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Richard A. Ortt, Jr., Director

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COMPILATION OF COASTAL PLAIN GROUNDWATER-QUALITY DATA FROM MULTIPLE DATA SOURCES IN ANNE ARUNDEL, WICOMICO AND WORCESTER COUNTIES, MARYLAND

by

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(B) **AA_WI_As_Cl_Fe_Mn.shp**: GIS shapefile including arsenic, chloride, iron, and manganese from Anne Arundel County Health Department, U.S. Geological Survey, and Maryland Geological Survey.
(C) **AA_WI_MDE.xlsx**: Water-quality data spreadsheet Anne Arundel and Wicomico Counties from Maryland Department of the Environment.
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INTRODUCTION

Groundwater-quality data are collected throughout Maryland by state, county, and federal agencies. The data are collected for different purposes, using different collection and analytical protocols with different detection and reporting levels, and are stored in different locations and in different formats. As a result of these variations between agencies the data are not easily accessed or used by water managers and others who might benefit from the data. In addition, the source aquifer for many of the groundwater-quality data—primarily the county data—is unknown or inaccurate.

In 2012, the Maryland Geological Survey (MGS) (Maryland Department of Natural Resources) and the U.S. Geological Survey (USGS), in coordination with the Maryland Department of the Environment (MDE) Water Supply Program, developed the Maryland Coastal Plain Aquifer Information System (MCPAIS). This information system integrated large amounts of existing aquifer data, including aquifer depths, hydraulic characteristics, and geophysical logs into a GIS-based environment that could be accessed to evaluate Groundwater Allocation and Use Permits. Because of funding constraints, however, water-quality data were not incorporated into the MCPAIS (with the exception of arsenic data).

In this report, existing groundwater-quality data from Anne Arundel, Wicomico and Worcester Counties, all of which are located in the Maryland coastal plain, were compiled into a GIS database. The purpose of this work is to incorporate groundwater-quality datasets identified by source aquifer from multiple data sources into a consistent and standard format that can be used for analysis by water managers and others, and that will provide a prototype for the future inclusion of additional counties. Groundwater-quality data were compiled from the Anne Arundel, Wicomico, and Worcester County Health Departments, the U.S. Geological Survey's National Water Information System (NWIS)-QWDATA database, the MDE Public Drinking Water database, and MGS project data. ArcGIS layers were generated for five constituents (arsenic, chloride, iron, manganese, and nitrate) that show the distribution of these constituents by aquifer. The ArcGIS layers are organized by aquifer and symbolized by concentration ranges in an ArcMap project. The work was funded under an agreement between the Maryland Geological Survey (Maryland Department of Natural Resources) and the Maryland Department of the Environment.

MARYLAND COASTAL PLAIN GROUNDWATER-QUALITY DATA INVENTORY

The initial task in this project was to conduct a survey of all county health departments in the Maryland coastal plain regarding their groundwater-quality data. The survey included the type, format, and quantity of groundwater-quality data (Appendix A). Based on the survey results, three counties (Anne Arundel, Wicomico, and Worcester) were selected to obtain available data and create a spatial database identified by aquifer source. Anne Arundel County was selected because of the large amount of available data, the relatively high degree of data organization, and because the County has a number of known groundwater quality issues including radium, arsenic, and brackish-water intrusion (Fleck and others, 1996; Bolton and Hayes, 1999; Bolton, 2000; Drummond and Bolton, 2010). Wicomico and Worcester Counties were selected because they represent the other end of the spectrum, with a generally smaller amount of data and constituents analyzed, and because of the prevalence of elevated nitrate in the shallow, unconfined Surficial aquifer. These three counties also provide a varied hydrogeological and geographic distribution from predominately Cretaceous to Miocene-age aquifers near the western margin of the coastal plain (Anne Arundel County) to predominantly Miocene- to Pleistocene-age aquifers farther out on the coastal plain (Wicomico and Worcester Counties)(Tables 1 and 2).

Table 1. Rock-stratigraphic and hydrogeologic units in Anne Arundel County.

System	Series	Rock-stratigraphic units		Hydrostratigraphic units
Tertiary	Pliocene (?)	Upland deposits		Surficial Upland aquifer
	Miocene	Chesapeake Group (Calvert, Choptank, and St. Marys Formation undivided)		Calvert aquifer system (minor aquifer)
				Calvert confining unit
	Eocene	Pamunkey Group	Nanjemoy Formation	Nanjemoy confining unit
	?		Marlboro Clay	Marlboro Clay confining unit
	Paleocene		Aquia Formation	Aquia aquifer
			Brightseat Formation	Matawan confining unit
Cretaceous	Upper Cretaceous	Severn Formation		
		Matawan Formation		
		Magothy Formation		Magothy aquifer
	?	Potomac Group	Patapsco Formation	Magothy-Patapsco confining unit
	Lower Cretaceous			Upper Patapsco aquifer system
				Patapsco confining unit
				Lower Patapsco aquifer system
			Arundel Clay	Arundel Clay confining unit
			Patuxent Formation	Patuxent aquifer system

Table 2. Rock-stratigraphic and hydrogeologic units in Wicomico and Worcester Counties.

[Fm, Formation]

System	Series	Rock-stratigraphic units		Hydrostratigraphic units
Quaternary	Pleistocene	Parsonsburg Fm, Sinepuxent Fm[1], Ironshire Fm[1] Kent Island Fm[2] Omar Fm, Walston Silt[2]		Surficial aquifer
	?			
Tertiary	Pliocene	Beaverdam Fm Pensauken Fm[2]		
	?			
	Miocene	Chesapeake Group	Eastover (?) Formation (in Maryland and Virginia) / Bethany Formation (in Delaware) / "Ocean City Beds"	Upper Chesapeake confining unit 1
				Pocomoke aquifer
				Upper Chesapeake confining unit 2
				Ocean City aquifer
				Upper Chesapeake confining unit 3
			Cat Hill Formation (in Delaware)	Manokin aquifer
			St. Marys Formation	St. Marys confining unit
			Choptank Formation	Choptank aquifer (Milford in Delaware)

[1] - Not present in Wicomico County
[2] - Not present in Worcester County

SOURCES OF GROUNDWATER-QUALITY DATA

Groundwater-quality data were compiled from six sources: (1) the Anne Arundel County Health Department (AAHD); (2) the Wicomico County Health Department (WIHD); (3) the Worcester County Health Department (WOHD); (4) the USGS NWIS database; (5) the MDE Public Drinking Water database; and (6) data collected and maintained by MGS from studies of arsenic and cadmium in the coastal plain. Each of these datasets are discussed briefly below. Wells having water-quality data from the above sources in Anne Arundel, Wicomico, and Worcester Counties are shown in Figures 1-3. Spreadsheets and GIS shapefiles of the datasets are provided in Ancillary data files A-F.

Anne Arundel County Health Department

Water-quality data from AAHD contains a total of 21,188 well-water analyses (21,343 wells sampled). Some wells have more than one sample. The majority of wells are for domestic supply. Constituents in the database include pH, hardness, nitrate, chloride, turbidity, specific conductance, iron, cadmium, arsenic, gross alpha-particle activity, radium-226, and radium-228. Not all samples have data for all constituents. The samples were assumed to be unfiltered ("raw") water. AAHD has no standard procedure for purging wells (removing stored casing water before sampling), therefore it's unknown to what degree the samples fully represent the formation water. Geographic coordinates either were provided as GPS readings or were determined from geocoding the street address or property parcel centroid. Water-quality data are contained in a spreadsheet (Ancillary file A) with a subset (arsenic, chloride, iron, and manganese) in a GIS shapefile (Ancillary file B).

Wicomico County Health Department

Water-quality data from WIHD contains a total of 1,607 well-water analyses (1,276 wells sampled). Some wells have more than one sample. The majority of wells are for domestic supply. Constituents include nitrate, nitrite, iron, chloride, arsenic, and lead, with the vast majority of samples having only nitrate analysis. The samples were assumed to be unfiltered ("raw") water. WIHD has no standard procedure for purging wells (removing stored casing water before sampling), therefore it's unknown to what degree the samples fully represent the formation water. Geographic coordinates were either provided as GPS readings (746 samples, mostly collected since 2011) or were determined from geocoding the street address or property parcel centroid (530 samples, most prior to 2011). Water-quality data are contained in a spreadsheet (Ancillary file A) with a subset (arsenic, chloride, iron, and manganese) in a GIS shapefile (Ancillary file B).

Worcester County Health Department

Water-quality data from WOHD contains a total of 9,161 well-water analyses (9,161 wells sampled). The majority of wells are for domestic supply. Constituents include nitrate, iron, pH, and chloride. The samples were assumed to be unfiltered ("raw") water. WOHD has no standard procedure for purging wells (removing stored casing water before sampling), therefore it's unknown to what degree the samples fully represent the formation water. Geographic coordinates were either provided as GPS readings or were determined from geocoding the street address or property parcel centroid. Water-quality data are contained in a spreadsheet (Ancillary file E) and GIS shapefile (Ancillary file F).

