

Maryland Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Richard A. Ortt, Jr., Director

REPORT OF INVESTIGATIONS NO. 81

**EVALUATION OF LEAD CONCENTRATIONS
IN WELL WATER FROM THE PIEDMONT AREA
OF HARFORD COUNTY, MARYLAND**

by

Katherine Burgy,
John Resline, and
Peter Smith



Prepared in cooperation with the
Harford County Health Department,
and the
Maryland Department of Health and Mental Hygiene

DNR Publication No. 12-10162013-672

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ABBREVIATIONS AND ACRONYMS:

USEPA	U.S. Environmental Protection Agency
MGS	Maryland Geological Survey
DHMH	Department of Health and Mental Hygiene
MDE	Maryland Department of the Environment
CDC	Centers for Disease Control
HCHD	Harford County Health Department
COMAR	Code of Maryland Regulations
SDWA	Safe Drinking Water Act
NADP	National Atmospheric Deposition Program
PVC	Polyvinyl chloride
TDS	total dissolved solids
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
µg/dL	micrograms per deciliter
ml	milliliter
ft	feet

EVALUATION OF LEAD CONCENTRATIONS IN WELL WATER FROM THE PIEDMONT AREA OF HARFORD COUNTY, MARYLAND

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KEY RESULTS

A water-quality study was conducted of domestic wells located in the Piedmont terrane of Harford County to evaluate the reported occurrence of elevated lead concentrations in drinking water. Samples were collected from 80 wells and were analyzed for lead, pH, specific conductance, nitrate, and chloride. Three different water samples were collected and analyzed for lead at each site: a pre-distribution (“purge”) sample, and two post-distribution samples (a first-draw sample and a 30-second-flush sample). The key results of this study are:

- Six first-draw samples exceeded the U.S. Environmental Protection Agency Action Level for lead in drinking water (0.015 milligrams per liter), while none of the 30-second-flush samples did so. The range of reported concentrations for first-draw lead samples was less than 0.005 milligrams per liter (the laboratory reporting level) to 0.039 milligrams per liter. The range for 30-second-flush samples was less than 0.005 milligrams per liter to 0.013 milligrams per liter.
- All pre-distribution system (purge) well-water samples tested below the U.S. Environmental Protection Agency Action Level of 0.015 milligrams per liter for lead. Only one sample (0.006 milligrams per liter) tested above the laboratory reporting limit of 0.005 milligrams per liter.
- No geologic sources of lead in drinking water were identified in this study or correlated with lead results. All but one lead detection appear to be the result of distribution-system contributions.
- pH values ranged from 4.7 to 8.3, with a median value of 6.1. The ground water is predominantly acidic, with 90 percent of pH values less than 7.0.
- Specific conductance, which can be used as a proxy for total dissolved solids, was highly variable, ranging from 22 to 1,706 microsiemens per centimeter at 25 degrees Celsius.
- Nitrate concentrations ranged from less than 0.2 to 18.25 milligrams per liter as nitrogen, with a median concentration of 3.94 milligrams per liter. Four samples exceeded 10 milligrams per liter, the U.S. Environmental Protection Agency Maximum Contaminant Level (standard related to health effects).
- Chloride concentrations ranged from less than 10 to 552 milligrams per liter. The U.S. Environmental Protection Agency Secondary Maximum Contaminant Level (a non-enforceable standard related to taste, odor, or other aesthetic considerations) for chloride in drinking water is 250 milligrams per liter; only one sample exceeded this standard.
- Plumbing materials, including faucets, valves, sink pipes, and well tanks, were evaluated with respect to lead detections. Lead was present in water samples passing through a variety of materials, although only five of 75 samples included fixtures adhering to the new, reduced lead content plumbing codes set forth in Maryland’s 2012 Code of Regulations.
- Lead detections did not show an association with any particular part of the distribution system.
- All lead detections greater than 0.015 milligrams per liter were from samples where the pH was less than 6.2. All lead detections were from samples where the pH was less than 6.3.
- The age of the single-family homes sampled in this study, which relates to acceptable lead content in plumbing fixtures, did not appear to be associated with first-draw lead results, as compared to other factors such as pH and stagnation time of the distribution system supplying the sample.
- The U.S. Environmental Protection Agency recommendations for reduction of lead in drinking water, including using only the cold-water line as a source for cooking and drinking water, and flushing the system by allowing water to run for a few minutes before use, are supported by the findings of this study.

INTRODUCTION

This study was prompted in response to reports of lead concentrations from water samples collected from several wells in the Piedmont physiographic province of Harford County that exceeded the U.S. Environmental Protection Agency's (USEPA) Action Level of 0.015 milligrams per liter (mg/L). Elevated lead concentrations, defined for this report as those exceeding 0.015 mg/L, have not been common in previous studies of Maryland counties with similar hydrogeologic conditions (Dine and others, 1995; Bolton, 1996; 1998); however, lead concentrations had not been systematically investigated in Harford County. Eighty percent of the land area in Harford County is located within the Piedmont physiographic province, with the remaining 20 percent located in the Coastal Plain (Nutter, 1977). Of the approximately 70,044 improved properties in the Piedmont, roughly 24,400 (35 percent) are supplied by well water. In order to determine the source of lead in drinking water (ground water, household distribution system, or both), the Maryland Geological Survey (MGS) (part of the Resource Assessment Service of the Maryland Department of Natural Resources), in cooperation with the Harford County Health Department (HCHD) (a division of the Maryland Department of Health and Mental Hygiene [DHMH]), conducted a ground-water-quality- investigation that focused on lead concentrations in domestic wells situated in the Piedmont portion of the County.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the lead concentrations in well water in the Piedmont region of Harford County (the part of the county north and west of Interstate 95). This report describes the hydrogeology of the region, the health effects of lead, and sampling methodology used. The collected data is presented and potential sources of lead are identified. The evaluation of lead concentrations with respect to various factors is discussed in depth.

LOCATION OF STUDY AREA

This study was conducted in the Piedmont portion of Harford County, which is underlain by fractured crystalline rock (metamorphic and igneous), in areas that are not serviced by public water supplies. Almost 80 percent of the county is located in the Piedmont physiographic province (Nutter, 1977), where topography varies from gently rolling slopes to fairly steep hills (fig. 1).

PREVIOUS INVESTIGATIONS

The occurrence and movement of ground water in the crystalline rock terrane of the Piedmont was explored by Nutter and Otton (1969) and in Baltimore and Harford Counties by Dingman and Ferguson (1956). Additional research into the quality and availability of ground water in Harford County was completed by Nutter and Smigaj (1975) and Nutter (1977). Ground-water quality was also investigated as part of the Statewide ground-water-quality network by Bolton (1996) and of the Piedmont region of neighboring Baltimore County by Bolton (1998).

Southwick and Owens (1968) produced the most recent geological map of Harford County, which was based on the Maryland Geological Survey (1904) map and was heavily influenced by the geologic descriptions of Piedmont crystalline rocks in Howard and Montgomery Counties (Hopson, 1964). The geologic map was followed by a report on the geology of Harford County (Southwick and others, 1969). Known economic mineral (including lead-bearing) localities were described in Maryland by Ostrander and Price (1940) and specifically in the Piedmont uplands by Heyl and Pearre (1965).

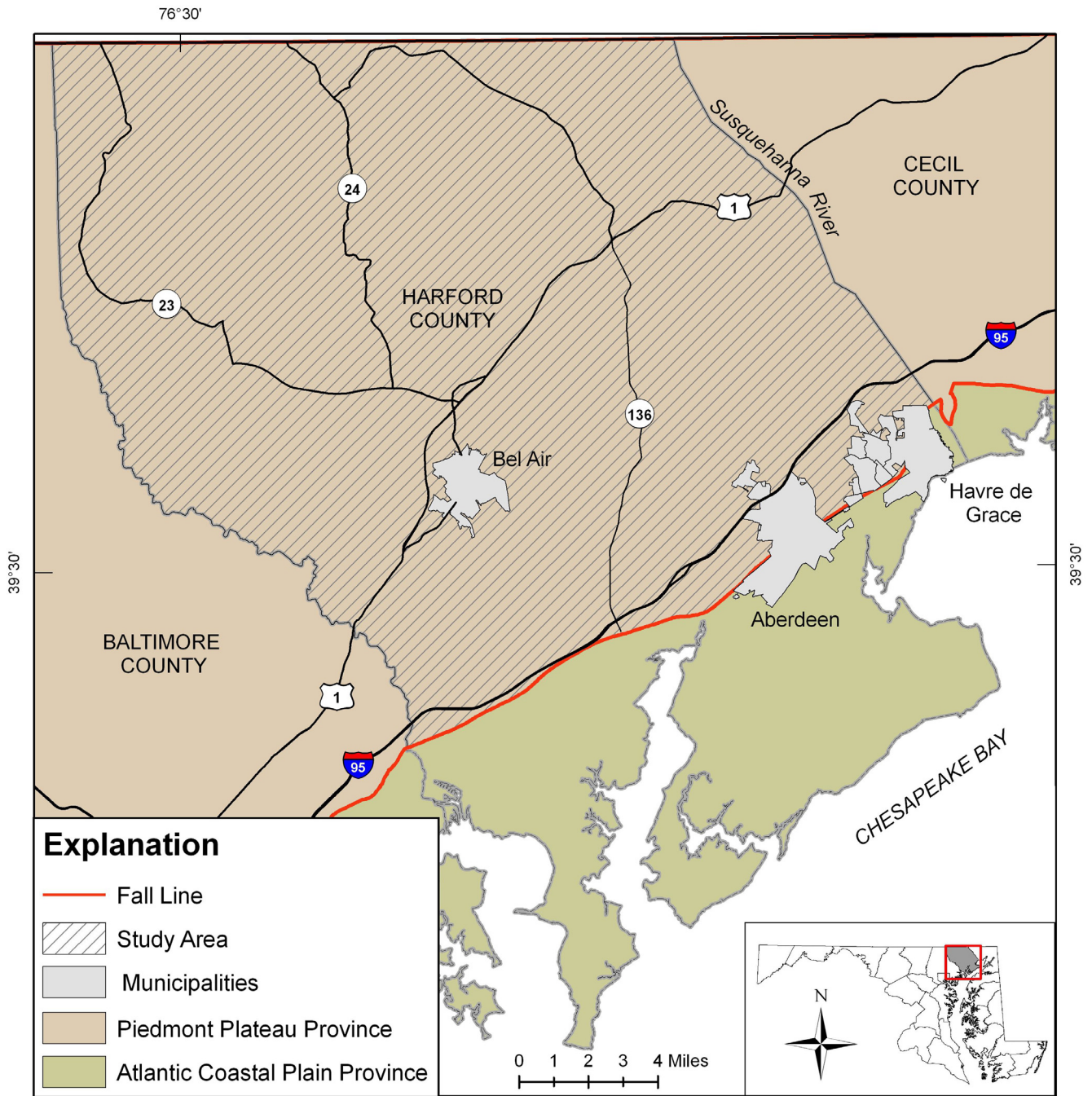


Figure 1. Location of the study area.

HEALTH EFFECTS OF LEAD

Lead is a naturally occurring metal that has been used by humans for at least 5,000 years (Brown and Margolis, 2012). Anthropogenic sources of lead include atmospheric deposition from combustion of lead-bearing materials (which has decreased considerably since the removal of tetraethyl and tetramethyl lead in gasoline in the 1970's), acid mine drainage, and a variety of consumer products (which may still contain small percentages of lead), including gasoline, paint, ceramics, plumbing materials, solders, batteries, ammunition, cosmetics, and other goods (Llopis, 1991; Katz and others, 1999; Wilkins, 2007; Kim and others, 2011; U.S. Environmental Protection Agency, 2013b).

As a result of these uses, blood lead levels increased sharply among children in the United States between 1900-1975, prompting changes to federal laws (Brown and Margolis, 2012). These laws, including the Clean Air Act (enacted in 1970), Safe Drinking Water Act of 1974 (amended in 1986 and 1996), Consumer Product Safety Commission (enacted in 1978), and the Lead and Copper Rule (1991), reduced or eliminated lead from gasoline, food packaging, house paint, water pipes, plumbing fixtures, and solder used in plumbing and beverage containers. After the various laws went into effect, lead concentrations in air, tap water, food, dust, and soil diminished, and blood lead levels began to decline (Brown and Margolis, 2012).

Humans are generally exposed to lead by ingestion of food or water containing lead, use of dishware that contains lead, hand-to-mouth contact where the hands have had contact with lead-contaminated dust or soil, inhalation of lead dust from older homes with deteriorating lead paint, and/or hobbies where lead is used (U.S. Environmental Protection Agency, 2013b). The health effects of lead exposure are cumulative and the cognitive effects were described as early as 1943 (Brown and Margolis, 2012).

In Maryland, the major source of lead exposure in children is the ingestion of lead-paint dust (Maryland Department of the Environment [MDE], 2011). In children, the central nervous system is the most sensitive system to lead and demonstrates effects even at low levels of lead exposure, resulting in permanent damage that is manifested in learning and behavioral problems, hearing problems, slowed growth, and anemia. Seizures, coma, and death can result in rare cases. Children 6 years old and younger are the most susceptible to lead's effects (U.S. Environmental Protection Agency, 2013b).

