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Hydrogeology and Ground-Water Quality of the Piney Point-Nanjemoy and Aquia Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland

Water-Resources Investigations Report 01-4029

U.S. Department of the Interior
U.S. Geological Survey

Cover. Aerial view of Naval Air Station Patuxent River, St. Marys County, Maryland.
(Photo courtesy U.S. Navy)

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by Cheryl A. Klohe and C. Erin Feehley

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Baltimore, Maryland
2001

U.S. Department of the Interior
GALE A. NORTON, Secretary

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Charles G. Groat, Director

For additional information contact:

District Chief
U.S. Geological Survey
8987 Yellow Brick Road
Baltimore, MD 21237

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
acre	0.4047	hectare
acre	0.4047	square hectometer
acre	0.004047	square kilometer
square mi (mi^2)	259.0	hectare
square mi (mi^2)	2.590	square kilometer
gallon per day (gal/d)	0.003785	cubic meter per day
picocurie per liter (pCi/L)	0.037	becquerel per liter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Hydrogeology and Ground-Water Quality of the Piney Point-Nanjemoy and Aquia Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland

By **Cheryl A. Klohe** *and* **C. Erin Feehley**

Abstract

Rapid population growth in southern Maryland has brought ground-water quality and ground-water quantity issues to the forefront. Historical and current water-quality data, ground-water withdrawal data, and water-level data were compiled to help water managers at the Naval Air Station Patuxent River understand how water-management practices affect regional ground-water resources, in particular the Piney Point-Nanjemoy and the Aquia aquifers.

Lithologic and borehole geophysical data were interpreted to create a local hydrogeologic framework of the Piney Point-Nanjemoy and Aquia aquifers. Ground-water withdrawal data and personnel data were compared to ground-water levels in both aquifers. Water samples were collected and analyzed to determine basic ground-water quality of both aquifers, and to compare these data with data collected from the 1940's through the early 1960's. The data were analyzed to determine changes in water quality over the past 50 years, and to investigate indications of saltwater intrusion.

The Piney Point-Nanjemoy aquifer is 50 to 70 feet thick, with a top altitude of 220 to 255 feet below sea level and a hydraulic conductivity of 2 feet per day at Naval Air Station Patuxent River. This aquifer is 65 feet thick, with a top altitude of 260 feet below sea level and a hydraulic conductivity of 2 feet per day at Webster Outlying Field. Ground-water withdrawal from the Piney Point-Nanjemoy aquifer has decreased and water levels have remained constant since the 1950's. The water is calcium-magnesium-sodium-bicarbonate rich, and shows no evidence of saltwater intrusion.

The Aquia aquifer is 100 to 145 feet thick, with a top altitude of 450 feet below sea level and a hydraulic conductivity of 6 to 10 feet per day at Naval Air Station Patuxent River. This aquifer is 50 feet thick, with a top altitude of 470 feet below sea level and a hydraulic conductivity of 6 to 10 feet per day at Webster Outlying Field. Although ground-water withdrawal in the Aquia aquifer has decreased, water levels continue to decline at Naval Air Station Patuxent River and Webster Outlying Field due to increased municipal withdrawal near the air station. The water is sodium-bicarbonate rich at Naval Air Station Patuxent River and at Webster Outlying Field; at Webster Outlying Field, however, the specific conductance, acid-neutralizing capacity, and concentrations of sodium, sulfate, boron, and iodide are noticeably different from the water at the main facilities. There is no evidence of saltwater intrusion at either site, although the specific conductance and the concentrations of some constituents are higher at Webster Outlying Field, which could indicate early stages of saltwater intrusion.

Introduction

Development at the Naval Air Station Patuxent River and in the suburban Washington, D.C. area (approximately 50 miles northwest of the air station) (fig. 1) has resulted in rapid population growth in southern Maryland, especially in St. Marys, Charles, and Calvert Counties. Because of the population increase, many County and State water managers, private citizens, and air station officials have become concerned with water-supply issues in the region. In 1998, the U.S. Geological Survey (USGS), in cooperation with the Naval Air Station (NAS) Patuxent River, began investigating the water resources of the Piney Point-Nanjemoy and Aquia aquifers at the air station to understand the effects of the air station's water-use practices on regional water resources.

Published potentiometric surface maps of major aquifers in southern Maryland show recent expansion of large, deep cones of depression in areas served by high-capacity wells. For instance, in the Lexington Park area, the potentiometric surface of the Aquia aquifer in 1997 was approximately 90 ft (feet) lower than in 1982 (Curtin and others, 1999). Achmad and Hansen (1997) simulated ground-water flow for the Piney Point-Nanjemoy and Aquia aquifers in southern Maryland until the year 2020 with ground-water withdrawal values based on projected population growth statistics. The simulations show that water levels in the Lexington Park, Maryland, area could be as low as -95 ft m.s.l. (mean sea level) in the Piney Point-Nanjemoy aquifer, and -235 ft m.s.l. in the Aquia aquifer. These levels are about 100 ft lower than pre-pumping conditions in the Piney Point-Nanjemoy aquifer and about 250 ft lower than pre-pumping conditions in the Aquia aquifer. These levels are 75 ft lower than the Piney Point-Nanjemoy aquifer in April 2000 (-20 ft m.s.l.) and 100 ft lower than the Aquia aquifer in January 2000 (-150 ft m.s.l.).

Background

Naval Air Station Patuxent River was commissioned in 1943 as part of an effort to centralize U.S. Navy facilities. Webster Outlying Field (WOLF), near St. Inigoes, Maryland, serves as an auxiliary landing field for NAS Patuxent River. Testing and development of aircraft and weaponry at NAS Patuxent River and WOLF increased during the Korean and Vietnam Wars and continues today. In the 1990's, the Navy began consolidating their technical resources and NAS Patuxent River became a receiver station as a result of Base Realignment and Closure of other facilities (Naval Air Station Patuxent River, 2000). With this consolidation, the facilities and personnel at NAS Patuxent River and WOLF grew from 10,000 employees in 1981 to 13,000 in 1996, and to 18,000 by 1998 (James Darcy, Public Affairs Office, Naval Air Station Patuxent River, written commun., 2000).

Purpose and Scope

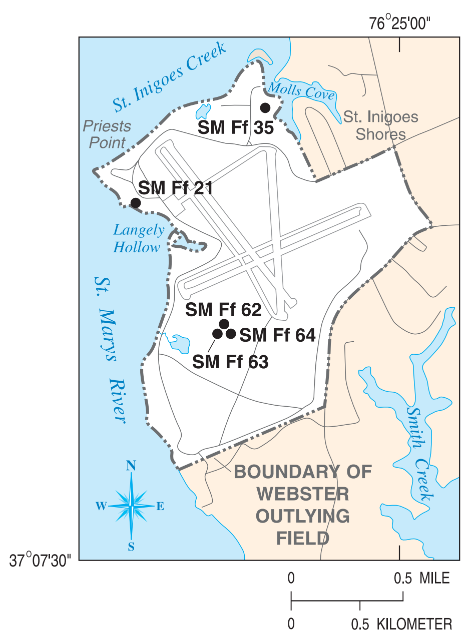
The purpose of this report is to (1) describe the hydrogeologic framework at the air station and its relation to the regional hydrogeologic framework, (2) analyze the relation between the water levels in the Piney Point-Nanjemoy and Aquia aquifers, ground-water withdrawal, and personnel growth at the air station, and (3) characterize the quality of water in the Piney Point-Nanjemoy and Aquia aquifers. The hydrogeology of the area is described on the basis of information from previous reports, State of Maryland Drilling Permits, State of Maryland Well Completion Reports, and USGS historical well files that include water levels, geophysical logs, and well-construction data. The water-level data (for the 1940's to the present) are from the USGS National Water Information System (NWIS) data base. Ground-water-withdrawal records for NAS Patuxent River were obtained from correspondence between the USGS and the air station in the 1940's, 1950's, and 1970's, and continuous records kept by the air station from 1989 to the present. Ground-water-withdrawal data for southern Maryland were obtained from the USGS State Water-Use Data System (SWUDS) data base and the Maryland Department of the Environment (MDE) Regulatory Analysis Management System (RAMS) data base. Water-quality analysis is based on ground-water samples collected in September 1999, and data published in previous reports by Chapelle and Drummond (1983) and Bennett (1944).

Study Area

The NAS Patuxent River is in southern Maryland in St. Marys County, southwest of the convergence of the mouth of the Patuxent River and Chesapeake Bay (fig. 1). WOLF is southwest of the air station, on the St. Marys River near St. Inigoes, Maryland (fig. 1). Together, the total facilities include approximately 7,800 acres of land and five runways, with the longest runway measuring 11,800 ft. The air operations consist of 50,000 mi^2 (square miles) available for operations, 5,000 mi^2 of controlled airspace, and 780 mi^2 of restricted airspace. There are 935 buildings, 10 double bay hangers, more than 140 aircraft representing all Navy types and models, and 21 tenant aircraft (Naval Air Station Patuxent River, 2000).

The locations of the ground-water wells discussed in this report are shown in figure 2. Most of the wells are production wells, or were production wells in the past but have since been sealed and replaced by new wells. In this report, wells are listed by their USGS identification number. For example, well SM Df 14 is a well located in St. Marys county indicated by the first two letters "SM," in the 5-minute quadrangle "Df," indicated by the second two letters, and is the 14th well mapped in the 5-minute quad, indicated by the last two numbers "14." The 5-minute quadrangles are designated by uppercase letters from north to south, and lowercase letters from west to east. The USGS well numbers can be cross-referenced to air station well names and building numbers listed in table 1.

Figure 1. Location of Naval Air Station Patuxent River and Webster Outlying Field study areas, and outcrop areas of the Piney Point-Nanjemoy and Aquia aquifers, southern Maryland.



EXPLANATION

WETLAND

SM Df 1 ● WELL LOCATION AND IDENTIFIER

Figure 2. Well locations at Naval Air Station Patuxent River and Webster Outlying Field, southern Maryland.

Previous Investigations

In 1944, the Commanding Officer of NAS Patuxent River asked the USGS to collect information on the availability of ground water at the Naval establishments in the Solomons–Patuxent River area, Maryland (Bennett, 1944). Bennett compiled available records of the wells, ran brief aquifer tests, and measured static and pumping water levels of some of the wells at the new facilities. Bennett noted that interpretation of the data was difficult because information on the subsurface geology in the area was sparse, and the aquifer tests were of short duration. Nonetheless, his study provides some insight into the properties of the Piney Point-Nanjemoy aquifer and Aquia aquifer, the number of wells screened in each aquifer, and the quantity of water pumped from the wells at the NAS Patuxent River in the early 1940's.

