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COMPILATION AND REVIEW OF GIS-BASED GROUND-WATER QUALITY DATA FROM MULTIPLE DATABASES FOR GARRETT COUNTY, MARYLAND

by

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Prepared in cooperation with the
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KEY RESULTS

An ArcGIS database of ground-water quality data was constructed for Garrett County, Maryland. Data sources included the Garrett County Health Department PatTrac database and radon records, the U.S. Geological Survey National Water Information System, the Maryland Department of the Environment Public Water Supply database, and the Maryland Geological Survey methane database. Data were obtained from more than 2,200 sites (including both wells and springs). Four parameters—arsenic, chloride, manganese and radon—were selected for a more focused review and analysis by both geographic information system (GIS) and statistical methods. These and other constituents were examined with respect to regulatory levels. Key results from this project are as follows

- Arsenic concentrations exceeded the Maximum Contaminant Level of 0.010 milligrams per liter in about 7 percent of sites sampled. About 20 percent of sites in the Hampshire Formation exceeded the Maximum Contaminant Level; the exceedance rate was less than 8 percent for the other geological formations.

- Chloride concentrations of sites exceeded the Secondary Maximum Contaminant Level of 250 milligrams per liter in about 3 percent of all sites.

- Manganese exceeded the Secondary Maximum Contaminant Level of 0.050 milligrams per liter in about 55 percent of all sites. The highest percentage of manganese exceedances was from the Pottsville Formation (about 70 percent), and the lowest was from the Hampshire Formation (39 percent). Manganese and iron concentrations were positively correlated.

- Radon exceeded 4,000 picocuries per liter in samples from three sites, with a maximum of 32,800 picocuries per liter.

- Maximum Contaminant Levels were exceeded at a small number of sites for barium, fluoride, lead, nitrate, nitrite, gross alpha-particle activity, and radium-226-plus-radium-228. Many of these exceedances were from monitor or observation wells, rather than water-supply wells.

- Additional data review and/or water-quality testing is recommended for sites where very high concentrations of regulated water-quality constituents were observed.

- Lack of information on sampling, collection, and analytical procedures limits the amount of interpretation possible on the combined data set.

- Baseline water-quality testing is recommended for private wells prior to the development of the Marcellus Shale for natural gas. This would provide a basis for determining if ground water has been altered by gas-development activities.

- Garrett County should consider conducting a sampling program to test a representative number of private wells for regulated chemical constituents that are not currently tested in order to better assess and characterize concentrations of these chemicals in ground water in the county. This is recommended regardless of whether the Marcellus Shale is developed or not.

- Additional documentation and refinements of the Garrett County Health Department PatTrac database could help facilitate construction of a more robust geographic information system-based information system. This includes addition of data fields for water-sample type and source, and more information on location and elevation data, well-permit number, constituent units, and verification of property information.

- The databases used in this study, which were derived from different county, state, and federal government sources, required extensive reformatting in order to link them to one another. Data interoperability would be greatly enhanced by developing and implementing strategies for better linkages between databases.

INTRODUCTION

In Garrett County, the potential development of the Marcellus Shale for natural gas production has increased the awareness of ground-water quality and the risks that such development may pose in the region. The first step in any evaluation of water resources is to obtain and evaluate existing data so that issues may be identified and data gaps noted. Toward this end, in 2013 and 2014, the Maryland Geological Survey (MGS; a unit of the Maryland Department of Natural Resources) began collecting and assembling available Garrett County ground-water quality data from multiple sources and incorporating the data into an ArcGIS format.

Ground-water quality data are collected throughout Maryland by local, state, and federal agencies and organizations. These data are collected for different purposes, using different collection protocols, analytical techniques, and detection and reporting levels. For example, new private water wells in Garrett County are tested by the Garrett County Health Department (GCHD) for nitrate, bacteria, arsenic, and other constituents prior to being issued a Certificate of Potability. Public-supply wells are tested for constituents with drinking water standards established by the U.S. Environmental Protection Agency (USEPA). In addition, local and regional ground-water studies have been conducted by state and local agencies to investigate specific research topics. The data are stored in different locations, using different formats (both paper and electronic), and include different types of ancillary data, depending upon the needs of the collecting agencies.

PURPOSE AND SCOPE

The purpose of this study was to acquire and evaluate (to the extent possible) existing ground-water quality data in Garrett County from available sources, including the GCHD, the Maryland Department of the Environment (MDE), the U.S. Geological Survey (USGS), and the Maryland Geological Survey. Site-specific information, including well-permit numbers and well-construction data, were also obtained. These data were compiled into a geographic information system (GIS) using ESRI's ArcGIS software. ArcGIS files, including map layers and displays, were generated, with input from GCHD. This report discusses, for each data source, how the data were acquired, processed, and edited, and how the data were incorporated into ArcGIS. The ArcGIS files and related files were provided to the GCHD along with this report. Graphic displays were developed for four constituents requested by the GCHD (arsenic, radon, chloride, and manganese). Other inorganic and organic chemical data are evaluated with respect to Primary and Secondary Maximum Contaminant Levels (MCLs/SMCLs). Recommendations are made regarding collection of additional water-quality and other data to enhance GCHD's PatTrac database. This report is a deliverable to MDE, under the terms of Agreement AR/H 13-002. The report has not been peer-reviewed.

LOCATION OF STUDY AREA

Garrett County, the westernmost county in Maryland, is located in the Appalachian Plateau Physiographic Province (fig. 1). The region is underlain mostly by gently folded Paleozoic sandstones, siltstones, and shale, with smaller amounts of coal and limestone. A series of northeast-southwest-trending anticlines and synclines form the geologic structure of the area. Pennsylvanian-age rocks (including coal beds) are exposed along the axes of the synclines, and Devonian-age rocks are exposed along the axes of the anticlines.

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GROUND-WATER QUALITY DATA

SOURCES OF DATA

Water-quality data were compiled from five sources: (1) the GCHD PatTrac database; (2) well-water radon data collected by GCHD; (3) the USGS National Water Information System (NWIS); (4) the MDE Public Water Supply Program; and (5) data collected by MGS as part of a study of methane in well water. These data sets are described below and are summarized in table 1.

Garrett County Health Department PatTrac Database

Ground-water quality data collected by GCHD is stored in the client-management software package PatTrac. Several springs and surface-water sites (public swimming areas) are also included in the database. The database used in this project includes well-water samples collected between August 1995 and April 2013. The database consists of 1,771 wells and a total of 5,334 water analyses. Most wells were sampled multiple times. The PatTrac database includes alkalinity (as $CaCO_3$), arsenic, chloride, conductivity, coliform and fecal coliform bacteria, fluoride, hardness (as $CaCO_3$), iron (total), manganese (total), nitrate, nitrite, hardness, pH, total solids, and turbidity. Not all samples were analyzed for all constituents. The samples were collected by GCHD and analyzed by the Maryland Department of Health and Mental Hygiene (DHMH) laboratory. The database includes samples taken before and after treatment along with follow-up samples. Typically, the initial sample collected is "raw" (untreated) water, and subsequent samples are collected post-treatment to determine the effectiveness of the water treatment.

In compiling the data set for this project, some modifications were made to the original database. Changes made include refinements to well-location coordinates using satellite imagery and Maryland property-map information (property addresses and centroid coordinates), adding missing well-permit numbers, removal of sites with no permit numbers, removal of sites where locations could not be accurately determined, and other minor corrections. A detailed list of changes made is provided to GCHD as part of the GIS deliverables.

Garrett County Health Department Radon Data

Well-water radon samples were collected from 289 wells between 1994 and 1998 by GCHD personnel (37 wells whose locations could not be verified were not included in the data set). The radon data were recorded in paper files at GCHD and were summarized in a printout of an electronic spreadsheet that also included owner names, tax map/grid/parcel numbers, property acreage, and 911 street addresses (for some wells). Because the original electronic spreadsheet was not available, the printout was scanned into an Excel spreadsheet, and well-permit numbers, radon sample dates, and location coordinates were added to the spreadsheet. Addresses were verified and modified or added as necessary, based on tax map and parcel information. The location of each radon sample represents the location of the centroid of the house on the property as determined from the Garrett County database for 911 addresses. The 911 address centroid is typically closer to the well than the location of the property centroid, particularly for larger properties. Two radon measurements were usually made at each site; in this report, discussion of radon values refers to the average of the two values (if more than one sample was collected).

U.S. Geological Survey National Water Information System

Data were retrieved from the USGS NWIS. One hundred and sixty-six water-quality records were retrieved from 105 wells and springs in Garrett County. These data were all assumed to be untreated water samples. The data were collected between 1946 and 2012, although most samples were collected since 1993. Data retrieval was conducted on September 22, 2013. Water-quality constituents include inorganic constituents (major ions and trace elements), pesticides and other organic compounds, and radionuclides. Not all samples were tested for all constituents; the majority of the samples were tested only for inorganic constituents. The samples come from a variety of sources, including private water-supply wells, public-supply wells, monitor wells, and springs.

Maryland Department of the Environment Public Water Supply Data

MDE's Water Management Administration, Water Supply Program, provided data extracted from the Public Drinking Water Information System (PDWIS) database for use in this project. The extracted data were transferred as a set of separate Microsoft Access tables accompanied by a set of portable document format (PDF) files defining the table attributes and structures. The various tables included information on water-quality analyses, water sources, water-treatment plants (WTPs), and code and contaminant definitions. The dates of water-quality samples in the data provided range from January 8, 1990, to July 29, 2013. The project-specific data derived from information provided by MDE is referred to as the MDE Public Water Supply (MDE-PWS) data set.

In compiling the MDE-PWS data set for this project, an effort was made to determine which analyses corresponded to raw or untreated water samples and the source or location of each sample. This required relating and joining data from separate tables in order to query and extract pertinent records. Water sources include wells, springs and surface water. Water from some sources is routed to WTPs for processing and subsequent distribution. Many plants have more than one water source. Geospatial coordinates were not available for all sources and all plants. Those without coordinates were not included in this study.

It should be noted that information on "plants" and their locations is not limited strictly to WTPs. Coordinates for locations of "purchased water" that supplies a public water system in Garrett County are also provided. In addition, where a plant's specific location had not been officially recorded, or where a multi-source water system does not have a centralized plant, an estimated central position was provided by MDE. A few plants close to, but outside of, the county boundary were included in this study because their data had the potential to provide information on regional natural water quality. A file of all "plants" (WTPs, purchased water, and representative system centroids) that appear to pertain to Garrett County and have coordinates is included in the GIS files for this study. Based on unique plant identifiers there are 168 plants in this file. The method MDE used for determining the coordinates used for each "plant" is identified in the attribute table in the associated ArcGIS feature class.

Most of the analytical results for volatile organic chemicals (VOCs), synthetic organic chemicals (SOCs), inorganic chemicals (IOCs) and radiological parameters could be traced back to samples collected at a particular plant. At some plants, sampling was conducted many times and at different places in the water system. In many cases the record of a sampling event had sample-location information, sampling remarks, or a notation about raw or finished water that provided guidance as to whether the sample represented raw/untreated water or not. Most analyses for VOCs, SOCs, IOCs and radiological parameters were conducted on water samples collected post-treatment, referred to as "finished" water. For samples that did appear to be raw water and were collected from a plant with multiple sources, it was not always clear which source (or combination of sources) was sampled. Data on the plants did provide information on treatment processes at each plant. Where "no treatment" was indicated for a particular plant, water sample(s) from that plant were considered relevant for this project even though these water samples could represent more than one source and may have been considered "finished" water.

