ANALYSIS OF CADMIUM IN GROUND WATER AND SEDIMENT SAMPLES IN THE AQUIA AQUIFER IN CENTRAL ANNE ARUNDEL COUNTY, MARYLAND

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ANALYSIS OF CADMIUM IN GROUND WATER AND SEDIMENT SAMPLES IN THE AQUIA AQUIFER IN CENTRAL ANNE ARUNDEL COUNTY, MARYLAND

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INTRODUCTION

In 2003, samples from several domestic water-supply wells in the Aquia aquifer in the Woodland Beach community in Anne Arundel County exceeded the U.S. Environmental Protection Agency's (USEPA) Maximum Contaminant Level (MCL) of 5 micrograms per liter (µg/L) for cadmium (K. Topovski, Anne Arundel County Health Department [AAHD], 2005, written communication). The available data had suggested that elevated groundwater cadmium levels are associated with low pH and elevated chlorides. Cadmium can damage the lungs, cause kidney damage, irritate the digestive tract, and may reasonably be anticipated to be a carcinogen (ATSDR, 2005).

To further investigate this issue, the Maryland Geological Survey (MGS) collected additional water samples in June 2005 from residential wells in the Aquia aquifer in central Anne Arundel County. These samples were used along with existing data to better define the distribution, hydrogeologic and geochemical relations, and sources of cadmium in ground water in the Aquia aquifer. Sediment samples from the Aquia Formation in four previously drilled test wells were also analyzed for cadmium and other trace elements.

GEOLOGIC AND HYDROLOGIC UNITS

In central Anne Arundel County, the "Aquia aquifer" consists of three geologic formations that are hydraulically connected. From youngest to oldest, they are the Aquia Formation, the Brightseat Formation, and the Severn Formation (tab. 1). They are underlain by the Matawan Formation, which typically is a confining unit, although the upper part is sufficiently sandy on the Broadneck Peninsula to serve as an aquifer for some private water-supply wells. The Brightseat Formation is a leaky confining unit, and is often difficult to distinguish from the Severn Formation (Andreasen, 2002). The Marlboro Clay, a confining unit, overlies the Aquia Formation south and east of the Aquia outcrop area. Additional information on these units may be found in Glaser (1971), Mack and Andreasen (1991), Fleck and others (1996), and Andreasen (2002).

CADMIUM IN THE AQUIA AQUIFER IN CENTRAL ANNE ARUNDEL COUNTY

Methods

Nineteen residential wells in the Aquia aquifer were selected throughout a northeast-trending five-mile-wide band extending from the lower Broadneck Peninsula to Davidsonville in central Anne Arundel County (fig. 1). Five additional samples were collected from observation wells screened in the Aquia aquifer on Kent Island in Queen Anne's County, Maryland. Residential wells were selected from a list of candidate wells provided to MGS by Maryland Department of the Environment (MDE) personnel. The wells were evaluated for suitability (aquifer, well construction, and availability), and water samples from the wells were tested for cadmium, chloride, pH, specific conductance, and dissolved oxygen. Samples were collected from spigots or other outlets that were identified by the owners as sources of untreated water. Samples were collected in a consistent manner to optimize data comparability. Wells were purged until field parameters (specific conductance, pH, and water temperature) had stabilized. During the well purging, field measurements were taken at 5-minute intervals until the water was clear and three consecutive readings were within the following ranges of tolerance: specific conductance, ±5 percent (if specific conductance was more than 100 microsiemens per centimeter [μS/cm] at 25 degrees Celsius) or ±5 μS/cm (if specific conductance was less than 100 μS/cm); pH, ±0.1 pH unit; temperature, ±0.5 degree Celsius. After the stabilization criteria were met, two 1-liter cubitainers (one each for cadmium and chloride analysis) were rinsed and filled with raw (unfiltered) water. The cubitainer for cadmium analysis was acidified in the field to pH less than 2 with ultrapure nitric acid; the cubitainer for chloride analysis was untreated. Cadmium and chloride analysis was conducted by the Maryland Department of Health and Mental Hygiene Laboratory in Baltimore. Cadmium was analyzed by inductively coupled plasma-mass spectroscopy (USEPA Method 200.8), with a minimum reporting limit of 2.5 μg/L. Chloride was analyzed by the automated colorimetric method (USEPA Method 325.2), with a minimum reporting limit of 10 milligrams per liter (mg/L). Cadmium speciation calculations were performed using data from Langmuir (1997). Dissolved oxygen was measured in the field by titration using a Hach test kit (modified Winkler method). Specific conductance and pH were measured in the field; this equipment was calibrated daily with appropriate standards and buffers.

Forty-six sediment samples from four wells in Anne Arundel and Prince George's Counties were analyzed for cadmium and 58 other elements. Samples were collected either from split-spoon samples, core samples, or washed samples from samples stored in the MGS core repository. Samples were prepared via aqua regia digestion followed by elemental analysis by inductively-coupled plasma/mass spectroscopy. Analysis was performed by Actlabs, Ltd. in Ancaster, Ontario, Canada.

Results

Cadmium concentrations in the water samples collected by MGS ranged from less than 2.5 to 66 μg/L (tab. 2). Four of the 19 samples exceeded the MCL of 5 μg/L (fig. 2). (In this report, "elevated" cadmium levels are defined as those greater than the MCL of 5 μg/L.) Cadmium concentrations in sediments ranged from less than 0.01 to 1.41 milligrams per kilogram (mg/kg) (tab. 3). In addition to the samples collected by MGS in 2005, water-quality data from two other sources were included in this evaluation. Data were obtained from the U.S. Geological Survey National Water Information System (NWIS) database for 34 samples collected from the Aquia aquifer in Maryland (8 in Anne Arundel County, 21 in Kent County, and 4 in Queen Anne's County). Cadmium and other data from 22 wells in the Woodland Beach community were provided by the Anne Arundel County Health Department. These data were included to provide additional insights into factors related to elevated cadmium concentrations in the area.

Evaluation of the water-quality and sediment data from the study area has led to the following observations regarding cadmium levels:

1. Groundwater cadmium concentrations exceeding 5 μg/L are found only within the weathered upper part of the Aquia Formation.

Within the Aquia Formation in central Anne Arundel County, a predominantly weathered or oxidized zone was identified previously in test wells and is also evident on most drillers' logs (Glaser, 1971; Hansen, 1977; Mack and Andreasen, 1991; Wilde, 1994) (figs. 3 through 7). The weathered zone was delineated from core descriptions, drillers' logs (where a transition occurs from weathered red or brown sand to unweathered “salt and pepper” [glauconitic] sand), and by low calcium concentrations in the core analyses. The weathered zone extends to the base of the Aquia Formation at Sandy Point State Park (Mack and Andreasen, 1991). The zone is typically characterized by iron oxide minerals, the absence of shell material, and relatively small amounts of glauconite (Mack, 1974). The zone is up to 80 feet thick in areas where it is well documented, and is oriented along a northeast-trending axis that extends from Edgewater to Sandy Point State Park on the Broadneck Peninsula, with the depth of the weathered zone increasing along strike (Glaser, 1971). The deepest part of the weathered zone appears to be about 50 feet below sea level near Woodland Beach. The weathered zone apparently is limited mostly to Anne Arundel County; it appears to thin to the west in Prince George’s County, and was not encountered in exploratory wells on Kent Island on the Eastern Shore of the Chesapeake Bay, where the entire Aquia Formation contains abundant shell material (Drummond, 1988).

Four of the MGS-sampled wells are screened in the weathered zone; eight more are screened in the unweathered zone of the Aquia Formation (figs. 1, 3-7). The remaining seven wells are screened in the Matawan or Severn Formations. All four water samples collected from within the weathered zone exceeded 5 µg/L cadmium; all samples from outside this zone contained less than 5 µg/L cadmium. The elevated cadmium samples from the Woodland Beach community are from wells completed in the weathered part of the Aquia Formation (fig. 5).

2. Water quality in the weathered part of the Aquia Formation appears to be distinct from the unweathered part.

In addition to having higher cadmium concentrations, ground water in the weathered zone of the Aquia Formation differs from the unweathered zone in other water-quality characteristics (tab. 4). Well water within the weathered part of the Aquia Formation is more acidic (median pH: 4.8 versus 7.3) and has higher chloride (median: 159 mg/L versus less than 10 mg/L), specific conductance (median: 596 µS/cm versus 343 µS/cm), and dissolved-oxygen concentrations (median: 7.1 mg/L versus less than 1 mg/L) compared with ground water in the unweathered Aquia Formation (tab. 4).

3. Ground-water cadmium concentrations in the weathered Aquia Formation increase with decreasing pH and increasing chloride concentrations.

All samples having elevated cadmium levels had pH values less than about 5.5, with cadmium concentrations tending to increase with decreasing pH (fig. 8). Many samples with cadmium less than 5 µg/L had pH less than 5.5; most of these were either from the unweathered zone in Anne Arundel County or from wells on the Eastern Shore. Three of the MGS-sampled wells on cross-section E-E′ (AA Cf 156 through 158), which had pHs ranging from 4.4 to 5.2, had little or no cadmium present (fig. 7). These wells are screened in the Severn and Matawan Formations, but are considered to be part of the Aquia aquifer.

Most samples having more than 50 mg/L chloride also had cadmium concentrations greater than 5 µg/L, with cadmium concentrations tending to increase with increasing chloride concentrations (fig. 9). Almost all the samples with more than 50 mg/L chloride were from the weathered zone, which is shallower and more susceptible to surface-based chloride sources than the unweathered zone. Cadmium was below reporting limits in samples from three neutral-pH wells in the (unweathered) Aquia Formation on Kent Island that had been affected by brackish-water intrusion (chloride concentrations were greater than 5,000 mg/L) (fig. 9).

4. Cadmium concentrations in sediments do not appear to be consistently higher in the weathered zone of the Aquia Formation relative to the unweathered zone.

There is little overall difference in sediment-cadmium concentrations between the weathered and unweathered zones (median values: 0.19 and 0.17 mg/kg, respectively) (tab. 4; fig. 12). Only well AA De

100 showed consistently higher cadmium in the weathered versus the unweathered zone. The aqua regia digestion used to process the sediment samples contains a combination of concentrated hydrochloric and nitric acids that leach sulfides, some oxides, and some silicates; it is likely that the digestion dissolved any glauconite and other altered silicates that may have been present (Actlabs, Inc. personnel, oral communication, 2006). The sediment analysis therefore doesn't indicate whether the cadmium was present on the mineral surfaces or within the crystalline matrix

DISCUSSION

Sorption Processes as a Possible Control on Cadmium Levels in Ground Water

The relations between cadmium, chloride, and pH in the weathered zone of the Aquia Formation are similar to those of radium, pH, and chloride in the Magothy and Potomac Group aquifers in Anne Arundel County, suggesting that cadmium levels in ground water may be related to mobilization processes such as sorption and desorption (Bolton, 2000).

A possible scenario is that cadmium is loosely bound to the surfaces of the iron oxides and other minerals in the weathered part of the Aquia Formation. In areas of low chloride concentrations and pH greater than 5.5, as ions exchange between the sediment surfaces and ground water, there are few other ions in solution to compete with cadmium for sorption sites, and cadmium is re-adsorbed onto the sediment surfaces. (Chloride, being a non-reactive ion, is viewed as a surrogate for sodium and other exchangeable cations in solution.) In the presence of high concentrations of hydrogen ions (low pH) or cations, desorbed cadmium is less able to compete successfully for sorption sites, and more cadmium remains in solution than under high-pH, low-chloride conditions. Cadmium has a lower sorption affinity than other metals, including copper and lead, and under this scenario would be preferentially desorbed relative to other metals. In well AA De 211, the lead concentration (4 µg/L) from an earlier sample (source: Bolton and Hayes, 1999) is lower than cadmium (39 µg/L), even though sediment cadmium concentrations (all less than 2 mg/kg) are lower than lead (3 to 40 mg/kg). This is consistent with the sorption/desorption hypothesis. The lack of elevated groundwater cadmium in the unweathered zone may be due to cadmium mineral precipitation, increased cadmium sorption in the neutral pH environment of this zone (which is characterized by a higher percentage of glauconite and shell material than the weathered zone), or other factors. Even for chloride concentrations of more than 5,000 mg/L, cadmium was not detected in the unweathered part of the Aquia aquifer.

Figure 10 shows pH plotted against chloride for elevated and non-elevated cadmium levels. The data suggests that although most cadmium exceedances are clustered in the high-chloride part of the plot, there is no distinct minimum chloride threshold for elevated cadmium greater than 5 µg/L. On the other hand, pH 5.5 appears to be the upper boundary for elevated cadmium levels. Multiple samples from well AA De 157 show that when pH is above 5.0, cadmium levels are variable but less than 5 µg/L; below pH 5.0, there is a fairly linear inverse relationship with pH (fig. 11a). Cadmium and chloride, however, have a more linear response over the entire chloride range of 25 to 270 mg/L (fig. 11b). Thus it appears that elevated cadmium levels are a concern only at pH levels below 5.5; below that, both pH and chloride appear to be similarly associated with increased cadmium. Not all low-pH wells in the weathered zone in the Aquia Formation show increased cadmium concentrations. The relationships with pH and chloride suggest that the concentration of groundwater cadmium is not determined by solubility constraints; if they were, cadmium concentrations would level off after a certain pH or chloride concentration were reached.