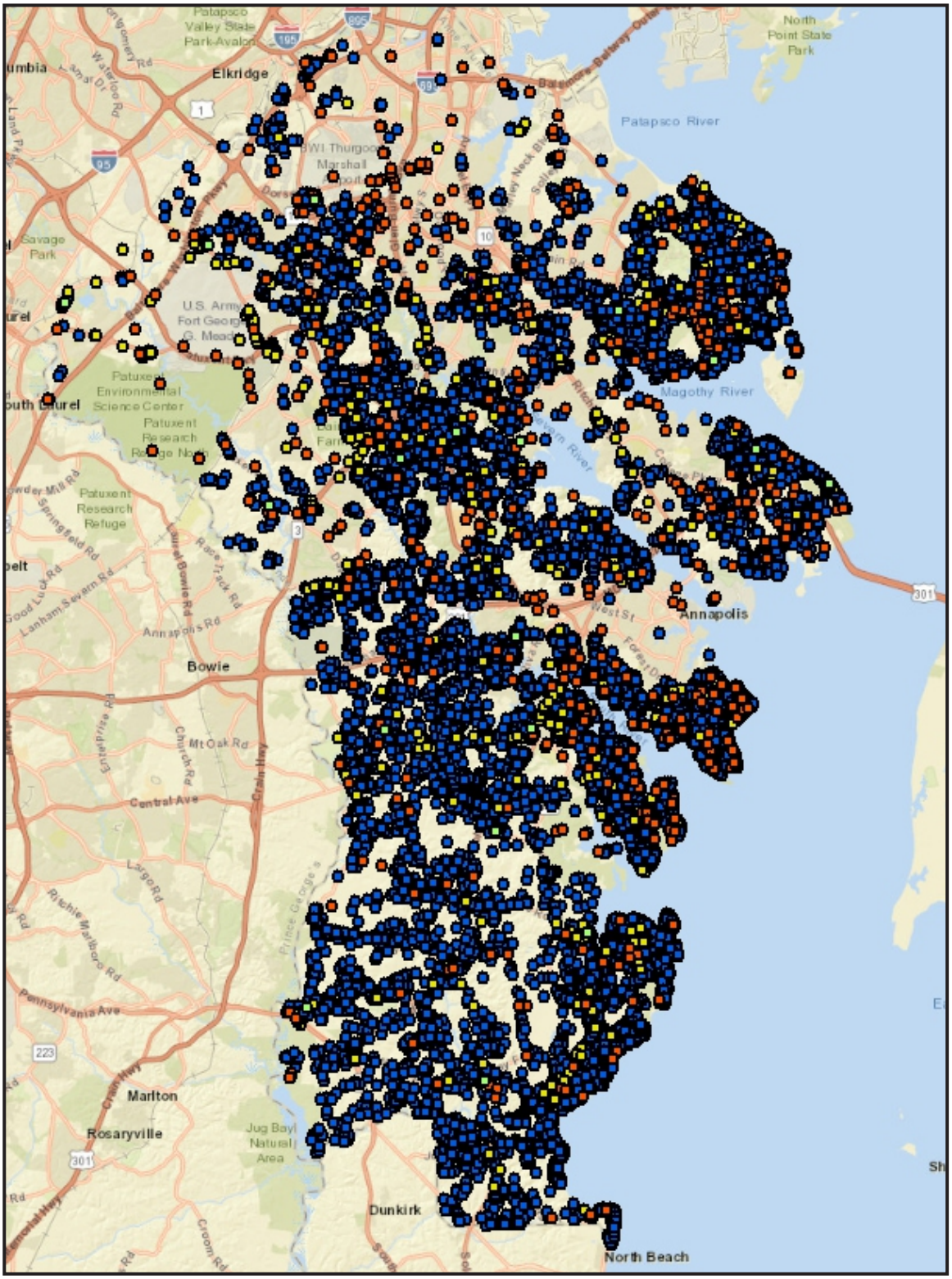

Figure 1. Locations of wells having water-quality data in Anne Arundel County. Sources of data include Anne Arundel County Health Department (blue), Maryland Geological Survey (green), U.S. Geological Survey (red), and Maryland Department of the Environment (yellow).

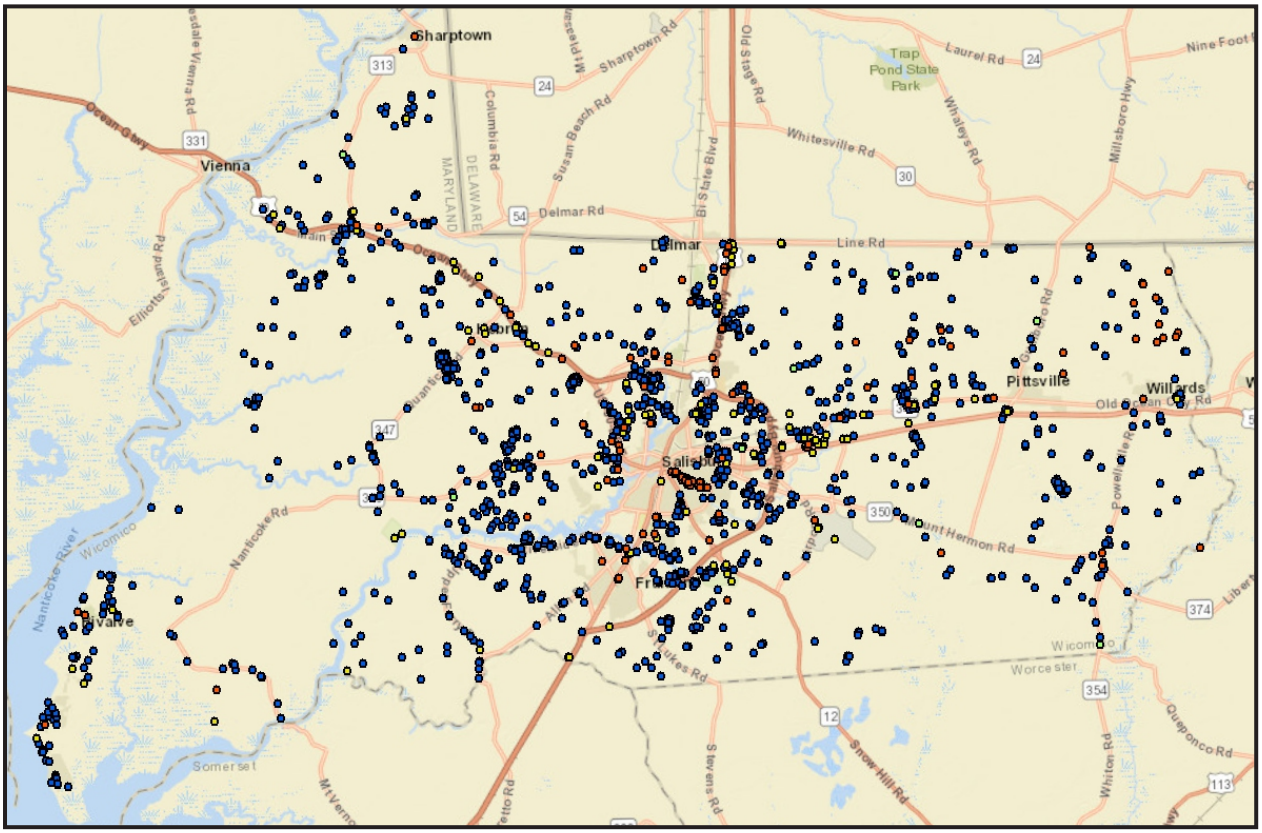

Figure 2. Locations of wells having water-quality data in Wicomico County. Sources of data include Wicomico County Health Department (blue), Maryland Geological Survey (green), U.S. Geological Survey (red), and Maryland Department of the Environment (yellow).

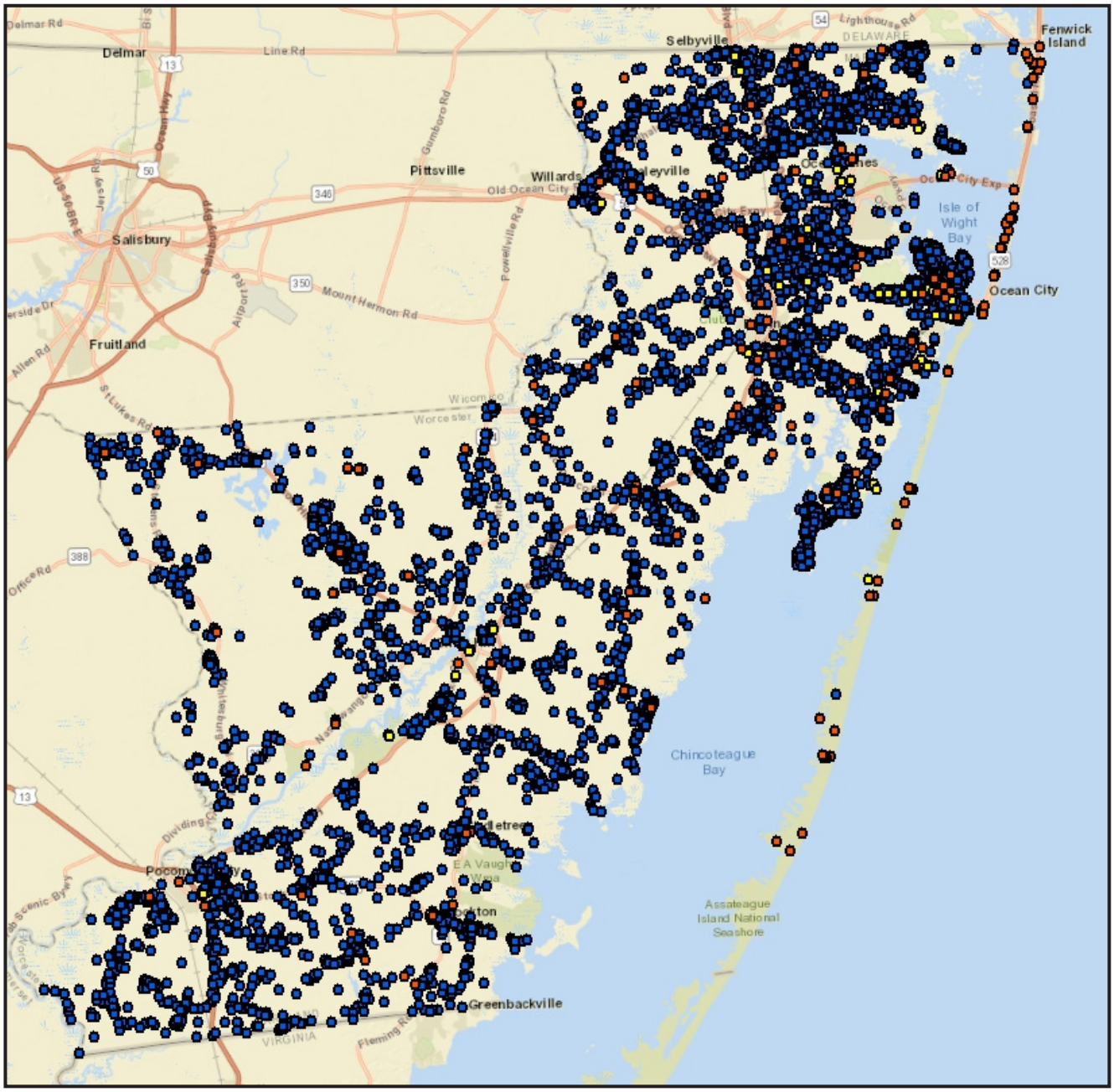

Figure 3. Locations of wells having water-quality data in Worcester County. Sources of data include Worcester County Health Department (blue), U.S. Geological Survey (red), and Maryland Department of the Environment (yellow).

Maryland Department of the Environment

Water-quality data from MDE's Public Drinking Water Information System (PDWIS) contains a total of 1,596 analyses (116 in Anne Arundel County, 64 in Wicomico, and 1,416 in Worcester County). The total number of wells sampled in Anne Arundel, Wicomico, and Worcester was 116, 64, and 54, respectively. Samples are a combination of unfiltered and filtered water samples. Geographic coordinates were provided in the PDWIS dataset. Water-quality data are contained in spreadsheets (Ancillary files C and E) and a GIS shapefile (Ancillary file F).

U.S. Geological Survey

A total of 765 samples were retrieved from Anne Arundel County (from 554 wells). A total of 330 samples were retrieved from Wicomico County (from 142 wells). A total of 836 samples were retrieved from Worcester County (from 145 wells). Samples are a combination of unfiltered and filtered water samples. Geographic coordinates were obtained from the USGS Ground Water Site Inventory (GWSI) database, which is a required input parameter for that database. Most of the coordinates were determined either by GPS or manually by project personnel using topographic maps at the time the wells were inventoried. Water-quality data are provided in spreadsheets (Ancillary files A and E) and GIS shapefiles (Ancillary files B and F).

Maryland Geological Survey

In 2001-2002, MGS collected samples from 250 wells throughout the coastal plain as part of a regional study of arsenic in groundwater (Drummond and Bolton, 2010). Eighteen of the wells were in Anne Arundel County, 8 were in Wicomico County, and 14 were in Worcester County. All 40 wells were sampled for (unfiltered) arsenic, specific conductance, pH, and dissolved oxygen. One of the wells in Wicomico County was also tested for major ions (filtered sample). In 2005, 21 wells were sampled in Anne Arundel County as part of a local-scale study of cadmium in central Anne Arundel County (Bolton, 2006); additional constituents included chloride, specific conductance, pH, and dissolved oxygen. In both studies, all constituents except field measurements (specific conductance, pH, dissolved oxygen, and alkalinity) were analyzed by the Maryland DHMH Laboratory. Latitude-longitude coordinates were determined manually (map). Water-quality data are provided in spreadsheets (Ancillary files A and E) and GIS shapefiles (Ancillary files B and F).