Because the data could not be consistently and unequivocally traced back to a particular water source, the VOC, SOC, IOC, and radiological data from MDE were linked to plants and their locations. Any

analytical results that could not be linked to a plant or source with coordinates were removed. The use of plant coordinates to geospatially locate these parameter results is in contrast to other data sets in this study in which water-quality data are linked to sources, primarily specific water wells and their coordinates.

The results of analyses for arsenic, chloride, manganese and radon were extracted from the IOC and radiological data sets for particular focus in this study. This subset of parameters is provided as a separate GIS feature class from its "parent" data set. In this data set there are 103 records, each representing one sample in which of one or more of these four parameters were analyzed. These 103 samples were collected from 55 different plants and represent a sampling frequency at each plant that varied from one to 12 times.

The water-quality data from MDE also included samples analyzed for ground water under the direct influence of surface water (GWUDI). Maryland evaluates new ground-water systems for vulnerability to surface-water contamination. Untreated raw water samples are analyzed for E. coli, turbidity, temperature, and pH. Data associated with GWUDI samples do have sources identified so these analyses are tied to coordinates for their respective sources.

Like the sampling for the MDE parameters discussed above, sampling for GWUDI testing was often repeated at the same site through time. In the original file of GWUDI sample results, there were 994 records (each representing a sample) that were collected from a total of 178 sources. This reflects a sampling frequently at each source that ranged from once to 29 times. Three of these sources, however, did not have coordinates so records of 962 samples collected from 175 sources are included in the GIS files provided with this study.

Maryland Geological Survey Methane Data

Water samples from 69 wells in Garrett County were collected by MGS staff in 2012 and 2013 as part of a study of methane in well water in the Maryland Appalachian Plateau. Laboratory-analyzed constituents included methane, ethane, ethene, propane, n-butane, and isobutane (although not all samples were analyzed for n-butane and isobutane). Laboratory analyses were conducted by ALS Environmental[1] of Middletown, Pennsylvania. Field measurements included alkalinity, chloride, hardness, specific conductance, pH, and dissolved oxygen. All analyses were performed on unfiltered and untreated water.

DISCUSSION OF SELECTED GROUND-WATER QUALITY DATA

Four water-quality constituents (arsenic, chloride, manganese, and radon) were selected for evaluation with respect to geology and other factors, at the request of the GCHD. These constituents were selected for the following reasons:

- Arsenic, a known carcinogen, routinely exceeds the USEPA's MCL of 10 micrograms per liter (μg/L) in Garrett County well water. All new wells in Garrett County are tested for arsenic prior to issuance of a Certificate of Potability.

- Chloride concentrations may become elevated in ground water resulting from application of road deicing salts, and possibly other sources. In Garrett County, State-maintained roads and Interstate 68 are often treated with deicing salts during the winter months. Chloride levels exceeding 250 milligrams per liter (mg/L) have been reported from several wells in Garrett County. Furthermore, there are a small number of wells whose high chloride concentrations do not appear to be due to deicing salts, but rather from other sources such as naturally-occurring brackish water. High chloride concentrations in water can cause corrosion in appliances, and are

[1] The use of company names, tradenames, or product names in the report is for identification purposes only, and does not constitute endorsement by the Maryland Geological Survey.

commonly associated with elevated sodium concentrations, which may be detrimental to individuals on sodium-restricted diets.

- The GCHD requested an evaluation of manganese, citing an association of manganese with increased neural tube defects in fetuses and newborns (S. Sherrard, Garrett County Health Department, oral commun., 2013). Manganese and iron (which generally co-occurs with manganese in well water) are also nuisance contaminants that can cause discoloration of plumbing fixtures and laundry.

- Radon is a known carcinogen (World Health Organization, 2002). In the 1990's, well-water radon data had been collected from 263 wells around the county. Radon exceeded 28,000 picocuries per liter (pCi/L) in separate samples from one well, and several other wells had radon levels greater than 1,000 pCi/L.

Evaluation of the water-quality data are constrained by limitations of and differences between data sets. The data sets consist of samples that were collected by different organizations, using different sample collection, processing, reporting, and analytical methods and protocols (even within the same data set). Samples were collected for different purposes, including compliance monitoring, certificate-of-potability testing, and research projects. The type of well also varies by project; samples are from public and private water wells, observation wells, and springs. MGS has made no attempt to verify the accuracy of the water-quality data, nor have we verified transcription accuracy prior to collating the data at MGS. Although MGS has attempted to identify duplicate sites and samples in the different databases, it is possible that some sites may have been duplicated as a result of the use of different identifiers. For the MDE-PWS water-quality data, samples were linked to the water plant from which they were obtained, but they could not be uniquely linked to individual sources if the plant was connected to more than one well or spring or surface-water source. Furthermore, for some MDE-PWS sources that had no water treatment, the "plant" consisted of a centralized location near the sources rather than the location of an actual plant. As a result, the evaluation of water-quality data in this report is an overview rather than an in-depth analysis of the sources and/or causes of elevated constituent concentrations. Locations of sites having arsenic, chloride, manganese, or radon data are shown by data set in figure 2a. Locations of all sites from all databases are shown in figure 2b.

For the purpose of evaluating the concentrations of arsenic, chloride, manganese, and radon in this report, the following general methodology was used. (The generation of GIS map layers follows a different process). A spreadsheet was assembled from the separate data sets that included the concentrations of the four constituents, site identifiers, locations, and other relevant data. Each row represented one sample from one site (where a site was either a well, a spring, or a water plant). Many sites had several samples.

From this "master" spreadsheet, four separate constituent spreadsheets were created (one each for arsenic, chloride, radon, and manganese). Each constituent spreadsheet had more than one column for each constituent (for example, arsenic was reported as both "arsenic" and "filtered arsenic"), corresponding to how the data were reported in each original data source. These columns were combined into a single number representing one value per sample. When samples had more than one result for the same sampling event, the highest value was used (as with the NWIS data set, where most trace-element samples were analyzed for both filtered and unfiltered iron and manganese). When a site had data reported for different sampling dates, the sample with the highest concentration was used. This approach was taken because lower concentrations frequently represented treated samples, particularly in the PatTrac data set where there was no indication of which samples were treated or untreated. This also represents a conservative approach, whereby the data represent the "worst case" scenario for constituent concentrations. For chloride, when field-measured and laboratory-measured values were reported for the same sample, the laboratory-measured value was used, regardless of whether it was higher or lower than the field value, because the analysis was considered to be more accurate. Radon concentrations from the GCHD data set are averages of two samples collected sequentially at each site.

Arsenic

Arsenic concentrations were reported for 1,408 sites in Garrett County. Reported arsenic concentrations ranged from less than 0.002 mg/L (2 µg/L) to 8 mg/L (8,000 µg/L). Overall, about 7 percent of the wells (102 out of 1,408 sites) exceeded the USEPA MCL of 0.010 mg/L (fig. 3). Arsenic was detected in all geologic formations in Garrett County except the Harrell-Brallier-Sherr Formations (which had only one sample) (fig. 4). Geologic units cited in this report are from Brezinski and Conkwright (2013). Arsenic concentrations exceeded the MCL in all the geologic formations except the Harrell-Brallier-Sherr Formations; however, the highest percentage of exceedances was from sites in the Hampshire Formation (about 20 percent), compared with less than 8 percent for other formations (tab. 2; fig. 4). Overall, about 15 percent of the sites situated in Devonian-age rocks exceeded the MCL, while the Mississippian and Pennsylvanian formations had about 2 to 3 percent exceedances. Three sites (GA951085, GA942547, GA950758) exceeded 1 mg/L arsenic, which is an extraordinarily high value (more than 100 times the MCL). A follow-up sample on GA950758 (Greenbrier Formation) had an arsenic concentration of 0.007 mg/L, which may represent a post-treatment sample. There were no follow-up arsenic samples on GA942547 or GA951085. If records have not been retained to determine whether any of these values are the result of transcription errors, the County may wish to resample these wells.

Naturally-occurring sources of arsenic include arsenopyrite (in which arsenic is incorporated into the crystal structure of pyrite, an iron sulfide mineral) and other sulfide minerals such as realgar and orpiment. Coal beds, which often contain pyrite, are found in the Pennsylvanian-age rocks in the study area. Arsenopyrite is a common source of arsenic in ground water; if it is present in the coal seams of Garrett County, either it is in low concentrations or else other factors limit arsenic mobility in ground water. Ground-water arsenic in northeastern Ohio has been associated with reductive dissolution of and arsenic desorption from ferric hydroxides (Matisoff and others, 1982); however, the lack of clear correlation between iron and arsenic concentrations in Garrett County well water do not support this hypothesis (fig. 5). Identification of arsenic sources in ground water is complicated by the fact that arsenic has several oxidation states and can exist in both organic and inorganic forms.

Chloride

Samples with chloride concentrations from PatTrac and MDE-PWS data sets were not reported as either filtered or unfiltered; they were assumed to be unfiltered. Chloride analyses for these data sets were performed by the DHMH Environmental Chemistry Laboratory. MGS Methane data set chloride samples were analyzed on unfiltered samples and were analyzed by field titration with Hach titration kits. NWIS chloride values were on filtered samples and were analyzed at the USGS National Water Quality Laboratory (NWQL).

Chloride concentrations were reported from 1,799 sites in Garrett County. Concentrations ranged from less than 10 mg/L to 4,300 mg/L (tab. 3). Samples from 52 of the 1,799 sites (about 3 percent) exceeded the SMCL of 250 mg/L (fig. 6). Most of these sites are near Interstate or State-maintained roads, and likely have been affected by road salt or other surface-based sources of chloride. However, several of the samples from the NWIS data set are from wells that show indications of a different chloride source, such as brackish water (as determined by chloride/bromide ratios). Other potential sources of chloride to well water include septic-system discharge and agricultural chemicals. The percentage of sites with chloride concentrations greater than 250 mg/L varied between 0 and 5 percent among the geologic formations (tab. 3); the variation is likely more related to distribution of anthropogenic chloride sources than hydrogeological characteristics.

Garrett County should consider testing wells for bromide if the wells have elevated (greater than 100 mg/L) chloride concentrations. This may help to identify areas where the depth to base of fresh water is relatively shallow. Only 21 sites examined in this study had been tested for bromide. On-site measurements of chloride or specific conductance can be used to identify samples with elevated chloride, as there is a positive correlation between chloride and specific conductance (fig. 7). Several wells that do not fit this trend have high specific conductance values that are related to high sulfate rather than high

chloride concentrations; these samples are from the NWIS database and represent wells associated with coal-mining areas. Specific conductance is also closely correlated with total dissolved solids (fig. 8). Garrett County may also want to evaluate the relation between chloride concentrations and distance to roads (roads that regularly receive deicing salts as well as those that do not); this would help identify anomalously high-chloride areas that could be further investigated. Both recommendations would provide information on the depth to the base of fresh water. The concern is that the two wells showing evidence of a deep chloride source (GA Bc 61 and 62) (wells GA942391 and GA941962, respectively) also have radium-226-plus-radium-228 or gross alpha-particle activity levels that exceed the MCL for these parameters.