In adults, lead exposure negatively affects the nervous and cardiovascular systems, decreases kidney function, and may produce reproductive problems in both men and women (U.S. Environmental Protection Agency, 2013b). Pregnant women exposed to lead may release lead from their bones into the developing bones of the fetus. Lead is also circulated through the mother's bloodstream to the fetus. As a result, the mother may have a miscarriage, the growth rate of the fetus may be reduced, or the birth may be premature (U.S. Environmental Protection Agency, 2013b).

In 1991, the Centers for Disease Control and Prevention (CDC) defined blood lead levels equal to or exceeding 10 micrograms per deciliter ($\mu\text{g}/\text{dL}$) as the level of concern for children aged 1 to 5 years. As recently as 2012, this level of concern was reevaluated and reduced to equal to or exceeding 5 $\mu\text{g}/\text{dL}$ for children of this age group (Brown and Wheeler, 2013). According to the USEPA, the main sources of lead exposure are ingestion of paint chips and inhalation of dust, but an estimated 10 to 20 percent of human exposure to lead may come from drinking water, including infants whose main nutritional source is baby formula and concentrated juices that are mixed with lead-contaminated water (U.S. Environmental Protection Agency, 2012a).

In Maryland, CDC's National Surveillance Data for 2011 showed 107,750 children had their blood lead levels tested. Of those children, 424 were at or above 10 $\mu\text{g}/\text{dL}$, and 2,804 children were between 5 and 9 $\mu\text{g}/\text{dL}$ (Centers for Disease Control and Prevention, 2013).

ACKNOWLEDGEMENTS

This study was a cooperatively-funded project between the HCHD and the MGS. Gary Browning, Cari Biscoe, Dustin Ferguson, and Andrew Bena (HCHD) provided site identification, scheduling, and sampling assistance. Additional thanks to Kevin Barnaba, Environmental Health Director, and Susan Kelly, Harford County Health Officer for facilitating this project. Thanks also to Phung Pham (formerly MGS) for help with sampling protocols, Heather Quinn (MGS) for GIS assistance and helpful comments, Dr. James Reger (MGS retired) for geological insights, and David Bolton (MGS) for project administration and manuscript review. Donajean Appel (MGS) was also instrumental in manuscript preparation. Colleague reviews by Clifford S. Mitchell, MS, MD,

MPH (Director of Environmental Health Bureau [DHMH]), and Eric Willem (HCHD) improved this manuscript with helpful comments and suggestions. The authors gratefully acknowledge the cooperation of the residents of Harford County who agreed to have their wells tested as a part of this study.

HYDROGEOLOGIC SETTING

Harford County consists of two physiographic provinces, the crystalline-rock Piedmont province to the north and the unconsolidated sediments of the Coastal Plain to the south (fig. 1), which are separated by the Fall Line (Nutter, 1977). The topography in the Piedmont varies from gently rolling slopes to fairly steep hills. Saprolite, also known as overburden, is a combination of soil and decomposing rock fragments that lies on top of bedrock. In the Piedmont of Maryland, saprolite can range from just a few feet (ft) to more than 100 ft, while the average thickness is around 45 ft (Nutter and Otton, 1969). In Harford County, the average thickness of saprolite is thought to be 33 to 50 ft thick (Dingman and Ferguson, 1956).

Wells in the crystalline, or fractured-rock, terrane of the Piedmont receive water from fluid-filled fractures in the rock that are intersected by the borehole (fig. 2). Due the lack of storage capacity in the fractures, most well-water recharge comes from the saprolite overlying the bedrock (fig. 3) (Nutter and Otton, 1969). In order to prevent possible surface contaminants from entering the well directly, the Maryland Code of Regulations (COMAR) requires wells to have a minimum casing length of 20 ft and a minimum seating distance of 2 ft into competent bedrock (Code of Maryland Regulations, 2012a).

The geologic units used in this report are those presented in the 1968 geologic map of Harford County (fig. 4) (Southwick and Owens, 1968). The geologic nomenclature of the Maryland Piedmont has undergone several revisions; however, these revisions reflect reinterpretations of the geologic history of the region. The lithology and mineralogy of the individual units has not changed (app. A) (Southwick and others, 1969; Crowley, 1976; Crowley and others, 1976; Gates and others, 1999; Reger, unpub. data, 2013).

The crystalline rocks in the Piedmont of Harford County can be grouped into two distinct mineralogical groups, felsic and mafic rocks. Felsic rocks are primarily composed of silicate and aluminosilicate minerals such as quartz, plagioclase feldspar, potassium feldspar, and various micas. Schists and gneisses of sedimentary and igneous origin, as well as metasedimentary rocks, comprise this group in Harford County. They include the Baltimore Gneiss, Setters Formation, James Run Gneiss, the muscovite quartz monzonite gneiss, Port Deposit Gneiss, Cardiff Metaconglomerate and Cockeysville Marble, Peach Bottom Slate, and the Wissahickon Formation. The Wissahickon Formation includes five members which have been the focus of ongoing debate since the time of the 1968 map (app. A).

The mafic rocks in the study area are composed of pyroxene, hornblende, amphibole, and hypersthene. Ultramafic rocks, a subgroup of the mafic-rock type, also include large amounts of serpentinite. Units in Harford County include the Baltimore Gabbro, Quartz gabbro and quartz diorite gneiss (mapped together), metagabbro and amphibolite, as well as mafic and ultramafic intrusives (Southwick and Owens, 1968; Southwick and others, 1969; Crowley, 1976).

The rocks in the Piedmont have been intensely deformed, metamorphosed, and intruded by mafic to granitic plutons, such that original features are not typically preserved (Southwick and others, 1969). The southeastern portion of the county is dominated by metamorphosed plutonic and volcanic rocks, while to the northwest the metamorphosed sedimentary rocks of the Wissahickon Formation, Peach Bottom Slate, and Cardiff Metaconglomerate constitute the majority.

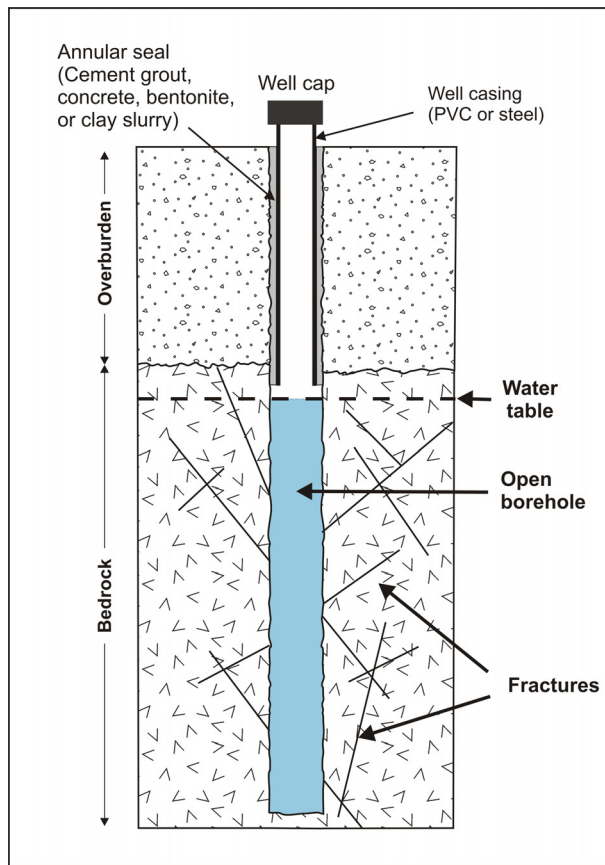


Figure 2. Typical well construction in fractured-rock terrane. (From Burgy and Duigon, 2012.)

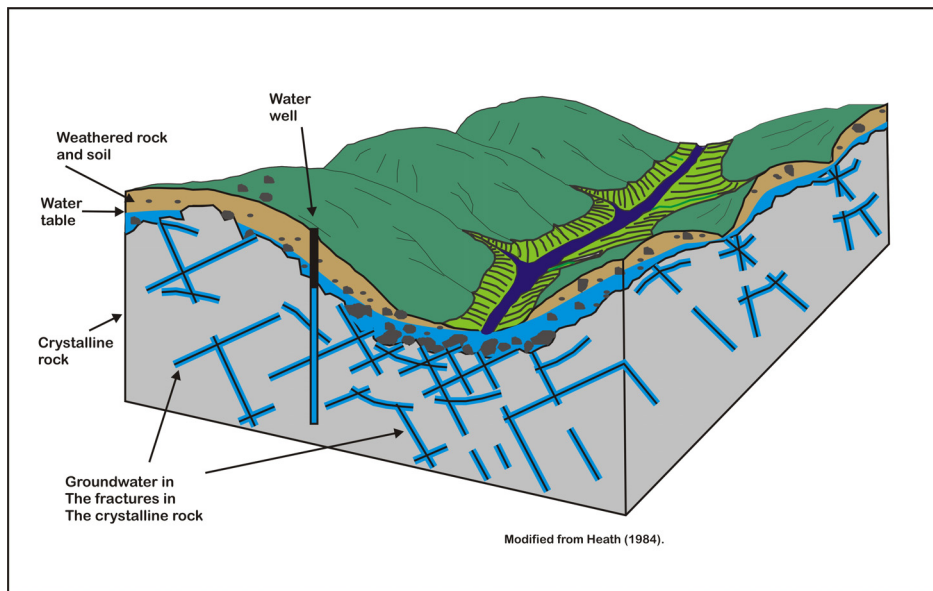


Figure 3. Ground water in fractured-rock terrane.

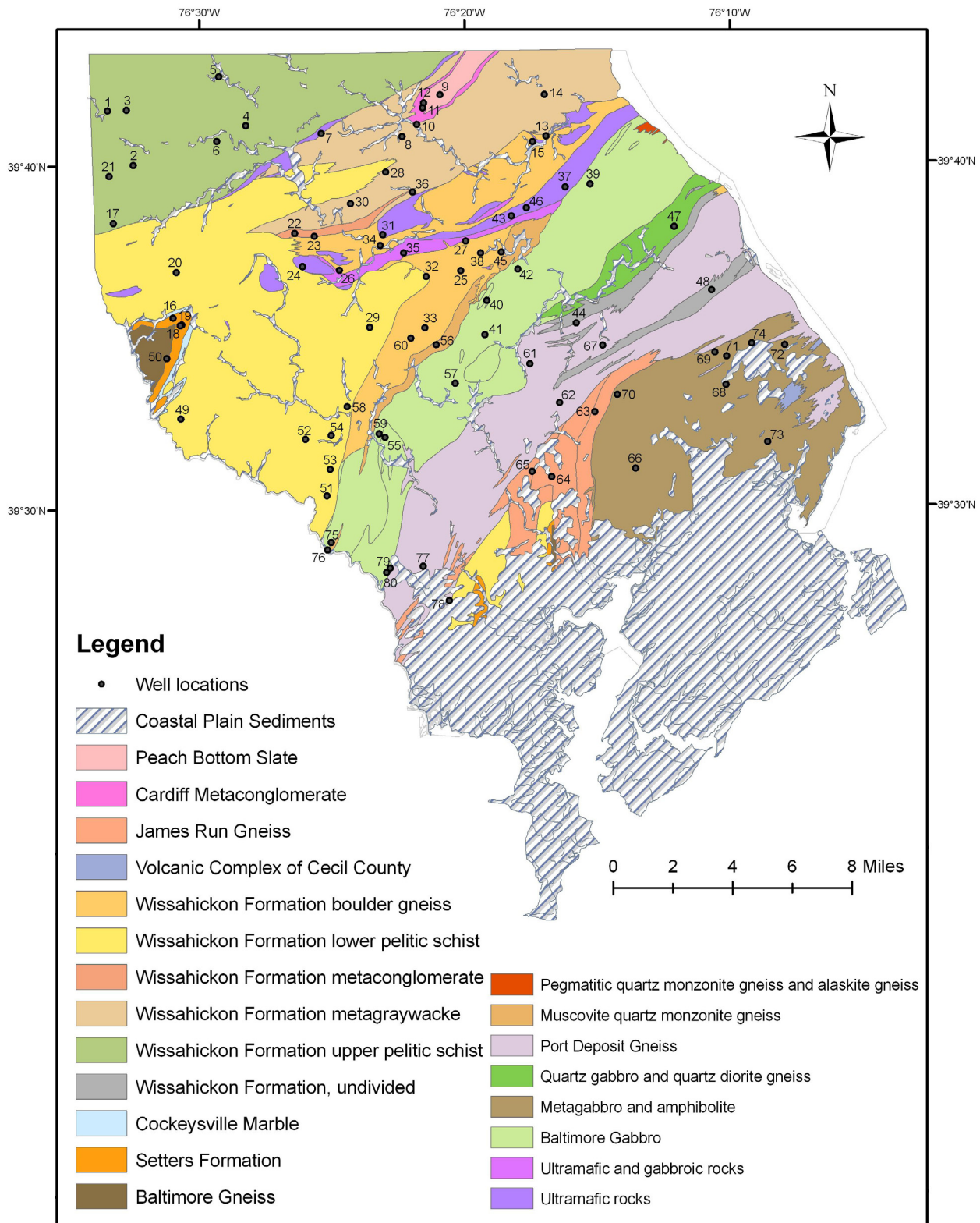


Figure 4. The geology of Harford County and the locations of sampled wells in the study area. Well numbers are referenced in Appendix B. (Based on the geologic map of Harford County by Southwick and Owens [1968]).