METHODS IN DATA PROCESSING

After data were obtained from the sources, locational data were assessed and standardized. Wells for which geographic coordinates (latitude and longitude) were provided were converted to decimal degrees (if necessary). Latitude and longitude in the county Health Department datasets were generated for wells lacking them by either geocoding the street addresses or centroid of the property parcel. Although geocoding and property parcel centroids do not correspond exactly to the well locations, they were considered sufficiently accurate at the county scale to be justified. None of the well locations were verified in the field.

Once wells were assigned latitude and longitude coordinates, aquifer assignments were made by comparing well-screen elevations to hydrogeologic unit (aquifer and confining unit) elevations from MCPAIS (Andreasen and others, 2013) . The first step in the process required

adjusting well-screen depth (reported in feet below land surface) to elevations (depth relative to sea level). The depth to top and bottom of the screened interval was obtained either from the provided data sources or from the MDE wells database. Land-surface elevation was determined for each well using an elevation raster (derived from the USGS's National Elevation Dataset) contained in the MCPAIS; in some cases land-surface elevation was obtained from NWIS. From this, the depth to the top and bottom of the screened (open) interval was subtracted, resulting in depth to the open interval relative to sea level Aquifer determination was then made by comparing the open interval elevation to the elevations of the aquifers and confining units stored in MCPAIS using ArcGIS Spatial Analyst in conjunction with logical formulas in an Excel spreadsheet. For wells having no information on screen depths, the bottom of the well (total depth) was used. Where calculations indicated screened intervals in multiple aquifers, the aquifer was determined by best judgment through "manual" inspection, and a single-aquifer determination was made. For wells with top of screen elevation only the bottom of the screen was estimated to be the total depth of the well.

For the three datasets (MDE, MGS and USGS) where aquifer assignments are available the MCPAIS-determined aquifer assignments generally agree. Approximately 10 percent of all wells were determined to be screened in confining units. This may be an erroneous determination resulting from imprecise well locations and incorrect well-screen elevations. It may be possible, however, that some wells may be completed in sandy zones within a confining unit. Furthermore, the MCPAIS aquifer and confining unit elevations may differ from the actual surfaces in areas lacking data.

Most analyses were performed on unfiltered water samples. USGS samples were mostly filtered samples; for samples that had both filtered and unfiltered constituents (mostly iron and manganese), the unfiltered samples were used because they are more representative of water that is being consumed.

GIS DATABASE

The GIS shapefiles (Ancillary files B, D, and F) generated from the spreadsheets of water-quality data (Ancillary files A, C, and E) were assembled into a geodatabase (Ancillary file G). The geodatabase was incorporated into an ArcMap project (Ancillary file H) with the water-quality data organized by aquifer. Concentration ranges for each aquifer symbolized select constituents (arsenic, chloride, iron, and manganese for Anne Arundel and Worcester Counties and chloride, iron, manganese, and nitrate for Worcester County).

DISCUSSION OF SELECTED GROUNDWATER-QUALITY DATA

Five chemical constituents (arsenic, chloride, iron, manganese, and nitrate) were selected for the development of a prototype GIS groundwater-quality database (ArcMap project). A brief overview of the individual constituents for each county is presented below.

Anne Arundel County

Arsenic. Arsenic concentrations in many wells completed in the Aquia aquifer on the Mayo Peninsula exceed the U.S. Environmental Protections Agency's (USEPA) Maximum Contaminant Level (MCL) of 10 micrograms per liter (µg/L) (0.010 milligrams per liter [mg/L]). The few other arsenic samples exceeding 10 µg/L are widely dispersed around the County, including one on Pasadena Neck (in the Magothy aquifer) and one in the Crofton area (also in the Magothy aquifer) (fig. 4).

Chloride. Most of the elevated (>50 mg/L) and high (>250 mg/L USEPA Secondary Maximum Contaminant Level (SMCL)) chloride levels are located on the peninsulas near the Chesapeake Bay and its tributaries (fig. 5). This likely reflects brackish-water intrusion in the area; however, some of the areas are densely populated and have shallow wells, and may be affected by surface-based salt sources. Most of the elevated-chloride wells located away from shoreline are close to major roads in the County, and likely are affected by road salt.

Iron and manganese. Iron concentrations above the USEPA SMCL of 300 µg/L (0.3 mg/L) are ubiquitous throughout the County and the aquifers (fig. 6). There appears to be no clear-cut relation between iron concentrations and position in the aquifers (updip versus downdip). Manganese concentrations above 50 µg/L (0.05 mg/L) are also very common in all aquifers throughout the County with the exception of an area in southern Anne Arundel County where manganese concentrations are consistently below 50 µg/L (fig. 7).

Wicomico County

Arsenic. Only one well had an arsenic concentration above the 10 µg/L MCL (an observation well in the surficial aquifer). All others were below the MCL.

Chloride. Four wells exceeded 250 mg/L chloride (fig. 8). Three of these are in the Choptank aquifer and adjacent to state highways; the fourth is completed in the surficial aquifer.

Iron and manganese. Iron and manganese exceeding their respective SMCLs occur throughout the county and the aquifers. Iron concentrations are shown in Figure 9.

Worcester County

Chloride. One-hundred and thirteen wells were at or above the MCL (250 mg/L) for chloride (fig. 10). Most exceedances of the MCL are in the Manokin aquifer. Two areas of elevated chloride occur in southern Worcester County in the Ocean City and Manokin aquifers.

Iron and manganese. Iron and manganese exceeding their respective SMCLs occur throughout the county and the aquifers. Iron concentrations are shown in Figure 11.

Nitrate. Nitrate exceeding the MCL (10 mg/L as nitrogen) occurs throughout the county and the aquifers (fig. 12).

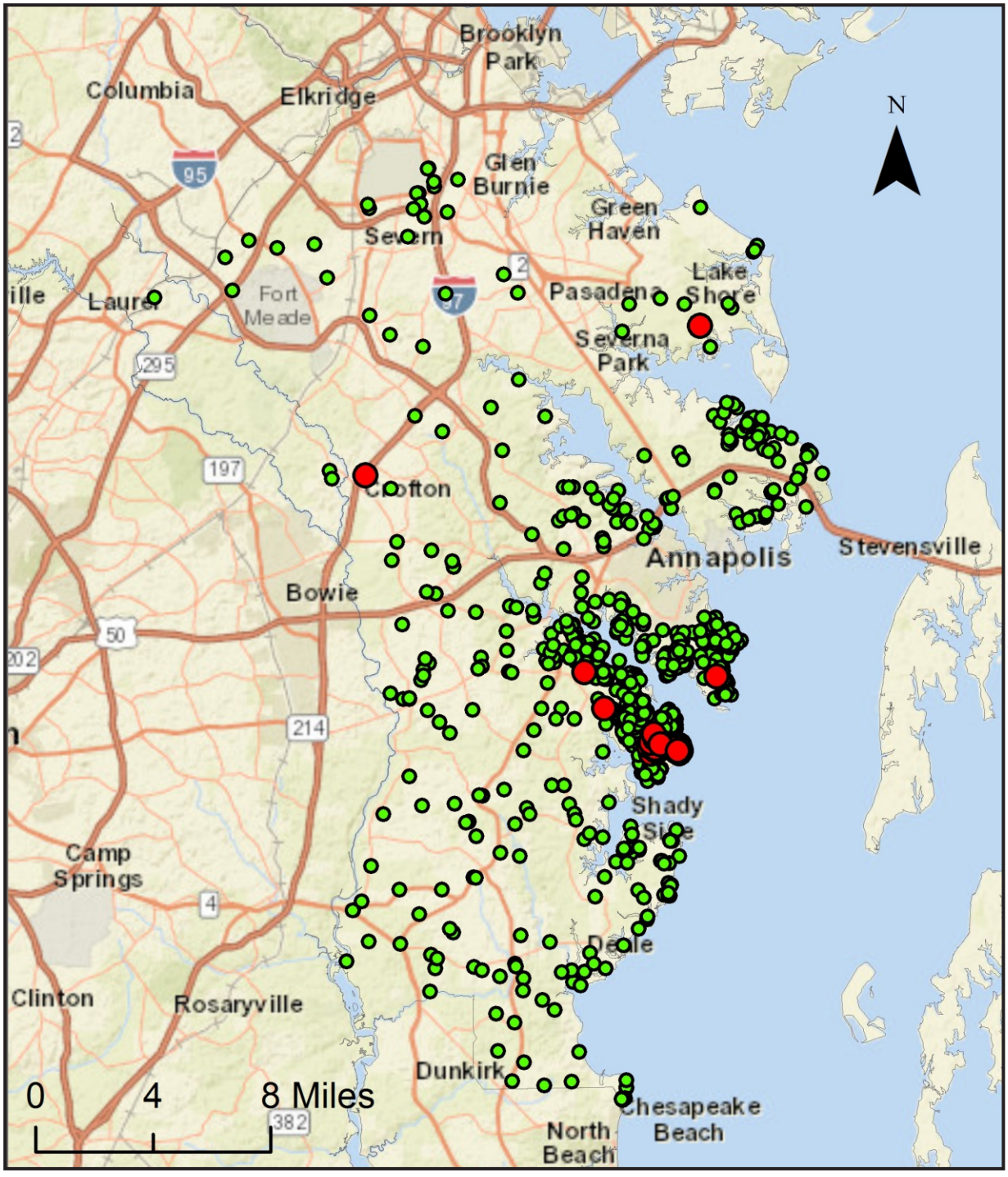

Figure 4. Arsenic concentrations in groundwater in Anne Arundel County. Wells with red circles exceed the U.S. Environmental Protection Agency Maximum Contaminant Level of 10 micrograms per liter.