Manganese

Manganese values were reported in MDE-PWS, NWIS, and PatTrac data sets. Samples from PatTrac and MDE-PWS were not reported as either filtered or unfiltered, but were assumed to be unfiltered. Both filtered and unfiltered manganese values were reported for most samples in the NWIS data set; for these samples, the higher of the two values was used.

Manganese values were reported from 1,573 sites in these data sets. Reported manganese values from 863 of these sites (55 percent) exceeded the SMCL of 0.05 mg/L (tab. 4; fig. 9). Samples from 700 sites were reported as less than 0.05 mg/L; most of these were from the PatTrac data set, for which the reporting level was equal to the SMCL of 0.05 mg/L. Manganese values from another 10 sites were reported as less than 0.10 mg/L; how many of these samples exceeded the SMCL of 0.05 mg/L is not known**.** The percentage of sites with manganese exceeding 0.05 mg/L ranged from 39 percent in the Hampshire and Mauch Chunk Formations to 70 percent in the Pottsville Formation (tab. 4).

The relation between manganese and iron concentrations is shown in figure 10. Iron and manganese are positively correlated (correlation coefficient 0.425, Pearson Product Moment correlation, $P<0.05$), although there is a wide amount of scatter in the plot. (For the purpose of calculating correlation, only samples that were at or above the reporting level for both iron and manganese were used.) The lack of better correlation may be due to varying concentrations and mineral phases of iron and manganese in the aquifers, variations between filtered and unfiltered samples (iron and manganese may be present in colloidal as well as dissolved forms), and other factors.

Radon

Radon values were obtained from Garrett County radon, NWIS, and MDE-PWS data sets. Radon samples were analyzed from 263 sites. There is currently no USEPA drinking water standard established for radon in public-water supplies; however, the USEPA had proposed in 1999 a standard of 4,000 pCi/L if a state develops a multimedia mitigation program to reduce radon levels, and 300 pCi/L if it does not (U.S. Environmental Protection Agency, 2012).

Reported radon concentrations ranged from 20 to 32,800 pCi/L, with a median value of 255 pCi/L (tab. 5; fig. 11). The well with the highest radon concentration was sampled twice (about 6 weeks apart); radon concentrations were 28,150 and 32,800 pCi/L (each value is the average of two samples at each sampling event). The well, located about 5 miles (mi) southeast of Grantsville, is completed in the Hampshire Formation**.** Because the resample value confirmed the initial value, and the duplicate samples taken each time were similar, it seems unlikely that the analyses are incorrect or that the samples' values were transcribed incorrectly. This area should receive additional scrutiny. Radon poses a health risk in drinking water if it degasses, collects in the indoor air, and is inhaled. The health risk of ingesting (swallowing) water containing radon is much smaller. Garrett County may wish to request that homeowners in this area monitor their homes for airborne radon. Additionally, more water testing in the area, particularly for radon and gross alpha- and gross-beta particle activity, would indicate if other harmful constituents are in well water in the area. All other radon concentrations were less than 5,000 pCi/L. Two other sites exceeded 4,000 pCi/L; these wells are located in the same neighborhood as the highest-radon well. The proposed MCL was exceeded in 122 of the 263 wells. When evaluated by

geologic formation, the highest median radon concentration were from wells in the Hampshire and Mauch Chunk Formations (980 and 1,140 pCi/L, respectively), and the lowest median concentration (40 pCi/L) was from the Allegheny Formation, although the sample size was small (14 wells) (fig. 12). For plotting purposes, the one value reported as less than 80 pCi/L (GA Da 17; well GA670179) was entered as 40 pCi/L.

Other Inorganic Constituents in Relation to Drinking Water Standards

In addition to arsenic, chloride, manganese, and radon, other inorganic constituents with established Primary or Secondary Drinking Water Standards are summarized with respect to the established standards in tables 6 and 7. For samples other than arsenic, chloride, manganese, and radon, this summary reflects evaluation of the NWIS, PatTrac, and MGS Methane data sets. The MDE-PWS data set was not included because of time constraints and the complexity of the underlying data sets supplied by MDE. For each constituent, all samples with data for that constituent were combined from the individual data sets. Some constituents were reported in more than one format; for example, iron is reported as both "filtered" and "unfiltered" in the NWIS data set. In such cases, data from the columns were combined in a single column. If two values were reported for the same sampling event, the maximum value was used. For wells with multiple samples collected on different dates, the highest value was extracted, resulting in one sample per well.

Primary Drinking Water Standards (MCLs) are enforceable standards for public-water supplies that have been established to protect the public against consumption of drinking water contaminants that present a risk to human health. Secondary Drinking Water Standards (SMCLs) are guidelines for public-water systems that are established for aesthetic considerations such as taste, color and odor. These contaminants are not considered to present a risk to human health at the SMCL (U.S. Environmental Protection Agency, 2014a; 2014b).

MCLs have been established for 18 constituents that were present in the data sets examined in this study (tab. 6). Eight constituents exceeded MCLs (arsenic, barium, fluoride, lead, nitrate, nitrite, alpha-particle activity, and radium-226-plus-radium-228). Five of these contaminants (barium, fluoride, nitrate, alpha-particle activity, and radium-226-plus-radium-228) exceeded the MCL only once. Only one out of 1,204 sites exceeded the MCL for nitrate-plus-nitrite (hereafter referred to as nitrate, although the analysis is actually the sum of nitrate plus nitrite.) The low exceedance rate for nitrate is likely due in part to the anoxic (reducing) conditions found in many wells in Garrett County (as indicated by the low dissolved-oxygen levels encountered in the MGS Methane study, as well as high iron and manganese in water samples) (Bolton and Pham, 2013). Ground-water nitrate generally originates from ammonium released from septic effluent and agricultural soil amendments, and is then converted to nitrite and then to nitrate under oxidizing conditions. Thus, ground water may not be chemically suitable for the conversion of ammonia to nitrate. The MCL for nitrite (1 mg/L as N) was exceeded in 5 out of 46 sites. These sites are most likely non-community transient water systems, which are required to be analyzed for nitrite (private water wells and other sites are tested only for nitrate-plus-nitrite) (C. Umbel, Garrett County Health Department, written commun., 2014). It is possible that this may be a reporting or labeling error. The nitrate-plus-nitrite values were not analyzed with these particular samples, so the relation between nitrite and nitrate-plus-nitrite is unclear. Because the MCL for is much lower for nitrite than nitrate-plus-nitrite, the County should investigate these nitrite samples further to determine if nitrite is a problem. Garrett County should consider analyzing samples for both nitrite and nitrate-plus-nitrite.

Well GA951231 had a reported fluoride concentration of 15 mg/L, which greatly exceeds the MCL (4 mg/L). This value is extraordinarily high. This may represent an analytical or data-recording error; regardless, this should be investigated further. Barium and radium-226-plus-radium-226 exceeded their respective MCLs in GA Bc 61 (GA942391), and gross-alpha particle activity exceeded the MCL in GA Bc 62 (GA941962). These two wells are located about 1,500 feet apart approximately 2 miles north of the Town of Accident. These samples are slightly brackish (chloride concentrations 1,050 to 1,250 mg/L), and chloride/bromide ratios from these wells suggest that the chloride is not derived from road salt. Two sites greatly exceeded the lead MCL of 0.015 mg/L. The highest value was 0.06 mg/L from GA951488. Although it is unlikely that the lead is derived from a geological source, the wells could be

resampled using full-purge methods to assure the samples do not have a long residence time in the distribution system, which has been shown to be associated with increased lead concentrations (Burgy and others, 2013).

SMCLs or Health Advisories were exceeded for 10 constituents (tab. 7). Many of these exceedances are from monitor wells rather than water-supply wells, and are not representative of the drinking water source. Aluminum concentrations from six sites exceeded 0.20 mg/L. Most of these were from samples having pH less than 4, or having high levels of sulfate, and likely reflect activities related to coal mining. Aluminum is relatively insoluble at intermediate pH environments (Hem, 1989). Other sites had SMCL or Drinking Water Advisory exceedances for chloride, color, fluoride, iron, manganese, pH, sulfate, total dissolved solids (TDS), and sodium. Some constituents are related; for example, elevated TDS is generally associated with high chloride levels (figs. 7, 8). One site (GA951231) had a reported fluoride value of 15 mg/L, which greatly exceeds both the MCL (4 mg/L) and the SMCL (2 mg/L).

Table 6 indicates that only a small number of constituents with MCLs have been widely evaluated in wells, particularly for trace elements and radioactivity indicators. Samples from the NWIS data set have the most extensive analyses, but many of these are from monitor wells rather than drinking water wells. While there is no indication that these constituents pose a health concern, Garrett County should consider additional sampling for trace elements and gross alpha-particle and beta-particle activity in areas lacking this information.

Organic Chemicals

Organic chemical constituents are reported from the NWIS and MDE-PWS databases. It should be noted while these constituents are discussed in terms of mg/L in this report (to be consistent with other parameters and MCLs), in the ArcGIS files all organic constituents are reported in µg/L. In addition, organic constituents from the MDE-PWS database were divided into VOCs and SOCs and this subdivision was retained in the ArcGIS files for this project.

The NWIS database contains organic chemical analyses from five sites. These sites were tested for about half of the organic constituents for which MCLs have been established (although not all sites were tested for the same constituents) (tabs. 8 and 9). Organic chemicals were detected at two of the five sites. Four pesticides (atrazine, carbofuran, diazinon, and metolachlor) were detected at one site. Atrazine and carbofuran concentrations at this site were below their respective MCLs. Diazinon and metolachlor do not have MCLs established. The gasoline additive MTBE was detected at a second site; no MCL has been established for this chemical either. All organic chemical detections were below 0.002 mg/L.

In the MDE-PWS data set, it appears that there were 21 “plants” with raw/untreated water samples that were analyzed for VOCs and 19 “plants” with raw/untreated water samples tested for SOCs. Of these samples, 13 “plants” had at least one sample with one or more VOC detected (i.e., present at a concentration above the laboratory detection limit). There were 11 “plants” that had at least one sample with one or more SOC detected. For VOCs and SOCs with established MCLs, none of the detected concentrations were above the respective MCL.

RECOMMENDATIONS

WATER-QUALITY TESTING

1) Field-test all new wells for chloride; when they exceed about 100 mg/L, collect a sample for bromide analysis. This will help determine whether sites have been affected by road salt or other sources.

2) Analysis of both nitrite and nitrate-plus-nitrite should be performed on samples in agricultural areas, to determine the frequency of nitrite MCL exceedances.

3) Garrett County should consider baseline water-quality testing of private water wells prior to the development of the Marcellus Shale. A suite of major ions, minor and trace elements, organic chemicals, and other parameters is given in table 10. These data would help identify existing water-quality "signatures" of aquifers that could be used to identify unusual occurrences of specific constituents in the future.

4) Irrespective of the development of the Marcellus Shale gas resources, Garrett County should consider conducting a sampling program to test private water-supply wells for underrepresented regulated contaminants. Specifically, there is a lack of data from private water wells for trace elements (including antimony, barium, beryllium, cadmium, chromium, copper, selenium, thallium, and uranium) and gross alpha-particle and beta-particle activity. The data would provide a basis for determining whether or not these constituents are a health concern for County residents.

