Maryland Department of Natural Resources
Resource Assessment Service
Maryland Geological Survey
Richard A. Ortt, Jr., Director

OPEN-FILE REPORT NO. 15-02-01

HYDROGEOLOGY OF THE PATUXENT AQUIFER SYSTEM IN THE WALDORF AREA, CHARLES COUNTY, MARYLAND

by

Andrew W. Staley

Prepared in cooperation with the
Charles County Department of Planning and Growth Management

DNR Publication No. 12-292015-749

2015

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS—Continued

TABLES

ABBREVIATIONS

alt.	altitude
COMAR	Code of Maryland Regulations
GAPA	gross alpha-particle activity
GBPA	gross beta-particle activity
GPS	Global Positioning System
MCL	Maximum Contaminant Level
MDE	Maryland Department of the Environment
MGS	Maryland Geological Survey
NASA	National Aeronautics and Space Administration
NAVD88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NSA	National Security Agency
NWQL	National Water Quality Laboratory
PEPCO	Potomac Electric Power Company
SMCL	Secondary Maximum Contaminant Level
TDL	total depth logged
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WSSC	Washington Suburban Sanitary Commission
WWTP	waste water treatment plant

deg C	degrees Celsius
E	estimated
ft	feet
ft/mi	feet per mile
ft^2/day	feet squared per day
hr	hour
ft/yr	feet per year
in.	inch(es)
gpm or GPM	gallons per minute
(gal/min)/ft	gallons per minute per foot
Mgal/d or MGD	million gallons per day
mg/L	milligrams per liter
pCi/L	picocuries per liter
µg/L	micrograms per liter
µS/cm @ 25 deg C	microsiemens per centimeter at 25 degrees Celsius
<	less than

HYDROGEOLOGY OF THE PATUXENT AQUIFER SYSTEM IN THE WALDORF AREA, CHARLES COUNTY, MARYLAND

by

Andrew W. Staley

KEY RESULTS

- Four test wells were constructed in the Waldorf area of north-central Charles County to (1) provide basic geological and hydrogeological data necessary to help characterize the Patuxent aquifer system, and (2) begin to provide long-term water-level data to help determine the effects of existing regional and potential local withdrawals from the Patuxent aquifer system.

- The top of the Patuxent aquifer system in the Waldorf area as determined from the test wells ranges from 1,002 to 1,633 feet below sea level. Total thickness of the Patuxent aquifer system ranges from 285 to 440 feet, and sand percentage ranges from 30 to 40 percent of total thickness. Sands in the Patuxent aquifer system in the Waldorf area are thinner, less frequent, and finer-grained than in more productive areas to the west in the Bryans Road - Indian Head area and to the north in Prince George's and Anne Arundel Counties.

- Transmissivity of the Patuxent aquifer system as determined from the test wells ranges from 77 to 335 feet squared per day for the pumping phases of the tests and from 106 to 618 feet squared per day for the recovery phases of the tests.

- Water levels measured in the test wells during November of 2014 range from 20 to 42 feet below sea level. Water levels are declining at a rate of 3 to 6 feet per year. These declines are occurring in the absence of any local pumpage from the Patuxent aquifer system, and are likely a response to withdrawals in the Bryans Road - Indian Head area to the west or the Chalk Point Power Plant to the east.

- Water samples collected from the test wells were a sodium-bicarbonate type, with total dissolved solids ranging from 269 to 605 milligrams per liter. None of the samples exceeded the U.S. Environmental Protection Agency's Primary Drinking Water Standards. Secondary standards were exceeded for iron, total dissolved solids, aluminum, and color in one or more of the wells. Polonium-210 concentrations were all less than 2 picocuries per liter.

- There is more than 760 feet of available drawdown in the Patuxent aquifer system in the Waldorf area; however, use of the aquifer may be constrained by deep drilling depths, declining water levels, and relatively low transmissivity.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to present data collected from four test wells completed in the Patuxent aquifer system (the deepest Coastal Plain aquifer) in the Waldorf area of north-central Charles County during 2013. Information collected for this project includes lithologic descriptions from drill cuttings, borehole geophysical data, aquifer-test data and analyses, water-quality analyses, and water-level data. In addition, the report discusses implications for the potential of the aquifer system for water-supply development in the Waldorf area, based on data collected during the test drilling.

LOCATION OF STUDY AREA

The study area is located in the north-central portion of Charles County and is referred to as the Waldorf area (fig. 1). The study area is centered approximately on the intersection of U.S. Route 301 and Maryland Route 228 (Berry Road), and includes the public water-distribution area and population center of Waldorf. The public water system serving the Waldorf area is the largest water system in the county, supplying water to the populations of Waldorf, St. Charles, Bensville, and portions of White Plains. The Bensville water system, previously a separate system, was connected to the Waldorf system in 2008.

The study area lies completely within the Coastal Plain Province of Maryland. The province is underlain by a wedge of unconsolidated clastic sediments of mostly Cretaceous and younger age which generally become deeper and thicker to the southeast (fig. 2). Sand and gravel layers form aquifers, which transmit water to wells; clay and silt layers form confining units, which slow or impede flow between the aquifers and provide storage for the aquifer system. These unconsolidated sediments rest unconformably on the consolidated basement rocks of mainly Precambrian to Jurassic age in the study area.

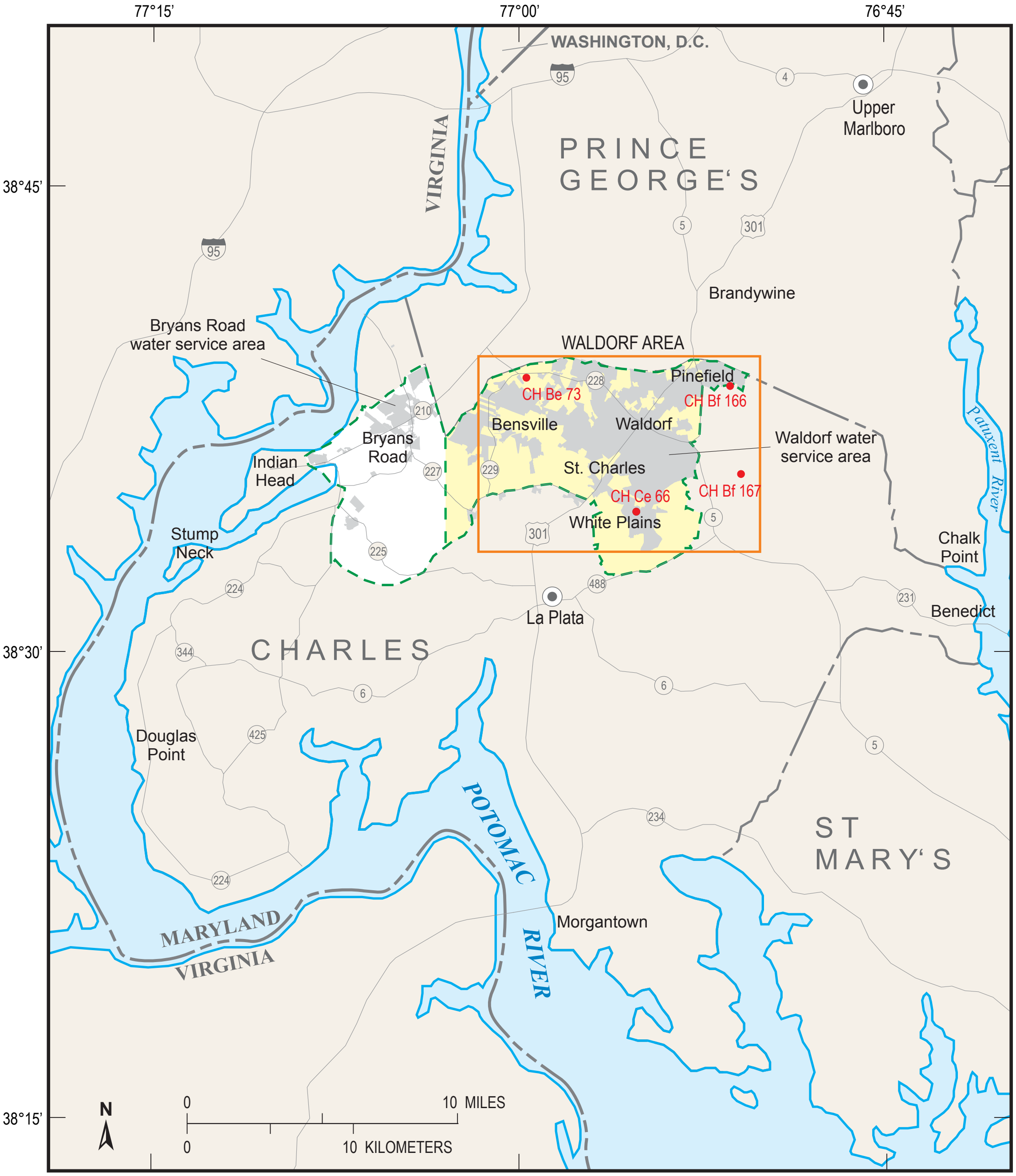
BACKGROUND

The Waldorf area relies almost entirely on groundwater for its freshwater supply and the extent of use of various aquifers has increased over time to meet growing water-supply demands. The earliest groundwater development for a centralized public water-supply system occurred in 1962, when the Magothy aquifer began to be pumped. Further development of the Magothy aquifer continued for the following 20 years until concerns over a decline in water levels of as much as 85 feet (ft) led state and county water managers to shift withdrawals from the Magothy aquifer to the deeper Lower Patapsco aquifer system (Mack and Mandle, 1977; Mack and others, 1983). In 1986, production wells screened in the Lower Patapsco aquifer system were added to the Waldorf system. Additional development of the Lower Patapsco aquifer system near Waldorf has helped to stabilize water levels in the Magothy aquifer (Staley, 2014).

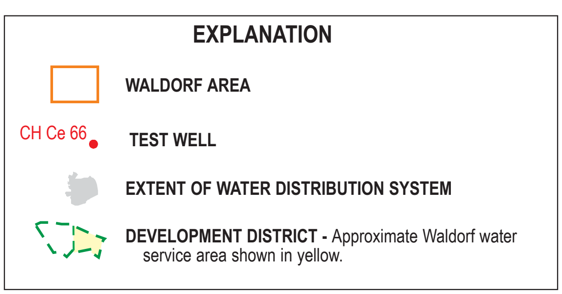
Rapid development and an associated increase in population have occurred in recent decades throughout the county and in the Waldorf area in particular. The population of Charles County has increased by 22 percent between 2000 and 2010. In the Waldorf area, population is projected to increase by 57 percent between 2010 and 2040 (Charles County Draft Comprehensive Plan, 2014). This increasing population has created an ever larger demand for groundwater in the Waldorf area. It became apparent in 2007 that water levels in the Lower Patapsco aquifer system in western Charles County were declining at unsustainable rates, while Lower Patapsco wells at Waldorf and La Plata recorded some of the deepest water levels in the Maryland Coastal Plain (Staley and others, 2014).

The current Waldorf water system draws groundwater from 16 production wells; 9 of which are in the Magothy aquifer, and 7 in the Lower Patapsco aquifer system. The Waldorf well system is supplemented by an additional 1.4 million gallons per day (Mgal/d) capacity provided by an interconnection with the Washington Suburban Sanitary Commission (WSSC) surface-water distribution system.

The Patuxent aquifer system was identified in previous studies as having the potential to meet projected water demands in the western portion of the county (Bryans Road - Indian Head area) while reducing drawdown in the increasingly stressed Lower Patapsco aquifer system (Andreasen, 2003; 2004). Previous studies (Andreasen and Mack, 1998; Andreasen, 1999) have presented information



BASE MODIFIED FROM U.S. GEOLOGICAL SURVEY, 1:250,000



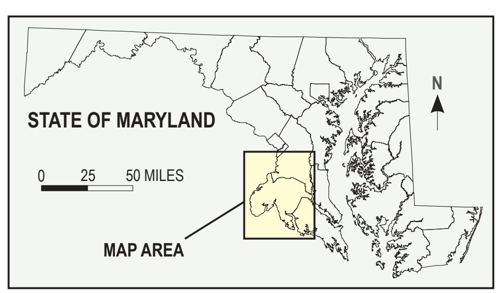


Figure 1. Study area and location of test wells.

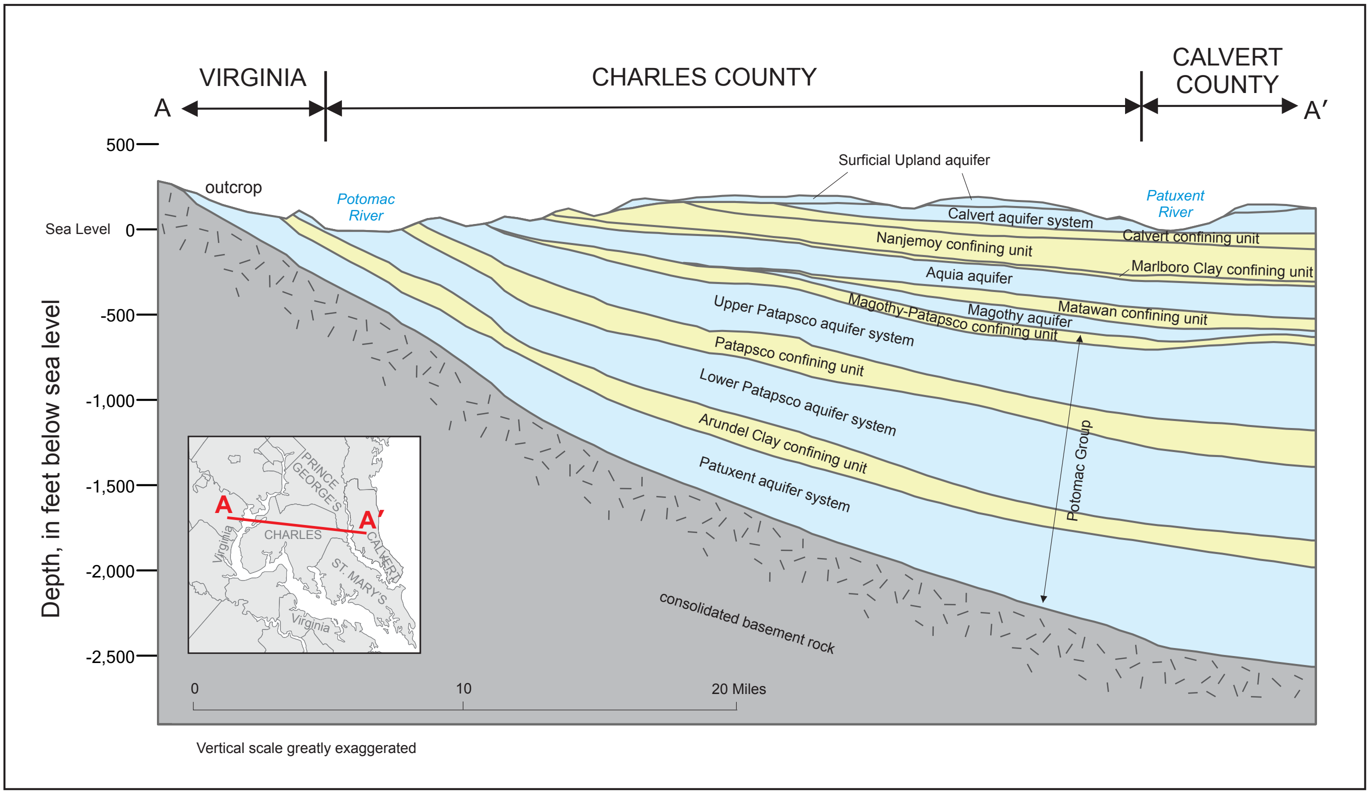


Figure 2. Schematic hydrogeologic cross section showing relation of aquifers through northern Charles County.

regarding the hydraulic characteristics of the Patuxent aquifer system in the western part of the county (Bryans Road - Indian Head area). Patuxent aquifer-system test wells have been drilled and documented at La Plata (Mack, 1999) and St. Charles in the Waldorf area (Wilson and Fleck, 1990); however little was known of the aquifer characteristics of the Patuxent aquifer system in north-central Charles County (hereafter referred to as the Waldorf area).

ACKNOWLEDGMENTS

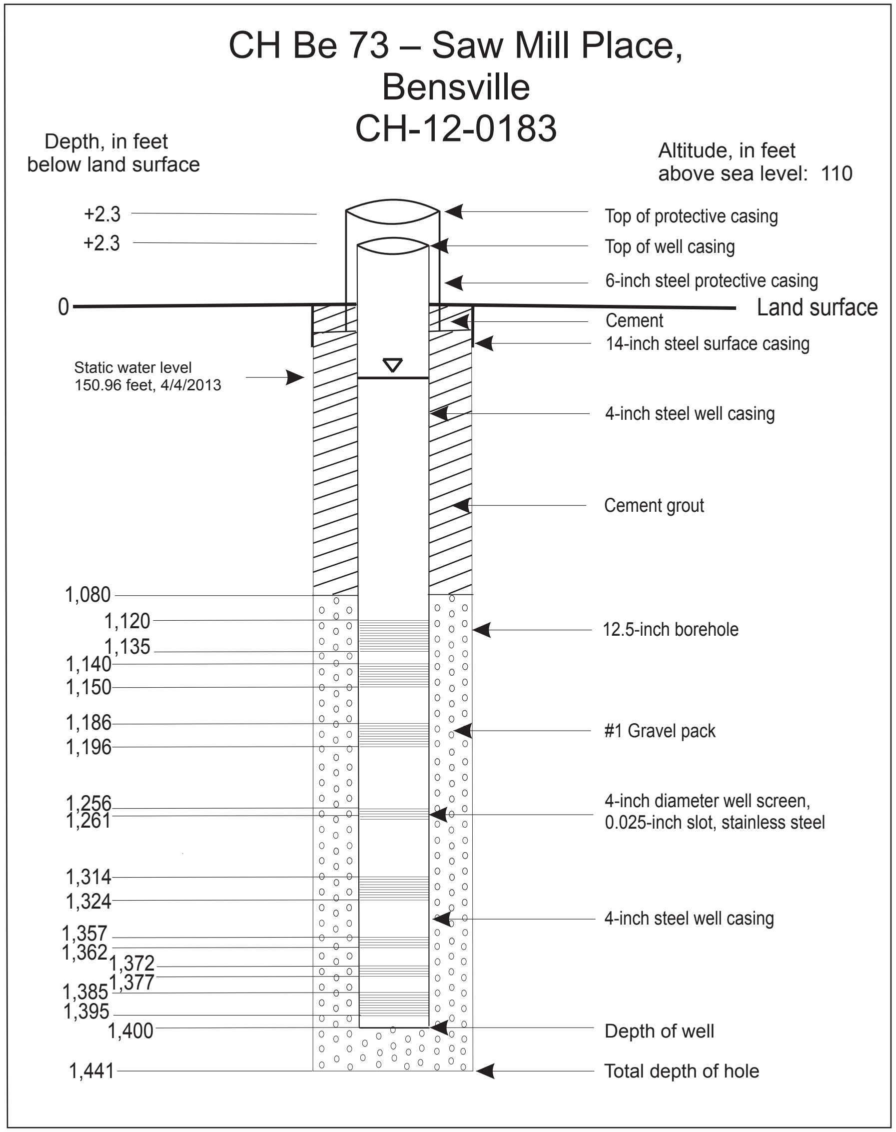
Financial support for this study, including the construction of test wells and collection and analysis of data, was provided by the Board of Commissioners of Charles County and the Maryland Geological Survey (MGS). Charles County Department of Planning and Growth Management personnel who participated in the planning and logistics of the project included Jason Groth, Zak Krebeck, Charles Strawberry, and John Mudd. Field data were collected with assistance from Lindsay Keeney, David Andreasen, David Bolton, David Drummond, Minh Phung Pham, and Katherine Burgy (currently or formerly with MGS). Donajean Appel of MGS assisted in report preparation. The report was reviewed by Michael Brayton of the U.S. Geological Survey (USGS), and by Robert Peoples and John Grace of the Maryland Department of the Environment (MDE).

METHODS

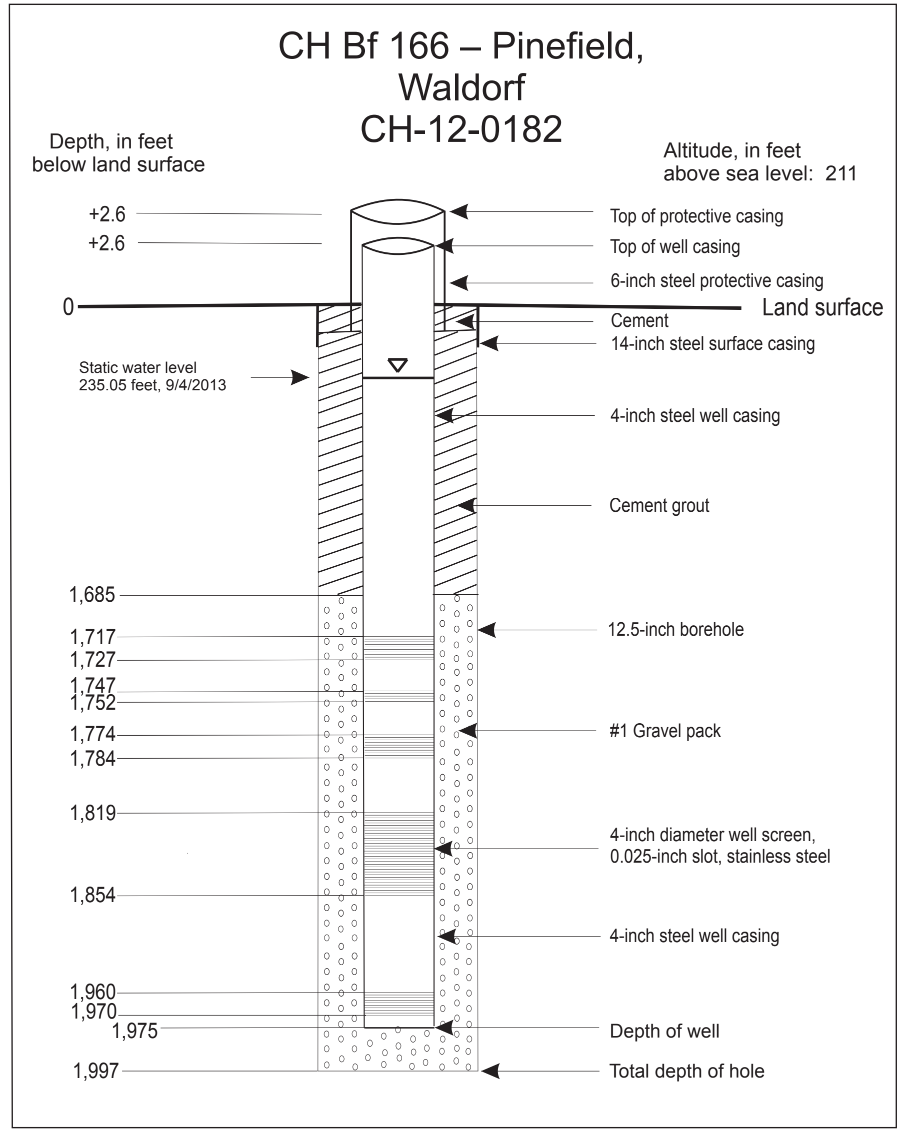
DRILLING AND TEST-WELL CONSTRUCTION

Drilling and construction of four test wells took place between February 5, 2013 and October 23, 2013 (app. A, figs. 3a and 3b). Borehole depths ranged from 1,441 ft to 2,120 ft. All wells were drilled by A.C. Schultes of Maryland, Inc.[1] using the

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



Not to scale



Not to scale

Figure 3a. Construction features of test wells CH Be 73 and CH Bf 166.

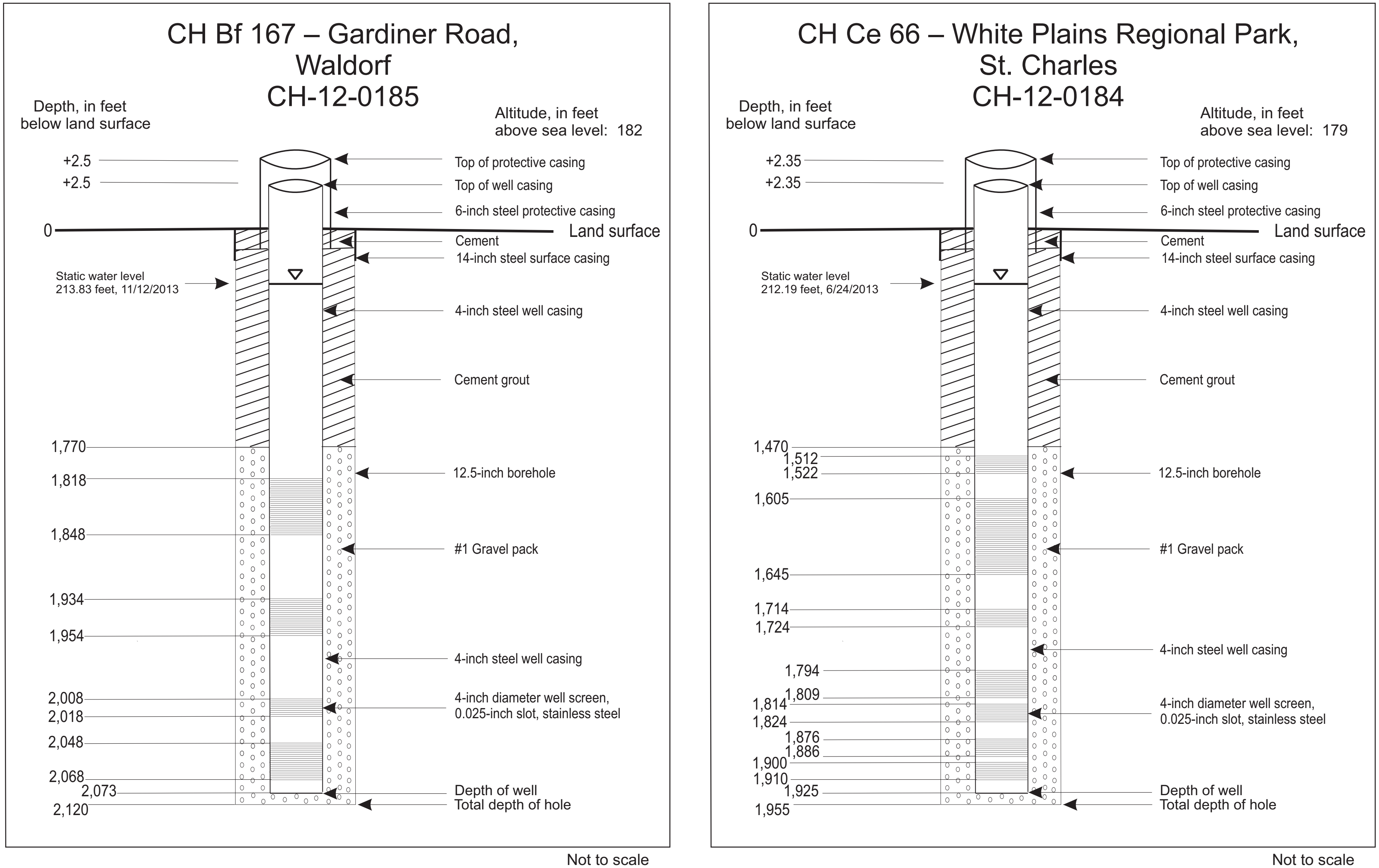


Figure 3b. Construction features of test wells CH Bf 167 and CH Ce 66.

direct hydraulic mud-rotary method. Drag bits were used for the unconsolidated sediments, and tricone-roller bits were used when drilling the contact between the Coastal Plain sediments and the consolidated basement rock. Drill cuttings were collected at 10-ft intervals and also during any noticeable change in sediment type. Every effort was made to circulate drilling fluid for sufficient time to allow drill cuttings to reach the surface before proceeding to the next depth interval; however, some recirculation and mixing of sediments between intervals was unavoidable, especially at deeper drilling depths. Descriptions of the recovered sediments were made by a geologist on site (app. B). Each well was drilled to basement rock with the exception of well CH Bf 166 where drilling conditions necessitated finishing prior to reaching consolidated rock.

After each borehole was drilled to total depth, the drilling fluid was thinned and geophysical logs were run in the uncased holes (figs. 4a-4d). Geophysical logs were run to within 2 to 10 ft of total drilled depth. Geophysical logs included gamma radiation, multi-point resistivity, single-point resistance, and self-potential. Geophysical logging was performed by A.C. Schultes of New Jersey, USGS Maryland-Delaware-Washington, D.C. (MD-DE-DC) Water Science Center, and Earth Data, Inc. Each well was constructed with multiple screens in the most promising sand layers of the Patuxent aquifer system, as determined from geophysical logs and lithologic cuttings. Cumulative screen lengths of the wells ranged from 70 to 105 ft. The test wells were constructed with 4-inch- (in.) diameter steel casing and 4-in. wire-wound, stainless-steel well screens. A 5- to 15-ft section of casing was installed below the deepest screen section in each well to allow settling of sediment without clogging the well screen. Screened intervals were gravel packed, and the annular space outside the well casing above the highest screen was grouted using cement grout. The 4-in. well casing was extended approximately 2.5 ft above land surface for each well.

After construction, the wells were developed using a combination of compressed air, swabbing, and pump-and-surge to remove fine-grained material from the well casing and screen openings. Development continued until the water was free of sediment and discoloration, and a well yield acceptable for aquifer testing was obtained. Once the wells were constructed and developed at each site, aquifer tests consisting of 24 hours (hrs) of pumping followed by 24 hrs of recovery were conducted, during which water samples were collected for chemical analysis. Each site was equipped with a 6-in.-diameter steel protective casing topped with a flange capable of accommodating a water-level recorder shelter. Land-surface altitude at each site was determined using global positioning system (GPS) coordinates to match to LIDAR-derived digital elevation data from the USGS National Elevation Dataset (NED) Point Query Service.

Wells are referred to in this report by both their USGS well identifiers and their geographical identifiers, as follows: CH Be 73 (Saw Mill Place); CH Bf 166 (Pinefield), CH Bf 167 (Gardiner Road), and CH Ce 66 (White Plains Regional Park).

LITHOLOGIC DESCRIPTIONS

Descriptive lithologic logs of drill cuttings were recorded by MGS geologists on site (app. B). Samples were washed on site using a 250-micron sieve, examined with a hand lens, and described. Selected samples were later examined in detail in the laboratory using a binocular microscope. Samples from the Patuxent aquifer system were then dried, bagged, and archived. Sample intervals of similar lithology were grouped together when compiling the descriptive logs in order to more easily recognize gross changes in sediment type.

There are several potential sources of error in collecting representative sediment samples from drilling fluid that become more pronounced as drilling depth increases. Much of the clayey material was likely pulverized by the drill bit and entrained in the drilling fluid, and is therefore underrepresented in the sediment samples. It is also likely that many of the sediment samples were partially contaminated with up-hole material as a result of agitation and turbulence in the fluid-filled borehole, and recirculation of sediment in the fluid through the mud pump. In particular, glauconite grains (and to a lesser extent shell fragments) were present in many of the samples; however, glauconite has not been documented in the Magothy or Potomac Group Formations in outcrops or core holes in Maryland. It is likely that the occurrence of glauconite and shell fragments in samples from these formations is a result of recirculation and contamination from shallower intervals (particularly the Aquia and Piney Point Formations) where glauconite is common. For these reasons, drill cuttings, no matter how carefully collected and described, are not fully representative of *in situ* sediment materials, and should be used only as a gross indicator of lithology.