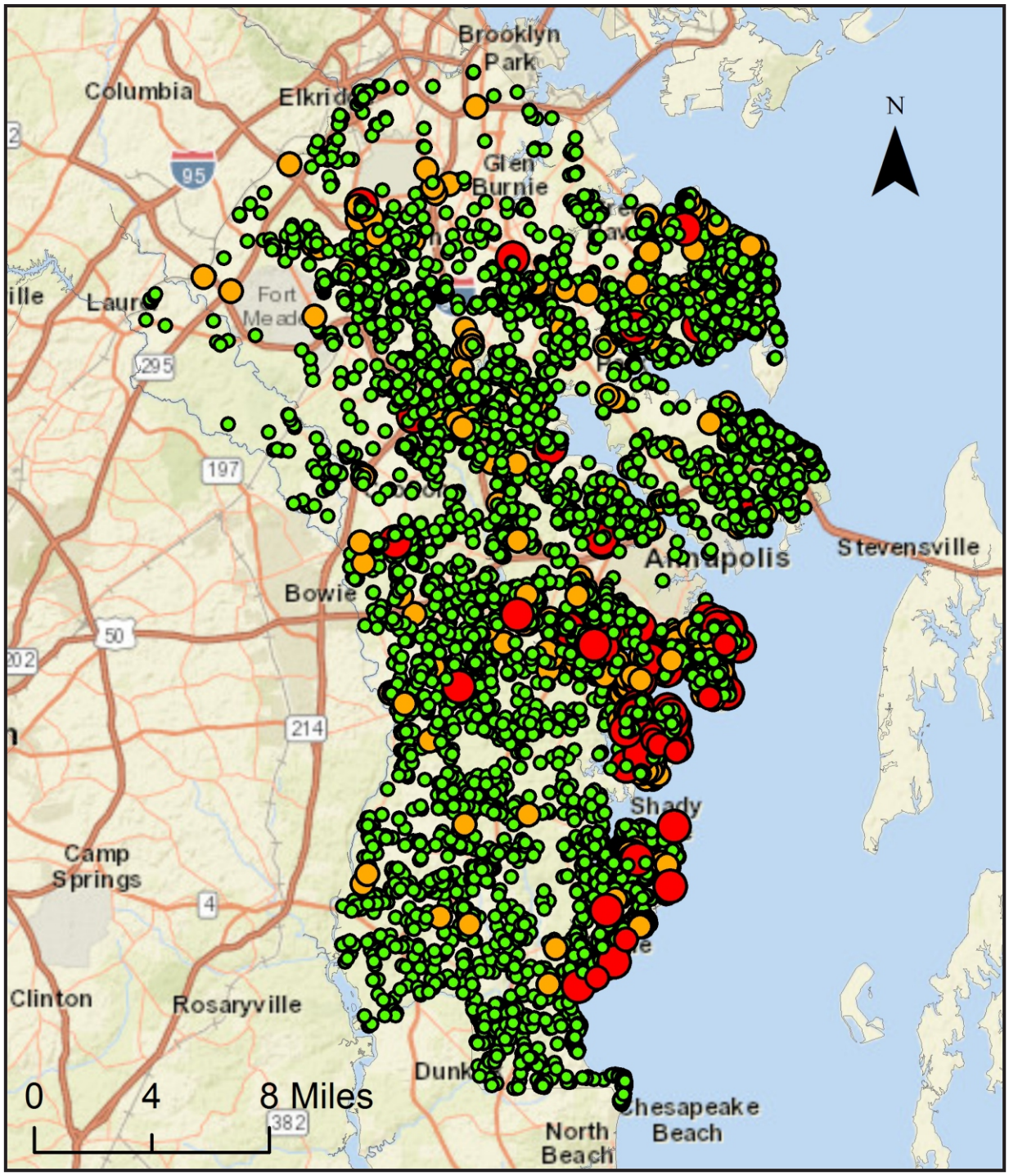

Figure 5. Chloride concentrations in groundwater in Anne Arundel County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 250 milligrams per liter.

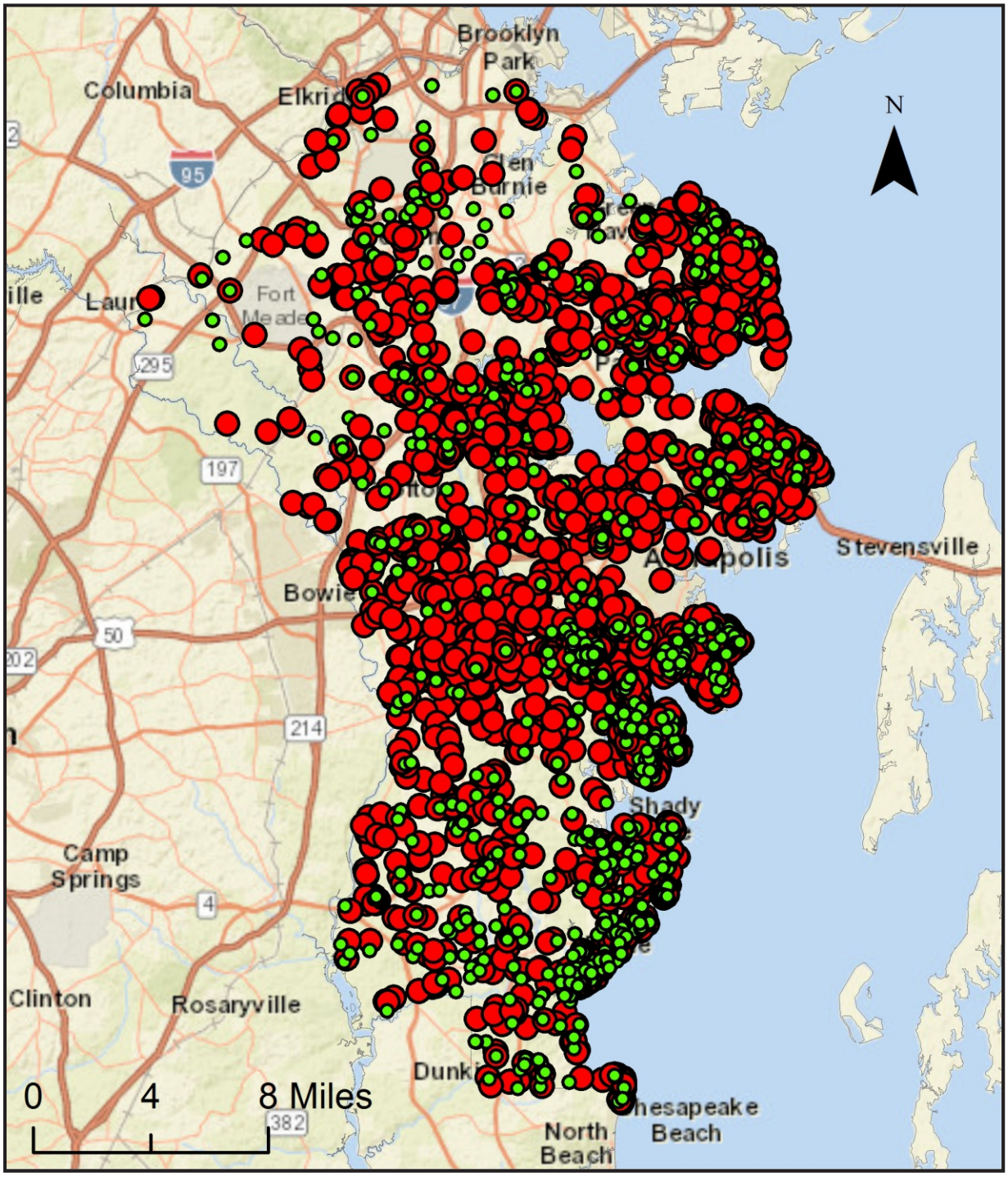

Figure 6. Iron concentrations in Groundwater in Anne Arundel County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 300 micrograms per liter.

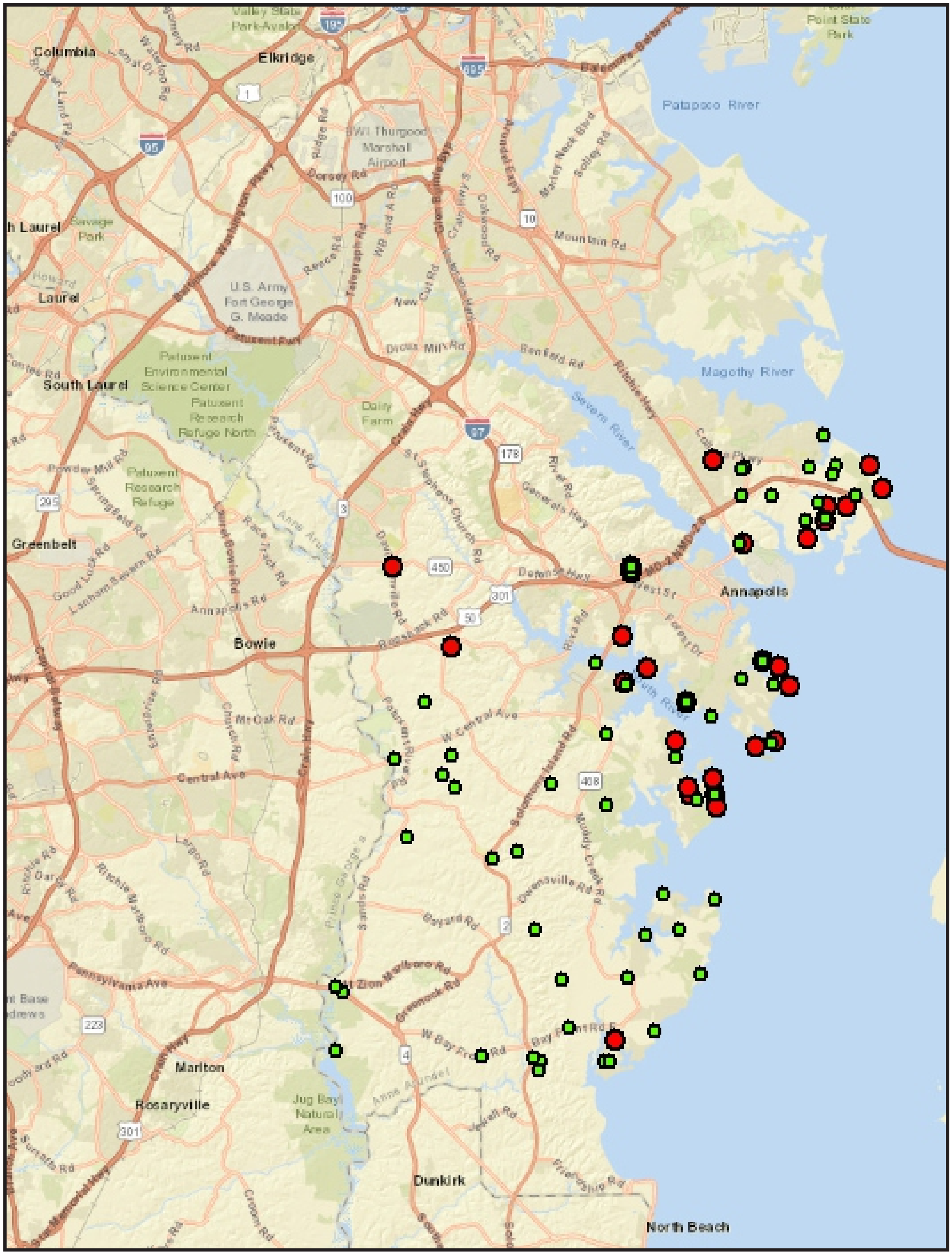

Figure 7. Manganese concentrations in the Aquia aquifer in Anne Arundel County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 50 micrograms per liter.

