101	Ng25-04	2000, 2008, 2018	Resampled, trend	97993	Sussex	1994	Plastic	139	8	99	139	18.5	33.7	38.6
384526075091601	Ni51-32	2000, 2008, 2018	Resampled, trend	55833	Sussex	1984	Plastic	139	16	85	135	21.0	27.1	26.4
384428075355701	Oc15-11	2000, 2008, 2018	Resampled, trend	10319	Sussex	1955	Unknown	119	12	100	119	13.0	25.0	28.2
384139075230101	Of42-01	2000, 2008, 2018	Resampled, trend	10325	Sussex	1948	Unknown	120	6	Unknown	120	19.5	26.7	32.4

Table 1. Well-construction data for sampled public water-supply wells screened in the Columbia aquifer in Delaware and modeled ages of groundwater sampled during the 2000, 2008, and 2018 sampling periods.—Continued

[USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; DNREC, Delaware Natural Resources and Environmental Control; Equip. blank, a sample collected in which blank water is processed through the equipment used for environmental sample collections. It is similar to a field blank, but done in a controlled environment such as a laboratory; Resampled, 23 public water-supply wells sampled in 2008 and 2018; Resampled, trend, 17 public water-supply wells used as trend wells, sampled in 2000, 2008, and 2018; Replacement, 7 public water-supply wells sampled only in 2018; --, no data]

USGS site identification number	DGS local well number	Sampling periods	Well description	DNREC permit number	County	Year well con-structed	Casing material	Depth of well (feet)	Diameter of well (inches)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Average age in 2000 (years)	Average age in 2008 (years)	Average age in 2018 (years)
384428075135501	Oh12-07	2008, 2018	Resampled	181528	Sussex	2001	Plastic	118	4	108	118	--	22.4	34.6
384322075051101	Oi25-18	2000, 2008, 2018	Resampled, trend	93955	Sussex	1993	Plastic	38	4	23	38	9.0	8.0	8.2
384326075050801	Oi25-19	2000, 2008, 2018	Resampled, trend	93496	Sussex	1992	Unknown	37	4	27	37	9.0	14.7	17.7
383823075382101	Pc22-06	2008, 2018	Resampled	74465	Sussex	1988	Steel	103	16	63	103	--	19.5	30.4
383815075271001	Pe23-185	2000, 2008, 2018	Resampled, trend	72060	Sussex	1987	Plastic	120	4	100	110	18.5	34.6	44.8
383732075191301	Pg31-12	2008, 2018	Resampled	35113	Sussex	1975	Plastic	73	12	53	73	--	16.1	20.7
383729075101601	Ph35-25	2008, 2018	Resampled	63104	Sussex	1986	Unknown	58	8	58	73	--	21.3	28.5
383914075080501	Pi12-11	2008, 2018	Resampled	75500	Sussex	1988	Plastic	68	4	58	68	--	18.1	16.1
383713075085501	Pi32-15	2008, 2018	Resampled	10653	Sussex	1972	Unknown	90	6	75	85	--	21.8	26.3
383346075340301	Qd21-42	2018	Replacement	79306	Sussex	1989	Steel	100	10	75	100	--	--	21.3
382805075330301	Rd22-01	2000, 2008, 2018	Resampled, trend	66041	Sussex	1986	Plastic	60	2	52	60	15.0	25.5	26.3
382755075341501	Rd31-24	2018	Replacement	10665	Sussex	1976	Plastic	98	4	79	89	--	--	24.4
382807075070701	Ri23-15	2018	Replacement	186732	Sussex	2002	Plastic	80	6	55	65	--	--	22.9
390918075291701	USGS Office at Dover, Delaware	2000, 2008, 2018	Observation, Equip. blank	Unknown	Kent	2000	Unknown	Unknown	Unknown	Unknown	Unknown	--	--	--

Table 2. Information for per- and polyfluorinated alkyl substances (PFAS) for which unfiltered groundwater samples from public water-supply wells were analyzed in the Columbia aquifer in Delaware in 2018 under the modified U.S. Environmental Protection Agency Method 537 (U.S. Environmental Protection Agency, 2009).

[NWIS, National Water Information System; ppt, parts per trillion; RDL, reportable detection limit; MDL, method detection limit]

PFAS name	PFAS abbreviation	NWIS parameter code	Parameter unit	RDL	MDL
6:2 Fluorotelomer sulfonate	6:2 FTS	53593	ppt	20	6.6
8:2 Fluorotelomer sulfonate	8:2 FTS	53594	ppt	20	6.6
Perfluorobutane sulfonate	PFBS	53588	ppt	20	5.4
Perfluorobutanoic acid	PFBA	53577	ppt	20	5.5
Perfluorodecane sulfonate	PFDS	53591	ppt	20	6
Perfluorodecanoic acid	PFDA	53583	ppt	20	6.1
Perfluorododecanoic acid	PFDoA	53585	ppt	20	5
Perfluoroheptanoic acid	PFHpA	53580	ppt	20	7.4
Perfluorohexane sulfonate	PFHxS	53589	ppt	20	5.6
Perfluorohexanoic acid	PFHxA	53579	ppt	20	3.5
Perfluorononanoic acid	PFNA	53582	ppt	20	8.7
Perfluorooctane sulfonamide	PFOSA	53592	ppt	20	3.4
Perfluorooctane sulfonate	PFOS	53590	ppt	20	6
Perfluorooctanoic acid	PFOA	53581	ppt	20	3.3
Perfluoropentanoic acid	PFPeA	53578	ppt	20	7.5
Perfluorotetradecanoic acid	PFTeDA	53587	ppt	20	2.7
Perfluorotridecanoic acid	PFTrDA	53586	ppt	20	3.8
Perfluoroundecanoic acid	PFUnA	53584	ppt	20	2.5

sampled in 2008 were available for resampling and used for comparison between the 2008 and 2018 samples. Of the 23 resampled wells, 17 wells were sampled in 2000, 2008, and 2018; these wells were used for statistical trend analysis. PFAS censored data (less than or undetected at the method detection limit; table 3) were set to nondetects before any analyses or ranks and in the figures. PFAS concentrations with E values indicated that PFAS concentrations were detected below the reporting detection limit but above the method detection limit, and these were set as detections. All statistical tests were evaluated at the 95-percent confidence level (a=0.05). The R statistical program (ver. 4.0.2) was used to perform all the statistical analyses. All water-chemistry data collected for this report are available through the National Water Information System (NWIS) web page (https://waterdata.usgs.gov/nwis/) and ScienceBase (Reyes, 2021).

Quality-Control Sampling

Quality-control samples including equipment and field blanks, sequential replicate samples, and laboratory spikes, were collected to evaluate and estimate potential contamination bias and measure variability from water-quality data-collection processes following protocols described in Koterba and others (1995). An equipment blank was collected prior to sampling; seven field blanks and three replicates for PFAS were collected during field activities at selected wells (Reyes, 2021); all 30 wells have replicate samples for SF_6 and dissolved gases for groundwater-age estimation. Field collection procedures for quality-control samples were established using the USGS National Field Manual (U.S. Geological Survey, variously dated) and in a manner consistent with procedures for the acquisition of environmental samples.

Equipment and field blanks were collected to estimate the accuracy of concentrations and to ensure that sample collection and processing did not result in contamination. No PFAS were detected in equipment or field blanks, indicating that selected equipment, cleaning, sampling, and handling procedures are sufficient to provide data that reflect environmental conditions.

Replicate field samples measure the combined precision of sampling and laboratory analysis procedures. All the replicate samples had results similar to or consistent (within a relative percent difference of 30 percent) with their respective environmental samples.

Spikes were analyzed to determine the extent of degradation of the analyte concentration during sample processing and analysis, recovery bias, and variability (Koterba and others,

Table 3. Concentrations and detections of per- and polyfluoroalkyl substances (PFAS) in sampled public water-supply wells in the Columbia Aquifer in Delaware, sampled in 2018 using the modified U.S. Environmental Protection Agency Method 537.