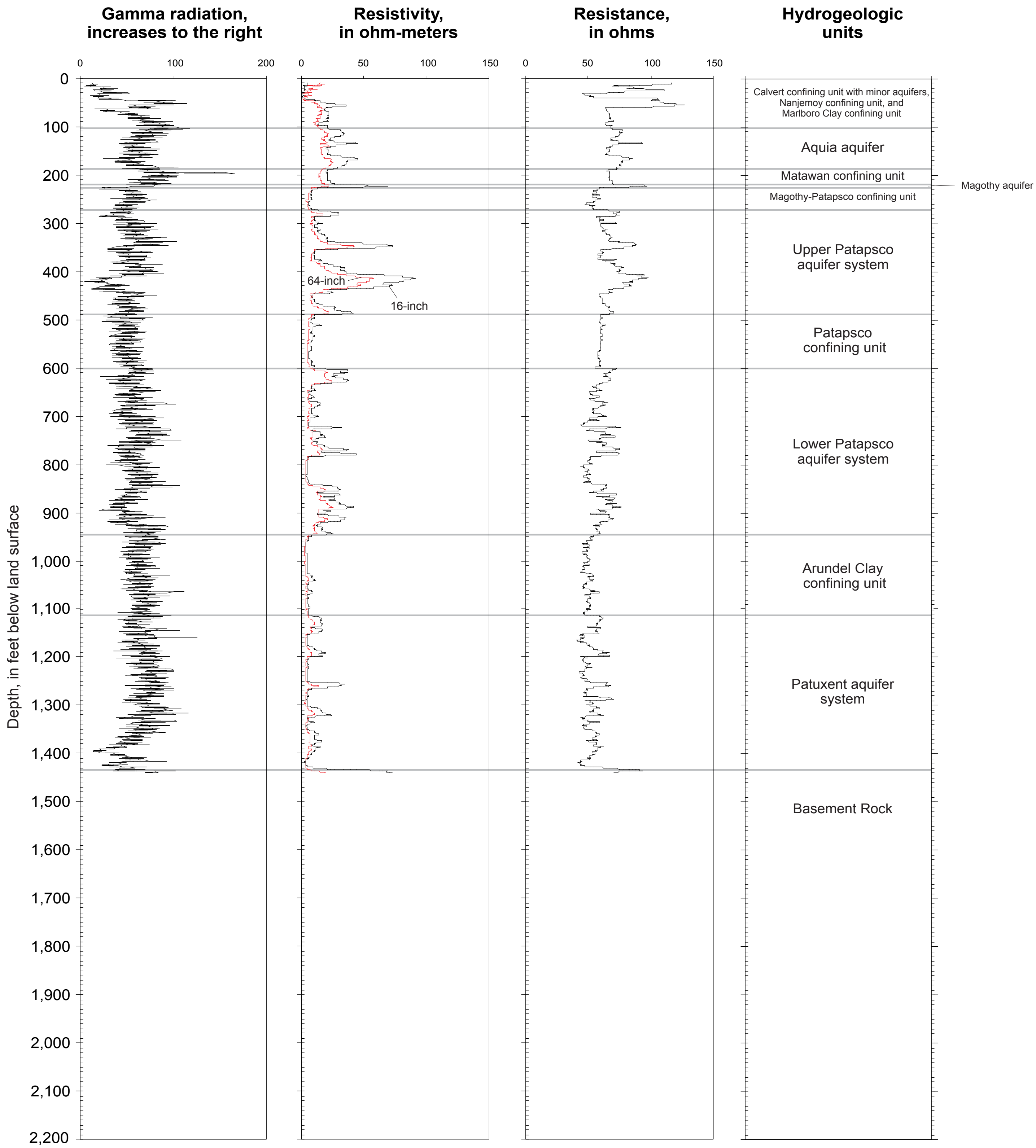


Figure 4a. Borehole geophysical logs of test well CH Be 73, at Saw Mill Place.

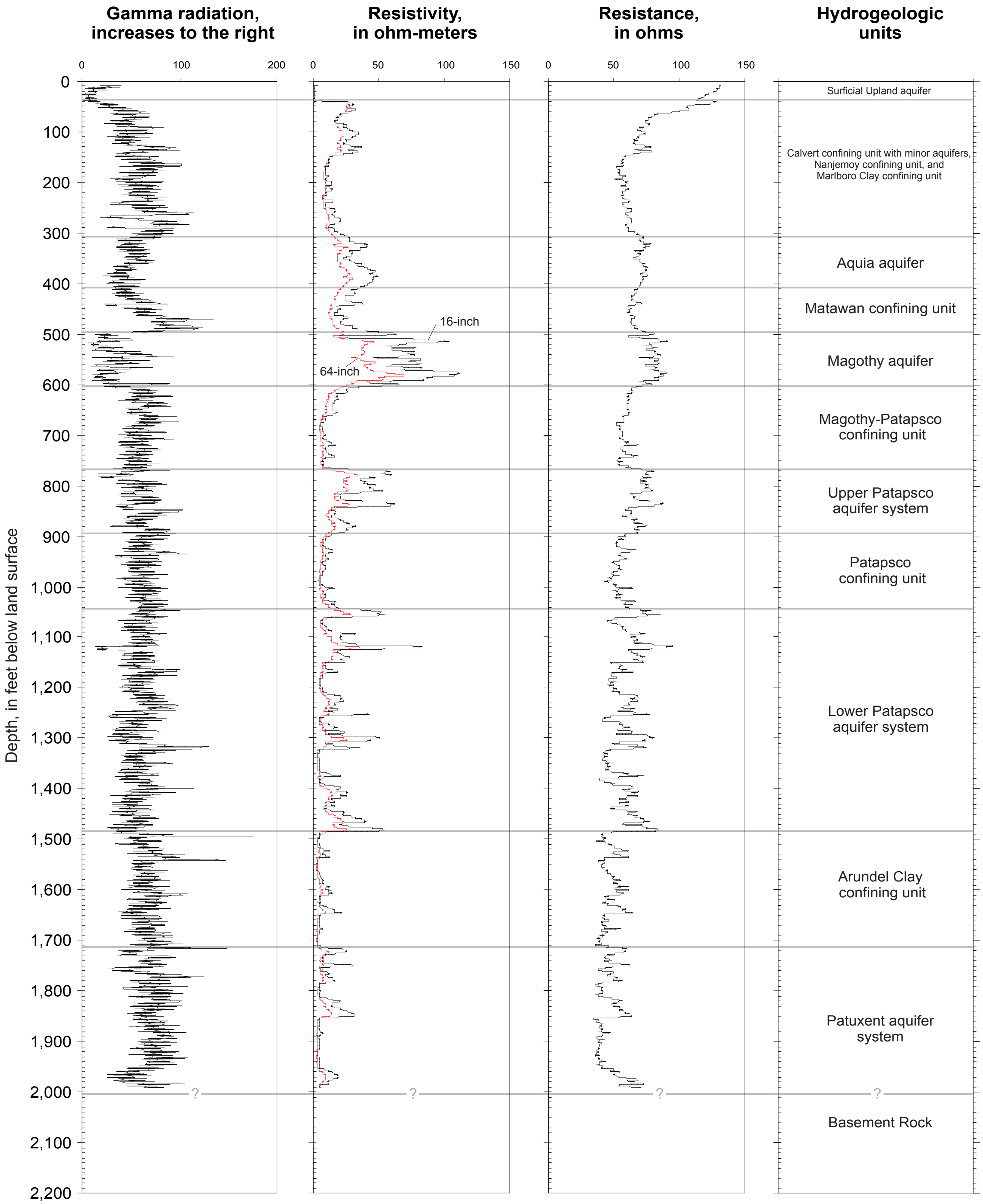


Figure 4b. Borehole geophysical logs of test well CH Bf 166, at Pinefield.

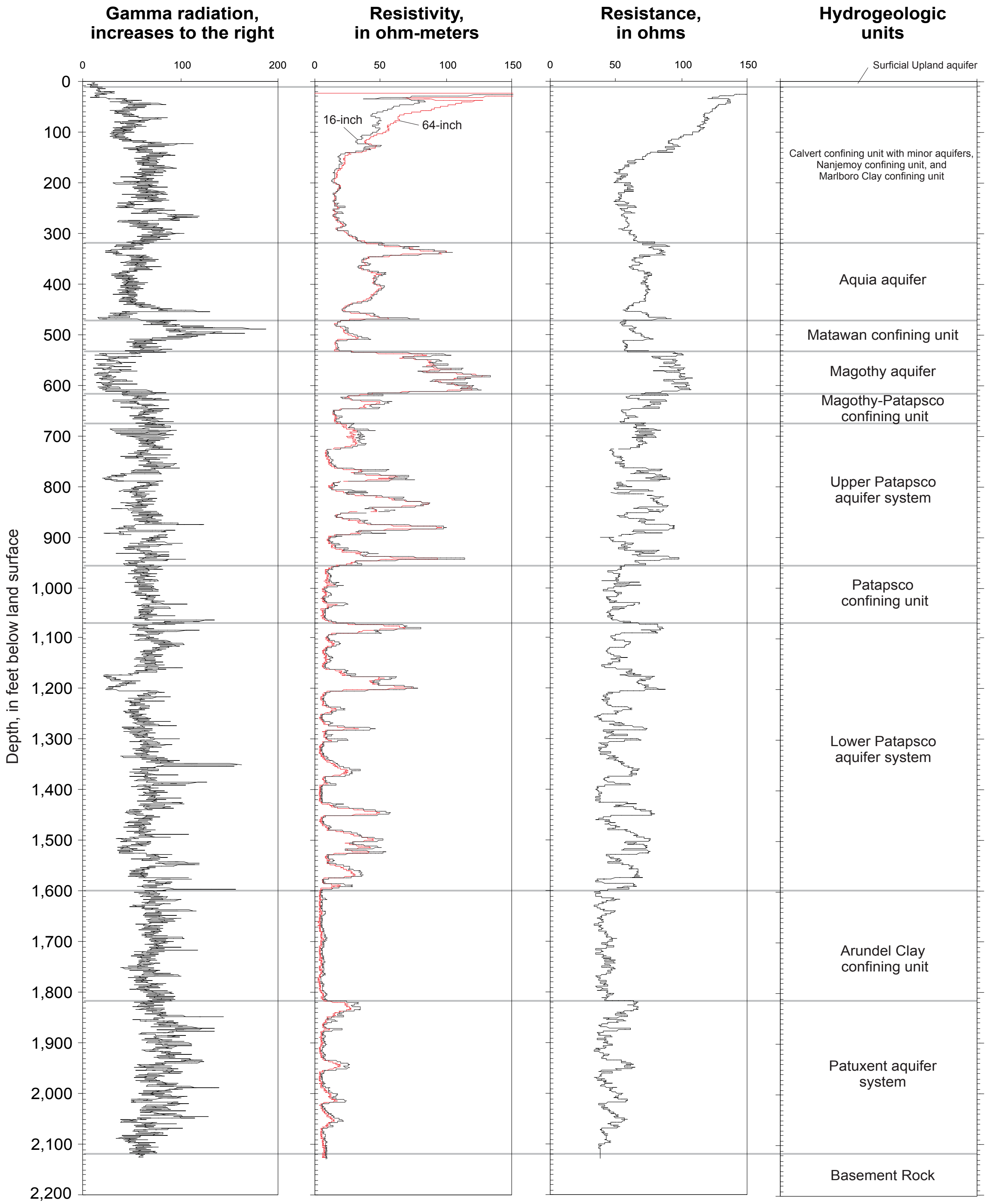


Figure 4c. Borehole geophysical logs of test well CH Bf 167, at Gardiner Road.

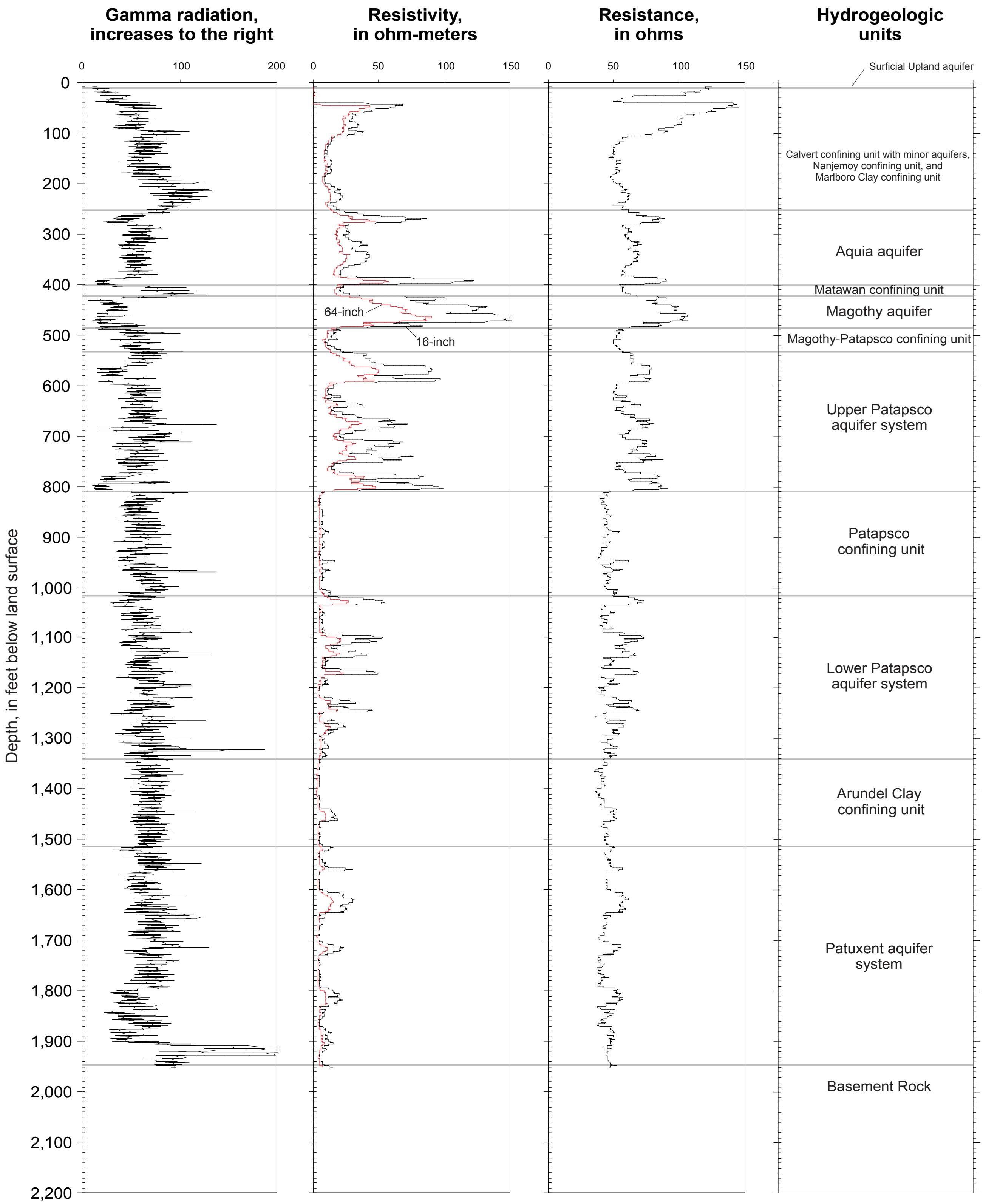


Figure 4d. Borehole geophysical logs of test well CH Ce 66, at White Plains Regional Park.

GEOPHYSICAL LOGS

Geophysical logging was performed in the uncased boreholes after they were drilled to final depth. Geophysical logs (figs. 4a - 4d) include natural gamma, multi-point resistivity (including 8-in., 16-in., 32-in., and 64-in. electrode spacings), and single-point resistance. The geophysical logs for wells CH Be 73, CH Bf 166, and CH Ce 66 were run by A. C. Schultes of New Jersey. The geophysical log for well CH Bf 167 was run by Earth Data, Inc.

The gamma log for well CH Ce 66 shows an unusually high value (greater than 500 counts per second) through the 1,915-1,920-ft depth interval (fig. 4d). The presence of the gamma anomaly was confirmed by an additional gamma log run by the USGS MD-DE-DC Water Science Center. The source of the high radioactivity is likely attributed to gamma-emitting minerals in the clayey saprolite overlying the basement rock.

Geophysical logs were used in concert with lithologic cuttings to determine generalized sediment types in the boreholes. Gamma radiation generally is higher in clays and silts, and lower in sands and gravels; resistivity and resistance generally are lower in clays and silts, and higher in sands and gravels. Geophysical logs were also used to determine the most promising coarse-grained sand intervals for screen placement in the test wells. Additionally, the logs were used in conjunction with geophysical logs from other boreholes in the region for stratigraphic correlation and for sand-percentage and sand-thickness estimates.

HYDROGEOLOGY

HYDROGEOLOGIC FRAMEWORK

This study is primarily focused on the deepest unconsolidated Coastal Plain deposits which form the Lower Cretaceous Potomac Group, consisting of the Patuxent, Arundel Clay, and Patapsco Formations. Aquifers and confining units penetrated by the test wells are shown in the generalized hydrostratigraphic chart (tab. 1). In particular, this report details the investigation of the hydrogeology of the Arundel Formation, the Patuxent Formation, and the underlying consolidated basement rock in the study area. Descriptions of the overlying Patapsco Formation and other younger formations are presented in Wilson and Fleck (1990) and Drummond (2007).

Hydrogeologic cross sections, which include borehole geophysical data and interpreted hydrostratigraphic contacts, were constructed along three transects through the study area (location map and transects are shown in figs. 5-8). The cross sections utilized well-construction and borehole geophysical information from the project test wells (app. A) in addition to regional boreholes (app. C). Overall, the cross sections illustrate the high degree of complexity and heterogeneity of the hydrogeologic units throughout the study area. Correlation of individual sand or clay units in the Potomac Group is problematic, though aquifer systems or confining units can be broadly grouped according to the dominant sediment texture. The aquifer systems and confining units generally correspond to sandy and clayey zones, respectively.

Faulting is likely to influence the structure of the Lower Potomac Group sediments in Charles County, as first described by Jacobeen (1972). A significant system of *en echelon*, east-dipping, high-angle, reverse faults – the Brandywine fault system – runs through the northern part of Charles County into southern Prince George’s County. The total offset of the fault could be as much as 250 ft and this displacement extends at least to the top of the Arundel Formation. Though the data available for this report was not sufficient to delineate the fault through the hydrogeologic units, its approximate location is included on the cross sections, as well as the structure-contour and thickness maps presented later in this report.

Arundel Clay Confining Unit

The Arundel Clay confining unit in the Waldorf area consists of a generally massive section of dense clays and clayey silts of the Lower Cretaceous Arundel Formation and adjacent clays in the Patapsco and Patuxent Formations (Andreasen and others, 2013). These sediments represent a prolonged period of deposition during which fine-grained overbank and floodplain deposits dominated and channel and point-bar sand deposits were quite rare. Overall, the composition of the unit is

Table 1. Rock-stratigraphic and hydrostratigraphic units underlying north-central Charles County, Maryland (modified from Andreasen and others, 2013).

System		Series	Rock-stratigraphic units		Hydrostratigraphic units
Quaternary		Holocene and Pleistocene	Lowland deposits		Minor local aquifer
Tertiary	Neogene	Pliocene (?)	Upland deposits		Surficial Upland aquifer
		Miocene	Chesapeake Group (Calvert, Choptank, and St. Marys Formation undivided)		Calvert aquifer system (minor aquifer)
					Calvert confining unit
	Paleogene	Eocene	Pamunkey Group	Piney Point Formation	Nanjemoy confining unit
				Nanjemoy Formation	
		?		Marlboro Clay	Marlboro Clay confining unit
		Paleocene		Aquia Formation	Aquia aquifer
				Brightseat Formation	Matawan confining unit
Cretaceous		Upper Cretaceous	Severn Formation		
			Matawan Formation		
			Magothy Formation		Magothy aquifer
		?	Potomac Group	Patapsco Formation	Magothy-Patapsco confining unit
					Upper Patapsco aquifer system
					Patapsco confining unit
					Lower Patapsco aquifer system
		Lower Cretaceous		Arundel Formation	Arundel Clay confining unit
				Patuxent Formation	Patuxent aquifer system
Basement complex consisting of undifferentiated crystalline and sedimentary rocks ranging from Precambrian (?) to Jurassic (?) age					

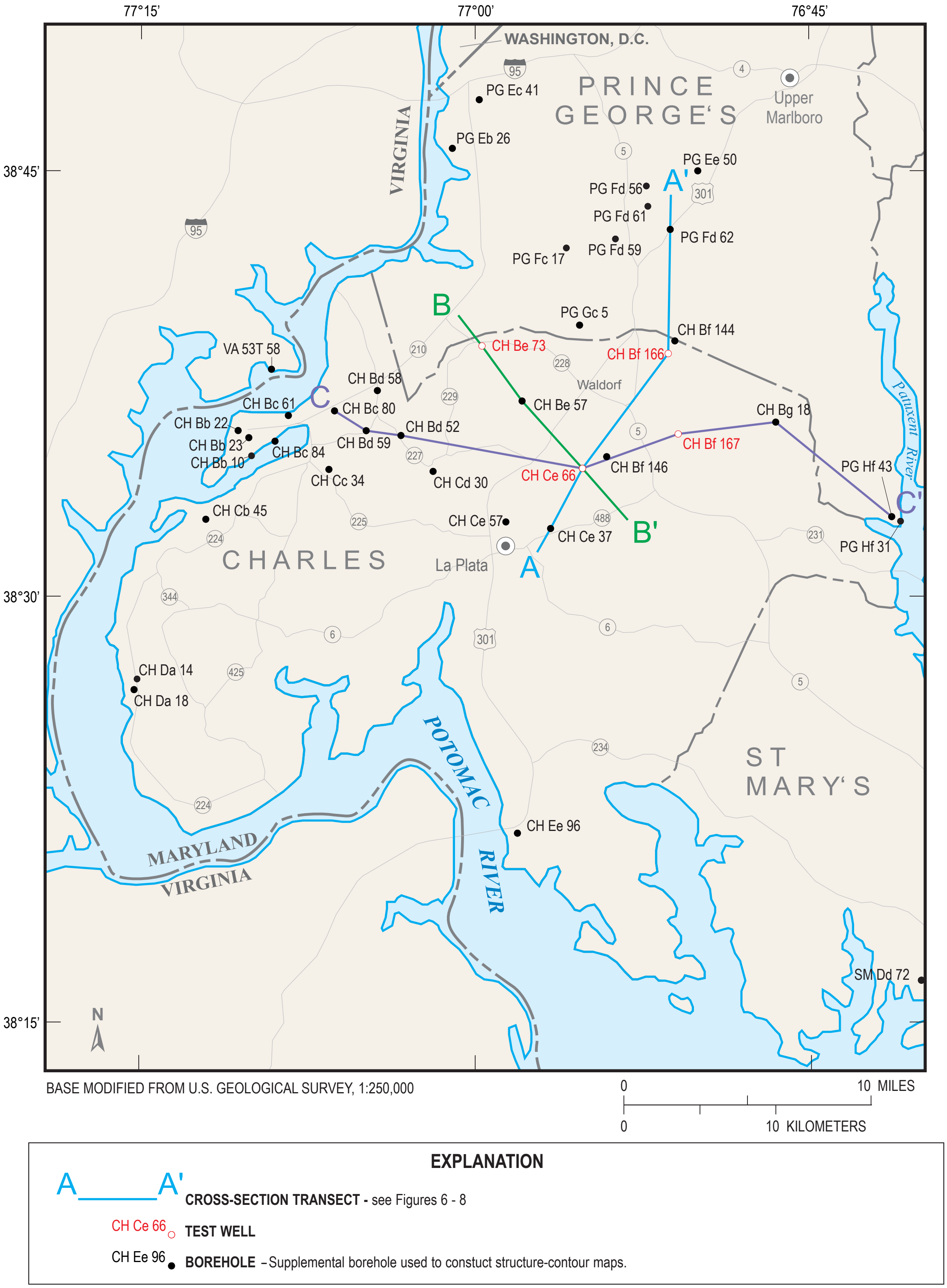


Figure 5. Locations of test wells and supplemental boreholes used to construct cross sections, structure-contour maps, and thickness maps.

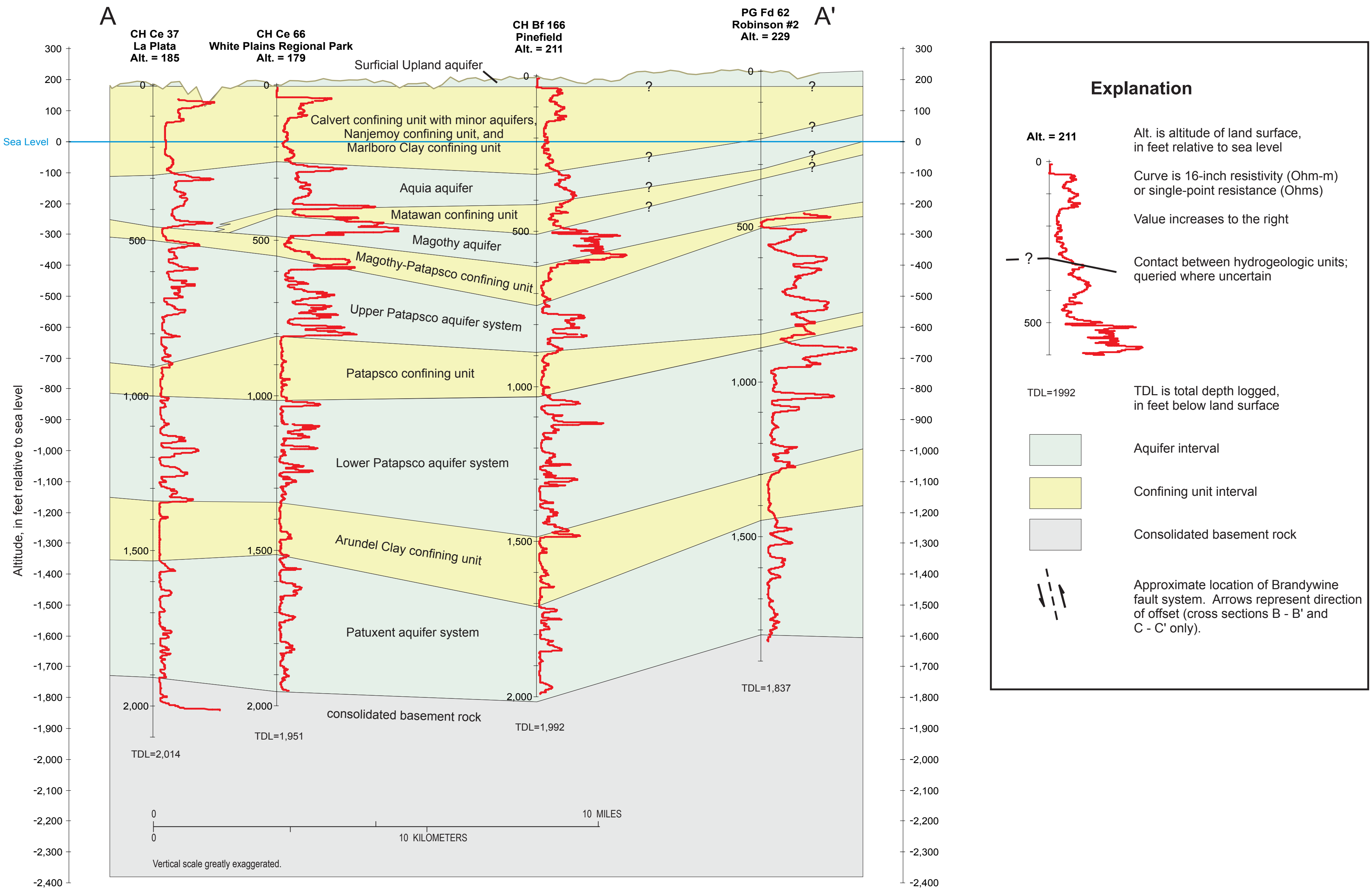


Figure 6. Hydrogeologic cross section A – A', extending from La Plata, Charles County to southern Prince George's County. Location of cross section shown in Figure 5.

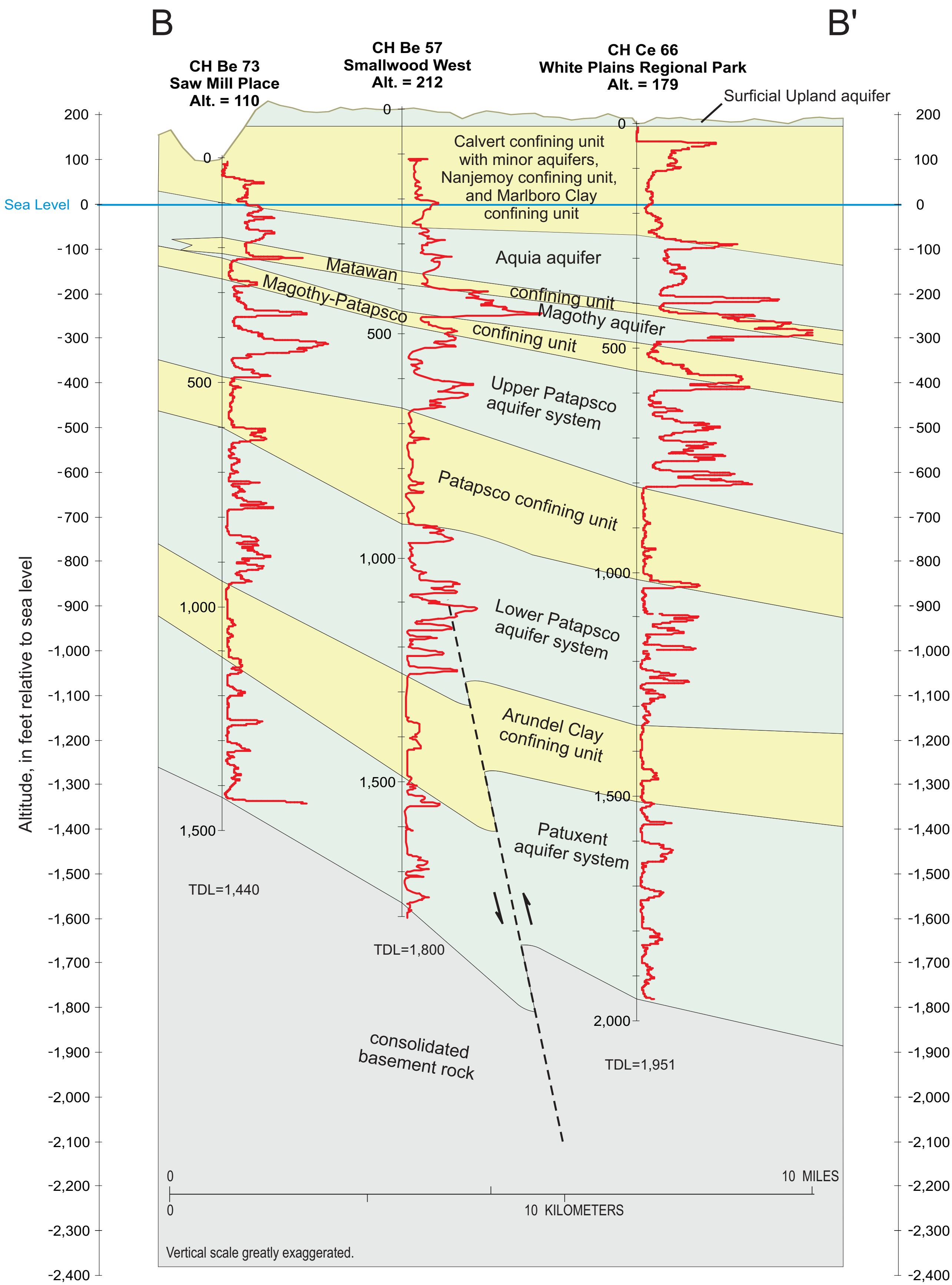


Figure 7. Hydrogeologic cross section B – B', extending from southern Prince George's County to White Plains, Charles County. See Figure 6 for explanation. Location of cross section shown in Figure 5.

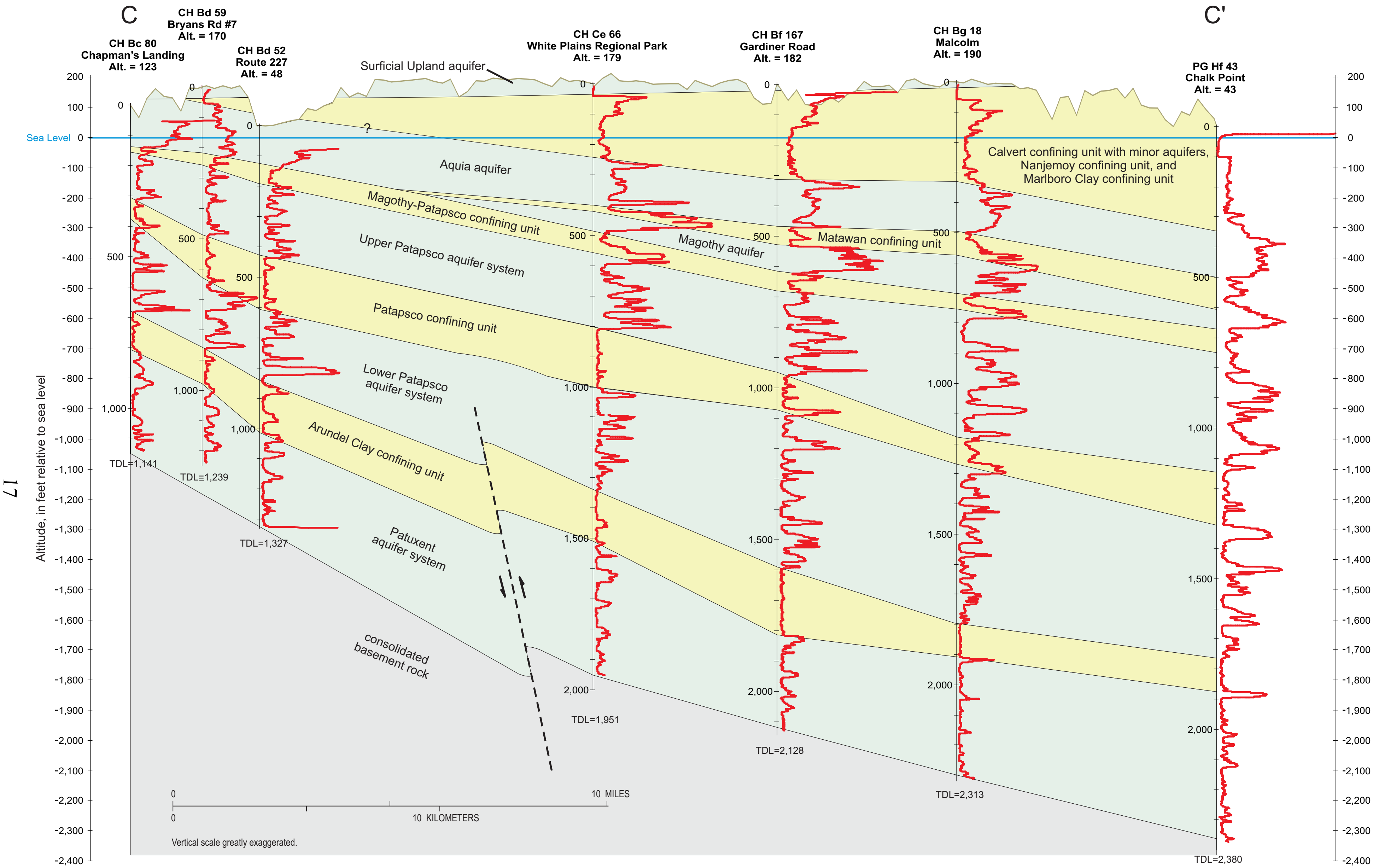


Figure 8. Hydrogeologic cross section C – C', extending from Chapman's Landing, Charles County to Chalk Point, Prince George's County. See Figure 6 for explanation. Location of cross section shown in Figure 5.

lithologically similar to other units of the Potomac Group, with the major distinction being the relative dominance of fine-grained sediment. The unit can be correlated throughout the study area, and is recognizable on geophysical logs as a predictable interval of low resistivity (figs. 6–8). The Arundel Clay confining unit is not traceable to the south in Virginia, however, where subdivisions within the Potomac Group become unrecognizable (McFarland and Bruce, 2006).