Since 1982, the USGS has published maps of the potentiometric surfaces of the Aquia aquifer in southern Maryland. Each year, the maps show an increase in the size and depth of the cone of depression in the potentiometric surface of the Aquia aquifer near Lexington Park, Maryland. Chappelle and Drummond (1983) described the Piney Point-Nanjemoy and Aquia aquifers in southern Maryland, but detailed information on the Lexington Park, Maryland, the NAS Patuxent River, and WOLF areas was not included. Chapelle and Drummond (1983) included results of ground-water-flow simulations and described the chemical evolution of water in the Aquia and Piney Point-Nanjemoy aquifers in southern Maryland. A more recent publication, by Achmad and Hansen (1997), also describes ground-water flow simulations of the Piney Point-Nanjemoy and Aquia aquifers. Assuming the amount of water pumped from the aquifers each year is equal to the 1995 maximum Ground-Water Appropriation Permits (GAP) rates, Achmad and Hansen's simulations predict that in the NAS Patuxent River/ Lexington Park area, water levels in the year 2020 will average -235 ft m.s.l. in the Aquia aquifer. At that pumping rate, the simulated cell average water level, for the model cell near the center of the cone of depression, comes to within 122 ft of the 80-percent available drawdown management level of -357 ft m.s.l. In well SM Df 42, in Lexington Park, the simulated water level was about -330 ft m.s.l., which is within 27 ft of the 80-percent available drawdown management level of -357 ft m.s.l.

Acknowledgments

The authors would like to thank the personnel at NAS Patuxent River who assisted the project, especially those in the Public Works Department, the Environmental Support Group, and the Public Affairs Office. In addition, the authors thank the many reviewers of this report for their helpful comments, and the USGS employees who assisted in field data collection.

Hydrogeologic Framework

The Coastal Plain of southern Maryland is underlain by a gently dipping wedge of sediments composed mainly of unconsolidated clay, silt, sand, and gravel. These sediments range in age from Holocene to Lower Cretaceous (Chapelle and Drummond, 1983), and crop out subparallel to the Fall Line (fig. 1), which is the approximate boundary between the Coastal Plain and the Piedmont Physiographic Provinces. The hydrogeologic units discussed in this report, from youngest to oldest are: the surficial aquifer, the upper confining unit, the Piney Point-Nanjemoy aquifer, the middle confining unit, and the Aquia aquifer (table 2). The Piney Point-Nanjemoy aquifer and the Aquia aquifer are relatively deep, confined aquifers in the Coastal Plain Physiographic Province of Maryland. In this report, hydraulic conductivity values have been calculated from transmissivity values given in Chapelle and Drummond (1983), divided by thickness of the aquifer determined from geophysical and lithologic logs.

Surficial Aquifer and the Upper Confining Unit

The surficial aquifer contains Holocene to Pliocene sediments that range from clays and silts to sands and gravels. The sediments are undifferentiated in the study area, ranging in thickness from 10 to 100 ft. In the past, when dug or driven wells were common, the unconfined surficial aquifer was used as a source of water for domestic and agricultural use (Achmad and Hansen, 1997).

The upper confining unit comprises the Chesapeake Group (undivided) clays and silts of Miocene age. The upper confining unit lies below the surficial aquifer and above the unnamed beds of Oligocene (?) or Miocene (?) age. The upper confining unit is approximately 210 to 250 ft thick at the air station.

Piney Point-Nanjemoy Aquifer

The Piney Point-Nanjemoy aquifer is composed of the basal beds of the Chesapeake Group (the Calvert Formation), unnamed Oligocene (?) or Miocene (?) beds, the Piney Point Formation, and the upper sands of the Nanjemoy Formation (Achmad and Hansen, 1997). The Calvert Formation is early Miocene and consists of fine- to medium- grained, yellowish-green to greenish-light gray quartz sand, and is slightly glauconitic with some shell fragments, phosphate pebbles, and fine gravel (Achmad and Hansen, 1997). The unnamed Oligocene (?) Miocene (?) beds consist of clayey sands that are brown to olive green, slightly glauconitic, and fossiliferous (Achmad and Hansen, 1997). The Piney Point Formation is middle Eocene and consists of medium- to coarse-grained, quartz sands that are grayish-green to grayish-white in color, glauconitic with calcite cemented beds (Chapelle and Drummond, 1983). The upper sands of the Nanjemoy Formation are sometimes indiscernible from the lower sands of the Piney Point Formation, based on routinely collected drill cuttings and drillers' logs. The sands from these four formations are hydraulically connected and are collectively referred to as

Table 1. *Records for selected wells at Naval Air Station Patuxent River and Webster Outlying Field, Maryland*

[USGS, U.S. Geological Survey; no., number; (° ' "), degree, minute, second; –, no data available; n/a, not applicable; geophyscial log types—G, Gamma; SP, Spontaneous Potential; R, Resistance; SN, Short Normal; LN, Long Normal]

USGS well no.	State of Maryland well permit no.	Naval Air Station well no.	Building no.	Latitude (° ' ")	Longitude (° ' ")	Altitude of land surface (feet)	Depth of well (feet below land surface)	Casing diameter upper-lower (inches)
SM Df 1	–	1A	522	38 15 53	76 26 50	93	587	8
SM Df 10	–	3B	531	38 17 12	76 26 18	45	534	8–6
SM Df 14	–	1P	532	38 17 20	76 26 48	17	262	8
SM Df 43 [A]	–	–	–	38 16 47	76 25 24	39	553	8
SM Df 61	55823	2A	524	38 16 05	76 27 13	110	600	8
SM Df 93	SM–92–0358	1B	529	38 16 37	76 26 04	41	567	8–6
SM Df 94	SM–92–0357	3A	574	38 16 14	76 26 59	99	612	8–6
SM Df 95	SM–92–0369	4A	584	38 16 17	76 26 30	79	582	8–6
SM Df 96	SM–93–0036	5B	590	38 17 24	76 25 40	8	539	8
SM Df 97	SM–94–0925	2B	530	38 16 58	76 26 01	47	568	8–6
SM Df 98	SM–94–0410	5A	587	38 16 34	76 27 05	74	575	8–6
SM Df 99	SM–92–0642	4B	2276	38 17 10	76 25 57	44	600	16–8
SM Dg 1 [A]	–	–	–	38 16 08	76 24 24	18	480	8
SM Dg 4	SM–00–3978	–	966	38 17 27	76 23 47	19	295	2
SM Dg 5	–	2Q	651	38 18 02	76 22 58	21	494	8
SM Dg 9 [A, B]	SM–73–0095	–	–	38 18 05	76 23 30	19	586	n/a
SM Dg 11 [A]	–	–	–	38 17 25	76 23 05	9	290	6
SM Dg 14	SM–92–0370	1Q	617	38 18 11	76 23 27	19	542	8–6
SM Dg 15	SM–92–0570 SM–92–0245	1C	523	38 16 17	76 24 29	20	500	8–6
SM Dg 16	SM–94–0411	3C	583	38 16 20	76 23 56	10	520	8
SM Dg 17	SM–92–0643	–	2275	38 16 17	76 24 42	19	591	12–8
SM Dg 18	SM–94–0926	2C	575	38 16 10	76 24 11	17	553	8–6
SM Dg 19	SM–81–3345	CTR	2136	38 17 46	76 22 36	9	532	8
SM Dg 20	SM–88–0946	–	2100	38 17 20	76 23 42	11	335	4–2
SM Dg 21	SM–94–0074	1H	1633	38 18 10	76 24 44	9	315	4
SM Dg 22	–	Weapons	253	38 17 31	76 24 24	11	670	2
SM Ff 21	–	–	–	38 05 54	76 26 12	9	486	8
SM Ff 35	SM–73–1496	Coast Guard (well 5)	8130	38 09 15	76 25 40	4	537	8–4
SM Ff 62	SM–94–1128	New Well	8195	38 08 21	76 25 59	9	539	8–6
SM Ff 63	–	New Well	8195	38 08 22	76 25 57	9	545	8–4
SM Ff 64 [B]	–	–	–	38 08 21	76 25 55	9	534	–

[A] Well no longer exists.

[B] Test hole.

Screen position (feet below land surface)	Screen length (feet)	Geophysical logs	Driller	Date of construction	Aquifer	USGS well no.
567–587	20	G	Washington Pump and Well Co.	1943	Aquia	SM Df 1
514–534	20	–	Washington Pump and Well Co.	1943	Aquia	SM Df 10
247–262	20	G	Washington Pump and Well Co.	1943	Piney Point-Nanjemoy	SM Df 14
514–534	20	G	Sydnor Pump and Well Co.	1955	Aquia	SM Df 43 [A]
580–600	20	G	Patuxent Pump and Well Co.	1964	Aquia	SM Df 61
515–565	50	G, SP, R	A.C. Schultes of Maryland, Inc.	1994	Aquia	SM Df 93
560–610	50	G, SP, R	A.C. Schultes of Maryland, Inc.	1994	Aquia	SM Df 94
530–580	50	G, SP, R	A.C. Schultes of Maryland, Inc.	1994	Aquia	SM Df 95
489–539	50	G, SP, R	A.C. Schultes of Maryland, Inc.	1994	Aquia	SM Df 96
515–565	50	–	A.C. Schultes of Maryland, Inc.	1997	Aquia	SM Df 97
525–575	50	–	A.C. Schultes of Maryland, Inc.	1996	Aquia	SM Df 98
490–600	110	–	Vans Construction Co., Inc.	1994	Aquia	SM Df 99
460–480	20	G	Washington Pump and Well Co.	1943	Aquia	SM Dg 1 [A]
275–295	20	–	J.J. Payne	1949	Piney Point-Nanjemoy	SM Dg 4
475–494	19	–	Washington Pump and Well Co.	1950	Aquia	SM Dg 5
n/a	n/a	G, SP, R	Shannahan Artesian Well Co.	1972	Aquia	SM Dg 9 [A, B]
–	–	G, SP, R, SN, LN	Calvert Well Drilling Co.	1980	Piney Point-Nanjemoy	SM Dg 11 [A]
490–540	50	G	A.C. Schultes of Maryland, Inc.	1994	Aquia	SM Dg 14
450–500	50	G	Patuxent Pump and Well Co.	1993	Aquia	SM Dg 15
470–520	50	–	A.C. Schultes of Maryland, Inc.	1996	Aquia	SM Dg 16
481–591	110	–	Vans Construction Co., Inc.	1995	Aquia	SM Dg 17
500–550	50	–	A.C. Schultes of Maryland, Inc.	1997	Aquia	SM Dg 18
480–510	30	–	Sydnor Pump and Well Co.	–	Aquia	SM Dg 19
325–335	10	–	Watson and Johnson Well Drilling, Inc.	1991	Piney Point-Nanjemoy	SM Dg 20
295–315	20	G	Southern Well and Recovery Corp.	1996	Piney Point-Nanjemoy	SM Dg 21
640–670	30	–	–	1990	Aquia	SM Dg 22
464–486	22	G	Washington Pump and Well Co.	1945	Aquia	SM Ff 21
487–537	50	G, SP, R	A.C. Schultes of Maryland, Inc.	1975	Aquia	SM Ff 35
486–536	50	G, SP, R, SN, LN	A.C. Schultes of Maryland, Inc.	1997	Aquia	SM Ff 62
–	–	–	–	1987	Aquia	SM Ff 63
–	–	G	–	–	Aquia	SM Ff 64 [B]