Sources of Cadmium

The data, while illustrating strong correlations between cadmium, chloride, and pH, are inconclusive as to the source of cadmium in ground water. The presence of cadmium in sediments of the weathered and unweathered zones does not indicate whether the cadmium is occurring naturally or has anthropogenic sources. The association of cadmium and chloride concentrations suggests that anthropogenic sources of dissolved solids are associated with elevated cadmium levels, but sheds no light on the potential cadmium source. It was beyond the scope of this study to determine whether the sediment cadmium concentrations are sufficient to account for groundwater cadmium levels via sorption/desorption, mineral dissolution, or other mechanisms.

Natural sources of cadmium include the cadmium sulfide minerals greenockite and hawleyite (both CdS), which are analogs of zinc sulfide minerals; otavite ($CdCO_3$), an analog of the zinc carbonate mineral smithsonite; and cadmium oxide. There is no known native metal. Cadmium minerals are relatively rare, and the largest sources of commercially extracted cadmium are sphalerite and other zinc ores, where cadmium occurs as an accessory element to zinc (Brobst and Pratt, 1973). It is unlikely that these cadmium minerals are currently present in the weathered zone of the Aquia Formation because they likely would have leached out during the weathering process. These minerals may have been present when the Aquia sediments were originally deposited – sphalerite and other ore minerals have been documented in many areas of the Piedmont province, the presumed sediment source (Heyl and Pearre, 1965) – but these minerals have not been described in the Aquia Formation. It is likely that some of the cadmium in the aquifers is sorbed onto mineral surfaces. The sediment analysis did not include determination of cadmium in the individual minerals comprising the sediment.

Anthropogenic sources of environmental cadmium include industrial discharges and mining wastes. Cadmium is used in electroplating, manufacture of pigments, batteries, and fluorescent and video tubes (Hem, 1985). Cadmium has been shown to leach from PVC, where it is sometimes added as a UV stabilizer (Parker and others, 1990; Hewitt, 1992). All domestic wells sampled in this study had plastic (presumably PVC) casings and screens. Galvanized pipes within a distribution system are another potential source of leachable cadmium. Cadmium and other metals in roadside soils have been associated with the composition of gasoline, motor oil, and car tires (Lagerwerff and Specht, 1970). Cadmium in streambed sediments has been found to be higher in samples from urban settings compared with agricultural or forested settings (Rice, 1999). The four wells with elevated cadmium are all located in residential areas, where industrial discharges seem unlikely (although historical land use was not investigated in this study). However, the sites are all near heavily used roads, which raises the possibility of anthropogenic cadmium in roadside soils as a source. The pH of precipitation in the area is sufficiently low (less than 5.0) to support cadmium in solution, although the formation of complexes with soil organic material may inhibit cadmium transport to the water table. The high-cadmium samples have all been affected to some degree by human activity, as indicated by the relatively high chloride concentrations; the salt source itself cannot be ruled out as a cadmium source at this time. In a study of groundwater quality at storm-water-management sites in Maryland, storm-water runoff was identified as the sole source of cadmium to groundwater beneath a storm-water retention pond behind Annapolis Mall (Wilde, 1994). The maximum storm-water cadmium concentration was 16 μg/L.

Potential for Migration of Cadmium-Enriched Ground Water

The presence of cadmium in the unconfined parts of the Aquia aquifer raises the question as to whether cadmium-enriched ground water may migrate downdip as part of the regional groundwater system. This scenario is considered unlikely for two reasons. First, it appears that cadmium is immobile in the unweathered part of the Aquia Formation, possibly due to sorption or precipitation of cadmium carbonate minerals (Drever, 1997). Second, it is likely that most of the shallow ground water discharges to local rivers, streams, or the Chesapeake Bay, rather than migrating to the deeper, confined parts of the aquifer (Fleck and others, 1996).

Minimum Depths Necessary to Avoid High Cadmium Concentrations

Figure 13 shows a preliminary map of the depth to the base of the weathered zone of the Aquia Formation, based on exploratory wells and drillers' logs in the area. If the altitude of a given location is known, a minimum depth to the low-cadmium zone can be determined for that location. Data are sparse on the lower eastern Broadneck Peninsula, and more cadmium samples should be acquired in order to more accurately determine the depth to the bottom of the weathered zone. This map can be used to guide depth specifications for new wells.

Implications for Water Treatment

Selection of the appropriate water-treatment system for cadmium removal must take into account the specific form in which cadmium exists in ground water, which include the divalent ion (Cd^{2+}) and inorganic, and organic complexes. Organic-carbon concentrations in the Aquia aquifer in the study area are fairly low (less than 2 mg/L) (Wilde, 1994; Bolton, 1996), suggesting that organic complexing is not a significant process in the study area. At chloride levels of several hundred mg/L (i.e., non-potable levels), cadmium can form several different chloride complexes, including $CdCl^{+}$, $CdCl_2^{o}$, and $CdCl_3^{-}$. These complexes have different electrical charges, which can reduce the effectiveness of water-softening systems. However, speciation calculations performed on data from this study suggest that at 100 mg/L chloride (which is representative of chloride levels found with elevated cadmium), only about 5 percent of the total cadmium is complexed with chloride; with the remaining 95 percent in the form of Cd^{2+}, which can be removed with a standard ion-exchange water system. This is consistent with pre- and post-water-softener samples collected from AA De 211, in which cadmium levels were 44 and less than 2.5 µg/L, respectively. However, water having more than 100 µg/L cadmium (which was not encountered in this study) and also having more than about 100 mg/L chloride may theoretically contain more 5 µg/L cadmium-chloride complexes (i.e. 5 percent), and alternate treatment options may need to be considered.

SUMMARY AND RECOMMENDATIONS

Cadmium concentrations frequently exceed 5 µg/L (the USEPA drinking-water standard) for wells completed in a weathered zone of the Aquia Formation in central Anne Arundel County, Maryland. The maximum cadmium concentration encountered in the study area was 66 µg/L. The weathered zone has been tentatively mapped to a maximum depth of about 50 feet below sea level near the Woodland Beach community, and extends northeast from east of Davidsonville to Sandy Point State Park. The high cadmium levels are from water samples having pH less than 5.5, and increase with decreasing pH. High cadmium concentrations are also associated with increasing chloride concentrations (particularly chloride greater than 50 mg/L). The source of the cadmium could not be definitively identified in this study, and both natural and human sources may be involved. The following recommendations are based on data evaluated for this report:

- Collect additional cadmium samples in wells in the weathered zone on Broadneck Peninsula (Cape St. Claire, etc.) to determine the eastern extent of the high-cadmium zone.

- Analyze road salt and water-softener salt for cadmium in order to confirm or refute these materials as a primary source of groundwater cadmium and other trace elements.

- Specify minimum well depths in the study area, based on the depth to the bottom of the weathered zone of the Aquia Formation.

- Continue to update the minimum-well-depth map with additional cadmium data.

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Table 1. Generalized stratigraphic, lithologic, and hydrologic characteristics of geologic formations in the study area. Shaded cells indicate aquifers sampled by Maryland Geological Survey in 2005. Modified from Andreasen (2002).

System	Series	Group	Formation	Average thickness (feet)	General lithology	Hydrologic character	Hydrogeologic unit
Quaternary	Holocene		Alluvium and terrace deposits	20	Sand, gravel, silt, and clay	Confining unit in most places, limited aquifer in some places	Not recognized
	Pleistocene		Talbot Formation	20	Clay, silt, brown to gray with some glauconite and pebbles	Confining unit	Talbot confining unit
Tertiary	Miocene	Chesapeake	Calvert Formation	75	Sandy clay and fine sand, fossiliferous, diatomaceous earth	Confining unit and limited aquifer	Chiefly a water-table aquifer
	Eocene	Pamunkey	Nanjemoy Formation	50	Glauconitic sand, silt, and clay	Confining unit and limited aquifer	Nanjemoy aquifer
	Paleocene		Marlboro Clay	15	Clay, silvery gray to pink	Confining unit	Marlboro confining unit
			Aquia Formation	130	Glauconitic, greenish to brown sand with thin indurated or "rock" layers, and silt layers	Aquifer	Aquia aquifer (weathered)
			Brightseat Formation	15	Silt and clay, olive-gray to black, glauconitic	Leaky confining unit	Aquia aquifer (unweathered)
Cretaceous	Upper Cretaceous		Severn Formation	45	Sand, silty to fine, glauconitic	Limited aquifer	
			Matawan Formation	60	Silt and fine sand, clayey, dark green to black, glauconitic	Confining unit	Matawan confining unit
			Magothy Formation	120	Sand, light-gray to white, with interbedded layers of gray and black, organic clay	Aquifer	Magothy aquifer
	Lower Cretaceous	Potomac	Patapsco Formation	>250(?)	Sand, fine to coarse, brown, with layers of tough variegated clay.	Aquifer and confining unit	Patapsco aquifer and confining unit

Table 2. Cadmium, chloride, and other water-quality and well-construction data for samples collected during this study.

µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; DHMH, Department of Health and Mental Hygiene; µS/cm, microsiemens per centimeter; ft, feet; ASL, above sea level; BLS, below land surface

Well number	Well permit number	Sample date	DHMH sample number	Cadmium (unfiltered) (µg/L)	Follow-up cadmium sample (unfiltered) (µg/L)	pH	Chloride (mg/L)
AA Cf 156	AA-94-5934	6/10/2005	MGS-Cd-1,2	<2.5	--	5.2	<10
AA Cf 157	AA-94-1626	6/10/2005	MGS-Cd-3,4	2.8	--	5.0	97
AA Cf 158	AA-94-6716	6/10/2005	MGS-Cd-5,6	<2.5	--	4.4	26
AA Dd 52	AA-73-3159	6/23/2005	MGS-Cd-47,48	<2.5	--	7.5	19
AA Dd 53	AA-74-3937	6/30/2005	MGS-Cd-59,60	<2.5	--	6.1	<10
AA Dd 65	AA-92-0399	6/21/2005	MGS-Cd-23,24	22	21.7	4.8	131
AA Dd 66	AA-73-6750	6/30/2005	MGS-Cd-57,58	<2.5	--	7.2	<10
AA De 211	AA-94-1197	6/23/2005	MGS-Cd-41,42	39	44	4.8	107
AA De 212	AA-88-1851	6/23/2005	MGS-Cd-43,44	<2.5	--	6.8	<10
AA De 218	AA-93-0566	6/21/2005	MGS-Cd-21,22	<2.5	--	7.4	<10
AA De 221	AA-94-1758	6/16/2005	MGS-Cd-10,11	66	74.7	4.4	204
AA De 222	AA-88-6641	6/16/2005	MGS-Cd-12,13	<2.5	--	6.6	12
AA De 223	--	6/21/2005	MGS-Cd-27,28	16	17.6	5.3	186
AA Df 161	AA-94-3875	6/16/2005	MGS-Cd-14,15	<2.5	--	7.2	28
AA Df 162	AA-94-1362	6/30/2005	MGS-Cd-51,52	<2.5	--	7.4	18
AA Ed 67	AA-81-2213	6/23/2005	MGS-Cd-49,50	<2.5	--	7.5	<10
AA Ed 69	AA-94-2457	6/30/2005	MGS-Cd-53,54	<2.5	--	6.9	<10
AA Ee 86	AA-93-0710	6/21/2005	MGS-Cd-25,26	<2.5	--	7.0	58
AA Ee 100	AA-94-3205	6/23/2005	MGS-Cd-45,46	<2.5	--	7.7	<10
QA Eb 156	QA-81-0475	9/14/2005	MGS-GWQ-104	<2.5	--	6.8	7,200
QA Eb 157	QA-81-0475	9/14/2005	MGS-GWQ-105	<2.5	--	7.3	4
QA Ea 77	QA-81-0474	9/12/2005	MGS-QWN-101	<2.5	--	7.1	5,600
QA Ea 78	QA-81-0474	9/12/2005	MGS-QWN-103	<2.5	--	7.5	4
QA Ea 81	QA-81-0474	9/12/2005	MGS-QWN-102	<2.5	--	7.8	30

Table 2. Cadmium, chloride, and other water-quality and well-construction data for samples collected during this study--Continued.

Well number	Specific conductance (µS/cm at 25 deg. C)	Dissolved oxygen (mg/L)	Water temperature (degrees Celsius)	Use of well	Aquifer	Formation	Altitude (ft ASL)	Depth of screen interval (ft BLS)
AA Cf 156	68	--	16.0	Domestic	Aquia	Matawan	100	133-140
AA Cf 157	351	--	15.1	Domestic	Aquia	Severn	50	100-110
AA Cf 158	125	--	--	Domestic	Aquia	Matawan	50	120-127
AA Dd 52	276	<1	16.6	Domestic	Aquia	Severn	110	78-90
AA Dd 53	205	<1	15.2	Domestic	Aquia	Aquia (unweathered)	130	75-80
AA Dd 65	436	7	16.0	Domestic	Aquia	Aquia (weathered)	70	70-75
AA Dd 66	265	<1	15.1	Domestic	Aquia	Severn	110	134-139
AA De 211	439	3.3	16.4	Domestic	Aquia	Aquia (weathered)	20	41-51
AA De 212	181	<1	15.8	Domestic	Aquia	Aquia (unweathered)	20	84-92
AA De 218	300	<1	14.7	Domestic	Aquia	Aquia (unweathered)	15	80-87
AA De 221	759	7.4	15.9	Domestic	Aquia	Aquia (weathered)	50	57-70
AA De 222	241	1.1	14.4	Domestic	Aquia	Severn	20	85-90
AA De 223	752	7.2	15.4	Domestic	Aquia	Aquia (weathered)	70	<50[1]
AA Df 161	401	<1	15.4	Domestic	Aquia	Aquia (unweathered)	30	100-107
AA Df 162	371	--	15.4	Domestic	Aquia	Aquia (unweathered)	70	105-112
AA Ed 67	333	1.7	16.2	Domestic	Aquia	Aquia (unweathered)	140	170-180
AA Ed 69	311	--	15.4	Domestic	Aquia	Severn	100	241-248
AA Ee 86	381	1.5	16.0	Domestic	Aquia	Aquia (unweathered)	5	36-43
AA Ee 100	352	<1	15.4	Domestic	Aquia	Aquia (unweathered)	10	120[2]
QA Eb 156	22,330	--	16.0	Monitor well	Aquia	Aquia (unweathered)	12	210-220
QA Eb 157	338	--	15.0	Monitor well	Aquia	Aquia (unweathered)	11.9	110-120
QA Ea 77	17,490	--	16.7	Monitor well	Aquia	Aquia (unweathered)	10.8	195-205
QA Ea 78	323	--	16.1	Monitor well	Aquia	Aquia (unweathered)	11.8	125-135
QA Ea 81	491	--	17.1	Monitor well	Aquia	Aquia (unweathered)	12.4	300-310

[1] depth reported by owner
[2] estimated from well permit application

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties.