DISTRIBUTION SYSTEMS FOR DOMESTIC WELL SITES

The Safe Drinking Water Act (SDWA), passed by the United States Congress in 1974 and amended in 1986 and 1996, is intended to protect drinking water and its sources with respect to public-water systems (U.S. Environmental Protection Agency, 2004). The Lead and Copper Rule, which set the Action Level for lead in public water systems, went into effect in 1991. However, both the Safe Drinking Water Act and the Lead and Copper Rule do not regulate private water systems that serve fewer than 25 individuals (Brown and Margolis, 2012). As a result, most private homes are not tested for lead.

Private water systems are generally regulated by state or local regulations. In Maryland, the installation of drinking-water wells is regulated by the Code of Maryland Regulations (COMAR) 26.04.04 (Well Construction) and the associated distribution system, piping, fittings, and fixtures are regulated by COMAR 09.20.01 (State Plumbing Code). In 2012, some changes were made to the Maryland State Plumbing Code which adjusted the limit of lead content in plumbing components used for potable water applications. COMAR 09.20.01.03 now requires that the weighted average of plumbing components used for potable water contain no more than 0.25 percent lead with respect to the wetted surface of the applicable component (Code of Maryland Regulations, 2012b). Prior to this change, no more than 8 percent lead content was permissible in potable water plumbing components (U.S. Environmental Protection Agency, 2012b). Maryland has joined California and Vermont with regard to this lead standard. Furthermore, Federal Public Law 111-380 will take effect on January 4, 2014, setting this standard for the entire United States of America (U.S. Government Printing Office, 2011b).

METHODS OF INVESTIGATION

SITE SELECTION

Eighty domestic water wells located in the crystalline- (fractured) rock terrane of the Piedmont were sampled during this study (app. B). Well locations were selected primarily by geologic unit, based on the designations of the 1968 Geologic Map of Harford County (Southwick and Owens, 1968). The number of wells sampled in a given geologic unit was generally proportional to the outcrop area of the unit (tab.1). Wells were excluded if a well permit and the corresponding well-completion report could not be located in county and state records. MGS and HCHD well-identification resources included both personnel and available well databases. All sampling was completed via voluntary participation by homeowners.

WELL CHARACTERISTICS

Well Depth

Well depths in this study ranged from 62 to 525 ft, with a median depth of 200 ft. However, the majority of wells in this study (68 out of 80) are shallower than 300 ft and one-quarter of the wells studied were drilled to a depth between 150 to 200 ft, regardless of geologic unit (fig. 5). It is therefore questionable that well depth reflects the availability of water within a given geologic unit and instead reflects the well driller's propensity to cease drilling when "enough" water or storage capacity for the intended use is reached (for example, eight wells in the study are drilled to exactly 300 ft).

Casing Depth

Casing depths in this study ranged from 19 to 109 ft, with a median depth of 49 ft. The majority of wells are cased to depths between 20 and 70 ft (fig. 6). Casing depth is often used as a proxy for the saprolite/overburden thickness, as COMAR requires well casing to extend through the saprolite and be emplaced at least 2 ft into competent bedrock (COMAR, 2012a). While the reliability of this proxy has not been thoroughly investigated, the

Table 1. Sampled geologic units and aquifer lithology designations.

Geologic unit	Aquifer lithology	Symbol	Number of wells sampled
Peach Bottom Slate	Felsic	Op	3
Setters Formation/Baltimore Gneiss	Felsic	pCsq & pCb	4
James Run Gneiss	Felsic	pCjg & pCja	3
Wissahickon Formation, undivided	Felsic	pCw	2
Wissahickon boulder gneiss	Felsic	pCwb	10
Wissahickon metaconglomerate	Felsic	pCwc	2
Wissahickon metagraywacke	Felsic	pCwg	6
Wissahickon lower pelitic schist	Felsic	pCwl	8
Wissahickon upper pelitic schist	Felsic	pCwu	8
Metagabbro and amphibolite	Mafic and Ultramafic	Pzga	8
Quartz gabbro and quartz diorite gneiss/ Baltimore gabbro	Mafic and Ultramafic	Pzgg/Pzb & Pzbm	10
Muscovite quartz monzonite gneiss	Felsic	Pzm	2
Port Deposit gneiss	Felsic	Pzpd & Pzpbs	6
Ultramafic and gabbroic rocks/ Ultramafic rocks	Mafic and Ultramafic	Pzug/Pzum	8
Total			80

casing depths in this study are consistent with Nutter and Otton’s (1969) observed values of saprolite thickness of several feet to over 100 ft with an average of 45 ft.

SAMPLING METHODS

Sample Collection and Analysis

Three water samples were collected for lead analysis at each site: (1) a first-draw, post-distribution-system sample, (2) a thirty-second-flush, post-distribution system sample, and (3) a purged, pre-distribution-system sample. Chloride and nitrate samples were also collected from the pre-distribution-system sampling location, and temperature, pH, and specific conductance were recorded at that location as well. Wells are referenced by numbers 1 through 80 in figure 4 and appendix B.

Prior to the scheduled sampling, HCHD employees contacted property owners to request they not use their sink for at least 6 hours prior to sampling, but not to allow more than 18 hours of stagnation time. If the stagnation time is less than 6 hours, leaching is unlikely to occur at a detectable amount. However, a stagnation time that exceeds 18 hours would likely produce leaching levels not reflective of normal household conditions (U.S. Environmental Protection Agency Lead and Copper Rule). HCHD also requested that any refrigerator ice makers or other water dispensers connected to the same cold-water line as the sink also not be used.

Any manipulation of the distribution system such as turning control valves normally unused prior to sample collection can impact the accuracy of the results. When this is done, small scrapings of metal from the control valve interior may be dislodged. The first-draw or flush sample may capture these scrapings and the result is inaccurately inflated (U.S. Environmental Protection Agency, 1994). Therefore, upon arrival at the site, and

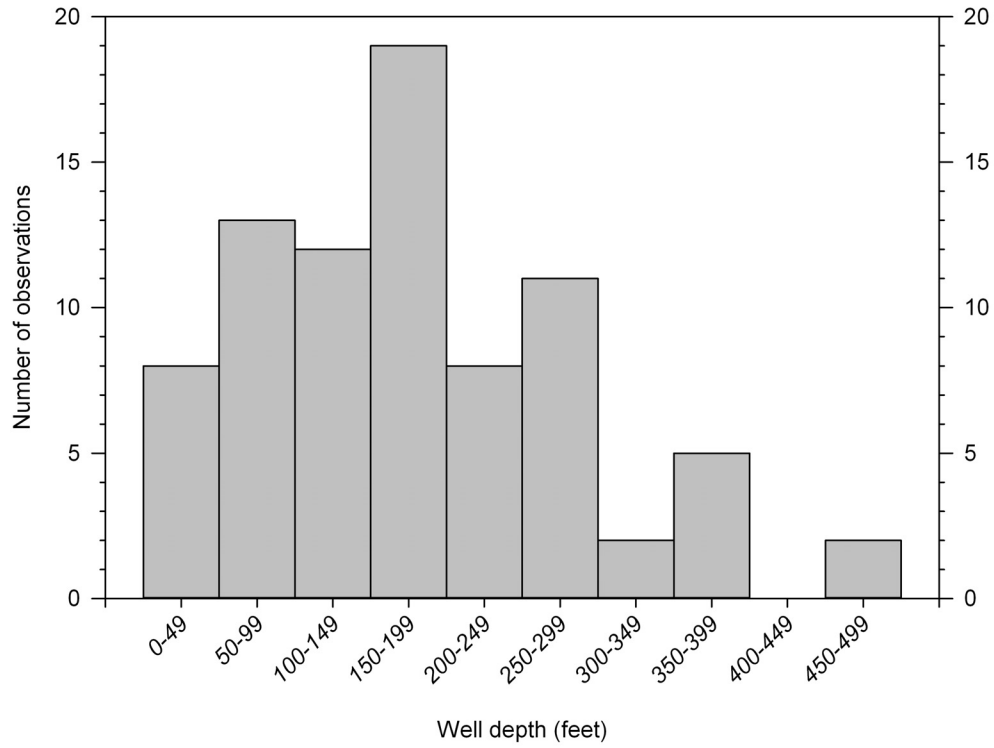


Figure 5. Distribution of well depths for wells sampled in this study.

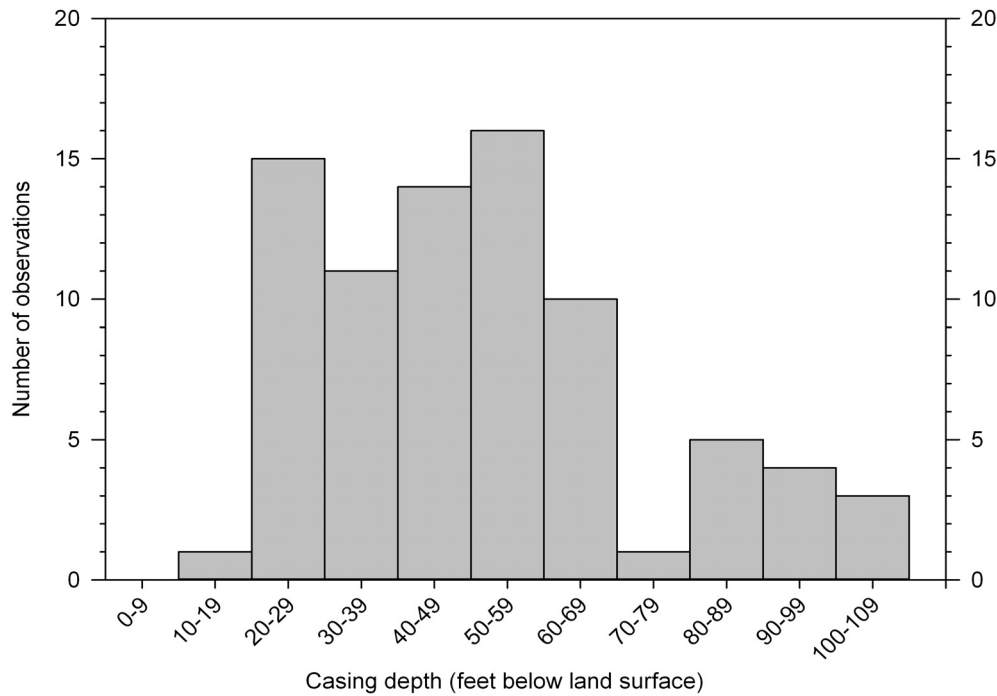


Figure 6. Distribution of casing depths for wells sampled in this study.

before any treatment systems were turned off, two post-distribution-system water samples were drawn from the sink for lead analysis by HCHD personnel. The first-draw sample was collected from the cold-water line tap, then the water was allowed to run for 30 seconds, and the flush sample was collected. Samples were collected in standard 1,000 milliliter (ml) cube containers provided by HCHD. Samples were then packed in ice for transport. Once the post-distribution-system samples were collected, MGS personnel began preparations for pre-distribution (purge) sample collection.

Pre-sampling preparations included calibration of the ThermoOrion¹ Star A329 pH meter using a two-buffer standardization procedure and an YSI EcoSense EC300 specific conductance meter using a single standard. Buffers for pH and specific conductance were selected based on the anticipated pH and specific conductance of the sample. Samples were collected from the site in the home closest to the well. Most samples were collected at either the indoor pressure-tank spigot or from an outside spigot that bypassed treatment systems. In all pre-distribution sampling, the water treatment system (if any) was bypassed or turned off. A hose was connected either directly to the pressure-tank spigot or outdoor spigot, or through a Y-valve attached to the spigot. The hose was then run to a bucket where the pH and specific conductance were measured. Temperature, pH, and specific conductance were monitored at 5-minute intervals until the following stabilization criteria were met over three consecutive intervals: temperature, ± 0.2 degrees Celsius; pH, ± 0.05 ; specific conductance, ± 5 percent of three previous readings (or ± 3 percent for readings less than 100 microsiemens per centimeter at 25 degrees Celsius [$\mu\text{S}/\text{cm}$]). Several wells did not completely meet the stabilization criteria despite additional purge time, and in order to respect homeowner concerns regarding water availability, were sampled when parameters most closely approximated the sampling criteria in the judgment of field staff.

After stabilization criteria were met and the measurements recorded,, lead and nitrate samples (unfiltered) were collected and chilled in 1000 ml cube containers by HCHD personnel. A sample was also collected by MGS staff and analyzed onsite for chloride with a Hach Chloride testing kit utilizing the Hach Water Analysis Handbook Mercuric Nitrate Method 8206. Samples being analyzed for lead were acidified with HNO_3 to a pH less than 2.0; samples being analyzed for nitrate+nitrite were acidified with H_2SO_4 to a pH less than 2.0. Samples were repacked in ice and sent via courier to the State of Maryland Department of Health and Mental Hygiene Multi-Element Section laboratory, in Baltimore, Maryland. Lead and nitrate analyses were performed using EPA Method 200.8 (lead) and EPA Method 353.2 (nitrate). Specific conductance, pH, and chloride results are based on field measurements.

Data Analysis

Samples were evaluated for statistical significance using the Mann-Whitney Rank Sum Test and the Kruskal-Wallis One-Way Analysis of Variance on Ranks (ANOVA) and for trends using the Pearson Product Moment Correlation. Differences between well groups were considered to be statistically different if $P < 0.05$ (that is, if there was less than a 5 percent chance of incorrectly concluding that there is a true association between the variables). In this report, references to statistical significance refer to the Kruskal-Wallis ANOVA test at the $P < 0.05$ significance level. None of the data were normally distributed, as determined by the Kolmogorov-Smirnov and Shapiro-Wilk normality tests. Data analysis also included descriptive statistics of wells and subsets of wells.