[PFAS descriptions and list of analytical compounds are provided in table 2. A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; ppt, parts per trillion; Environmental, groundwater sample from the public water-supply well; E, value is between method detection limit and reporting detection limit; <, less than, undetected at the method detection limit; HAL, EPA health advisory level for combined concentrations of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS); ND, nondetected PFAS]

			PFAS concentrations (ppt)																			
USGS site identification number	DGS local well number	Sample type	PFBA	PF-PeA	PF-HxA	PFH-pA	PFOA	PFNA	PFDA	PFU-nA	PF-DoA	PFTrDA	PFT-eDA	PFBS	PF-HxS	PFOS	PFDS	PFO-SA	6:2-FtS	8:2-FtS	Number of PFAS detect-ed per well	HAL (70 ppt)[a]
394100075334501	Cd52-40	Environmental	34	39	45	25	57[a]	<20	<20	<20	<20	<20	<20	<20	22	20[a]	<20	<20	<20	<20	7	77[a]
393928075440202	Db11-27	Environmental	E13	E14	E15	E12	23	<20	<20	<20	<20	<20	<20	E11	E9.4	<20	<20	<20	<20	<20	7	23
393916075440802	Db11-28	Environmental	E12	E16	E16	E12	22	<20	<20	<20	<20	<20	<20	<20	E9	E13	<20	<20	<20	<20	7	35
393739075394202	Dc31-15	Environmental	<20	<20	<20	<20	29	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	1	29
390538075325101	DE-KE 187731	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
383101075141001	DE-SU 56105	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
384139075230101	Georgetown 1	Environmental	E5.8	<20	E5.6	<20	E11	<20	<20	<20	<20	<20	<20	<20	E12	23	<20	<20	<20	<20	5	34
391747075364202	Hc34-03	Environmental	<20	<20	E5.5	<20	E9.7	<20	<20	<20	<20	<20	<20	E7.2	<20	E10	<20	<20	<20	<20	4	19.7
391060075282801	Ie42-03	Environmental	<20	<20	<20	<20	E5.9	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	1	5.9
390703075371801	Jc33-12	Environmental	<20	<20	E5	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	1	ND
385522075251802	Le55-09	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
385448075341801	Md11-04	Environmental	<7	<4.1	<6.4	<7.1	<7.4	<4.9	<4.1	<4.3	<6.8	<6.9	<6.7	<5.1	<5.2	<5.2	<7.2	<6.6	<5.9	<5.9	0	ND
384818075354101	Nc25-37	Environmental	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	0	ND
384819075190101	Ng21-03	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
384856075151101	Ng25-04	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
384526075091601	Ni51-32	Environmental	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	0	ND
384428075355701	Oc15-11	Environmental	<5.5	<7.5	<3.5	<7.4	E5.1	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	1	5.1
384428075135501	Oh12-07	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
384322075051101	Oi25-18	Environmental	20	67	44	E12	28	<20	<20	<20	<20	<20	<20	E15	E16	21	<20	<20	<20	<20	8	49
384326075050801	Oi25-19	Environmental	<20	<20	<20	<20	29	<20	<20	<20	<20	<20	<20	<20	32	21	<20	<20	<20	<20	3	50
383823075382101	Pc22-06	Environmental	<20	<20	E5.6	<20	E5.4	<20	<20	<20	<20	<20	<20	E5.5	<20	<20	<20	<20	<20	<20	3	5.4
383815075271001	Pe23-185	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	0	ND
383732075191301	Pg31-12	Environmental	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	0	ND
383729075101601	Ph35-25	Environmental	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	0	ND
383914075080501	Pi12-11	Environmental	<5.5	<7.5	<3.5	<7.4	<3.3	<8.7	<6.1	<2.5	<5	<3.8	<2.7	E7.1	<5.6	<6	<6	<3.4	<6.6	<6.6	1	ND
383713075085501	Pi32-15	Environmental	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	0	ND
383346075340301	Qd21-42	Environmental	<7	<4.1	<6.4	<7.1	<7.4	<4.9	<4.1	<4.3	<6.8	<6.9	<6.7	<5.1	<5.2	<5.2	<7.2	<6.6	<5.9	<5.9	0	ND

Table 3. Concentrations and detections of per- and polyfluoroalkyl substances (PFAS) in sampled public water-supply wells in the Columbia Aquifer in Delaware, sampled in 2018 using the modified U.S. Environmental Protection Agency Method 537.—Continued

[PFAS descriptions and list of analytical compounds are provided in table 2. A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; ppt, parts per trillion; Environmental, groundwater sample from the public water-supply well; E, value is between method detection limit and reporting detection limit; <, less than, undetected at the method detection limit; HAL, EPA health advisory level for combined concentrations of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS); ND, nondetected PFAS]

USGS site identification number	DGS local well number	Sample type	PFAS concentrations (ppt)																		Number of PFAS detected per well	HAL (70 ppt)[a]
			PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	PFOS	PFDS	PFOSA	6:2-FtS	8:2-FtS		
382805075330301	Rd22-01	Environmental	<5.5	<7.5	<3.5	<7.4	E6	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	<5.6	<6	<6	<3.4	<6.6	<6.6	1	6
382755075341501	Rd31-24	Environmental	<5.5	E8.5	E9.8	<7.4	E11	<8.7	<6.1	<2.5	<5	<3.8	<2.7	<5.4	E9.2	E18	<6	<3.4	<6.6	<6.6	5	29
382807075070701	Ri23-15	Environmental	E15	32	35	E17	40[a]	<8.7	<6.1	<2.5	<5	<3.8	<2.7	100	130	59[a]	<6	<3.4	<6.6	<6.6	8	99[a]
Number of wells with PFAS detections			6	6	10	5	14	0	0	0	0	0	0	6	8	8	0	0	0	0	16	2

[a]Detections are above the health advisory level.

1995). In this study, samples were spiked in the laboratory with a known quantity of PFAS. Spike data are available upon request from the USGS Maryland-Delaware-D.C. Water Science Center in Baltimore, Maryland, Water-Quality Data Section (https://www.usgs.gov/centers/md-de-dc-water/about).

PFAS Results

All 30 wells were analyzed for 18 PFAS using the modified EPA Method 537 (U.S. Environmental Protection Agency, 2009; table 2). More than half (16) of the sampled wells had one or more PFAS detections, and as many as eight PFAS were detected in two wells (Ri23-15 and Oi25-18; table 3). The spatial distribution of PFAS detections across Delaware is shown in figure 3. Wells with higher numbers of compounds detected (five or more) were located in New Castle and Sussex Counties. Forty-four percent of the analyzed PFAS (8 of 18) were detected in the study well network, with individual compound concentrations detected raging from E5.0 to 130 ppt. The four most frequently detected PFAS were PFOA with 47 percent detection, PFHxA with 33 percent detection, and PFOS and PFHxS with 27 percent detection each (table 3).

Most of the PFAS detections were in oxic environments (dissolved oxygen levels greater than or equal to 1 mg/L), although higher concentrations of PFAS compounds (greater than or equal to 100 ppt) were observed in low-oxygen environments (fig. 4).

Two wells (Cd52-40 in New Castle County and Ri23-15 in Sussex County), out of the 14 wells with combined PFOS and PFAS detections, were above the EPA drinking-water HAL of 70 ppt (fig. 5). Both wells are treated to remove PFAS from their system.

Groundwater Age Results

Water that infiltrates the landscape and percolates downward toward the water table becomes recharge to the aquifer system. As additional recharge continues to enter the aquifer, older recharge is pushed deeper by the newer recharge, resulting in a trend of increasing groundwater age with depth. Groundwater age represents the average age of water withdrawn from the well, as well screens typically span several feet of aquifer sediment, thus integrating waters of various ages. Dissolved-gas analyses also were performed on samples of each well as part of the age-dating analysis to determine the average recharge temperature of the water in the aquifer (appendix 2; table 2.1). Recharge dates for groundwater samples were estimated based on measured concentrations of SF_6, which is a common chemical refrigerant that has been released into the environment. The reported age in this study was calculated by averaging the laboratory SF_6 ages estimated from each of two samples collected from each well (appendix 3; table 3.1).