[mg/kg, milligrams per kilogram; ug/kg, micrograms per kilogram; %, percent; <, less than]

Well	Depth (feet below land surface)	Cadmium mg/kg	Lithium mg/kg	Beryllium mg/kg	Boron Mg/kg	Sodium %	Magnesium %	Aluminum %	Potassium %	Bismuth mg/kg	Calcium %
AA Cf 153	8.5-10.5	0.56	3.7	2.4	2	0.008	0.30	1.04	0.86	0.44	0.04
	13.5-15.5	1.02	1.6	3.8	< 1	0.006	0.12	0.67	0.33	0.51	0.03
	28.5-30.5	0.17	3.4	1.4	2	0.016	0.25	0.70	0.75	0.23	0.08
	38.5-40.5	0.17	3.3	1.3	1	0.011	0.20	0.63	0.58	0.30	0.06
	43.5-45.5	0.13	4.6	1.5	2	0.008	0.32	0.87	0.97	0.35	0.09
	48.5-50.5	< 0.01	4.4	1.2	2	0.006	0.31	0.69	0.88	0.22	0.08
	58.5-60.5	< 0.01	5.6	1.7	4	0.010	0.42	0.78	1.40	0.26	0.07
	68.5-70.5	0.18	3.2	1.5	2	0.009	0.28	0.47	0.89	0.20	0.03
	78.5-80.5	0.14	4.5	1.6	3	0.016	0.31	0.56	0.97	0.09	0.04
	93.5-95.5	0.62	3.3	0.7	1	0.008	0.18	0.54	0.58	0.31	0.01
AA De 100	10-12	1.41	5.3	1.6	4	0.007	0.45	0.90	1.43	0.16	0.02
	19-20	0.39	5.8	2.1	3	0.008	0.46	0.82	1.48	0.16	0.04
	27-29	0.86	3.2	1.9	3	0.008	0.31	0.63	1.04	0.09	0.03
	35-37	0.52	2.9	1.0	3	0.006	0.32	0.56	1.02	0.13	0.03
	42-44	1.18	3.9	1.4	3	0.007	0.37	0.75	1.27	0.13	0.06
	53-55	1.19	5.3	1.6	3	0.008	0.43	0.82	1.31	0.27	0.06
	69-70	0.21	5.5	1.6	2	0.009	0.34	0.89	0.96	0.33	0.18
	77-78	< 0.01	8.1	1.6	3	0.008	0.45	0.96	1.20	0.53	0.28
	83-84	< 0.01	5.6	1.5	< 1	0.010	0.25	0.60	0.44	0.38	0.68
	88-89	< 0.01	4.6	0.9	< 1	0.010	0.19	0.51	0.42	0.28	0.19
AA De 101	30-35	< 0.01	6.8	1.3	3	0.011	0.37	0.73	1.29	0.10	0.06
	35-40	0.17	6.5	1.4	3	0.012	0.36	0.69	1.21	0.09	0.25
	40-45	0.30	6.0	1.2	3	0.010	0.32	0.65	1.12	0.11	1.37
	45-50	0.12	6.5	1.4	3	0.014	0.37	0.76	1.27	0.10	0.20
	50-55	0.20	7.9	1.7	4	0.011	0.47	0.88	1.63	0.18	0.23
	55-60	0.36	8.3	1.0	3	0.017	0.53	0.75	1.16	0.11	13.40
	60-65	0.43	7.7	0.9	3	0.023	0.50	0.69	1.13	0.12	13.10
	65-70	0.14	8.4	1.2	3	0.016	0.49	0.79	1.35	0.10	6.00
	70-75	0.16	8.3	1.2	3	0.014	0.51	0.81	1.38	0.10	5.33
	75-80	0.17	5.7	1.0	2	0.015	0.47	0.64	1.00	0.10	12.90
	80-85	0.33	6.6	1.0	3	0.018	0.45	0.68	1.18	0.08	10.90
	85-90	0.21	9.3	1.3	3	0.021	0.59	0.97	1.38	0.14	10.00
	90-95	0.19	7.4	1.1	2	0.017	0.47	0.65	1.03	0.15	8.63
	100-105	0.19	7.9	1.3	3	0.020	0.53	0.81	1.25	0.19	5.99
	110-115	0.16	6.4	1.0	2	0.025	0.49	0.61	0.67	0.21	18.30
PG Df 35	120-121	< 0.01	7.2	1.1	3	0.014	0.63	0.89	1.58	0.14	12.70
	123-125	< 0.01	11.4	1.8	4	0.013	0.72	1.24	1.96	0.12	1.46
	170-171	< 0.01	7.2	0.8	2	0.014	0.28	0.66	0.76	0.07	0.31
	163-165	0.20	12.0	0.9	2	0.016	0.41	0.89	0.89	0.06	0.61
	138-140	< 0.01	7.8	1.2	4	0.011	0.59	0.70	1.35	0.09	10.30
	132-135	< 0.01	11.0	1.6	5	0.016	0.69	1.12	1.81	0.16	4.68
	89-91	0.28	13.1	1.3	3	0.014	0.45	0.93	1.05	0.06	1.04
	99-101	0.15	7.2	1.1	3	0.015	0.58	0.70	1.28	0.22	16.60
	71-73	0.16	9.3	1.5	4	0.013	0.43	0.86	1.29	0.24	0.71
	60-61	0.32	8.0	1.7	5	0.013	0.49	0.81	1.67	0.22	0.26
	103-105	0.39	8.6	1.6	5	0.014	0.61	0.89	1.81	0.19	1.55

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties—Continued.

Well	Depth (feet below land surface)	Scandium mg/kg	Vanadium mg/kg	Chromium mg/kg	Manganese mg/kg	Iron %	Cobalt mg/kg	Nickel mg/kg	Copper mg/kg	Zinc mg/kg	Gallium mg/kg
AA Cf 153	8.5-10.5	3.7	242	187	64	11.90	4.1	11.0	50.00	71.8	3.97
	13.5-15.5	3.3	225	339	277	19.90	9.2	8.5	56.80	86.4	2.61
	28.5-30.5	3.1	126	111	77	4.97	2.8	6.1	33.30	44.8	3.22
	38.5-40.5	2.9	192	111	70	5.31	2.0	5.1	33.90	44.5	3.33
	43.5-45.5	3.7	209	128	60	5.69	3.4	8.1	31.20	57.8	4.51
	48.5-50.5	2.8	110	117	46	3.87	2.1	6.2	25.50	42.4	3.11
	58.5-60.5	2.4	88	128	34	5.18	2.2	7.3	15.40	56.1	3.51
	68.5-70.5	1.2	67	109	66	4.74	2.6	7.2	11.80	58.1	2.13
	78.5-80.5	1.8	50	119	49	4.78	1.9	9.0	12.60	72.2	2.75
	93.5-95.5	1.7	65	143	45	2.13	1.4	7.0	14.10	46.3	2.11
AA De 100	10-12	3.4	90	125	53	5.88	3.4	10.4	12.10	62.0	4.24
	19-20	2.9	76	142	51	6.14	6.2	19.8	56.40	116.0	3.99
	27-29	1.9	87	231	30	9.59	1.9	18.1	10.80	66.7	3.00
	35-37	2.0	82	131	25	5.16	1.7	13.8	38.40	57.2	2.95
	42-44	2.7	103	181	143	6.72	2.6	16.7	10.80	67.0	3.79
	53-55	3.2	196	252	80	9.54	4.8	17.2	14.00	64.4	3.79
	69-70	3.6	189	276	159	12.10	5.8	17.5	28.10	111.0	3.70
	77-78	3.4	285	214	303	10.40	9.0	28.8	6.75	73.3	4.52
	83-84	3.3	287	130	694	12.90	7.6	17.9	6.81	73.3	2.68
	88-89	2.0	178	102	248	5.51	4.2	12.9	7.64	30.9	2.17
AA De 101	30-35	2.2	67	109	39	4.84	1.8	5.9	7.52	33.1	4.39
	35-40	2.3	66	100	56	4.51	2.3	9.1	8.39	47.7	3.75
	40-45	2.1	65	102	105	4.22	2.9	11.2	5.80	43.8	3.39
	45-50	2.5	77	112	53	4.98	2.3	10.5	8.08	49.3	3.45
	50-55	3.2	90	150	93	6.71	4.0	15.4	5.37	55.5	4.51
	55-60	2.3	62	113	148	6.22	4.8	20.7	6.95	63.8	3.13
	60-65	2.2	61	105	112	4.96	3.7	19.7	5.87	70.2	3.30
	65-70	2.5	72	127	97	5.29	3.1	13.9	6.44	49.5	3.69
	70-75	2.5	85	152	107	6.27	3.7	17.6	5.89	62.7	3.77
	75-80	2.0	103	152	104	5.91	3.4	15.4	5.92	59.9	2.65
	80-85	2.5	91	141	142	6.04	2.7	12.6	5.05	59.1	2.63
	85-90	3.7	116	179	109	6.86	3.7	15.9	8.25	82.5	4.15
	90-95	2.7	139	165	181	8.30	4.2	15.8	6.09	73.4	2.86
	100-105	3.0	131	173	207	8.63	5.0	15.5	7.00	88.4	3.74
	110-115	1.9	123	123	317	6.72	4.2	16.9	6.90	84.1	2.36
PG Df 35	120-121	2.6	142	155	165	7.18	3.2	13.0	3.60	44.0	3.42
	123-125	3.8	179	232	83	8.96	7.2	17.4	3.27	134.0	4.78
	170-171	1.7	55	92.7	82	2.78	2.0	6.4	5.30	31.4	2.96
	163-165	2.5	76	121	105	3.84	4.6	17.5	5.12	40.7	4.35
	138-140	1.8	93	92.7	314	7.54	1.7	9.2	3.14	55.7	3.00
	132-135	3.3	140	168	112	7.55	4.3	14.4	4.59	53.5	4.30
	89-91	2.5	51	83	43	3.59	1.9	9.5	4.70	37.0	4.32
	99-101	1.8	49	142	189	5.46	1.8	13.3	2.82	167.0	3.07
	71-73	2.1	69	105	57	5.08	3.0	10.0	5.14	49.9	3.96
	60-61	2.4	61	107	27	5.20	1.8	9.0	3.98	52.1	4.12
	103-105	2.4	80	175	77	6.20	2.7	17.9	4.47	65.5	4.32

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties—Continued.