QUALITY ASSURANCE

Both field-duplicate and reference samples were used as quality-assurance indicators in this study. Field duplicates of first-draw, flush, and purge lead samples were collected at three different sites in order to demonstrate the reproducibility of lead test results. All original and duplicate samples tested below laboratory reporting limits (0.005 mg/L). A reference lead sample was also analyzed to determine the accuracy of the laboratory analysis. The reference sample was prepared by ERA, a commercial provider of certified reference materials, and was submitted along with actual samples for analysis. The result of the lead analysis of the reference sample was 0.034 mg/L, which was within the acceptable range of 0.0277 to 0.0378 mg/L.

¹ The use of trade names in this report is for identification purposes only, and does not constitute endorsement by the Maryland Geological Survey or the cooperating agencies.

RESULTS

GROUNDWATER QUALITY

Lead

Post-Distribution System Samples

Six first-draw samples exceeded the USEPA Action Level of 0.015 mg/L for lead, and all samples that exceeded the Action Level had a pH of less than or equal to 6.2. However, none of the flush samples exceeded the standard (figs. 7, and 8). Concentrations for first-draw samples ranged from the laboratory reporting limit of <0.005 mg/L to 0.039 mg/L. Lead concentrations for the flush samples ranged from <0.005 mg/L to 0.013 mg/L. The sample with the highest first-draw lead concentration of the study (Well 11, 0.039 mg/L) also had the maximum allowable distribution-system stagnation time (18 hours), the lowest recorded pH (4.7), and was sampled from a bathroom sink instead of the kitchen sink due to homeowner usage of the kitchen sink prior to sampling. Two sampled sites (Wells 58 and 78) had an increase in lead content between the first-draw and flush samples (which could be attributed to minor amounts of debris or other particles becoming mobilized during the flush), but the majority of samples with a first-draw lead concentration greater than 0.005 mg/L showed substantial decreases in lead in the 30-second-flush sample. All lead detections (above and below the Action Level) were from samples where the pH was less than 6.3.

Pre-Distribution System Samples

All of the pre-distribution (purge) well-water samples in this study were below the USEPA Action Level, and 79 out of 80 samples were below the laboratory reporting limit of 0.005 mg/L. The remaining sample was reported as 0.006 mg/L (fig. 9). Figure 10 illustrates the substantial reduction of lead concentrations between the first-draw, flush, and purge water samples. One sample (Well 61) also had a very slight increase in lead concentration across the three samples, going from <0.005 mg/L in the first-draw and flush samples to 0.006 mg/L in the purge sample. This could be due to the same mechanism as with Wells 58 and 78 (discussed earlier).

A standard garden hose was attached to the homeowner's pressure tank or outdoor spigot, and the other end was run into a bucket located in an appropriate drainage area (such as a yard or utility sink), which was then used as the sampling point for purged well water. Purge measurements were made in the water in the bucket and samples were collected from the end of the hose. This was done in order to prevent any disturbance to the valves or fixtures of the distribution system once purging began and thus prevent contamination of the well sample from dislodged debris. Some polyvinyl chloride (PVC) garden hoses do contain lead as a stabilizing element and this is a possible source of lead in the study. However, all purge water samples with the exception of Well 61 (at 0.006 mg/L) were below the laboratory reporting limit for lead. This suggests that the thorough well purging completed as part of the methodology sufficiently reduces the likelihood of lead contamination via the sampling equipment, and is also consistent with USEPA guidelines for flushing water in household fixtures before usage.

pH

The range of pH values in this study was 4.7 to 8.3, with a median value of 6.1 (fig. 11). Ninety percent of the pH values were below 7.0 and therefore considered acidic. Large differences exist among median pH values between the Peach Bottom Slate and the ultramafic/gabbroic units and the quartz gabbro/quartz diorite gneiss/Baltimore gabbro units (fig. 12); however, the small sampling size of the Peach Bottom Slate group (n=3) suggests more data are needed to confirm this result. The USEPA Secondary Maximum Contaminant Level (SMCL) for pH is 6.5 to 8.5 (U.S. Environmental Protection Agency, 2013d). However, this is only for cosmetic and/or aesthetic reasons and is not an enforceable standard. Drinking water with acidic pH values (below 7.0)

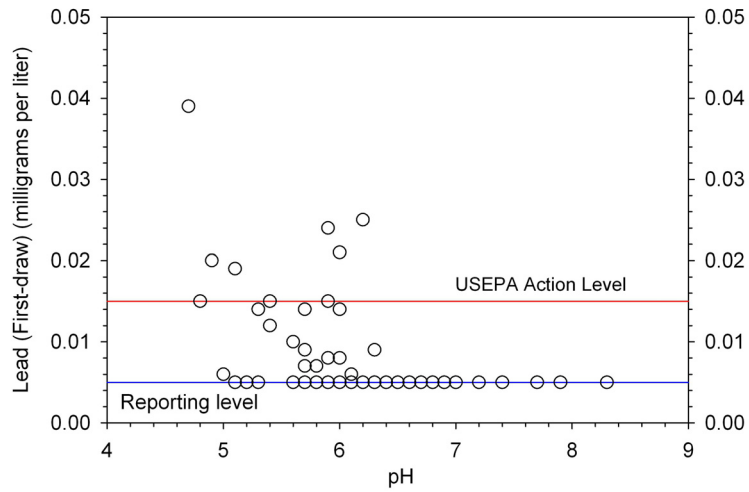


Figure 7. Relation between first-draw lead concentrations (post-distribution system) and pH. Lead values less than the reporting lead (0.005 mg/L) are plotted at 0.005 mg/L.

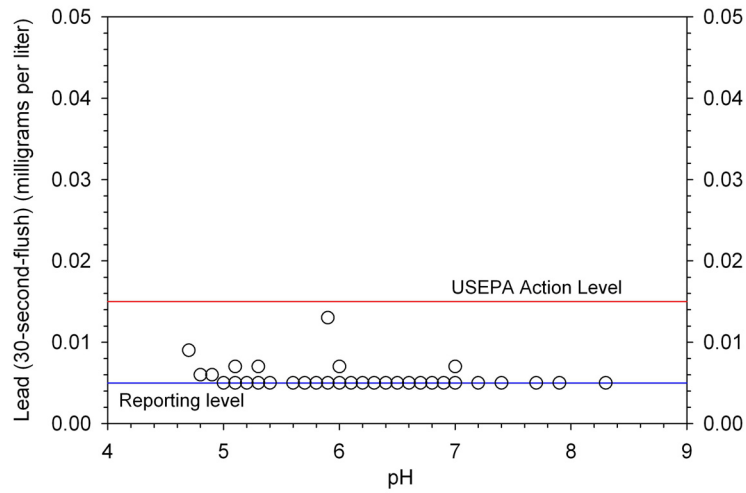


Figure 8. Relation between 30-second-flush lead concentrations (post-distribution system) and pH. Lead values less than the reporting lead (0.005 mg/L) are plotted at 0.005 mg/L.

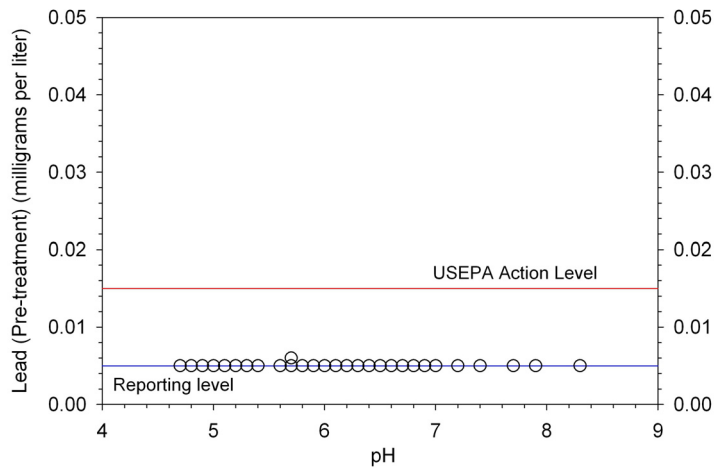


Figure 9. Relation between purge lead concentrations and pH. Lead values less than the reporting lead (0.005 mg/L) are plotted at 0.005 mg/L.

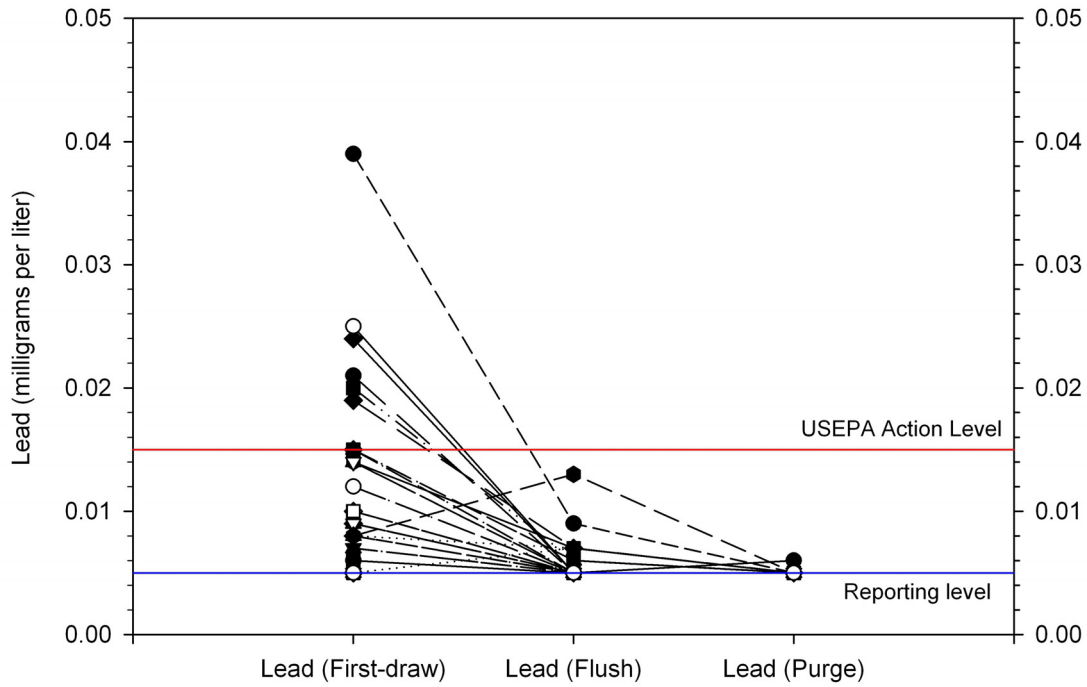


Figure 10. Comparison between lead concentrations from first-draw, 30-second flush, and purge water samples from the same well. Lines connect samples from the same wells. Lead values less than the reporting lead (0.005 mg/L) are plotted at 0.005 mg/L.

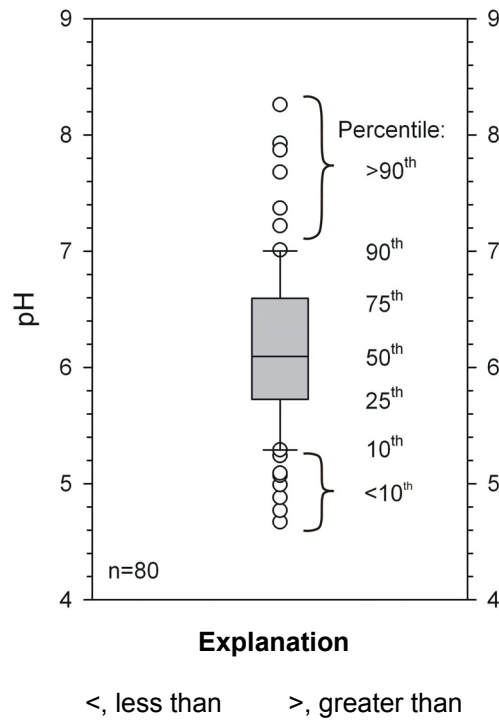


Figure 11. Box-and-whisker plot showing pH values observed in this study.

encourages corrosion of pipes and fixtures, while basic pH values (those above 7.0) promote the formation of scale deposits in plumbing systems.

Specific Conductance

Specific conductance is a measure of how well a water sample conducts electricity. Pure water is a poor conductor of electricity; higher specific conductance levels can indicate the relative amount of dissolved solids. In central Maryland well water, higher specific conductance often indicates elevated levels of chloride, but can also indicate high levels of nitrate, sulfate, sodium, magnesium, and calcium (U.S. Environmental Protection Agency, 2013c). Specific conductance can also sometimes be used as an inexpensive alternative for the measurement of total dissolved solids (TDS).

Specific conductance values ranged from 22 to 1,706 $\mu\text{S}/\text{cm}$ (fig. 13), with a median value of 199 $\mu\text{S}/\text{cm}$. Ninety percent of specific conductance values were below 525 $\mu\text{S}/\text{cm}$. There was no significant relationship between pH and specific conductance. The USEPA does not have an established primary or secondary drinking water standard for specific conductance.

Nitrate

Nitrate concentrations as discussed in this report refer to nitrate-plus-nitrite, (in mg/L as N), by the DHMH laboratory. Nitrate concentrations ranged from <0.2 (reporting level) to 18.25 mg/L (fig. 14). The median nitrate concentration was 3.94 mg/L. The USEPA Maximum Contaminant Level (MCL) for nitrate in drinking water is 10 mg/L and was exceeded in only four samples (Wells 17, 19, 32, and 54). Nitrate levels above the USEPA standard are considered a potential health hazard due to the risk of methemoglobinemia (blue baby syndrome) for infants, especially those younger than 6 months of age, and women who may be pregnant (USEPA, 2013d).