5) Site-specific follow-up testing should be considered for the following constituents:
   - Additional radon samples should be collected in the vicinity of wells GA940104, GA940399 and GA940122 to determine the geographical extent of the high (more than 4,000 pCi/L) radon values.
   - Well GA951231 should be resampled for fluoride. If the resampled value remains above 4 mg/L, additional fluoride testing should be done in nearby wells.
   - Previous arsenic tests from wells GA951085, GA942547, and GA950758 should be re-evaluated and additional testing conducted as necessary.

PATTRAC DATABASE

In developing this project, it became evident that additional documentation and refinements of the PatTrac database could help facilitate construction of a more robust GIS-based information system. The addition of several data fields and clarification of existing data fields would improve the utility of a GIS-based information system. A list of recommendations for additional documentation and refinements is given below:

1) Addition of a data field indicating water-sample type (untreated or treated).

2) Addition of a data field indicating sample source (well [residential/commercial/public supply]; spring; or surface water).

3) Greater locational accuracy (Global Positioning System or satellite imagery).

4) Identification of well-permit number.

5) Clarification of whether analysis is for total or dissolved constituents.

6) Clarification of constituent units.

7) Greater elevation accuracy using the USGS National Elevation Data service or other high-resolution elevation data source such as Lidar.

8) Verification of property information (address, acreage) using the Maryland property database.

9) Develop a protocol by which the ArcGIS data set developed during this project can be kept up-to-date with ongoing sampling.

DATABASE INTEROPERABILITY

The disparate nature of data sets encountered in this project was a significant challenge and limitation to integrating and reviewing existing water-quality data. As more water-resource data are collected and shared digitally and geospatially, it is increasingly apparent that county, state, and federal government agencies would benefit from developing and implementing strategies for better data interoperability. Designating key data sets and specifying appropriate procedures and contacts to get data corrections and updates integrated would be essential to beginning the process. Clearly the involvement and cooperation of multiple agencies would be needed for success.

The issue is exemplified by water-source information, a fundamental type of data stored and used by multiple agencies, which includes identifiers and location coordinates. Currently, water-source identifications used by different agencies are difficult to correlate and yet are essential to identifying existing water sources and connecting them to sampling locations, water-quality data, water withdrawals and water-treatment plants/distribution systems. In addition, geospatial coordinates for the same water source often vary across data sets due in part to changing methodology and technology through time. Developing a method or process to integrate and implement corrections and cross-references to existing key data sets would be beneficial to all.

SUMMARY

Existing ground-water quality data in Garrett County, Maryland were compiled from several databases and incorporated into an ArcGIS format to provide Garrett County with a system that will help them more effectively manage the resource. Water-quality and other data were obtained from the Garrett County Health Department, the U.S. Geological Survey National Water Information System, the Maryland Department of the Environment Public Water Supply Program, and the Maryland Geological Survey. Site-specific information, including well-permit numbers and location data, were also obtained.

Arsenic concentrations exceeded the Primary MCL of 0.010 mg/L in about 7 percent of sites sampled (102 out of 1,408 sites). About 20 percent of sites in the Hampshire Formation exceeded the arsenic MCL of 0.010 mg/L; exceedance rates for the other geologic formations were less than 8 percent. Chloride concentrations exceeded 250 mg/L in about 3 percent of sites (52 out of 1,799 sites). Most were likely affected by road deicing salts or other surface-based chloride sources, although some appear to be derived from deeper sources. Manganese exceeded the SMCL of 0.050 mg/L in about 55 percent of sites (863 of 1,573 sites). The Pottsville Formation had the highest percent exceedance (about 70 percent), while the Hampshire and Mauch Chunk Formations had the lowest (39 percent). Manganese and iron were positively correlated. Median radon concentration from 263 sites was 255 pCi/L. Radon from three sites exceeded 4,000 pCi/L, with the highest value being 32,800 pCi/L. A relatively small percentage of private wells have been tested for the full spectrum of inorganic constituents with MCLs. SMCLs or Health Advisory levels were exceeded for 10 constituents. Several are related to each other, such as TDS and chloride, and iron and manganese. Few sites aside from the MDE-PWS have been tested for organic chemicals, and detected amounts are very low. Five organic chemicals in the NWIS database were detected (atrazine, carbofuran, diazinon, metolachlor, and methyl *tert*-butyl ether); none of the detections exceeded MCL, although only about half of the organic chemicals for which MCLs have been established were tested. Recommendations to Garrett County include (1) additional evaluation of specific water-quality issues (including resampling previous sites and conducting more extensive water-quality testing of private wells); (2) recommendations for additional documentation and refinements to the PatTrac database, and (3) recommendations for improving the interoperability of the various databases that were used in this report.

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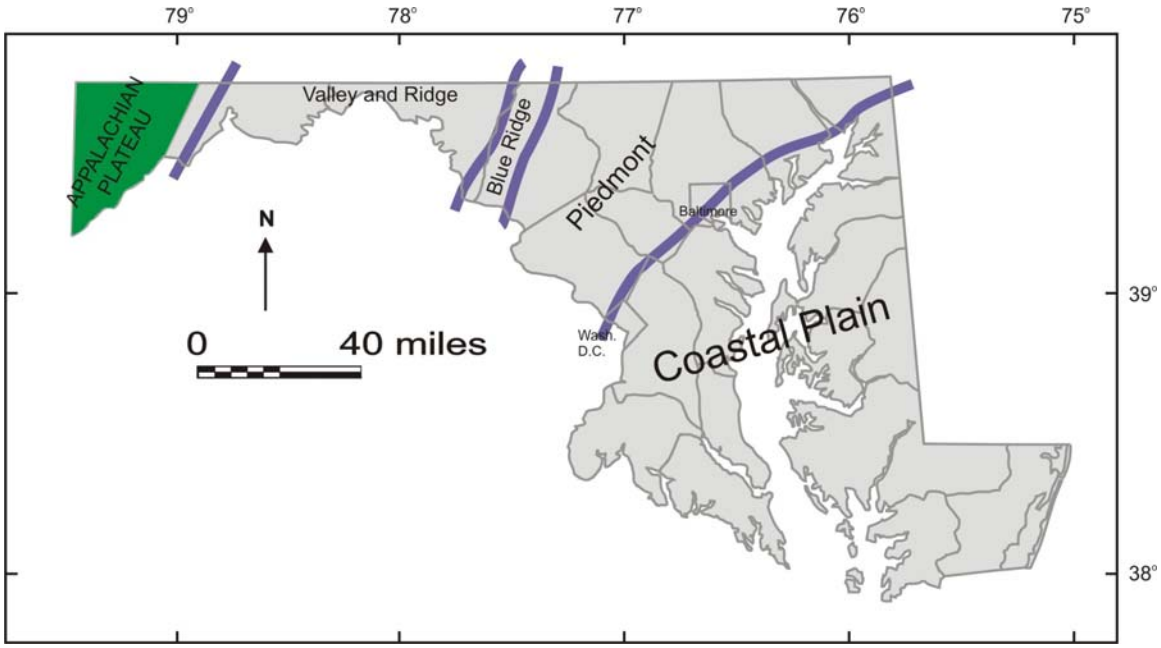

Figure 1. Location of the study area.

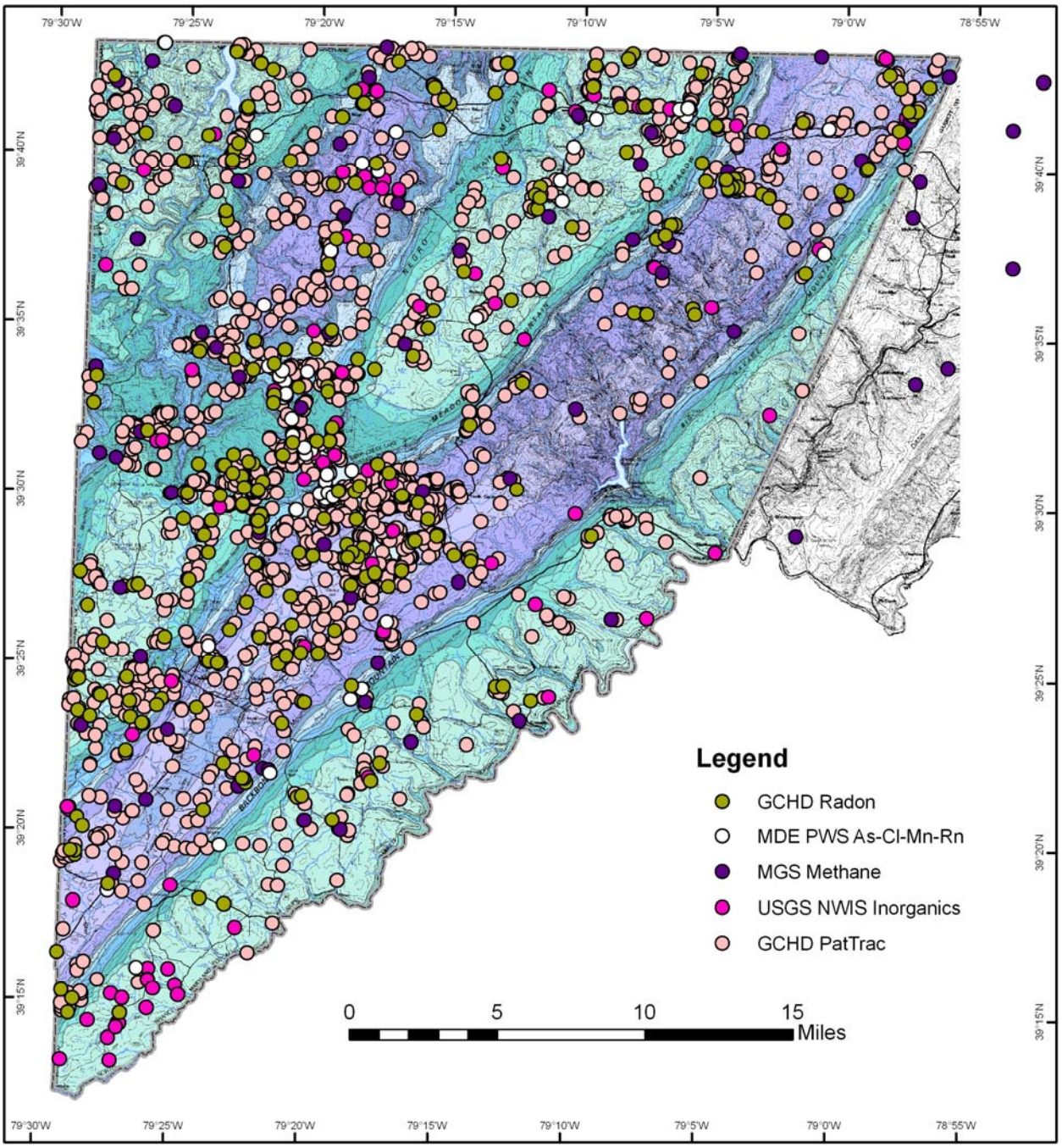

Figure 2a. Locations of sites from each data set having arsenic, chloride, manganese, or radon data.