Well	Depth (feet below land surface)	Germanium mg/kg	Arsenic mg/kg	Selenium mg/kg	Rubidium mg/kg	Strontium mg/kg	Yttrium mg/kg	Zirconium mg/kg	Niobium mg/kg	Molybdenum mg/kg	Silver mg/kg
AA Cf 153	8.5-10.5	0.3	21.4	1.4	47.9	5.6	15.30	4.2	0.3	0.81	0.334
	13.5-15.5	0.5	14.1	2.5	23.2	4.0	8.30	4.3	0.3	0.60	0.250
	28.5-30.5	0.1	11.8	0.7	41.5	4.5	5.33	4.3	0.1	0.32	0.192
	38.5-40.5	0.2	21.1	2.8	34.0	4.5	4.64	6.0	0.2	0.59	0.187
	43.5-45.5	0.2	21.2	1.1	56.4	4.7	8.05	7.1	0.2	0.40	0.182
	48.5-50.5	0.2	7.9	1.0	47.7	3.7	6.05	4.9	< 0.1	0.50	0.146
	58.5-60.5	0.4	8.7	1.0	77.7	3.2	5.93	5.2	0.2	0.34	0.093
	68.5-70.5	0.5	6.2	0.4	47.9	1.9	2.68	4.0	0.2	0.50	0.075
	78.5-80.5	0.4	7.8	1.2	54.9	3.8	5.47	4.8	0.1	0.36	0.057
	93.5-95.5	0.2	5.4	0.9	30.4	2.8	1.79	4.1	0.3	0.62	0.081
AA De 100	10-12	0.4	12.9	1.2	79.9	2.3	6.20	8.0	0.1	1.13	0.103
	19-20	0.3	9.3	0.9	83.7	3.9	6.97	6.2	< 0.1	0.53	0.239
	27-29	0.3	23.7	1.8	68.7	2.6	2.90	6.8	0.2	1.80	0.083
	35-37	0.2	9.9	0.8	58.2	2.4	3.10	5.6	0.1	0.84	0.080
	42-44	0.5	11.6	0.9	74.9	3.1	3.46	7.2	0.2	0.77	0.094
	53-55	0.3	14.9	5.9	80.7	4.7	2.47	9.7	0.2	0.56	0.071
	69-70	0.4	17.4	2.7	70.7	5.8	4.77	2.9	0.4	0.50	0.160
	77-78	0.4	16.8	1.1	71.5	10.0	6.16	9.8	0.2	0.48	0.053
	83-84	0.3	10.0	0.7	29.0	17.4	7.72	9.6	0.3	0.35	0.045
	88-89	0.2	6.5	0.6	25.8	7.4	4.02	5.9	0.2	0.39	0.025
AA De 101	30-35	0.3	18.7	1.1	66.3	7.0	1.35	7.1	0.3	0.79	0.042
	35-40	0.3	14.3	0.8	61.3	7.5	2.39	7.3	0.3	0.51	0.048
	40-45	0.2	17.0	1.2	56.6	16.9	4.18	6.9	0.2	0.55	0.027
	45-50	0.2	14.9	1.6	64.3	6.1	2.70	7.1	0.2	0.48	0.042
	50-55	0.2	19.5	1.6	80.4	8.0	3.89	8.3	0.3	0.55	0.057
	55-60	0.3	50.2	4.2	61.2	152.0	6.72	7.4	0.4	0.71	0.039
	60-65	0.3	35.6	2.4	54.1	232.0	3.95	6.0	0.3	0.71	0.035
	65-70	0.3	19.1	1.5	66.6	65.3	3.46	6.7	0.3	0.50	0.030
	70-75	0.3	26.3	1.8	68.1	57.4	3.72	6.8	0.2	0.71	0.024
	75-80	0.3	12.3	1.1	47.5	102.0	3.89	6.4	0.3	0.45	0.020
	80-85	0.4	11.8	1.6	54.2	114.0	4.31	6.2	0.3	0.49	0.032
	85-90	0.3	18.4	1.6	69.0	114.0	4.81	8.3	0.3	0.70	0.035
	90-95	0.3	15.1	3.1	50.6	87.3	5.39	7.8	0.3	0.63	0.035
	100-105	0.3	15.7	2.4	62.0	108.0	6.65	8.1	0.4	0.58	0.025
	110-115	0.2	10.4	1.0	34.6	218.0	4.70	6.3	0.3	0.40	0.024
PG Df 35	120-121	0.4	9.3	1.1	80.2	100.0	4.49	6.4	0.1	0.29	0.014
	123-125	0.4	16.5	0.7	95.6	53.8	3.66	8.1	0.1	0.36	0.013
	170-171	0.2	5.4	0.5	37.1	19.5	3.86	5.1	0.2	0.34	< 0.002
	163-165	0.2	19.6	1.5	47.7	38.0	4.02	6.1	0.4	1.64	0.024
	138-140	0.4	7.5	0.8	69.4	69.5	5.00	5.5	0.1	0.17	0.011
	132-135	0.3	11.3	1.9	88.5	150.0	3.54	7.4	0.1	0.29	0.014
	89-91	0.1	28.8	1.5	51.5	60.7	4.66	7.6	0.3	8.10	0.023
	99-101	0.3	10.4	1.4	60.6	157.0	3.33	4.4	0.2	0.79	0.004
	71-73	0.2	10.1	1.3	62.9	44.1	2.98	5.9	0.2	0.31	0.042
	60-61	0.2	9.4	1.0	82.6	14.4	3.12	5.2	0.2	0.50	0.039
	103-105	0.3	29.7	2.0	84.0	104.0	2.83	6.3	0.2	1.00	0.007

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties—Continued.

Well	Depth (feet below land surface)	Indium mg/kg	Tin mg/kg	Antimony mg/kg	Tellurium mg/kg	Cesium mg/kg	Barium mg/kg	Lanthanum mg/kg	Cerium mg/kg	Praseo-dymium mg/kg
AA Cf 153	8.5-10.5	0.04	0.80	1.39	0.21	1.37	20.3	18.3	39.0	5.4
	13.5-15.5	0.02	0.50	0.79	0.19	0.61	22.9	9.4	27.2	3.3
	28.5-30.5	0.02	0.56	0.76	0.03	1.02	12.5	10.4	30.2	3.1
	38.5-40.5	0.03	0.56	0.73	0.10	0.98	13.3	9.2	29.0	2.8
	43.5-45.5	0.03	0.62	0.91	0.14	1.44	15.3	15.0	48.0	4.5
	48.5-50.5	< 0.02	0.46	0.56	0.08	1.04	14.8	12.6	28.5	3.7
	58.5-60.5	< 0.02	0.87	0.61	0.11	1.16	16.8	10.1	16.2	2.8
	68.5-70.5	< 0.02	0.52	0.44	0.07	0.75	16.9	4.7	14.4	1.3
	78.5-80.5	< 0.02	0.69	0.28	< 0.02	0.93	21.0	10.6	29.3	3.0
	93.5-95.5	< 0.02	0.57	0.27	0.06	0.65	9.6	6.3	16.1	1.8
AA De 100	10-12	0.02	0.66	0.62	0.04	1.28	14.4	12.7	44.6	4.4
	19-20	< 0.02	1.36	0.64	< 0.02	1.43	19.2	14.4	63.1	4.5
	27-29	< 0.02	0.54	0.79	< 0.02	1.05	22.7	6.5	24.3	2.3
	35-37	< 0.02	0.88	0.51	0.05	0.99	21.8	8.4	27.5	2.3
	42-44	< 0.02	0.62	0.78	< 0.02	1.33	46.1	8.4	29.5	2.6
	53-55	0.03	0.98	1.10	0.15	1.35	13.7	6.6	22.7	2.2
	69-70	0.04	1.43	1.52	0.17	1.51	33.8	12.3	33.8	3.9
	77-78	0.03	0.73	1.22	0.33	1.71	26.9	15.2	48.8	4.6
	83-84	0.03	0.60	0.75	0.26	0.91	33.4	12.3	43.4	3.8
	88-89	0.02	0.57	0.47	0.15	0.74	18.3	9.8	32.0	3.0
AA De 101	30-35	< 0.02	0.60	0.32	0.04	1.30	14.1	6.1	16.2	1.5
	35-40	< 0.02	0.75	0.43	< 0.02	1.11	13.6	7.6	24.6	2.4
	40-45	< 0.02	0.49	0.50	< 0.02	1.12	14.7	9.6	37.9	3.4
	45-50	< 0.02	0.68	0.51	0.05	1.09	16.5	8.5	34.6	3.3
	50-55	0.03	0.82	0.77	0.08	1.35	19.8	12.9	50.7	4.7
	55-60	< 0.02	0.73	1.61	0.07	1.16	21.5	16.7	63.2	5.9
	60-65	< 0.02	0.55	1.05	0.05	1.03	18.8	11.5	36.7	3.4
	65-70	< 0.02	0.69	0.59	0.04	1.10	18.9	11.6	37.5	3.6
	70-75	< 0.02	0.61	0.87	0.05	1.19	19.9	11.4	37.4	3.5
	75-80	< 0.02	0.54	0.53	0.05	0.90	15.4	12.0	38.4	3.6
	80-85	< 0.02	0.49	0.50	0.03	0.96	17.7	12.1	39.2	3.6
	85-90	0.02	0.87	0.68	0.05	1.26	23.2	14.4	46.0	4.2
	90-95	< 0.02	0.52	0.84	0.06	0.97	23.8	13.4	44.7	4.1
	100-105	0.03	1.11	0.76	0.07	1.22	29.5	15.1	51.0	4.7
	110-115	< 0.02	0.64	0.95	0.09	0.91	61.0	10.8	30.5	3.2
PG Df 35	120-121	< 0.02	0.49	0.43	0.06	1.38	21.1	11.6	39.7	3.5
	123-125	0.04	0.68	0.42	0.05	2.16	41.7	15.9	57.1	4.9
	170-171	< 0.02	0.65	0.18	< 0.02	0.88	30.5	11.1	30.1	3.1
	163-165	< 0.02	0.74	0.49	< 0.02	1.25	34.5	12.3	38.2	3.7
	138-140	< 0.02	0.38	0.38	0.06	1.14	26.3	11.7	36.4	3.3
	132-135	0.03	0.56	0.48	0.06	1.71	39.9	14.2	45.7	4.3
	89-91	< 0.02	0.60	0.30	0.02	1.28	26.4	16.6	51.7	5.0
	99-101	0.02	0.64	0.30	0.03	1.12	33.2	8.5	25.8	2.3
	71-73	0.02	0.71	0.22	0.06	1.27	32.9	12.2	44.3	3.9
	60-61	0.02	0.59	0.24	0.04	1.45	20.1	10.8	40.5	3.5
	103-105	0.02	0.69	0.76	< 0.02	1.43	28.8	10.6	35.7	3.2

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties—Continued.

Well	Depth (feet below land surface)	Neodymium mg/kg	Samarium mg/kg	Europium mg/kg	Gadolinium mg/kg	Terbium mg/kg	Dysprosium mg/kg	Holmium mg/kg	Erbium mg/kg	Thulium mg/kg
AA Cf 153	8.5-10.5	22.1	4.1	0.9	3.9	0.5	2.87	0.6	1.5	0.2
	13.5-15.5	14.2	3.2	0.7	2.9	0.4	2.49	0.5	1.3	0.2
	28.5-30.5	12.1	2.4	0.5	2.2	0.3	1.49	0.3	0.7	0.1
	38.5-40.5	10.8	2.1	0.4	1.9	0.2	1.32	0.2	0.6	< 0.1
	43.5-45.5	17.6	3.6	0.7	3.2	0.4	2.24	0.4	1.0	0.1
	48.5-50.5	14.6	2.9	0.6	2.4	0.3	1.61	0.3	0.8	0.1
	58.5-60.5	11.3	2.2	0.4	1.8	0.2	1.33	0.2	0.6	< 0.1
	68.5-70.5	5.24	1.0	0.2	0.9	0.1	0.674	0.1	0.3	< 0.1
	78.5-80.5	11.8	2.2	0.4	1.8	0.2	1.24	0.2	0.6	< 0.1
	93.5-95.5	7.43	1.5	0.2	1.1	0.1	0.585	0.1	0.3	< 0.1
AA De 100	10-12	17.4	3.2	0.6	2.5	0.3	1.52	0.3	0.7	< 0.1
	19-20	17.6	3.3	0.6	2.7	0.3	1.52	0.3	0.7	< 0.1
	27-29	8.9	1.8	0.3	1.4	0.2	0.887	0.2	0.4	< 0.1
	35-37	8.64	1.5	0.3	1.2	0.1	0.662	0.1	0.3	< 0.1
	42-44	10.4	1.9	0.4	1.6	0.2	0.873	0.2	0.4	< 0.1
	53-55	8.48	1.6	0.3	1.2	0.2	0.827	0.1	0.4	< 0.1
	69-70	15.4	2.8	0.5	2.1	0.3	1.55	0.3	0.7	0.1
	77-78	17.8	3.5	0.7	2.7	0.4	1.96	0.3	0.9	0.1
	83-84	15.0	3.2	0.7	3.0	0.4	2.52	0.4	1.3	0.2
	88-89	11.8	2.4	0.4	2.0	0.2	1.31	0.2	0.6	< 0.1
AA De 101	30-35	5.33	0.9	0.1	0.7	< 0.1	0.433	< 0.1	0.2	< 0.1
	35-40	9.07	1.6	0.3	1.3	0.1	0.661	0.1	0.3	< 0.1
	40-45	13.8	2.5	0.5	2.0	0.2	1.11	0.2	0.5	< 0.1
	45-50	12.6	2.3	0.4	1.6	0.2	0.871	0.1	0.3	< 0.1
	50-55	18.0	3.3	0.6	2.4	0.3	1.30	0.2	0.5	< 0.1
	55-60	23.4	4.4	0.8	3.6	0.4	2.11	0.4	0.9	0.1
	60-65	13.1	2.4	0.4	1.7	0.2	1.05	0.2	0.5	< 0.1
	65-70	13.8	2.5	0.4	1.9	0.2	0.981	0.2	0.4	< 0.1
	70-75	13.4	2.4	0.4	1.8	0.2	1.06	0.2	0.5	< 0.1
	75-80	13.4	2.4	0.4	1.8	0.2	1.12	0.2	0.5	< 0.1
	80-85	14.0	2.6	0.5	2.0	0.2	1.20	0.2	0.5	< 0.1
	85-90	16.6	3.0	0.6	2.4	0.3	1.29	0.2	0.5	< 0.1
	90-95	15.5	2.9	0.6	2.3	0.3	1.46	0.2	0.7	< 0.1
	100-105	18.5	3.5	0.7	2.9	0.4	1.84	0.3	0.8	0.1
	110-115	12.6	2.4	0.5	1.8	0.2	1.30	0.2	0.6	< 0.1
PG Df 35	120-121	13.6	2.6	0.5	2.0	0.2	1.18	0.2	0.5	< 0.1
	123-125	19.1	3.6	0.6	2.6	0.3	1.36	0.2	0.5	< 0.1
	170-171	11.5	2.2	0.3	1.7	0.2	1.05	0.2	0.4	< 0.1
	163-165	13.9	2.6	0.5	2.0	0.2	1.18	0.2	0.5	< 0.1
	138-140	12.9	2.4	0.4	2.0	0.2	1.30	0.2	0.6	< 0.1
	132-135	16.8	2.8	0.5	2.2	0.2	1.14	0.2	0.5	< 0.1
	89-91	18.9	3.4	0.5	2.6	0.3	1.35	0.2	0.5	< 0.1
	99-101	8.8	1.6	0.3	1.3	0.2	0.759	0.1	0.3	< 0.1
	71-73	14.4	2.7	0.4	1.9	0.2	1.01	0.2	0.4	< 0.1
	60-61	13.3	2.3	0.4	1.8	0.2	0.879	0.1	0.3	< 0.1
	103-105	12.2	2.2	0.4	1.7	0.2	0.844	0.1	0.3	< 0.1

Table 3. Elemental concentrations of sediments in the Aquia Formation, Anne Arundel and Prince George's Counties—Continued.