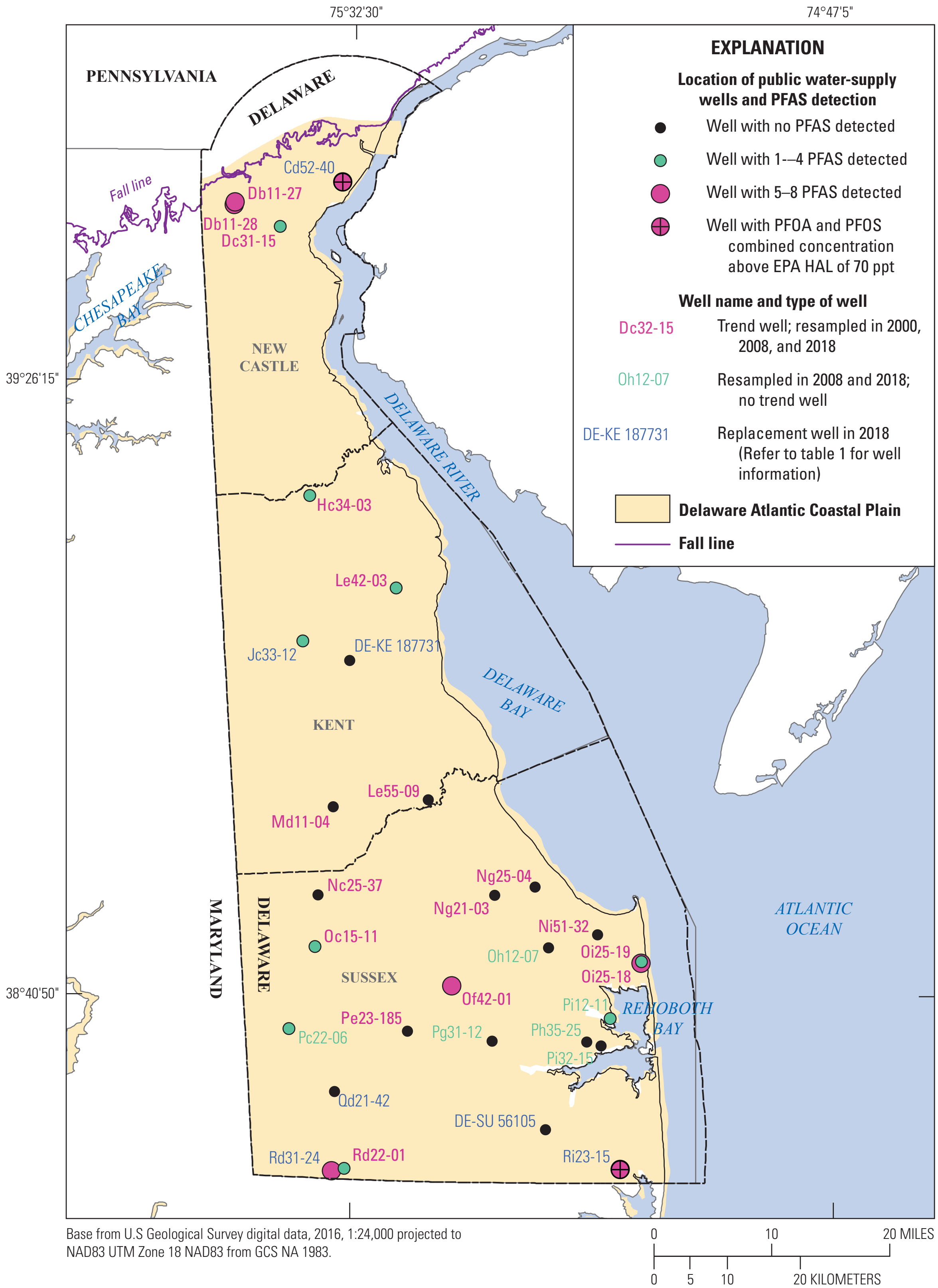


Figure 3. Location of public water-supply wells sampled in 2018 and per- and polyfluoroalkyl substances (PFAS) detection distribution in the Columbia aquifer in Delaware. EPA, U.S. Environmental Protection Agency; HAL, health advisory level; ppt, parts per trillion; PFOA, perfluorooctanoic acid; PFOS, perfluorooctane sulfonate.

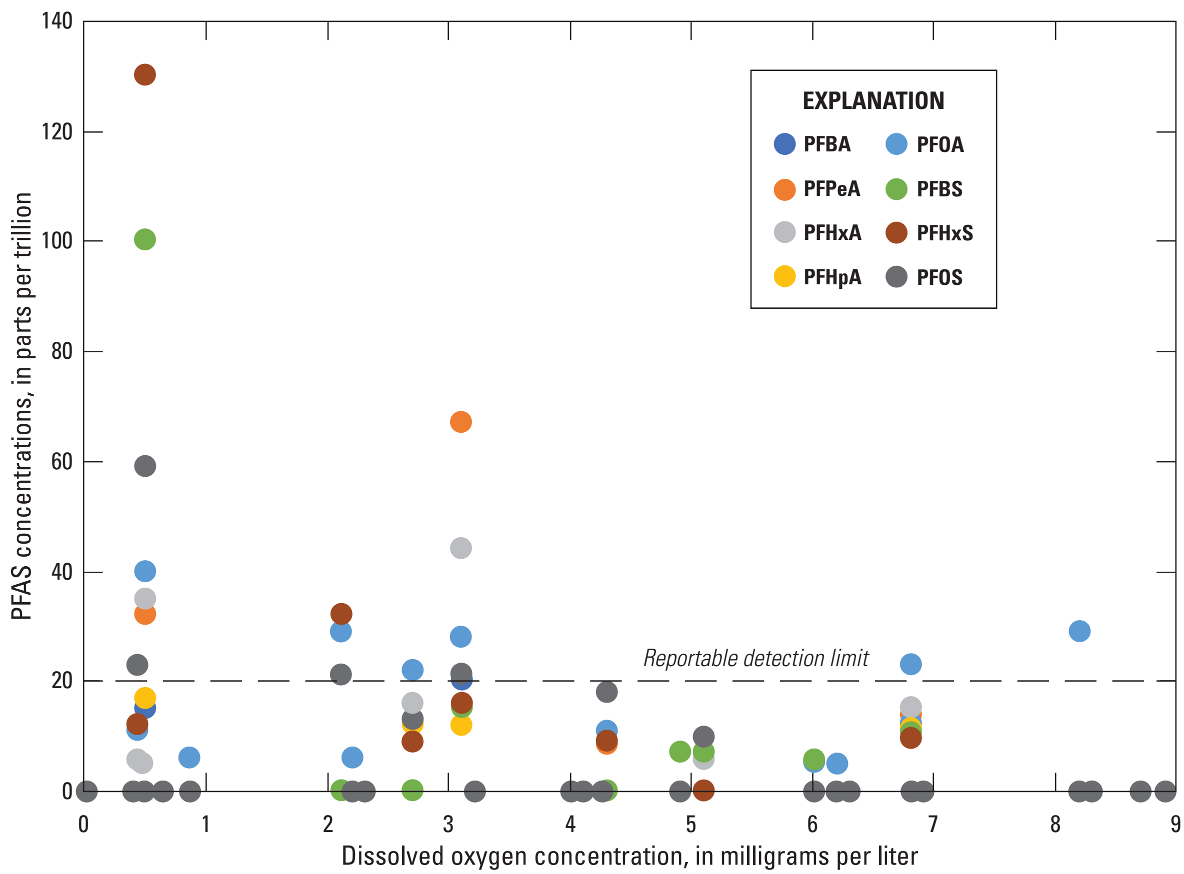


Figure 4. Distribution of per- and polyfluoroalkyl substances (PFAS) concentration by dissolved oxygen concentration in the Columbia aquifer, 2018. Refer to table 2 for PFAS descriptions and list of analytical compounds. Values plotted at 0 are nondetects, as discussed in the text.

The average groundwater age among the 30 wells sampled in 2018 ranged from 8.2 to 45.8 years, with a median of 25.7 years. Refer to table 1 for well-construction and groundwater-age data. The same relations from previous study years were observed; groundwater ages are positively correlated (R^2=0.6024, p-value<0.0004) with well depth (fig. 6*A*) and negatively correlated (R^2= –0.4293, p-value <0.018) with dissolved oxygen concentrations (fig. 6*B*) in the Columbia aquifer. The relation of groundwater-age data and total PFAS concentrations is shown in figure 7. This groundwater age-concentration relation supports the fact that PFAS are as result of anthropogenic activities and that these contaminants are relatively novel.

Comparison of the average modeled groundwater sample-age data (fig. 8*A*) from the 23 wells sampled in 2018 indicates that the average groundwater age was significantly different than the 2008 sample-age data; 2018 sample ages were, on average, 5 years older than 2008 sample ages. A similar pattern was found during cycle two (2008) of this study, where the 2008 average modeled groundwater age was, on average, 7 years older than the samples collected in 2000. The distribution of the groundwater sample ages among the 17 trend wells and during the three study cycles (fig. 8*B*) indicates that sample-age medians were statistically different than zero (p-value<0.00124). Well-water sample-age data show a slight increase in groundwater sample age. Groundwater age represents a mixture of older and young groundwater because well screens in public-supply wells are relatively long and pumping enhances the mixing of waters of disparate groundwater ages (Dunkle and others, 1993). The specific reason for the differences in groundwater ages is unknown, although Gholam and others (2006) indicated that this age difference could reflect a higher proportion of water drawn from slow-moving storage, possibly as a result of pumping for long periods of time, or a pumping increase that caused more water from older, deeper, or more distant sources to be drawn into the well.