Table 2. *Hydrogeologic units and corresponding geologic units at Naval Air Station Patuxent River*

[Modified from Achmad and Hansen, 1997] NOT TO SCALE

<table>
<tr><th>System</th><th>Series</th><th>Geologic Unit</th><th>Hydrogeologic Unit</th></tr>
<tr><td>Quaternary</td><td>Holocene to Pleistocene</td><td rowspan="2">Surficial units (undifferentiated)</td><td rowspan="2">Surficial aquifer</td></tr>
<tr><td rowspan="9">Tertiary</td><td>Pliocene</td></tr>
<tr><td rowspan="2">Miocene</td><td rowspan="2">Chesapeake Group (undivided)</td><td>Upper confining unit</td></tr>
<tr><td rowspan="3">Piney Point-Nanjemoy aquifer</td></tr>
<tr><td>Oligocene (?)</td><td>unnamed Oligocene (?) Miocene (?) beds</td></tr>
<tr><td rowspan="2">Eocene</td><td>Piney Point Formation</td></tr>
<tr><td>Nanjemoy Formation</td><td rowspan="2">Middle confining unit</td></tr>
<tr><td rowspan="3">Paleocene</td><td>Marlboro Clay</td></tr>
<tr><td>Aquia Formation</td><td>Aquia aquifer</td></tr>
<tr><td>Brightseat Formation</td><td rowspan="2">Lower confining unit</td></tr>
<tr><td colspan="2">Cretaceous</td><td>Upper and Lower Cretaceous Units</td></tr>
</table>

the Piney Point-Nanjemoy aquifer. Hydraulic conductivity (based on transmissivity from Chapelle and Drummond, 1983) for the Piney Point-Nanjemoy aquifer at NAS Patuxent River is approximately 2 ft/d (feet per day). The top of the Piney Point-Nanjemoy aquifer ranges from -220 to -255 ft m.s.l. (fig. 3). The thickness of the aquifer varies slightly, but is approximately 50 to 70 ft thick (fig. 4).

The Piney Point-Nanjemoy aquifer is not exposed at the surface; therefore, recharge occurs in the subsurface where the aquifer is in hydraulic connection with water that percolates through the surficial units and other formations above the aquifer. The approximate updip extent of the aquifer in the subsurface is shown in figure 1, along the northern boundaries of Calvert County, and St. Marys County, Maryland. The downdip extent of the aquifer runs through southeast Sussex County, Delaware, then southwest through central Wicomico County, Maryland, and then south through the west side of Somerset County, Maryland (Vroblesky and Fleck, 1991).

Two hydrogeologic sections (A–A′ and B–B′ ; locations shown in figure 5) were developed from lithologic logs, well-completion reports, and geophysical logs of boreholes. Hydrogeologic sections, A–A′ and B–B′, shown in figure 6, show the thickness and continuous extent of the Piney Point-Nanjemoy aquifer. The geophysical logs (natural gamma-ray and single-point resistance) are plotted on the hydrogeologic sections to show the characteristic peaks that define the contacts between the aquifers and confining units. The thickness and altitude of the Piney Point-Nanjemoy aquifer at the air station is consistent with previously published information on regional hydrogeologic sections (Achmad and Hansen, 1997, Plates 1 and 2).

Natural gamma-ray logs are available for most wells at the air station, but single-point resistance and spontaneous potential (SP) logs are available only for selected wells. Gamma, resistance, and SP logs for wells SM Df 93, SM Df 96, and SM Dg 9, along with gamma logs for wells SM Ff 21, SM Ff 35, and SM Ff 64 are included in Appendix A.

Natural gamma-ray logs are graphical plots of the emission of gamma rays from natural or artificial radioisotopes in the formations penetrated by the borehole. In general, silt and clay have much higher natural gamma activity than clean quartz sand and carbonates. Gamma radiation increases to the right on the gamma-ray log. Therefore, permeable sediments such as sand and gravel, which generally have low radioactivity, are indicated by log deflections toward the left, whereas silt and clay, which generally contain radioisotopes, are indicated by log deflections toward the right.

The single-point resistance curve is a record of electrical resistance of the formation, the formation fluid, and the borehole fluid. Most freshwater sands and gravels are indicated by sharp deflections to the right.

The SP log is a record of potentials or voltages due to electrochemical processes that are caused by salinity differences in borehole and interstitial fluids. The salinity differences usually occur at formation contacts, and reverse the potential, which is then represented as an inflection point on the log.

At WOLF, the top of the Piney Point-Nanjemoy aquifer is -260 ft m.s.l. and is approximately 65 ft thick. The altitude of the top of the aquifer is deeper than the top of the aquifer at NAS Patuxent River, but the thickness is the same. Although there are no production wells screened in the

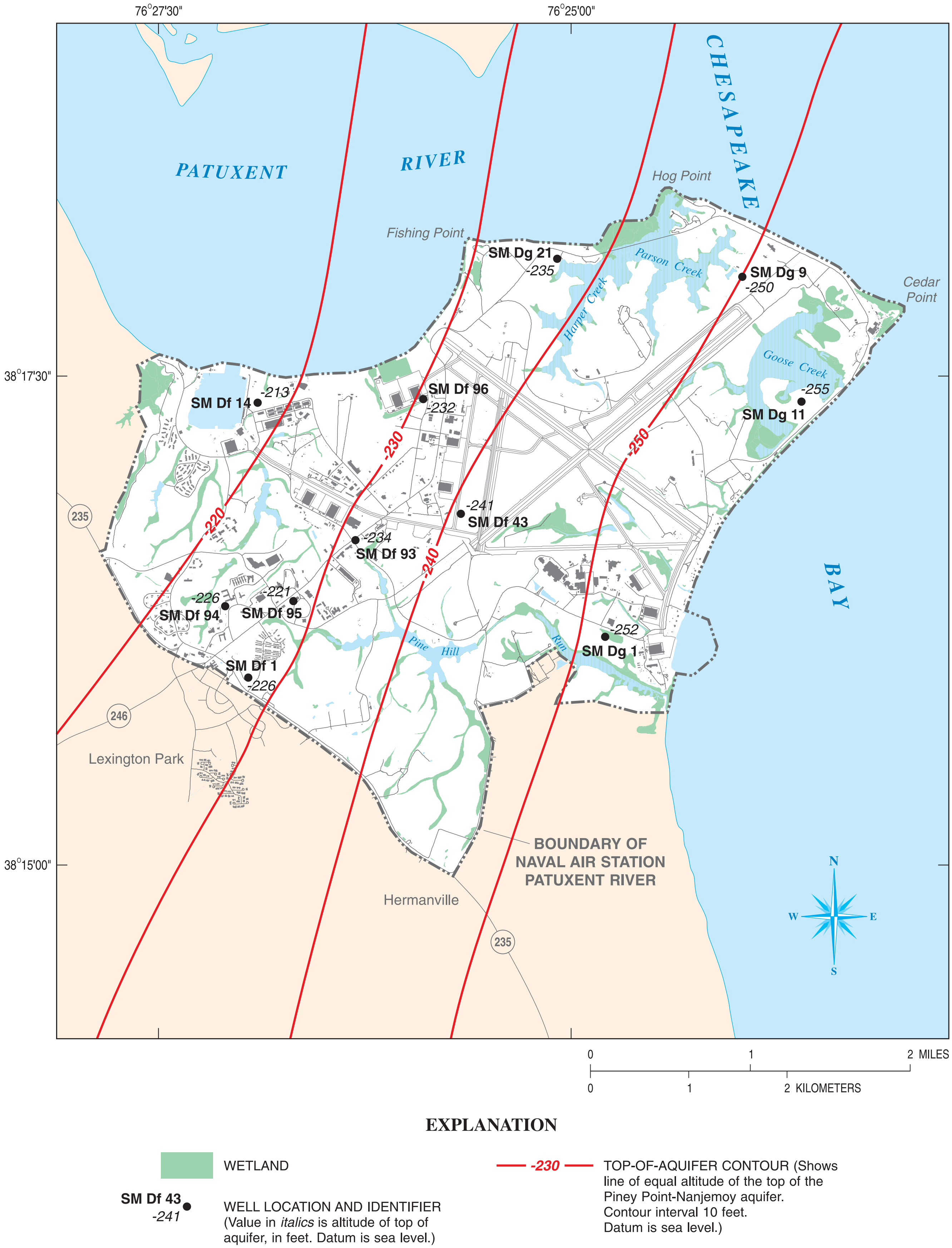


Figure 3. Altitude of the top of the Piney Point-Nanjemoy aquifer, Naval Air Station Patuxent River, Maryland.