Well	Depth (feet below land surface)	Ytterbium mg/kg	Lutetium mg/kg	Hafnium mg/kg	Tantalum mg/kg	Tungsten mg/kg	Rhenium mg/kg	Gold ug/kg	Thallium mg/kg	Lead mg/kg	Thorium mg/kg	Uranium mg/kg
AA Cf 153	8.5-10.5	1.2	0.2	< 0.02	< 0.05	0.5	0.002	< 0.2	0.06	30.4	5.9	0.8
	13.5-15.5	1.2	0.2	< 0.02	< 0.05	0.2	< 0.001	< 0.2	0.07	37.9	3.8	1.0
	28.5-30.5	0.6	< 0.1	0.14	< 0.05	< 0.1	< 0.001	< 0.2	0.06	14.7	3.8	0.7
	38.5-40.5	0.5	< 0.1	0.19	< 0.05	< 0.1	0.001	< 0.2	0.06	20.3	4.5	0.9
	43.5-45.5	0.9	0.1	0.22	< 0.05	< 0.1	< 0.001	< 0.2	0.06	16.8	5.4	1.1
	48.5-50.5	0.7	< 0.1	0.15	< 0.05	< 0.1	< 0.001	< 0.2	0.05	8.89	3.4	0.6
	58.5-60.5	0.5	< 0.1	0.18	< 0.05	< 0.1	0.004	< 0.2	0.11	5.13	2.4	0.6
	68.5-70.5	0.3	< 0.1	0.13	< 0.05	< 0.1	0.001	< 0.2	0.07	4.43	1.4	0.5
	78.5-80.5	0.5	< 0.1	0.16	< 0.05	< 0.1	0.001	< 0.2	0.06	3.38	1.8	1.5
	93.5-95.5	0.2	< 0.1	0.13	< 0.05	< 0.1	0.003	< 0.2	0.08	8.35	3.0	1.3
AA De 100	10-12	0.6	< 0.1	0.24	< 0.05	0.5	0.001	< 0.2	0.06	7.73	3.7	0.7
	19-20	0.5	< 0.1	0.18	< 0.05	0.5	< 0.001	< 0.2	0.06	4.86	2.5	1.7
	27-29	0.3	< 0.1	0.17	< 0.05	0.1	< 0.001	< 0.2	0.05	4.11	1.7	0.8
	35-37	0.3	< 0.1	0.16	< 0.05	0.3	0.001	< 0.2	0.04	3.48	2.0	0.4
	42-44	0.3	< 0.1	0.21	< 0.05	< 0.1	< 0.001	< 0.2	0.04	5.01	2.7	0.7
	53-55	0.4	< 0.1	0.31	< 0.05	0.3	0.003	< 0.2	0.09	8.43	4.3	0.7
	69-70	0.7	< 0.1	< 0.02	< 0.05	0.7	0.003	< 0.2	0.07	11.8	5.4	0.5
	77-78	0.8	0.1	0.30	< 0.05	0.2	0.002	< 0.2	0.05	20.6	6.0	0.5
	83-84	1.2	0.2	0.27	< 0.05	0.1	0.001	< 0.2	0.04	25.3	5.6	0.5
	88-89	0.6	< 0.1	0.17	< 0.05	0.1	0.001	< 0.2	0.03	10.5	4.3	0.3
AA De 101	30-35	0.1	< 0.1	0.21	< 0.05	< 0.1	0.001	< 0.2	0.05	3.61	2.5	0.6
	35-40	0.2	< 0.1	0.20	< 0.05	0.3	0.001	< 0.2	0.05	4.0	2.9	1.0
	40-45	0.3	< 0.1	0.21	< 0.05	0.4	0.001	< 0.2	0.05	5.08	2.9	1.0
	45-50	0.3	< 0.1	0.19	< 0.05	0.2	0.001	< 0.2	0.05	6.34	3.2	1.0
	50-55	0.4	< 0.1	0.27	< 0.05	0.9	0.007	< 0.2	0.09	9.12	4.8	1.3
	55-60	0.7	0.1	0.22	< 0.05	< 0.1	0.010	< 0.2	0.11	7.08	2.6	1.9
	60-65	0.4	< 0.1	0.17	< 0.05	0.4	0.008	< 0.2	0.08	7.19	2.3	1.4
	65-70	0.3	< 0.1	0.19	< 0.05	0.7	0.005	< 0.2	0.05	5.73	2.7	0.9
	70-75	0.4	< 0.1	0.18	< 0.05	0.9	0.004	< 0.2	0.06	7.18	2.9	0.8
	75-80	0.4	< 0.1	0.17	< 0.05	0.5	0.005	< 0.2	0.04	5.72	2.3	1.2
	80-85	0.4	< 0.1	0.17	< 0.05	0.5	0.005	< 0.2	0.04	5.16	2.5	0.9
	85-90	0.4	< 0.1	0.22	< 0.05	2.0	0.005	< 0.2	0.05	7.2	3.5	1.2
	90-95	0.6	< 0.1	0.22	< 0.05	1.5	0.004	< 0.2	0.04	12.1	2.7	0.8
	100-105	0.7	< 0.1	0.24	< 0.05	1.6	0.007	< 0.2	0.09	11.1	3.6	1.5
	110-115	0.5	< 0.1	0.18	< 0.05	0.9	0.005	< 0.2	0.06	9.86	3.0	0.5
PG Df 35	120-121	0.4	< 0.1	0.17	< 0.05	< 0.1	0.003	< 0.2	0.04	5.84	2.9	1.0
	123-125	0.4	< 0.1	0.23	< 0.05	< 0.1	0.005	< 0.2	0.06	9.8	4.2	0.9
	170-171	0.3	< 0.1	0.14	< 0.05	< 0.1	0.008	< 0.2	0.04	4.6	3.3	1.0
	163-165	0.4	< 0.1	0.21	< 0.05	< 0.1	0.027	< 0.2	0.14	5.21	3.6	1.3
	138-140	0.5	< 0.1	0.16	< 0.05	< 0.1	0.001	< 0.2	0.03	4.66	2.2	0.4
	132-135	0.4	< 0.1	0.21	< 0.05	< 0.1	0.005	< 0.2	0.04	9.48	3.9	0.9
	89-91	0.3	< 0.1	0.24	< 0.05	< 0.1	0.018	< 0.2	0.12	3.62	5.1	1.5
	99-101	0.3	< 0.1	0.15	< 0.05	0.2	0.039	< 0.2	0.08	2.54	2.0	3.6
	71-73	0.3	< 0.1	0.21	< 0.05	< 0.1	0.018	< 0.2	0.08	5.13	4.5	1.2
	60-61	0.3	< 0.1	0.16	< 0.05	< 0.1	0.006	< 0.2	0.07	6.22	3.2	0.9
	103-105	0.2	< 0.1	0.20	< 0.05	< 0.1	0.032	< 0.2	0.17	3.94	2.3	1.4

Table 4. Water-quality and sediment-quality characteristics of the weathered and unweathered zones of the Aquia Formation in central Anne Arundel County, Maryland. Top number is median value; values in parentheses contain the range.

mg/kg, milligrams per kilogram; µg/L, micrograms per liter; <, less than

Part of Aquia Formation	Sediment samples Cadmium (mg/kg)	Water samples Cadmium (µg/L)	pH	Chloride (mg/L)	Dissolved Oxygen (mg/L)
Weathered zone[1]	0.19 (<0.01—1.41)	31 (16-66)	4.8 (4.4--5.3)	159 (107--204)	7.1 (3.3--7.4)
Unweathered zone [2]	0.17 (<0.01—0.43)	All <2.5	7.3 (6.1--7.7)	<10 (<10-58)	<1 (<1-1.7)

[1] water samples: n=4; sediment samples: n=26
[2] water samples: n=8; sediment samples: n=20

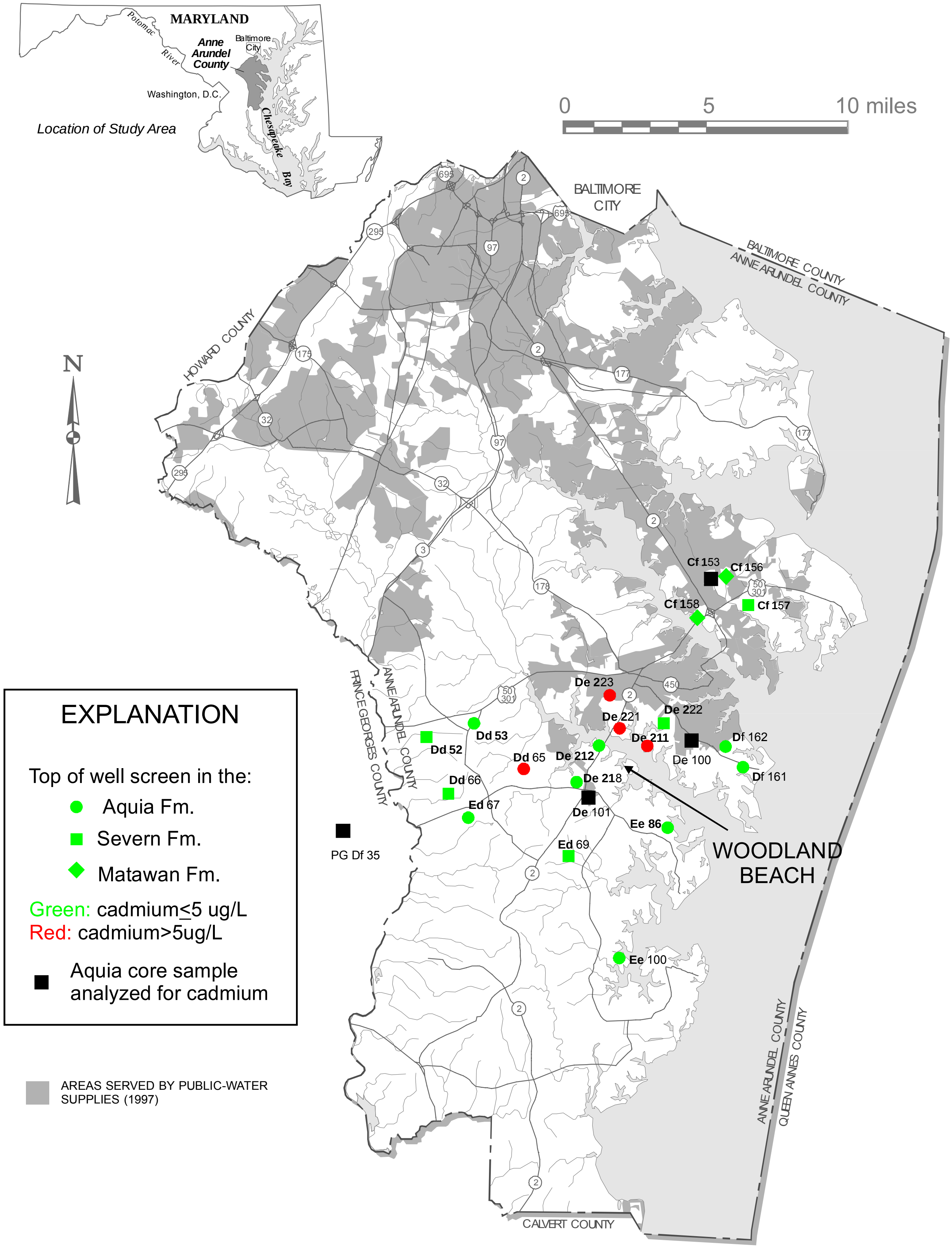

Figure 1. Locations of well-water and sediment samples analyzed for cadmium and other chemical constituents in Anne Arundel County in 2005.