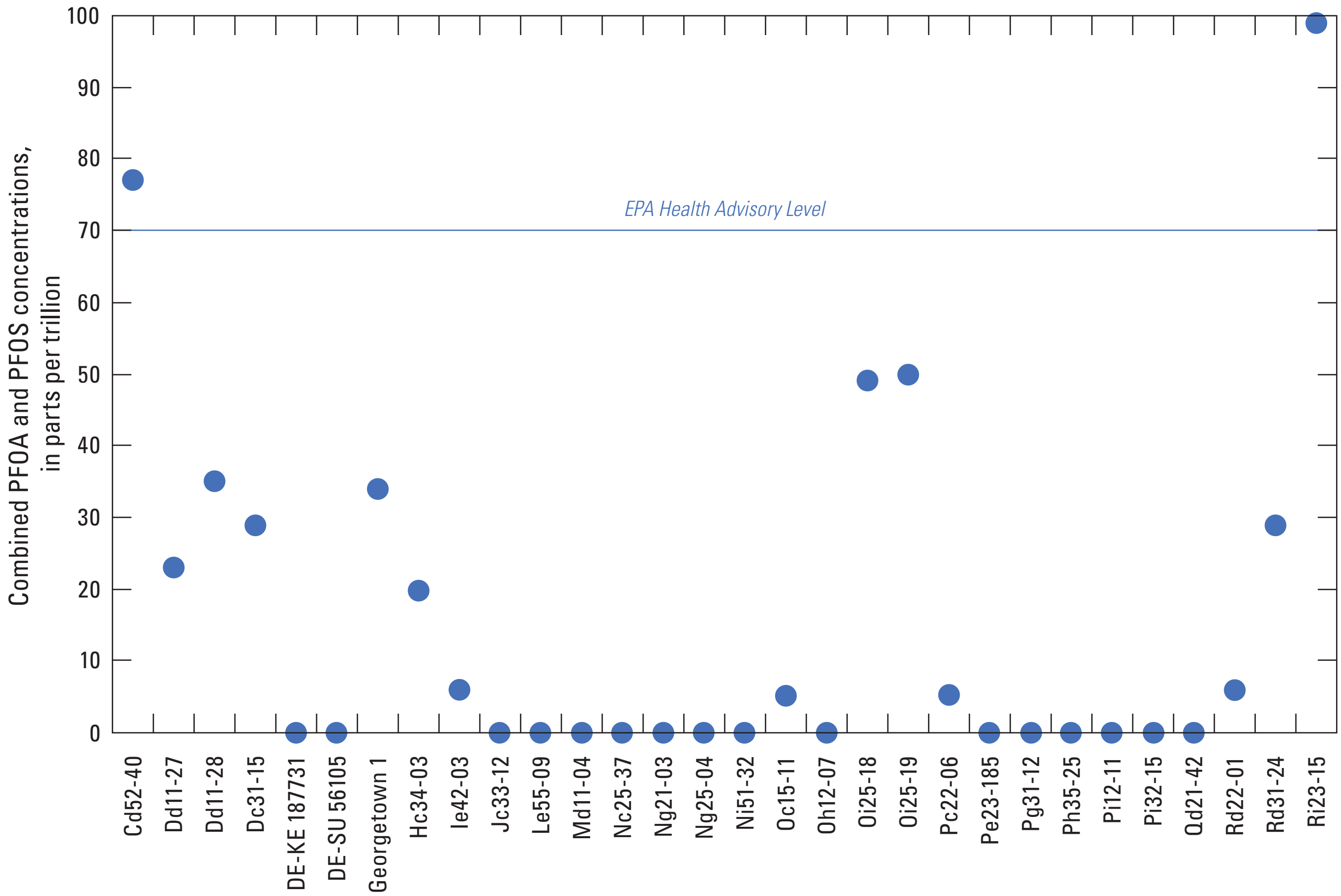


Figure 5. Comparison between combined concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) and the U.S. Environmental Protection Agency (EPA) drinking water health advisory level. Values plotted at 0 are nondetects, as discussed in the text.

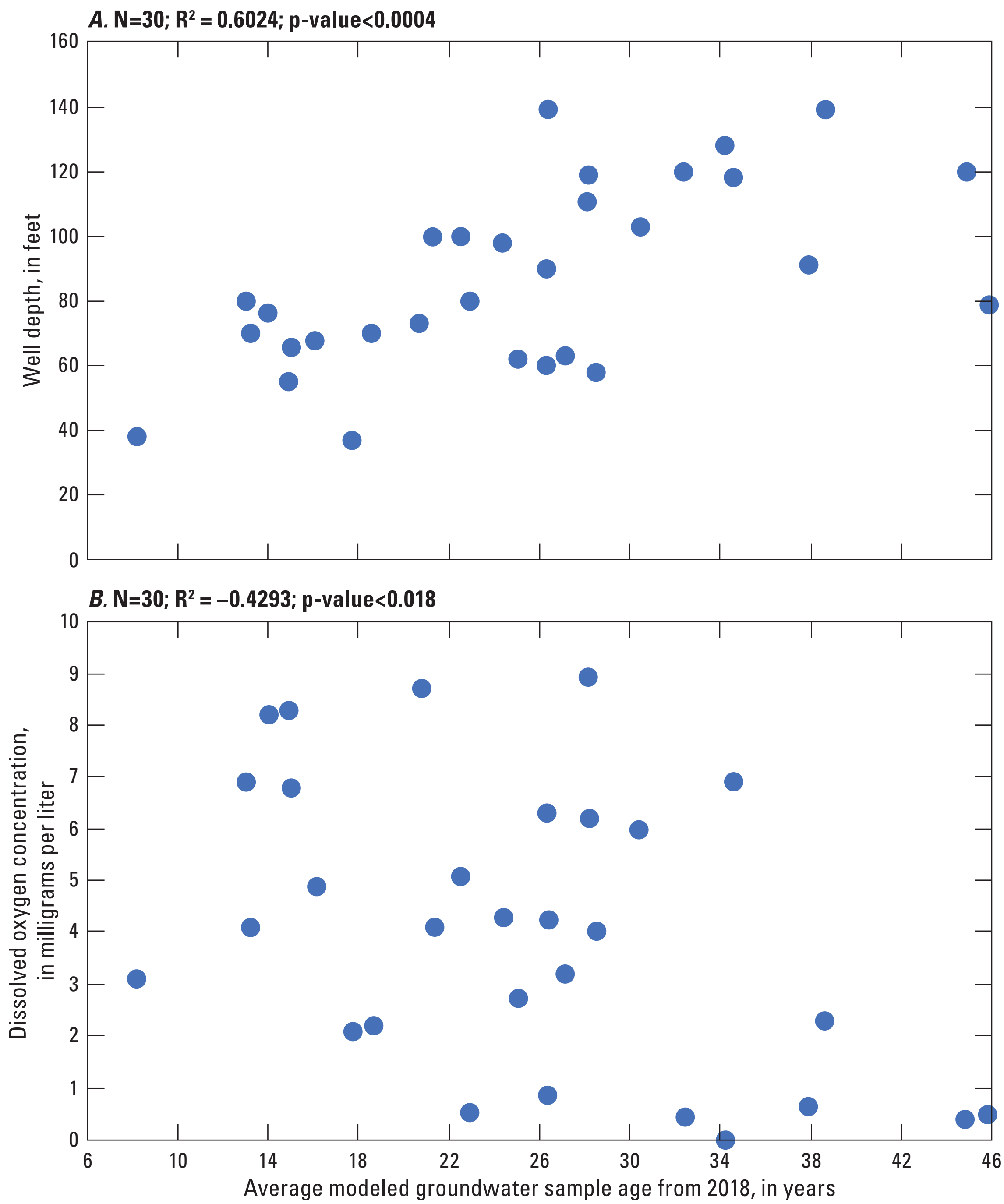


Figure 6. Relation of average modeled groundwater sample age to *(A)* well depth, and *(B)* dissolved oxygen concentrations in the Columbia aquifer in Delaware, 2018.

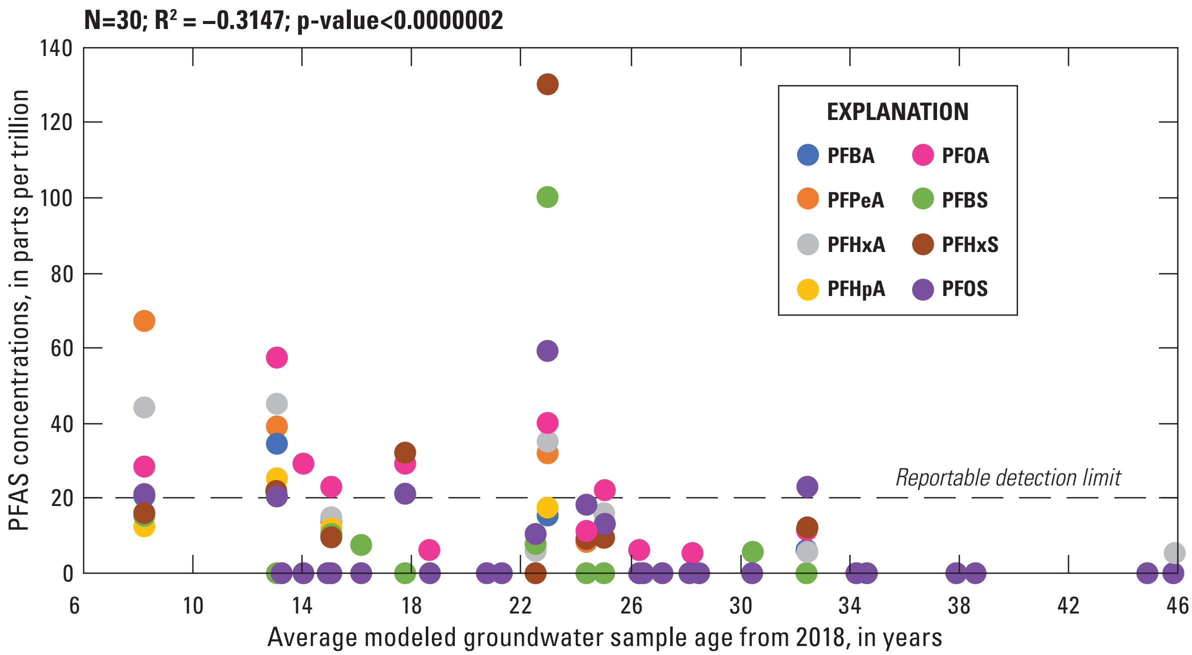


Figure 7. Relation of average modeled groundwater sample age to per- and polyfluoroalkyl substances (PFAS) concentrations in the Columbia aquifer in Delaware, 2018. Refer to table 2 for PFAS descriptions and list of analytical compounds. Values plotted at 0 are nondetects, as discussed in the text.