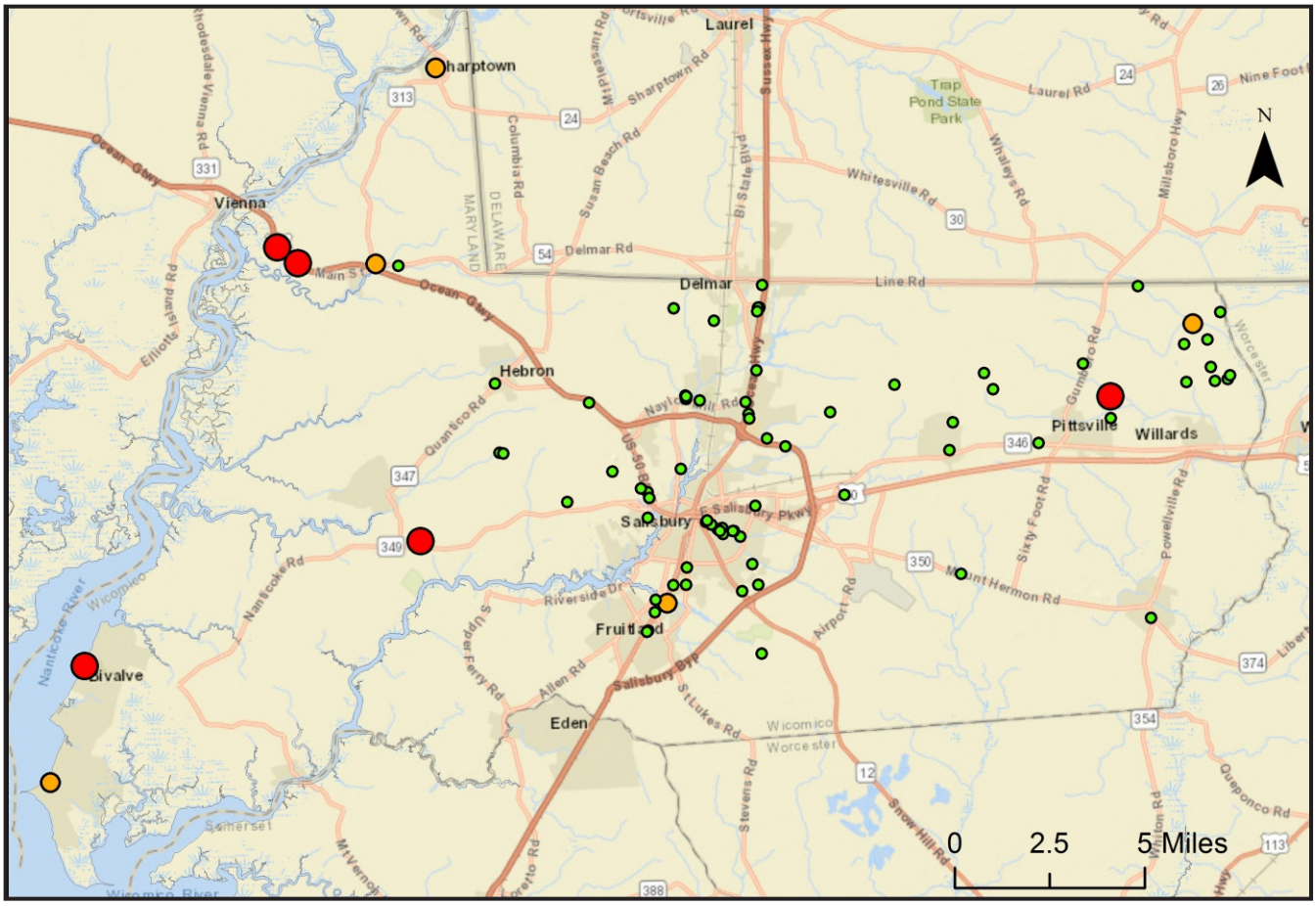

Figure 8. Chloride concentrations in groundwater in Wicomico County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 250 milligrams per liter.

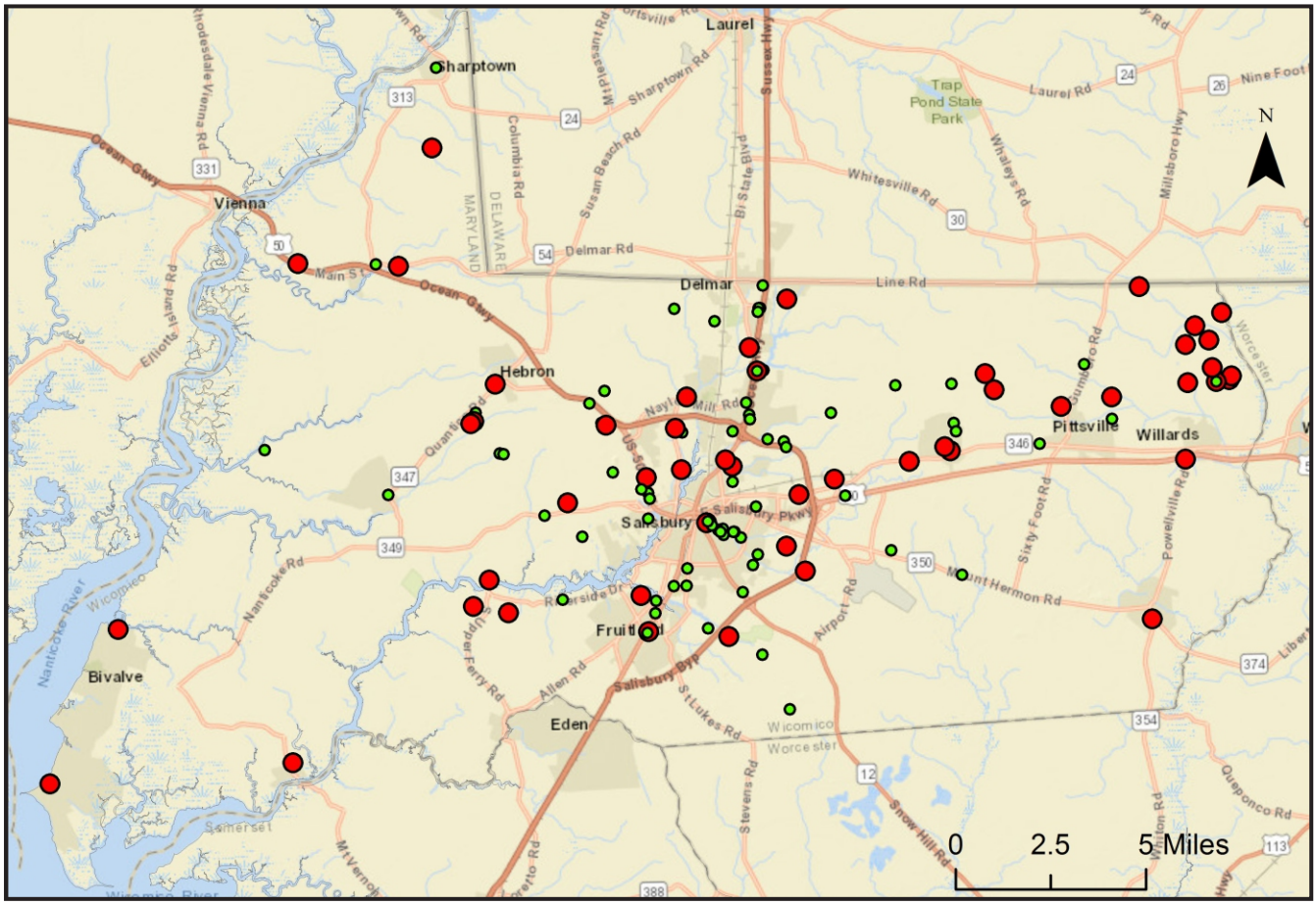

Figure 9. Iron concentrations in groundwater in Wicomico County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 300 micrograms per liter.

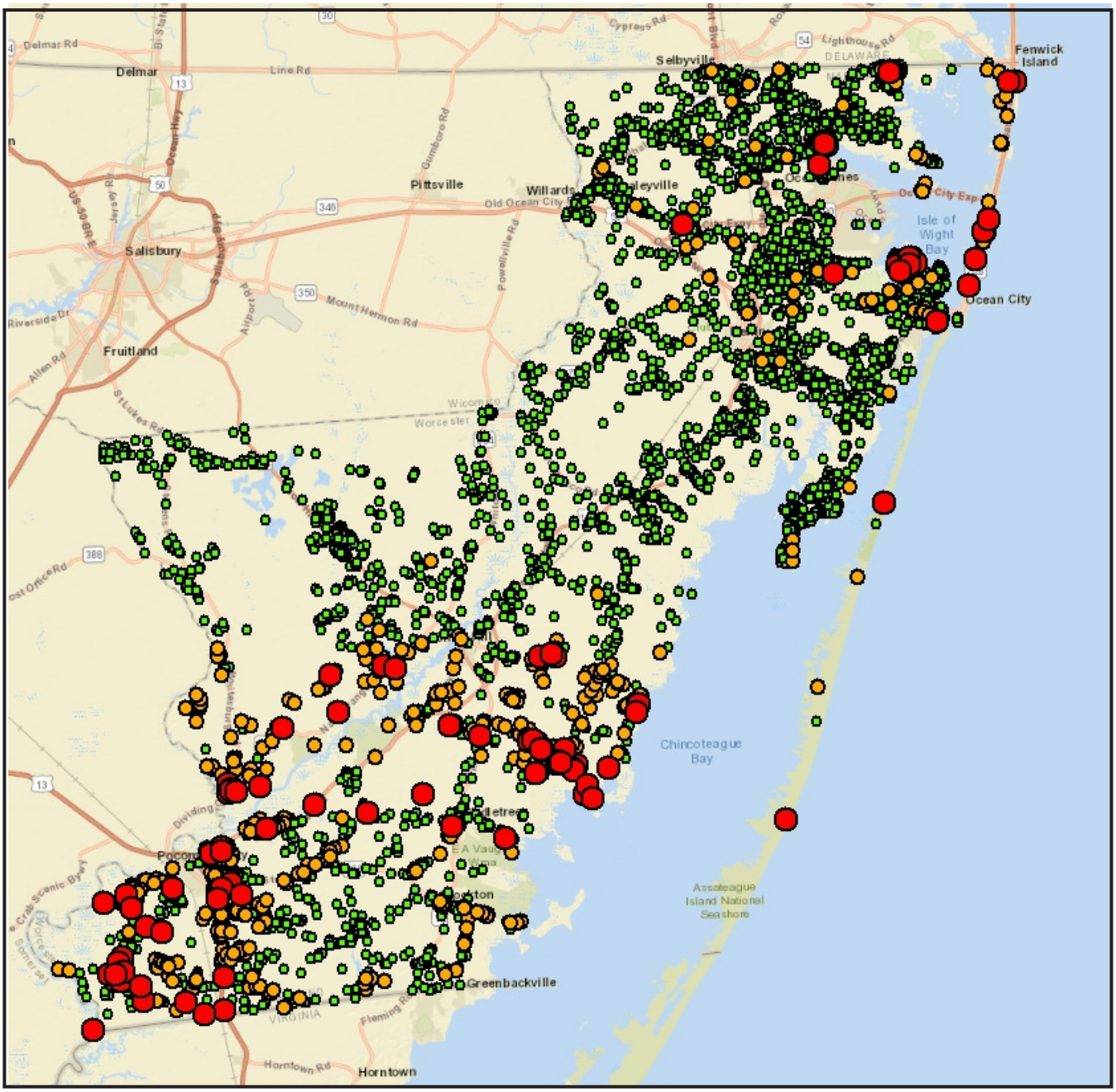

Figure 10. Chloride concentrations in groundwater in Worcester County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 250 milligrams per liter.