Chloride

Chloride concentrations ranged from less than 10 to 552 mg/L, with a median concentration of 13.5 mg/L (fig. 15). The USEPA SMCL for chloride is 250 mg/L due to cosmetic and/or aesthetic effects, but is non-enforceable (USEPA, 2013d). Of the 80 samples in this study, only one sample (Well 2) exceeded the chloride standard. Anthropogenic sources of chloride in the Maryland Piedmont include deicing salts and salts used for backflushing water softening systems. There are no significant geologic sources of chloride in the study area.

PLUMBING MATERIALS

As of January 1, 2012, the State of Maryland Plumbing Code (COMAR 09.20.03) has required the lead content of newly installed potable water-plumbing components to be reduced from 8 percent to 0.25 percent of the wetted surface. At each sampling site, the age of the faucet was assessed as to whether it was under the old or new plumbing code. Based on information provided by the homeowner, only five first-draw samples were taken from faucets installed after the effective date.

During the sample visit, the water-supply pipe material was also evaluated. Twenty-six first-draw samples were taken from copper pipes, 49 from plastic pipes, 4 from a combination of copper and plastic pipes, and 1 from other type of piping material. Nine of 26 (35 percent) of the samples taken from copper pipes had a first-draw lead detection, while 16 of 48 (33 percent) of the samples taken from plastic pipes had a first-draw lead detection, and no first-draw lead detections were found in the samples taken from a combination of materials or from samples taken from other types of plumbing material (fig. 16).

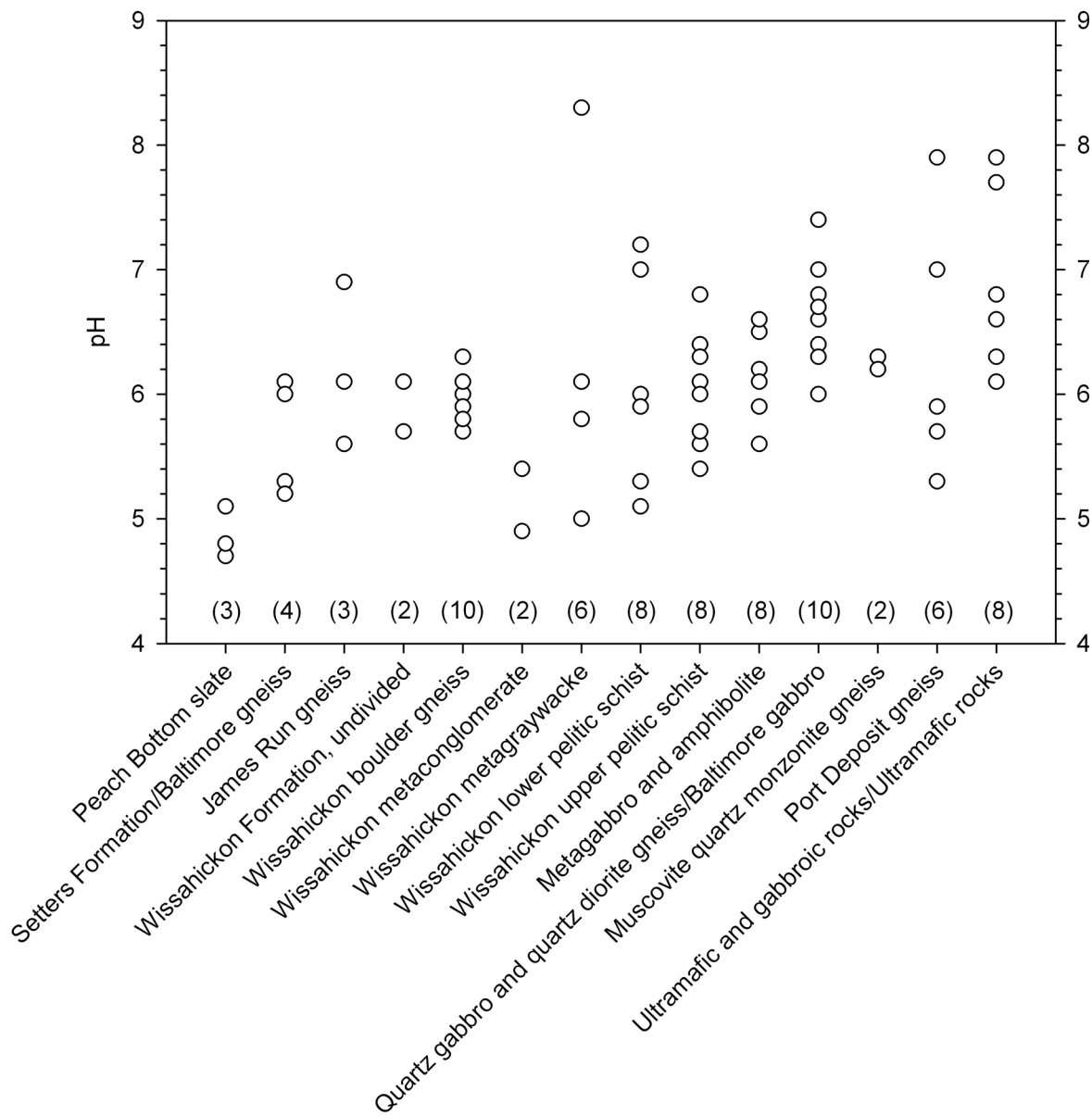


Figure 12. pH values from individual geologic units. (Geology based on Southwick and Owens [1968] Harford County geologic map.)

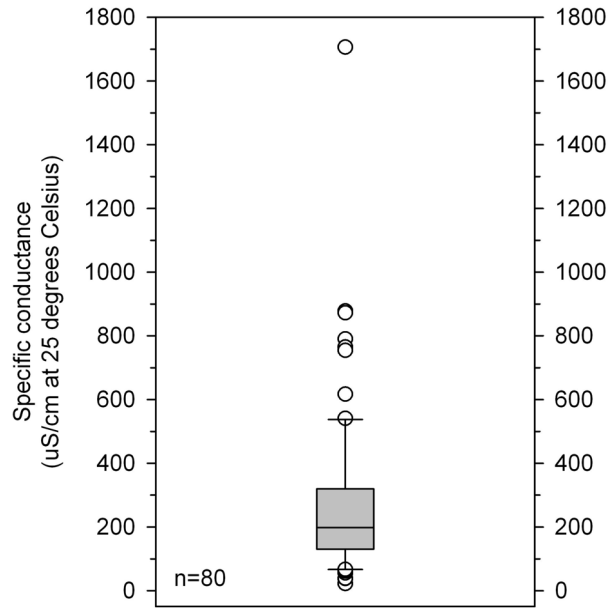


Figure 13. Box-and-whisker plot showing specific conductance values observed in this study. (See figure 11 for explanation of plots.)

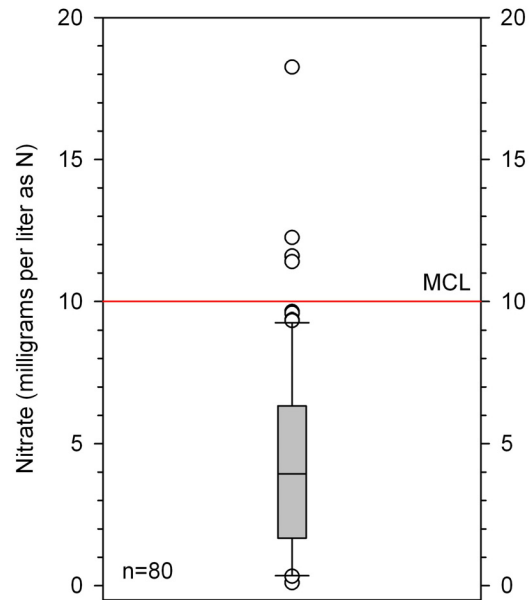


Figure 14. Box-and-whisker plot showing nitrate concentrations observed in this study. (See figure 11 for explanation of plots.) MCL, maximum contaminant level.

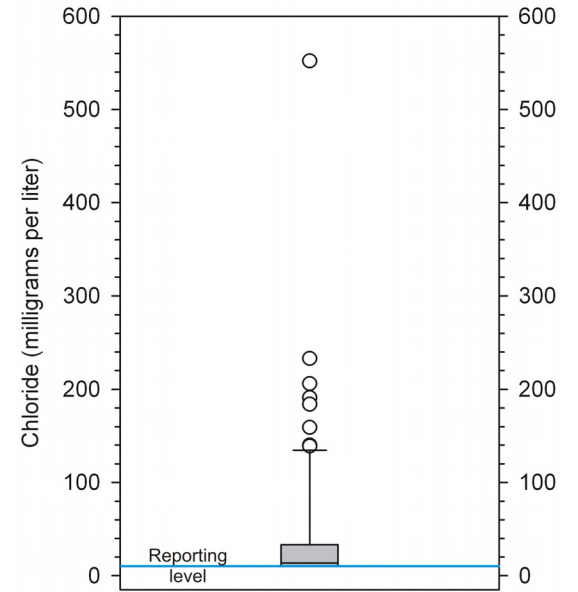


Figure 15. Box-and-whisker plot showing chloride concentrations observed in this study. (See figure 11 for explanation of plots.)

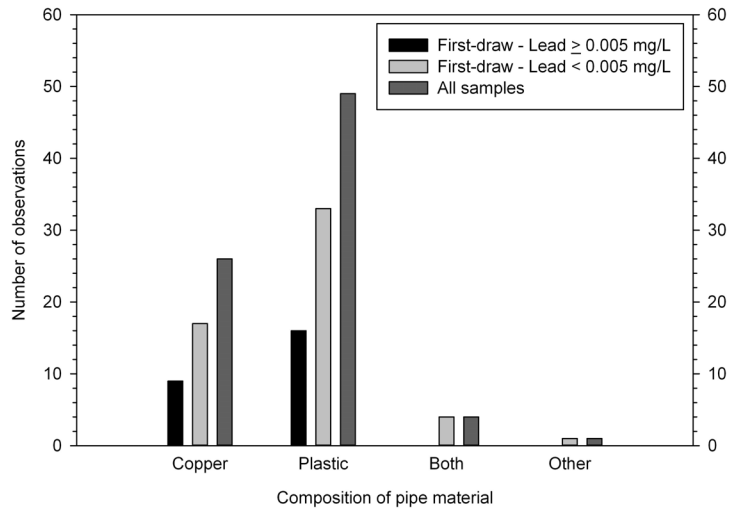


Figure 16. Relation of pipe materials and lead detections.

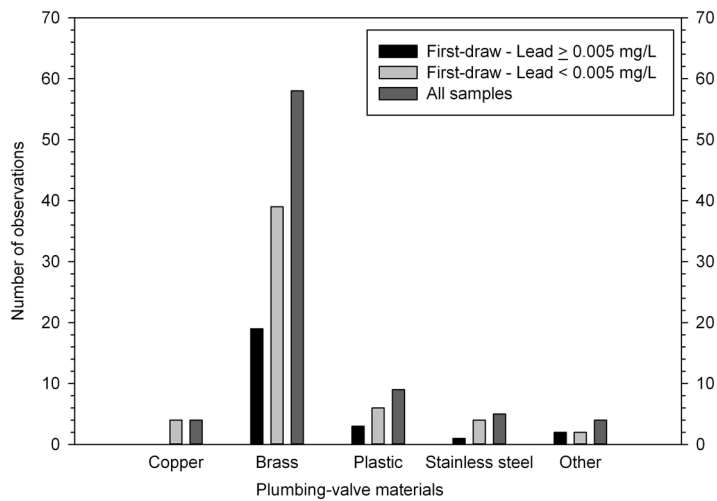


Figure 17. Relation of plumbing-valve materials and lead detections.

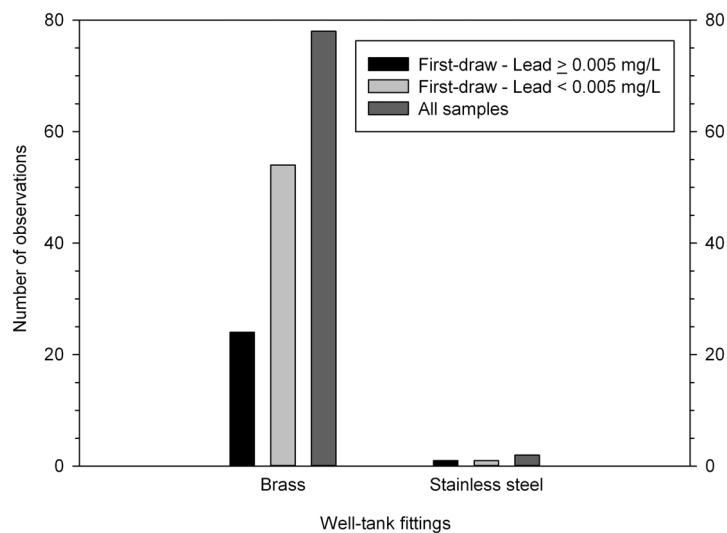


Figure 18. Relation of well-tank fittings and lead detections.