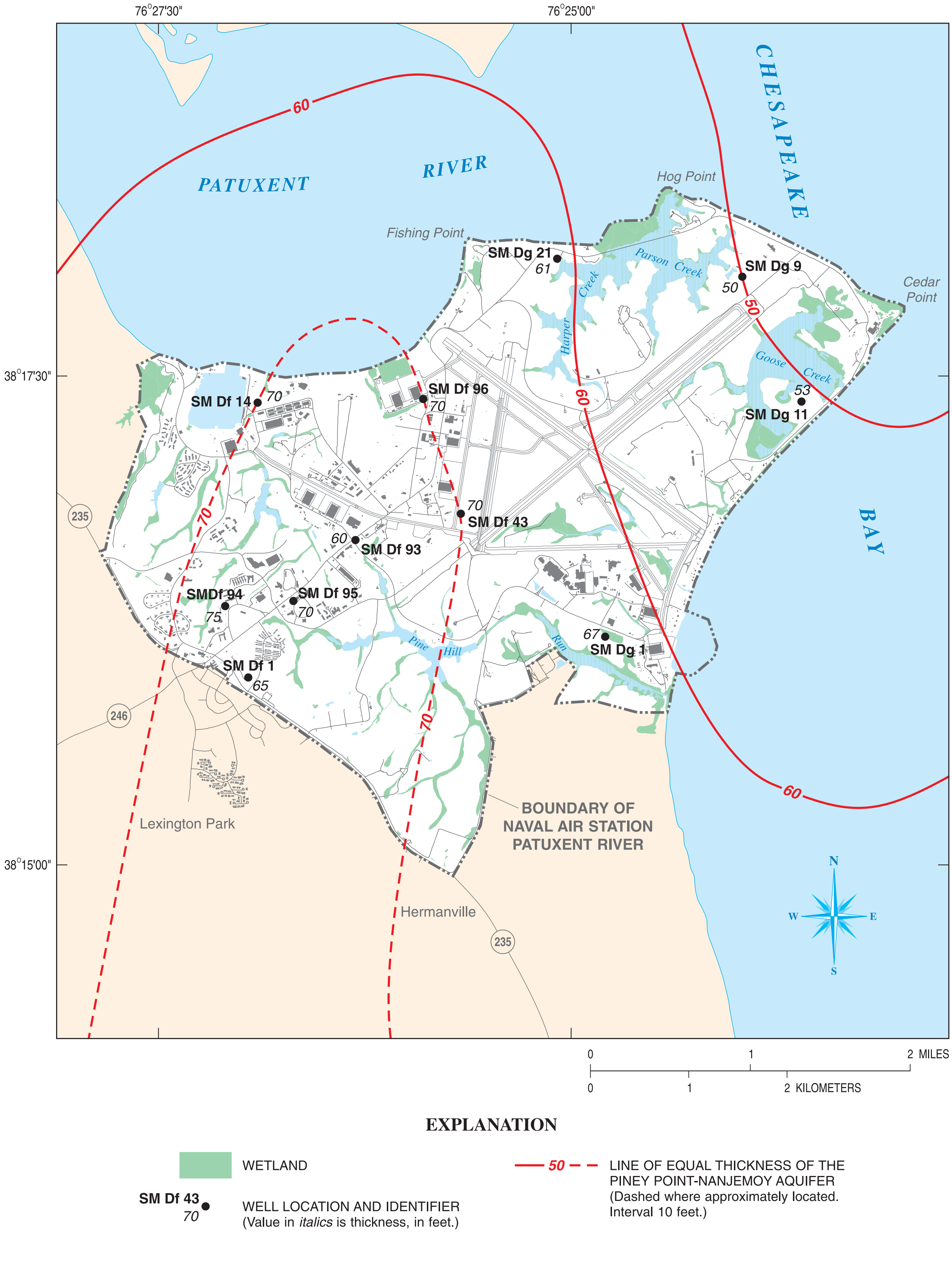


Figure 4. Thickness of the Piney Point-Nanjemoy aquifer, Naval Air Station Patuxent River, Maryland.

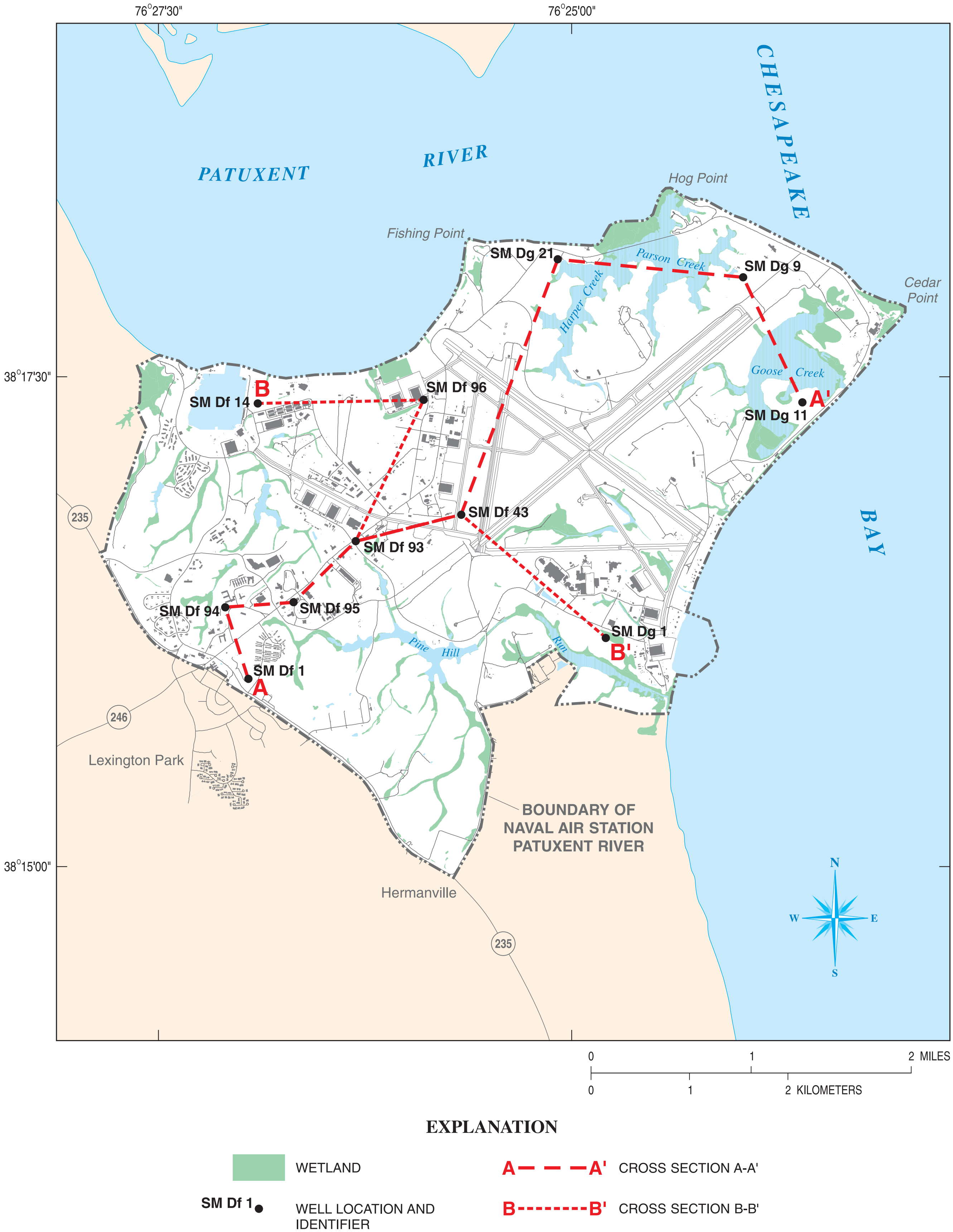


Figure 5. Location of hydrogeologic sections A-A' and B-B' at Naval Air Station Patuxent River, Maryland.

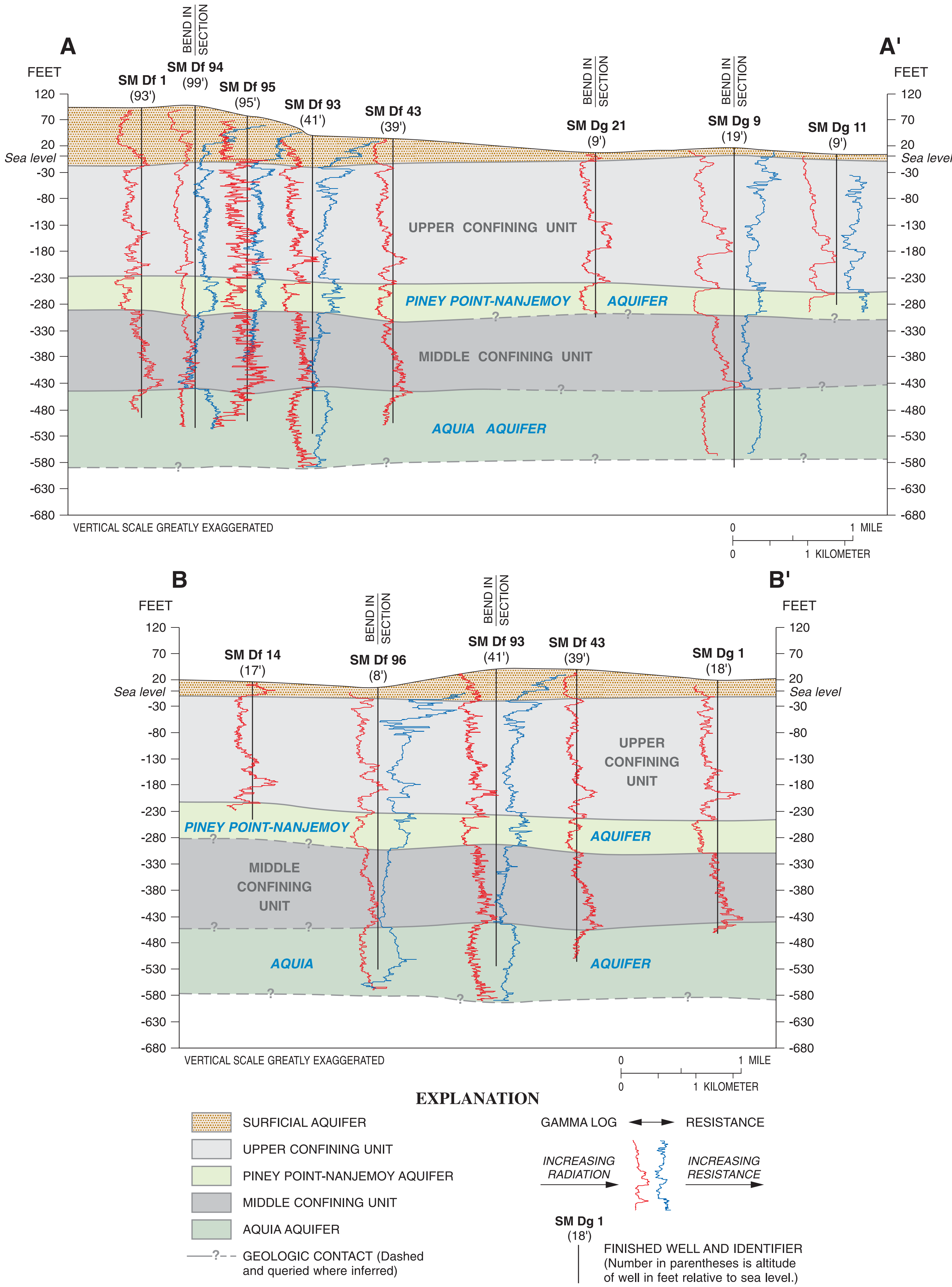


Figure 6. Hydrogeologic sections A-A' and B-B' at Naval Air Station Patuxent River, Maryland.