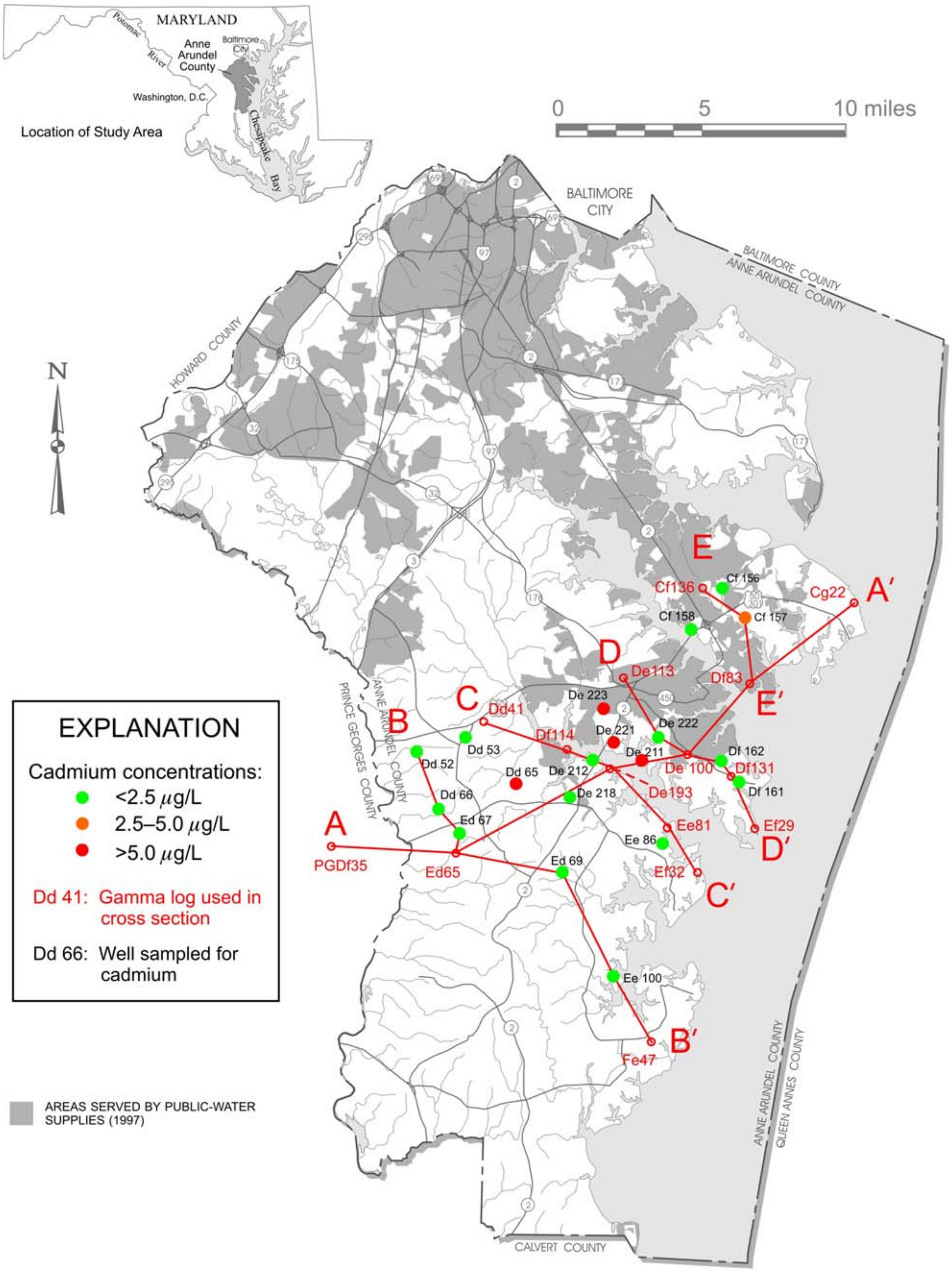

Figure 2. Locations of wells sampled for cadmium in 2005, and location of cross sections A-A′ through E-E′.

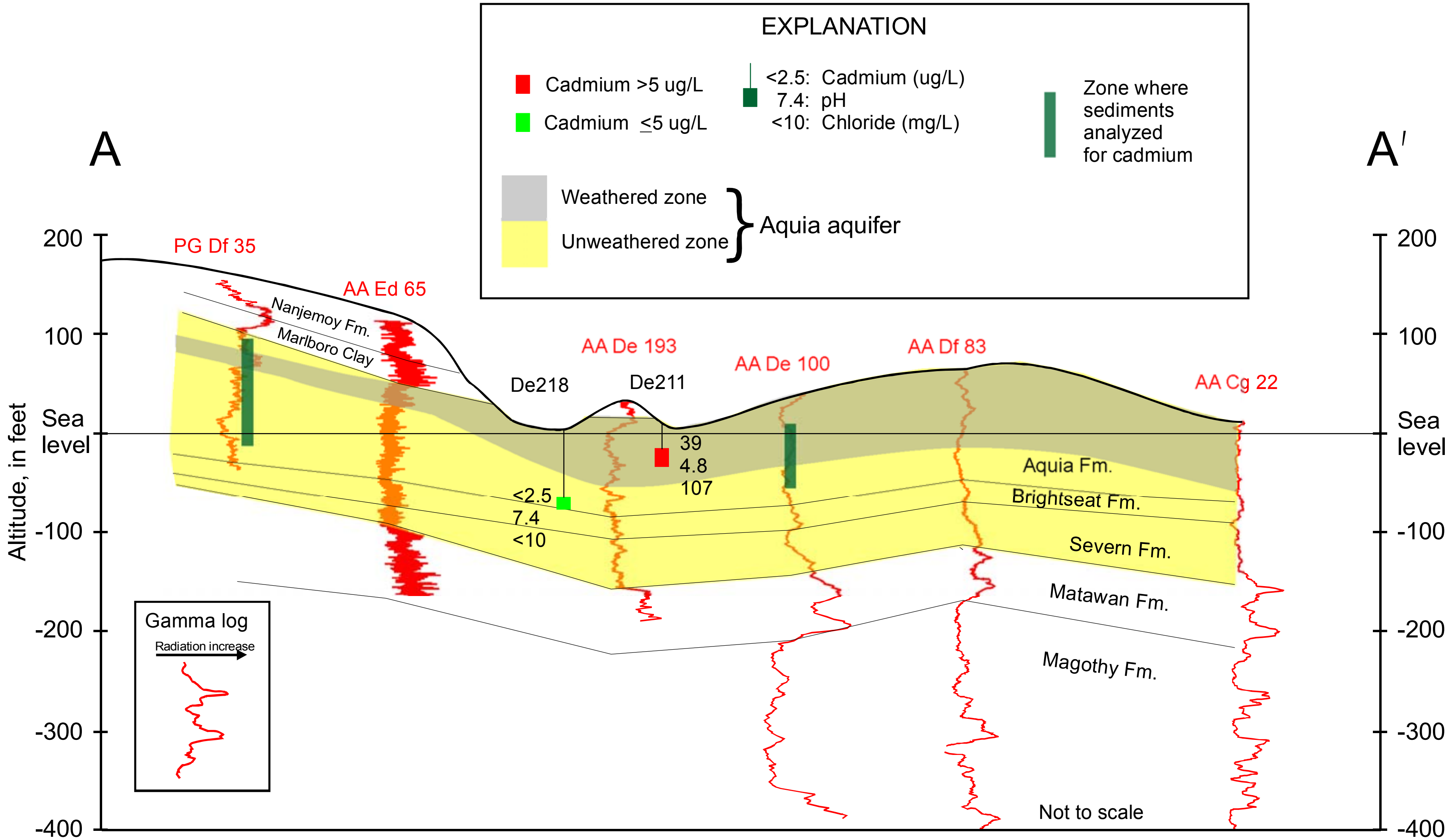

Figure 3. Cross-section A-A′ showing groundwater cadmium concentrations and other data in the Aquia aquifer in central Anne Arundel County, Maryland. Contacts are dashed where inferred. Location of cross section is shown in figure 2.

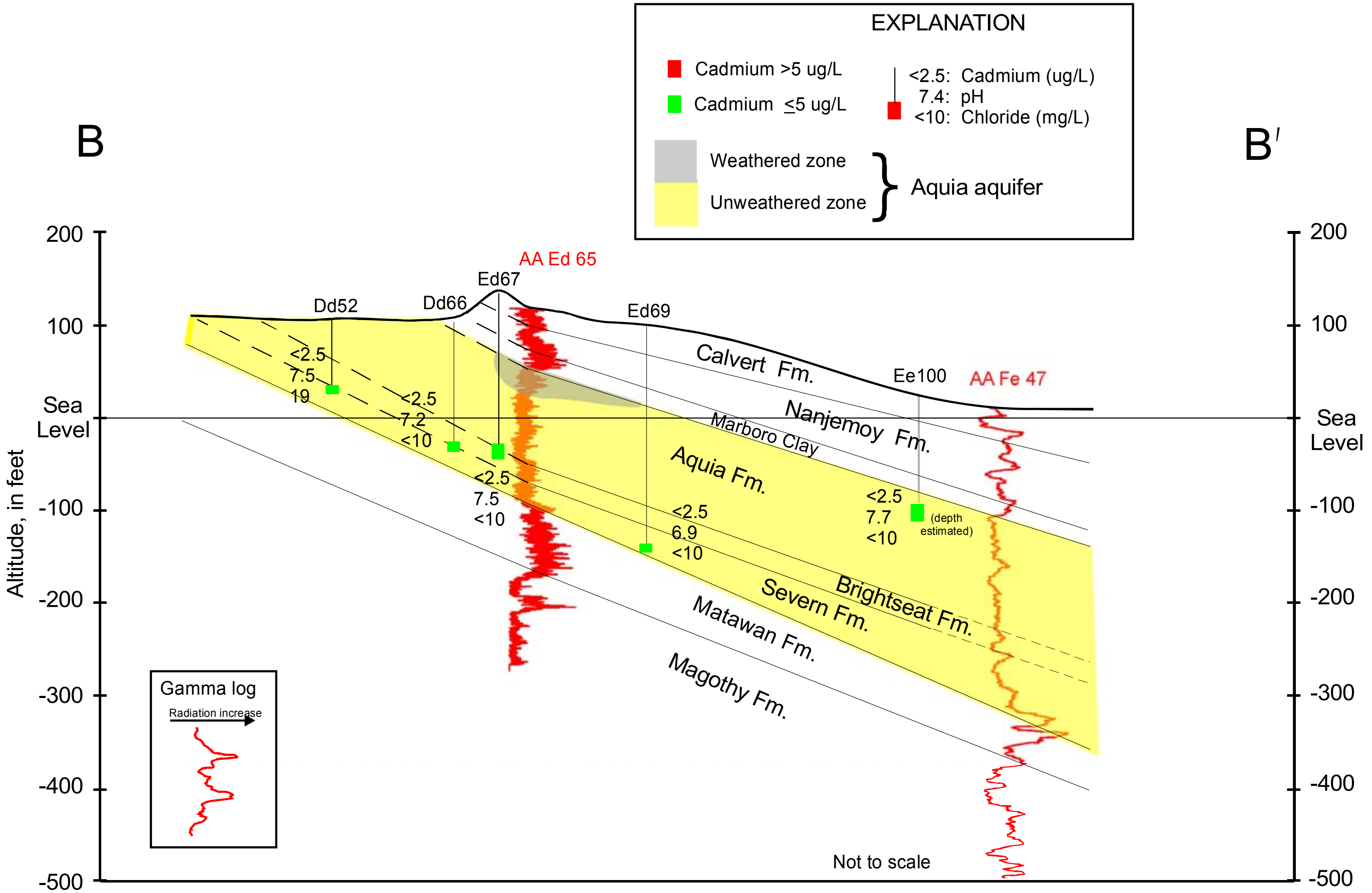

Figure 4. Cross-section B-B′ showing groundwater cadmium concentrations in the Aquia aquifer in central Anne Arundel County. Contacts are dashed where inferred. Location of cross section is shown in figure 2.

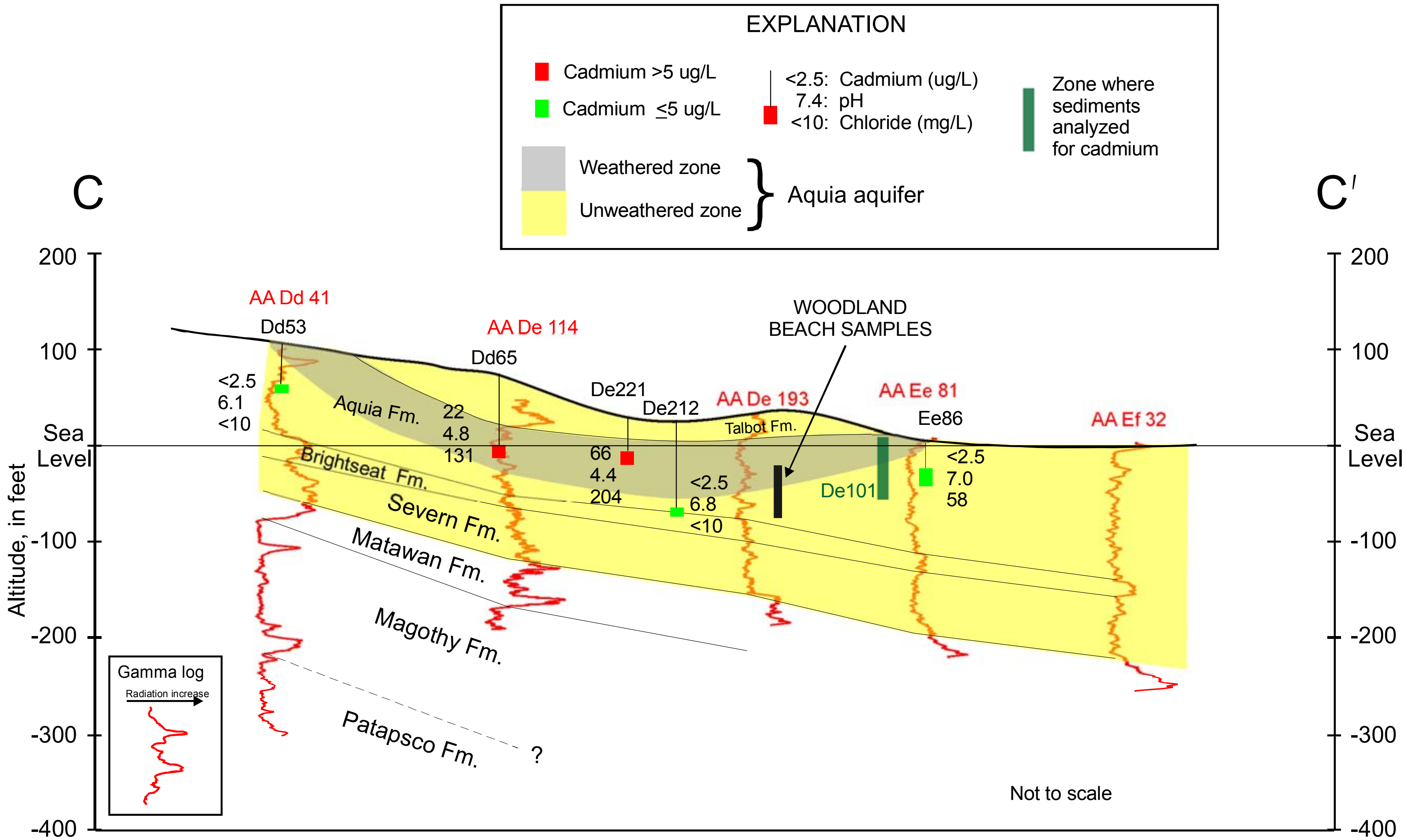

Figure 5. Cross-section C-C′ showing groundwater cadmium concentrations in the Aquia aquifer in central Anne Arundel County. Contacts are dashed where inferred. Location of cross section is shown in Figure 2.