The Arundel Clay confining unit outcrops along the western bank of the Potomac River in Virginia. The top of the Arundel Clay confining unit slopes gently to the east beneath Charles County at approximately 60 ft per mile (ft/mi.) (fig. 9). Its thickness ranges from 40 ft in the western portions of the county, to as much as 230 ft in the Waldorf area (fig. 10). Jacobeen (1972) has shown evidence that the Brandywine fault exhibits offset of the Coastal Plain sediments at least to the top of the Arundel Formation in the Waldorf area. It is uncertain how the presence of the fault affects the groundwater-flow system and the integrity of the Arundel Clay confining unit.

Geologist's logs of the Arundel Clay deposits (app. B) show a thick section of tough, dense clays and silts. The drillers reported slowed progress when drilling through this interval at all test-well sites. The clays are predominantly dark gray to brown and red, but may also occur in variegated colors including olive, tan, yellow, and white. Clays within the Arundel Clay commonly contain lignite and tough, indurated layers of siderite. There are interbedded lenses of sand within the Arundel Clay confining unit, some of which may have potential to yield water. In the test wells, however, sands within the Arundel Clay confining unit section comprised on average only about 15 percent of the total thickness, indicating that the sand bodies' limited connection to a broader flow system would likely reduce its potential for development. In the study area, its substantial thickness and low permeability is such that it forms an effective barrier to groundwater flow into and out of the upper layers of the Patuxent aquifer system.

Patuxent Aquifer System

The Patuxent aquifer system is the deepest unit of predominantly sandy sediments within the Lower Cretaceous Potomac Group deposits. It is recognizable as a distinct regional hydrostratigraphic unit throughout central and southern Maryland, but merges with the other Potomac Group aquifer units in the Virginia Coastal Plain where the Arundel Clay confining unit is absent (McFarland and Bruce, 2006: McFarland, 2013). In the study area it is a recognizable package of sediments bounded on the top by the Arundel Clay confining unit and on the bottom by the consolidated basement rock (figs. 6–8).

The Patuxent Formation sediments in the study area were deposited by mature meandering river systems during the Early Cretaceous period (fig. 11). Channel and point-bar deposits created lensoidal sand layers while fine-grained overbank and floodplain deposits created the internal confining units. The distribution of sands and clays in the Patuxent Formation is such that multiple layers of aquifer sands (six to nine layers in the test wells) are interlayered and separated by multiple internal confining units (figs. 6–8), all of which function hydraulically as a single interconnected aquifer. This is the primary reason the Patuxent aquifer has been classified as an aquifer system, as have the Upper and Lower Patapsco aquifers (Andreasen and others, 2013). Sediments comprising the Patuxent aquifer system in Anne Arundel and northern Prince George's Counties were deposited near the axis of the ancient depositional basin by higher-energy, braided rivers which contributed both a higher percentage of laterally extensive sands as well as generally coarser sands as compared to the lower-energy, meandering rivers that were present in southern Maryland, including the Waldorf area (Hansen, 1969; 1971).

Geologist's logs of the Patuxent Formation (app. B) show extensive and unpredictable lithologic variability. The aquifer system in the study area, in fact, contains dominant clay and silt proportions overall, both intermixed and interlayered with the aquifer sands. Fine-grained sediments exhibit a wide range of textures and colors, with colors ranging from dark gray and brick red to yellow and white. Sands range from fine to coarse, and vary in color from gray to reddish-brown. Sands are predominantly iron-stained quartz grains, but include a wide variety of accessory grains, and some cemented intervals.

The top of the Patuxent aquifer system is defined as the first occurrence of sand below the predominantly massive clays of the Arundel Clay confining unit. Due to the highly variable nature of the fluvial deposition of the unit, the top sand may occur at different altitudes even over very short lateral distances (fig. 12). The surface of the Patuxent aquifer system slopes gently to the east at

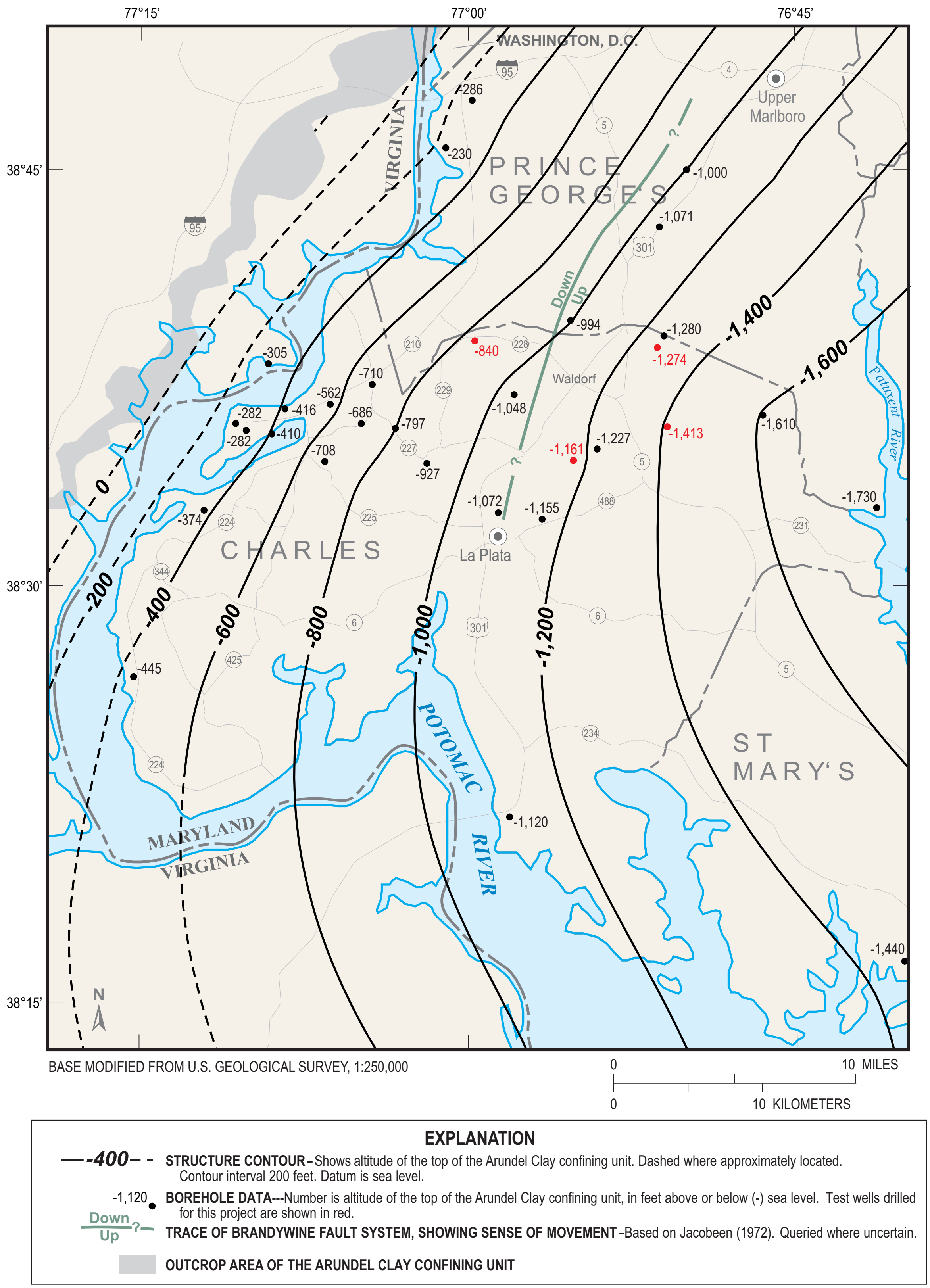
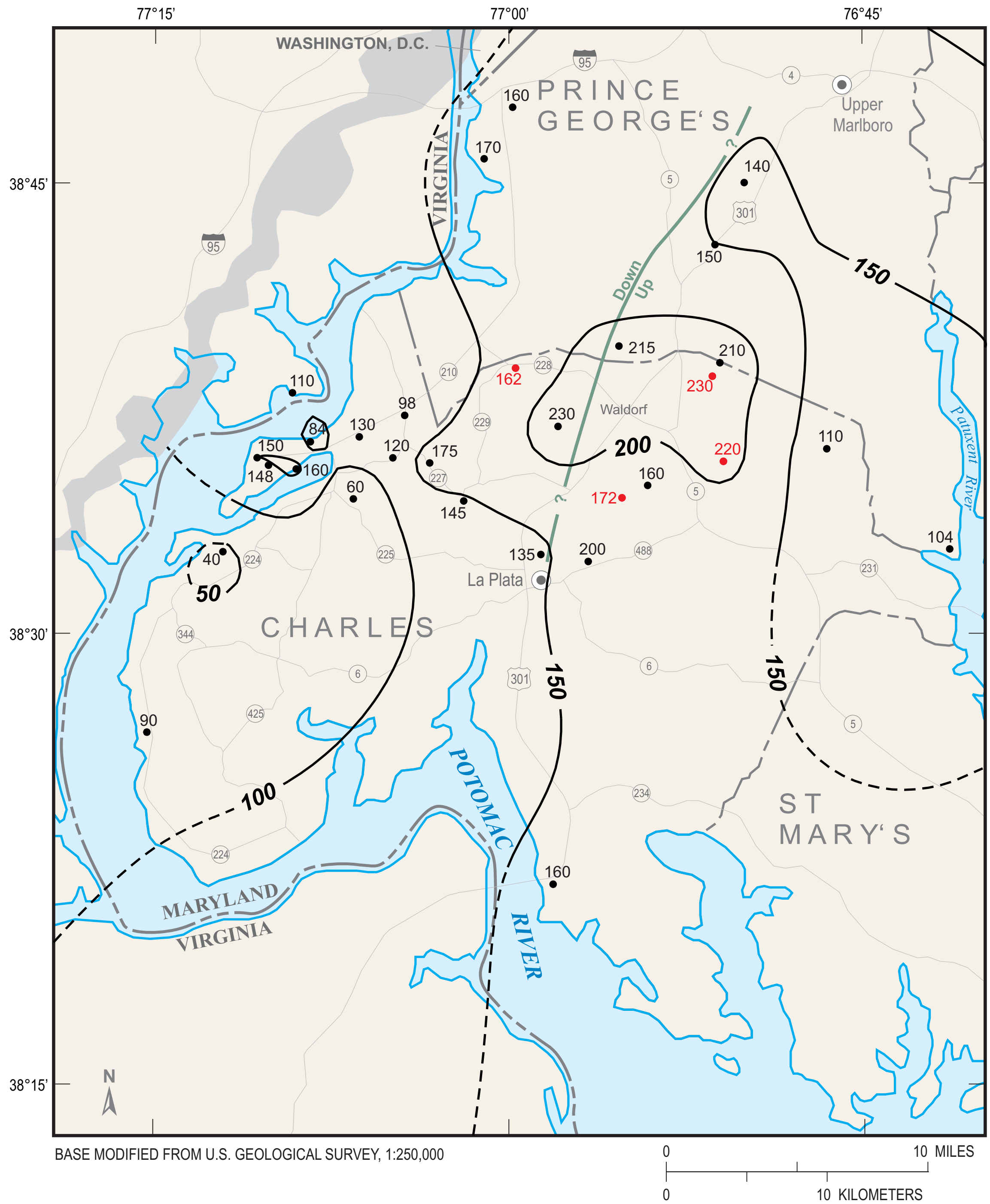


Figure 9. Altitude of the top of the Arundel Clay confining unit.



EXPLANATION

—150– – **LINE OF EQUAL CONFINING UNIT THICKNESS**– Contour interval 50 feet. Dashed where approximately located.

160 • **BOREHOLE DATA**–Number is thickness of the Arundel Clay confining unit, in feet. Test wells drilled for this project are shown in red.

Down/Up ? **TRACE OF BRANDYWINE FAULT SYSTEM, SHOWING SENSE OF MOVEMENT**---Based on Jacobeen (1972). Queried where uncertain.

OUTCROP AREA OF THE ARUNDEL CLAY CONFINING UNIT

Figure 10. Thickness of the Arundel Clay confining unit.

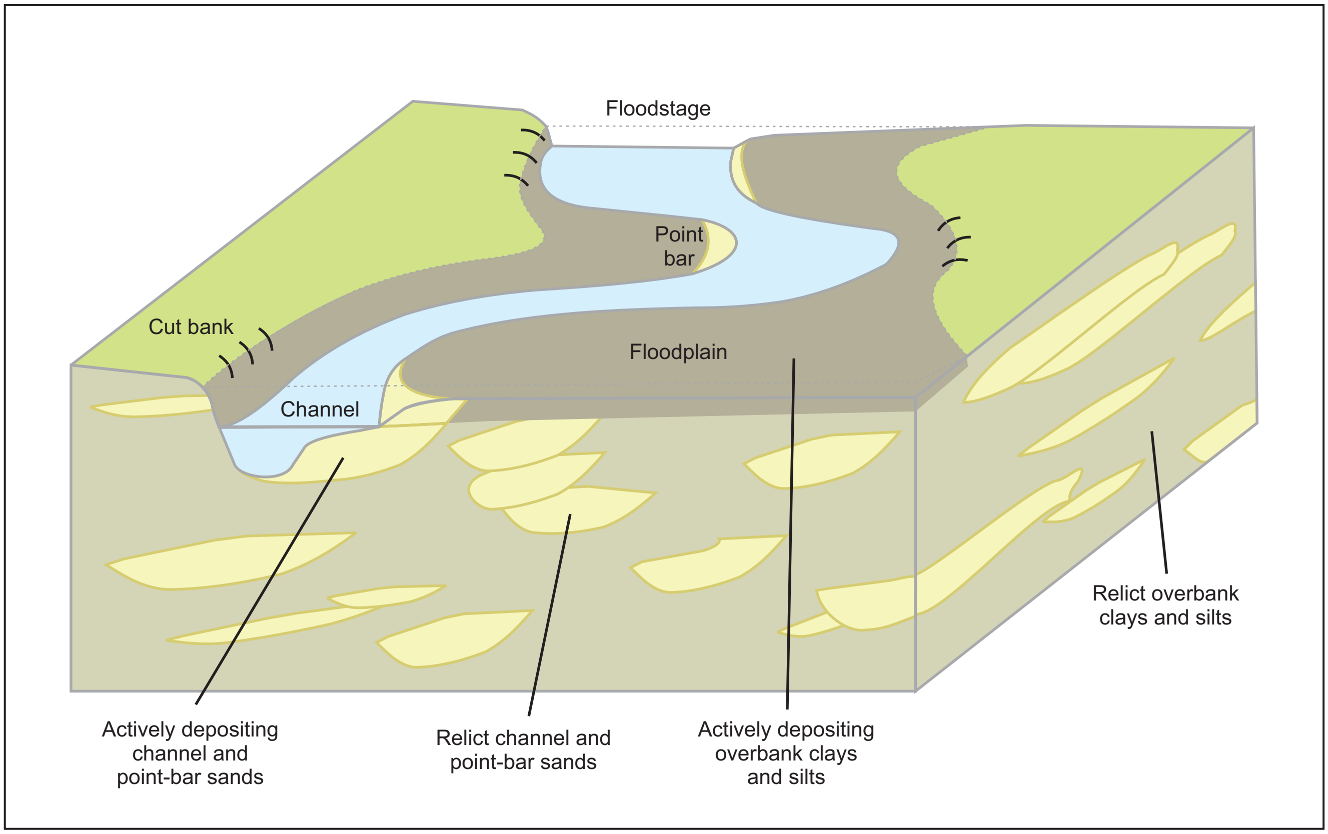


Figure 11. Generalized depositional environment of the Patuxent aquifer system in the study area (modified from McFarland, 2013).

approximately 50 ft/mi. (fig. 13). The Patuxent aquifer system outcrops along the inner edge of the Fall Line in Virginia, and its top ranges in depth from approximately 300 ft below sea level along the Potomac River near Stump Neck on the western margin of the county to approximately 1,800 ft below sea level at Benedict on the eastern margin of the county. Cumulative thickness of the Patuxent aquifer system is variable, but generally increases from west to east, ranging from 115 ft at Douglas Point to approximately 500 ft near Benedict (fig. 14). Cumulative thickness of the Patuxent aquifer system in the Waldorf area test wells ranges from approximately 300 to 440 ft. The base of the aquifer system is defined as the lowest permeable sands above the weathered or unweathered consolidated basement rock. Altitude of the base of the aquifer system shows variation similar to the top, with additional variation caused by relief of and faulting in the consolidated basement rock. It is unclear whether the presence of the fault system affects the groundwater-flow system in the study area.

The sand percentage of an aquifer system is a good indicator of hydraulic connectivity of individual sand bodies within the system, which in turn influences the overall water-supply potential of the aquifer system. Sand percentage was determined by analyzing the borehole resistivity log data from wells that penetrated the aquifer system (fig. 15). Resistivity logs generally show increasing values through intervals of sand and gravel, and decreasing values through intervals of clay and silt. These trends can be confirmed with lithological descriptions of the drill cuttings from depth intervals of interest. Sand percentages were calculated using the inflection method of Lynch (1962) for multi-point resistivity logs, and thicknesses of individual beds were corrected for bed-thickness effects (Keys and MacCary, 1971). Logs that partially penetrated hydrogeologic units were included if they penetrated at least 75 percent of the unit. This method may underestimate total sand thickness of some layers because the resistivity deflection disappears or reverses for sand beds thinner than the tool electrode spacing (1.3 ft for the 16-in. tool and 5.3 ft for the 64-in. tool [Keys and MacCary, 1971]).

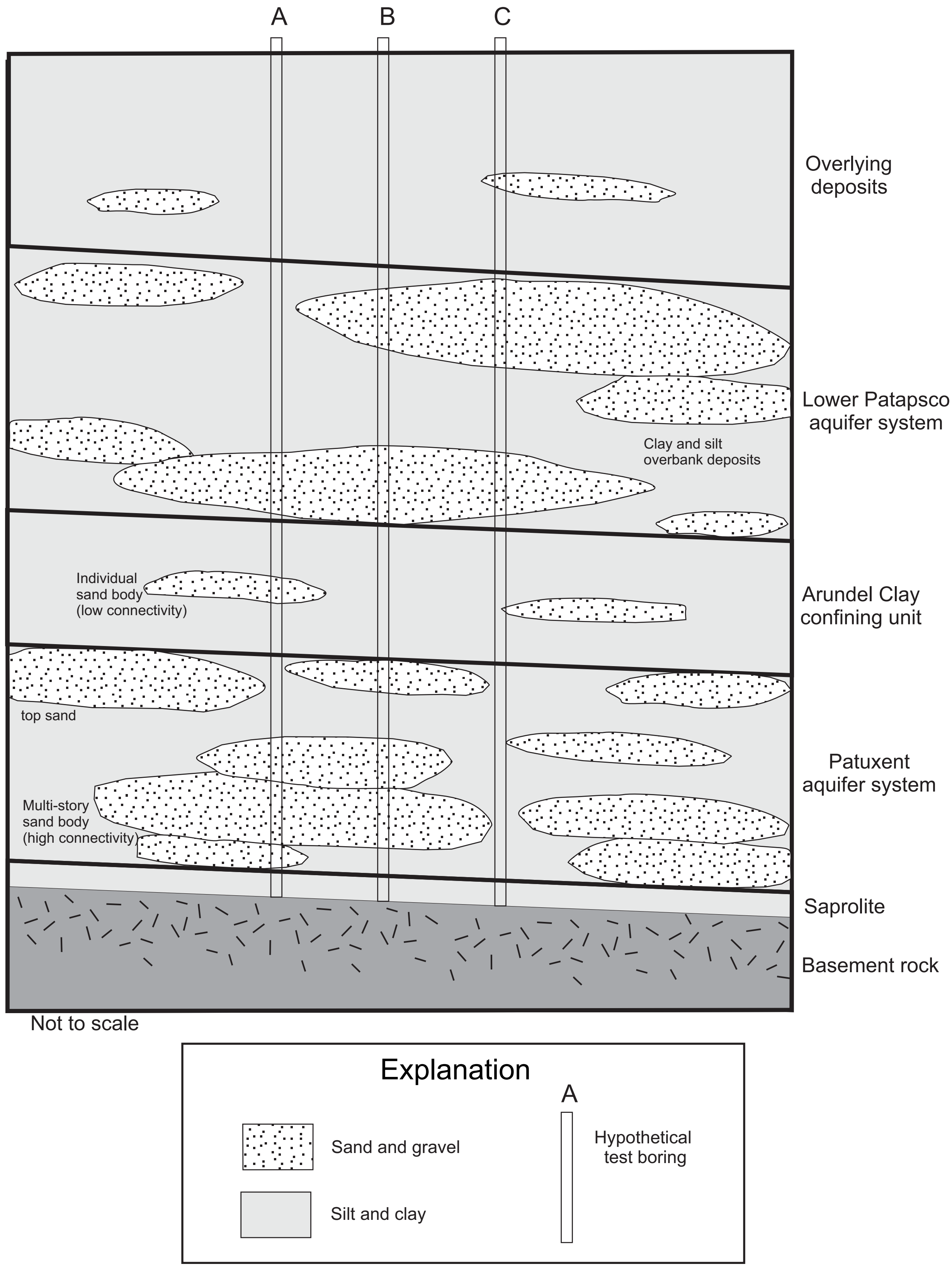
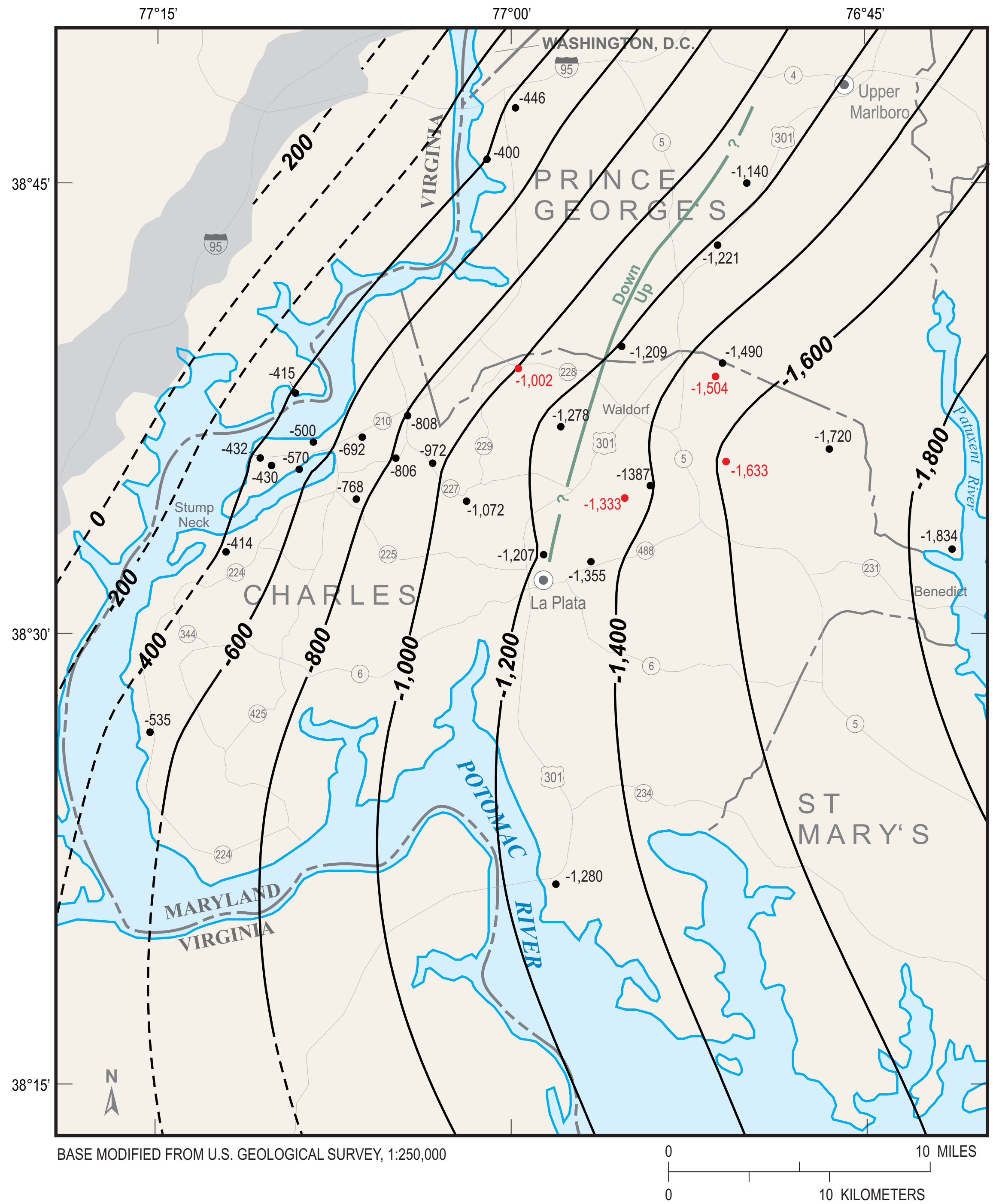


Figure 12. Conceptual cross section showing individual sand bodies in the Potomac Group (modified from Drummond, 2007).



EXPLANATION

—-600– – **STRUCTURE CONTOUR**–Shows altitude of the top of the Patuxent aquifer system. Dashed where approximately located. Contour interval 200 feet. Datum is sea level.

-1,280 • **BOREHOLE DATA**---Number is altitude of the top of the Patuxent aquifer system, in feet above or below (-) sea level. Test wells drilled for this project are shown in red.

Down/Up ?– **TRACE OF BRANDYWINE FAULT SYSTEM, SHOWING SENSE OF MOVEMENT**–Based on Jacobeen (1972). Queried where uncertain.

OUTCROP AREA OF THE PATUXENT AQUIFER SYSTEM

Figure 13. Altitude of the top of the Patuxent aquifer system.

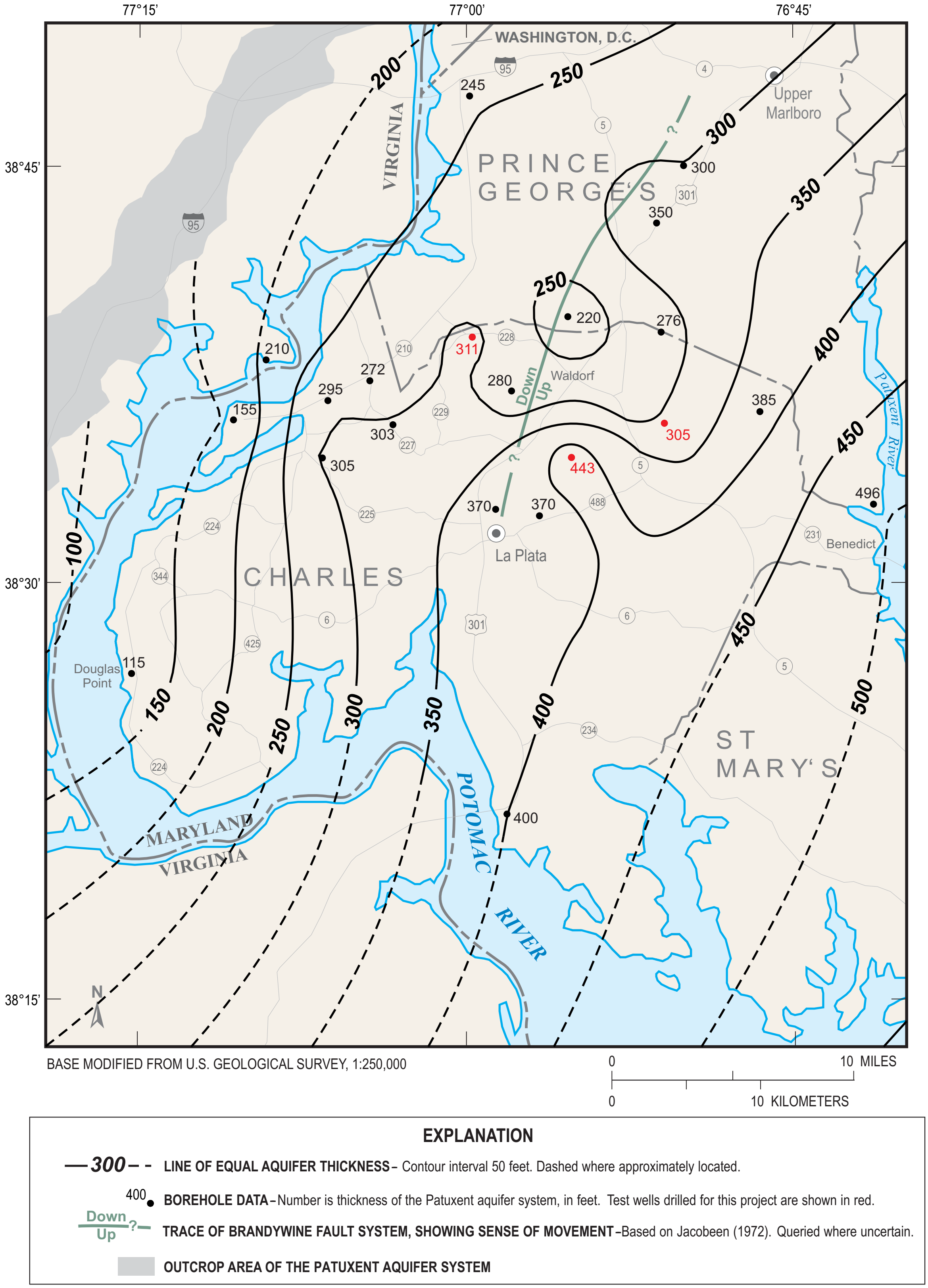
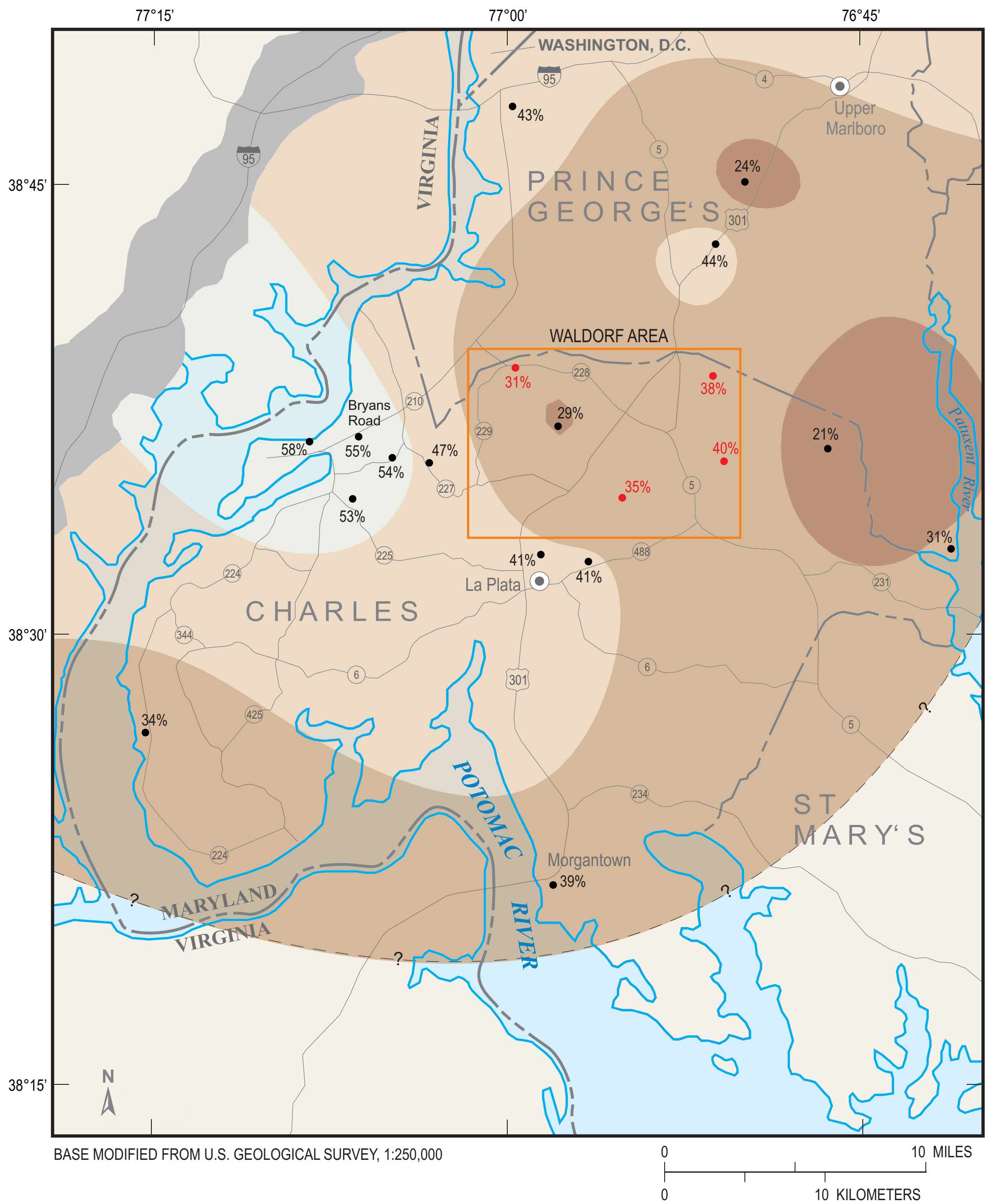


Figure 14. Thickness of the Patuxent aquifer system.