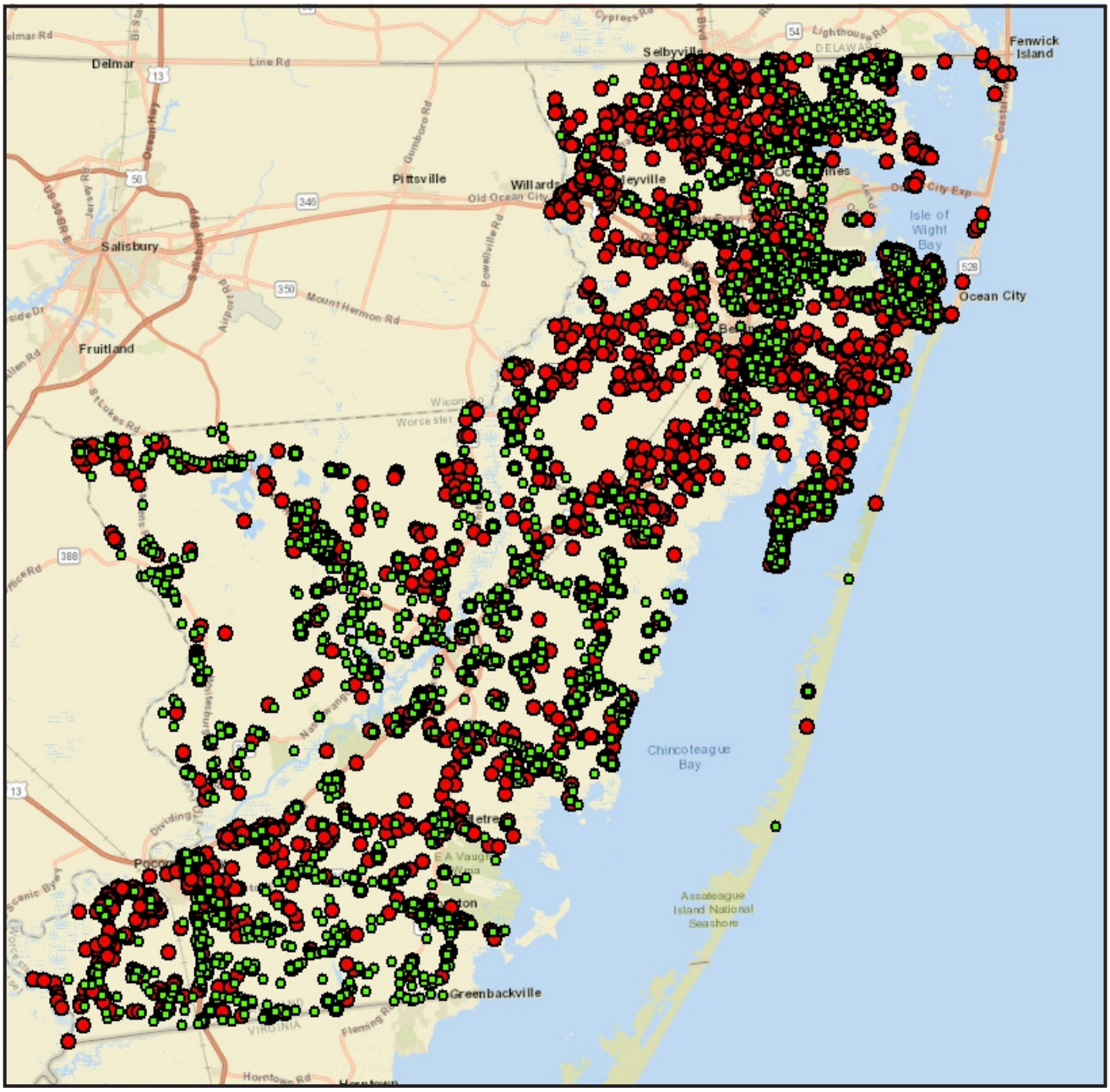

Figure 11. Iron concentrations in groundwater in Worcester County. Wells with red circles exceed the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level of 300 micrograms per liter.

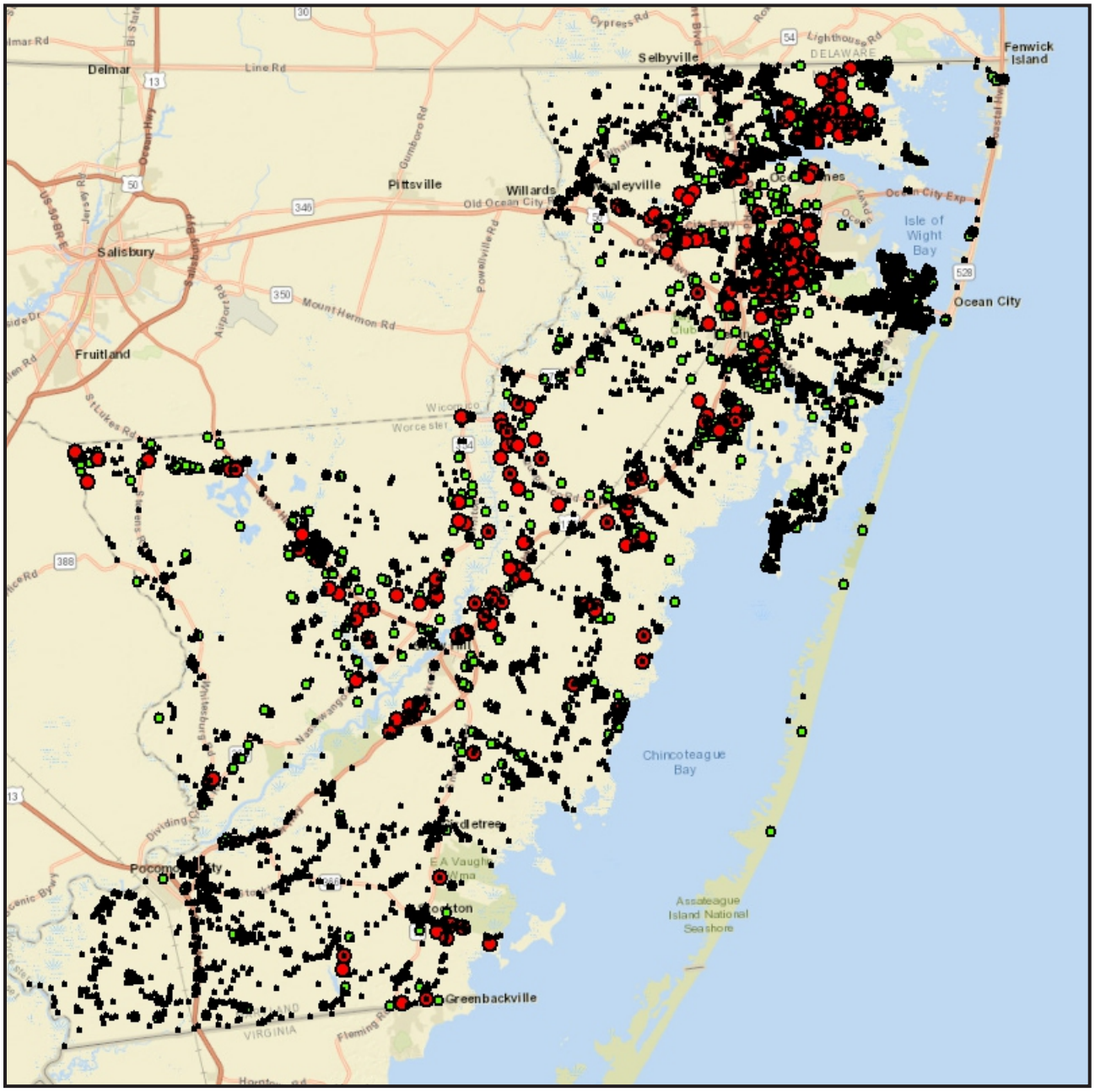

Figure 12. Nitrate concentrations in groundwater in Worcester County. Wells with red circles exceed the U.S. Environmental Protection Agency Maximum Contaminant Level of 10 milligrams per liter nitrogen.

SUMMARY AND OBSERVATIONS

This report presents the results of combining several groundwater-quality datasets from different sources in Anne Arundel, Wicomico, and Worcester Counties, Maryland into a GIS-based database (ArcMap project). In addition, an inventory of available groundwater-quality data from all Maryland coastal plain county health departments was conducted. The large number of groundwater-quality samples that have been collected by the counties, USGS, MDE, and MGS could potentially be a valuable resource for water managers and others for identifying potential problem areas and in providing insight into groundwater-quality patterns. Over time, the dataset could help to identify changes and trends in groundwater quality. The data sets also help to identify gaps in groundwater-quality data, particularly with respect to drinking-water standards. The following comments are our observations on data acquisition, function, limitations of the data and methodology.

- Samples having anomalously high or low values of particular constituents often cannot be evaluated as to the source of the problem, particularly if the sample is fairly old. Most counties do not maintain detailed records on sampling events, and hardcopies are often purged after just a few years. Order-of-magnitude errors can be easily spotted, but other erroneous data may not be so easily identified.
- GPS-determined locations have been required for each new well since about 2011. These values are likely to be more reliable than "manual" determinations. However, the quality of GPS measurements may vary due to number of satellites received, occupation time, and other factors.
- USGS data contains data quality indicators (DQIs). Samples collected since about 2000 are initially logged in as "presumed acceptable." These data are finalized by project leaders once all data are back, and at that time the DQIs for each constituent are changed to "acceptable" (or another category if not acceptable). Prior to about 2000, the data were accepted "as is."
- Many of the data samples are collected from monitor or observation wells that may not be representative of consumable well water. If counties do not indicate the type of well or water use, well type can be identified by cross-referencing with the MDE wells database. Screened or open intervals can also be retrieved from this database.
- Counties report non-detections and less-than values in different ways. Some counties report the non-detected compounds by entering the detection level, with no indicators specifying that it's less than that amount; others use "<" signs.
- Different analytical methods have different degrees of accuracy. For example, counties often determine pH in the field by colorometric means, which can be highly subjective.
- Samples retrieved for this project from the USGS database date from 1932 (Anne Arundel County) and 1947 (Wicomico). Older samples such as these may not reflect current conditions (particularly if they are from water-table aquifers), or the analytical methods may be obsolete. The data cannot be considered a "snapshot in time" of water quality.
- Aquifer designations determined using the MCPAIS may differ from those given in the source water-quality databases. Efforts should be made to resolve the differences.
- Many wells were determined to be completed in confining units. This may be caused by locational errors, screened intervals spanning aquifer-confining unit boundaries, or other factors. Resolving these discrepancies should focus on wells with chemical concentrations anomalously high or exceeding MCL or SMCL levels.

ACKNOWLEDGMENTS

The acquisition, formatting, and processing of the groundwater-quality data prepared in this project was made possible by many people. The authors would like to express gratitude to the Environmental Health Directors of Maryland's coastal plain counties for providing information on their groundwater-quality databases. In particular, Kerry Topovski, Bill Dehn, and Bridget Nadolny (AAHD), Richard Rhoads and Dennis Dicintio (WIHD), and Robert Mitchell (WOHD) provided data and other information from their respective counties. Nancy Reilman (MDE) provided datasets from the PDWIS database.

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Appendix A. Survey of groundwater-quality data from county health department databases for counties within Maryland's coastal plain.