Piney Point-Nanjemoy aquifer at WOLF, the horizontal hydraulic conductivity is estimated to be 2 ft/d on the basis of thickness data from nearby wells, and transmissivity data from Chapelle and Drummond, 1983.

Middle Confining Unit

Beneath the Piney Point-Nanjemoy aquifer is a confining unit that includes the lower part of the Nanjemoy Formation (Eocene) and the Marlboro Clay (Paleocene). The lower part of the Nanjemoy Formation consists largely of greenish-black to olive-black silts and clays. The Marlboro clay consists of pale red or gray plastic clay (Achmad and Hansen, 1997). The thickness of the middle confining unit ranges from 130 to 150 ft (fig. 6).

Aquia Aquifer

Below the middle confining unit is the Aquia Formation of Paleocene age. The Aquia contains greenish-black, quartz sand, glauconite, and lenses of silty clay and shell beds. Calcite precipitation is also common (Chapelle and Drummond, 1983). Most of the Aquia is water-bearing, and thus is known as the Aquia aquifer.

The top of the Aquia aquifer is approximately -450 ft m.s.l. (fig. 7), and the aquifer ranges in thickness from 100 to 145 ft (fig. 8). Most of the wells screened in the Aquia aquifer at the air station are production wells that do not penetrate the full thickness of the aquifer. The thickness of the aquifer was determined from data for wells that penetrate the entire aquifer. Geophysical logs from wells outside the air station boundary were used in addition to logs from the few fully penetrating wells within the air station boundaries. The thickness and extent of the aquifer was determined from lithologic logs, completion reports, and geophysical logs of boreholes, which are plotted on the hydrogeologic sections. Low gamma radiation and high resistance on the geophysical logs indicate the location of the Aquia aquifer, and are shown in the hydrogeologic sections (fig. 6). Geophysical logs for wells SM Df 93, SM Df 96, SM Dg 9, SM Ff 21, SM Ff 35, and SM Ff 64 are provided in Appendix A. The altitude and thickness of the Aquia aquifer at the air station are consistent with regional hydrogeologic sections (Achmad and Hansen, 1997, Plate 2). The Aquia aquifer is recharged primarily along its outcrop (fig. 1). In Maryland, the aquifer crops out in central Anne Arundel County, central Prince Georges County, and in northwest Charles County near the Potomac River. The horizontal hydraulic conductivity of the Aquia aquifer ranges from 6 to 10 ft/d.

At WOLF, the altitude of the top of the Aquia aquifer is approximately -470 ft m.s.l. The thickness of the aquifer is only 50 ft, less than half its thickness at NAS Patuxent River. This thickness corresponds to regional hydrogeologic sections that show the Aquia aquifer is approximately 40 ft thick at nearby Kitts Point (Achmad and Hansen, 1997, Plate 2). The horizontal hydraulic conductivity is approximately 6 to 10 ft/d. At WOLF, the aquifer sands are nearing their southeasternmost lateral extent (fig. 1), and although the Aquia Formation continues southeastward, it becomes thinner, finer-grained, and clayey (Achmad and Hansen, 1997).

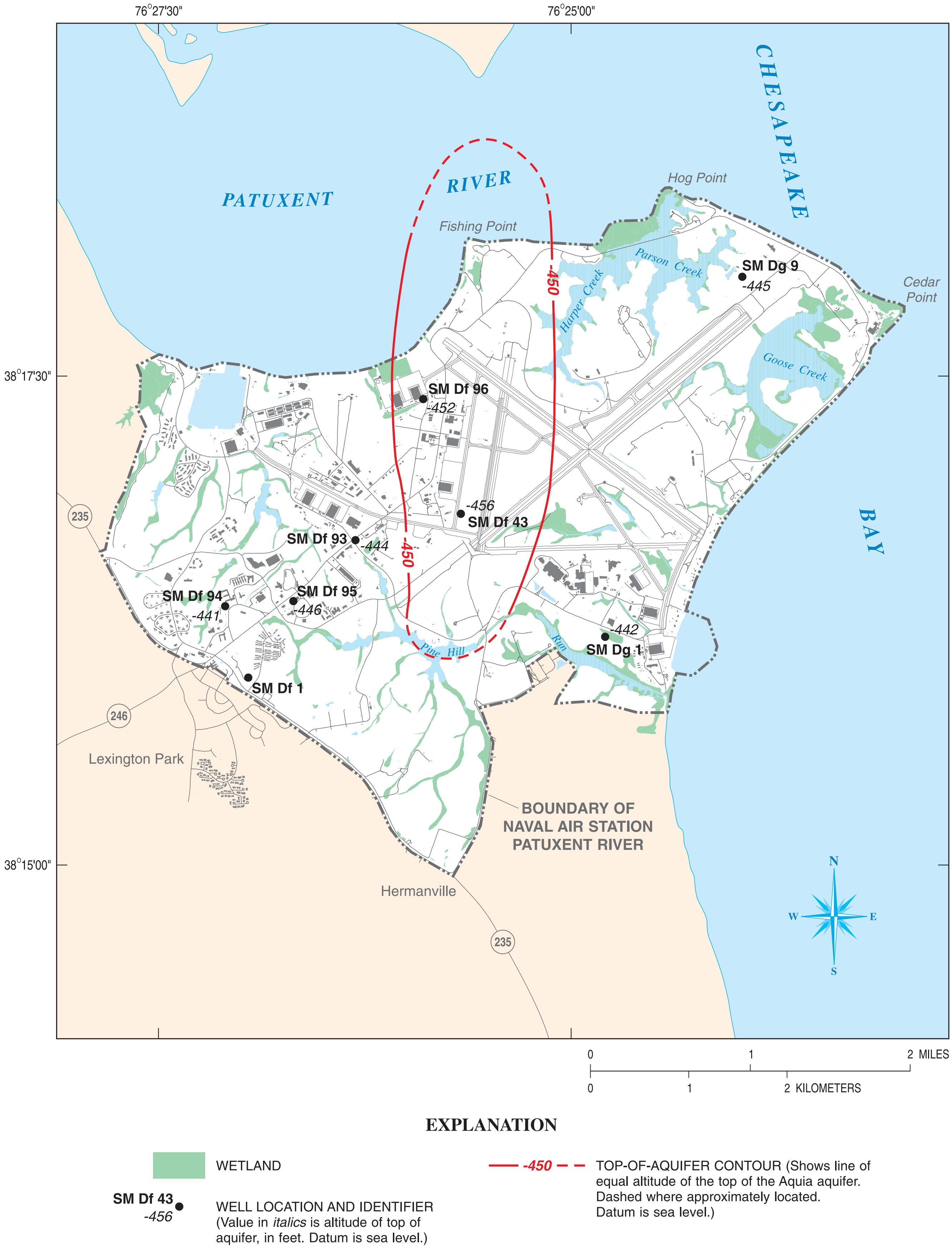
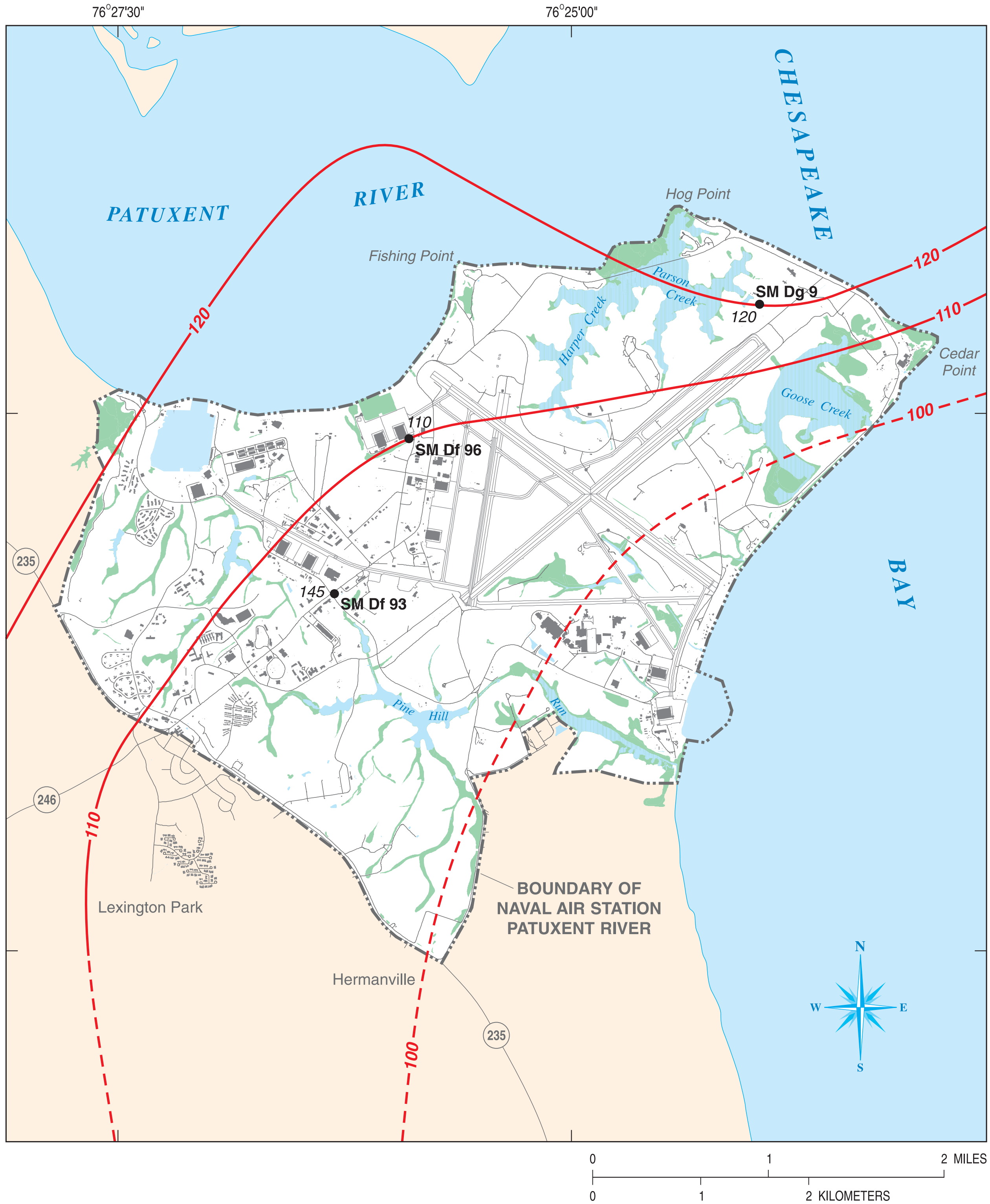


Figure 7. Altitude of the top of the Aquia aquifer, Naval Air Station Patuxent River, Maryland.