EXPLANATION

OUTCROP AREA OF THE PATUXENT AQUIFER SYSTEM–Aquifer is in the Patuxent Formation of Early Cretaceous age.

21-30% sand | 31-40% sand | 41-50% sand | 51-60% sand | %, percent. Queried where uncertain.

39% **BOREHOLE DATA**–Number is percent (%) of total thickness of the Patuxent aquifer system logged as sand. Test wells drilled for this project in red.

Figure 15. Sand percentage of the Patuxent aquifer system.

Sands comprise only 30 to 40 percent of the total thickness of the Patuxent aquifer system in most of the study area. In the four test wells, for an average of 330 ft of total sediment, only 115 ft is comprised of sands coarse enough to act as an aquifer. There are, on average, seven sandy intervals within the entire thickness of sediments. The average thickness of an individual sandy interval within the Patuxent aquifer system in the four test wells is approximately 16 ft. In contrast, Patuxent aquifer system sands comprise 50 to 60 percent of the total thickness of sediments in the Bryans Road region, and about 60 percent of the total thickness of sediments in northern Prince George's and Anne Arundel Counties (figs. 15 and 16). In general, individual sands within the Patuxent aquifer system in the Waldorf area are thinner, finer-grained, and less frequent as compared to the Patuxent aquifer system to the west at Bryans Road and to the north in Prince George's and Anne Arundel Counties.

Basement Rocks

Consolidated basement rock underlies the unconsolidated Coastal Plain sediments in the study area. The structural surface of the basement rock trends southeasterly, dipping at about 60 ft/mi throughout the study area (fig. 17). The structure contours exhibit regional trends of strike and dip implying apparent local-scale offsets which are shown as interruptions in the contours along the Brandywine fault zone. The age of the bedrock ranges from Precambrian to Jurassic. The basement, as determined primarily from drill cuttings of boreholes in the study area, consists of gneissic or granitic rocks of unknown age and consolidated red sandstones and shales of Triassic to Jurassic age (Hansen and Edwards, 1986). A layer of several feet of weathered clay residuum, called saprolite, may or may not be present above the top of the consolidated basement rock. The Brandywine area is considered to be near the northwestern boundary of an upfaulted, buried rift basin containing red consolidated Triassic sandstone and shale (Hansen and Edwards, 1986), the total thickness of which is unknown. In the study area, gneissic and granitic rocks are found in drill cuttings to the west of the fault system, while red and gray shales and sandstones are found to the east of the fault system.

Basement-rock cuttings were recovered from three of the four test wells drilled for this project (app. B). The only test well west of the Brandywine fault system, CH Be 73 (near Bensville), returned drill cuttings and a bit sample containing clasts of biotite garnet schist, which is consistent with previous descriptions of gneissic and granitic rocks from this area. Drill cuttings of basement rock from wells CH Ce 66 (White Plains Regional Park) and CH Bf 167 (Gardiner Road) contained predominantly red to orange and blue-gray mudstone or siltstone consistent with previous descriptions of Triassic redbeds found to the east of the Brandywine fault system. The borehole for well CH Bf 166 (Pinefield) failed to reach consolidated basement rock.

Very little is known about the hydraulic characteristics of the basement rocks in the study area. Based on limited drill cuttings and the difficult and slow progress when drilling into the upper basement interface, the consolidated basement rock (and its saprolitic cap) appears to be relatively impermeable and is, therefore, considered a confining unit. As such, it would prevent the movement of groundwater to and from the lower interface of the Patuxent aquifer system and is unlikely to have potential for large-scale groundwater production.

AQUIFER TESTS

Aquifer tests were performed on the four test wells drilled during this project to determine hydraulic properties of the Patuxent aquifer system at each location. Each test consisted of a 24-hr pumping phase, followed by a 24-hr recovery phase. During the pumping phase, each well was pumped at a constant rate (50 to 60 gallons per minute [gpm]) using the largest-capacity submersible pump available for a 4-in.- diameter cased well. Discharge was measured with a 4 x 2-in. orifice meter, and checked periodically with a 55-gallon container and stopwatch. Water levels were monitored during the tests using both a hand-held electric water-level meter and a pressure transducer.

Transmissivity is the measure of an aquifer's ability to transmit water. Transmissivity (T) was calculated for each pumped well using the Cooper-Jacob straight-line method, in which drawdown or residual drawdown data is plotted against elapsed time on semi-logarithmic axes (figs. 18a – 18d) (Cooper and Jacob, 1946). This method assumes that the following conditions are met: (1) the aquifer has infinite extent, and is homogeneous and isotropic; (2) well discharge is at a constant rate; (3) the well screen fully penetrates the confined aquifer,

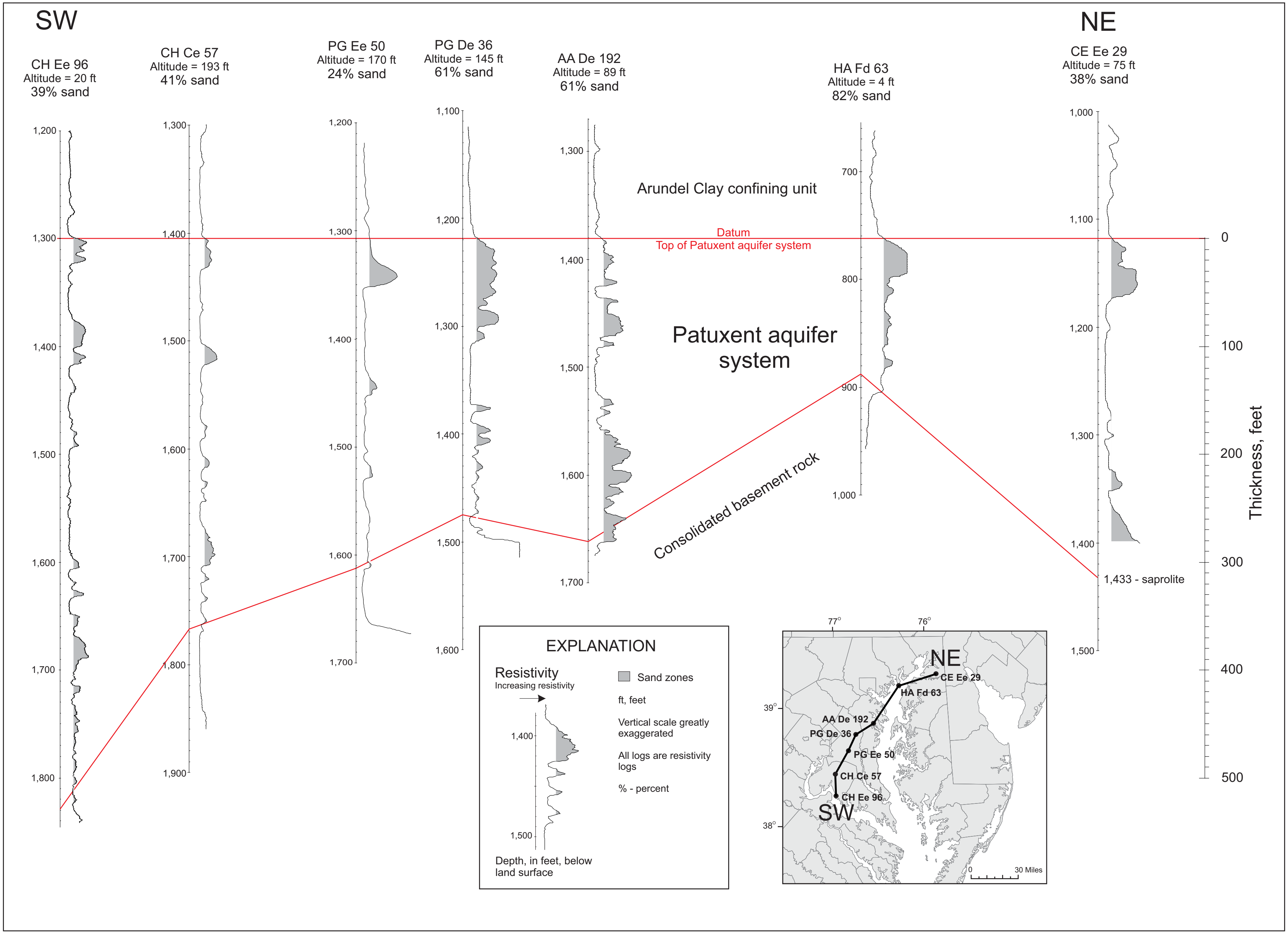
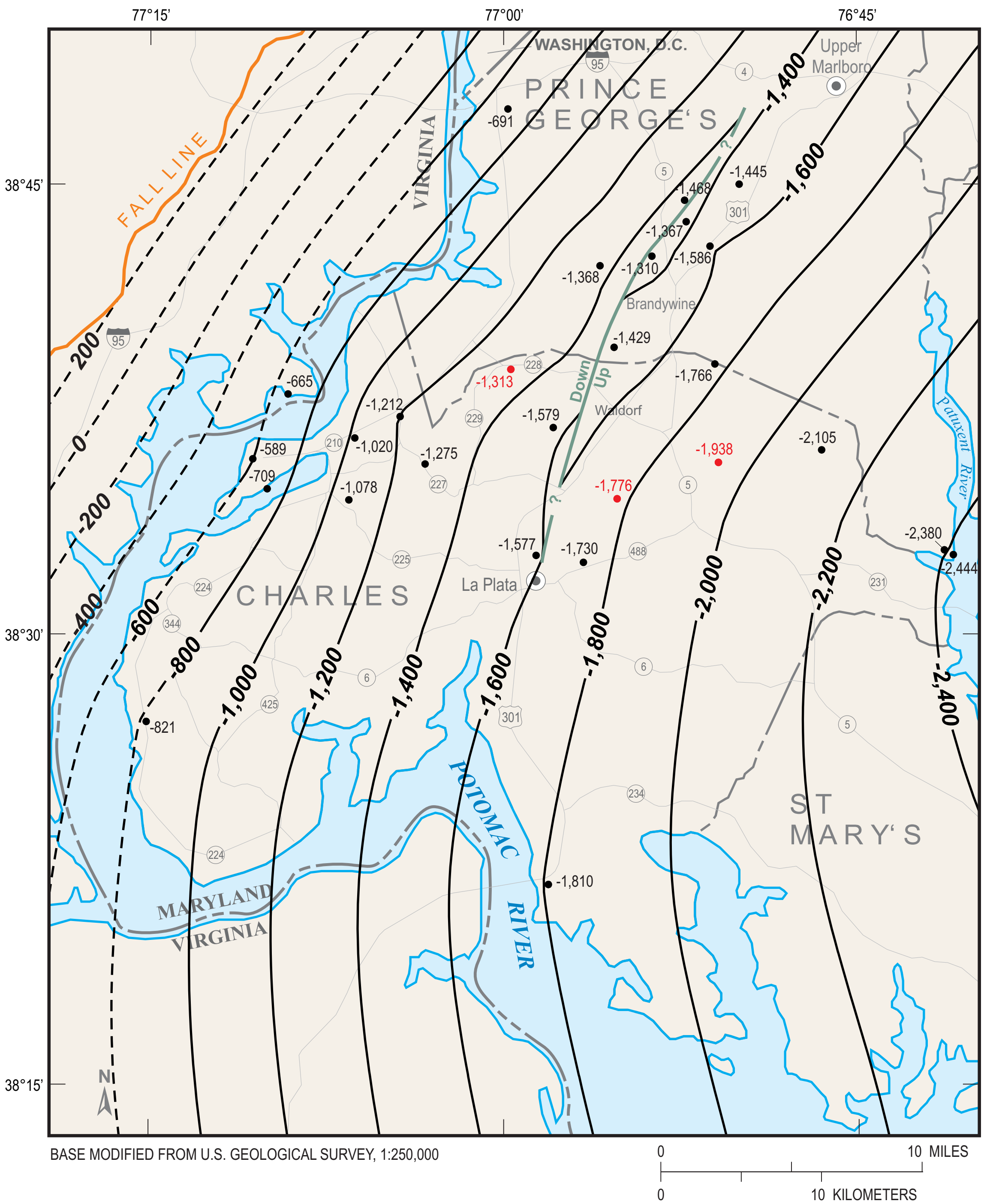


Figure 16. Hydrostratigraphic cross section showing thickness and percent sand content of the Patuxent aquifer system along strike (modified from Andreasen and others, 2013).



EXPLANATION

—-800– – **STRUCTURE CONTOUR**–Shows altitude of the top of the pre-Cretaceous basement rocks. Dashed where approximately located. Contour interval 200 feet. Datum is sea level.

-1,810 • **BOREHOLE DATA**---Number is altitude of the top of the pre-Cretaceous basement rocks, in feet above or below (-) sea level. Test wells drilled for this project are shown in red.

Down/Up ? **TRACE OF BRANDYWINE FAULT SYSTEM, SHOWING SENSE OF MOVEMENT**–Based on Jacobeen (1972). Queried where uncertain.

FALL LINE- Approximate location of the eastern edge of the outcrop of pre-Cretaceous basement rocks.

Figure 17. Altitude of the top of the pre-Cretaceous basement rocks.

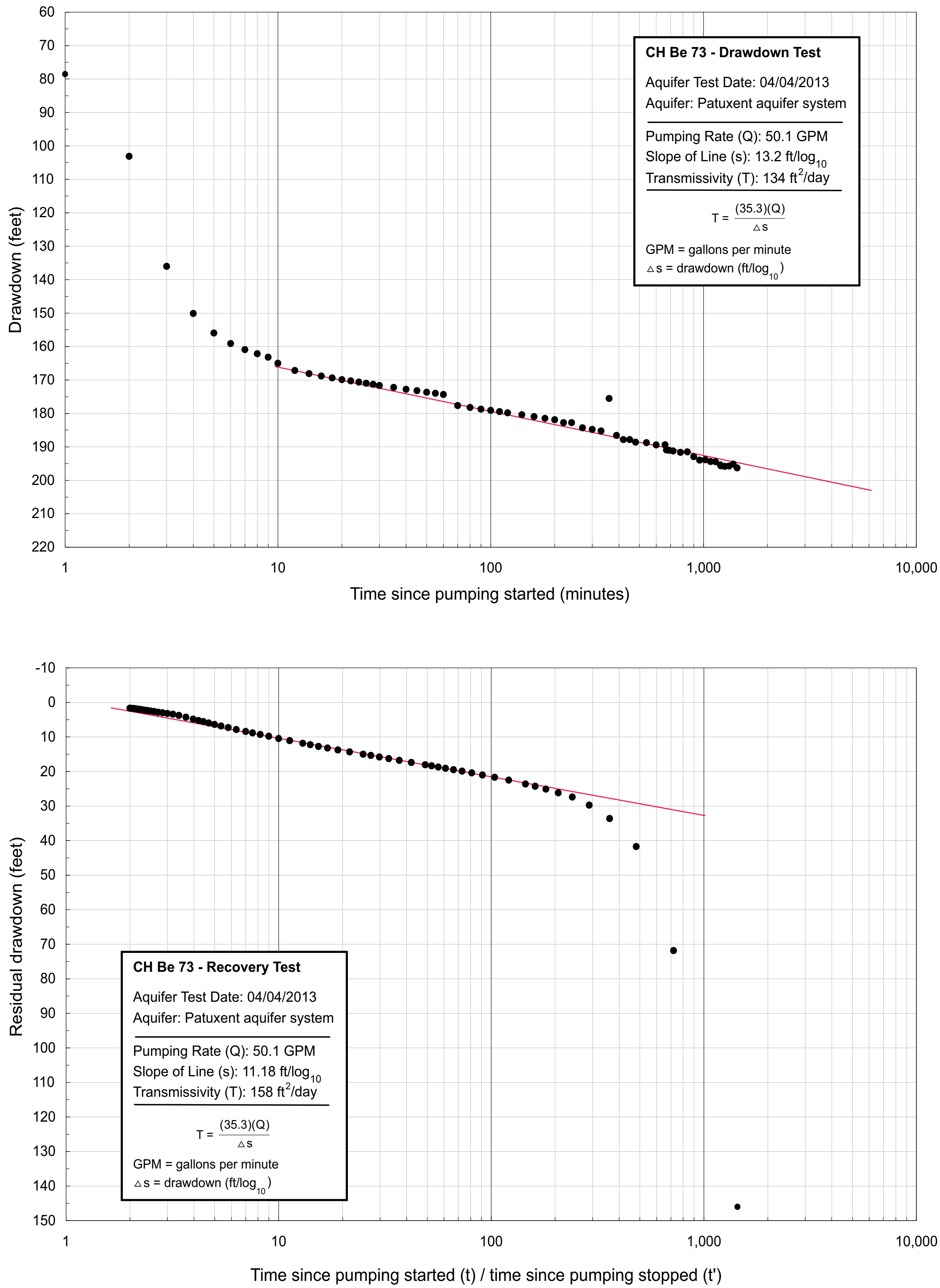
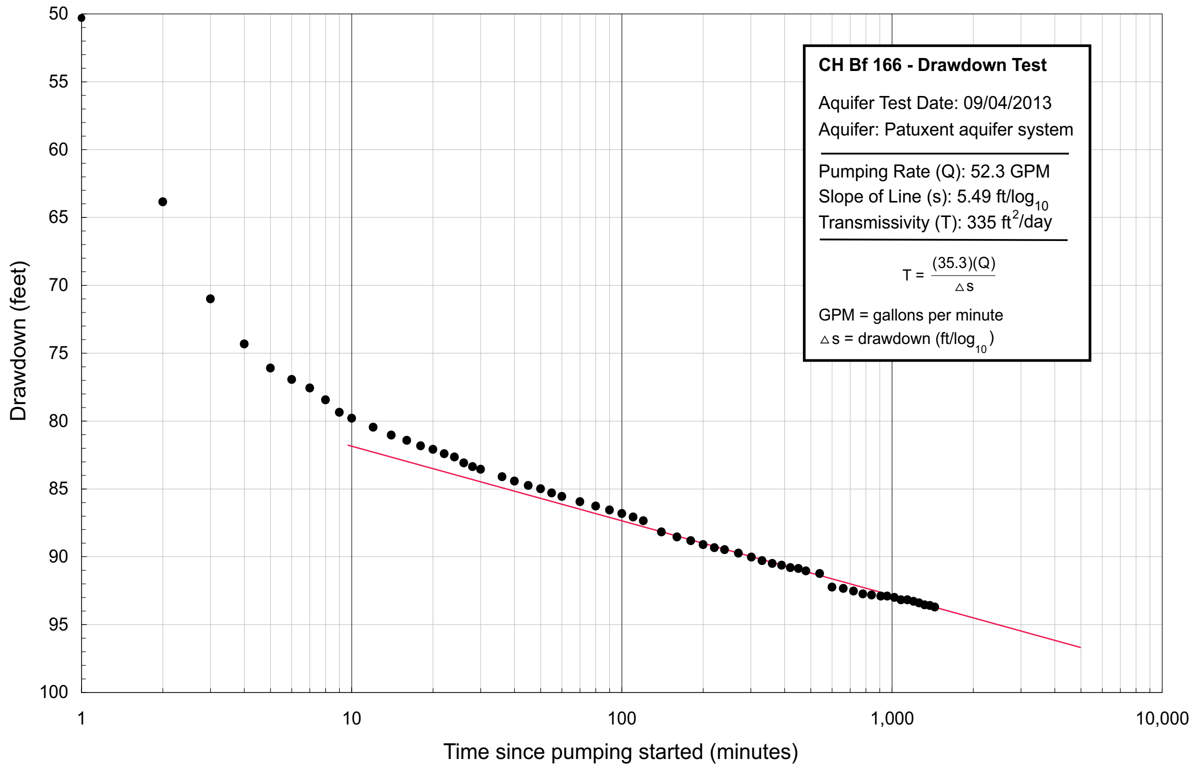


Figure 18a. Drawdown data, recovery data, and transmissivity calculations for aquifer test of well CH Be 73.



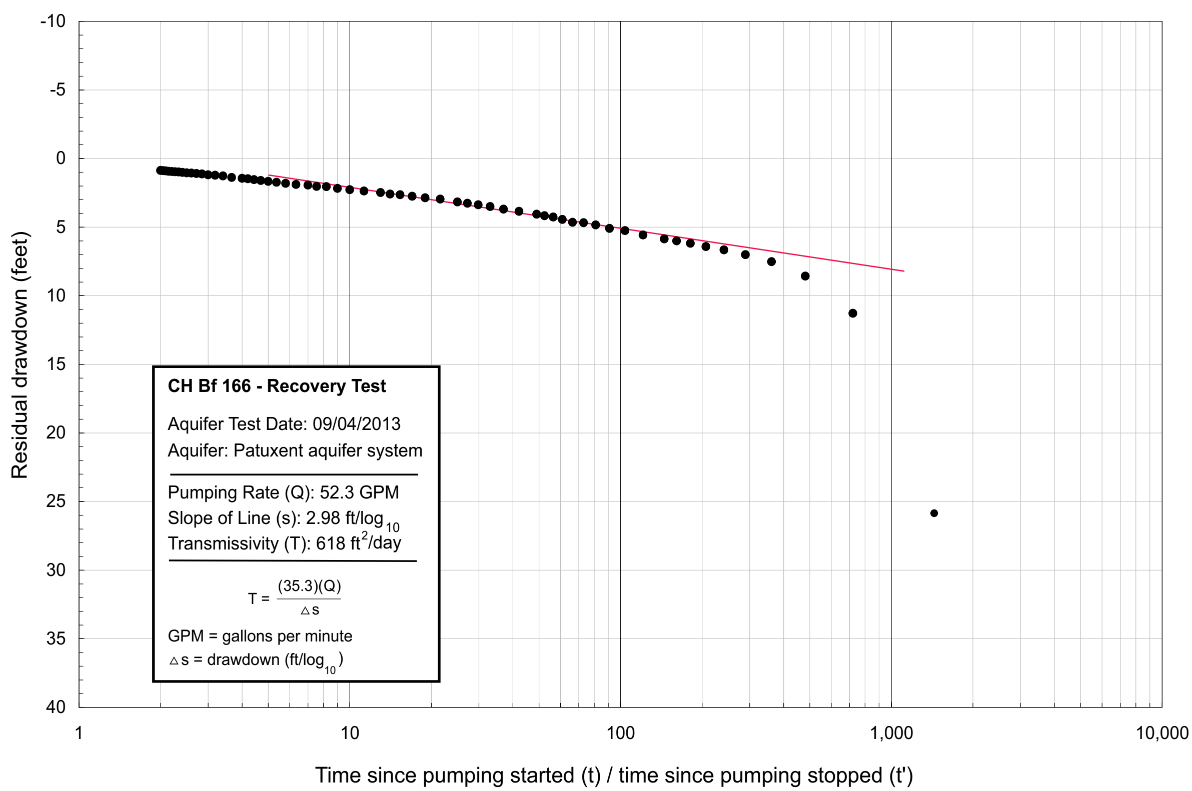
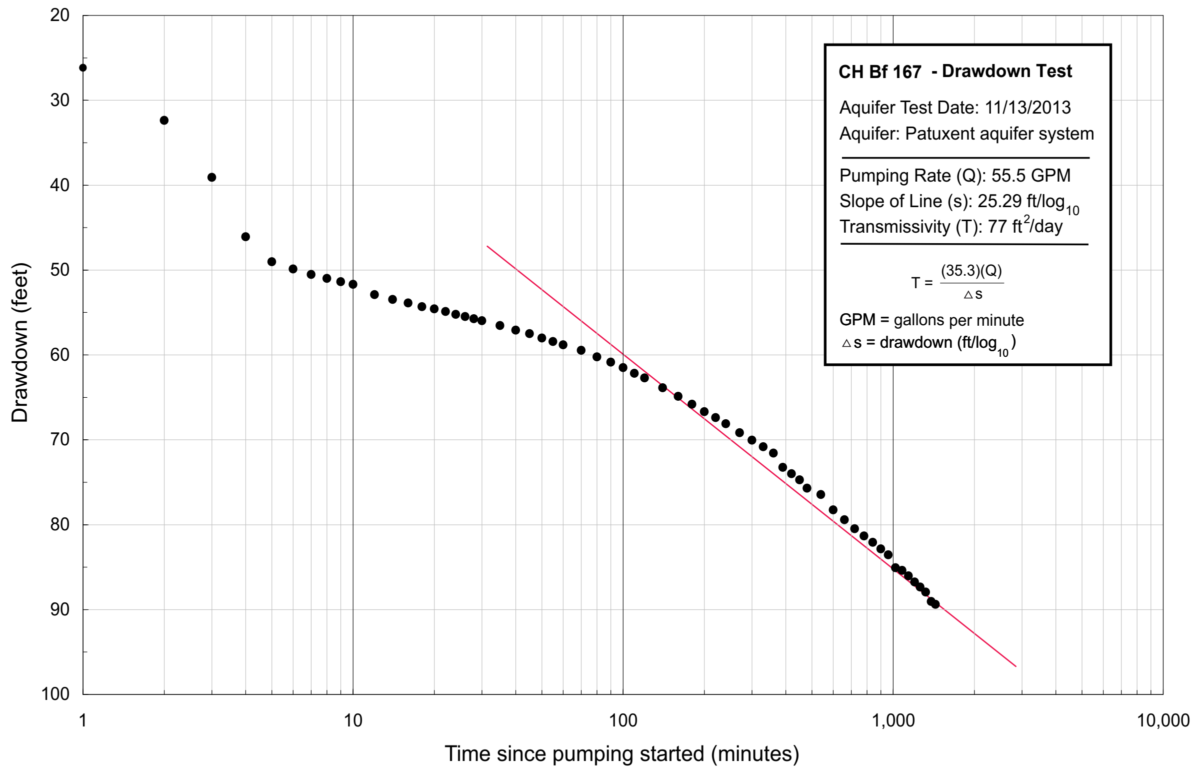


Figure 18b. Drawdown data, recovery data, and transmissivity calculations for aquifer test of well CH Bf 166.



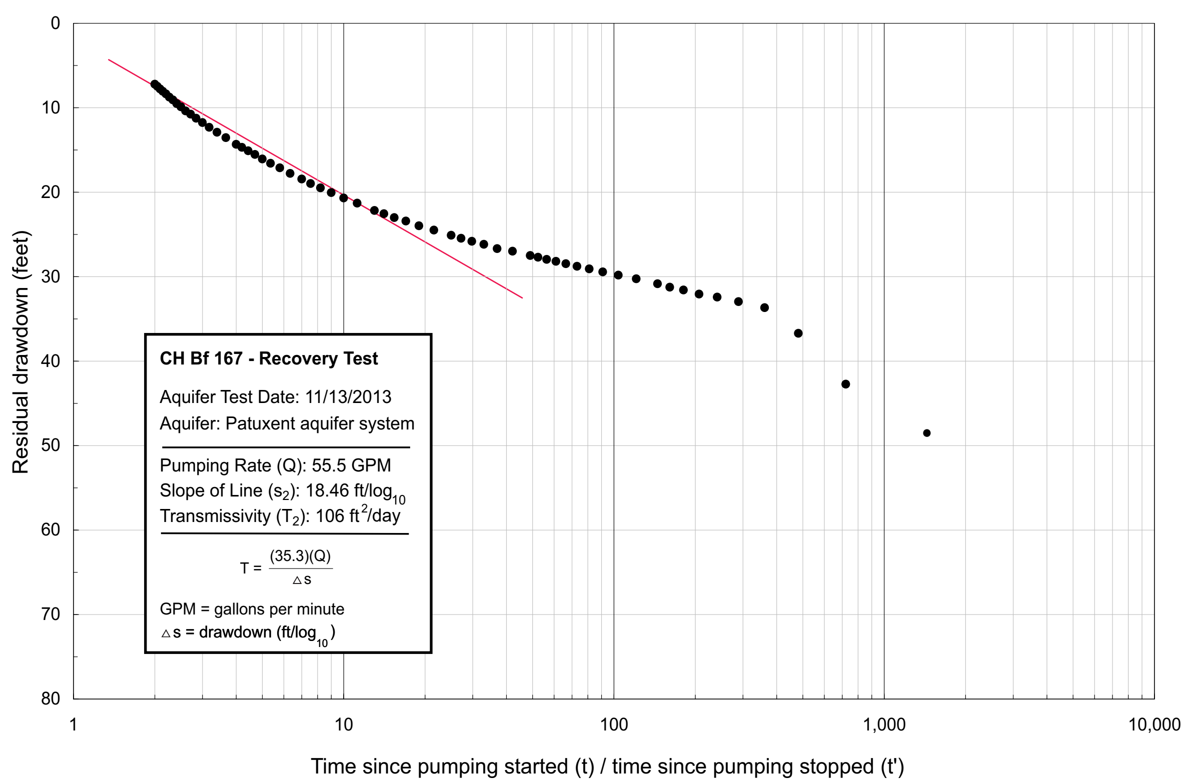
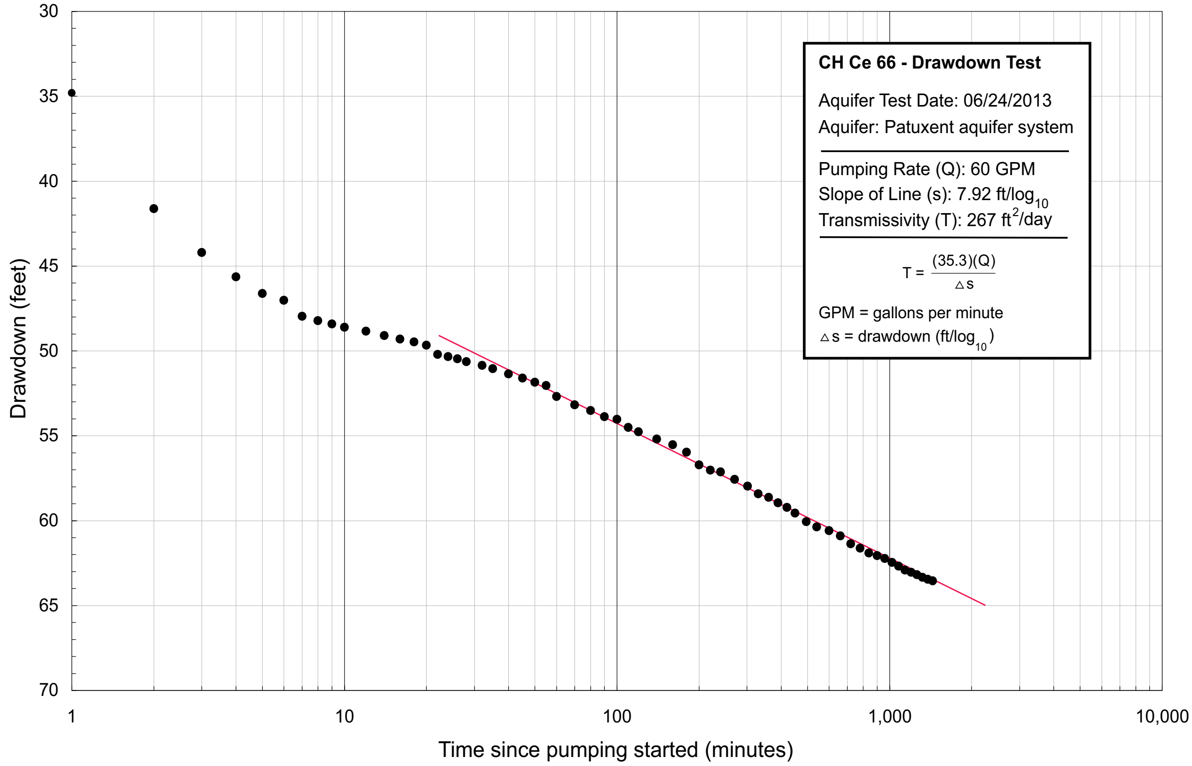


Figure 18c. Drawdown data, recovery data, and transmissivity calculations for aquifer test of well CH Bf 167.