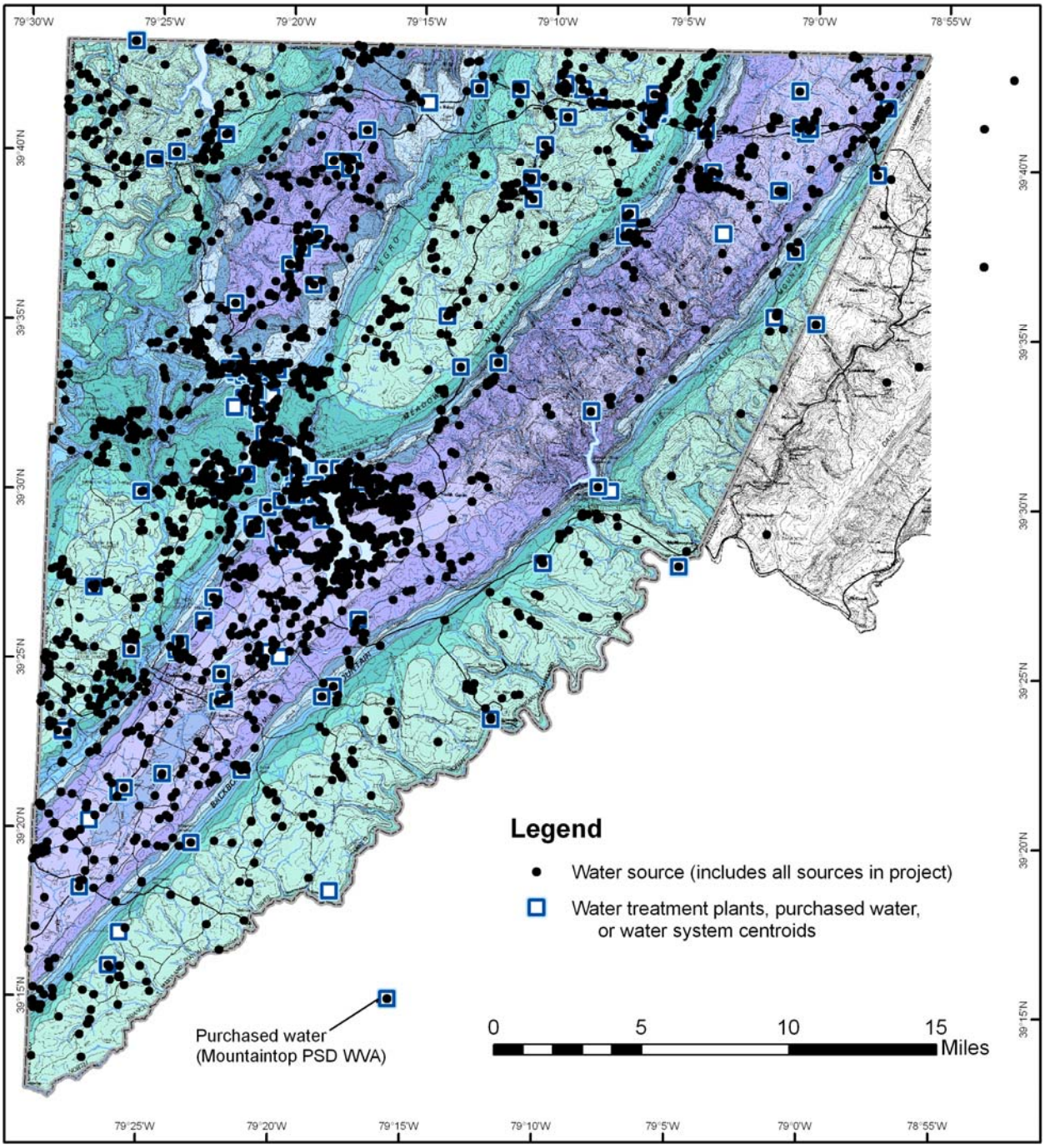

Figure 2b. Locations of sites used in this study. Black dots ("water sources") represent wells or springs with water-quality data used in this study. Blue squares represent water treatment plants with both treated and untreated samples.

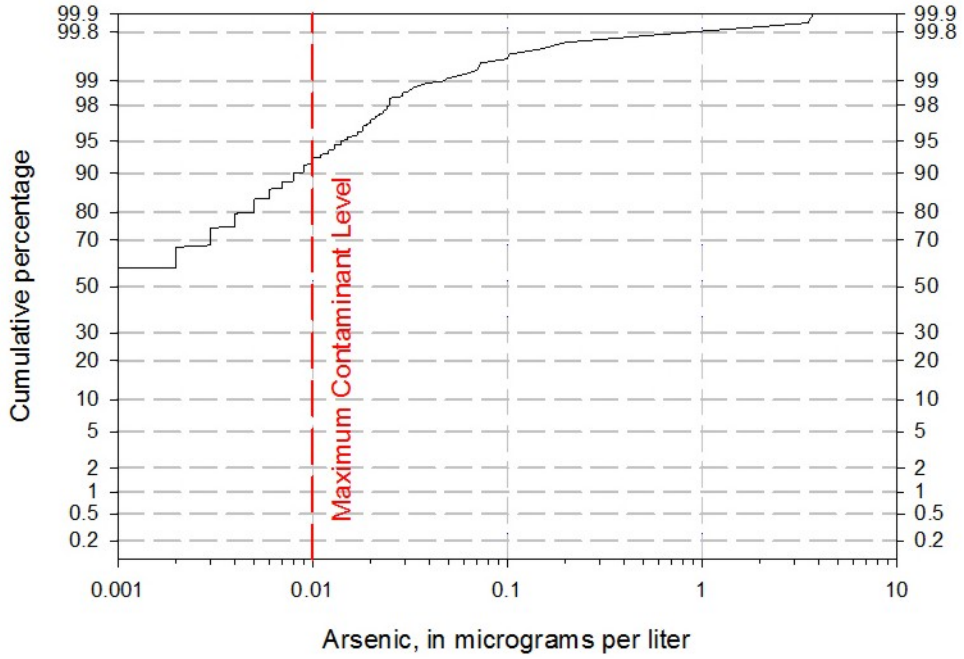

Figure 3. Cumulative-frequency plot of arsenic concentrations from sites in Garrett County, Maryland. Figure illustrates the percentage of samples that are less than or equal to the specified concentration.

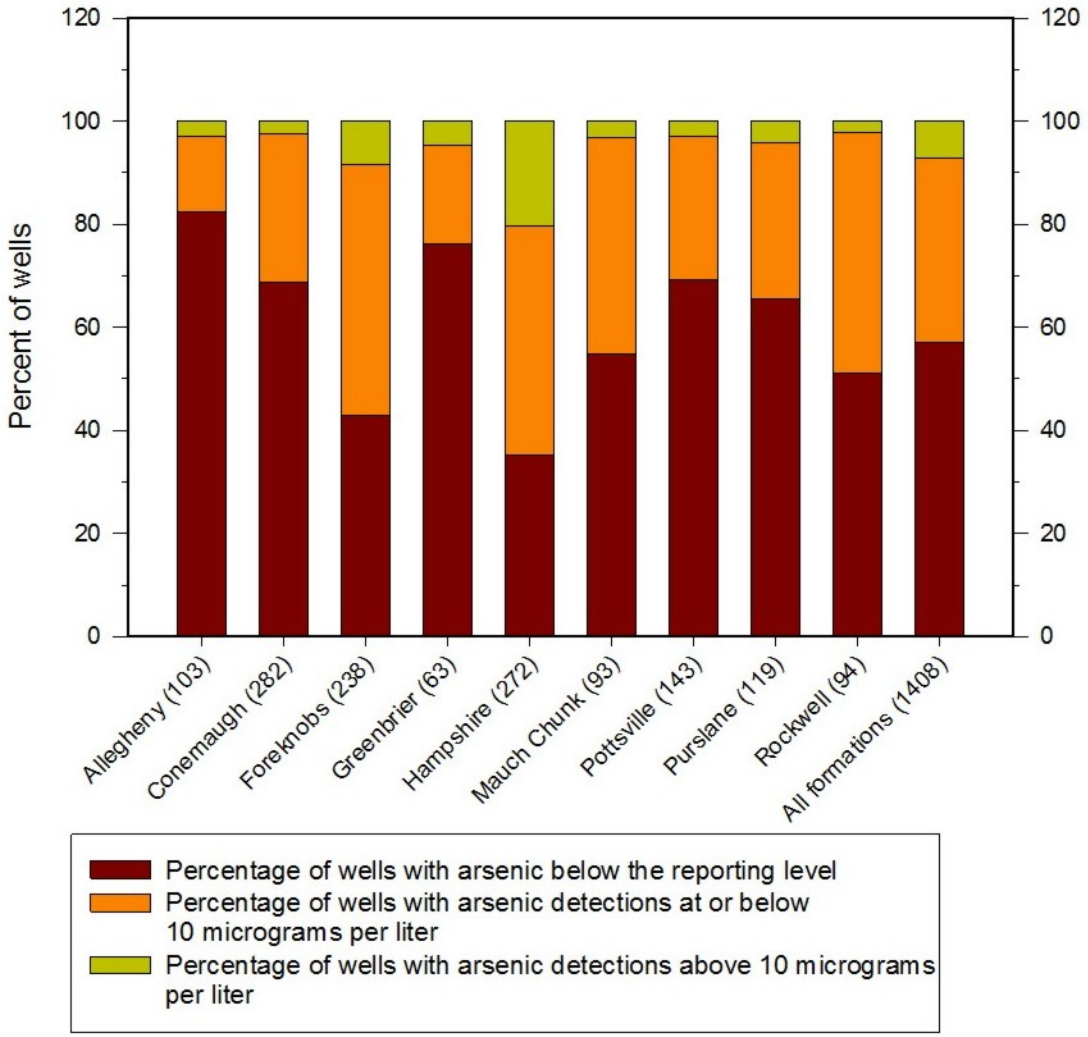

Figure 4. Percent of sites in Garrett County, Maryland having the specified range of arsenic concentrations in different geologic formations. Numbers in parentheses are the number of wells in each category. The one well in the Harrell-Brallier-Sherr Formation (which had arsenic < 0.002 micrograms per liter) is not included as separate bar, but is included in the total.