EXPLANATION

WETLAND

SM Df 9 ● *120* — WELL LOCATION AND IDENTIFIER (Value in *italics* is thickness, in feet.)

110 — LINE OF EQUAL THICKNESS OF THE AQUIA AQUIFER (Dashed where approximately located. Interval 10 feet.)

Figure 8. Thickness of the Aquia aquifer at selected locations, Naval Air Station Patuxent River, Maryland.

Ground-Water Withdrawal and Water Levels

Significant ground-water withdrawal in the Cedar Point and St. Inigoes areas began in 1942, when the U.S. Navy built NAS Patuxent River and WOLF. Before 1942, relatively little ground water was pumped in the area, except for domestic use in the town of Solomons, Maryland (Bennett, 1944, p. 2). Yearly withdrawal records obtained for this report date back to 1946, but are intermittent prior to 1989 (table 3). For each well, monthly withdrawal values (in gallons) were summed for a calendar year and then divided by the number of days in that year to calculate an average daily withdrawal value in gallons per day. The monthly withdrawal values were either measured with a flow meter or estimated. Data reported since 1989 are considered to be more comprehensive because complete withdrawal records were collected and furnished by NAS Patuxent River employees, whereas prior records may not include all withdrawal data.

Personnel data, furnished by the air station's Public Affairs Office, include the number of military, civilian, contractor, and other employees who worked at NAS Patuxent River and used its resources. For this report, military personnel data records cover the period from 1962–99, and total personnel data cover the period from 1981–99. Personnel data for WOLF were unavailable. The total number of personnel at the NAS Patuxent River has increased from 1981–99, with the greatest number of people working at the station between 1995–98 (fig. 9). The NAS Patuxent River has had the largest number of personnel on record in the latter half of the 1990's, yet overall ground-water withdrawal at NAS Patuxent River decreased during the same period. This decrease is due to water-use changes over the past few years. Old buildings with leaky water delivery systems have been demolished, and old water lines have been replaced. Industrial applications that use large amounts of water, such as jet engine testing, are declining. The steam generating plant that was used for heating buildings and water has been demolished recently and replaced by local high efficiency boilers, reducing water and energy loss (Don Shaver, Naval Air Station Patuxent River, oral commun., 2000). Overall, withdrawals from the Piney Point-Nanjemoy aquifer have decreased, declining from approximately 48,000 gal/d (gallons per day) in 1946 to approximately 500 gal/d in 2000 (table 3). According to records dating back to 1989, no water has been withdrawn from the Piney Point-Nanjemoy aquifer at WOLF. At NAS Patuxent River, withdrawals from the Aquia have decreased by approximately 386,000 gal/d, from an average of more than 1,128,000 gal/d in 1946 to an average of approximately 742,000 gal/d in 2000. At WOLF, withdrawals from the Aquia aquifer have decreased from approximately 74,000 gal/d in 1989 to approximately 28,000 gal/d in 1999.

Piney Point-Nanjemoy Aquifer

According to Chapelle and Drummond (1983, p. 23), development of the Piney Point-Nanjemoy aquifer in the late 1800's and early 1900's readily occurred as it is relatively shallow and many of the early wells flowed without pumping. Darton (1896, p. 128) reported 4 flowing Piney Point-Nanjemoy aquifer wells on Solomons Island, 1 in Leonardtown, and 10 in St. Inigoes that flowed 2 to 20 ft above land surface. Significant ground-water withdrawal from the Piney Point-Nanjemoy aquifer began during World War II when the U.S. Navy built several training facilities in the Lexington Park and Solomons areas. The wells stopped flowing when pumping caused the ground-water levels to decline. The Navy reduced its withdrawals from the Piney Point-Nanjemoy aquifer in the late 1940's in response to community complaints of declining water levels. Nevertheless, withdrawal from the aquifer continued to increase outside of the air station to support increasing domestic and municipal demands (Chapelle and Drummond 1983, p. 18). Limited withdrawal data from the 1960's through the late 1980's are available. Thus, discussion of water use prior to 1980 is not possible. The NAS Patuxent River data records indicate modest usage exclusively from one well in the Piney Point-Nanjemoy aquifer from 1989–93. In 1993, an additional well was pumped for part of the year, and in 1994, several more wells contributed to a large increase in withdrawal that decreased the following year. According to available records that date back to 1989, no water has been withdrawn from the Piney Point-Nanjemoy aquifer at WOLF.

Withdrawals from the Piney Point-Nanjemoy aquifer caused water levels in the NAS Patuxent River and Lexington Park area to decline. Otton (1955, Plate 10) reported the center of a cone of depression in the Piney Point-Nanjemoy aquifer at approximately -20 ft m.s.l. around the NAS Patuxent River by 1951, with the deepest recorded value of -32 ft m.s.l. northwest of well SM Df 43. Williams (1979, Plate 3) reported a 1976 water level in the Piney Point-Nanjemoy aquifer of -21 ft m.s.l. near well SM Df 1. A 1980 potentiometric surface map of the Piney Point-Nanjemoy aquifer (Chapelle and Drummond, 1983, Plate 8) shows a cone of depression around well fields at the NAS Patuxent River and Solomons Island. The lowest potentiometric levels reported for the Piney Point-Nanjemoy aquifer were -23 and -22 ft m.s.l., near the southwest border of the main facilities of the NAS Patuxent River and Solomons areas, respectively. Current potentiometric levels in wells in the Piney Point-Nanjemoy aquifer are shown in figure 10. Although the potentiometric surface of the Piney Point-Nanjemoy aquifer at WOLF has not been mapped, figures included in previous reports describing the area indicate that pumping in the surrounding areas has not caused the formation of an extensive cone of depression.

Table 3. *Ground-water withdrawal from the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and the Aquia aquifer at Webster Outlying Field, Maryland, 1946–2000*

[WOLF, Webster Outlying Field; –, no data collected; <, less than; >, greater than]

	NAVAL AIR STATION PATUXENT RIVER					WOLF
	Average daily withdrawal, in gallons per day			Percentage of total withdrawal		Average daily withdrawal, in gallons per day
Year	Piney Point-Nanjemoy aquifer	Aquia aquifer	Total daily withdrawal, in gallons per day	Piney Point-Nanjemoy aquifer	Aquia aquifer	Aquia aquifer
1946	47,761	1,128,458	1,176,218	4	96	–
1947	91,635	1,206,427	1,298,062	7	93	–
1948	99,895	1,313,130	1,413,025	7	93	–
1949	67,874	1,438,823	1,506,697	5	95	–
1953	84,000	1,559,000	1,643,000	5	95	–
1954	74,000	1,414,000	1,488,000	5	95	–
1955	73,780	1,354,143	1,427,923	5	95	–
1956	103,000	1,343,340	1,446,340	7	93	–
1970	107,868	1,249,720	1,357,588	8	92	14,479
1971	133,910	1,153,838	1,287,748	10	90	16,945
1974	75,916	1,152,264	1,228,180	6	94	–
1975	82,231	844,676	926,907	9	91	–
1989	93	1,038,654	1,038,748	<1	>99	73,705
1990	99	938,988	984,087	<1	>99	59,225
1991	99	1,118,700	1,118,799	<1	>99	78,390
1992	99	797,223	797,321	<1	>99	78,489
1993	55,689	808,236	863,925	6	94	55,774
1994	178,150	812,360	990,510	18	82	47,799
1995	43,156	748,439	791,595	5	95	42,627
1996	45,730	697,497	743,227	6	94	40,245
1997	58,984	754,685	813,669	7	93	26,498
1998	1,605	831,382	832,988	<1	>99	26,498
1999	24,061	832,636	856,697	3	97	29,536
2000 [A]	460	742,090	742,697	<1	>99	28,326

[A.] Values for 2000 are based on withdrawal values from January 1, 2000 through July 31, 2000.

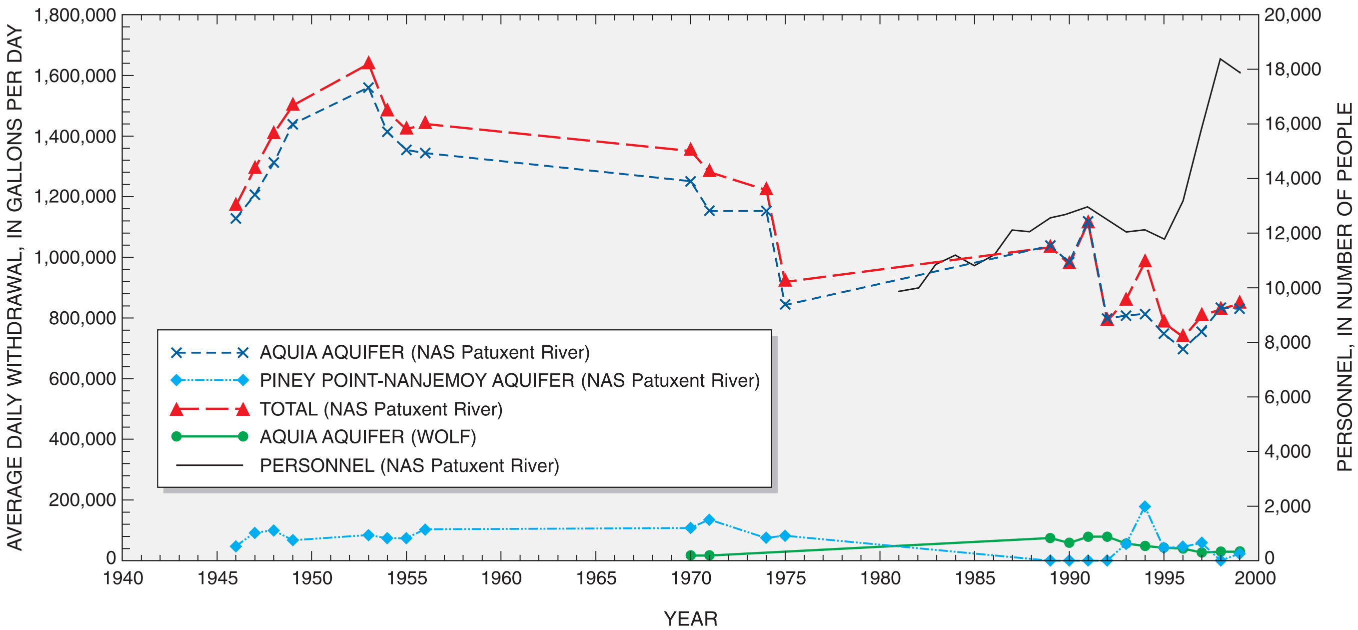


Figure 9. Ground-water withdrawal from the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station (NAS) Patuxent River, ground-water withdrawal from the Aquia aquifer at Webster Outlying Field (WOLF), and personnel at Naval Air Station (NAS) Patuxent River, 1946-99.