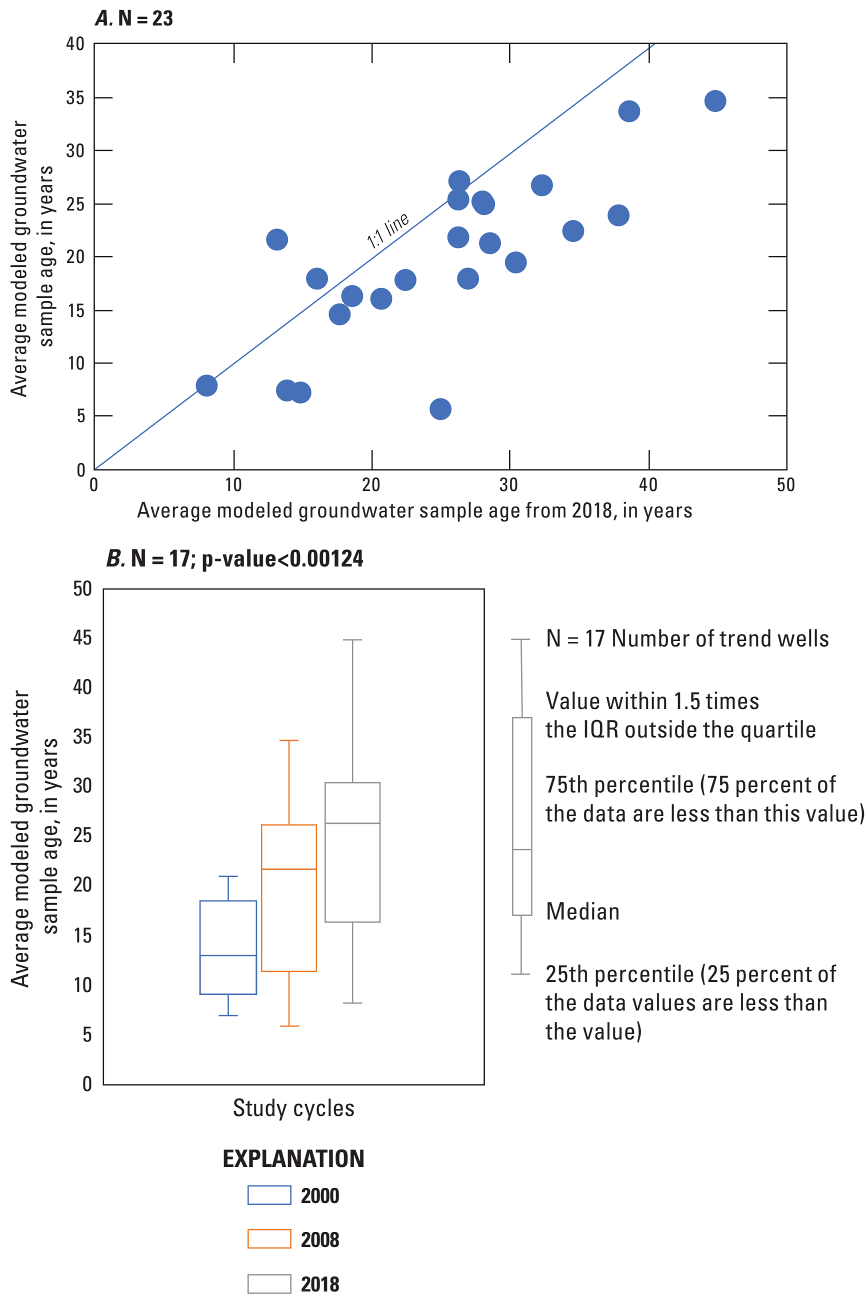


Figure 8. Average modeled groundwater sample age *(A)* comparison over the 10-year study period from the 23 sampled wells in the Columbia aquifer in Delaware between 2008 and 2018, and *(B)* distribution over the three sampling cycles in the Columbia aquifer in Delaware, 2000, 2008, and 2018. IQR, interquartile range.

Summary

This study's results mark a baseline for per- and polyfluorinated alkyl substances (PFAS) concentration in the Columbia aquifer. Many findings from this study suggest the need to continue active monitoring for these anthropogenic contaminants. There was a widespread distribution of PFAS detections throughout Delaware, as well as a significant number of detections per wells and the variety of compounds detected, including the higher concentrations and high number of detections in younger waters and the results of the U.S. Environmental Protection Agency's health advisory level exceedances for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) in source water samples. These findings show the susceptibility of this aquifer for these and other anthropogenic contaminants which may significantly affect the drinking water sources in the Columbia aquifer as a result of the aquifer's characteristics (surficial aquifer; good soil drainage; and sandy, transmissive aquifer sediments) and the persistence of these compounds. Comparison of the average modeled groundwater ages indicates that the 2018 samples were significantly older than the 2008 and 2000 samples. Among the resampled wells, the average groundwater age difference was 7 years from 2000 to 2008 and 5 years from 2008 to 2018.

References Cited

Agency for Toxic Substances and Disease Registry, 2018, Toxicological profile for perfluoroalkyls (Draft for public comment): U.S. Department of Health and Human Services, Public Health Service web page, accessed January 2020 at https://www.atsdr.cdc.gov/.

Benson, R.N., Andres, A.S., Roberts, J.H., and Woodruff, K.D., 1986, Seismic stratigraphy along three multichannel seismic reflection profiles off Delaware's coast: Delaware Geological Survey Miscellaneous Map No. 4, with discussion, 1 sheet.

Busenberg, E., Plummer, L.N., and Bartholomey, R.C., 2001, Estimated age and source of the young fraction of ground water at the Idaho National Engineering and Environmental Laboratory: U.S. Geological Survey Water-Resources Investigations Report 01-4265, 145 p.

Dewitz, J., 2019, National land cover database (NLCD) 2016 products (ver. 2.0, July 2020): U.S. Geological Survey data release, accessed January 2019 at https://doi.org/10.5066/P96HHBIE.

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 (CCl3 F and CCl2 F2) as dating tools and hydrologic tracers in shallow groundwater of the Delmarva Peninsula, Atlantic Coastal Plain, United States: Water Resources Research, v. 29, no. 12, p. 3837–3860, accessed May 2019 at https://doi.org/10.1029/93WR02073.

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, 62 p., accessed January 2019 at https://pubs.usgs.gov/of/2001/ofr01-327/pdf/ofr-01-327.pdf.

Gholam, A., Kazemi, G.A., Lehr, J.H., and Perrochet, P., 2006, Groundwater age: Hoboken, New Jersey, John Wiley & Sons, Inc., 325 p.

Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95-399, 113 p., accessed January 2019 at https://doi.org/10.3133/ofr95399.

Plummer, L.N., and Busenberg, E., 1999, Chlorofluorocarbons—Tools for dating and tracing young groundwater, chap. 15 *of* Cook, P., and Herczeg, A., eds., Environmental tracers in subsurface hydrology: Boston, Kluwer Academic Publishers, p. 441–478.

Plummer, L.N., and Busenberg, E., 2000, Data on the crystal growth of calcite from calcium bicarbonate solutions at 34 degrees C and CO_2 partial pressures of 0.101, 0.0156, and 0.00102 atmospheres: U.S. Geological Survey Open-File Report 99-247, 13 p.

Plummer, L.N., and Friedman, L.C., 1999, Tracing and dating young ground water: U.S. Geological Survey Fact Sheet 134-99, 4 p., accessed March 31, 2010, at https://pubs.usgs.gov/fs/FS-134-99/pdf/fs-134-99.pdf.

Reyes, B., 2010, Occurrence and distribution of organic chemicals and nutrients and comparison of water-quality data from public drinking-water supplies in the Columbia aquifer in Delaware, 2000–08: U.S. Geological Survey Scientific Investigations Report 2010-5206, 64 p., accessed January 2019 at https://doi.org/10.3133/sir20105206.

Reyes, B., 2021, Data in support of the occurrence and distribution of per- and polyfluoroalkyl substances in sampled source water of public drinking-water supplies in the surficial aquifer in Delaware, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9T0IA3Z.

U.S. Department of Agriculture, 2017 Census of Agriculture—State data: National Agricultural Statistics Service web page, accessed March 31, 2019, at https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_US_State_Level/st99_2_0001_0001.pdf.

U.S. Environmental Protection Agency, 2009, Method 537 determination of selected perfluorinated alkyl acids in drinking water by solid phase extraction and liquid chromatography/tandem mass spectrometry (LC/MS/MS) (ver. 1.1): U.S. Environmental Protection Agency, Office of Research and Development, EPA/600/R-08/092, 50 p., accessed June 2018 at https://www.well-labs.com/docs/epa_method_537_2009.pdf.

U.S. Environmental Protection Agency, 2014, External peer review of EPA's draft health effects documents for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS): Regulations.gov web page, accessed January 2020 at https://www.regulations.gov/document?D=EPA-HQ-OW-2014-0138-0027.

U.S. Environmental Protection Agency, 2016a, Drinking water health advisory for perfluorooctanoic acid (PFOA): U.S. Environmental Protection Agency Office of Water, EPA 822-R-16-005, May 2016, 103 p., accessed January 2020 at https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final-plain.pdf.