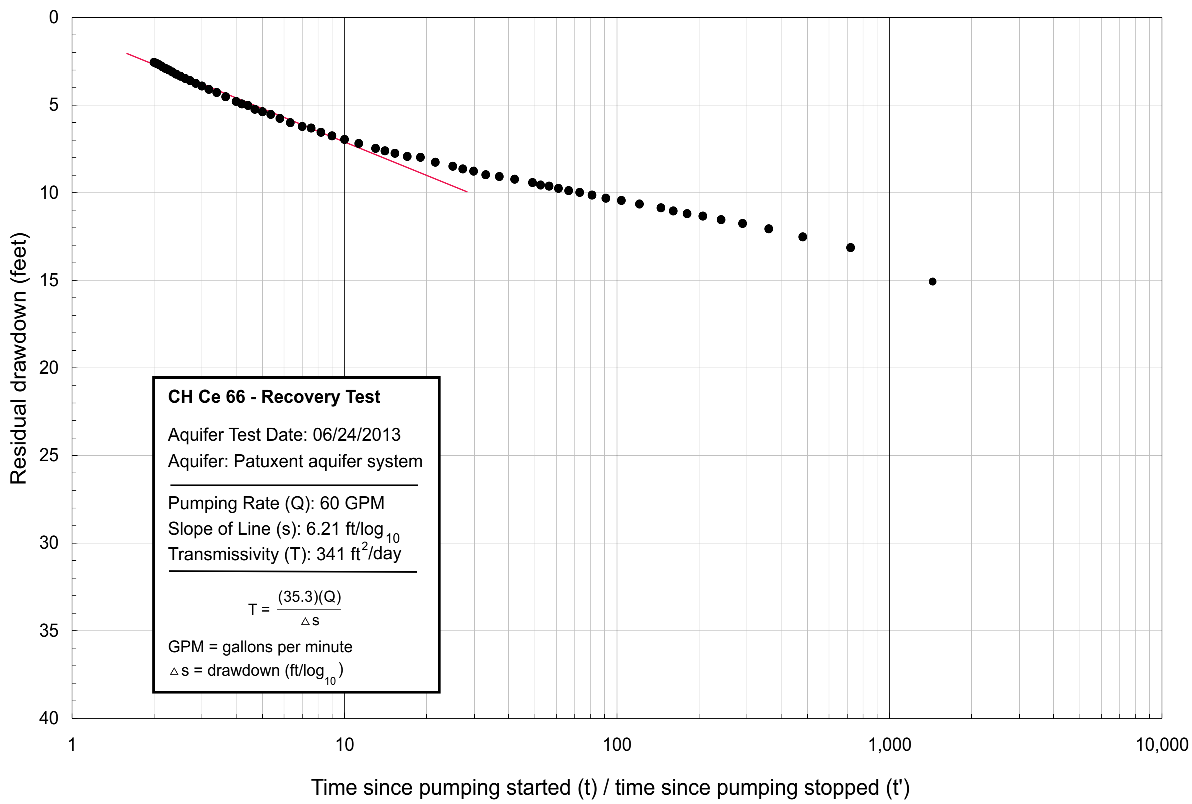


Figure 18d. Drawdown data, recovery data, and transmissivity calculations for aquifer test of well CH Ce 66.

resulting in horizontal flow to the well and the flow is laminar; (4) the aquifer has uniform thickness and is horizontal; (5) the potentiometric surface is horizontal initially; and (6) the aquifer is fully confined and discharge is derived exclusively from storage in the aquifer. If the assumptions are met, drawdowns plot in a straight line, and transmissivity is calculated from the slope of the line and the discharge rate, according to the formula:

$$T = 35.3 \times Q/\Delta s$$

where

T = transmissivity, feet squared per day (ft^2/day),

Q = pumping rate, gpm,

Δs = drawdown in one log cycle, ft.

Many of the assumptions of the Cooper-Jacob method, most notably that the aquifer be homogeneous and isotropic, are not fully met in the test wells. The complex and variable geometry of the Patuxent aquifer system makes aquifer hydraulic-property estimates complicated and limited in geographic relevance. As discussed previously, the individual sand bodies that make up the aquifer system are limited in lateral extent, have complex localized boundaries, and are lithologically heterogeneous. These factors create variable hydraulic boundaries that are nearly impossible to characterize with the sparse data available, and may strongly influence aquifer-test results if they are sufficiently close to the test wells. Despite these difficulties, transmissivity values were calculated from aquifer-test data for the four test wells. Analyzed transmissivity values for the test wells range widely from 77 to 335 ft^2/day for the pumping phases of the tests and from 106 to 618 ft^2/day for the recovery phases of the tests (figs. 18a – 18d).

The highest transmissivity values in Charles County are found in the Bryans Road area, and, more specifically, in the Chapman's Landing area, which has values up to approximately 2,600 ft^2/day (tab. 2; fig. 19). In southern Maryland, the highest transmissivity values are found in Anne Arundel County and northern Prince George's County, where values are as high as 8,500 ft^2/day. The general pattern of transmissivity distribution closely mirrors that of sand percentage of the Patuxent aquifer system as shown in Figure 15.

One important factor to consider when comparing transmissivity values is the diameter of the well casing and screen, which are indicated on the well-location symbols in Figure 19, as well as in Table 2. A production well with an 8-in. screen is more likely to have a higher single-well transmissivity value than a 4-in. test well at the same location, though the magnitude of difference cannot easily be quantified as there are many variables involved. One possible explanation for this phenomenon is the relative feasibility of fully developing a large diameter screen at great depth, as well as the economic incentive to do so, compared to the challenges of developing a deep and relatively inaccessible 4-in. screen in a test well. Additionally, many 4-in. test wells are constructed with short screen lengths positioned in a limited portion of the aquifer system (e.g., wells CH Bc 80 and CH Cc 34), and therefore do not fully represent the potential of the available aquifer sands at a given location. The test wells drilled for this project were constructed with screens positioned in all available aquifer sands throughout the Patuxent interval in an effort to eliminate the effects of partial penetration, and care was taken to develop the test-well screens until they were free of drilling mud and fine sediment. Despite these efforts, transmissivity values for this study's test wells should be considered conservative relative to potential large diameter production wells drilled at the same site.

WATER QUALITY

Water samples were collected from the four wells and analyzed for a suite of major ions, nutrients, trace elements, radon, gross alpha-particle activity (GAPA) and gross beta-particle activity (GBPA), and polonium-210 (app. D). Samples were collected from an in-line spigot during the drawdown phase of the aquifer test for each well. Samples were collected after specific conductance, pH, dissolved oxygen, and water temperature measurements had stabilized. Stabilization criteria were: pH, ± 0.05 pH unit; temperature, ± 0.5 degree Celsius; specific conductance, ± 1 percent; and dissolved oxygen, ± 0.2 milligrams per liter (mg/L), measured over a 10-minute period. Equipment calibrations were performed prior to each sample collection at the drill site using appropriate standards and buffers. Samples were shipped via overnight courier to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Samples being analyzed for GAPA and GBPA were shipped via overnight courier to Eberline Services Laboratory (the USGS-subcontracted laboratory for these constituents) in Richmond, California.

Table 2. Transmissivity of the Patuxent aquifer system in Charles County and adjacent areas.

Region	Well name	Location	Maryland State Plane Coordinate (North American Datum of 1983) (feet)		Well screen diameter (inches)	Transmissivity (feet squared per day)	
			Northing	Easting		Pumping phase	Recovery phase
North-central Charles County / Prince George's County	CH Be 57*	Smallwood West, Waldorf	346,628	1,322,262	4	--	30
	CH Be 73[1]	Bensville	358,420	1,313,643	4	134	158
	CH Bf 166[1]	Pinefield	356,782	1,353,571	4	335	618
	CH Bf 167[1]	Gardiner Road	339,570	1,355,819	4	77	106
	CH Bg 18*	Malcolm	342,110	1,376,789	4	20	20
	CH Ce 57*	La Plata	320,730	1,318,776	4	104	109
	CH Ce 66[1]	White Plains Regional Park	332,200	1,335,241	4	267	341
	PG Fd 59*	Moore Well 2, Brandywine	381,341	1,342,301	7	113	--
	PG Hf 43*	Chalk Point Power Plant	321,860	1,401,728	6	390	710
Western Charles County, Maryland / Virginia	CH Bb 23*	Naval Surface Warfare Center Main Base	338,940	1,263,509	10	770	850
	CH Bc 75*	Chapman's Landing	344,519	1,281,940	8	2,600	--
	CH Bc 77*	Chapman's Landing	344,416	1,284,242	6	1,830	--
	CH Bc 78*	South Hampton, Bryans Road	353,012	1,285,918	6	937	--
	CH Bc 80*	Chapman's Landing	344,519	1,281,940	4	51	--
	CH Bd 52*	Pomfret Road, Route 227	339,246	1,296,224	4	656	--
	CH Bd 58*	Bryans Road, fire house	346,628	1,322,262	6	--	1,360
	CH Bd 59*	Bryans Road Well 7	340,274	1,288,747	10	1,211	1,137
	CH Cb 45*	Naval Surface Warfare Center, Stump Neck	321,256	1,254,181	8	90	90
	CH Cc 34*	Mattawoman Wastewater Treatment Plant	331,977	1,280,734	4	152	--
	CH Cc 36*	Hunter's Brook Well 1	328,740	1,280,413	6	2,250	--
	CH Cc 39*	Hunter's Brook Well 2	328,740	1,280,413	8	1,480	1,540
	CH Da 18*	Douglas Point	284,820	1,238,831	8	--	637
	VA BV Ac 4**	Fairfax County, Virginia	373,970	1,272,080	--	670	--
	VA Quantico Well #2**	Prince William County, Virginia	309,315	1,227,296	--	520	--
	VA Quantico Well #4**	Prince William County, Virginia	312,764	1,230,788	--	440	--
Southern Charles County	CH Ee 96*	Morgantown Power Plant	254,068	1,321,262	6	290	280
Washington, DC Metropolitan area	PG Cc 3*	South of Bladensburg, Kenilworth Avenue	459,530	1,330,832	--	80	--
	PG Cc 5*	Bladensburg	466,105	1,330,511	--	1,336	--
	PG Cc 31*	Archdiocese of Washington, Eastern Avenue	469,741	1,314,473	8	668	--
	PG Eb 2*	Forest Heights, Well 2	417,945	1,310,836	8	936	--
	PG Ec 41*	Southlawn	411,167	1,313,053	6	1,340	--
	PG Ec 46*	Kerby Hill Pumping Station	405,400	1,312,815	6	534	--
	VA AX Bb 2**	Alexandria, Fairfax County, Virginia	419,344	1,298,316	--	2,673	--
	VA AX Bb 9**	Alexandria, Fairfax County, Virginia	419,344	1,298,316	--	1,203	--

[1] Test well drilled for this project - see Appendix B for well construction and test details.

* See Appendix C for well construction and test details.

** Details of well construction and tests can be found in Andreasen and others (2013).

-- No data.

Table 2. Transmissivity of the Patuxent aquifer system in Charles County and adjacent areas--Continued.

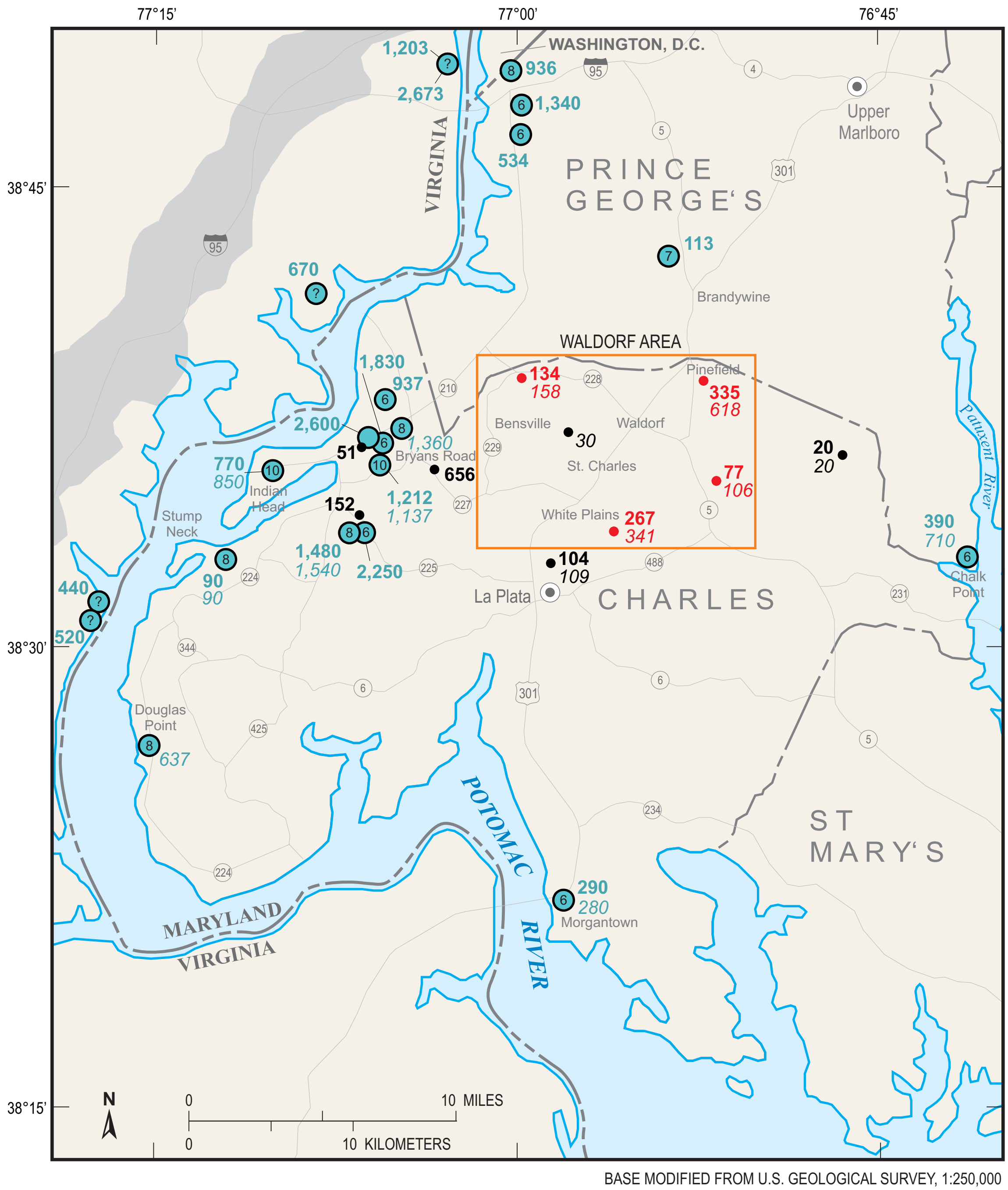
Region	Well name	Location	Maryland State Plane Coordinate (North American Datum of 1983) (feet)		Well screen diameter (inches)	Transmissivity (feet squared per day)	
			Northing	Easting		Pumping phase	Recovery phase
Northern Prince George's County / Anne Arundel County	AA Ad 90**	Hammonds Ferry Road	549,754	1,411,722	4	--	1,050
	AA Bb 74**	U.S. Army, Fort George G. Meade	525,060	1,377,528	6	1,340	1,290
	AA Bb 76**	Department of Defense Office Building	527,384	1,376,339	6	--	60
	AA Bb 82**	National Security Agency, Test Well 2	521,426	1,380,533	8	1,410	1,550
	AA Bb 87**	Jessup Water Tower, Brock Bridge Road	536,863	1,379,460	4	3,290 - 4,494	3,942 - 4,890
	AA Bb 88**	Maryland Correctional Institution for Women	533,817	1,375,212	4	1,322 - 1,550	1,346 - 1,560
	AA Bb 90**	NSA National Cryptologic Museum	527,851	1,376,488	4	1,260 - 1,311	1,310 - 1,347
	AA Bb 91**	NSA National Cryptologic Museum	545,501	1,376,488	4	238	252 - 370
	AA Bc 234**	U.S. Army, Fort George G. Meade, Well 3	517,293	1,389,453	12	8,150	--
	AA Bc 235**	U.S. Army, Fort George G. Meade	517,404	1,389,375	2	7,180	8,520
	AA Bd 57**	Dorsey Road, Well 2, Glen Burnie	545,712	1,413,155	10	1,260	1,070
	AA Bd 161**	Dorsey Road, Water Treatment Plant	545,712	1,413,155	8	1,080	1,100
	AA Bd 177**	Dorsey Road, Water Treatment Plant	545,196	1,410,401	8	640	610
	AA Bd 178**	Dorsey Road, Water Treatment Plant	545,196	1,410,401	10	--	1,142
	AA Cc 78**	Kings Heights	512,234	1,398,687	4	2,005 - 6,680	--
	AA Cc 86**	Kings Heights	486,777	1,398,071	20	2,673	--
	AA Cc 114**	Waugh Chapel Road	503,375	1,399,988	6	2,650	3,020
	AA Cc 119**	U.S. Army, Fort George G. Meade, Obs. Well 5	514,024	1,390,957	2	--	3,560
	AA Cc 138**	Crofton Meadows, Well 7	491,963	1,405,788	10	6,950	--
	AA Cd 102**	Crofton Meadows	491,365	1,408,237	2	4,870	--
	AA Ce 117**	Severndale, Water Treatment Plant	515,243	1,432,910	--	1,250	1,210
	AA Ce 149**	Severndale, Water Treatment Plant	515,148	1,434,250	10	2,870	3,010
	AA Cf 136**	Arnold, Water Treatment Plant	498,674	1,457,053	4	1,490	1,300-1,500
	AA Cg 22**	Sandy Point State Park	494,574	1,481,620	4	--	950
	AA De 192**	Broadcreek, Water Treatment Plant	494,574	1,481,621	3	3,110	--
	AA De 203**	Broadcreek, Water Treatment Plant	494,574	1,481,621	6	2,420	--
	PG Bd 33**	Muirkirk	507,982	1,344,932	8	80	--
	PG Be 22**	Patuxent Research Refuge	503,590	1,367,800	6	935	--
	PG Be 23**	Patuxent Research Refuge	499,150	1,372,938	6	--	650
	PG Be 24**	Patuxent Research Refuge	498,441	1,372,782	6	--	1,140
	PG Be 32**	Beltsville Airport	497,003	1,362,448	4	1,950	2,570
	PG Cd 25**	NASA Goddard Space Flight Center	483,735	1,354,026	6	2,440	--
	PG Cd 27**	NASA Goddard Space Flight Center	483,790	1,354,506	--	1,450	--
	PG Cf 64**	City of Bowie, PW 4	475,217	1,389,421	10	1,203	--
	PG Cf 66**	City of Bowie, PW 5	473,694	1,387,451	12	1,471	--
	PG De 36**	Oak Creek Golf Course, Landover Hills	444,950	1,382,711	6	1,970	2,130

[1] Test well drilled for this project - see Appendix B for well construction and test details.

* See Appendix C for well construction and test details.

** Details of well construction and tests can be found in Andreasen and others (2013).

-- No data.



EXPLANATION

290 / 280 — **PRODUCTION WELL TRANSMISSIVITY**, in feet squared per day, from aquifer tests. Number in symbol is the diameter of screen in inches, queried where unknown. Drawdown phase is in bold and recovery phase is in italics.

104 / 109 — **4-INCH TEST WELL TRANSMISSIVITY**, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics. Test wells drilled for this project are shown in red.

APPROXIMATE OUTCROP OF THE PATUXENT AQUIFER SYSTEM

Figure 19. Transmissivity of the Patuxent aquifer system.

Water samples from all four wells were slightly basic (pH 7.6 to 8.5) and had dissolved-solids values ranging from 269 to 605 mg/L. Higher pH at depth likely reflects the long residence time and, therefore, long contact and reaction time with aquifer minerals in deep wells such as these. All samples had a sodium-bicarbonate water type, as do other Patuxent aquifer water samples in the area (Andreasen, 1999). None of the constituents that were tested exceeded the U.S. Environmental Protection Agency's (USEPA) Primary Drinking Water Standards (Maximum Contaminant Levels [MCLs] that are related to health effects). GAPA (MCL: 15 picocuries per liter [pCi/L]) was less than 9 picocuries per liter in all samples. Concentrations of polonium-210, an alpha-particle-emitting radionuclide that has been detected in the Upper and Lower Patapsco aquifers at Chapel Point Woods and Mt. Carmel Woods, were all less than 2 pCi/L.

Iron concentrations in unfiltered samples exceeded 300 micrograms per liter (µg/L) (the Secondary Maximum Contaminant Level [SMCL]) in all four wells. Iron concentrations in filtered samples exceeded 300 µg/L in only two of these wells (CH Be 73 and CH Ce 66). In all four wells, the unfiltered-iron concentration was higher than the filtered-iron concentration, suggesting that much of the iron may be in the form of colloidal particles rather than dissolved ions. High iron concentrations are not uncommon in the Patuxent aquifer system, and may be due to dissolution of iron oxides and oxyhydroxides that often coat the mineral grains in the aquifer.

The water sample from well CH Ce 66 (White Plains Regional Park) had a dissolved-solids concentration (605 mg/L) that exceeded the SMCL of 500 mg/L. This well also had the highest chloride concentration (92.6 mg/L) of the four wells, although it was less than the SMCL for chloride (250 mg/L). In general, there appears to be a gradient in which chloride concentrations increase from the north to the south across Charles County, with a sample from well CH Ee 96 at Morgantown having the highest recorded concentration (387 mg/L). Drummond (2007) suggested that the source of this brackish water may be the updip portion of a wedge of relict salty water from the Atlantic Ocean that extends beneath the Eastern Shore of Maryland.

Two of the wells (CH Be 73 and CH Bf 66) had pH values (both 8.5) that equal the upper end of the acceptable SMCL range. It is possible that the pH in the Patuxent aquifer may exceed 8.5 in the area, thus requiring treatment. The sample from well CH Be 73 also exceeded the SMCL for aluminum (200 µg/L) and color (15 color units)

The water-quality data collected in this study suggests that, while no MCLs were exceeded, there may be constraints on water use due to SMCL exceedances. Dissolved solids, iron, pH and/or color may require either treatment or blending with another water source in order to reduce these constituents to acceptable levels.

WATER LEVELS

Water-level measurements were collected from the four test wells in order to monitor both short- and long-term trends. Hydrographs showing continuous and discrete water-level data from the test wells were created with groundwater levels adjusted to feet related to sea level using the North American Vertical Datum of 1988 (NAVD88) (fig. 20). Continuous water levels were recorded at 15-minute intervals using pressure transducers. The time periods recorded for each well varied because transducers were rotated between sites. Continuous water-level measurements were collected from June 20, 2013 to March 24, 2014 for well CH Be 73, October 30, 2013 to April 25, 2014 for well CH Ce 66, and April 2, 2014 to July 15, 2014 for wells CH Bf 166 and CH Bf 167. Hand-held water-level measurements were recorded every other month, on average, following well installation. Water levels in the test wells during November of 2014 ranged from approximately 20 ft below sea level in well CH Bf 166 (Pinefield) to approximately 42 ft below sea level in well CH Be 73 (near Bensville). Continuous water-level data from the test wells show a pattern in which short-term water levels fluctuate on the order of 0.2 to 0.6 ft over a period of 2 to 7 days. This pattern seems to correlate strongly with barometric pressure. There do not appear to be any short-term water-level fluctuations caused by pumping, as most withdrawals from the Patuxent aquifer system occur at a great distance (5 to 12 miles) from the test wells.

Regional water levels in the Patuxent aquifer system show a declining trend throughout Charles County, with the greatest rates of decline occurring near the sites of Patuxent aquifer system withdrawals in the region (fig. 21) (Staley, 2014). Static water levels measured in September 2013 were used to create a potentiometric-surface-contour map (fig. 22). This map shows two large cones of depression which coincide with the significant regional pumping centers and are affecting water levels throughout northern Charles County. The first large cone, with water levels as deep as 79 ft below

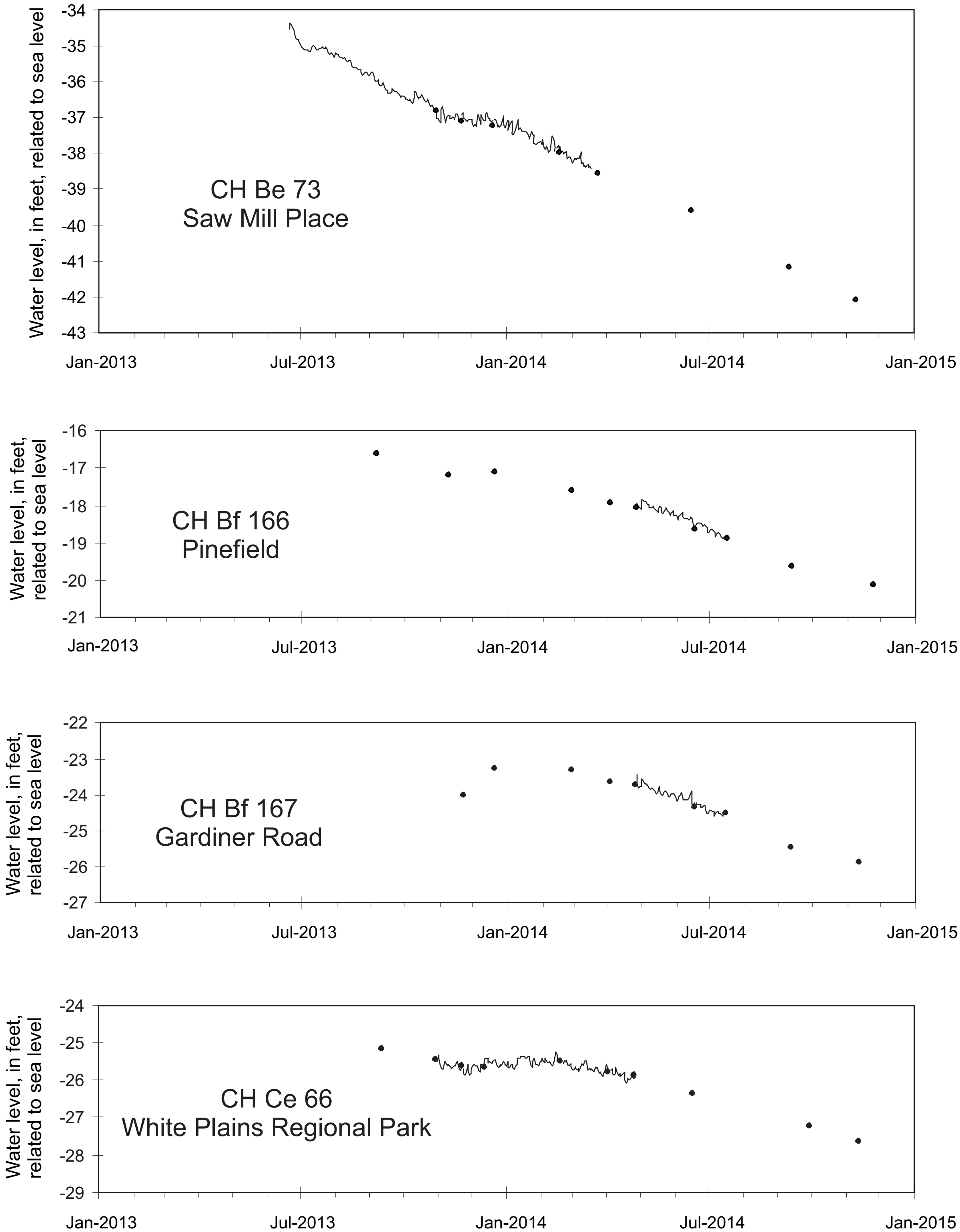


Figure 20. Hydrographs showing water-level fluctuations in test wells.

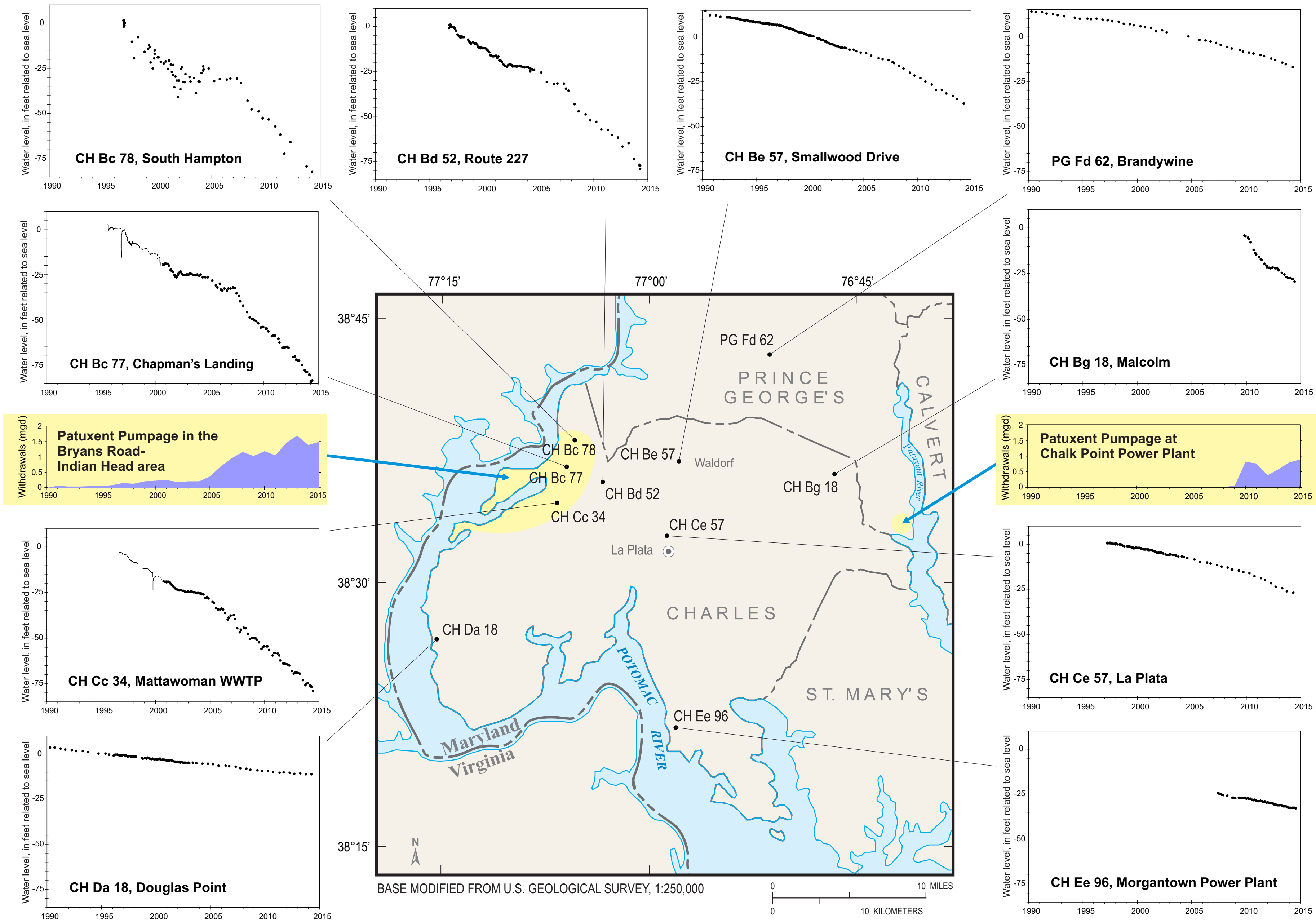


Figure 21. Water-level trends and annual average pumpage, in million gallons per day, in the Patuxent aquifer system in Charles County.