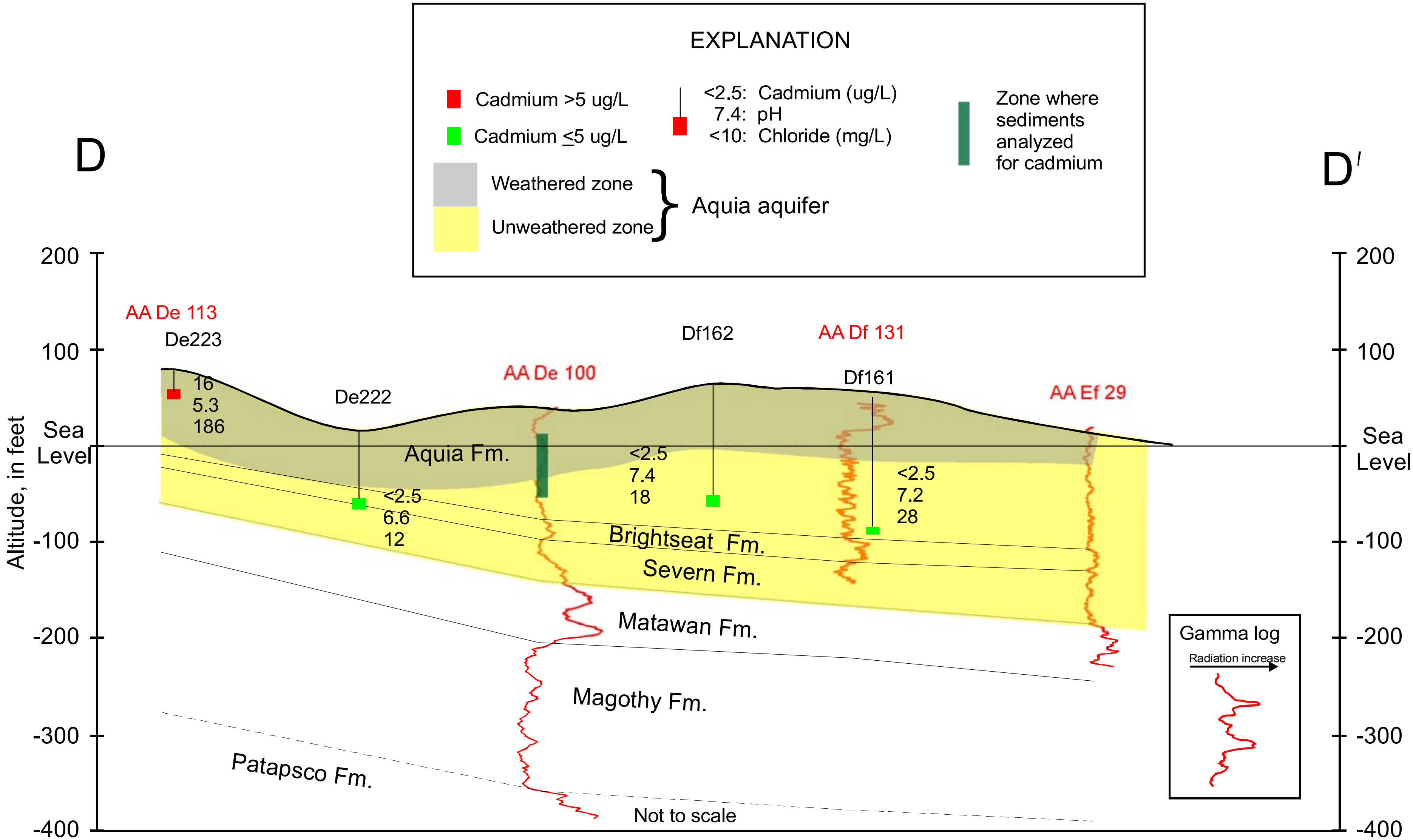

Figure 6. Cross-section D-D′ showing groundwater cadmium concentrations in the Aquia aquifer in central Anne Arundel County. Contacts are dashed where inferred. Location of cross section is shown in figure 2.

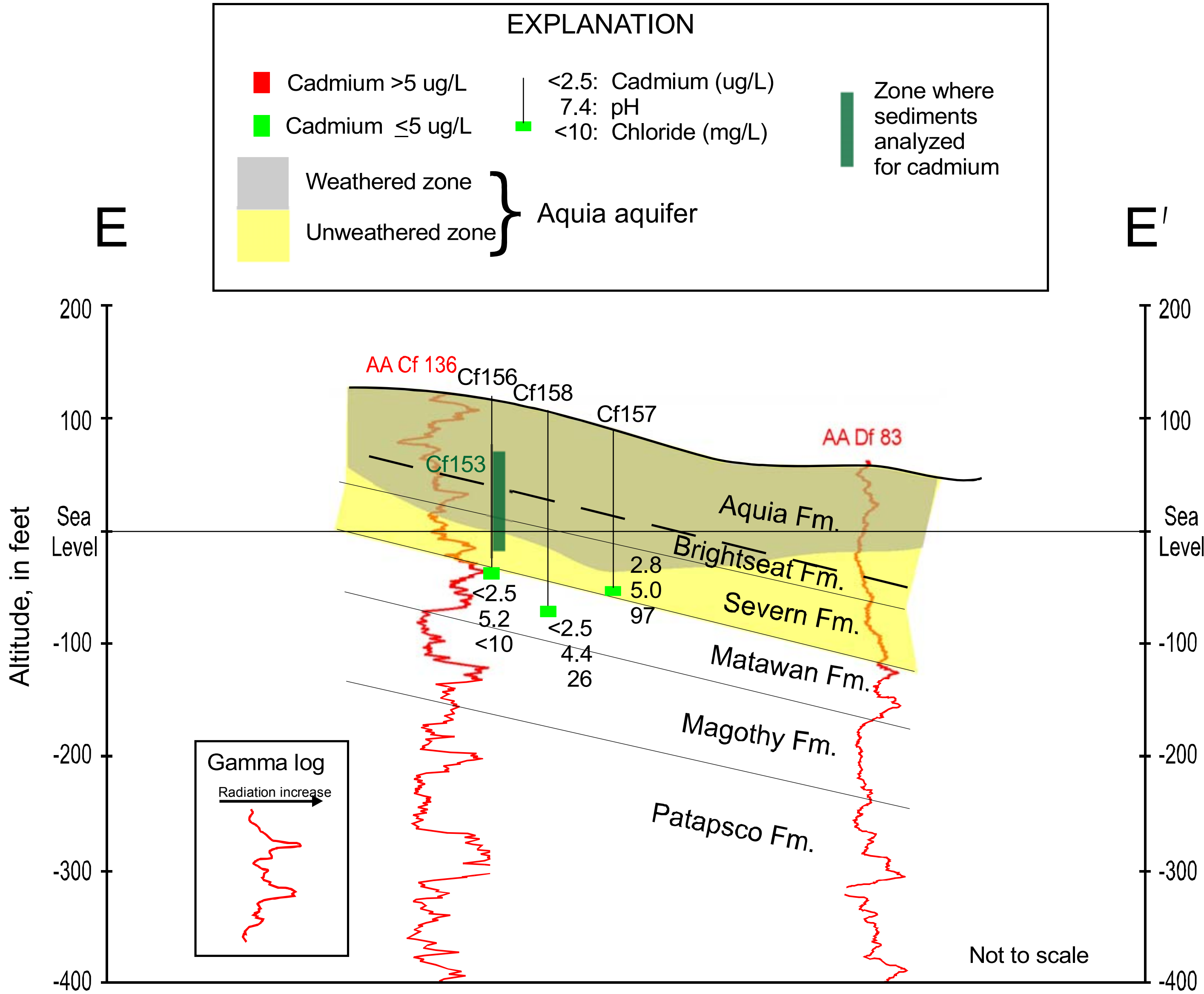

Figure 7. Cross-section E-E′ showing groundwater cadmium concentrations in the Aquia aquifer in central Anne Arundel County. Contacts are dashed where inferred. Location of cross section shown in figure 2.

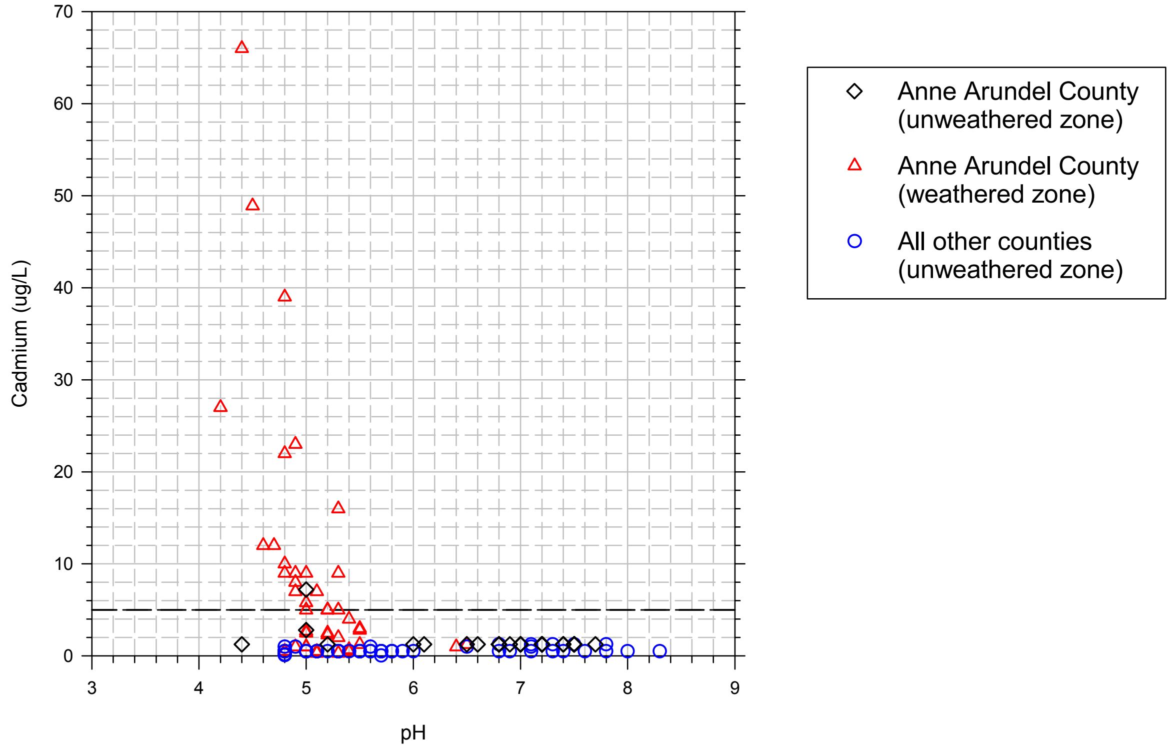

Figure 8. Relation of cadmium and pH in water samples from the Aquia aquifer. Plot includes multiple samples from individual wells.

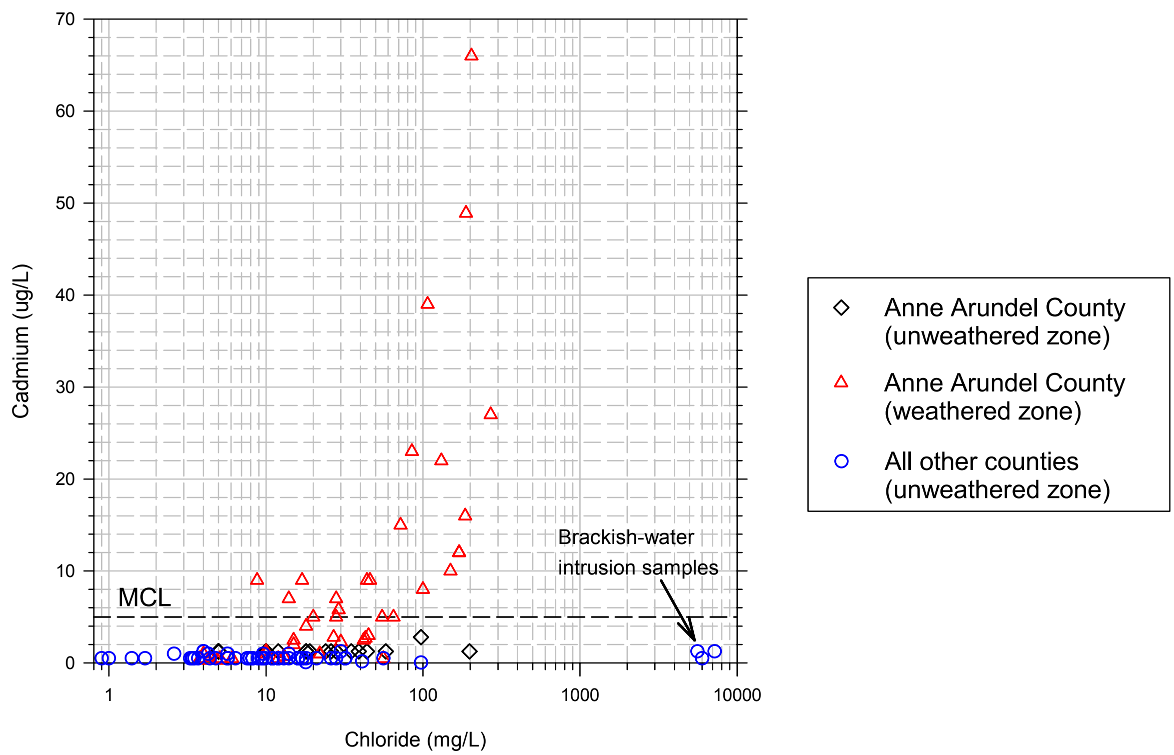

Figure 9. Relation of cadmium and chloride in water samples from the Aquia aquifer. Plot includes multiple samples from individual wells.