County	How are water-quality data stored?	How long are water-quality data retained?	Are raw-water samples identified separately from post-treatment water?	Are well permit numbers identified for the sampled wells?
Anne Arundel	Paper and digital	Paper-3 years Digital-indefinitely	Only raw water is sampled, unless exceedance of an MCL warrants treated sampling. Treated samples are identified as such.	Yes. Some wells without permit numbers have also been sampled.
Baltimore	Digital (both in an Oracle-based database and as tiff images)	In perpetuity	Yes, in some cases. It depends on whether it was noted by the collector.	Yes, in most cases. Some wells do not have permit number, so the address is used as well.
Calvert	In hard copy attached to each property file - usually test result sheets from the State lab or printed reports from private labs.	Paper copies of test results (primarily bacterial and some inorganic minerals) are retained in the files dating back into the mid to late 1970s.	Yes. Nearly all are raw water except for occasional tests to verify treatment adequacy (arsenic treatment, for example).	Yes, in all COP samples for new and replacement wells as permit numbers are found on attached permits/completion reports/COP's. For request samples (day care, adoption, curiosity, etc.), permit numbers may be included in the files if permits/completion reports are attached, but are not routinely identified or verified.
Caroline	PatTrac and paper file	Forever	Yes, an example is raw water arsenic sample and post R.O. treatment unit	Yes
Cecil	Paper	Forever	Not consistent historically. Recent samples (<10 years) identify treated samples, older samples may or may not indicate treatment.	Inconsistent
Charles	Data entered in custom PatTrac. Hard copies scanned into Docstar.	Forever	Yes	Yes

Appendix A. Continued.

County	Do the sampled wells have locational information?	Do you know of any other sources of water-quality data in your county?	If coordinates are given, what is the source?
Anne Arundel	Yes. Latitude/longitude, address, Tax map/block/parcel	No	GPS
Baltimore	Usually have street address and in some cases may have coordinates generated by a Trimble GPS unit.	Watershed Management and Monitoring Section handles water-quality data collected from streams that is used for TMDL and NPDES requirements. There is ongoing monitoring from wells at Eastern Sanitary Landfill, Hernwood Landfill and Parkton Landfill. These are compiled in annual reports for MDE submittal.	Trimble Geo XT GPS, State Plane 1983 HARN MD FT
Calvert	All samples include street addresses, tax map/parcel numbers and lot/block/section information. Some info is on the sample forms, while others are contained in the property file. Coordinate information is typically only on permit applications for new/replacement wells.	Municipal water supplies operated by the county or private operators usually are sampled for a much broader range of constituents than are individual domestic and commercial wells.	Typically, coordinate information is provided by the well driller on permit applications. The source varies and can include map coordinates and GPS using newer devices to capture.
Caroline	Street address	No	Street address
Cecil	Street address only	MDE PCO and PNC data	N/A
Charles	Yes	*Not answered*	GPS and street

Appendix A. Continued.

County	Is the sample source identified?	Are total and dissolved constituents identified?	Are constituent units identified?	Is land-elevation given for the well site?
Anne Arundel	Only wells are tested.	No	All results are in mg/L, except pH, bacteria, radionuclides, etc, where not appropriate. Units may not be identified in database, but are in letters sent to the homeowners.	No
Baltimore	Yes	Yes	Yes	No
Calvert	Yes.	Yes. Usually when requested for specific tests.	Yes.	No. It may be determined by referring to the county GIS to obtain approximate site elevations.
Caroline	Yes	*Not answered*	*Not answered*	No
Cecil	Yes	No, most only test nitrate and turbidity	Yes, standard State lab form	No
Charles	No	No	mg/L	No

Appendix A. Continued.

County	Alkalinity	Aluminum	Ammonia	Antimony	Arsenic	Barium	Beryllium	Bromide	Cadmium	Calcium	Chloride
Anne Arundel	<10	10-100		10-100	100-1000	10-100	10-100		100-1000		>1000
Baltimore	10-100	10-100	10-100	10-100	10-100	10-100	10-100	10-100	10-100		100-1000
Calvert	10-100				100-1000					100-1000	100-1000
Caroline					100-1000						
Cecil	10-100	10-100			10-100		10-100		10-100		10-100
Charles											

Appendix A. Continued.

County	Chromium	Copper	Dissolved oxygen	Fluoride	Gross Alpha Particle Activity	Gross Beta Particle Activity	Iron	Lead	Magnesium	Manganese
Anne Arundel	10-100				>1000		>1000	10-100	10-100	10-100
Baltimore	10-100				100-1000	100-1000	100-1000	10-100	10-100	10-100
Calvert		10-100		<10	<10	<10	100-1000	100-1000	100-1000	<10
Caroline							100-1000			
Cecil					10-100		100-1000			10-100
Charles										

Appendix A. Continued.

County	Mercury	Nitrate	Nitrite	pH	Potassium	Radium-226	Radium-228	Selenium	Silica	Silver	Specific Conductance
Anne Arundel	10-100	>1000	100-1000	>1000		100-1000	100-1000				100-1000
Baltimore	10-100	>1000	10-100			10-100	10-100				
Calvert		>1000	>1000	>1000	<10	<10	<10				<10
Caroline		>1000		>1000							
Cecil		100-1000	10-100	100-1000							
Charles			>1000								

Appendix A. Continued.

County	SOCs	Sodium	Sulfate	Thallium	Total dissolved solids	Turbidity	Uranium	VOCs	Zinc
Anne Arundel	10-100		10-100	10-100		>1000		100-1000	<10
Baltimore	10-100	10-100	10-100		10-100	>1000	10-100	100-1000	10-100
Calvert	<10	10-100	<10	<10	10-100	>1000	<10	10-100	<10
Caroline					100-1000	>1000			
Cecil		10-100			10-100	100-1000			10-100
Charles						>1000			

Appendix A. Continued.

County	How are water-quality data stored?	How long are water-quality data retained?	Are raw-water samples identified separately from post-treatment water?	Are well permit numbers identified for the sampled wells?
Dorchester	New well samples (including replacements) are entered in an Access database. Others are often paper records.	Indefinitely	Generally yes.	New well samples are related to the well permit number. Others are often not.
Harford	Paper and digital	Digital data is not purged. The residential property paper files are also maintained continuously. However, the TNCWS files have their paper records purged after 5 years, but their data is maintained.	In most cases yes.	In most cases yes.
Howard	Generally, it may be a combination of some paper storage which then would be entered or scanned into a digital version.	At this point, if they have been scanned into a digital version or directly entered into a computer spread sheet, there is no timetable for expulsion of data.	Generally yes - sample forms would indicate a pre or post treatment collection.	If samples are collected during yield tests, then yes. If collected or submitted as part of an Interim COP, they would be grouped with property and generally some reference to tag numbers would occur. If sampled beyond, then more likely a property address would be the main identifier.
Kent	Paper, current data base PatTrac for well-water samples.	All water-quality data is kept indefinitely at this time. Bacteria samples forms for the Transient Non Community Water program follow a 5 year retention schedule.	Yes, when known by sampler.	Currently in the database only or if property has multiple wells in service.
Prince George's	Digitally only for new wells or complaints. Paper files-new wells and complaints only	Forever	Only collect raw water samples	Yes

Appendix A. Continued.

County	Do the sampled wells have locational information?	Do you know of any other sources of water-quality data in your county?	If coordinates are given, what is the source?
Dorchester	Generally yes.	Public water supplies: MDE, City of Cambridge, Towns of Hurlock, Secretary, East New Market and Vienna. Existing geological reports	New well samples are related to the completion report which includes GPS coordinates. Others would be street address.
Harford	All samples would have a street address. Newer wells have their GPS coordinates recorded on the Well Completion Reports in decimal degrees.	*Not answered*	The GPS of the actual well location.
Howard	Could be a combination depending upon our reason for sampling. Generally after a property is in existence and occupied, the address would be the main locational information. If in a subdivision, there may be a subdivision name and lot number. We have also been locating wells through GPS for a number of years, so some may also have coordinates attached. But this info may be contained in different data bases.	May have some in the County's Public Works Dept. Environmental Services who oversee landfill and consulting contracts for various projects Environmental Assessment.	GPS
Kent	On paper form sampler uses at least two forms of identification minimum; street address and current owner last name. Tax map and/or parcel may be incorporated into the sample number.	Municipal water supplies.	Coordinates are recording in the well permit in the database. This information is provided by the well driller. Currently, most drillers are using Google Earth to gather this information. However not all wells have coordinates in the database.
Prince George's	Yes, currently latitude/longitude, street address, and previously Maryland grid coordinates.	Maybe USGS	GPS

Appendix A. Continued.

County	Is the sample source identified?	Are total and dissolved constituents identified?	Are constituent units identified?	Is land-elevation given for the well site?
Dorchester	Yes	*Not answered*	Yes	New wells yes, others no.
Harford	Yes	No	Yes	No.
Howard	Probably yes to some extent. We do very little spring and surface water testing - most would be residential or TNCWS	Sometimes. If our focus is on TDS or sodium and chlorides	Would use conventional lab units, however, units may not always entered.	Generally almost always no.
Kent	Yes, check boxes on forms.	No. Kent County does not regularly test for this in the well program. There are random results in the paper files and database.	On paper form yes. In the database no.	No, only well head stickup is required.
Prince George's	Yes by address	No	yes, ug/L	No

Appendix A. Continued.

County	Alkalinity	Aluminum	Ammonia	Antimony	Arsenic	Barium	Beryllium	Bromide	Cadmium	Calcium	Chloride
Dorchester					>1000						>1000
Harford											
Howard				10-100	10-100	10-100	10-100	<10	10-100	10-100	100-1000
Kent	100-1000	<10			>1000	<10	<10	<10	<10	<10	>1000
Prince George's											

Appendix A. Continued.

County	Chromium	Copper	Dissolved oxygen	Fluoride	Gross Alpha Particle Activity	Gross Beta Particle Activity	Iron	Lead	Magnesium	Manganese
Dorchester				10-100						
Harford										
Howard	10-100	10-100		10-100	>1000	>1000	100-1000			100-1000
Kent	<10	<10		100-1000			>1000	100-1000	<10	<10
Prince George's							>1000			

Appendix A. Continued.

County	Mercury	Nitrate	Nitrite	pH	Potassium	Radium-226	Radium-228	Selenium	Silica	Silver	Specific Conductance
Dorchester		>1000		>1000							
Harford		10-25									
Howard	10-100	>1000	100-1000	>1000	10-100	100-1000	100-1000	10-100		10-100	
Kent		>1000	100-1000	>1000	<10						
Prince George's		>1000		>1000							

Appendix A. Continued.

County	SOCs	Sodium	Sulfate	Thallium	Total dissolved solids	Turbidity	Uranium	VOCs	Zinc
Dorchester					10-100	>1000		10-100	
Harford						10-25		10-15	
Howard		100-1000			100-1000	>1000	10-100	100-1000	10-100
Kent	10-100				10-100	>1000		10-100	
Prince George's						>1000			

Appendix A. Continued.

County	How are water-quality data stored?	How long are water-quality data retained?	Are raw-water samples identified separately from post-treatment water?	Are well permit numbers identified for the sampled wells?
Queen Anne's	Paper and digial	Indefinitely	Almost all samples are raw water but treated is not identified	Yes
Somerset	Paper files	As long as well is in use	Yes	Yes
St. Mary's County	Digital	Indefinitely	Yes, if required for Certificate of Potability, but this is not routine.	Yes
Talbot	We store data in a digital database (PatTrac). We also retain paper copies in our records (Tax Map and parcel files) which are scanned into our database.	The records are never purged.	Yes. On the lab submittal form.	Not Always.
Wicomico	PatTrac - SQL based	Indefinitely	Yes, when necessary. Our county does not allow deviations to nitrates or coliform.	Yes
Worcester	Digital-in an Access-like program.	Forever.	Most of the water samples (since 1990) are raw water samples. It is noted if the sample is treated.	Yes

Appendix A. Continued.