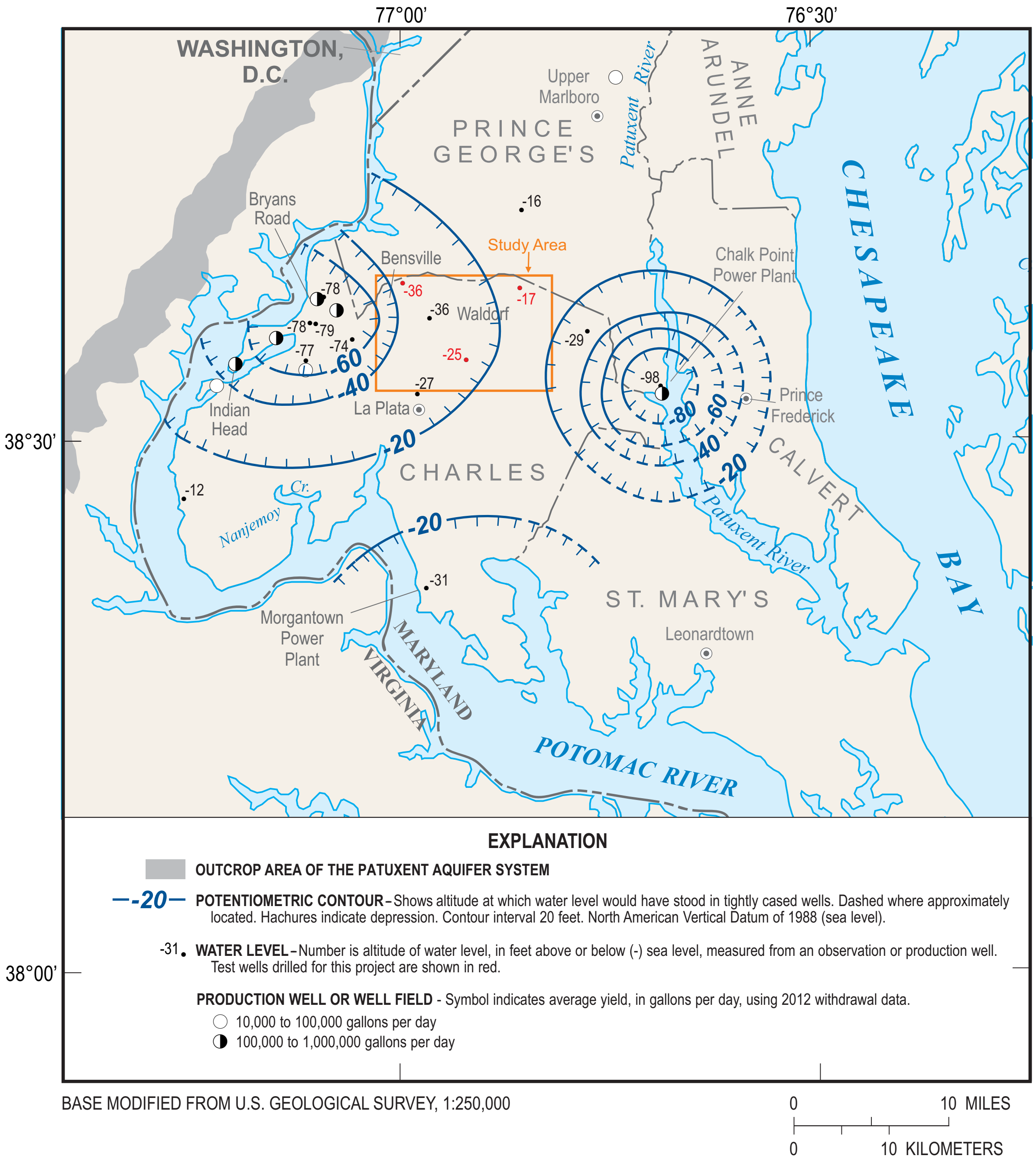


Figure 22. Potentiometric surface of the Patuxent aquifer system in Charles County and adjacent areas, September 2013 (modified from Staley and others, 2014).

sea level, is centered on the county well fields at Bryans Road in the western part of the county. The second large cone, with water levels as deep as 98 ft below sea level, is centered on the Chalk Point Power Plant in southeastern Prince George's County, near the easternmost extent of Charles County. The four test wells drilled for this project are located between the influence of the Bryans Road and Chalk Point cones of depression, and are influenced to varying degrees by these pumping centers.

Water levels in test wells at Pinefield (well CH Bf 166), Gardiner Road (well CH Bf 167), and White Plains Regional Park (well CH Ce 66) are higher due to the fact that the Patuxent aquifer system is unused in this area. The low water level west of Waldorf near Bensville (well CH Be 73), on the other hand, reflects its proximity to the use of the Patuxent aquifer system at Bryans Road and Indian Head. Rates of water-level decline also reflect this geographic distribution with water levels in well CH Be 73 falling at approximately 5.5 feet per year (ft/yr), while water levels in the wells near Waldorf are falling at a rate of approximately 3 to 4 ft/yr. The reason water levels are declining in the Patuxent aquifer system in the Waldorf area, where the aquifer system is not being pumped, is not known. One likely explanation is that the aquifer system is hydraulically connected on a regional scale and increased withdrawals in the Bryans Road - Indian Head area and at Chalk Point Power Plant (figs. 21 and 22) are producing cones of depression spreading into the Waldorf area.

DISCUSSION OF WATER-SUPPLY POTENTIAL FOR THE PATUXENT AQUIFER SYSTEM IN THE WALDORF AREA

Many factors can affect the water-supply potential of an aquifer. These factors may include management restrictions due to both quantity and quality of the groundwater, the economic feasibility of constructing wells in the aquifer and pumping water from a given depth, and limitations on yield related to hydraulic properties of the aquifer material.

Water levels in an aquifer system are used to assess the need for management restrictions, as well as to determine the economic feasibility of production-well construction and operation. The current primary management criterion for evaluating groundwater appropriations (permit applications) in the confined aquifers of the Maryland Coastal Plain is the 80-percent management level. MDE defines this level at a given location as 80 percent of the vertical distance between the prepumping water level and the top of the aquifer (Code of Maryland Regulations [COMAR] 26.17.06.D(4)) (fig. 23). MDE regulates large groundwater withdrawals (more than 10,000 gallons per day) to prevent the potentiometric surface from declining below this level. This regulation is intended to prevent water levels from declining below the top of an aquifer, and thus causing partial dewatering of the aquifer near large groundwater users. Remaining available drawdown (the vertical difference between current water levels and the 80-percent management water level) of the Patuxent aquifer system in the Waldorf area, as determined from the test wells, currently ranges from approximately 760 ft to 1,280 ft. Given the relatively large amount of remaining available drawdown in the study area, it is unlikely that use of the Patuxent aquifer system will be constrained by the 80-percent management level in the foreseeable future. However, increased energy and maintenance costs associated with deeper water levels may make use of the Patuxent aquifer system economically undesirable.

Relatively low transmissivity is a potential limitation for use of the Patuxent aquifer system in the Waldorf area. Transmissivity values calculated for the Patuxent aquifer system test wells range from 77 to 335 ft^2/day for the pumping phases of the aquifer tests and from 106 to 618 ft^2/day for the recovery phases of the aquifer tests. These values are significantly lower than transmissivity values of the Patuxent aquifer system where it is currently being used as a water supply in the Bryans Road – Indian Head area of Charles County, northern Prince George's County, and Anne Arundel County. Relatively low values in the Waldorf area indicate that Patuxent aquifer system wells may not be able to sustain pumping rates commensurate with other public-supply well fields in the Waldorf water system without resulting in large drawdowns of the potentiometric surface of the aquifer.

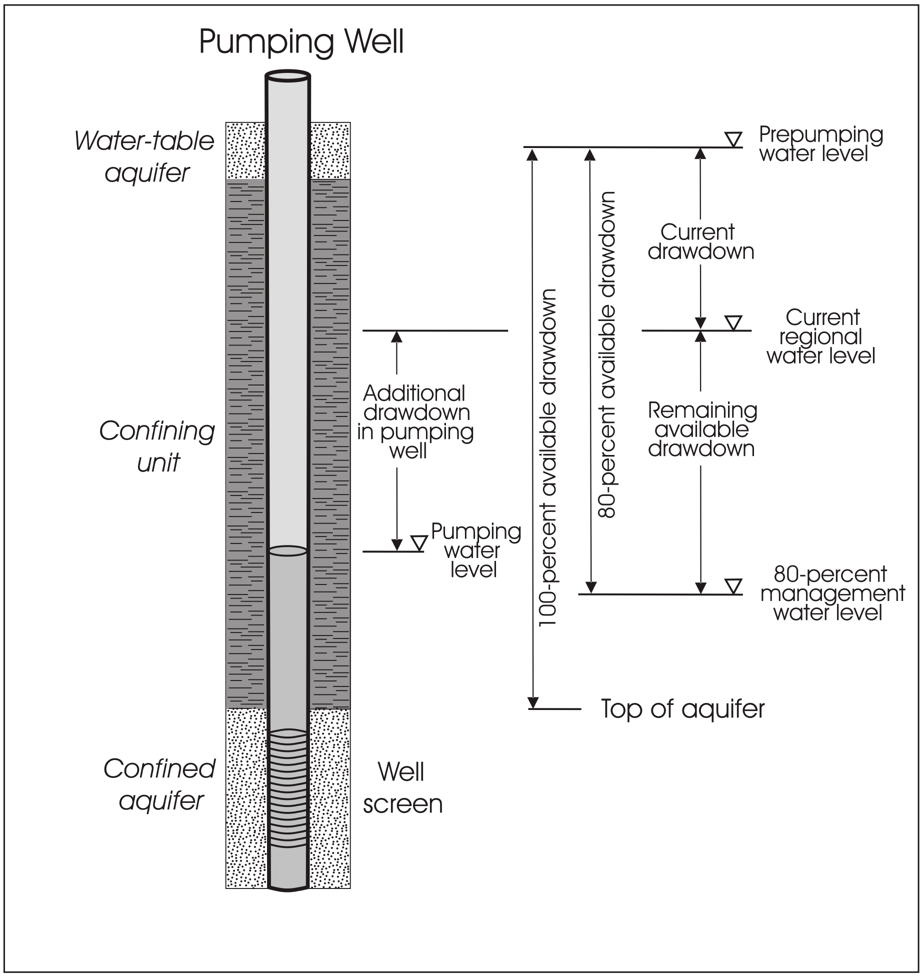


Figure 23. Schematic diagram showing the 80-percent management level and remaining available drawdown near a pumping well (modified from Drummond, 2007).

SUMMARY

In 2012, the Board of Commissioners of Charles County contracted with MGS to study the hydrogeologic characteristics of the Patuxent aquifer system in the Waldorf area. The Patuxent aquifer system (the deepest of the Coastal Plain aquifers) was identified by previous groundwater-flow modeling studies as having the potential to meet projected water demands in the Bryans Road - Indian Head area while reducing drawdown in the increasingly stressed Lower Patapsco aquifer system. Prior to the present study, information regarding the hydraulic characteristics of the Patuxent aquifer system was available for the western part of the county (Bryans Road - Indian Head area), but little was known regarding the Patuxent aquifer system in the Waldorf water-service area in north-central Charles County.

Four test wells were drilled into the Patuxent aquifer system between February 2013 and November 2013. Each well was drilled to basement rock with the exception of well CH Bf 166 (Pinefield) where drilling conditions necessitated finishing the well prior to reaching consolidated rock. Drill cuttings were collected and described in 10-ft intervals and also during any noticeable change in sediment type. Drilling depths ranged from 1,441 ft to 2,120 ft. Geophysical logs were run in the uncased holes. The wells were constructed using 4-in.-diameter steel casing and stainless-steel screen. Each well was screened in the most promising sand layers of the Patuxent aquifer system, as determined from geophysical logs and lithologic cuttings. Finished well depths ranged from 1,400 ft to 2,073 ft with cumulative well-screen lengths ranging from 70 to 105 ft.

Sands were found to comprise only 30 to 40 percent of the total thickness of the Patuxent aquifer system in the study area. In contrast, Patuxent aquifer system sands comprise 50 to 60 percent of the total thickness in Bryans Road, and about 60 percent of the total thickness in northern Prince George's County and Anne Arundel County. In general, Patuxent aquifer sands in the Waldorf area are thinner, finer-grained, and less commonly encountered as compared to the Patuxent aquifer system to the west in the Bryans Road - Indian Head area and to the north in Prince George's and Anne Arundel Counties.

Aquifer tests were performed on the four test wells with each test consisting of a 24-hr pumping phase, followed by a 24-hr recovery phase. During the pumping phase, each well was pumped constantly at a maximum sustainable rate (50 to 60 gpm) as allowed by the largest-capacity submersible pump available for a 4-in.-diameter cased well. Discharge was measured with an orifice meter, and checked periodically with container and stopwatch. Water levels were monitored during the tests using both a hand-held electric water-level meter and a pressure transducer. Analyzed transmissivity values for the test wells range widely from 77 to 335 ft^2/day for the pumping phases of the tests and from 106 to 618 ft^2/day for the recovery phases of the tests. These values suggest that the Patuxent aquifer system would be less productive in the study area than at Bryans Road or Chapman's Landing.

Water samples were collected from all wells and analyzed for major ions, nutrients, trace elements, radon, GAPA and GBPA, and polonium-210. All four water samples showed a sodium-bicarbonate water type, similar to other Patuxent aquifer water samples in the area. Polonium-210 concentrations were all less than 2 pCi/L. None of the tested constituents exceeded any USEPA MCL. SMCLs were exceeded for iron (all four wells) and total dissolved solids, aluminum, and color (one well each). The pH in two wells equaled the upper limit of the acceptable range for SMCL (8.5). These results indicate that water treatment or blending may be necessary in order for produced waters from the Patuxent aquifer in this area to be in compliance with USEPA drinking-water standards.

Water-level measurements were collected from the four test wells in order to monitor both short- and long-term trends. Continuous water levels were recorded in the test wells at 15-minute intervals using pressure transducers. Discrete water-level measurements were collected every other month following well completion. Water levels in the test wells during November of 2014 ranged from approximately 20 ft below sea level in well CH Bf 166 (Pinefield) to approximately 42 ft below sea level in well CH Be 73 (near Bensville). Water levels closer to Waldorf tend to be higher due to the fact that the Patuxent aquifer system is not currently utilized in this area. The lower water level west of Waldorf, near Bensville, reflects the greater usage of the Patuxent aquifer system in the Bryans Road - Indian Head area. Rates of water-level decline also reflect this geographic relationship, with water levels near Bensville falling at approximately 5.5 ft/yr, while water levels in the wells near Waldorf are declining at rates of approximately 3 to 4 ft/yr. It is unclear what is causing the water levels to decline at high rates in the Waldorf area, where the aquifer system is not being pumped. It is likely that the aquifer system is hydraulically connected on a regional scale and that recently increased withdrawals in the Bryans Road - Indian Head area to the west and at Chalk Point Power Plant to the east are producing cones of depression that have spread into the Waldorf area. Remaining available drawdown (the vertical difference between current water levels and the level below which water levels may not decline) ranges from approximately 760 ft to 1,280 ft in the study area. Due to the great depth of the top of the Patuxent aquifer system, management restrictions are unlikely in the near future, although costs associated with pumping from deep water levels may make the Patuxent aquifer system economically undesirable.

REFERENCES

Andreasen, D.C., 1999, The geohydrology and water-supply potential of the Lower Patapsco aquifer and Patuxent aquifers in the Indian Head-Bryans Road area, Charles County, Maryland: Maryland Geological Survey Report of Investigations No. 69, 119 p.

_____ 2003, Optimization of ground-water withdrawals in the Lower Patapsco aquifer, Waldorf, Maryland: Maryland Geological Survey Open-File Report No. 2003-02-17, 51 p.

_____ 2004, Optimization of ground-water withdrawals from the Lower Patapsco and Patuxent aquifers in the Bryans Road Service Area, Charles County, Maryland: Maryland Geological Survey Administrative Report, 21 p.

Andreasen, D.C., and Mack, F.K., 1998, Evaluation of the geohydrology and water-supply potential of the Lower Patapsco and Patuxent aquifers in the Indian Head-Bryans Road area, Charles County, Maryland: Initial findings: Maryland Geological Survey Open-File Report No. 98-02-9, 42 p.

Andreasen, D.C., Staley, A.W., and Achmad, Grufron, 2013, Maryland Coastal Plain aquifer information system: Hydrogeologic framework: Maryland Geological Survey Open-File Report No. 12-02-20, 121 p.

Charles County Planning Commission, 2014, Charles County, Maryland Comprehensive Plan, Planning Commission Draft Document, accessed October 20, 2014 at *http://www.charlescountyplan.org/document-library*.

Code of Maryland Regulations, 2015, Special criteria for issuance of ground water appropriation or use permit: Title 26 (Department of the Environment), Subtitle 17 (Water Management), chap. 06 (Water Appropriation or Use), Regulation 06D (4), accessed February 20, 2015.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union, Transactions, vol. 27, p. 526-534.

Drummond, D.D., 2007, Water-supply potential of the Coastal Plain aquifers in Calvert, Charles, and St. Mary's Counties, Maryland, with emphasis on the Upper Patapsco and Lower Patapsco aquifers: Maryland Geological Survey Report of Investigations No. 76, 225 p.

Hansen, H.J., 1969, Depositional environments of subsurface Potomac Group in southern Maryland: American Association of Petroleum Geologists Bulletin, v. 53, no. 9, p. 1923–1937.

_____ 1971, Transmissivity tracts in the Coastal Plain aquifers of Maryland: Southeastern Geology, v. 13, no. 3, p. 127–149.

Hansen, H.J., and Edwards, Jonathan, Jr., 1986, Lithology and distribution of pre-Cretaceous basement rocks beneath the Maryland Coastal Plain: Maryland Geological Survey Report of Investigations No. 44, 27 p.

Jacobeen, F.H., 1972, Seismic evidence for high angle reverse faulting in the Coastal Plain of Prince George’s and Charles Counties, Maryland: Maryland Geological Survey Information Circular No. 13, 21 p.

Keys, S.W., and MacCary, L.M., 1971, Application of borehole geophysics to water-resource investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, chap. E1, 126 p.

Lynch, E.J., 1962, Formation evaluation: New York, N.Y., Harper and Row, Inc., 422 p.

Mack, F.K., 1999, Hydrogeologic data from the Heritage Green test site, La Plata, Maryland: Maryland Geological Survey Open-File Report No. 99-02-11, 51 p.

Mack, F.K, and Mandle, R.J., 1977, Digital simulation and prediction of water levels in the Magothy aquifer in Southern Maryland: Maryland Geological Survey Report of Investigations No. 28, 42 p.

Mack, F.K., Wheeler, J.C., and Curtin, S.E., 1983, Water level declines in the Magothy aquifer in southern Maryland related to increases in pumpage: Maryland Geological Survey Open-File Report No. USGS 82-919, 29 p.

McFarland, E.R., 2013, Sediment distribution and hydrologic conditions of the Potomac aquifer, Virginia Coastal Plain: U.S. Geological Survey Scientific Investigations Report 2013–5116, 67 p., 3 attachments, 2 plates. (Also available at http://pubs.usgs.gov/sir/2013/5116/.)

McFarland, E.R., and Bruce, T.S., 2006, The Virginia Coastal Plain hydrogeologic framework: U.S. Geological Survey Professional Paper 1731, 118 p., 25 pls. (Also available at http://pubs.water.usgs.gov/pp1731/.)

Staley, A.W., 2014, Hydrographs and tables showing groundwater level records for selected observation wells in Charles County, Maryland: Maryland Geological Survey Administrative Report No. 14-02-05, 32 p.

Staley, A.W., Andreasen, D.C., and Curtin, S.E., 2014, Potentiometric surface and water-level difference maps of selected confined aquifers in Southern Maryland and Maryland's Eastern Shore, 1975-2013: Maryland Geological Survey Open-File Report No. 14-02-02, 29 p.

U. S. Environmental Protection Agency, 2015, National primary and secondary drinking water standards, http://water.epa.gov/drink/contaminants/index.cfmm, accessed February 2, 2015.

Wilson, J.M., and Fleck, W.B., 1990, Geology and hydrologic assessment of Coastal Plain aquifers in the Waldorf area, Charles County, Maryland: Maryland Geological Survey Report of Investigations No. 53, 137 p.

Appendix A. Well-construction information for the four test wells.

[ft, feet; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot; in., inch(es); Md., Maryland; N, North; USGS, U.S. Geological Survey; W, West]

Well number	CH Be 73	CH Bf 166	CH Bf 167	CH Ce 66
State permit number	CH-12-0183	CH-12-0182	CH-12-0185	CH-12-0184
Location	Saw Mill Place	Pinefield	Gardiner Road	White Plains Regional Park
USGS Site Identifier	383903076594302	383846076512001	383556076505201	383445076551301
Latitude	38°39'03.0"N	38°38'46.5"N	38°35'56.3"N	38°34'43.7"N
Longitude	76°59'43.5"W	76°51'20.2"W	76°50'52.2"W	76°55'11.5"W
Northing (Md. State Plane, ft.)	358420	356782	339570	332200
Easting (Md. State Plane, ft.)	1313643	1353571	1355819	1335241
Well driller	A.C. Schultes (Md.)	A.C. Schultes (Md.)	A.C. Schultes (Md.)	A.C. Schultes (Md.)
Date completed	3/18/2013	8/20/2013	10/23/2013	6/12/2013
Altitude of land surface (ft above sea level)	110	211	182	179
Depth drilled (ft below land surface)	1,441	1,997	2,120	1,955
Diameter of hole (interval, ft below land surface)	14 in. (0–42), 12.5 in. (42–1,420), 9.625 in. (1,420–1,441)	14 in. (0–42), 12.5 in. (42–1,997)	14 in. (0–30), 12.5 in. (30–2,100), 9.625 in. (2,100–2,120)	14 in. (0–42), 12.5 in. (42–1,950), 9.625 in. (1,950–1,955)
Depth of well (ft below land surface)	1,400	1,975	2,073	1,925
Diameter of well (in.)	4	4	4	4
Height of protective casing (ft above land surface)	2.3	2.6	2.5	2.35
Casing interval (ft relative to land surface)	-2.3–1,120 1,135–1,140 1,150–1,186 1,196–1,256 1,261–1,314 1,324–1,357 1,362–1,372 1,377–1,385 1,395–1,400	-2.6–1,717 1,727–1,747 1,752–1,774 1,784–1,819 1,854–1,960 1,970–1,975	-2.5–1,818 1,848–1,934 1,954–2,008 2,018–2,048 2,068–2,073	-2.35–1,512 1,522–1,605 1,645–1,714 1,724–1,794 1,809–1,814 1,824–1,876 1,886–1,900 1,910–1,925
Total length of casing (ft)	1,332.5	1,907.5	1,995.5	1,822.5
Depth to top of screen (ft below land surface)	1,120	1,717	1,818	1,512
Screen interval (ft below land surface)	1,120–1,135 1,140–1,150 1,186–1,196 1,256–1,261 1,314–1,324 1,357–1,362 1,372–1,377 1,385–1,395	1,717–1,727 1,747–1,752 1,774–1,784 1,819–1,854 1,960–1,970	1,818–1,848 1,934–1,954 2,008–2,018 2,048–2,068	1,512–1,522 1,605–1,645 1,714–1,724 1,794–1,809 1,814–1,824 1,876–1,886 1,900–1,910

Appendix A. Well-construction information for the four test wells--Continued.

Well number	CH Be 73	CH Bf 166	CH Bf 167	CH Ce 66
Total length of screen (ft)	70	70	80	105
Width of screen opening (in.)	0.025	0.025	0.025	0.025
Grout interval (ft below land surface)	0–1,080	0–1,685	0–1,770	0–1,470
Gravel interval (ft below land surface)	1,080–1,441	1,685–1,997	1,770–2,120	1,470–1,955
Aquifer	Patuxent	Patuxent	Patuxent	Patuxent
Water level, static (ft below land surface)	150.96	235.05	213.83	212.19
Water level, pumping (ft below land surface)	347.26	328.76	303.21	275.74
Drawdown (ft)	196.3	93.71	89.38	63.55
Date measured	4/4/2013	9/4/2013	11/12/2013	6/24/2013
Pumping rate (gal/min)	50.1	52.3	55.5	60
Hours pumped	24	24	24	24
Specific capacity [(gal/min)/ft]	0.26	0.56	0.62	0.94

Appendix B. Lithologic logs of test wells

Lithologic logs were processed and described on site by Lindsay Keeney, Andrew Staley, and David Andreasen. The hydrostratigraphic unit contacts shown on the lithologic logs were determined from the geophysical logs. This, in some instances, meant that changes in the described lithology did not always coincide with the actual lithologic and unit contacts. This disparity was in part caused by the time lag between when an interval was drilled and when the cuttings from the drilled interval reached the top of the borehole. Other difficulties regarding the collection of representative cuttings included mixing of the cuttings from different depths in the borehole as the cuttings were pumped up the hole and recirculation of the finer sediments within the borehole. Also, the very fine sediments and clays were difficult to sample routinely and these finer cuttings were often not well represented in the samples. The problems associated with the collection of drill cuttings increased with the depth of the hole.

CH Be 73 – Saw Mill Place Pump Station – Berry Road at Bensville Road
Land surface elevation = 110 feet above sea level

Depth, in feet below land surface	Description
Calvert confining unit with minor aquifers	
0 – 10	Silt, greenish gray, minor glauconite; minor fine to medium sand, rounded, well-sorted.
10 – 20	Gravel, mostly quartz with minor feldspar, subrounded to rounded, poorly-sorted, minor silt and glauconite.
Nanjemoy confining unit	
20 – 60	Clay, dark greenish gray; minor very fine to fine sand, subrounded to well-rounded, well-sorted; minor shell fragments, frequent glauconite.
60 – 70	Clay, greenish gray to light red; minor silt, minor glauconite, very minor shell fragments.
Marlboro Clay confining unit	
70 – 80	Clay, light red, tough; minor silt-sized dark minerals.
80 – 90	Clay, brown, tough; minor silt-sized dark minerals.
90 – 100	Clay, reddish yellow to dark greenish gray; minor silt-sized mica and dark minerals, gray clay occurring as flakey hard nodules.
Aquia aquifer (mostly non-aquifer facies)	
100 – 160	Clay, dark greenish gray to very dark greenish gray, minor silt to fine quartz sand, well-rounded, well-sorted, frequent glauconite and shell fragments.
160 – 190	Clay, sandy, dark greenish gray, frequent silt to medium quartz sand, frequent glauconite and shell fragments.
Matawan confining unit	
190 – 220	Clay, dark greenish gray to very dark greenish gray, minor silt to medium quartz sand, minor glauconite and minor shell fragments.
Magothy aquifer	
220 – 226	Sand, very coarse to gravel, mostly clear to blue quartz, subangular, well-rounded; minor gravel-sized black mineral, well-rounded, angular, frequent glauconitic sandstone, gravel, minor feldspar and shell fragments.

CH Be 73 (Continued)

Depth, in feet below land surface	Description
Magothy–Patapsco confining unit	
226 – 230	Sand, clayey. greenish gray, very coarse to gravel, mostly quartz, grain color ranges from clear to blue to yellow to red, subangular to subrounded, minor glauconitic sandstone and well-rounded, very coarse to gravel-sized dark mineral, notable very coarse pyrite fragments.
230 – 270	Clay, variegated greenish gray to red to yellow to light gray to light olive brown appearing in cuttings as tough fragments, frequent silt and very fine sand to gravel, mostly quartz, subangular to rounded, rare very fine to medium dark minerals, rare shell fragments.
270 – 280	Clay, sandy, light olive brown to red to light greenish gray appearing in cuttings as tough fragments, frequent silt and very fine sand to gravel, mostly quartz, well-rounded, rare shell fragments.
Upper Patapsco aquifer system	
280 – 290	Sand, clayey light greenish gray, frequent silt to coarse sand, mostly quartz, subrounded to rounded, occasional dark mineral and lignite fragments.
290 – 300	Sand, mostly quartz and rock fragments, subrounded to rounded, minor garnet, subrounded to rounded, minor light greenish gray clay, minor silt and lignite fragments.
300 – 310	Sand, clayey, silt-sized to coarse, mostly quartz, subangular to subrounded, minor garnet, subrounded to rounded, minor light greenish gray and red clay in fragments, minor lignite fragments.
310 – 350	Clay, variegated light grayish green to reddish yellow to red to yellow, minor silt to medium sand, mainly quartz, subangular to subrounded, lesser amounts of coarse to very coarse sand, rare lignite fragments.
350 – 360	Sand, silty, very fine to very coarse, mostly quartz, minor feldspar, subangular, frequent variegated clay with colors ranging from light grayish green to reddish yellow to red, rare lignite fragments.
360 – 400	Clay, variegated greenish gray to light greenish gray to reddish brown to red to olive yellow, minor silt to very coarse sand, mostly quartz, subangular to rounded, infrequent lignite.
400 – 430	Clay, sandy, greenish gray to red to olive yellow to light brown, frequent silt to coarse sand, mostly quartz, subangular to rounded, minor lignite.
430 – 460	Sand, clayey, silt-sized to very coarse, mostly quartz, light brown, moderately sorted, subangular to rounded, granule-sized rock fragments, red and dark minerals, minor pyrite, minor lignite.
460 – 480	Clay, sandy, light greenish gray to red to olive yellow to light brown, significant silt to coarse sand, mostly quartz, subrounded, granules of rock fragments, red and dark minerals, frequent lignite.
480 – 490	Sand, silty, fine to coarse, mostly quartz, minor sodium plagioclase, rare red mineral, subrounded, well-sorted; minor light brown clay, frequent lignite fragments.
490 – 500	Sand, medium to coarse, mostly quartz, minor sodium plagioclase, subrounded to rounded, well-sorted; minor clay, frequent lignite.
500 – 510	Sand, clayey, fine to coarse, mostly quartz, minor sodium plagioclase, subangular to subrounded, frequent lignite.
Patapsco confining unit	
510 – 520	Sand, clayey, very fine to medium, mostly quartz, minor sodium plagioclase, subangular, frequent variegated clay, frequent lignite.

CH Be 73 (Continued)

Depth, in feet below land surface	Description
Patapsco confining unit (Continued)	
520 – 550	Clay, sandy, very dark greenish gray to light red to olive yellow; significant very fine to coarse sand, mostly quartz, minor sodium plagioclase, subangular, frequent silt-sized lignite.
550 – 600	Clay, reddish yellow to dark greenish gray, occurs in fragments; minor very fine to medium sand, mostly quartz, subangular to subrounded, frequent lignite.
Lower Patapsco aquifer system	
600 – 610	Sand, clayey, light gray, mainly quartz, fine to medium, subangular to well-rounded; minor reddish yellow to dark greenish gray clay, minor lignite.
610 – 640	Sand, light gray, mainly quartz, fine to medium, subrounded to well-rounded, minor lignite and siderite.
640 – 660	Sand, gray, mainly quartz, fine to medium, subrounded to rounded, well-sorted, decreasing lignite, frequent red and black minerals.
660 – 720	Sand, clayey, very fine to coarse, mainly quartz, subangular to well-rounded; minor variegated clay in colors ranging from dark greenish gray to red to light greenish gray to light bluish gray to yellow, frequent lignite.
720 – 730	Sand, very fine to coarse, mainly quartz, subangular to subrounded, minor plagioclase; minor variegated clay in colors ranging from red to light greenish gray, minor lignite.
730 – 800	Sand, clayey, very fine to coarse, mainly quartz, subangular to well-rounded, minor plagioclase; significant variegated clay in colors ranging from dark greenish gray to red to light greenish gray to yellow, minor lignite.
800 – 820	Cuttings not recovered – no data.
820 – 850	Sand, clayey, very fine to coarse, mainly clear bluish quartz, subangular to subrounded, minor plagioclase; minor silty variegated clay in colors ranging from red to light greenish gray to yellow, frequent lignite.
850 – 870	Sand, very fine to coarse, predominantly quartz, subangular to rounded, minor plagioclase; minor variegated clay in colors ranging from red to light greenish gray to pale green to reddish brown to yellow to light gray, minor lignite.
870 – 880	Sand, mostly very coarse grading to very fine, predominantly clear blue quartz, subangular to rounded, minor plagioclase and pale green mineral; minor variegated clay in colors ranging from red to yellowish red to yellow.
880 – 900	Sand, fine to very coarse, predominantly quartz, subangular to rounded, minor plagioclase and pale green mineral; minor variegated clay in colors ranging from light greenish gray to pale green to reddish brown to yellowish brown to yellow to light bluish gray, minor lignite.
900 – 930	Sand, medium to coarse, predominantly quartz, subangular to subrounded, frequent plagioclase; rare clay.
930 – 940	Sand, fine to medium, predominantly quartz, subangular to rounded; rare clay.
940 – 950	Sand, fine to coarse, predominantly quartz, subangular to subrounded, minor plagioclase and pale green mineral; minor variegated clay in colors ranging from greenish gray to pale green to red.
Arundel Clay confining unit	
950 – 990	Sand, very fine to coarse, predominantly quartz, subrounded, minor plagioclase; minor pale green and reddish yellow clay.