It is difficult to make comparisons between the potentiometric surface maps for 1951, 1976, 1980, and recent levels of the potentiometric surface because of changes in the observation-well network. USGS water-level records for existing wells at NAS Patuxent River that are screened in the Piney Point-Nanjemoy aquifer date back only to the mid–1990's, with water levels measured in wells SM Df 14, SM Dg 20, and SM Dg 21 averaging -20 ft m.s.l. (fig. 11). Comparison of water levels from 1951 through 1980, reported by Otton (1955), Williams (1979), and Chapelle and Drummond (1983), to water levels from 1996 through 2000 (fig. 11) indicates that the Piney Point-Nanjemoy water levels in the NAS Patuxent River area have remained relatively stable for the past 50 years.

Aquia Aquifer

Withdrawal records indicate that the Aquia aquifer has historically provided most of the ground water used by NAS Patuxent River, WOLF, and surrounding areas. At least 90 percent of the withdrawal at NAS Patuxent River has consistently been from the Aquia aquifer, and all withdrawal at WOLF has been from the Aquia aquifer (table 3). The use of the Aquia aquifer in southern Maryland increased, just as it did for the Piney Point-Nanjemoy aquifer during World War II (Chapelle and Drummond 1983, p. 18). In the early 1950's, the Korean War necessitated an increase in development and improvement of aircraft, thereby elevating water use (Marcoa Publishing Inc., 1998). Water use fluctuated during the 1990's, but withdrawal from the Aquia aquifer generally decreased at the NAS Patuxent River, from approximately 1,000,000 gal/d in 1989 to approximately 742,000 gal/d in 2000 (table 3; fig. 9). Aquia aquifer withdrawal data for WOLF from 1989–2000 show a decrease in withdrawal, except for a slight increase in 1999. Overall, withdrawal decreased from approximately 74,000 gal/d in 1989 to approximately 28,000 gal/d in 2000.

Potentiometric surface maps of the Aquia aquifer in southern Maryland from 1951–97 show a dynamic cone of depression in the Lexington Park-Solomons-NAS Patuxent River areas. This cone formed in an oblong shape around the Lexington Park area, expanding deeper and wider over time during the period of record (Weigle and Webb, 1970); Chapelle and others, 1981; Chapelle and Drummond, 1983; Mack and others, 1983; Mack and others, 1985, 1987; Mack and others, 1987, 1989, 1990; Mack and others, 1991, 1992; Curtin and others, 1993, 1996, 1997, 1999; Curtin and others, 1994, 1995). Otton (1955, Plate 9) prepared the first potentiometric-surface map of the Aquia aquifer in southern Maryland (Chapelle and Drummond, 1983, p. 17). This map shows a large cone of depression in the Lexington Park area in 1951. A similar cone of depression was described by Weigle and Webb (1970), but water levels had declined approximately 20 ft near Leonardtown as a result of increased municipal withdrawal. A potentiometric surface map created by Chapelle and Drummond (1983) delineates a cone of depression in the NAS Patuxent River-Lexington Park area with levels reported as low as -63 ft m.s.l. along the western boundary of the NAS Patuxent River and

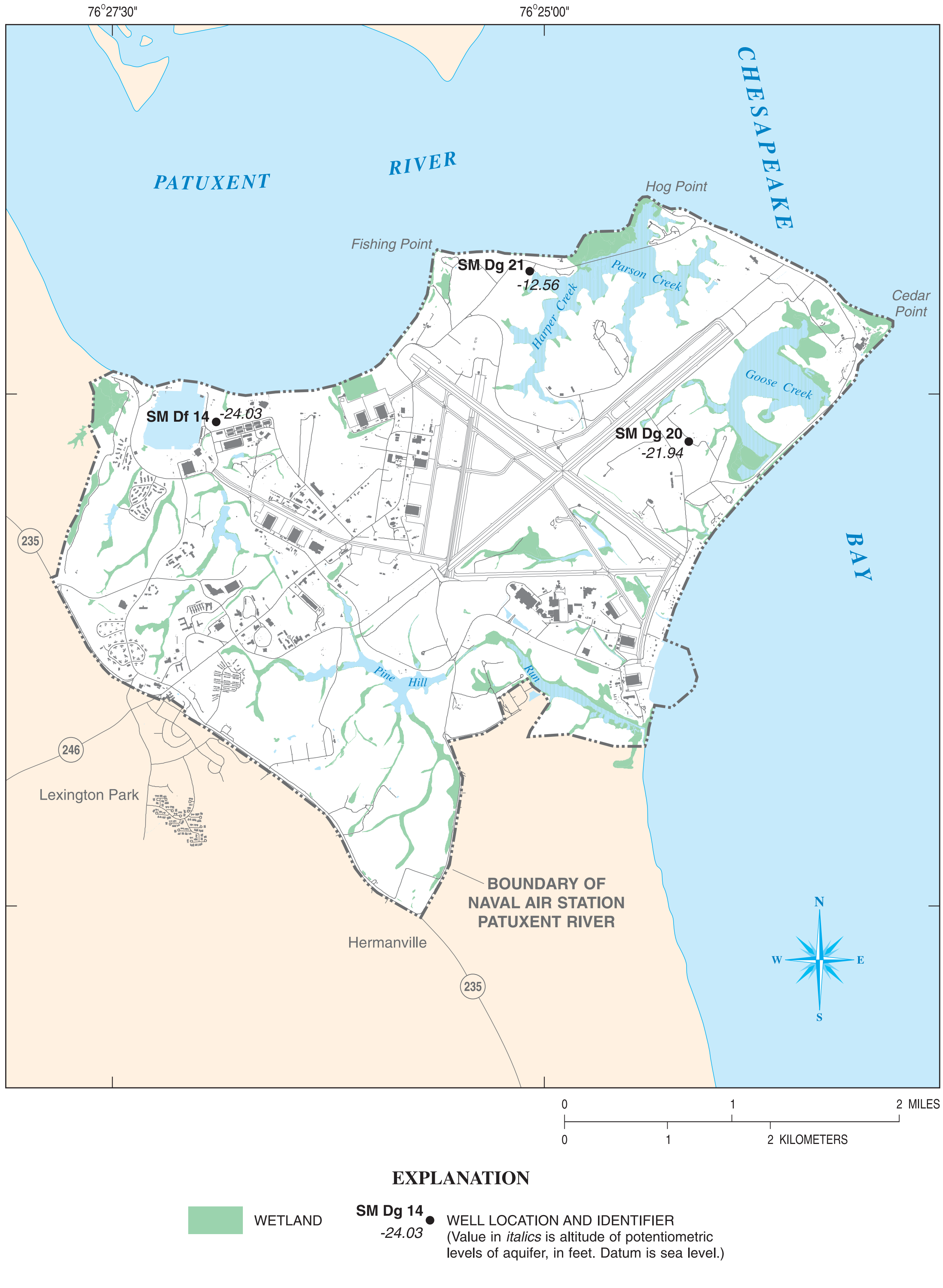


Figure 10. Altitude of the potentiometric levels of the Piney Point-Nanjemoy aquifer on April 20, 2000, Naval Air Station Patuxent River, Maryland.

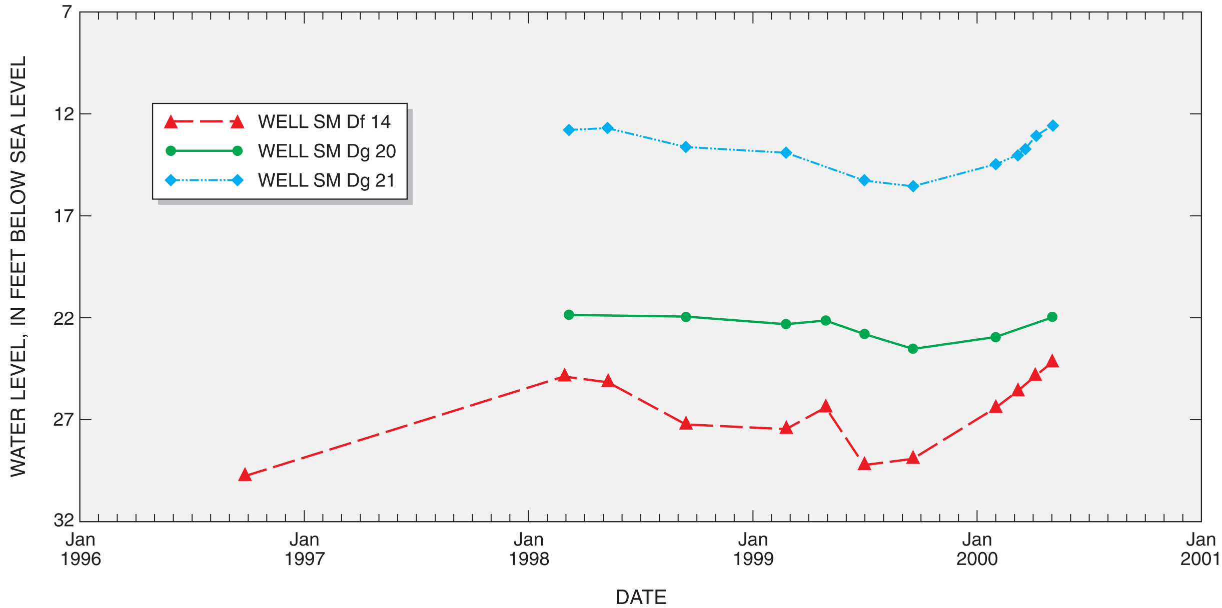


Figure 11. Hydrographs for selected wells screened in the Piney Point-Nanjemoy aquifer at Naval Air Station Patuxent River, Maryland, 1996-2000.