Plumbing valves below the sink were evaluated for type of material (fig. 17). Four first-draw samples were taken from copper shut-off valves, 58 from brass shut-off valves, 9 from plastic shut-off valves, 5 from stainless-steel shut-off valves, and 4 from other shut-off valve material. No first-draw lead detections were found in the samples taken from shut-off valves made of copper, 19 of 58 samples (about 33 percent) of the samples taken from brass shut-off valves had a lead detection, 3 of 9 (33 percent) of the samples taken from plastic shut-off valves had a lead detection, 1 of 5 (20 percent) of the samples taken from stainless-steel shut-off valves had a lead detection, and 2 of 4 (50 percent) of the samples taken from other shut-off valve material had a lead detection.

Well-tank fittings were also evaluated for type of material (fig. 18). Seventy-eight of the distribution systems had brass well-tank fittings while two of the distribution systems utilized a stainless-steel fitting. Twenty-four of 78 (31 percent) samples taken from brass fittings had a lead detection at the first-draw sample location. One of the two distribution systems utilizing stainless-steel fittings had a lead detection in the first-draw sample location.

DISCUSSION

FACTORS ASSOCIATED WITH LEAD DETECTIONS

The Distribution System

The ability of a water-distribution system to leach lead is well documented throughout history. As early as 1793, a warning was issued in Germany about the use of lead in drinking-water pipes (Brown and Margolis, 2012). The United States recognized the adverse health effects of lead-contaminated water in 1845 (Brown and Margolis, 2012). The USEPA considers the corrosion of lead-containing plumbing material to be the main source of lead in drinking water today (U.S. Government Printing Office, 2011a).

Well-water lead concentrations in this study indicate that the lead is derived from the distribution systems after the well water enters the house. Lead can be leached from many plumbing components, such as water-supply lines, lead-based solder used in conjunction with copper pipes, valves, fittings, and/or the actual faucet itself. In the case of older public-water-system infrastructure, the service lines were made of lead, but, in most single-family homes, the source of lead originates from either lead-based solder or brass plumbing fittings or fixtures (U.S. Environmental Protection Agency, 2012a). Brass is predominately comprised of copper and zinc; however, lead has been a trace manufacturing ingredient for decades. Other factors that contribute to lead leaching are the pH and temperature of the water flowing through the distribution system, the stagnation time (the length of time that the water sits undisturbed within the distribution system) and the manipulation of the distribution-system components prior to sample collection (U.S. Environmental Protection Agency, 2012a). Acidic water is more corrosive to metal plumbing (piping, fittings, and fixtures) than water within the USEPA recommended pH range of 6.5 to 8.5. Corrosion scale (mineral deposits formed in pipes and fixtures as a result of water interaction with the material) may include lead-bearing minerals such as cerussite (PbCO_3), hydrocerussite ($\text{Pb}_3(\text{CO}_3)_2(\text{OH})_2$), plumbonacrite ($\text{Pb}_{10}(\text{CO}_3)_6(\text{OH})_6\text{O}$), litharge (PbO), and plattnerite (PbO_2) (American Water Works Research Foundation, 1990; Kim and others, 2011).

The properties sampled during this study were divided into three categories based on the potential risk to leach lead in the distribution system (tab. 2). These categories were established from information presented during a 2012 Maryland Department of the Environment Drinking Water Certification Class and the Code of Federal Regulations Section 141.86, Monitoring requirements for lead and copper in tap water (U.S. Government Printing Office, 2011a). The three categories are:

- Single-family homes built between 1982 and 1986. This was considered the highest risk group to leach lead because of the presence of copper piping with lead-based solder.
- Single-family homes built before 1982. This group would likely be at a lesser risk level to leach lead because the mineral deposits that occur within pipes over time typically coat the solder joints, thus limiting the amount of leachable material.
- Single-family homes built after 1986. This group would likely be at the lowest risk level to leach lead because the amount of copper piping and lead solder would be reduced as a result of the increased prevalence of plastic piping and components.

Table 2. Comparison of risk categories versus lead detections.

Category based on age of home	Number of houses in category	Number of houses in category having:			
		pH <6.5	First-draw lead detections >0.015 mg/L	Flush-sample lead detections >0.015 mg/L	Purge-sample lead detections >0.015 mg/L
1982 to 1986	8	5	0	0	0
Prior to 1982	34	24	3	0	0
After 1986	38	27	3	0	0

The age of the single-family home does not appear to be related to the first-draw lead results of this study, as compared to pH and stagnation time in the distribution system supplying the faucet sampled. Of eight homes in the highest risk category (built between 1982 and 1986), none had lead detections above the USEPA Action Level of 0.015 mg/L on the first-draw, flush, or purge sample. Only three homes in each of the remaining two categories (houses built prior to 1982 and houses built after 1986) had first-draw lead detections above the USEPA Action Level.

Geologic Sources

In nature, lead is typically found in mineral ore deposits which may also contain varying amounts of zinc, copper, and silver, and, less commonly, gold, fluorine, barium, cadmium, antimony, bismuth, and arsenic (Heyl, 1976; Kropschot and Doebrich, 2011). There are three main types of lead deposits, including sedimentary exhalative, Mississippi Valley-type, and volcanogenic massive sulfides (Kropschot and Doebrich, 2011). Major lead deposits located in the continental United States (Heyl, 1976) include:

- 1) The Appalachian Fold Belt from Maine to Alabama (Blue Ridge, Valley and Ridge, and Piedmont provinces),
- 2) Domed uplifts in the greater Mississippi Valley (Central Lowland),
- 3) The Ouachita Mountains Fold Belt in Arkansas and Oklahoma (Ozark Plateaus),
- 4) The Rocky Mountains from Mexico to western Wyoming and eastern Idaho (Middle and Southern Rocky Mountains),
- 5) The Cordillera including the Basin and Range of New Mexico, Arizona, Nevada, western Utah, southeastern California, and southern Idaho, the Sierra Nevada and Oregon Plateaus (Columbia Plateaus), and
- 6) The Pacific Fold Belt (Pacific Border Province) in western California.

Of relevance for this study, the deposits located in the Appalachian Fold Belt contain relatively minor amounts of lead, and are predominantly zinc or zinc-copper deposits (in which lead is a secondary mineral occurring with zinc) (Heyl, 1976). Lead from ore deposits is not normally mobile in ground- or surface-water conditions because of the tendency of lead cations to combine with carbonate, hydroxide, sulfide, or sulfate anions to form insoluble products or to be adsorbed by ferric hydroxide (Hem, 1976; Lovering, 1976).

Lead can be found in small amounts in non-ore rock and soil materials, including trace amounts found in minerals such as feldspars. However, in the Piedmont of Harford County there are no known major lead-bearing minerals or ore deposits, such as galena (PbS), anglesite (PbSO₄), or cerussite (PbCO₃) (Ostrander and Price, 1940; Heyl and Pearre, 1965; Fleischer, 1976). The virtual lack of lead detections in the full-purge water samples is consistent with this information.

ADDITIONAL WATER-QUALITY DATA

Aquifer Lithology and pH

The geology of a region can directly influence ground-water quality, as precipitation in the form of rain and snow infiltrates and interacts with soil and rock, leading to the dissolution of minerals and the subsequent enrichment of ground water in dissolved solids. Precipitation, which is already somewhat acidic in Maryland, with an average winter rainfall pH value of 4.89 at the Wye River National Atmospheric Deposition Program (NADP) (National Atmospheric Deposition Program, 2013), percolates through the soil and becomes more acidic (pH decreases) by reacting with carbon dioxide in the soil in pore spaces (tab. 3, reaction 1) (Freeze and Cherry, 1979; Spears, 1986). Additional chemical reactions which can decrease the pH of ground water include decomposition of organic matter, pyrite oxidation, precipitation of ferric hydroxide, and nitrification of ammonium (tab. 3, reactions 2 through 5) (Drever, 1982; Canter, 1996). Acidic ground water enhances dissolution of the underlying rock, leading to an increase in dissolved solids, including constituents of possible concern for ground-water quality.

Felsic rocks in Harford County include schists, gneisses, and the metasedimentary rocks of the Wissahickon Formation and the Peach Bottom Slate. These rocks are primarily composed of silicate and aluminosilicate minerals (e.g., quartz, plagioclase feldspar, potassium feldspar, biotite mica, muscovite mica) (Southwick and others, 1969). While quartz is mostly unreactive in the presence of acidic ground water, the other minerals are reactive, and through their breakdown release cations such as calcium, magnesium, potassium, and iron, which can increase pH values (Freeze and Cherry, 1979; Bolton, 1998).

The schists, gneisses, and metasediments in this study are grouped together under the broad category of felsic composition (tab. 1), although there is variation in individual lithologies. The felsic rocks (n = 51) in this study have a pH range of 4.7 to 8.3, with a median value of 5.9. The pH values from the three Peach Bottom Slate samples (4.7, 4.8, 5.1) were among the lowest measured, and some attention should be given to possible causes of this. Southwick and others (1969) describe the rock as uniform, blue-black, hard, and lustrous with an almost phyllitic appearance that is dominated by sub-vertical, slaty cleavage. Petrographically, the Peach Bottom Slate is composed of fine grained quartz, muscovite, and chlorite, with widespread occurrences of dusty ilmenite and small pyrite cubes (Southwick and others, 1969). Pyrite oxidation (tab. 3, reaction 3) is a possible cause of the low pH values observed in this unit. The combination of mineral assemblage and the structural influence of the near-vertical slaty cleavage planes may allow acidic precipitation to readily enter the unit and react with the minerals present, lowering ground-water pH levels. However, additional information such as the dissolved oxygen levels in the unit are needed to support the assertion of pyrite oxidation.

Table 3. Chemical reactions that can decrease pH of ground water. Modified from Drever (1982) and Canter (1996).

[s, solid phase; aq, aqueous phase; g, gas phase]

Description	Reaction
(1) Carbonic acid generation:	$\text{CO}_2 (\text{g}) + \text{H}_2\text{O} = \text{H}_2\text{CO}_3 (\text{aq}) = \text{H}^+ + \text{HCO}_3^-$
(2) Decomposition of organic matter:	$\text{C}_{106}\text{H}_{263}\text{O}_{110}\text{N}_{16}\text{P} + 138\text{O}_2 (\text{g}) = 106\text{CO}_2 (\text{g}) + 16\text{NO}_3^- + \text{HPO}_4^{2-} + 122\text{H}_2\text{O} + 18\text{H}^+$
(3) Pyrite oxidation:	$\text{FeS}_2 (\text{s}) + \text{H}_2\text{O} + 3.5\text{O}_2 (\text{g}) = \text{Fe}^{2+} + 2\text{H}^+ + 2\text{SO}_4^{2-}$
(4) Precipitation of ferric hydroxide:	$\text{Fe}^{2+} + 0.25\text{O}_2 (\text{g}) + 2.5 \text{H}_2\text{O} = \text{Fe}(\text{OH})_3 (\text{s}) + 2\text{H}^+$
(5) Nitrification of ammonium:	$\text{NH}_4^+ + 2\text{O}_2 (\text{g}) = \text{NO}_3^- + \text{H}_2\text{O} + 2\text{H}^+$

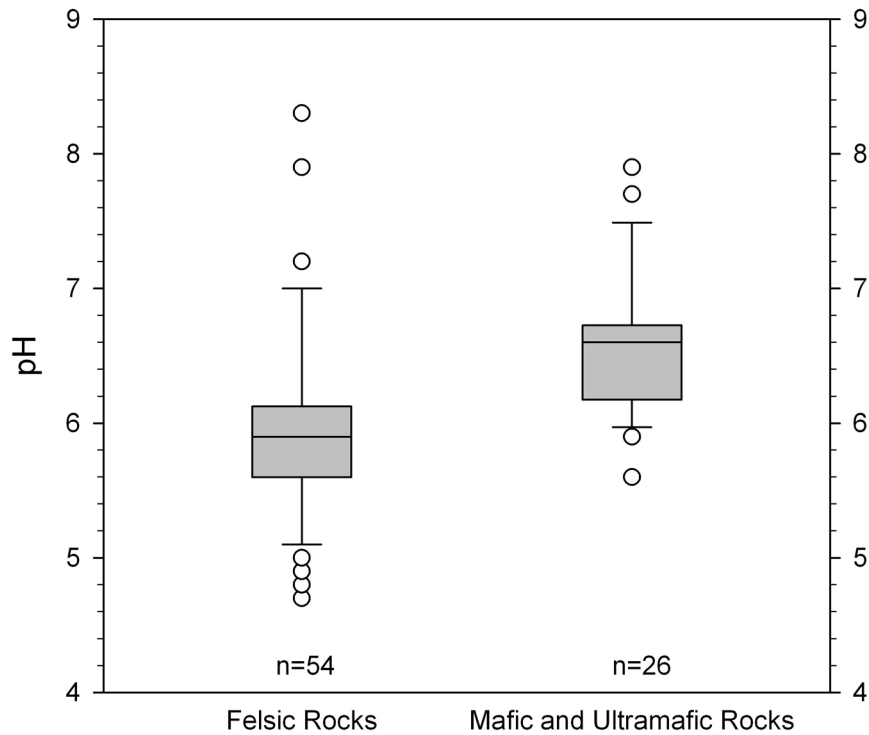


Figure 19. Box-and-whisker plot showing pH with respect to aquifer lithology. Felsic rocks include schists, gneisses, and the metasedimentary rocks of the Wissahickon Formation and the Peach Bottom Slate. Mafic and ultramafic rocks include the Baltimore Gabbro, Quartz gabbro and quartz diorite gneiss (mapped together), metagabbro and amphibolite, as well as mafic and ultramafic intrusives. See figure 11 for explanation of plots.