CH Be 73 (Continued)

Depth, in feet below land surface	Description
Arundel Clay confining unit (Continued)	
*990 – 1,000	Sand, silty, fine to very coarse, predominantly quartz, subrounded, minor plagioclase; significant silty clay in colors ranging from greenish gray to pale green to red to reddish yellow to yellow.
*1,000 – 1,010	Sand, clayey, fine to coarse, predominantly quartz, subrounded; significant silty greenish gray to pale green.
1,010 – 1,020	Clay, sandy, variegated in colors ranging from light greenish gray to pale green to red; significant medium to very coarse sand, predominantly quartz, subrounded, minor lignite.
1,020 – 1,060	Sand, clayey, fine to coarse, predominantly quartz, subrounded to rounded; significant variegated clay fragments in colors ranging from dark gray to light gray to red to olive.
1,060 – 1,070	Clay, variegated fragments in colors ranging from dark gray to light gray to red to white; minor sand, fine to medium, predominantly quartz, subrounded to rounded.
1,070 – 1,120	Clay, sandy, variegated in colors ranging from dark gray to light gray to red to white; significant sand, fine to coarse, predominantly quartz, subangular to rounded, minor lignite, siderite, black minerals.
Patuxent aquifer system	
1,120 – 1,140	Sand, clayey, fine to medium, predominantly quartz, subrounded to rounded, minor lignite, siderite, black minerals; minor variegated clay fragments in colors ranging from dark gray to light gray to red to olive.
1,140 – 1,160	Sand, fine to coarse, predominantly quartz, subangular to rounded, minor lignite, siderite, black minerals; minor variegated clay fragments in colors ranging from dark gray to light gray to red to olive.
1,160 – 1,170	Clay, sandy, variegated in colors ranging from dark gray to light gray to red to olive to light greenish gray; significant sand, fine to coarse, mainly gray quartz, but diverse assemblage of mineralogy, subangular to angular.
1,170 – 1,180	Clay, variegated in colors ranging from dark gray to light gray to red to olive to light greenish gray; very infrequent sand, fine to coarse, mainly gray quartz, but diverse assemblage of mineralogy, subangular to angular.
1,180 – 1,230	Clay, sandy, variegated in colors ranging from dark gray to light gray to red to olive to light greenish gray; minor sand, fine to medium, mainly quartz, angular to subrounded, minor lignite, siderite and black mineral.
*1,230 – 1,240	Clay, gray.
*1,240 – 1,290	Clay, dark gray with specks of red, trace lignite.
*1,290 – 1,300	Clay, dark gray with specks of red; very minor amount of coarse sand, diverse grains including clear, white, purple, pink, angular to subrounded, trace amounts of hard red particles – possibly siderite.
1,300 – 1,310	Sand, fine to medium, predominantly light gray quartz, angular to subangular, minor black and red minerals; minor dark gray clay.
1,310 – 1,320	Sand, medium to coarse, predominantly light gray quartz, angular to subangular, minor black, red, and green minerals; minor dark gray clay.
1,320 – 1,330	No sample recovered.
1,330 – 1,420	Sand, fine to medium, predominantly light gray quartz, angular, diverse accessory minerals including black, red, and green minerals as well as angular green and black rock clasts; minor dark gray clay.

[*] Sample may not be representative due to problems with the mud pump.

CH Be 73 (Continued)

Depth, in feet below land surface	Description
Basement rock	
1,420 – 1,440	(Driller reports hard rock at 1,423 feet)
	Angular quartz, fine to medium, some clasts coated with black or green mineral; diverse accessory minerals including white, black, red, and green minerals as well as mica, garnet, and angular green and black rock clasts.
1,441	(bit and collar sample): clasts of biotite garnet schist (?) embedded in light gray to light brown clay.

CH Bf 166 -- Pinefield – Pinefield Road, Waldorf
Land surface elevation = 211 feet above sea level

Depth, in feet below land surface	Description
Artificial Fill	
0 – 10	Artificial fill, fine to very coarse sand and angular rock fragments, gray clay, fragments of wood.
Surficial Upland aquifer	
10 – 40	Sand, medium to very coarse and pebble-sized, subrounded to angular, mostly quartz with some feldspar (10 percent) and dark colored mineral or rock fragments; minor amounts of greenish-gray clay.
Calvert confining unit and minor aquifers	
40 – 50	Clay, greenish gray; minor amounts of fine quartz sand, subrounded to angular.
50 – 60	Sand, clayey, silt to fine, mostly quartz, subrounded to rounded; clay in soft chunks, overall color is greenish gray with light yellowish brown, pale green, and brownish yellow; minor lignite.
60 – 130	Clay, dark greenish gray, minor silt to coarse sand, mostly quartz, subrounded to rounded, minor shell fragments, minor silt to fine size dark mineral – glauconite?, minor silt to very fine mica, angular quartz pebbles (most likely from above).
130 – 140	Clay, sandy, dark greenish gray, major very fine to medium sand (mostly fine), quartz, rounded to subrounded, minor lignite.
140 – 150	Clay, sandy, very dark greenish gray, frequent silt to rounded, very fine quartz sand.
Nanjemoy confining unit	
150 – 170	Clay, very dark greenish gray, frequent silt to very fine sand (quartz and mica), minor subangular coarse to very coarse quartz sand.
170 – 260	Clay, dark greenish gray to very dark greenish gray, major amount of glauconite, minor to frequent very fine to coarse sand, rounded to angular, composed mainly of quartz with mica and rock fragments, rare pyrite and shell fragments.
260 – 300	Clay, dark greenish gray and light reddish brown, significant glauconite, frequent silt to coarse sand, subrounded to rounded, mostly quartz, minor to significant shell fragments.
Marlboro Clay confining unit	
300 – 320	Clay, greenish gray to light reddish brown to pinkish gray, significant amount of glauconite, frequent very fine to coarse sand, mostly quartz, subrounded to well-rounded, frequent shell fragments.
Aquia aquifer	
320 – 380	Clay, light red to greenish gray to grayish green, significant amount of glauconite, frequent very fine to coarse sand, mostly quartz, subrounded to well-rounded, rare to frequent shell fragments, rare lignite, rare cemented glauconitic sandstone fragments.
380 – 420	Sand, fine, mostly quartz, subrounded to well-rounded, significant amount of glauconite, frequent to rare shell fragments.
Matawan confining unit	
420 – 430	Sand, very fine to fine, mostly quartz, subrounded to rounded, significant amount of glauconite, very minor shell fragments.

CH Bf 166 (Continued)

Depth, in feet below land surface	Description
Matawan confining unit (Continued)	
430 – 450	Sand, clayey, very fine to fine, mostly quartz, subrounded to rounded, significant amount of glauconite, significant clay, rare shell fragments.
450 – 470	Sand, clayey, very fine to medium, mostly quartz, subrounded to rounded, significant amount of glauconite, significant clay, significant shell fragments (25 percent).
470 – 490	Clay, sandy, greenish gray, fair amount glauconite, significant very fine to medium sand, mostly quartz, subrounded to rounded, significant amount of shell fragments.
490 – 500	Sand, clayey, very fine to medium, rounded to well-rounded quartz, significant shell fragments, significant dark mineral (lignite?), minor clay.
Magothy aquifer	
500 – 510	Sand, very fine to medium, rounded and well-sorted quartz, significant lignite, minor shell fragments, very minor clay and silt.
510 – 520	Sand, clayey, very fine to medium, subangular to rounded quartz, significant amount clay, fair amount of lignite, very minor shell fragments.
520 – 530	Sand, medium, quartz, rounded to well-rounded, frequent lignite, minor shell fragments, very minor clay.
530 – 540	Sand, very fine to medium, quartz, subrounded to well-rounded, frequent pebble-sized lignite, minor very fine shell fragments.
540 – 560	Sand, fine to coarse, quartz, subrounded to rounded, frequent coarse lignite, frequent shell fragments, minor greenish gray clay.
560 – 600	Sand, very fine to coarse, well-sorted quartz, pinkish and purplish gray, angular to subrounded, minor lignite, minor black mineral.
Magothy-Patapsco confining unit	
600 – 620	Sand, very fine to coarse, well-sorted quartz, pinkish and purplish gray, angular to subrounded, minor lignite, minor black mineral, minor pyrite.
620 – 630	Sand, clayey, very fine to coarse, well-sorted quartz, pinkish and purplish gray, angular to subrounded, minor lignite, minor black mineral, minor pyrite, significant soft greenish gray clay.
630 – 650	Clay, sandy, variegated colors: greenish gray to pinkish gray; minor medium to coarse angular quartz sand, significant lignite, significant dark botryoidal mineral.
650 – 660	Sand, very fine, 50 percent quartz / 50 percent botryoidal black mineral, subordinate amount of red particles (possibly clay or iron oxide).
660 – 720	Clay, greenish gray with occasional slight reddish hue, minor amount of very fine quartz grains and botryoidal black mineral grains, clay cuttings occur as very fine particles or alternately liquefied.
720 – 730	Clay, red, with some very fine clear quartz sand, very fine red particles (clay or iron oxide?) and occasional white particles (floating shell?).
730 – 740	Clay, with moderate amount of gritty material; clay is washing out.
Upper Patapsco aquifer system	
740 – 760	Sand, coarse, purple, clear, and occasional pink quartz grains, trace fine particles of pyrite, occasional white particles (floating shells?).
760	(bit sample): Clay, tough, variegated, predominantly brick red with greenish gray and gray.
760 – 770	Sand, medium to coarse, clear quartz; clay in red to gray, fine to medium particles.

CH Bf 166 (Continued)

Depth, in feet below land surface	Description
Upper Patapsco aquifer system (Continued)	
770 – 780	Clay, fine to medium particles, red and gray, with significant amount of medium to coarse clear quartz sand, minor lignite.
780 – 790	Sand, medium, clear with pink and purple grains, well-sorted, trace pyrite.
790 – 870	Clay, occurring in fine to coarse angular particles, variegated in color ranging from brick red to red to gray to brownish yellow; minor sand, medium to coarse, subangular to angular, clear quartz; minor lignite, rare pyrite, spherical medium to coarse tan clasts (concretions?) in lower section.
870 – 880	Sand, clayey, medium to very coarse; medium grains are spherical tan clasts (concretions?); coarse to very coarse grains are angular clear quartz; minor lignite, pyrite, and gray and brick red clay.
880 – 890	Clay, sandy,variegated in grayish green and yellowish brown, minor medium sand, spherical tan clasts (concretions?), minor lignite.
Patapsco confining unit	
890 – 900	Clay, sandy, variegated in grayish green and yellowish brown, minor medium sand, spherical tan clasts (concretions?), minor lignite.
900 – 1,000	Clay, cuttings occurring in fragments, variegated in colors ranging from brick red to greenish gray to gray to yellowish brown; very minor to minor sand, fine to medium angular quartz and fine dark botryoidal mineral, minor lignite.
1,000 – 1,020	Clay, sandy, variegated in angular fragments, significant fine to medium sand, lignite.
1,020 – 1,030	Clay, cuttings occurring in fragments, variegated in colors ranging from brick red to greenish gray to gray to yellowish brown; very minor to minor sand, fine to medium angular quartz and fine dark botryoidal mineral, minor lignite.
Lower Patapsco aquifer system	
1,030 – 1,040	Clay, sandy, variegated in angular fragments, significant fine to medium sand, lignite.
1,040 – 1,060	Sand, medium to coarse, subangular to angular, mainly quartz, well-sorted; very minor clay fragments.
1,060 – 1,070	Sand, clayey, medium to coarse, subangular to angular, well-sorted; significant variegated clay.
1,070 – 1,090	Clay, sandy, variegated; significant medium to coarse, subangular to angular, well-sorted quartz sand.
1,090 – 1,110	Sand, clayey, fine to coarse, subangular to angular; significant variegated clay.
1,110 – 1,120	Sand, fine to medium clean quartz, subrounded, lignite.
1,120 – 1,130	Sand, clayey, fine to coarse, subangular to angular; significant variegated clay.
1,130 – 1,150	Clay, sandy, variegated; significant fine to coarse sand, predominantly quartz, angular.
1,150 – 1,160	Sand, clayey, medium to coarse, subangular to angular quartz, significant variegated clay.
1,160	(bit sample): Clay, tough, variegated (greenish gray and brick red).
1,160 – 1,170	Clay, variegated in colors ranging from greenish gray to gray to brick red; very minor medium to coarse, angular sand, lignite.
1,170 – 1,240	Clay, sandy, variegated; minor medium, angular quartz sand and medium spherical tan clasts (concretions?), lignite.
1,240 – 1,250	Sand, fine to medium, subrounded, well-sorted quartz, significant lignite, significant pyrite, occasional dark botryoidal grains, very minor variegated clay fragments.

CH Bf 166 (Continued)

Depth, in feet below land surface	Description
Lower Patapsco aquifer system (Continued)	
1,250 – 1,270	Sand, clayey, medium, subrounded to subangular quartz; significant variegated clay, significant lignite.
1,270 – 1,320	Sand, medium to coarse, subangular, well-sorted clean quartz, overall bluish-gray in color, occasional botryoidal dark grains, minor variegated clay fragments.
1,320 – 1,330	Sand, clayey, medium to coarse, subangular to subrounded quartz; significant variegated clay.
1,330 – 1,350	Clay, sandy, variegated (mostly brick red); significant medium to coarse, subangular to subrounded quartz sand.
1,350 – 1,360	Clay, variegated; very minor medium quartz sand.
1,360 – 1,370	Clay, sandy, variegated; significant medium to coarse, subangular to angular quartz sand.
1,370 – 1,380	Clay, sandy, variegated; significant fine, subrounded to rounded quartz sand.
1,380 – 1,430	Sand, clayey, fine, subrounded to rounded, well-sorted quartz and botryoidal dark grains, significant variegated clay fragments.
1,430 – 1,500	Sand, fine to coarse, subrounded to rounded, quartz and dark botryoidal grains; minor variegated clay.
Arundel Clay confining unit	
1,500 – 1,520	Clay, sandy, variegated; significant sand, medium to coarse, subrounded to subangular, minor lignite, minor botryoidal dark grains.
1,520 – 1,540	Sand, clayey, fine to coarse, subangular to angular quartz, botryoidal dark grains, lignite; significant variegated clay fragments.
1,540 – 1,570	Clay, sandy, variegated; significant medium to coarse, subangular to angular quartz sand.
1,570 – 1,590	Sand, clayey, coarse, subangular to angular quartz, minor botryoidal dark grains; significant variegated clay fragments.
1,590 – 1,630	Sand, clayey, fine to coarse, subrounded to angular quartz, significant botryoidal dark grains, lignite, pebble-sized rust-colored flat clast; significant variegated clay fragments.
1,630 – 1,650	Sand, medium to coarse, subrounded to angular, well-sorted quartz; minor variegated clay fragments.
1,650 – 1,670	Clay, sandy, occurring in fragments, variegated in colors of greenish gray and brick red; minor medium to fine, angular quartz sand.
1,670 – 1,700	Clay, variegated but mostly greenish gray and brick red; very minor medium to coarse, angular quartz sand.
1,700 – 1,710	Clay, sandy, variegated; minor medium to coarse, subangular to angular quartz sand, lignite.
Patuxent aquifer system	
1,710 – 1,750	Sand, fine to coarse, subrounded to subangular, well-sorted quartz, overall color is bluish gray; minor variegated clay.
1,750 – 1,760	Sand, clayey, fine to medium, subrounded to angular quartz; significant variegated clay fragments.
1,760 – 1,770	Clay, sandy, occurring in fragments, variegated; minor medium to coarse, subangular to angular quartz sand.
1,770 – 1,790	Sand, fine to coarse, subrounded to subangular, fairly clean quartz, trace lignite and botryoidal dark grains, minor variegated clay fragments.
1,790 – 1,810	Clay, sandy, occurring in angular fragments, variegated but mostly greenish gray and brick red; significant fine to coarse, subangular quartz sand.

CH Bf 166 (Continued)

Depth, in feet below land surface	Description
Patuxent aquifer system (Continued)	
1,810 – 1,830	Sand, clayey, fine to coarse, subrounded to subangular, poorly-sorted; significant variegated clay fragments, lignite.
1,830 – 1,860	Sand, fine to coarse, subrounded to angular, poorly-sorted quartz with dark mineral grains, minor lignite; minor variegated clay fragments.
1,860 – 1,890	Clay, sandy, variegated, clay is washing out of sample (soft?); minor sand, medium to coarse, subangular to angular quartz, pyrite clast noted.
1,890 – 1,900	Sand, clayey, fine to medium, very well-rounded to subangular quartz, spherical tan clasts (concretions?), botryoidal dark mineral grains; significant variegated clay fragments.
1,900 – 1,980	Clay, occurring in fine red and gray particles; very minor to minor amount of very fine clear quartz sand.
1,980 – 1,990	Sand, fine, clear quartz; minor fine red clay particles.
1,990 – 1,995	Clay, occurring in very fine red and gray particles; occasional very fine blebs of gray silt with black included particles (greasy smear texture).
1,995 – 1,997	Sand, medium clear quartz, some grains have black mineral stain, trace greenish clay.
	Drilling conditions necessitated finishing prior to reaching basement rock.

CH Bf 167 – Gardiner Road, Waldorf
Land surface elevation = 182 feet above sea level

Depth, in feet below land surface	Description
Surficial Upland aquifer	
0 – 10	Sand to cobbles, mostly quartz (some chert), wide size range from coarse to cobble, but mostly very coarse, overall rounded; minor reddish yellow clay.
10 – 20	Clay, yellow; minor very fine to coarse sand with pebbles and granules as well, mostly quartz with very fine to fine dark mineral, subrounded to rounded (coarse grains and larger have likely fallen from shallower portion of well).
20 – 30	Sand, clayey, silt to very coarse, but mostly coarse, mostly quartz with minor dark mineral grains and rock fragments; significant amount of clay, coating and globules; clay coating is yellow, clay globules are greenish gray and pink; minor organic material.
Calvert confining unit and minor aquifers	
30 – 40	Clay, sandy, yellow to greenish gray to pink; significant amount of silt to coarse sand, subrounded to rounded, mostly quartz, very minor dark minerals.
40 – 50	Clay, grayish green to yellow; frequent silt-sized to coarse sand, mostly quartz and rock fragments with frequent dark minerals, subrounded to rounded.
50 – 60	Clay, dark greenish gray to white to reddish yellow; minor silt-sized to coarse sand, subrounded, mostly quartz with minor rock fragments and dark minerals.
60 – 70	Clay, tough, dark greenish gray; rare fine to coarse quartz sand.
70 – 80	Clay, tough, dark greenish gray; minor silt-sized to very coarse quartz sand with minor rock fragments and frequent dark mineral grains, rounded to subangular, with larger size grains being more angular.
80 – 90	Clay, dark greenish gray; very minor silt-sized to very fine quartz sand with minor dark minerals, well-rounded.
90 – 100	Clay, dark greenish gray; frequent silt-sized to medium quartz sand with minor dark minerals, rounded.
100 – 110	Clay, dark greenish gray; frequent silt-sized to very fine quartz sand with minor dark minerals, rounded, rare angular, very coarse rock fragments (likely fallen from shallower portion of well).
110 – 130	Clay, dark grayish green; frequent silt- to granule-sized sand composed of quartz and rock fragments, smaller grains are mostly rounded quartz while larger grains are mostly angular to subangular rock fragments (chert and grains with oxidized iron) and quartz, frequent lignite.
130 – 140	Clay, dark greenish gray; significant very fine to granule-sized sand, smaller grains are rounded quartz and larger grains are angular rock fragments and quartz, frequent lignite.
Nanjemoy confining unit	
140 – 180	Clay, sandy, dark greenish gray; minor very fine to pebble-sized sand, smaller grains are rounded quartz and larger grains are angular rock fragments (glauconitic sandstone, chert, and quartzite) and quartz, major amount of dark mineral, minor lignite and shell fragments.
180 – 190	Clay, grayish olive; frequent silt-sized to medium quartz sand, subangular, significant amount of dark minor grains (note: sample seems to underrepresent clay content).
190 – 240	Sand, clayey, very fine to coarse, mostly quartz, subrounded, major amount of angular fine dark mineral grains, rare angular and very coarse rock fragments (from above?); significant grayish to dark grayish olive clay.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Nanjemoy confining unit (Continued)	
240 – 250	Sand, very fine to coarse, subrounded quartz, major amount of dark mineral grains; frequent grayish olive clay.
250 – 260	Clay, sandy, grayish olive; significant sand, very fine to mostly coarse, quartz with significant dark mineral grains and rare angular rock fragments.
260 – 270	Clay, sandy, dark grayish green; significant very fine to very coarse sand, quartz with major amount of coarse dark mineral grains, subrounded.
270 – 280	Clay, sandy, light to dark grayish green to light brown; significant amount of silt-sized to coarse sand, mainly subrounded quartz, significant medium and subrounded to rounded dark mineral grains, minor coarse to very coarse angular rock fragments.
280 – 290	Clay, dark greenish gray to light brown; major amount of medium and subrounded dark mineral grains, frequent very fine to medium quartz sand, subrounded.
Marlboro Clay confining unit	
290 – 300	Clay, dark greenish gray to light brown; major amount of fine to medium and subrounded to rounded dark mineral grains, frequent very fine to medium quartz sand, subrounded to rounded.
300 – 310	Clay, sandy, dark greenish gray to light brown; significant amount of very fine to medium rounded sand, significant amount of dark mineral (glauconite?), minor shell fragments.
Aquia aquifer	
310 – 330	Clay, sandy, dark greenish gray to light brown to light and dark grayish olive; frequent very fine to coarse quartz sand, subrounded to rounded, significant glauconite, frequent shell fragments.
330 – 340	Sand, very fine to fine subrounded quartz and very coarse angular glauconitic sandstone fragments, minor shell, minor grayish olive clay.
340 – 360	Sand, clayey, fine to granules, mostly rock fragments, including glauconitic sandstone; clear quartz is rare, significant shell fragments, rare muscovite; significant grayish olive and brown clay.
360 – 380	Clay, sandy, light olive and brown; significant amount of very fine to coarse sand, mostly rounded quartz but also angular glauconitic sandstone fragments, significant amount of glauconite, very minor shell fragments.
380 – 400	Sand, clayey, very fine to granules, rounded to angular (larger clasts are more angular), mostly quartz but larger clasts are mostly rock fragments), significant glauconite, very minor shell fragments, rare muscovite; frequent light olive green to light brown clay.
400 – 410	Clay, sandy, grayish olive to light brown; significant very fine to very coarse sand (very fine to medium clasts are mostly rounded to well-rounded quartz; larger grains are mostly angular rock fragments), significant amount of glauconite, very minor shell fragments.
410 – 420	Sand, clayey very fine to granules (very fine to medium clasts are mostly rounded to well-rounded quartz; larger grains are mostly angular rock fragments), significant shell fragments; significant amount of light reddish brown to gray to dark grayish green clay.
420 – 430	Clay, sandy, dark olive green; significant very fine to very coarse sand (very fine to medium clasts are mostly rounded to well-rounded quartz; larger grains are less frequent and are mostly angular rock fragments), significant amount of glauconite, rare shell fragments.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Aquia aquifer (Continued)	
430 – 440	Clay, sandy, light red to reddish gray to dark olive green; significant very fine to very coarse sand (very fine to medium clasts are mostly rounded to well-rounded quartz; larger grains are mostly angular rock fragments), significant amount of glauconite, frequent shell fragments.
440 – 450	Sand, clayey, fine to medium, subangular, abundant rounded glauconite, significant shell fragments; minor light gray silty clay.
450 – 480	Sand, fine to very coarse (predominantly subangular, fine to medium grains with occasional very coarse subangular purplish quartz), significant medium to very coarse glauconite, rare shell fragments; minor pinkish red clay.
Matawan confining unit	
480 – 500	Sand, medium to very coarse, rounded to subangular pinkish to purple quartz; noted pyrite and glauconite; minor pink clay.
500 – 540	Sand, clayey, medium subangular to subrounded quartz, significant glauconite, shell fragments, noted pinkish-tan, rice-grain shaped, medium-sized microfossils; significant clay in colors ranging from gray to pink to brick red.
Magothy aquifer	
540 – 550	Sand, very fine to fine, clean white quartz, subangular to subrounded, very infrequent glauconite, very infrequent pink clay.
550 – 570	Sand, medium to coarse, subangular, minor glauconite, noted pinkish-tan, rice-grain shaped, medium-sized microfossils.
570 – 600	Sand, fine to medium, well-sorted, clean white quartz, very minor glauconite, rare to frequent lignite; very minor variegated clay.
600 – 610	Sand, fine to very coarse, subrounded, well-sorted, clean white sand, very minor lignite; very minor variegated clay.
610 – 620	Sand, fine to very coarse (dominant), subangular to rounded, fairly well-sorted, mostly varicolored quartz, very minor rock fragments, rare pyrite; very minor clay.
Magothy-Patapsco confining unit	
620 – 630	Sand, clayey, fine to coarse (dominant), subangular to subrounded, mostly well-sorted, clear quartz, rare pyrite, very minor green mineral, very minor lignite; significant amount of light greenish gray clay.
630 – 640	Sand, clayey, very fine to very coarse (mostly fine to medium), subangular to rounded, mostly clear quartz, significant lignite; significant yellow and greenish gray clay.
640 – 680	Clay, sandy, yellow to greenish gray to dark greenish gray; significant very fine to very coarse sand, subangular to rounded, mostly clear quartz, poorly-sorted to moderately well-sorted, significant glauconite, significant to rare lignite, rare shell fragments.
Upper Patapsco aquifer system	
680 – 690	Clay, sandy, yellow to greenish gray to dark greenish gray; significant very fine to medium sand, subrounded to rounded, mostly clear quartz, mostly well-sorted, significant amount of glauconite, very minor shell fragments.
690 – 710	Sand, very fine to medium, well-sorted, subrounded to rounded clear quartz, frequent glauconite, minor lignite, minor greenish gray clay.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Upper Patapsco aquifer system (Continued)	
710 – 730	Clay, sandy, greenish gray; significant very fine to medium, well-sorted, rounded clear quartz sand, frequent glauconite, minor lignite.
730 – 740	Clay, sandy, pale green to grayish green to light grayish green; significant very fine to coarse, subangular to rounded sand, predominantly quartz with very minor rock fragments, frequent glauconite, minor lignite.
740 – 760	Clay, light grayish green to pale green to light reddish brown to light red; frequent very fine to coarse, angular to rounded quartz sand with very minor rock fragments, frequent glauconite, significant lignite, very minor shell fragments.
760 – 780	Sand, very fine to very coarse, angular to rounded, poorly sorted, significant lignite, minor glauconite, rare shell fragments, significant variegated clay.
780 – 790	Sand, very fine to coarse, subrounded to rounded, well-sorted, mostly quartz, minor lignite, very minor variegated clay.
790 – 810	Sand, fine to medium, clear to white to occasional pink grains, lignite, minor dark green clay.
810 – 820	Sand, medium, well-sorted, clear to white to occasional pink and purple grains.
820 – 830	Sand, fine to medium, clear to white to occasional pink grains, lignite, minor dark green clay.
830 – 840	Sand, fine to medium, clear to white to occasional pink grains, lignite, significant dark green clay.
840 – 850	Sand, fine to medium, with occasional coarse grains, clear to white and occasional pink and purple grains, trace lignite and black hematite nodules, moderate amount of green clay with very fine black particles in matrix.
850 – 860	Clay, dark olive green, soft, with silt-sized black particles.
860 – 870	Clay, (poor quality sample: very “soupy” consistency, clay washing out).
870 – 890	Sand, very fine to fine, well-sorted, clean, equal amounts of clear and white grains.
890 – 950	Sand, very fine to silt-sized, abundant small fragments of lignite, occasional dark green liquefied clay.
Patapsco confining unit	
950 – 990	Sand, fine to medium, angular to subrounded, mostly quartz, significant fine dark globular nodules, significant lignite, notable tan and orange spherical medium and fine clasts (concretions?), minor green clay.
990 – 1,010	Sand, clayey, fine to coarse, angular to subrounded, quartz, significant lignite, significant fine dark nodules, significant variegated clay in colors ranging from grayish green to pink to dark and light gray to brick red.
1,010 – 1,020	Clay, sandy, variegated but mostly greenish gray; significant fine to medium, angular to subangular quartz sand.
1,020 – 1,040	Sand, clayey, fine to coarse, angular to subrounded, quartz, significant lignite, significant fine dark nodules, significant variegated clay in colors ranging from grayish green to pink to dark and light gray to brick red.
1,040 – 1,060	Clay, sandy, soft (washing out), dark greenish gray to light gray; significant fine to medium, angular to subangular quartz sand, dark nodules and lignite present.
1,060 – 1,070	Sand, clayey, fine to medium, angular to subrounded, quartz, significant lignite, significant fine dark nodules, significant variegated clay in colors ranging from grayish green to pink to dark and light gray to brick red.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Lower Patapsco aquifer system	
1,070 – 1,080	Sand, clayey, fine to medium, angular to subrounded, quartz, significant lignite, significant fine dark nodules, significant variegated clay in colors ranging from grayish green to pink to dark and light gray to brick red.
1,080 – 1,090	Sand, fine to coarse, fairly clean subangular to subrounded quartz, minor lignite, minor dark nodules, very minor gray clay.
1,090 – 1,100	Clay, sandy, variegated but mostly dark greenish gray; significant fine to coarse, fairly clean subangular to subrounded quartz sand, minor lignite, minor dark nodules.
1,100 – 1,110	Clay, sandy, variegated in color ranging from dark greens to reds to light brown; significant very fine to medium subrounded to rounded quartz sand.
1,110 – 1,130	Clay, light brown to dark red; significant dark mineral (lignite?), minor to frequent very fine to medium, rounded quartz sand.
1,130 – 1,140	Sand, clayey, very fine to medium, rounded, mostly quartz; significant amount of clay in colors ranging from pale green to grayish green to pink to light brown to dark red, significant lignite.
1,140 – 1,210	Sand, very fine to coarse, subrounded to rounded, mostly quartz; minor to significant variegated clay in colors from grayish green to dark red to pink to light brown, significant lignite.
1,210 – 1,220	Sand, clayey, very fine to medium, rounded to well-rounded, mostly quartz; significant amount of variegated clay in colors ranging from dark gray green to red to brown, significant lignite.
1,220 – 1,260	Sand, very fine to coarse, mostly rounded to well-rounded quartz with occasional muscovite fragments; frequent variegated clay in colors ranging from red to grayish green to pink to brown, frequent lignite, rare shell fragments.
1,260 – 1,270	Sand, clayey, very fine to coarse, subrounded to well-rounded quartz; significant variegated clay in colors from dark red to grayish green to pink to light brown, frequent lignite, rare shell fragments.
1,270 – 1,320	Sand, very fine to coarse, subangular to rounded quartz; minor to frequent variegated clay in colors from grayish green to dark red to brown, minor to frequent lignite.
1,320 – 1,330	Sand, clayey, very fine to coarse, subrounded to rounded quartz; significant variegated clay in colors ranging from grayish green to dark red to light brown to pink, frequent lignite.
1,330 – 1,340	Sand, medium to coarse, clear white, purple, and green grains, well-sorted.
1,340 – 1,360	Sand, medium, mostly clear and purple grains, well-sorted.
1,360 – 1,390	Sand, very fine to fine, well-sorted, mostly clear grains; minor fraction of clay and silt.
1,390 – 1,400	Sand, very fine to medium, well-sorted, clear, white, and purple grains; minor dark gray green clay.
1,400 – 1,410	Sand, medium, well-sorted, clear, white, purple, and green grains; fragments of red clay.
1,410 – 1,460	Sand, medium; clay – poor sample (very “soupy” and appears that clay is being washed out or liquefied in sample).
1,460 – 1,470	Sand, very fine to fine, well-sorted, mostly clear quartz (interval drilled smoothly and quickly).
1,470 – 1,480	Sand, very fine, clear quartz with moderate amounts of very fine to silt-size black particles (botryoidal – hematite?).
1,480 – 1,490	Silt, clear quartz, with minor specks of black particles (hematite?) and trace mica.
1,490 – 1,500	Sand, very fine, well-sorted, very clean and clear with white quartz.
1,500 – 1,560	Sand, very fine to coarse (mostly quartz), subrounded to rounded, mostly quartz, minor dark mineral (lignite?), minor pale green grains; minor brown, red, and green clay.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Lower Patapsco aquifer system (Continued)	
1,560 – 1,590	Sand, coarse, subrounded to rounded, very well-sorted quartz with very minor dark mineral grains; minor to very minor clay.
Arundel Clay confining unit	
1,590 – 1,610	Sand, very fine to coarse, subrounded to rounded, mostly quartz with very minor dark mineral; minor clay.
1,610 – 1,620	Sand, clayey, very fine to coarse, subrounded to rounded, mostly quartz, very minor lignite; significant amount of green, red, and yellow clay.
1,620 – 1,640	Clay, sandy, grayish green to dark red to brown; significant amount of very fine to coarse, subrounded to rounded quartz sand, frequent lignite.
1,640 – 1,720	Clay, sandy, occurring in fragments colored pale green to light greenish gray to pink to dark red to dark brown to yellow; significant amount of very fine to coarse, subrounded to subangular quartz sand, frequent lignite, fine dark botryoidal grains (seem to occur within a gray to dark gray clay).
1,720	(bit sample): Clay, very stiff and tough, variegated but predominantly reddish brown; thin layers of fine to medium sand occur within clay.
1,720 – 1,750	Clay, sandy, occurring in fragments, variegated but mostly brick red and greenish gray but also white and tan; minor medium to coarse, angular to subrounded quartz sand, lignite, botryoidal dark grains.
1,750 – 1,770	Sand, clayey, coarse to very coarse, subangular to rounded (mostly subrounded), quartz; significant variegated clay occurring in fragments or in medium-sized spherical concretions.
1,770 – 1,810	Clay, sandy, variegated in fine to medium angular fragments; significant fine to medium, angular to subangular sand, lignite, botryoidal dark mineral.
Patuxent aquifer system	
1,810 – 1,880	Sand, fine to medium, subrounded clean quartz, tan-gray in overall color, minor fine lignite; very minor to minor gray and red clay.
1,880 – 1,890	Sand, clayey, fine to medium, subrounded clean quartz, tan-gray in overall color, minor fine lignite; significant variegated clay in fragments.
1,890 – 1,930	Clay, sandy, variegated, occurring in fragments; significant medium to coarse, subangular to subrounded quartz sand, lignite, botryoidal dark mineral.
1,930 – 1,940	Sand, clayey, fine to medium, angular to subangular quartz, lignite, botryoidal black mineral; significant variegated occurring in coarse fragments.
1,940 – 1,950	Sand, fine to medium, subrounded clean quartz, bluish gray in overall color, lignite; very minor gray clay.
1,950 – 1,960	Sand, clayey, medium to coarse, angular to subrounded quartz, lignite; significant variegated clay in coarse fragments.
1,960 – 1,980	Clay, sandy, tough, variegated in coarse angular fragments; significant fine to medium angular to subangular sand.
1,980 – 1,990	Sand, clayey, fine to medium, angular to subangular quartz, lignite, botryoidal dark mineral; significant variegated clay fragments.
1,990 – 2,010	Sand, fine to medium, subangular to subrounded quartz, lignite, fine botryoidal dark mineral; minor to frequent variegated clay fragments.
2,010 – 2,060	Sand, medium to coarse, subangular to subrounded quartz, lignite, fine botryoidal dark mineral; minor to frequent variegated clay fragments.