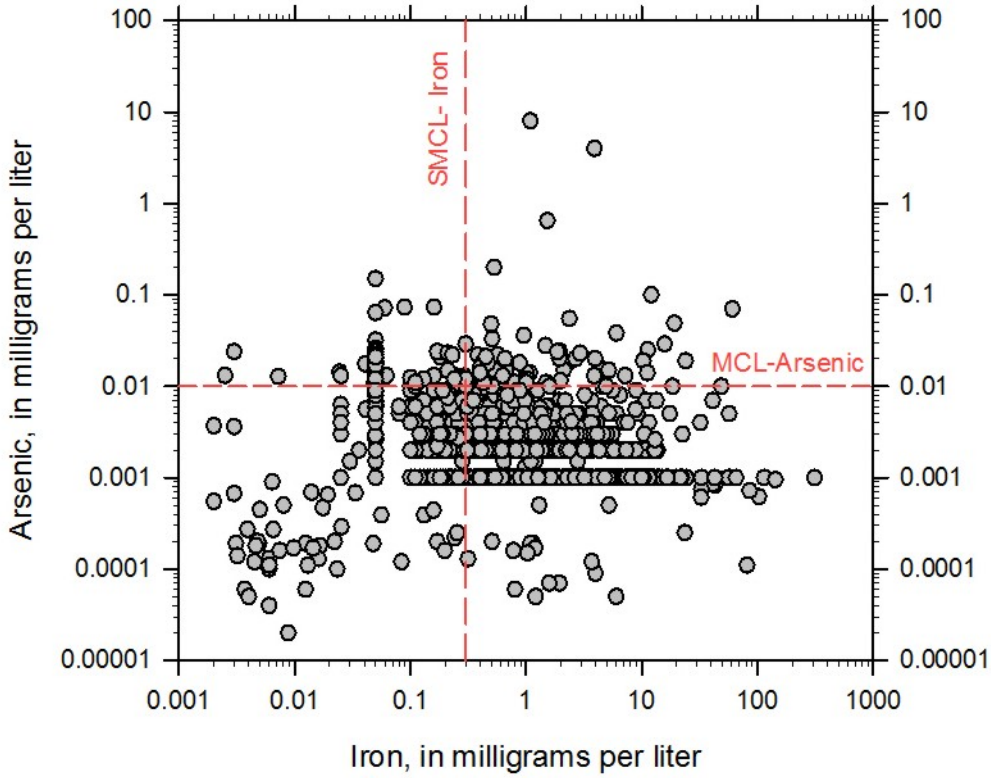

Figure 5. Relation between iron and arsenic concentrations for sites in Garrett County, Maryland. Data are from NWIS and PatTrac data sets only. Samples include both filtered and unfiltered arsenic. Multiple samples from the same well are included. "Less than" values are plotted at one-half the "less than" value. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level.

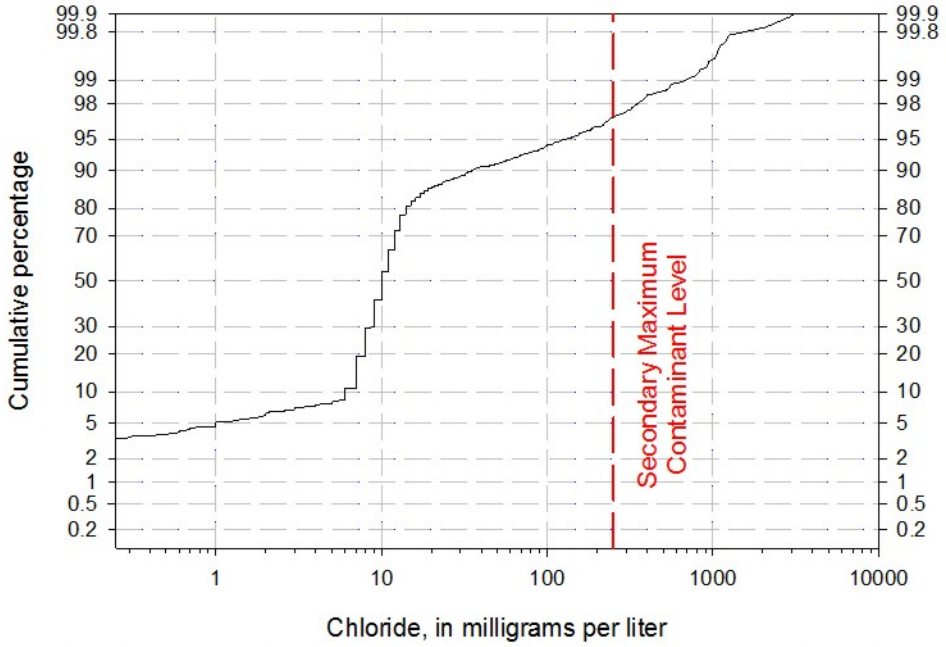

Figure 6. Cumulative-frequency plot of chloride concentrations from sites in Garrett County, Maryland. Figure illustrates the percentage of samples that are less than or equal to the specified concentration.

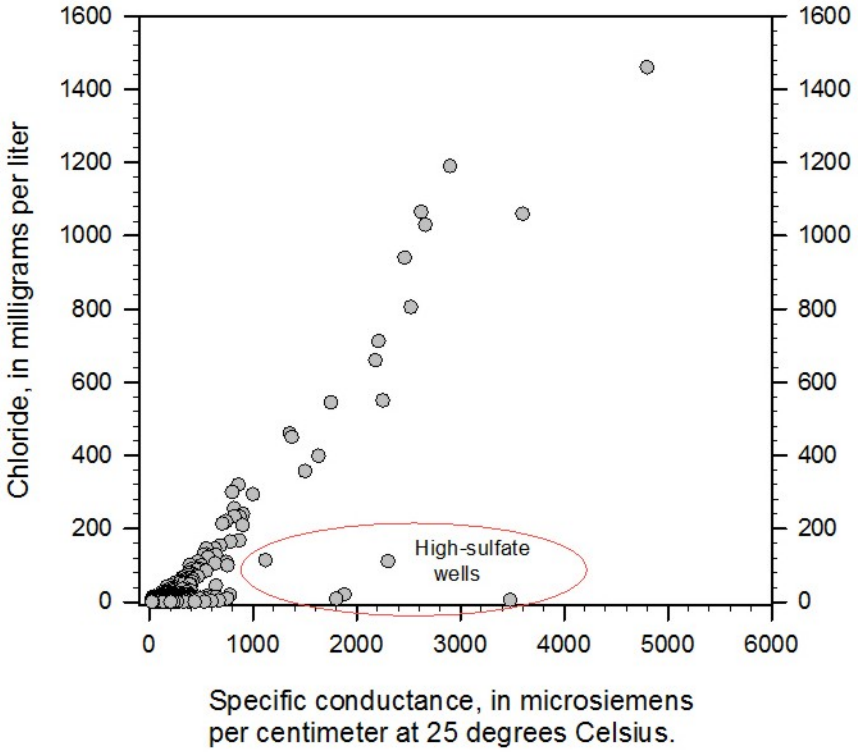

Figure 7. Relation between specific conductance and chloride concentrations for sites in Garrett County, Maryland.

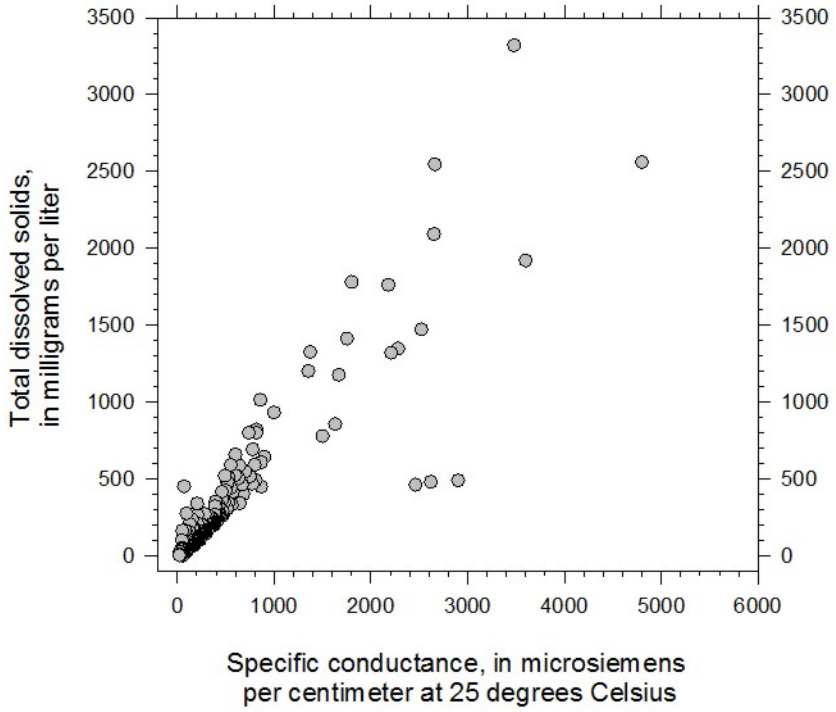

Figure 8. Relation between specific conductance and total dissolved solids for sites in Garrett County, Maryland.

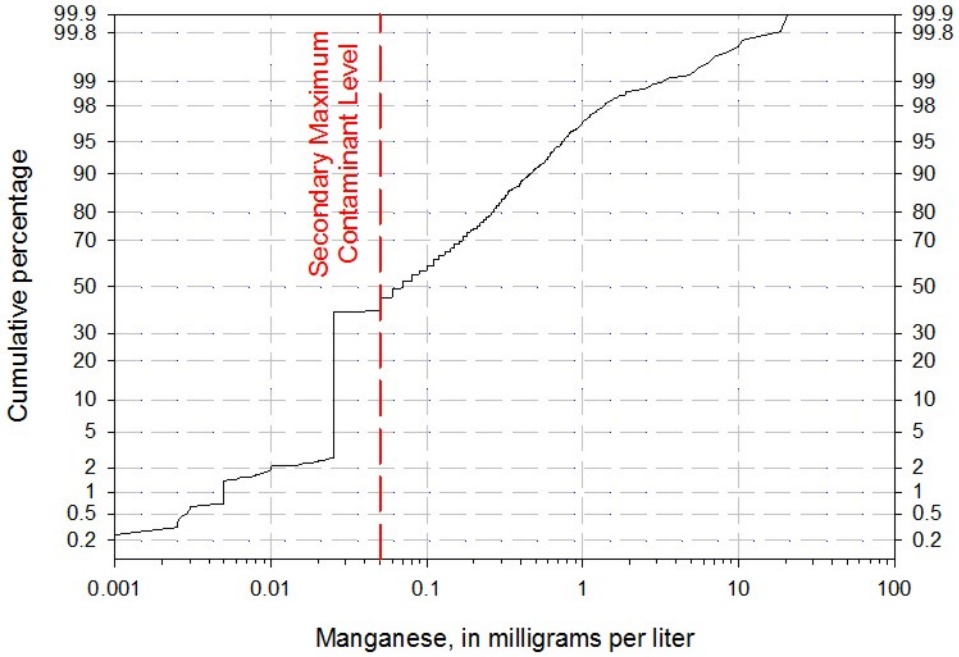

Figure 9. Cumulative-frequency plot of manganese concentrations from sites in Garrett County, Maryland. Figure illustrates the percentage of samples that are less than or equal to the specified concentration. The large change at 0.025 milligrams per liter (mg/L) reflects samples reported as less than 0.050 mg/L and plotted as 0.025 mg/L.