Samples from the mafic and ultramafic rocks in this study (n=26) had a statistically significant higher pH than that of samples from the more felsic rocks, with a range of values from 5.6 to 7.9, and a median pH of 6.6. The ultramafic and mafic rocks are composed primarily of serpentinite, soapstone, amphibole, pyroxene, and plagioclase, which are more susceptible to weathering and dissolution than the silicate minerals and likely account for the higher pH values (Crowley, 1976; Bolton, 1998).

Well Casing and pH

In this study there is a positive correlation between pH and casing depth (as casing depth increases, pH increases) (fig. 20). This contrasts with the lack of correlation between pH and well depth previously mentioned. One possible explanation for this is that casing depth is more correlative to the location of fractures higher up in the borehole, which contain ground water that has taken shorter flow paths to the well. Shorter flow paths would indicate less residence time in the surrounding saprolite and rock, and therefore less interaction time to experience the moderating effects on pH. Considering that the precipitation-weighted mean concentration data from the nearby NADP Wye River monitoring station indicates an average winter rainfall pH value of 4.89, this is a likely contributor to acidic ground-water pH values (National Atmospheric Deposition Program, 2013). Well depth and pH are also likely not correlative because well depth does not necessarily correlate to the location of fractures in the borehole, especially if the borehole depth was drilled for storage capacity only. No other water-quality

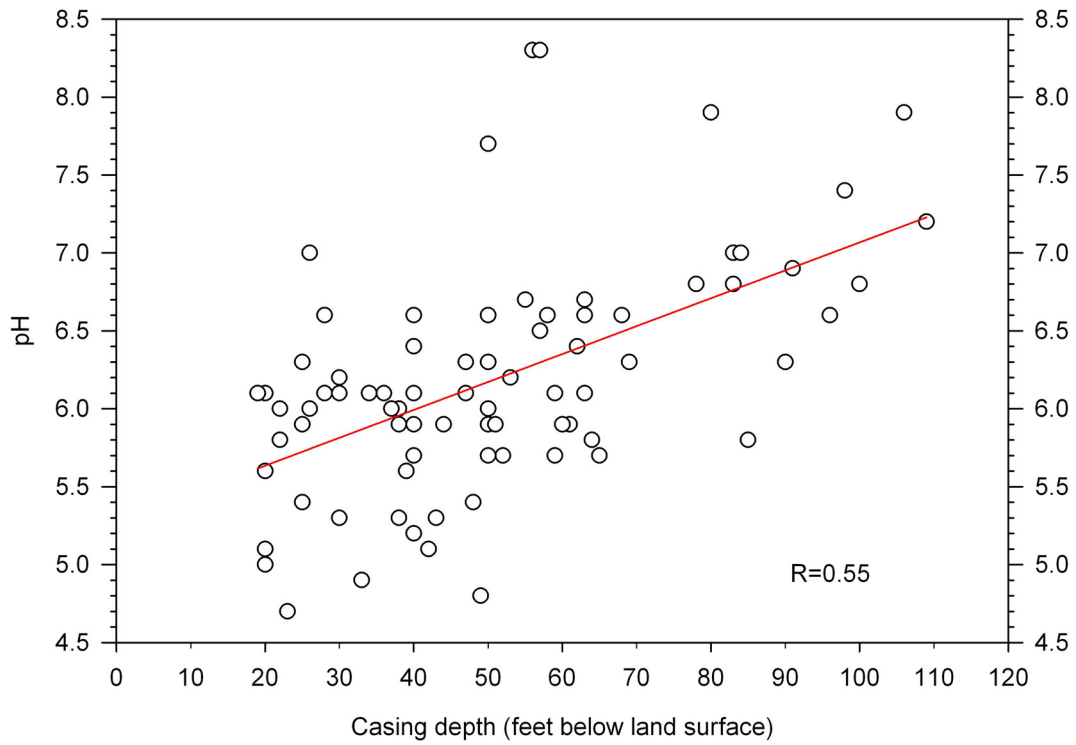


Figure 20. Relation of casing depth and pH.

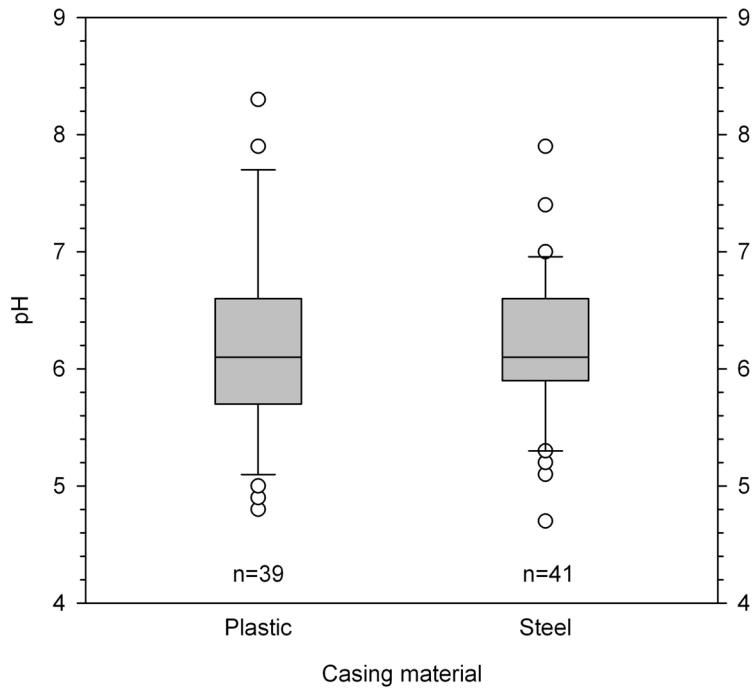


Figure 21. Box-and-whisker plot showing pH with respect to casing material. See figure 11 for explanation of plots.

parameter in this study was correlative with casing depth. Additionally, no statistical difference was seen between casing material and pH or purge-water lead results (fig. 21), although some previous studies have indicated a possible correlation between casing material and elevated lead levels (Llopis, 1991; Katz and others, 1999).

SUMMARY

A well-water-quality study was conducted within the Piedmont region of Harford County in response to reports of lead concentrations exceeding the USEPA's Action Level of 0.015 mg/L, in water samples collected from some private wells in the area. The objective of the study was to evaluate lead concentrations in private water wells and to determine what the likely source was. Samples were drawn from 80 domestic wells and analyzed for lead, pH, specific conductance, nitrate, and chloride. Three different lead samples were analyzed: a first-draw sample, a 30-second-flush sample (both collected from kitchen sink or other faucet), and a fully-purged sample collected from an untreated spigot.

Six out of 80 first-draw water samples exceeded the USEPA Action Level for lead (0.015 mg/L), while none of the 30-second-flush samples exceeded the Action Level. Lead concentrations for first-draw samples ranged from less than 0.005 mg/L to 0.039 mg/L. Lead concentrations in the 30-second-flush samples ranged from less than 0.005 mg/L to 0.013 mg/L. All pre-distribution system (fully purged) well-water samples tested below the USEPA Action Level for lead, and only one purge sample (0.006 mg/L) tested above the laboratory reporting limit of <0.005 mg/L. The data support the conclusion that lead in the water samples is not derived from geologic sources, and that all elevated lead concentrations appear to be the result of distribution-system contributions. All lead detections greater than 0.015 mg/L were from waters where the pH was less than 6.2.

Ground water in the Harford County Piedmont is typically acidic, with a pH range of 4.7 to 8.3; 90 percent of the values were below 7.0. Specific conductance was also highly variable, ranging from 22 to 1,706 $\mu\text{S}/\text{cm}$ at 25 degrees Celsius. Nitrate concentrations in the wells ranged from <0.2 to 18.25 mg/L, with four wells exceeding the USEPA MCL of 10 mg/L. Chloride concentrations ranged from <10 to 552 mg/L, and only one well exceeded the USEPA SMCL of 250 mg/L.

Plumbing fixtures, including faucets, valves, sink pipes, and well-tank fittings, were evaluated with respect to their material composition. The data do not show that any one component of the plumbing system is dominantly associated with lead (or elevated lead) concentrations in well water. Age of the single-family home is also not related to the first-draw lead result, as compared to other factors such as pH and stagnation time of the distribution system supplying the faucet sampled.

Based on the data obtained, it appears that low pH is necessary to leach lead, but by itself does not result in elevated lead concentrations. It also appears that a minimum flush time of 30 seconds can reduce lead concentrations to below 0.015 mg/L. The USEPA recommends drawing water from a cold-water tap, flushed for 30 seconds to 2 minutes (or run until it becomes as cold as it will get) for food preparation, cooking, and drinking purposes. This procedure, employed whenever water sits undisturbed for 6 or more hours in the plumbing system, should effectively purge lead from the distribution system. Other corrective measures may include neutralizing the well-water pH if it is below 7.0, and/or replacing brass fixtures and fittings (U.S. Environmental Protection Agency, 2013a).

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Appendix A. Historic and modern names of crystalline rocks in Harford County. Geologic formations may not be entirely correlative between authors.

Age	Symbol	Name from Southwick and Owens (1968)	Modified from Crowley (1976) and Reger (unpub. data, 2013)
Cambro-Ordovician?	Op	Peach Bottom Slate	Peach Bottom Slate
Cambro-Ordovician?	Oc	Cardiff Metaconglomerate	Cardiff Metaconglomerate
Cambro-Ordovician?	pCja and pCjg	James Run Gneiss	James Run Formation
Cambro-Ordovician?	pCv	Volcanic Complex of Cecil County	---
Cambro-Ordovician?	pCw	Wissahickon, undivided	---
Cambro-Ordovician?	pCwu	Wissahickon upper pelitic schist	Prettyboy Schist/Pleasant Grove Shear Zone
Cambro-Ordovician?	pCwg	Wissahickon metagraywacke	Oella Formation/ Piney Run Formation
Cambro-Ordovician?	pCwc	Wissahickon metaconglomerate	Sykesville Formation
Cambro-Ordovician?	pCwb	Wissahickon boulder gneiss	Sykesville Formation
Cambro-Ordovician?	pCwl	Wissahickon lower pelitic schist	Loch Raven Schist
Cambro-Ordovician?	pCc	Cockeysville Marble	Cockeysville Marble
Cambro-Ordovician?	pCsq, pCsg	Setters Formation	Setters Formation
Cambrian?	Pzma	Pegmatitic quartz monzonite gneiss and alaskite gneiss	---
Cambrian?	Pzm	Muscovite quartz monzonite gneiss	---
Cambrian?	Pzpd, Pzpds	Port Deposit Gneiss	Bel Air Belt
Cambrian?	Pzgg	Quartz gabbro and quartz diorite gneiss	Baltimore Mafic Complex/ Bel Air metagabbro
Cambrian?	Pzga	Metagabbro and amphibolite	Baltimore Mafic Complex/ Bel Air metagabbro
Cambrian?	mpx	metapyroxenite	Baltimore Mafic Complex/ Bel Air metagabbro
Cambrian?	Pzb, Pzbm, Pzbp	Baltimore Gabbro of Cloos and Hershey (1936)	Baltimore Mafic Complex/ Bel Air metagabbro
Cambrian?	Pzug	Ultramafic and gabbroic rocks	undifferentiated allochthonous ultramafic rocks
Cambrian?	Pzum	Ultramafic rocks	undifferentiated allochthonous ultramafic rocks
Precambrian	pCb	Baltimore Gneiss	Baltimore Gneiss

Appendix B. Well records and sample information

Abbreviations used in Appendix B

bls	below land surface
dd-mm-ss	degrees–minutes–seconds
ft	feet
mg/L	milligrams per liter
NAD	North American Datum
$\mu\text{S/cm @ 25 deg. C.}$	microsiemens per centimeter at 25 degrees Celsius
<	less than

Codes for composition of plumbing:

B	brass
C	copper
P	plastic
O	other
SS	stainless steel

Appendix B. Well records and sample information—Continued

Well number on figure 4	Date sampled	Geologic unit symbol¹	Well depth (ft)	Casing depth (ft bls)	Casing material	Specific conductance (μS/cm @ 25 deg. C)
1	12/11/2012	pCwu	250	40	Plastic	61
2	1/3/2013	pCwu	200	39	Plastic	1,706
3	1/11/2013	pCwu	400	40	Plastic	100
4	12/14/2012	pCwu	225	25	Plastic	156
5	12/14/2012	pCwu	220	78	Steel	160
6	1/15/2013	pCwu	405	38	Plastic	67
7	2/7/2013	Pzum	200	50	Plastic	245
8	11/30/2012	pCwg	425	56	Plastic	135
9	12/7/2012	Op	300	20	Plastic	108
10	12/18/2012	pCwg	350	20	Plastic	55
11	2/8/2013	Op	300	23	Steel	64
12	2/15/2013	Op	75	49	Plastic	66
13	12/18/2012	pCwb	205	69	Plastic	198
14	1/10/2013	pCwg	75	34	Steel	38
15	1/29/2013	pCwb	200	64	Plastic	378
16	11/28/2012	pCsq	250	63	Steel	218
17	1/3/2013	pCwu	100	59	Plastic	790
18	1/9/2013	pCsq	125	30	Steel	123
19	1/9/2013	pCsq	200	40	Steel	617
20	2/6/2013	pCwl	500	109	Plastic	166
21	3/1/2013	pCwu	300	90	Plastic	66
22	1/22/2013	pCwc	260	33	Plastic	22
23	1/23/2013	pCwc	225	48	Plastic	38
24	1/30/2013	Pzum	130	40	Plastic	96
25	11/14/2012	pCwb	320	50	Plastic	135
26	11/15/2012	pCwb	200	36	Plastic	326
27	11/30/2012	Pzug	280	63	Steel	380
28	12/7/2012	pCwg	255	85	Plastic	141
29	12/13/2012	pCwl	345	22	Steel	754
30	1/16/2013	pCwg	198	20	Steel	75
31	1/31/2013	Pzum	175	50	Plastic	169
32	2/6/2013	pCwb	400	50	Plastic	872
33	2/8/2013	pCwb	160	38	Plastic	200
34	2/20/2013	pCwb	125	22	Steel	397
35	2/28/2013	Pzug	300	83	Plastic	245
36	2/28/2013	pCwg	300	57	Plastic	203
37	11/13/2012	Pzum	155	106	Steel	394
38	11/14/2012	pCwb	300	40	Plastic	129
39	11/29/2012	Pzb	180	96	Steel	117
40	1/15/2013	Pzb	200	50	Steel	122
41	1/16/2013	Pzb	150	84	Steel	334
42	1/18/2013	Pzb	185	63	Steel	175
43	2/1/2013	Pzum	150	47	Steel	159
44	2/5/2013	pCw	205	59	Plastic	199

¹ See table 1 for explanation of symbols.