CH Bf 167 (Continued)

Depth, in feet below land surface	Description
Patuxent aquifer system (Continued)	
2,060 – 2,070	Sand, coarse, angular, mainly quartz but increasing variety of grain composition, some light green and pink clasts, some quartz grains appear to be coated with dark mineral on surface; minor variegated angular clay fragments.
2,070 – 2,080	Sand, clayey, fine to medium, angular to subangular quartz, variety of grain composition, frequent botryoidal dark mineral, frequent lignite, spheroidal tan clay concretions; significant variegated clay in fragments.
2,080 – 2,090	Sand, medium, subangular to subrounded, mainly quartz, but diverse mineralogy; frequent variegated clay fragments.
2,090 – 2,110	Sand, coarse, angular to subangular, diverse mineralogy, some quartz grains appear to have surface staining (red or green), lignite, pyrite; blue-green clay (saprolite?) along with variegated clay clasts (including white spheroidal clasts). [Bit started ratcheting at 2,099 feet.]
2,110 – 2,120	Sand, coarse, angular, diverse mineralogy, mainly quartz (conchoidally-fractured?); bluish crumbly clay (saprolite?) along with variegated clay fragments.
Basement rock	
2,120	(bit sample): Clay, tough, variegated but predominantly gray to blue gray to orange; pebble- to cobble-sized fragments are predominantly red to orange and blue-gray mudstone or siltstone (appears to be consistent with Triassic metasedimentary “red-bed” petrology), rare cobbles and pebbles of clear quartz.

CH Ce 66 – White Plains Regional Park, St. Charles
Land surface elevation = 179 feet above sea level

Depth, in feet below land surface	Description
Surficial Upland aquifer	
0 – 10	Sand and gravel, medium to very coarse, mainly quartz sand with occasional gravel up to 2 centimeters, reddish yellow, poorly-sorted, subangular to rounded.
Calvert confining unit and minor aquifers	
10 – 30	Clay, silty, greenish gray to light-yellowish brown.
30 – 60	Clay, soft, silty greenish gray, very fossiliferous with marine mollusk fossils (many aragonitic).
60 – 70	Sand, clayey, very fine to very coarse, mostly quartz, subrounded to subangular, minor dark greenish-gray clay, frequent shell fragments.
70 – 80	Clay, dark greenish gray, fair amount of very coarse, subangular quartz sand, frequent shell fragments and fossils (including tubular-shaped fossils).
80 – 90	Clay, sandy, olive gray, very coarse, subangular, mostly quartz sand, frequent shell fragments and fossils (including tubular-shaped fossils).
90 – 100	Clay, olive gray to yellow, rare shell fragments, minor glauconite.
100 – 110	Clay, sandy, olive gray, fine to very coarse quartz sand, subrounded, frequent glauconite and fossil fragments.
110 – 120	Clay, olive gray to brownish yellow to greenish gray, minor very coarse, subangular, quartz sand, frequent glauconite and fossil fragments.
Nanjemoy confining unit	
120 – 130	Clay, greenish gray, frequent glauconite, fair amount of very fine to medium sand, quartz, rounded to subrounded, rare shell fragments; concreted slab-like clay chunks 1 inch and larger in size.
130 – 140	Clay, as above, but no concreted chunks; minor sand is very fine to medium, increasing glauconite.
140 – 150	Clay, dark greenish gray to reddish yellow, very frequent glauconite, minor very fine to granule-sized, rounded to subrounded quartz sand, rare shell fragments.
150 – 230	Clay, dark greenish gray, significant amount of glauconite, minor very fine to pebble-sized, subrounded to rounded quartz sand, rare shell fragments.
Marlboro Clay confining unit	
230 – 250	Clay, light reddish brown to dark greenish gray.
Aquia aquifer (mostly non-aquifer facies)	
250 – 280	Clay, dark greenish gray, significant amount of shell fragments and glauconite, rare fine to medium, rounded quartz sand, angular fragments of cemented quartz sand.
280 – 290	Clay, pale green, significant amount of glauconite, frequent shell fragments, minor fine to medium, rounded quartz sand, angular pebbles of quartz sandstone.
290 – 400	Clay and sandy clay, dark greenish gray with minor occurrence of reddish brown, significant amount of glauconite; frequent very fine to coarse, rounded quartz sand, minor shell fragments.

CH Ce 66 (Continued)

Depth, in feet below land surface	Description
Matawan confining unit	
400 – 420	Clay, sandy, dark greenish gray; minor sand, very fine to coarse, subangular to rounded quartz, frequent glauconite, rare shell fragments.
Magothy aquifer	
420 – 430	Sand, clayey, very fine to coarse, subangular to subrounded quartz, minor dark greenish gray clay, frequent glauconite, rare shell fragments.
430 – 460	Sand, very fine to very coarse, angular to subrounded, mostly quartz, minor feldspar and pyrite; minor dark greenish gray and pink clay, minor glauconite.
460 – 480	Sand, fine to very coarse, mostly quartz, minor feldspar, angular to rounded, moderately-sorted, minor glauconite, rare clay.
480 – 490	Sand, fine to very coarse, mostly quartz, minor feldspar, subangular to rounded, well-sorted, minor glauconite, rare clay.
Magothy-Patapsco confining unit	
490 – 530	Clay, sandy, light gray to pink to yellow to gray, significant very fine to medium subrounded quartz sand, minor angular pebbles of quartz, sodium plagioclase, and potassium feldspar, frequent lignite.
530 – 550	Sand, clayey, very fine to coarse, mostly rock fragments, angular to subrounded, frequent greenish gray to yellow to white clay, frequent lignite, rare shell fragments.
Upper Patapsco aquifer system	
550 – 570	Sand, very fine to medium, subrounded quartz, rare angular quartz granules, minor lignite, minor grayish green clay.
570 – 580	Clay, sandy, gray to yellow to white, significant amount of very fine to very coarse quartz sand, minor rock fragments and plagioclase, minor lignite.
580 – 600	Sand, fine to coarse, mostly quartz, subrounded to subangular, minor clay, rare lignite, rare shell fragments.
600 – 620	Clay, sandy, variegated colors: white to light gray to very pale brown; significant fine to very coarse, subangular to angular quartz sand, significant lignite.
620 – 630	Sand, clayey, fine to coarse, subangular to angular, diverse clast composition (pink, green, rock fragments, mica), minor light brownish gray clay.
630 – 640	Sand, medium to coarse, subrounded to subangular, mostly quartz with minor coarse-sized black constituent (looks botryoidal like glauconite).
640 – 810	Sand, clayey, fine to very coarse, subrounded to subangular, mostly quartz with minor coarse-sized black constituent (looks botryoidal like glauconite), minor to significant variegated clay in colors ranging from light brownish gray to light gray to yellow to pinkish gray.
Patapsco confining unit	
810 – 830	Clay, sandy, red to white to pinkish white to bluish gray, frequent fine to coarse quartz sand, fairly well-sorted, angular to subrounded, minor lignite.
830 – 840	Clay, red to white to pinkish white to bluish gray, very minor fine to medium, rounded sand, minor lignite.
840 – 850	Clay, sandy, red to white to pinkish white to bluish gray, minor medium to very coarse, rounded to angular quartz sand.

CH Ce 66 (Continued)

Depth, in feet below land surface	Description
Patapsco confining unit (Continued)	
850 – 900	Clay, variegated in colors ranging from red to yellowish red to dark reddish brown to light gray to light bluish gray to yellow to greenish gray to dark greenish gray; very minor fine to very coarse quartz sand, subrounded to angular, frequent lignite.
900 – 930	Clay, sandy, variegated in colors ranging from red to yellowish red to dark reddish brown to light gray to light bluish gray to yellow to greenish gray to dark greenish gray; frequent very fine to coarse quartz sand, subangular to rounded, significant lignite.
930 – 940	Clay, variegated in colors ranging from red to yellowish red to dark reddish brown to light gray to light bluish gray to yellow to greenish gray to dark greenish gray.
940 – 970	Clay, gray and red, recovered in coarse fragments, occasional white quartz grains.
970 – 1,010	Clay, dark gray to red to purple, recovered in fragments.
Lower Patapsco aquifer system	
1,010 – 1,020	Clay, light to dark gray, red, and purplish brown, recovered in larger fragments.
1,020 – 1,030	Clay, as above, with trace fine gritty material.
1,030 – 1,040	Sand, medium to coarse, clear, light pink, light purple, subrounded; driller reports streaky layers of sand and clay in interval.
1,040 – 1,050	Sand, as above but fine grained and included clay chips. Driller reports drilling like clay – very slow progress.
1,050 – 1,060	Clay, sandy, variegated in color ranging from light gray to light brownish gray to reddish brown; significant fine to medium, subrounded to angular sand.
1,060 – 1,100	Clay, variegated in color ranging from light gray to light brownish gray to reddish brown; very minor amount of fine to medium sand.
1,100 – 1,110	Sand, coarse, predominantly clear and bluish quartz, subrounded to angular, well-sorted; very minor clay.
1,110 – 1,130	Clay, sandy, variegated; significant sand, quartz, medium to coarse, subrounded to subangular.
1,130 – 1,140	Sand, clayey, medium to coarse, predominantly quartz, subrounded to subangular; significant variegated clay.
1,140 – 1,180	Clay, sandy, variegated; significant fine to medium sand, predominantly quartz, subrounded to subangular.
1,180 – 1,190	Clay, variegated; minor amounts of fine to medium sand.
1,190 – 1,210	Sand, clayey, medium to coarse, quartz, subangular; significant tough variegated clay returned in fragments.
1,210 – 1,240	Sand, clayey, very fine to very coarse, predominantly quartz, subangular to rounded, minor lignite; significant variegated clay fragments in colors ranging from red to light greenish gray to dark bluish gray to pale green to white.
1,240 – 1,280	Clay, sandy, variegated in colors ranging from red to light greenish gray to dark bluish gray to pale green to pink to white; significant sand, very fine to coarse, mainly subangular quartz, rare lignite.
1,280 – 1,300	Sand, clayey, very fine to very coarse, subangular to rounded, mostly quartz; minor variegated clay in colors ranging from red to light greenish gray to dark bluish gray to pale green to pink to white, rare lignite fragments.
1,300 – 1,350	Clay, sandy, variegated in colors ranging from red to light greenish gray to dark bluish gray to pale green to pink to white to yellow to pale olive; minor sand, very fine to coarse, mainly quartz, subangular to rounded, rare lignite fragments.

CH Ce 66 (Continued)

Depth, in feet below land surface	Description
Arundel Clay confining unit	
1,350 – 1,360	Clay, variegated in colors ranging from yellowish red to dark greenish gray to light greenish gray to white to dark red to yellow to pink; minor sand, very fine to very coarse, mainly quartz, subangular to angular, minor lignite.
1,360 – 1,370	Clay, sandy, tough, variegated in colors ranging from yellowish red to dark greenish gray to light greenish gray to white to dark red to yellow to pink; minor sand, very fine to coarse, mainly quartz, subangular, minor rounded dark mineral.
1,370 – 1,400	Clay, variegated in colors ranging from gray to red to green to brown, fine particle size, minor amounts of clear quartz silt and very fine sand, occasional black botryoidal grains of very fine size.
1,400 – 1,430	Clay, variegated in colors ranging from red to gray to white, minor very fine clear quartz sand, trace black botryoidal grains of very fine size.
1,430 – 1,450	Clay, variegated in colors ranging from red to light gray to dark gray, minor very fine clear, purple, and pink quartz sand.
1,450 – 1,470	Sand, very fine to silt, clear quartz with some light purple grains; driller reports clay layers as well.
1,470 – 1,490	Clay, red and gray; minor silt.
1,490 – 1,500	Clay, variegated in colors ranging from light gray to reddish brown to light brownish gray; minor sand, medium to coarse, subangular to angular.
Patuxent aquifer system	
1,500 – 1,520	Sand, clayey, fine to medium, subangular to angular, poorly sorted, significant lignite; significant variegated clay in angular fragments.
1,520 – 1,540	Sand, medium to coarse, subrounded to subangular, well-sorted; minor variegated clay fragments.
1,540 – 1,560	Sand, clayey, fine to coarse, subangular to angular, poorly sorted; significant variegated clay fragments, minor lignite.
1,560 – 1,570	Sand, medium to coarse, subrounded to subangular, well-sorted, mainly quartz; minor variegated clay, lignite.
1,570 – 1,610	Sand, clayey, fine to coarse, subangular to angular, poorly sorted, lignite; significant variegated clay.
1,610 – 1,630	Sand, fine to medium, overall tan color, subrounded to subangular, well-sorted; minor variegated clay fragments, lignite.
1,630 – 1,640	Sand, medium to coarse, subrounded to subangular, well-sorted, mainly clean quartz with very little lignite.
1,640 – 1,650	Sand, clayey, medium to coarse, subrounded to angular, quartz; significant variegated clay fragments.
1,650 – 1,670	Clay, sandy, variegated in colors ranging from reddish yellow to light greenish gray to dark greenish gray to yellowish red; minor very fine to coarse sand, subrounded to rounded, mainly quartz, minor lignite.
1,670 – 1,710	Clay, variegated in colors ranging from reddish yellow to light greenish gray to dark greenish gray to yellowish red; minor sand, silt to medium, subrounded to rounded, quartz, minor lignite.
1,710 – 1,720	Sand, clayey, very fine to coarse, subrounded, quartz, minor lignite.
1,720 – 1,740	Sand, very fine to very coarse, subrounded to subangular, quartz, minor lignite; very minor to frequent variegated clay in colors ranging from greenish gray to red to white to reddish yellow.

CH Ce 66 (Continued)

Depth, in feet below land surface	Description
Patuxent aquifer system (Continued)	
1,740 – 1,750	Clay, sandy, variegated in colors ranging from greenish gray to red to white to reddish yellow; frequent sand, very fine to very coarse, subangular to subrounded, quartz, minor lignite.
1,750 – 1,760	Clay, variegated in colors ranging from pink to greenish gray to white to yellow to dark reddish brown; very minor fine to very coarse quartz sand, angular to subrounded, very minor lignite.
1,760 – 1,780	Clay, sandy, variegated in colors ranging from pink to greenish gray to white to yellow to dark reddish brown; significant fine to coarse quartz sand, subrounded to angular, poorly sorted, diverse composition, significant lignite.
1,780 – 1,790	Sand, clayey, fine to medium, subrounded to angular, quartz; minor variegated clay.
1,790 – 1,800	Clay, sandy, variegated ; minor sand, fine to medium, subrounded to angular, quartz.
1,800 – 1,840	Sand, fine to very coarse, subangular to angular, quartz, significant botryoidal dark mineral; minor light grayish green clay.
1,840 – 1,870	Sand, fine to coarse, subrounded to angular, quartz and rock fragments; significant variegated clay fragments.
1,870 – 1,880	Sand, fine to medium, subrounded, well-sorted, clear quartz; minor variegated clay fragments.
1,880 – 1,890	Sand, clayey, medium to coarse, subangular to angular, quartz; minor variegated clay fragments.
1,890 – 1,920	Sand, medium to very coarse, angular,quartz; minor variegated soft clay.
1,920 – 1,950	Sand, clayey, fine to very coarse, subangular to angular, quartz and rock fragments, lignite, flakey rust-like iron mineral, increasing fraction of dark fines (makes sample appear "salt-and-peppery"); significant variegated clay including bluish and brick-red clay fragments.
Basement rock	
1,950 – 1,955	Sand and broken crystalline rock, angular coarse fragments of quartz and weathered rock, fine dark (hematite?) concretions, small plates of mica (?) embedded in cruddy, waxy, weathered rock, angular fragments of brick-red rotten siltstone.
**1,955	(bit and collar sample): Very dense brick-red clay with stringers of bluish-green saprolite, some rock fragments recovered: light greenish-blue metasedimentary rock (?), tough brick- red siltstone, frequent dark minerals, one fragment has frequent pyrite.

** Sample may not be representative of indicated depth.

Appendix C. Well-construction records for selected wells and test holes in the study area.

Well number	Permit number	Owner	Driller	Altitude of land surface (feet)	Completion year	Hole depth (feet below land surface)	Diameter of screen (inches)	Screen interval (feet below land surface)	Aquifer	Pumping-test data						Remarks
										Static water level (feet below land surface)	Date reported	Yield (gallons per minute)	Drawdown (feet)	Specific capacity (gallons per minute per foot)	Duration of test (hours)	
CH Bb 10	--	US Navy	--	26	1920	1,200	--	--	Basement	--	--	--	--	--	--	m
CH Bb 22	CH-88-0847	US Navy	US Geological Survey	98	1989	700	2	200 - 205	Lower Patapsco	130	1990	--	--	--	--	m
CH Bb 23	CH-94-6563	US Naval Surface Warfare Center, Indian Head	A.C. Schultes of Maryland	110	2005	725	10	540 - 710*	Patuxent	175	11/28/2005	543	151	3.6	24	m
CH Bc 61	CH-05-6515	Potomac Heights, Test Well	Layne-Atlantic	70	1964	875	2	439 - 444	Lower Patapsco	122	4/10/1964	6	--	--	48	m
CH Bc 75	CH-92-0500	Chapman's Landing	Sydnor Hydrodynamics	124.59	1993	1,160	8	820 - 923*	Patuxent	121	6/25/1993	500	85	5.9	72	
CH Bc 77	CH 88-1028	Chapman's Landing	Branham Contractors	96.64	1990	990	6	925 - 955	Patuxent	94	8/10/1990	270	80	3.4	24	h
CH Bc 78	CH-88-1028	Charles Co. DPF, South Hampton Well 2	Sydnor Hydrodynamics	34	1995	815	6	675 - 790*	Patuxent	16	9/15/1995	750	294	2.6	24	h
CH Bc 80	CH-94-0897	MD Geological Survey	A.C. Schultes of Maryland	123.13	1996	1,140	4	1,085 – 1,115*	Patuxent	129.07	8/29/1996	37	146.41	0.3	12	c,m
CH Bc 84	CH-95-0855	Town of Indian Head #6R	A.C. Schultes of Maryland	30	2009	820	8	602 - 792*	Patuxent	162	4/6/2009	300	316	1	24	m
CH Bd 52	CH-94-0899	MD Geological Survey	A.C. Schultes of Maryland	47.5	1996	1,043	4	1,043 – 1,095*	Patuxent	48.5	10/8/1996	60	50.1	1.2	12	c,h,m
CH Bd 58	CH-94-5552	Charles Co. DPF, Bryans Road #6	A.C. Schultes of Maryland	180	2003	1,274	6	990 - 1,098*	Patuxent	198	3/16/2004	622	275	2.3	72	m
CH Bd 59	CH-12-0403	Charles Co. DPF, Bryans Road #7	A.C. Schultes of Maryland	170	2014	1,241	10	981 - 1,198*	Patuxent	262.24	4/14/2014	550	204.46	2.7	72	c,m
CH Be 57	CH-81-1194	Charles Co. DPF, Smallwood West	Layne-Atlantic	212.26	1985	1,802	4	1,660 – 1,696	Patuxent	199.4	6/12/1985	36	80	0.5	--	c,h,m
CH Bf 144	CH-73-2423	Charles Co. DPF, Pinefield	Layne-Atlantic	210	1979	1,967	12	479.5 - 700*	Magothy	203.5	2/1/1980	520	38	13.7	--	m
CH Bf 146	CH-81-0593	Charles Co. DPF, St. Paul	Sydnor Hydrodynamics	193	1983	1,654	6	1,059 - 1,417*	Lower Patapsco	200	12/23/1983	165	49	3.4	8	m
CH Bg 18	CH-95-1036	Malcolm, Chalk Point off-site Observation Well	A.C. Schultes of Maryland	190	2009	2,316	4	1,914 - 2,049*	Patuxent	200	9/28/2009	41	259	0.2	24	c,h,m
CH Cb 10	--	US Navy (Powder Factory)	Washington Pump & Well	20	1945	610	--	--	Patuxent	--	1953	52	--	--	--	m
CH Cb 35	CH-81-0572	US Navy	East Coast Well & Pump	25	1984	503	4	433 - 486*	Patuxent	84	12/6/1984	226	171	1.3	24	
CH Cb 45	CH-94-6564	US Naval Surface Warfare Center, Stump Neck	A.C. Schultes of Maryland	130	2005	720	8	542 - 698*	Patuxent	183	9/22/2005	115	127	0.9	24	m
CH Cc 34	CH-94-0898	MD Geological Survey	A.C. Schultes of Maryland	41.82	1996	1,170	4	874 - 955*	Patuxent	48.52	7/19/1996	50	141.65	0.4	12	h,m
CH Cc 36	CH-94-2108	Charles Co. DPF, Hunter's Brook #1	Sydnor Hydrodynamics	135	1999	1,165	--	915 - 1,155*	Patuxent	159.5	5/6/2005	300	167	1.8	24	
CH Cc 39	CH-94-5757	Charles Co. DPF, Hunter's Brook #2	A.C. Schultes of Maryland	130	2005	1,220	8	924 - 1,142*	Patuxent	142	5/9/2005	303	59	5.1	24	
CH Cd 30	CH-68-0042	Utilco, Inc., Pomfret Estates	Sydnor Hydrodynamics	193	1968	1,346	4	936 - 1,330*	Lower Patapsco	175	6/28/1968	68	107	0.6	12	m
CH Ce 37	CH-73-0219	US Geological Survey	Sydnor Hydrodynamics	185	1974	2,014	4	1,147 - 1,340*	Lower Patapsco	189	11/12/1973	120	30	4	24	c,m
CH Ce 57	CH 94-1112	Town of La Plata	Sydnor Hydrodynamics	193.47	1997	1,871	4	1,406 – 1,698*	Patuxent	--	--	--	--	--	--	h,m
CH Da 18	CH-73-0586	PEPCO, Douglas Point	A.C. Schultes of Maryland	89.9	1975	772	8	684 - 740*	Patuxent	--	--	--	--	--	--	h,m
CH Ee 96	CH-95-0158	Mirant Corp., Morgantown Power Plant	A.C. Schultes of Maryland	20	2006	1,844	6	1,434 - 1,721*	Patuxent	49	12/12/2006	299	221	1.4	72	h,m
PG Eb 1	--	WSSC, Forest Heights, Well 1	Layne-Atlantic	20	1945	603	8	357 - 588*	Patuxent	100	12/18/1945	439	240	1.8	48	
PG Eb 2	PG-339	WSSC, Forest Heights, Well 2	Layne-Atlantic	22	1946	630	8	277 - 605*	Patuxent	102	9/10/1946	540	122	4.4	24	
PG Eb 26	PG-25967	WSSC, Fort Foote	Layne-Atlantic	150	1957	828	12	239 - 578*	Patuxent	143	4/16/1957	143	113	1.3	12	m

Appendix C. Well-construction records for selected wells and test holes in the study area--Continued.

Well number	Permit number	Owner	Driller	Altitude of land surface (feet)	Completion year	Hole depth (feet below land surface)	Diameter of screen (inches)	Screen interval (feet below land surface)	Aquifer	Pumping-test data: Static water level (feet below land surface)	Pumping-test data: Date reported	Pumping-test data: Yield (gallons per minute)	Pumping-test data: Drawdown (feet)	Pumping-test data: Specific capacity (gallons per minute per foot)	Pumping-test data: Duration of test (hours)	Remarks
PG Ec 41	PG-38527	WSSC, Southlawn	Layne-Atlantic	179	1960	875	6	241 - 650*	Lower Patapsco & Patuxent	150 147	6/24/1960 6/24/1960	320 275	75 53	4.3 5.2	6 6	m
PG Ec 46	PG-39072	WSSC, Kerby Hill Pumping Station	Layne-Atlantic	71	1960	804	6	577 - 597	Patuxent	46	9/22/1960	285	164	1.7	8	
PG Ee 50	PG-5	Washington Gas Light Co., Butler No. 2	Eakle & Holder Drilling	165	1957	1,720	--	--	Patuxent	--	--	--	--	--	--	m
PG Fc 17	PG-12	Washington Gas Light Co., Thorne No. 2	Eakle & Holder Drilling	59	1955	1,728	--	712 - 716	Lower Patapsco	28.62	10/27/1955	--	--	--	--	m
PG Fd 56	PG-11	Washington Gas Light Co., Dennison No. 3	Eakle & Holder Drilling	233	1955	1,743	--	--	Patuxent	--	--	--	--	--	--	m
PG Fd 59	PG-4	Washington Gas Light Co., Moore No. 2	Eakle & Holder Drilling	172	1955	1,517	--	712 - 716	Patuxent	--	12/ / 1955	60	--	--	--	m
PG Fd 61	PG-3	Washington Gas Light Co., Mudd No. 3	Eakle & Holder Drilling	118	1955	1,719(?)	--	--	Patuxent	--	--	--	--	--	--	m
PG Fd 62	PG-10	Washington Gas Light Co.	Eakle & Holder Drilling	228.6	1956	1,812	--	1,545 – 1,580	Patuxent	184	8/15/1956	--	--	--	--	c,h,m
PG Gc 5	PG-2	Washington Gas Light Co., Wedding No. 2	Eakle & Holder Drilling	196	1955	1,723(?)	--	--	Patuxent	--	--	--	--	--	--	m
PG Hf 31	PG-73-0065	PEPCO, Chalk Point	Shannahan Artesian Well Co.	10.02	1973	2,453	4	1,007 - 1,541*	Lower Patapsco	6 feet above land surface	7/7/1973	93	31	3	24	m
PG Hf 43	PG-95-0927	Mirant Corp., Chalk Point Power Plant	A.C. Schultes of Maryland	43	2007	2,420	6	1,878 - 2,308*	Patuxent	79	1/31/2007	222	207	1.1	72	c,m
SM Dd 72	SM-94-3616	MD Geological Survey	A.C. Schultes of Maryland	109.99	2001	1,650	4	1,300 - 1,330	Lower Patapsco	131	5/16/2001	70	29	2.4	24	m
VA 53T 58	--	Hallowing Point Estates	--	30	--	696	--	--	--	--	--	--	--	--	--	m

<u>Owner abbreviations</u>:

Co.	Company or county
Corp.	Corporation
DPF	Department of Facilities
Inc.	Incorporated
MD	Maryland
PEPCO	Potomac Electric Power Company
US	United States
VA	Virginia

<u>Other abbreviations:</u>

-- = none or no data
* = screen interval includes blank sections
c = included in cross sections
m = included on structure contour or thickness map
h = hydrograph

Appendix D. Water-quality data from test wells.

[Orange shading indicates value exceeds Secondary Maximum Contaminant Level; yellow shading indicates value equals Secondary Maximum Contaminant Level. .All constituents 0.45µ-filtered, unless otherwise indicated. mg/L, milligrams per liter; µS/cm at 25 deg. C, microsiemens per centimeter at 25 degrees Celsius; E, estimated; <, less than; deg. C, degrees Celsius; µg/L, micrograms per liter; pCi/L, picocuries per liter]

Constituent	Well number and sample date			
	CH Be 73 4/4/2013	CH Ce 66 6/24/2013	CH Bf 166 9/4/2013	CH Bf 167 11/12/2013
Color (platinum-cobalt units), unfiltered	**100**	5	15	12
Dissolved oxygen, mg/L, unfiltered	0.3	0.1	0.3	0.1
pH, field, unfiltered	8.5	7.6	8.5	8.2
Specific conductance, µS/cm @ 25 deg. Celsius, unfiltered	522	993	418	461
Temperature, deg. C, unfiltered	21.7	26	27.2	25.9
Total dissolved solids (residue on evaporation at 180 deg. C)	356	**605**	269	286
Calcium, mg/L	0.828	2.25	0.936	0.748
Magnesium, mg/L	0.365	0.817	0.279	0.217
Potassium, mg/L	2.26	2.72	1.14	1.16
Sodium, mg/L	119	213	98.7	106
Alkalinity, mg/L as $CaCO_3$, unfiltered	232	362	212	219
Bromide, mg/L	0.067	0.339	E0.026	0.031
Chloride, mg/L	19.5	92.6	5.26	6.9
Fluoride, mg/L	0.63	1.27	0.65	0.73
Silica, mg/L	15.2	40.1	15.4	20.4
Sulfate, mg/L	7.57	10.4	8.57	9.1
Ammonia, mg/L as N	0.07	0.09	0.05	0.05
Nitrate + Nitrite, mg/L as N	<0.040	<0.040	<0.040	<0.040
Nitrite, mg/L as N	0.001	<0.001	0.001	<0.001
Orthophosphate, mg/L as P	0.185	0.178	0.195	0.219
Phosphorus, mg/L	0.2	0.16	0.19	0.2
Aluminum, µg/L	**248**	2.7	38.7	32.9
Barium, µg/L	17.1	47.1	9.95	8.98
Beryllium, µg/L	0.135	0.015	0.009	<0.020
Cadmium, µg/L	<0.016	0.018	<0.016	<0.030
Chromium, µg/L	0.16	<0.07	<0.07	<0.30
Cobalt, µg/L	0.309	<0.023	0.172	0.138
Copper, µg/L	<0.80	<0.80	<0.80	<0.80
Iron, µg/L	**568**	**578**	169	213
Iron, unfiltered, µg/L	**1480**	**736**	**370**	**487**
Lead, µg/L	0.376	<0.025	0.046	<0.040
Lithium, µg/L	5.18	17.9	5.64	6.21
Manganese, µg/L	26.4	26.9	8.01	8.63
Manganese, unfiltered, µg/L	31.3	23.1	11	10.1
Molybdenum, µg/L	0.119	1.65	0.695	0.689
Nickel, µg/L	0.24	0.3	0.19	<0.20
Silver, µg/L	<0.005	<0.005	<0.005	<0.020
Strontium, µg/L	11.4	37.7	13.1	9.56
Thallium, µg/L	<0.010	<0.010	<0.010	<0.030

Appendix D. Water-quality data from test wells—Continued.

Constituent	Well number and sample date			
	CH Be 73 4/4/2013	**CH Ce 66** 6/24/2013	**CH Bf 166** 9/4/2013	**CH Bf 167** 11/12/2013
Vanadium, µg/L	0.91	0.15	0.16	0.14
Zinc, µg/L	1.6	2.5	<1.4	<2.0
Antimony, µg/L	<0.027	<0.027	0.035	<0.027
Arsenic, µg/L	0.11	0.28	0.21	0.19
Boron, µg/L	80	156	99	117
Selenium, µg/L	<0.03	0.03	<0.03	<0.05
Gross alpha particle activity, Th-230, short-term, pCi/L	3.9	<1	1.7	<1
Gross alpha particle activity, Th-230, long-term, pCi/L	8.5	<1	<1	<1
Gross beta particle activity, Cs-137, short-term, pCi/L	2.1	5.7	2	<1.32
Gross beta particle activity, Cs-137, long-term, pCi/L	5.4	7.8	2.5	1.7
Polonium-210, pCi/L	1.16	<0.0478	0.2	0.09
Radon-222, pCi/L, unfiltered	700	400	460	380
Uranium, µg/L	0.102	0.013	0.024	0.019

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.

MARYLAND DEPARTMENT OF NATURAL RESOURCES
Resource Assessment Service
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401
Toll free in Maryland: 1-877-620-8DNR
Out of State call: 1-410-260-8021
TTY users: Call via the Maryland Relay
Internet Address: www.dnr.Maryland.gov

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
Telephone Contact Information: 410-554-5500
Internet Address: www.mgs.md.gov

DNR Publication Number 12-292015-749

2015