U.S. Environmental Protection Agency, 2016b, Groundwater and drinking water, drinking water health advisories for PFOA and PFOS, October 16, 2020: U.S. Environmental Protection Agency web page, accessed January 2020 at https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos.

U.S. Environmental Protection Agency, 2016c, Health effects support document for perfluorooctanoic acid (PFOA): U.S. Environmental Protection Agency Office of Water, EPA 822-R16-003, May 2016, 322 p., accessed January 2020 at https://www.epa.gov/sites/production/files/2016-05/documents/pfoa_hesd_final-plain.pdf.

U.S. Environmental Protection Agency, 2017, Technical fact sheet—Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), November 2017: U.S. Environmental Protection Agency web page, 8 p., accessed January 2020 at https://www.epa.gov/sites/production/files/2017-12/documents/ffrrofactsheet_contaminants_pfos_pfoa_11-20-17_508_0.pdf.

U.S. Environmental Protection Agency, 2018, Basic information on PFAS: U.S. Environmental Protection Agency web page, accessed November 2020 at https://www.epa.gov/pfas/basic-information-pfas#tab-3.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, accessed May 2019 at https://water.usgs.gov/owq/FieldManual/.

Glossary

H

health advisory level (HAL): A nonregulatory health-based reference level of chemical traces (usually in parts per million) in drinking water at which there are no adverse health risks when ingested over certain periods of time. Levels are established for 1 day, 10 days, long-term, and lifetime exposure periods. They contain a wide margin of safety and are set forth by the U.S. Environmental Protection Agency (EPA).

M

maximum contaminant level (MCL): As used in this report, an EPA drinking-water standard that is legally enforceable, and that sets the maximum permissible level of a contaminant in water that is delivered to any user of a public water system, at which no known or anticipated adverse effect on the health of persons occurs, and which allows an adequate margin of safety.

S

secondary maximum contaminant level (SMCL): As used in this report, an EPA secondary drinking-water standard, and non-enforceable guidelines regulating contaminants that may cause cosmetic or aesthetic effects (such as taste, odor, or color) in drinking water. The EPA recommends secondary standards for water systems but does not require compliance. However, states may choose to adopt them as enforceable standards.

source water: Is the raw (ambient) water collected at the supply well prior to water treatment. Following water treatment, source water is finished or drinking water.

Appendix 1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Field parameters.

Table 1.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Field parameters.

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; °C, degrees Celsius; mm Hg, millimeters of mercury; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 °C; pH is given in standard units; $CaCO_3$, calcium carbonate; --, no data]

		Field parameters						
USGS site identification number	DGS local well number	Water temperature (°C)	Air temperature (°C)	Air pressure (mm Hg)	Specific conductance, field (µS/cm)	Dissolved oxygen (mg/L)	pH (field, standard units)	Alkalinity (mg/L as $CaCO_3$)
394100075334501	Cd52-40	15.6	26	--	394	6.9	5.54	19.5
393928075440202	Db11-27	14.8	11.5	775.8	389	6.8	5.41	15.5
393916075440802	Db11-28	17.9	12.5	773	637	2.7	5.46	23
393739075394202	Dc31-15	14.8	29	769	381	8.2	5.54	--
390538075325101	DE-KE 187731	12.9	11	766.8	191	8.3	5.575	10.9
383101075141001	DE-SU 56105	15.25	2	776	268	0.01	5.77	21
384139075230101	Georgetown 1	17.4	32	768	533	0.42	5.14	17.7
391747075364202	Hc34-03	16	24	772	250	5.1	5.45	10.4
391060075282801	Ie42-03	15.9	26.5	767	192	2.2	5.555	11.4
390703075371801	Jc33-12	14.9	12.5	767.5	258	0.48	7.045	125.7
385522075251802	Le55-09	14.3	7	767	266	0.63	5.685	10.9
385448075341801	Md11-04	17.6	29	--	333	4.1	5.77	19.5
384818075354101	Nc25-37	17.3	29	761.5	175	3.2	5.46	6.8
384819075190101	Ng21-03	15.6	19.5	765.5	197	8.9	6.87	3.1
384856075151101	Ng25-04	14.3	--	765.5	119	2.3	6.045	6.2
384526075091601	Ni51-32	16.64	28.5	768.5	187	4.24	5.48	9.6
384428075355701	Oc15-11	15.9	22	767.2	201	6.2	5.295	7.8
384428075135501	Oh12-07	13.9	--	767.6	121	6.9	5.52	6.2
384322075051101	Oi25-18	16.1	22.5	769	245	3.1	5.61	24.1
384326075050801	Oi25-19	15.1	21	763	292	2.1	5.47	18.9
383823075382101	Pc22-06	17.02	31	769.8	191	6	4.57	0
383815075271001	Pe23-185	15.8	14	764	89.5	0.4	5.995	38.7
383732075191301	Pg31-12	16.9	29	770	125	8.7	5.19	8.3
383729075101601	Ph35-25	15.8	26	768.9	92	4	5.55	8.1
383914075080501	Pi12-11	14.6	11.1	767	155	4.9	5.5	8.6
383713075085501	Pi32-15	15.6	24	768.9	162	6.3	5.44	9.2
383346075340301	Qd21-42	16	14.5	771.5	128	4.1	5.04	4.4
382805075330301	Rd22-01	15.5	9	769.4	113	0.85	5.5	22.3
382755075341501	Rd31-24	14.3	4	--	143	4.3	5.375	14
382807075070701	Ri23-15	15.425	7	--	130	0.49	5.86	25.6

Appendix 2. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating, dissolved-gas data.

Table 2.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating, dissolved-gas data.

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; °C, degrees Celsius; mg/L, milligrams per liter; CH_4, methane; CO_2, carbon dioxide; N_2, nitrogen; O_2, oxygen; Ar, argon]

					Dissolved-gas data									
					Concentration (mg/L)					Partial pressures at field temperatures (atmospheres)				
USGS site identification number	DGS local well numbe	Sampling date (MM/DD/YYYY)	Field temperature (°C)	Recharge elevation (feet)	CH_4	CO_2	N_2	O_2	Ar	CH_4	CO_2	N_2	O_2	Ar
394100075334501	Cd52-40	9/26/2018	16.65	31	52.8474	19.5414	3.6531	0.6791	3.6531	0.000000	0.027771	0.9460	0.0771	0.01048
394100075334501	Cd52-40	9/26/2018	16.65	31	55.2778	19.4356	3.7599	0.6767	3.7599	0.000000	0.029048	0.9409	0.0794	0.01044
393928075440202	Db11-27	10/18/2018	14.80	79	68.8482	19.4053	3.5948	0.6840	3.5948	0.000000	0.034145	0.9080	0.0731	0.01017
393928075440202	Db11-27	10/18/2018	14.80	79	69.3144	19.4602	3.7539	0.6861	3.7539	0.000000	0.034376	0.9105	0.0764	0.01020
393916075440802	Db11-28	10/18/2018	17.80	71	91.8770	20.5688	1.5426	0.7056	1.5426	0.000184	0.050008	1.0163	0.0333	0.01113
393916075440802	Db11-28	10/18/2018	17.80	71	87.5226	20.2808	1.0831	0.6978	1.0831	0.000167	0.047638	1.0021	0.0234	0.01101
393739075394202	Dc31-15	9/26/2018	14.85	69	47.7767	17.7711	5.6729	0.6491	5.6729	0.000000	0.023732	0.8323	0.1155	0.00966
393739075394202	Dc31-15	9/26/2018	14.85	69	46.3701	17.7760	5.7130	0.6493	5.7130	0.000000	0.023034	0.8325	0.1163	0.00966
390538075325101	DE-KE 187731	11/19/2018	12.40	38	22.0549	18.3485	1.1274	0.6611	1.1274	0.000000	0.010122	0.8196	0.0218	0.00934
390538075325101	DE-KE 187731	11/19/2018	12.40	38	25.5813	18.2641	0.8505	0.6565	0.8505	0.000000	0.011740	0.8158	0.0164	0.00928
383101075141001	DE-SU 56105	12/11/2018	15.20	45	51.9034	24.0309	0.2993	0.6773	0.2993	0.008374	0.026069	1.1328	0.0061	0.01015
383101075141001	DE-SU 56105	12/11/2018	15.20	45	52.7459	24.1872	0.2713	0.6780	0.2713	0.008541	0.026492	1.1402	0.0056	0.01016
384139075230101	Georgetown 1	8/29/2018	17.40	100	168.7824	21.2382	0.2148	0.6858	0.2148	0.000354	0.090758	1.0420	0.0046	0.01074
384139075230101	Georgetown 1	8/29/2018	17.40	100	163.6883	21.0437	0.2231	0.6827	0.2231	0.000337	0.088018	1.0325	0.0048	0.01069
391747075364202	Hc34-03	9/25/2018	15.76	47	38.5056	21.5703	0.2418	0.6648	0.2418	0.000000	0.019683	1.0275	0.0050	0.01008
391747075364202	Hc34-03	9/25/2018	15.76	47	39.8315	21.7603	0.2152	0.6684	0.2152	0.000000	0.020361	1.0365	0.0045	0.01013
391060075282801	Ie42-03	8/15/2018	15.90	100	44.7366	20.6919	0.2708	0.6684	0.2708	0.005749	0.022968	0.9881	0.0056	0.01016
391060075282801	Ie42-03	8/15/2018	15.90	100	47.2036	20.2884	0.2280	0.6564	0.2280	0.005469	0.024235	0.9689	0.0047	0.00998
390703075371801	Jc33-12	10/17/2018	14.90	65	3.6587	23.4469	0.3115	0.8119	0.3115	0.000247	0.001820	1.0991	0.0063	0.01209
390703075371801	Jc33-12	10/17/2018	14.90	65	3.4303	23.7118	0.3039	0.8183	0.3039	0.000247	0.001707	1.1115	0.0062	0.01219
385522075251802	Le55-09	11/14/2018	14.30	25	22.1631	23.5053	0.2382	0.6907	0.2382	0.000786	0.010818	1.0894	0.0048	0.01016
385522075251802	Le55-09	11/14/2018	14.30	25	25.2027	23.4349	0.2300	0.6897	0.2300	0.000741	0.012302	1.0862	0.0046	0.01015
385448075341801	Md11-04	9/6/2018	17.60	100	70.9495	19.5759	0.2325	0.6915	0.2325	0.000000	0.038384	0.9639	0.0050	0.01087
385448075341801	Md11-04	9/6/2018	17.60	100	69.9906	19.4861	1.6293	0.6916	1.6293	0.000000	0.037865	0.9595	0.0350	0.01087
384818075354101	Nc25-37	8/22/2018	17.30	100	64.0824	21.8024	2.1495	0.7288	2.1495	0.000000	0.034353	1.0678	0.0460	0.01139
384818075354101	Nc25-37	8/22/2018	17.30	100	65.6991	21.8657	1.5268	0.7300	1.5268	0.000000	0.035220	1.0709	0.0327	0.01141
384819075190101	Ng21-03	11/1/2018	15.40	19	8.9095	18.8242	0.2538	0.6807	0.2538	0.000000	0.004503	0.8907	0.0052	0.01024
384819075190101	Ng21-03	11/1/2018	15.40	19	0.0000	9.4851	19.5802	0.2304	0.6814	0.000000	0.004794	0.9265	0.0047	0.01025
384856075151101	Ng25-04	11/1/2018	14.20	9	0.0020	19.6182	22.5871	0.3021	0.7716	0.000072	0.009545	1.0449	0.0061	0.01133
384856075151101	Ng25-04	11/1/2018	14.20	9	0.0021	18.4492	22.6336	0.3042	0.7767	0.000075	0.008976	1.0471	0.0061	0.01140
384526075091601	Ni51-32	8/21/2018	16.64	100	0.0000	35.2573	19.2657	1.8738	0.6591	0.000000	0.018522	0.9325	0.0396	0.01017
384526075091601	Ni51-32	8/21/2018	16.64	100	0.0006	38.1656	20.0639	2.7172	0.6844	0.000024	0.020050	0.9711	0.0574	0.01056