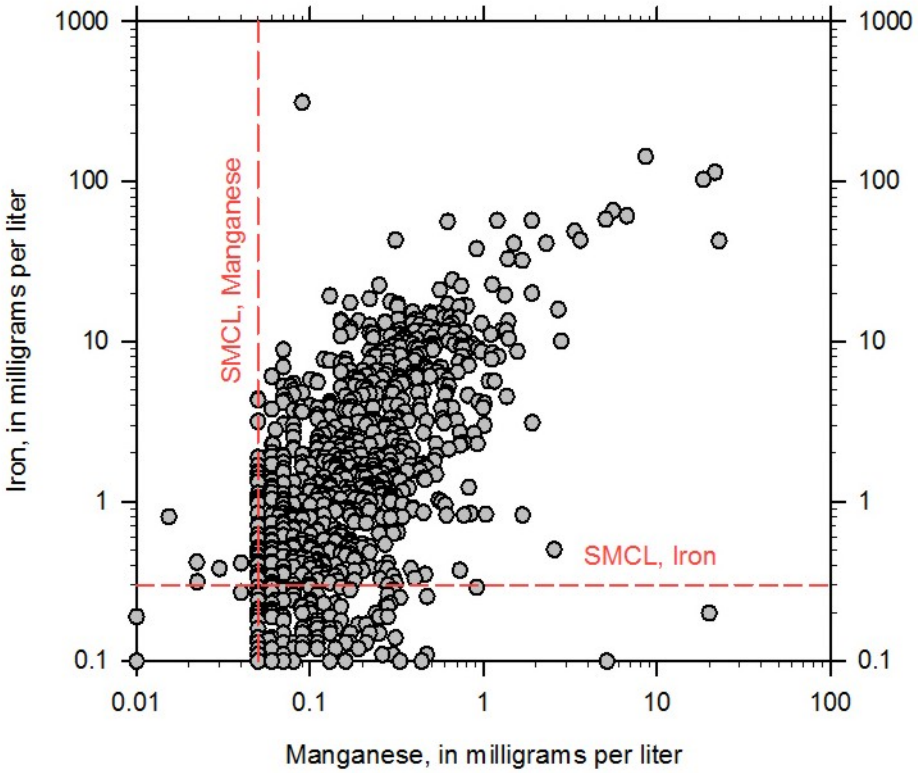

Figure 10. Relation between manganese and iron concentrations for sites in Garrett County, Maryland. SMCL, Secondary Maximum Contaminant Level.

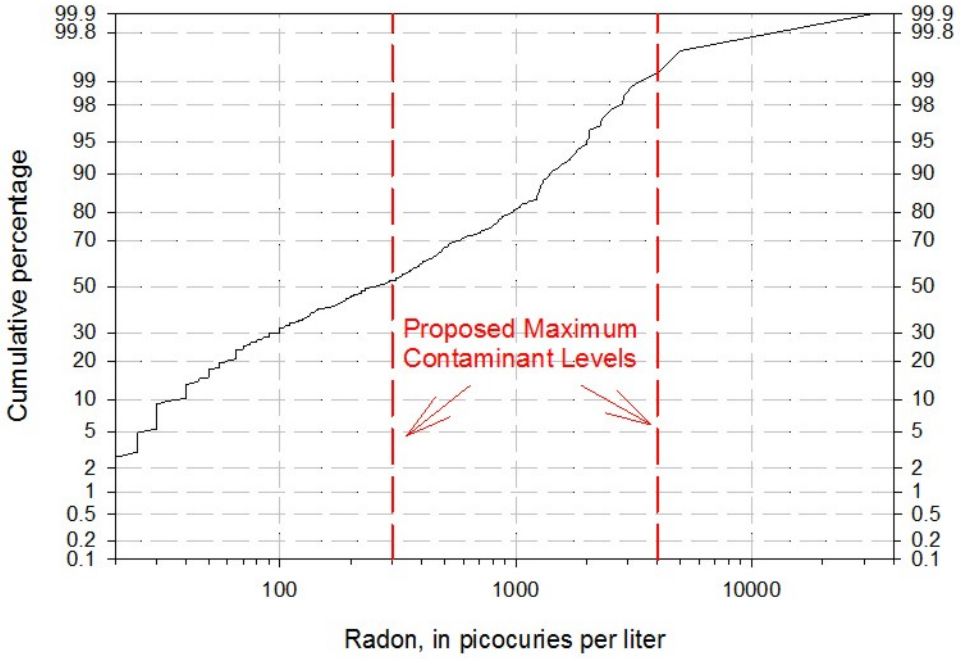

Figure 11. Cumulative-frequency plot of radon concentrations from sites in Garrett County, Maryland. Figure illustrates the percentage of samples that are less than or equal to the specified concentration.

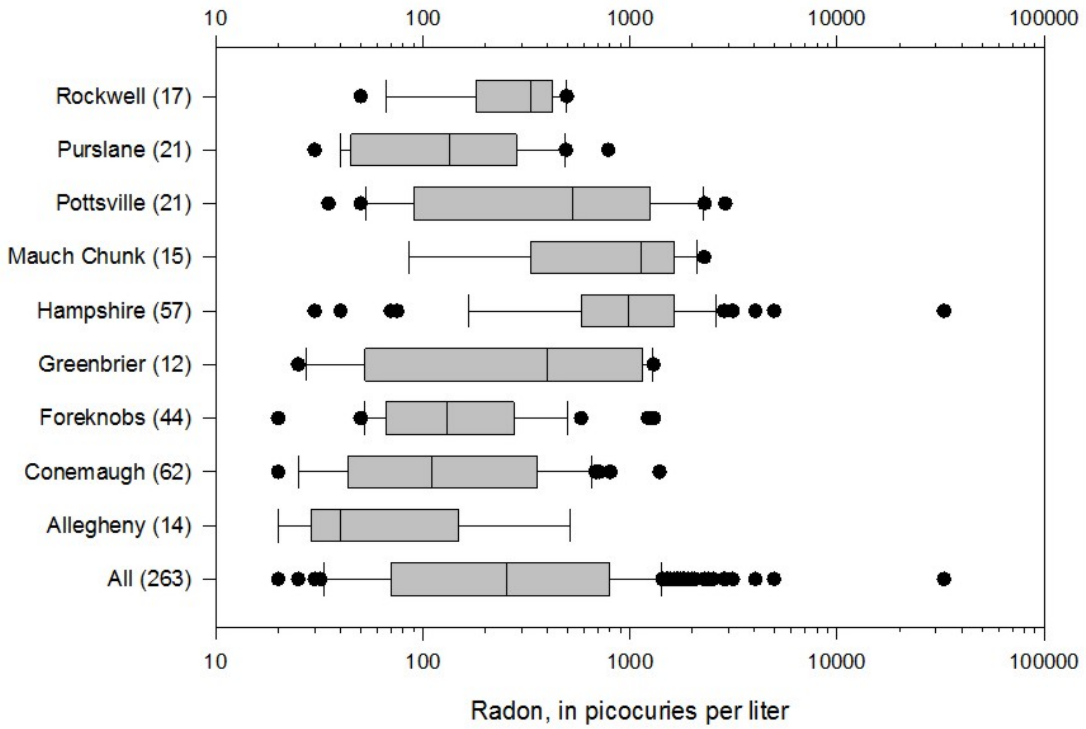

Figure 12. Radon concentrations with respect to geologic formation for sites in Garrett County, Maryland. Numbers in parentheses are the number of samples shown in box plot.

Table 1. Sources of data and number of samples and sites in each data set.

Source	Name of data set	Number of samples[1]	Number of sites	Date range for data
Garrett County Health Department	PatTrac	5,334	1,771	8/1995-4/2013
Garrett County Health Department	Radon	252[2]	252[2]	1/1994-10/1998
U.S. Geological Survey	NWIS	166	105	12/1946-12/2012
Maryland Geological Survey	Methane	69	69	6/2012-7/2013
Maryland Department of the Environment	MDE-PWS	103[3]	55[3]	1/1990-7/2013

[1] Includes sites with multiple samples. All samples were not analyzed for all constituents.
[2] Does not include 37 wells for which locations could not be verified.
[3] Indicates the number of water-treatment plants having arsenic, chloride, manganese, or radon data. The number of wells and springs supplying water to each water-treatment plant could not be determined with the available information.

Table 2. Summary of reported arsenic concentrations by geologic formation in Garrett County, Maryland.

[MCL, Maximum Contaminant Level; ≤, less than or equal to]

Geologic formation[2]	Total number of sites with arsenic data	Arsenic concentrations above MCL		Arsenic concentrations less than Reporting Level[1]		Arsenic concentrations above Reporting Level and ≤MCL	
		Number of sites	Percent of sites	Number of sites	Percent of sites	Number of sites	Percent of sites
Allegheny	103	3	2.9	85	82.5	15	14.6
Conemaugh	282	7	2.5	194	68.8	81	28.7
Foreknobs	238	20	8.4	102	42.9	116	48.7
Greenbrier	63	3	4.8	48	76.2	12	19.0
Hampshire	272	55	20.2	96	35.3	121	44.5
Mauch Chunk	93	3	3.2	51	54.8	39	41.9
Pottsville	143	4	2.8	99	69.2	40	28.0
Purslane	119	5	4.2	78	65.5	36	4.2
Rockwell	94	2	2.1	48	51.1	44	46.8
Harrell-Brallier-Sherr	1	0	0	1	100	0	0
All	1,408	102	7.2	802	57.0	504	35.8

[1] Reporting level varies, although more than 95 percent of less-than values has 0.002 milligrams per liter as the reporting level.
[2] Geologic formations based on Brezinski and Conkwright (2013)

Table 3. Summary of reported chloride concentrations by geologic formation in Garrett County, Maryland.

[mg/L, milligrams per liter; <, less than; >, greater than]

Geologic formation	Total number of sites with chloride data	Median concentration (mg/L)	Maximum concentration (mg/L)	Number of sites with chloride concentrations (mg/L):			
				<10	10-100	101-250	>250
Allegheny	130	10	830	57	69	2	2
Conemaugh	373	10	4,300	153	180	24	16
Foreknobs	311	10	2,060	133	165	4	9
Greenbrier	98	10.5	1,190	33	58	2	5
Hampshire	340	10	1,250	120	204	6	10
Mauch Chunk	121	10	910	56	62	1	2
Pottsville	172	10	520	85	84	0	3
Purslane	150	10	240	73	72	5	0
Rockwell	102	12	1,065	34	56	7	5
Harrell-Brallier-Sherr	2	13.5	16	0	2	0	0
All	1,799	10	4,300	744	952	51	52

Table 4. Summary of reported manganese concentrations by geologic formation in Garrett County, Maryland.

[mg/L, milligrams per liter; <, less than]

Geologic formation	Total number of sites with manganese data	Median concentration (mg/L)	Maximum concentration (mg/L)	Manganese concentrations above 0.05 mg/L	
				Number of sites	Percent of sites
Allegheny	121	0.17	10	83	69
Conemaugh	322	0.08	22.78	194	60
Foreknobs	261	0.06	7.11	131	50
Greenbrier	78	<0.05	21.6	36	46
Hampshire	291	<0.05	4.72	113	39
Mauch Chunk	105	<0.05	0.99	41	39
Pottsville	164	0.13	5.99	114	70
Purslane	130	0.113	5.06	85	65
Rockwell	100	0.11	20.01	65	65
Harrell-Brallier-Sherr	1	0.13	0.1	1	100
All	1,573	0.07	22.78	863	55

Table 5. Summary of reported radon concentrations by geologic formation in Garrett County, Maryland.

[pCi/L, picocuries per liter; >, greater than; --, no data]

Geologic formation	Total number of sites with radon data	Median concentration (pCi/L)	Maximum concentration (pCi/L)	Number of sites with radon concentrations:	
				301-4,000 pCi/L	>4,000 pCi/L
Allegheny	14	40	515	2	0
Conemaugh	62	110	1,390	18	0
Foreknobs	44	130	1,305	8	0
Greenbrier	12	400	1,300	8	0
Hampshire	57	980	32,800	47	3
Mauch Chunk	15	1,140	2,285	12	0
Pottsville	21	530	2,885	13	0
Purslane	21	135	785	5	0
Rockwell	17	330	495	9	0
Harrell-Brallier-Sherr	0	--	--	--	--
All	263	255	32,800	122	3

Table 6. Summary of water-quality data with respect to Maximum Contaminant Levels for inorganic constituents. Shaded rows indicate constituents with samples exceeding the MCL.