Appendix B. Well records and sample information—Continued

Well number on figure 4	Chloride (mg/L)	pH	Lead (first-draw) (mg/L)	Lead (30-second-flush) (mg/L)	Lead (purge) (mg/L)	Nitrate + nitrite (mg/L as N)	Year house constructed
1	<10	6.1	<0.005	<0.005	<0.005	2.18	2006
2	552	5.6	0.010	<0.005	<0.005	2.64	1992
3	<10	6.4	<0.005	<0.005	<0.005	5.84	1920
4	15	5.4	0.012	<0.005	<0.005	9.33	1989
5	<10	6.8	<0.005	<0.005	<0.005	2.64	1978
6	<10	6.0	0.014	0.005	<0.005	<0.2	2005
7	<10	7.7	<0.005	<0.005	<0.005	1.61	1996
8	<10	8.3	<0.005	<0.005	<0.005	<0.2	2011
9	11	5.1	0.019	0.007	<0.005	5.96	1997
10	<10	5.0	0.006	<0.005	<0.005	1.48	1996
11	14	4.7	0.039	0.009	<0.005	3.55	2000
12	<10	4.8	0.015	0.006	<0.005	4.06	1995
13	<10	6.3	<0.005	<0.005	<0.005	3.82	2004
14	<10	6.1	<0.005	<0.005	<0.005	1.01	1850
15	95	5.8	<0.005	<0.005	<0.005	1.80	2009
16	31	6.1	<0.005	<0.005	<0.005	<0.2	1979
17	159	5.7	0.009	<0.005	<0.005	11.60	1935
18	<10	5.3	<0.005	<0.005	<0.005	8.63	1977
19	140	5.2	<0.005	<0.005	<0.005	11.40	1981
20	11	7.2	<0.005	<0.005	<0.005	<0.2	2009
21	<10	6.3	<0.005	<0.005	<0.005	2.41	1987
22	<10	4.9	0.020	0.006	<0.005	0.53	2010
23	<10	5.4	0.015	<0.005	<0.005	0.33	1961
24	12	6.6	<0.005	<0.005	<0.005	4.40	1994
25	<10	6.0	<0.005	<0.005	<0.005	4.15	1995
26	21	6.1	<0.005	<0.005	<0.005	5.60	2010
27	25	6.6	<0.005	<0.005	<0.005	3.56	1993
28	17	5.8	<0.005	<0.005	<0.005	6.49	2012
29	184	6.0	0.008	<0.005	<0.005	4.51	1978
30	<10	6.1	<0.005	<0.005	<0.005	2.89	1978
31	11	6.6	<0.005	<0.005	<0.005	5.68	2010
32	206	5.7	0.014	<0.005	<0.005	18.25	2010
33	17	5.9	<0.005	<0.005	<0.005	7.79	2002
34	94	5.8	0.007	<0.005	<0.005	0.57	1987
35	<10	6.8	<0.005	<0.005	<0.005	5.89	2012
36	<10	8.3	<0.005	<0.005	<0.005	<0.2	2006
37	30	7.9	<0.005	<0.005	<0.005	2.75	1971
38	<10	5.9	0.008	<0.005	<0.005	5.78	2006
39	<10	6.6	<0.005	<0.005	<0.005	1.65	2006
40	<10	6.3	<0.005	<0.005	<0.005	1.05	1900
41	31	7.0	<0.005	<0.005	<0.005	5.04	1950
42	<10	6.7	<0.005	<0.005	<0.005	1.22	1990
43	<10	6.3	<0.005	<0.005	<0.005	1.13	1977
44	<10	6.1	<0.005	<0.005	<0.005	8.12	1996

Appendix B. Well records and sample information—Continued

Well number on figure 4	Composition of plumbing:			Water treatment
	Sink valves	Sink pipes	Well-tank fitting	
1	B	P	B	none
2	B	P	B	neutralizer, softener
3	B	P	B	sediment filter
4	O	P	B	none
5	C	C	B	none
6	B	P	B	neutralizer, softener
7	B	P	B	sediment filter, softener
8	SS	P	B	none
9	B	P	B	reverse osmosis
10	B	P	B	sediment filter
11	B	C	B	none
12	P	P	B	none
13	B	P	B	none
14	B	P	B	none
15	B	P, C	B	sediment filter
16	B	P	B	neutralizer, softener
17	O	C	B	sediment filter
18	B	C	B	iron treatment, softener
19	B	C	B	conditioner, neutralizer
20	C	C	SS	sediment filter
21	B	P	B	sediment filter
22	SS	P	B	sediment filter
23	B	C	B	none
24	B	P	B	sediment filter
25	B	P, C	B	none
26	B	P	B	sediment filter
27	B	C	B	sediment filter
28	B	P	B	none
29	B	P	SS	none
30	B	P	B	sediment filter
31	B	P	B	none
32	B	C	B	sediment filter, ultraviolet light
33	B	P	B	none
34	B	P	B	neutralizer, softener
35	P	P	B	sediment filter
36	B	P	B	neutralizer, softener
37	B	P	B	sediment filter
38	B	P	B	none
39	P	P, C	B	sediment filter
40	P	P, C	B	sediment filter
41	B	P	B	sediment filter, softener
42	B	P	B	sediment filter, softener
43	C	C	B	none
44	O	O	B	sediment filter

Appendix B. Well records and sample information—Continued

Well number on figure 4	Date sampled	Geologic unit symbol¹	Well depth (ft)	Casing depth (ft bls)	Casing material	Specific conductance (µS/cm @ 25 deg. C)
45	2/19/2013	pCwb	350	30	Steel	87
46	3/1/2013	Pzum	185	19	Plastic	508
47	1/17/2013	Pzgg	240	100	Steel	329
48	1/31/2013	pCw	275	52	Plastic	765
49	12/4/2012	pCwl	80	42	Steel	371
50	2/19/2013	pCb	125	26	Steel	296
51	1/8/2013	pCwl	100	44	Steel	354
52	12/4/2012	pCwl	300	26	Steel	255
53	12/13/2012	pCwl	200	50	Steel	401
54	1/4/2013	pCwl	300	43	Plastic	298
55	11/13/2012	Pzbm	100	28	Steel	203
56	11/15/2012	Pzm	275	25	Steel	189
57	12/12/2012	Pzb	110	98	Steel	193
58	1/4/2013	pCwl	62	25	Steel	878
59	1/22/2013	Pzb	105	55	Steel	213
60	1/29/2013	pCwb	305	61	Plastic	206
61	11/8/2012	Pzpd	100	40	Steel	193
62	12/5/2012	Pzpds	200	65	Plastic	188
63	1/10/2013	pCja	225	91	Plastic	400
64	2/13/2013	pCjg	175	47	Plastic	126
65	2/27/2013	pCja	175	20	Steel	301
66	2/13/2013	Pzga	149	68	Steel	201
67	1/11/2013	Pzpd	180	51	Steel	271
68	2/1/2013	Pzga	225	20	Steel	200
69	12/12/2012	Pzga	98	57	Steel	194
70	1/23/2013	Pzga	200	58	Steel	291
71	2/5/2013	Pzga	124	60	Steel	541
72	12/5/2012	Pzga	99	40	Steel	211
73	1/17/2013	Pzga	525	30	Plastic	177
74	2/15/2013	Pzga	250	28	Plastic	161
75	1/8/2013	Pzb	125	62	Steel	196
76	1/18/2013	Pzm	75	53	Steel	180
77	11/27/2012	Pzpd	425	80	Plastic	204
78	12/19/2012	Pzpds	200	83	Plastic	233
79	12/19/2012	Pzpd	225	38	Steel	85
80	1/30/2013	Pzbm	80	37	Steel	173

¹ See table 1 for explanation of symbols.

Appendix B. Well records and sample information—Continued

Well number on figure 4	Chloride (mg/L)	pH	Lead (first-draw) (mg/L)	Lead (30-second-flush) (mg/L)	Lead (purge) (mg/L)	Nitrate + Nitrite (mg/L as N)	Year house constructed
45	<10	6.1	<0.005	<0.005	<0.005	1.21	1985
46	91	6.1	0.006	<0.005	<0.005	1.78	1971
47	12	6.8	<0.005	<0.005	<0.005	6.46	1962
48	191	5.7	0.007	<0.005	<0.005	5.30	2003
49	80	5.1	<0.005	<0.005	<0.005	9.64	1984
50	60	6.0	0.008	0.007	<0.005	2.48	1935
51	78	5.9	<0.005	<0.005	<0.005	5.54	1967
52	30	7.0	<0.005	<0.005	<0.005	2.48	1978
53	89	5.9	0.015	<0.005	<0.005	6.75	1975
54	43	5.3	0.014	0.007	<0.005	12.25	2003
55	34	6.6	<0.005	<0.005	<0.005	1.78	1982
56	<10	6.3	0.009	<0.005	<0.005	6.79	1988
57	13	7.4	<0.005	<0.005	<0.005	7.51	1971
58	233	5.9	0.008	0.013	<0.005	1.81	1966
59	18	6.7	<0.005	<0.005	<0.005	1.86	1984
60	23	5.9	<0.005	<0.005	<0.005	7.70	2001
61	12	5.7	<0.005	<0.005	0.006	9.36	1979
62	22	5.7	<0.005	<0.005	<0.005	6.99	1991
63	70	6.9	<0.005	<0.005	<0.005	4.49	1920
64	<10	6.1	<0.005	<0.005	<0.005	5.85	1900
65	54	5.6	<0.005	<0.005	<0.005	9.59	1989
66	12	6.6	<0.005	<0.005	<0.005	5.01	1966
67	39	5.9	0.024	<0.005	<0.005	6.64	1970
68	24	5.6	0.010	<0.005	<0.005	6.44	1971
69	19	6.5	<0.005	<0.005	<0.005	4.98	1985
70	27	6.6	<0.005	<0.005	<0.005	5.14	1952
71	139	5.9	<0.005	<0.005	<0.005	1.75	1986
72	21	6.1	<0.005	<0.005	<0.005	4.88	1985
73	12	6.2	0.025	<0.005	<0.005	3.57	1966
74	27	6.1	<0.005	<0.005	<0.005	3.81	1959
75	<10	6.4	<0.005	<0.005	<0.005	2.19	1980
76	19	6.2	<0.005	<0.005	<0.005	6.00	1988
77	<10	7.9	<0.005	<0.005	<0.005	<0.2	1969
78	<10	7.0	<0.005	0.007	<0.005	<0.2	2004
79	17	5.3	<0.005	<0.005	<0.005	1.05	1982
80	10	6.0	0.021	<0.005	<0.005	0.60	1973

Appendix B. Well records and sample information—Continued

Well number on figure 4	Composition of plumbing:			Water treatment
	Sink valves	Sink pipes	Well-tank fitting	
45	P	P	B	sediment filter
46	P	P	B	sediment filter, ultraviolet light
47	B	C	B	sediment filter
48	B	P	B	softener
49	B	C	B	neutralizer, sediment filter
50	B	P	B	none
51	B	P	B	sediment filter
52	B	C	B	sediment filter
53	B	C	B	none
54	B	P	B	sediment filter
55	C	C	B	none
56	B	P	B	sediment filter
57	O	C	B	sediment filter
58	B	C	B	none
59	SS	C	B	sediment filter
60	P	P	B	sediment filter
61	B	P	B	neutralizer
62	SS	P	B	none
63	B	P	B	neutralizer
64	B	P	B	none
65	B	C	B	neutralizer, sediment filter
66	B	C	B	sediment filter
67	B	C	B	softener
68	P	C	B	sediment filter
69	B	C	B	none
70	B	P	B	none
71	B	P	B	iron treatment, sediment filter, softener
72	SS	P	B	none
73	B	C	B	sediment filter
74	B	P	B	none
75	B	C	B	sediment filter, softener
76	B	P	B	sediment filter, softener
77	B	C	B	softener
78	B	P	B	softener
79	P	P	B	neutralizer, softener
80	B	P	B	none

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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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DNR Publication Number 12-10162013-672
November 2013



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