Table 2.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating, dissolved-gas data.

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; °C, degrees Celsius; mg/L, milligrams per liter; CH_4, methane; CO_2, carbon dioxide; N_2, nitrogen; O_2, oxygen; Ar, argon]

					Dissolved-gas data									
					Concentration (mg/L)					Partial pressures at field temperatures (atmospheres)				
USGS site identification number	DGS local well numbe	Sampling date (MM/DD/YYYY)	Field temperature (°C)	Recharge elevation (feet)	CH_4	CO_2	N_2	O_2	Ar	CH_4	CO_2	N_2	O_2	Ar
384428075355701	Oc15-11	9/10/2018	15.90	100	0.0000	49.4550	21.0576	3.7781	0.7356	0.000000	0.025391	1.0056	0.0786	0.01118
384428075355701	Oc15-11	9/10/2018	15.90	100	0.0000	52.5790	21.0302	4.6456	0.7362	0.000000	0.026995	1.0043	0.0966	0.01119
384428075135501	Oh12-07	10/31/2018	13.90	11	0.0000	12.3962	20.0780	2.4075	0.7103	0.000000	0.005974	0.9235	0.0481	0.01036
384428075135501	Oh12-07	10/31/2018	13.90	11	0.0000	11.8774	20.2001	2.0207	0.7150	0.000000	0.005724	0.9291	0.0403	0.01043
384322075051101	Oi25-18	9/27/2018	16.10	14	0.0005	66.6818	18.5353	0.6754	0.6599	0.000019	0.034449	0.8884	0.0141	0.01007
384322075051101	Oi25-18	9/27/2018	16.10	14	0.0006	60.1163	18.6686	0.2564	0.6603	0.000021	0.031057	0.8948	0.0054	0.01008
384326075050801	Oi25-19	9/27/2018	15.05	16	0.0005	69.1981	20.2120	0.2518	0.6969	0.000017	0.034591	0.9502	0.0051	0.01041
384326075050801	Oi25-19	9/27/2018	15.05	16	0.0009	67.4162	20.4884	0.2444	0.6925	0.000033	0.033701	0.9631	0.0050	0.01035
383823075382101	Pc22-06	8/16/2018	17.00	100	0.0000	26.4196	22.7365	5.3385	0.7136	0.000000	0.014034	1.1076	0.1135	0.01109
383823075382101	Pc22-06	8/16/2018	17.00	100	0.0000	29.6218	22.4266	5.4670	0.7090	0.000000	0.015735	1.0925	0.1162	0.01101
383815075271001	Pe23-185	10/29/2018	15.80	45	0.0208	22.9528	22.6964	0.2746	0.7867	0.000767	0.011748	1.0819	0.0057	0.01193
383815075271001	Pe23-185	10/29/2018	15.80	45	0.0175	20.8462	22.5136	0.2620	0.7805	0.000645	0.010669	1.0732	0.0054	0.01184
383732075191301	Pg31-12	8/27/2018	16.90	100	0.0000	18.1929	19.2523	6.4418	0.6980	0.000000	0.009634	0.9362	0.1367	0.01082
383732075191301	Pg31-12	8/27/2018	16.90	100	0.0000	19.6172	19.0474	4.7741	0.6873	0.000000	0.010388	0.9263	0.1013	0.01066
383729075101601	Ph35-25	10/3/2018	15.80	10	0.0022	17.0579	27.2156	0.3027	0.8748	0.000083	0.008730	1.2973	0.0063	0.01327
383729075101601	Ph35-25	10/3/2018	15.80	10	0.0026	21.0300	26.8148	0.3144	0.8732	0.000098	0.010763	1.2782	0.0065	0.01325
383914075080501	Pi12-11	10/24/2018	14.60	21	0.0000	20.5907	18.4821	0.2571	0.6686	0.000000	0.010147	0.8615	0.0052	0.00990
383914075080501	Pi12-11	10/24/2018	14.60	21	0.0000	17.9845	16.9586	0.2280	0.6138	0.000000	0.008863	0.7905	0.0046	0.00909
383713075085501	Pi32-15	10/3/2018	15.60	9	0.0000	30.9825	18.3921	0.9265	0.6667	0.000000	0.015758	0.8735	0.0192	0.01007
383713075085501	Pi32-15	10/3/2018	15.60	9	0.0000	30.5532	18.4681	0.2690	0.6648	0.000000	0.015540	0.8771	0.0056	0.01004
383346075340301	Qd21-42	10/16/2018	16.00	35	0.0000	33.7830	20.2067	2.0274	0.6984	0.000000	0.017399	0.9667	0.0423	0.01064
383346075340301	Qd21-42	10/16/2018	16.00	35	0.0000	34.9999	20.4046	2.6175	0.7061	0.000000	0.018025	0.9762	0.0546	0.01075
382805075330301	Rd22-01	10/25/2018	15.40	49	0.0050	64.7183	22.1146	0.2301	0.7361	0.000184	0.032711	1.0464	0.0047	0.01108
382805075330301	Rd22-01	10/25/2018	15.40	49	0.0045	66.2592	21.6313	0.2385	0.7248	0.000163	0.033490	1.0235	0.0049	0.01091
382755075341501	Rd31-24	11/15/2018	14.30	49	0.0059	52.4434	21.5068	0.2743	0.7226	0.000210	0.025598	0.9968	0.0055	0.01063
382755075341501	Rd31-24	11/15/2018	14.30	49	0.0055	52.5961	21.2735	0.2540	0.7182	0.000195	0.025673	0.9860	0.0051	0.01057
382807075070701	Ri23-15	12/11/2018	15.40	4	0.0775	42.7689	20.1309	0.2630	0.6914	0.002836	0.021617	0.9525	0.0054	0.01040
382807075070701	Ri23-15	12/11/2018	15.40	4	0.0752	41.7015	20.2346	0.3057	0.6932	0.002753	0.021077	0.9574	0.0063	0.01043

Appendix 3. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating with sulfur hexafluoride data.

Table 3.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating with sulfur hexafluoride data.