County	Do the sampled wells have locational information?	Do you know of any other sources of water-quality data in your county?	If coordinates are given, what is the source?
Queen Anne's	Yes street address and tax map	No	*Not answered*
Somerset	Street address or tax map and parcel until a couple of years ago. Now use latitude/longitude.	No	GPS
St. Mary's County	Yes, latitude/longitude, street address, and tax map	The Metropolitan Commission (public water/sewer utility)	GPS
Talbot	Older records have the Tax Map and Parcel numbers and/or street address. Newer records will have latitude/longitude coordinates (2011 to current).	*Not answered*	GPS in decimal degrees
Wicomico	Yes. GPS coordinates are entered from well permits and stored in database.	Only private labs that are used during real estate transactions.	GPS, lat/long in decimal format.
Worcester	The sample location is identified by Tax Map and Parcel, road. Within the last few years, the GPS coordinates have been added to the database.	No	MD Merlin or Google Maps.

Appendix A. Continued.

County	Is the sample source identified?	Are total and dissolved constituents identified?	Are constituent units identified?	Is land-elevation given for the well site?
Queen Anne's	Yes	No	Yes	No
Somerset	Yes	No	Yes	No
St. Mary's County	Yes	On requests only.	Yes	No
Talbot	Usually on the lab slip	No	Yes	No
Wicomico	Yes, mostly individually water supplies.	No	mg/l or ppm	No
Worcester	It has only wells and the name of the property-no springs or surface water used here.	PH, Fe, Cl and NO3	Yes	No

Appendix A. Continued.

County	Alkalinity	Aluminum	Ammonia	Antimony	Arsenic	Barium	Beryllium	Bromide	Cadmium	Calcium	Chloride
Queen Anne's					100-1000						
Somerset											>1000
St. Mary's County	<10				>1000						
Talbot	>1000				100-1000						>1000
Wicomico	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	10-100
Worcester											>1000

Appendix A. Continued.

County	Chromium	Copper	Dissolved oxygen	Fluoride	Gross Alpha Particle Activity	Gross Beta Particle Activity	Iron	Lead	Magnesium	Manganese
Queen Anne's							>1000	<10		
Somerset							100-1000			
St. Mary's County				10-100			10-100	10-100	10-100	
Talbot				10-100				10-100		
Wicomico	<10	10-100	<10	<10	<10	<10	>1000	10-100	<10	<10
Worcester							>1000			

Appendix A. Continued.

County	Mercury	Nitrate	Nitrite	pH	Potassium	Radium-226	Radium-228	Selenium	Silica	Silver	Specific Conductance
Queen Anne's		>1000									
Somerset		>1000		>1000							
St. Mary's County		>1000								10-100	
Talbot		>1000									
Wicomico	<10	>1000	<10	100-1000	<10	<10		<10	<10	<10	<10
Worcester		>1000		>1000							

Appendix A. Continued.

County	SOCs	Sodium	Sulfate	Thallium	Total dissolved solids	Turbidity	Uranium	VOCs	Zinc
Queen Anne's								<10	
Somerset						>1000			
St. Mary's County						>1000		10-100	
Talbot						>1000		<10	
Wicomico	<10	10-100	<10	<10	10-100	>1000	<10	>1000	<10
Worcester									

APPENDIX B.

Additional Information on Data Sources for Groundwater-Quality Data from Anne Arundel and Wicomico Counties, Maryland

1. Anne Arundel County Health Department (AAHD) data (worksheet "AAHD data" in Excel file "AA_WI_ all_data.xls")

- Hardness, nitrate, chloride, iron are in milligrams per liter (mg/L). Arsenic and cadmium are in micrograms per liter (µg/L). Gross alpha particle activity (GAPA) and radium values are in picocuries per liter (pCi/L). Hardness is total hardness in mg/L.
- A zero for the result means either that there was no result, or that a private lab result was a non-detect. A non-detect is entered that is just below the minimum detection limit (MDL). For example, the MDL for Cadmium is 2.0 µg/L. A non -detect would be entered as 1.99. Iron is listed in mg/L and is reported up to a maximum concentration of 10 mg/L. A 10 would indicate that the level is 10 mg/L or more, but there is not a way to denote that in the AAHD system. Iron values that are greater than 10 were likely analyzed at a private laboratory.
- Sample dates:
    - **ArDate** = Arsenic Sample Date
    - **CadDate** = Cadmium Sample Date
    - **AlphaRDate** = Gross Alpha Raw Sample Date
    - **RRawDate** = Radium 226/228 Raw Sample Date
    - **ChemDate** = Chemical Sample Date (Iron, Turbidity, Nitrate/Nitrite, Chloride, Hardness)
    - Private lab sample results may not have a date values entered. Some dates are entered in as "00000000" which indicates AAHD did not receive a result or a date was not entered in error. Dates entered in as "99999999" indicate the well sampling was not completed and have been marked as an inactive file (usually due to well owner not responding).
- All the pH and specific conductivity measurements were taken in the field. pH testing was done with reagents and conductivity was measured using a meter. **SpecCond** data is the field-collected values using a meter. The **CondVal** is a value that is sometimes included on private lab results for chemical testing of new or replacement wells. This field is not consistent.
- **Welltype** (**C** = closed loop geothermal, **D** = domestic, **F** = farm, **G** = geothermal, **I** = Industrial, **P** = public, and **T** = Test)
- **Latitude/longitude** coordinates in decimal degrees were determined by the well driller (method used not reported). AAHD has indicated that these values are not accurate enough for their GIS purposes.
- **Depth** is the total well depth.
- **NitVal** is nitrate or total nitrate+nitrite (undifferentiated) depending on the testing lab.
- **CondVal** is a value that is sometimes included on the general chemical results report for a water sample of a new or replacement well. Only a few labs include this value so entries are rare.
- **SpecCond** is a specific conductivity measurement AAHD made in the field using a meter at the time a water sample was collected for GAPA. AAHD only collected specific conductance during the initial testing years of GAPA and radium.
- **IronVal** indicates total iron.

- **CadpH** and **ArpH** is the pH value from the field using reagents when a water sample was collected for either lab test.
- **AlphaRawVa** is the results of that sample from a raw-water source. There was a period when AAHD collected and tested water samples from a treated source to ensure the treatment system was functioning effectively. They did not include that information in this data set. **AlphaRaw** indicates a raw-water source (unused field).
- **AlphapH** is the pH value measured in the field at the time a water sample was collected for GAPA.

2. Wicomico County Health Department (WIHD) data (worksheet "WIHD data" in Excel file "AA_WI_ all_data.xls")

- The data from the WIHD contains predominantly nitrate data in parts per million (ppm) for residential domestic wells. All of the data represents unfiltered (raw) water samples. The majority of the more recent data have GPS coordinates that were based on a review of the well permits. Coordinates with longitude values lacking the "minus" sign were likely determined by the well driller. All of the other location data is based on 911 addresses associated with a tax map property ID.
- Non detects are typically reported as 0 or in some instance as "<".

3. U.S. Geological Survey NWIS database (worksheets "AA_USGS data" and "WI_USGS data" in in Excel file "AA_WI_ all_data.xls")

- Units of measurement in the USGS dataset are indicated in the column headers. Generally, major ions are in milligrams per liter, trace elements are in micrograms per liter, nitrogen species are in milligrams per liter as total nitrogen, and radionuclides are in picocuries per liter.
- The **GUNIT** code is an aquifer code that is assigned by the sampler when the sample is logged into the system. It is often, but not always, the same as in the column labeled **aquif_AIS** which is the aquifer determined from the MCPAIS.
- There are several designations for nitrogen, alkalinity, and other constituents. Filtered nitrate+nitrite was used when present; if not present, then either unfiltered nitrate-plus-nitrite or filtered nitrate was used. (Nitrite is negligible in most cases.) **Alkalinity** and **Acid-neutralizing capacity (ANC)** are considered the same (difference is that alkalinity is filtered while ANC is unfiltered). We assume that virtually all alkalinity/ANC is bicarbonate, given the pH ranges encountered here.

4. Maryland Geological Survey data (worksheets "MGS Arsenic" and "MGS Cadmium" in in Excel file "AA_WI_ all_data.xls")

The arsenic worksheet includes 26 sites that were sampled for arsenic and one site that was resampled for major ions. The cadmium worksheet contains data from 21 wells.

APPENDIX C.

Additional Information on Data Sources for Groundwater-Quality Data from Worcester County, Maryland

1. Worcester County Health Department data (worksheet "WO Co HD" in Excel file "WO_all data.xls")

NO3_N = nitrate, in milligrams per liter (mg/L) as N.

NO3ExactRe:

If = 0, then NO3_N equals the value in the NO3_N column

If = 1, then NO3-N is less than value listed in NO3_N column.

Cl = chloride concentration, in mg/L

CLExactRea: Health Department personnel did not know what this indicates. It does not appear to indicate "less than" values.

Fe = iron concentration, in mg/L

FeExactRe:

If = 0, then Fe equals the value in the Fe column

If = 1, then Fe is less than value listed in Fe column

2. U.S. Geological Survey data (worksheet "USGS data" in Excel file "WO_all data.xls")

Worksheet includes all data from all wells in USGS-NWIS database, retrieved 5/30/2017. Units for each constituent are specified in the worksheet.

GUNIT = geologic unit as listed in NWIS-GWSI database. These units were not used in our GIS work. Hydrogeologic units were determined using MCPAIS information in conjunction with well construction and elevation data.

3. Town of Ocean City data (worksheet "Town of Ocean City data" in Excel file "WO_all data.xls")

Worksheet includes iron, chloride, and pH data for wells supplying the Town of Ocean City (J. Thompson, Whitman Requardt & Associates, LLP, written commun., 9/1/17). Data include samples collected between May and August, 2017.

4. Maryland Department of the Environment data:

a. Original format (worksheet "MDE original data" in Excel file "WO_all data.xls")

Each line represents an individual constituent analysis for each sampling event. The "Concatenated formula" column contains the formula used to determine the constituent concentration (if greater than the detection level indicated in columns N and O) or the less-than value if below the detection level. The "Concatenated value" column is simply the number determined by the "Concatenated formula."

b. Transposed data (worksheet "MDE transposed data" in Excel file "WO_all data.xls")

Each line contains all constituent concentrations from a single sampling event. This worksheet was generated using the "Consolidate" command on the data from the "MDE original data" worksheet. "Less than" symbols (<) have been replaced by negative signs to facilitate use in ArcGIS.

5. Maryland Geological Survey data (worksheet "MGS data" in Excel file "WO_all data.xls")

Data were collected in 2001 and 2002 as part of a Maryland Coastal Plain study of arsenic in all major aquifers. Specific conductance (Spc), pH, dissolved oxygen (DO), and hardness were measured in the field by MGS personnel. Arsenic analysis was by Maryland Department of Health and Mental Hygiene (now the Department of Health) Laboratory in Baltimore.

A message to Maryland's citizens

The Maryland Department of Natural Resources (DNR) seeks to balance the preservation and enhancement of the living and physical resources of the state with prudent extraction and utilization policies that benefit the citizens of Maryland. This publication provides information that will increase your understanding of how DNR strives to reach that goal through the earth science assessments conducted by the Maryland Geological Survey.

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