[MCL, Maximum Contaminant Level; mg/L, milligrams per liter; MF/L, million fibers per liter; --, no data; TT, treatment technique; N, nitrogen; pCi/L, picocuries per liter; mrem/yr, millirems per year]

Contaminant	Data set	MCL[1]	Number of sites tested	Number of sites whose highest value exceeded the MCL	Maximum concentration
Antimony	NWIS	0.006 mg/L	34	0	0.000346 mg/L
Arsenic	NWIS, PATRAC, MDE-PWS	0.010 mg/L	1,408	102	8 mg/L
Asbestos	none	7 MF/L	--	--	--
Barium	NWIS	2 mg/L	40	1	3.65 mg/L
Beryllium	NWIS	0.004 mg/L	35	0	0.0008 mg/L
Cadmium	NWIS	0.005 mg/L	40	0	0.001 mg/L
Chromium (total)	NWIS	0.1 mg/L	40	0	0.00081 mg/L
Copper	NWIS	1.3 mg/L TT	40	0	0.0259 mg/L
Cyanide (as free cyanide)	none	0.2 mg/L	--	--	--
Fluoride	NWIS, PATRAC	4.0 mg/L	91	1	15 mg/L
Lead	NWIS, PATRAC	0.015 mg/L	57	2	0.06 mg/L
Mercury (inorganic)	NWIS	0.002 mg/L	15	0	0.000752 mg/L
Nitrate (as N)	NWIS, PATRAC	10 mg/L	1,204	1	12 mg/L
Nitrite (as N)	NWIS, PATRAC	1 mg/L	46	5	4.2 mg/L
Selenium	NWIS	0.05 mg/L	37	0	0.0027 mg/L
Thallium	NWIS	0.002 mg/L	33	0	0.00004 mg/L
Alpha particles	NWIS	15 pCi/L	21	1	20 pCi/L
Beta particles and photon emitters	NWIS	4 mrem/yr	22	--[2]	12 pCi/L
Radium-226 plus Radium-228	NWIS	5 pCi/L	4	1	8 pCi/L
Uranium	NWIS	0.030 mg/L	37	0	0.00445 mg/L
Radon	NWIS, MDE-PWS PatTrac, Radon	300 and 4,000 pCi/L (proposed)[3]	263	3 >4,000 pCi/L 125 >300 pCi/L	32,800 pCi/L

[1] Source: http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf, accessed 1/6/2014.
[2] No reliable equivalent to pCi/L.
[3] See text for explanation.

Table 7. Summary of water-quality data with respect to Secondary Maximum Contaminant Levels and Drinking Water Advisories for inorganic constituents. Shaded rows indicate constituents with samples exceeding the SMCL. No data were reported for corrosivity, foaming agents, or odor. (Sources for SMCLs and Drinking Water Advisory: U.S. Environmental Protection Agency, 2003; 2014b.)

[SMCL, Secondary Maximum Contaminant Level; mg/L, milligrams per liter; >, greater than; <, less than]

Contaminant	Database	SMCL	Number of sites	Number of sites above SMCL or Reference level	Maximum concentration
Aluminum	NWIS	0.05-0.20 mg/L	48	6 >0.20 mg/L 10 >0.05 mg/L	19 mg/L
Chloride	NWIS, MDE-PWS, PatTrac, Methane	250 mg/L	1,799	52	4,300 mg/L
Color	NWIS	15 color units	76	4	130
Copper	NWIS	1.0 mg/L	40	0	0.0259 mg/L
Fluoride	NWIS, PatTrac	2.0 mg/L	91	1	15 mg/L
Iron	NWIS, PatTrac	0.3 mg/L	1,558	884	312 mg/L
Manganese	NWIS, MDE-PWS, PatTrac	0.05 mg/L	1,573	863	23 mg/L
pH	NWIS, PatTrac Methane	6.5-8.5	945	41 >8.5 32 <6.5	10
Silver	NWIS	0.10 mg/L	37	0	0.000017 mg/L
Sulfate	NWIS	250 mg/L	101	9	2,300 mg/L
Total dissolved solids	NWIS, PatTrac	500 mg/L	598	35	3,320 mg/L
Zinc	NWIS	5 mg/L	40	0	0.607 mg/L
Sodium	NWIS	60[1]	102	18	1,800 mg/L

[1] Drinking Water Advisory

Table 8. Summary of organic chemical detections with respect to Maximum Contaminant Levels for sites in Garrett County, Maryland. Organic constituents lacking MCLs that were detected are also shown. Source: U.S. Geological Survey NWIS database.

[MCL, Maximum Contaminant Level; NWIS, National Water Information System; mg/L, milligrams per liter]

Contaminant	MCL (mg/L)	Number of sites tested	Detections	Detected concentration (mg/L)
Alachlor	0.002	4	0	
Atrazine	0.003	4	1	0.000024 mg/L
Benzene	0.005	5	0	
Carbofuran	0.04	1	1	0.000026 mg/L
Chlorobenzene	0.1	2	0	
2,4-D	0.07	1	0	
Diazinon	none	1	1	0.000007 mg/L
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	1	0	
o-Dichlorobenzene	0.6	2	0	
p-Dichlorobenzene	0.075	2	0	
1,2-Dichloroethane	0.005	2	0	
1,1-Dichloroethylene	0.007	2	0	
cis-1,2-Dichloroethylene	0.07	1	0	
trans-1,2-Dichloroethylene	0.1	2	0	
Dichloromethane	0.005	2	0	
1,2-Dichloropropane	0.005	2	0	
Ethylbenzene	0.7	5	0	
Lindane	0.0002	1	0	
Metolachlor	none	4	1	0.000005 mg/L
MTBE (methyl *tert*-butyl ether)	none	3	1	0.0012 mg/L
Simazine	0.004	4	0	
Styrene	0.1	2	0	
2,4,5-TP (Silvex)	0.05	1	0	
1,2,4-Trichlorobenzene	0.07	1	0	
1,1,1-Trichloroethane	0.2	2	0	
1,1,2-Trichloroethane	0.005	2	0	
Trichloroethylene	0.005	2	0	
Vinyl chloride	0.002	2	0	
Xylenes (total)	10	5	0	

Table 9. Organic chemicals that were not in the NWIS data set that have Drinking Water Standards.

[NWIS, National Water Information System]

Acrylamide	Diquat	Hexachlorocyclopentadiene
Benzo(a)pyrene (PAHs)	Endothall	Methoxychlor
Carbon tetrachloride	Endrin	Oxamyl (Vydate)
Chlordane	Epichlorohydrin	Polychlorinated biphenyls (PCBs)
Dalapon	Ethylene dibromide	Pentachlorophenol
Di(2-ethylhexyl) adipate	Glyphosate	Picloram
Di(2-ethylhexyl) phthalate	Heptachlor	Tetrachloroethylene
Dinoseb	Heptachlor epoxide	Toluene
Dioxin (2,3,7,8-TCDD)	Hexachlorobenzene	Toxaphene

Table 10. Constituents that should be considered for private water-well testing prior to gas drilling activities.

[modified from National Ground Water Association (2013)]

Major ions and others:	
Alkalinity Calcium Chloride Magnesium Potassium Sodium Nitrite Nitrate-plus-nitrite	Sulfate pH Specific conductance Total dissolved solids Turbidity Gross alpha-particle activity Gross beta-particle activity Dissolved oxygen
Minor and trace elements: Arsenic Barium Boron Bromide Chromium Iron Manganese Selenium Uranium	Organic chemicals: BTEX (benzene, toluene, ethyl benzene, xylene) Methane Gasoline range organics Total petroleum hydrocarbons or oil and grease Total organic carbon

Appendix A. Information on GIS compilation and related metadata.

Most of the files for Geographic Information Systems (GIS) were compiled and built in ESRI's ArcGIS 9.3.1 software by the Maryland Geological Survey (MGS). The transition to ESRI's ArcGIS version 10 is still in progress at MGS as of January, 2014. There are important changes to file metadata formats with version 10 that involve the transition from the Federal Geographic Data Committee (FGDC) metadata standards and FGDC editor of ArcGIS 9.3.1 to the International Organization for Standardization (ISO) standards and metadata in version 10. As a result of the changes in software and metadata standards which are not readily compatible or interchangeable (especially for metadata embedded on GIS files), the metadata for the project has been compiled and provided to a large extent as stand-alone files which are explained below.

Most of the components of metadata related to data sources and compilation of the water-quality data sets are included in the project report (which is included as a digital file along with the ArcGIS files). Explanations of the columns in the ArcGIS feature classes (i.e., attribute table definitions) are provided as stand-alone tables in Microsoft Excel format. These are readable via the ArcCatalog as well as Excel.

For this project all GIS files were projected to the Maryland State Plane coordinate system, North American Datum (NAD) 1983, meters. Base map files were largely derived from existing GIS files that are downloadable from government agencies. Many of these are provided as shapefiles. Most of the water features were extracted from the National Hydrologic Dataset (http://nhd.usgs.gov/data.html). Most of the GIS files of roads and boundaries were derived from the Maryland State Highway Administration files available at http://www.sha.maryland.gov/Index.aspx?PageId=282. Most of the geologic data and the image of the topographic base-map image were derived from the *Geologic Map of Garrett, Allegany and Western Washington Counties in Maryland* (version 1.02) (Brezinski and Conkwright, 2013) (http://www.mgs.md.gov/publications/map_pages/garrett_allegany_washington_geo_map.html).

Existing metadata was retained to the extent feasible on the GIS files themselves. The original metadata was updated minimally by MGS where appropriate but maintained in the standard of its original format (FGDC or ISO). The metadata was exported as stand-alone .xml files. These .xml files represent the native format of the metadata either as FGDC standards or as ISO standards. By providing these files in .xml format it is hoped that the transition to the user's desired format and software will be facilitated. Metadata attached to the GIS files compiled in ArcGIS 9.3.1 will need to be manually upgraded to the appropriate style and standard desired in version 10.

Appendix B. Abbreviations appearing in this report.

As-Cl-Mn-Rn	arsenic, chloride, manganese, radon
DHMH	Maryland Department of Health and Mental Hygiene
FGDC	Federal Geographic Data Committee
GCHD	Garrett County Health Department
GIS	Geographic Information System
GWUDI	Ground water under the direct influence of surface water
IOC	Inorganic chemicals
ISO	International Organization for Standards
MCL	Maximum Contaminant Level
MDE	Maryland Department of the Environment
MDE-PWS	Maryland Department of the Environment Public Water Supply data set
MF/L	million fibers per liter
mg/L	milligrams per liter
MGS	Maryland Geological Survey
mi	mile
mrem/yr	millirems per year
N	nitrogen
NAD	North American Datum
NWIS	National Water Information System
NWQL	National Water Quality Laboratory (U.S. Geological Survey)
PatTrac	Garrett County Health Department client-management software package
pCi/L	picocuries per liter
PDWIS	Maryland Department of the Environment Public Drinking Water Information System database
SMCL	Secondary Maximum Contaminant Level
SOC	synthetic organic chemicals
TDS	total dissolved solids
TT	treatment technique
µg/L	micrograms per liter
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound
WTP	water treatment plant
WVa	West Virginia
--	no data
<	less than
≤	less than or equal to
>	greater than