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; NOAA, National Oceanic and Atmospheric Administration; °C, degrees Celsius; mL, milliliters; fMol/L, fentomoles per liter; --, no data]

				Sulfur hexafluoride (SF_6) data						
USGS site identification number	Sample number	DGS local well number	Sampling date (MM/DD/YY)	NOAA scale (fMol/L)	Excess air (mL)	Recharge temperature (°C)	Elevation (feet)	Estimated date of recharge[1]	Estimated age of groundwater (year)[1]	Comments
394100075334501	1	Cd52-40	09/26/18	2.1993	2.8	13.8	31	2002.5	16.2	--
394100075334501	2	Cd52-40	09/26/18	2.8895	2.8	13.8	31	2009.0	9.7	--
393928075440202	1	Db11-27	10/18/18	2.2615	2.4	12.7	79	2003.0	15.8	--
393928075440202	2	Db11-27	10/18/18	2.5839	2.4	12.7	79	2004.5	14.3	--
393916075440802	1	Db11-28	10/18/18	1.4374	3.4	12.7	71	1993.0	25.8	--
393916075440802	2	Db11-28	10/18/18	1.6702	3.4	12.7	71	1994.5	24.3	--
393739075394202	1	Dc31-15	09/26/18	1.8148	1.0	13.7	69	2002.0	16.7	--
393739075394202	2	Dc31-15	09/26/18	2.3839	1.0	13.7	69	2007.5	11.2	--
390538075325101	1	DE-KE 187731	11/19/18	2.2728	1.6	13.6	38	2005.0	13.9	--
390538075325101	2	DE-KE 187731	11/19/18	2.0348	1.6	13.6	38	2003.0	15.9	--
383101075141001	1	DE-SU 56105	12/11/18	0.7104	3.9	15.1	45	1985.0	33.9	--
383101075141001	2	DE-SU 56105	12/11/18	0.6437	3.9	15.1	45	1984.5	34.4	--
384139075230101	1	Georgetown 1	08/29/18	0.7349	3.7	14.2	100	1986.0	32.7	--
384139075230101	2	Georgetown 1	08/29/18	0.7951	3.7	14.2	100	1986.5	32.2	--
391747075364202	1	Hc34-03	09/25/18	1.6734	3.6	15.6	47	1996.5	22.2	--
391747075364202	2	Hc34-03	09/25/18	1.6693	3.6	15.6	47	1996.0	22.7	--
391060075282801	1	Ie42-03	08/15/18	2.1818	3.5	15.7	100	2000.5	18.1	--
391060075282801	2	Ie42-03	08/15/18	2.0580	3.5	15.7	100	1999.5	19.1	--
390703075371801	1	Jc33-12	10/17/18	0.2823	4.1	6.5	65	1975.0	43.8	--
390703075371801	2	Jc33-12	10/17/18	0.1484	4.1	6.5	65	1971.0	47.8	--
385522075251802	1	Le55-09	11/14/18	0.4087	4.0	14.3	25	1980.5	38.4	--
385522075251802	2	Le55-09	11/14/18	0.4997	4.0	14.3	25	1981.5	37.4	--
385448075341801	1	Md11-04	09/06/18	2.4578	2.3	12.1	100	2005.0	13.7	--
385448075341801	2	Md11-04	09/06/18	2.6963	2.3	12.1	100	2006.0	12.7	--
384818075354101	1	Nc25-37	08/22/18	1.5370	4.7	12.3	100	1991.5	27.1	--
384818075354101	2	Nc25-37	08/22/18	--	4.7	12.3	100	1952.0	--	Bottle cracked-not analyzed
384819075190101	1	Ng21-03	11/01/18	1.0538	2.2	12.8	19	1990.5	28.3	--
384819075190101	2	Ng21-03	11/01/18	1.1624	2.2	12.8	19	1991.0	27.8	--
384856075151101	1	Ng25-04	11/01/18	0.5413	4.2	8.9	9	1980.5	38.3	--

Table 3.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating with sulfur hexafluoride data.—Continued

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; NOAA, National Oceanic and Atmospheric Administration; °C, degrees Celsius; mL, milliliters; fMol/L, fentomoles per liter; --, no data]

				Sulfur hexafluoride (SF_6) data						
USGS site identification number	Sample number	DGS local well number	Sampling date (MM/DD/YY)	NOAA scale (fMol/L)	Excess air (mL)	Recharge temperature (°C)	Elevation (feet)	Estimated date of recharge[1]	Estimated age of groundwater (year)[1]	Comments
384856075151101	2	Ng25-04	11/01/18	0.4791	4.2	8.9	9	1980.0	38.8	--
384526075091601	1	Ni51-32	08/21/18	1.2251	3.2	15.6	100	1992.0	26.6	--
384526075091601	2	Ni51-32	08/21/18	1.3179	3.2	15.6	100	1992.5	26.1	--
384428075355701	1	Oc15-11	09/10/18	1.3177	3.1	10.0	100	1991.5	27.2	--
384428075355701	2	Oc15-11	09/10/18	1.1335	3.1	10.0	100	1989.5	29.2	--
384428075135501	1	Oh12-07	10/31/18	0.6699	2.5	11.0	11	1984.5	34.3	--
384428075135501	2	Oh12-07	10/31/18	0.6414	2.5	11.0	11	1984.0	34.8	--
384322075051101	1	Oi25-18	09/27/18	2.6700	2.0	14.1	14	2007.5	11.2	--
384322075051101	2	Oi25-18	09/27/18	3.3588	2.0	14.1	14	2013.5	5.2	--
384326075050801	1	Oi25-19	09/27/18	2.4008	3.6	13.5	16	2001.5	17.2	--
384326075050801	2	Oi25-19	09/27/18	2.2765	3.6	13.5	16	2000.5	18.2	--
383823075382101	1	Pc22-06	08/16/18	0.9893	6.8	16.1	100	1987.0	31.6	--
383823075382101	2	Pc22-06	08/16/18	1.2720	6.8	16.1	100	1989.5	29.1	--
383815075271001	1	Pe23-185	10/29/18	0.2262	3.7	7.9	45	1974.0	44.8	--
383815075271001	2	Pe23-185	10/29/18	0.2120	3.7	7.9	45	1974.0	44.8	--
383732075191301	1	Pg31-12	08/27/18	1.5463	1.6	11.2	100	1997.0	21.7	--
383732075191301	2	Pg31-12	08/27/18	1.8065	1.6	11.2	100	1999.0	19.7	--
383729075101601	1	Ph35-25	10/03/18	1.7933	7.6	6.5	10	1989.5	29.3	--
383729075101601	2	Ph35-25	10/03/18	2.0591	7.6	6.5	10	1991.0	27.8	--
383914075080501	1	Pi12-11	10/24/18	1.9002	1.1	16.5	21	2003.5	15.3	--
383914075080501	2	Pi12-11	10/24/18	1.7669	1.1	16.5	21	2002.0	16.8	--
383713075085501	1	Pi32-15	10/03/18	1.2219	1.5	13.1	9	1992.5	26.3	--
383713075085501	2	Pi32-15	10/03/18	1.1681	1.5	13.1	9	1992.5	26.3	--
383346075340301	1	Qd21-42	10/16/18	2.0305	3.2	12.5	35	1997.5	21.3	--
383346075340301	2	Qd21-42	10/16/18	2.0272	3.2	12.5	35	1997.5	21.3	--
382805075330301	1	Rd22-01	10/25/18	1.6356	4.7	12.3	49	1992.5	26.3	--
382805075330301	2	Rd22-01	10/25/18	1.6343	4.7	12.3	49	1992.5	26.3	--

Table 3.1. Groundwater-quality data for sampled public water-supply wells in the Columbia aquifer in Delaware, sampled in 2018—Age dating with sulfur hexafluoride data.—Continued

[A total of 30 public water-supply wells were sampled in 2018. USGS, U.S. Geological Survey; DGS, Delaware Geological Survey; NOAA, National Oceanic and Atmospheric Administration; °C, degrees Celsius; mL, milliliters; fMol/L, fentomoles per liter; --, no data]

USGS site identification number	Sample number	DGS local well number	Sampling date (MM/DD/YY)	Sulfur hexafluoride (SF_6) data: NOAA scale (fMol/L)	Excess air (mL)	Recharge temperature (°C)	Elevation (feet)	Estimated date of recharge[1]	Estimated age of groundwater (year)[1]	Comments
382755075341501	1	Rd31-24	11/15/18	1.8067	4.3	12.5	49	1994.5	24.4	Wrong cap
382755075341501	2	Rd31-24	11/15/18	--	4.3	12.5	49	1952.0	--	Broken in shipping; not analyzed
382807075070701	1	Ri23-15	12/11/18	1.7413	3.4	13.5	4	1996.0	22.9	--
382807075070701	2	Ri23-15	12/11/18	1.7504	3.4	13.5	4	1996.0	22.9	--

[1]Model ages corrected for excess air.

For additional information, contact:

Director, Maryland-Delaware-D.C. Water Science Center
U.S. Geological Survey
5522 Research Park Drive
Catonsville, MD 21228

or visit our website at https://www.usgs.gov/centers/md-de-dc-water/

Publishing support provided by the West Trenton Publishing Service Center

Reyes—**Occurrence and Distribution of PFAS in Sampled Source Water of Public Drinking-Water Supplies in the Surficial Aquifer in Delaware, 2018**—OFR 2021–1109

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20211109