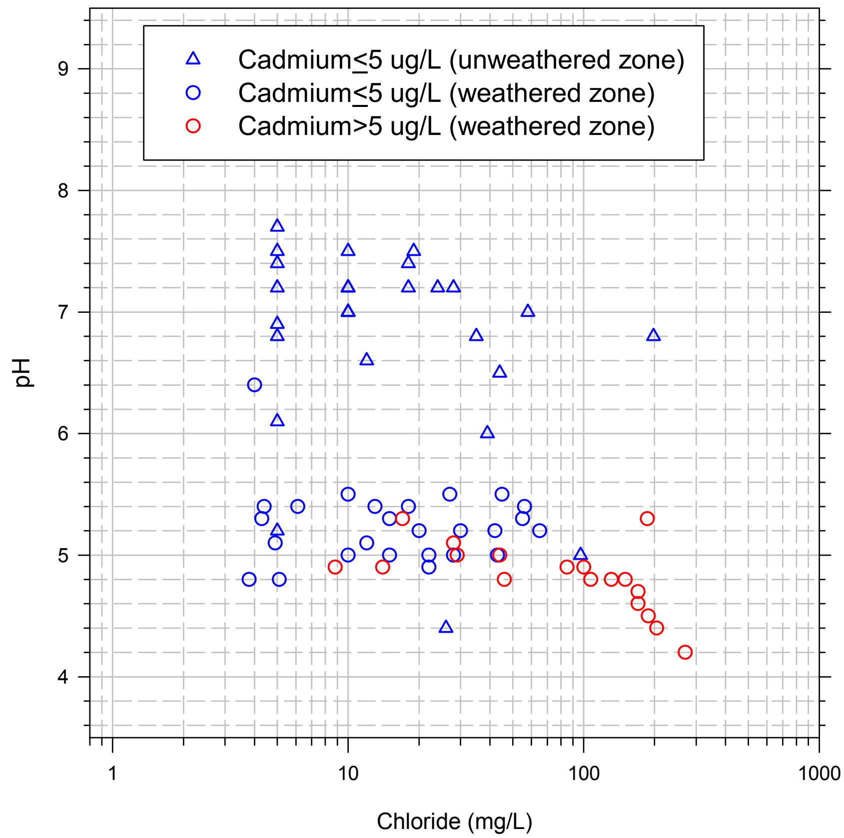

Figure 10. Relation of pH and chloride in water samples from weathered and unweathered zones of the Aquia aquifer in Anne Arundel County. Plot includes multiple samples from individual wells.

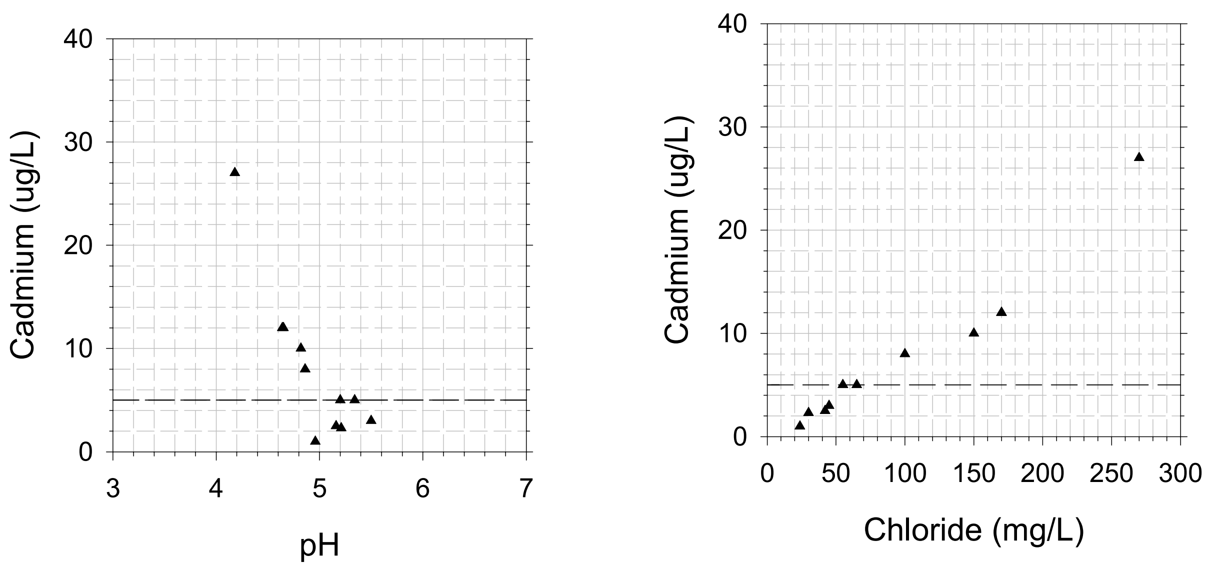

Figure 11. Cadmium concentrations in well AA De 157 in relation to (a) pH, and (b) chloride. Data are from Wilde (1994).

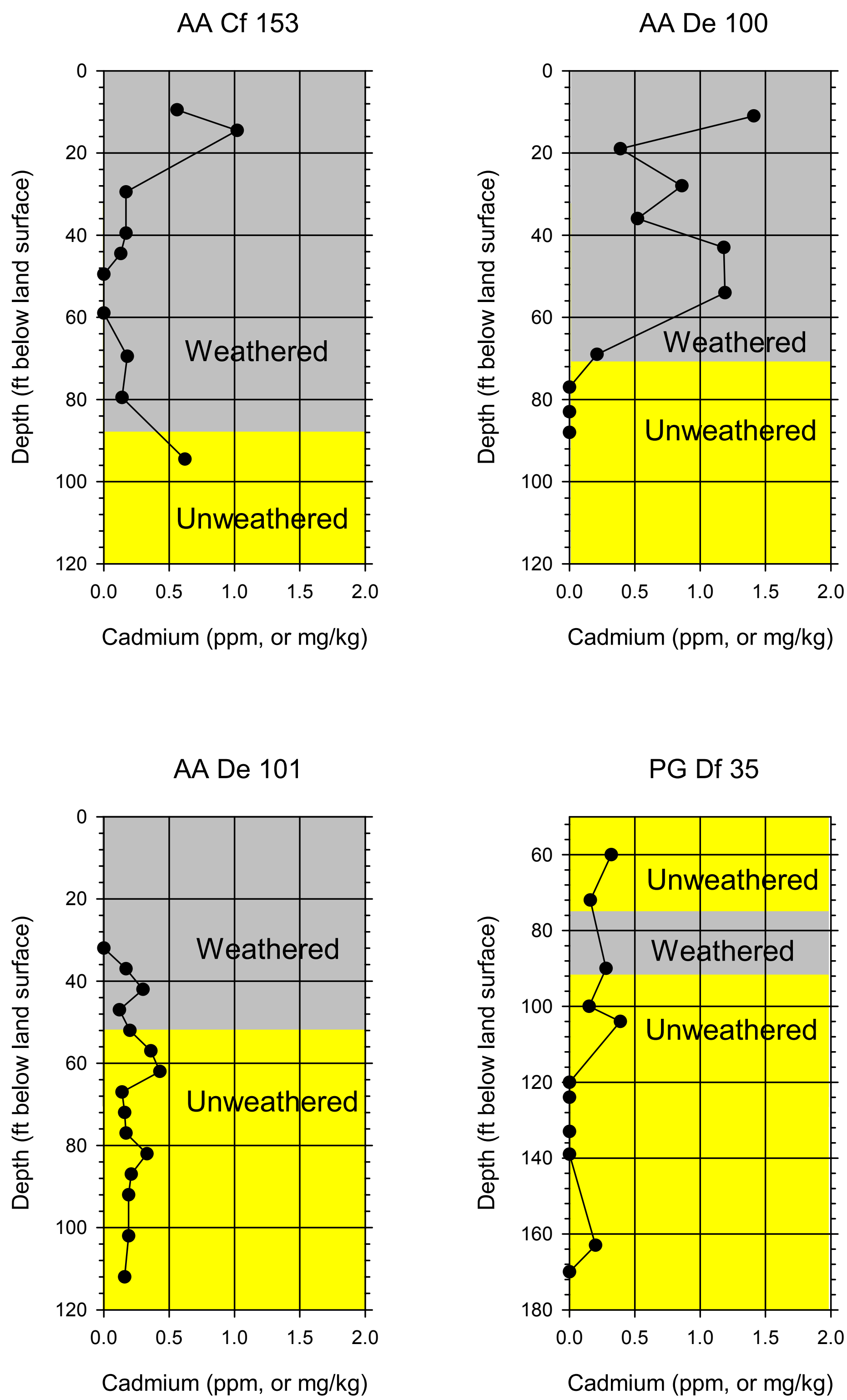

Figure 12. Sediment cadmium concentrations in relation to the weathered and unweathered zones in the Aquia Formation.

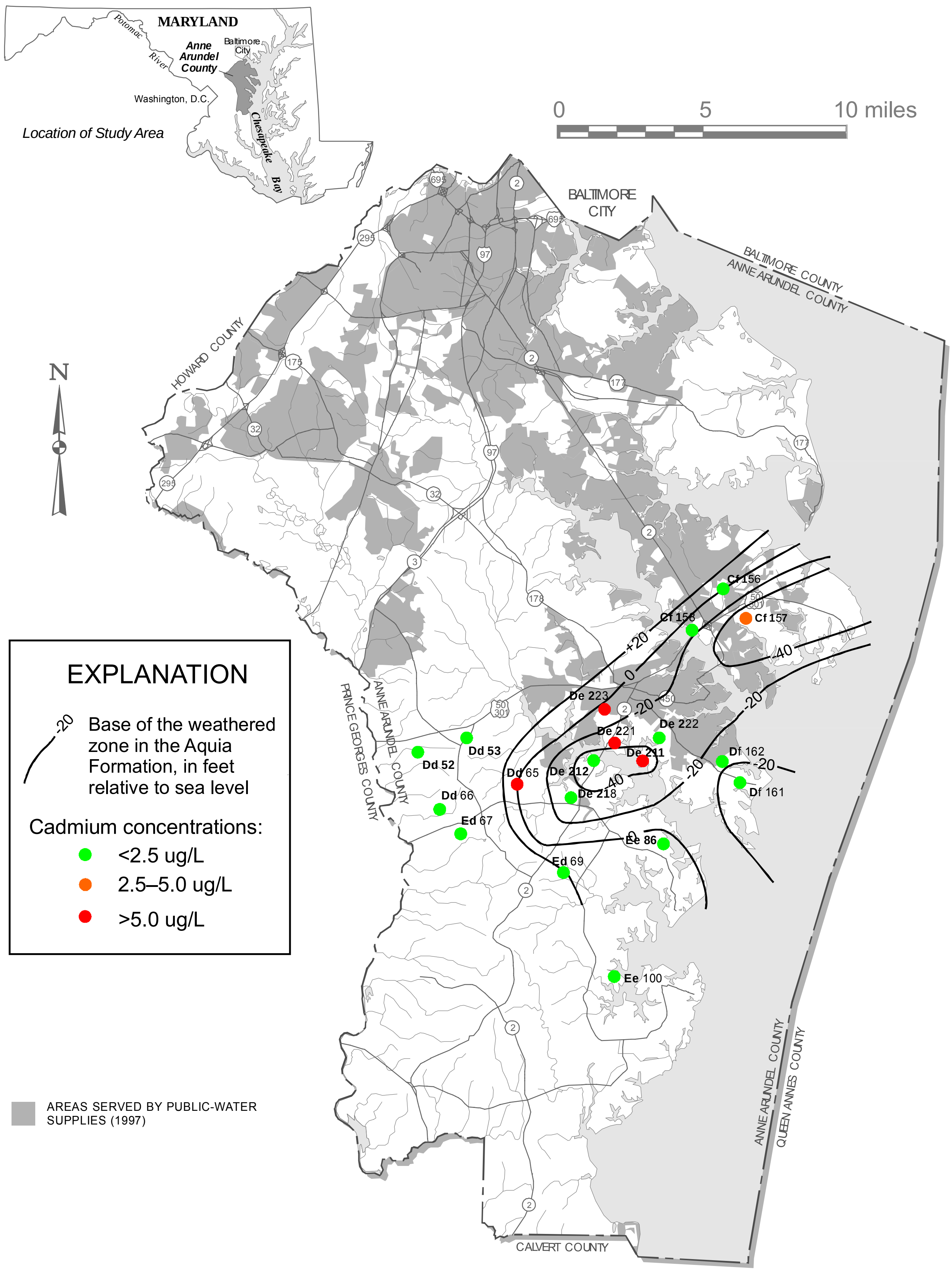

Figure 13. Depth to the bottom of the weathered zone of the Aquia Formation in central Anne Arundel County.