-83 ft m.s.l. just outside the NAS Patuxent River in Lexington Park in 1981. Curtin, Andreasen, and Mack (1999, p. 1) show an extensive cone of depression in the Aquia aquifer around well fields at Lexington Park and Solomons Island during September 1997. Ground-water levels were more than -80 ft m.s.l. in a 60-mi^2 area surrounding the deepest part of the cone of depression, with measured values at the NAS Patuxent River approximately -120 ft m.s.l. The lowest measurement was -143 ft m.s.l. in one well in Lexington Park, Maryland. Ground-water-level measurements recorded at the NAS Patuxent River in January 2000 ranged from about -116 ft m.s.l. (well SM Dg 19) on the eastern side to -154 ft m.s.l. (well SM Df 98) on the western side (fig. 12). None of the potentiometric surface maps of the Aquia aquifer specifically include water levels recorded at WOLF; however, a water level collected by USGS personnel on December 30, 1999, for well SM Ff 64 was -80 ft m.s.l. Curtin, Andreasen, and Mack (1999, p. 1) show the change in the potentiometric surface of the Aquia aquifer between September 1982 and September 1997. This map shows a decline of the potentiometric surface during the 15-year period of 60 to 80 ft at the NAS Patuxent River, a decline of 95 ft at Lexington Park, and a decline of 42 ft near St. Marys City, just north of WOLF.

Water-level records for wells measured by the USGS at the NAS Patuxent River and WOLF date as far back as the early 1940’s, but were not measured on a regular basis until the 1980’s. Hydrographs of water levels for which 15 or more years of record exist show a declining trend in Aquia water levels, decreasing 60 to 80 ft in the last 15 years, with faster rates of decline after 1987 (fig. 13). For wells where monthly water-level data are available, seasonal trends show that water levels are higher in the spring and lower in the fall. Records for water levels at WOLF are not as extensive. The longest water-level record for WOLF is for well SM Ff 21; however, this well was removed in 1991. It appears that the declining water levels occurring at NAS Patuxent River are also occurring at WOLF (fig. 13).

The potentiometric surface maps in previous reports and the hydrographs in this report (fig. 13) show substantial declines in the hydraulic head in the Aquia aquifer, caused by withdrawal of water from the aquifer. In Maryland, large users permitted to withdraw more than 10,000 gal/d are required to report monthly withdrawal values to State permitting agencies. These reported data are then transferred and stored in the USGS SWUDS data base. Withdrawal values for large users of the Aquia aquifer within a 13-mi radius of the NAS Patuxent River in parts of both St. Marys and Calvert Counties (east of Leonardtown, north of St. Marys City, and south of Calvert Cliffs Nuclear Power Plant) were pulled from the SWUDS data base. Figure 14 shows that from 1989–99, withdrawal from the Aquia aquifer by large users within the 20-mi radius of the NAS Patuxent River increased from approximately 2 Mgal/d (million gallons per day) to approximately 4 Mgal/d. During this period, withdrawal from the Aquia aquifer at the NAS Patuxent River decreased from 1 Mgal/d to approximately 0.75 Mgal/d.

EXPLANATION

WETLAND

SM Dg 15 -122.96 — WELL LOCATION AND IDENTIFIER (Value in *italics* is altitude of potentiometric surface of aquifer, in feet. Datum is sea level.)

-120 — POTENTIOMETRIC CONTOUR (Shows line of equal altitude of the potentiometric surface of the Aquia aquifer. Dashed where approximately located. Contour interval 10 feet. Datum is sea level.)

Figure 12. Altitude of the potentiometric surface of the Aquia aquifer on January 12, 2000, Naval Air Station Patuxent River, Maryland.

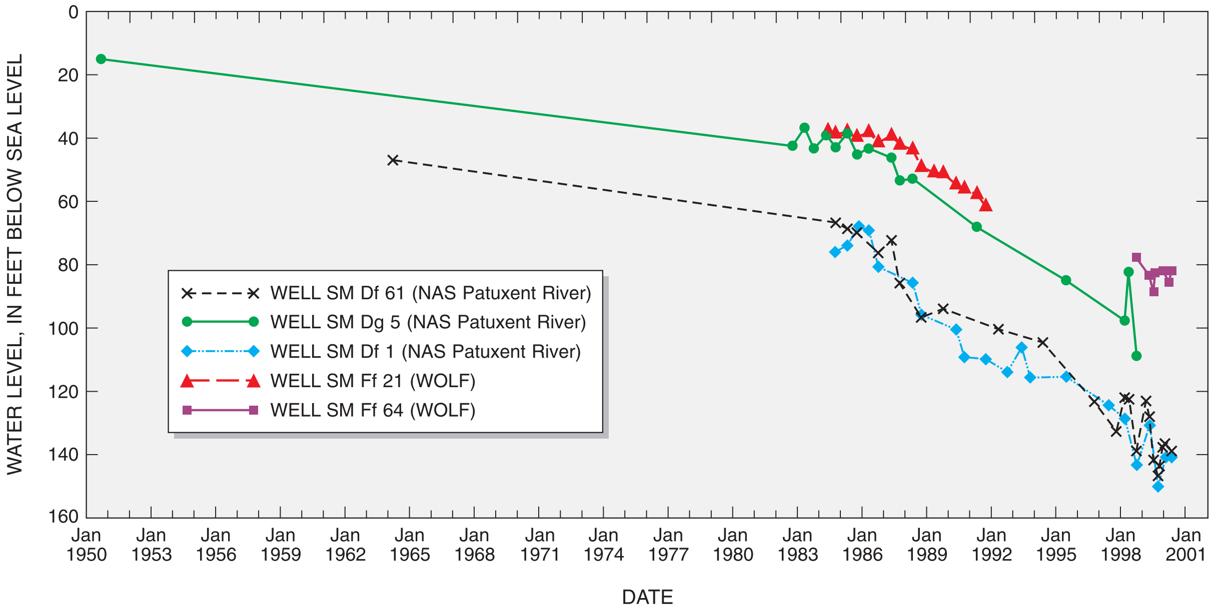


Figure 13. Hydrographs for selected wells screened in the Aquia aquifer at Naval Air Station (NAS) Patuxent River and Webster Outlying Field (WOLF), 1950-2000.

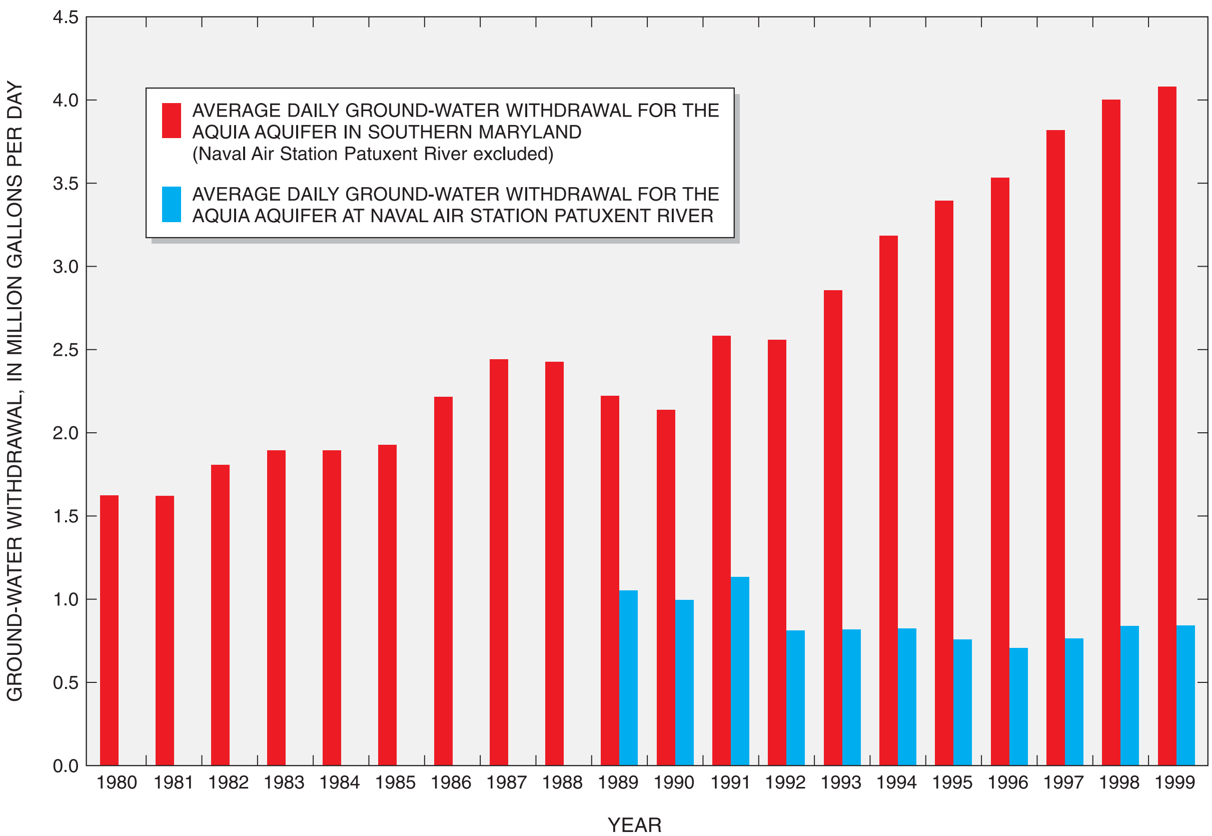


Figure 14. Average daily ground-water withdrawal from the Aquia aquifer for large users in parts of Calvert and St. Marys Counties, Maryland, 1980-99. (Average daily ground-water withdrawal values for the Aquia aquifer at Naval Air Station Patuxent River are not available from 1980-88.)

Ground-Water Quality

This section describes procedures used in the collection of water samples, laboratory methods used to analyze different chemical constituents, and data-analysis methods. Results of the ground-water and quality-control sample analyses can be found in table 4, and are discussed later in this section.

In August 1999, USGS field personnel collected water samples from one well screened in the Piney Point-Nanjemoy aquifer at the NAS Patuxent River, six wells screened in the Aquia aquifer at the NAS Patuxent River, and two wells screened in the Aquia aquifer at WOLF. At production wells, most of which had some type of chlorine treatment, samples were taken from spigots before the water was treated. The samples for laboratory analysis were collected after the wells were purged and water temperature, pH, and specific conductance had stabilized. USGS personnel (1) measured field parameters such as air temperature, water temperature, pH, specific conductance, dissolved oxygen, and acid-neutralizing capacity (ANC) (unfiltered, digital-titration method); (2) collected the raw (unfiltered and unacidified) water samples; (3) filtered the water for selected laboratory samples with a 0.45-micron capsule filter and a peristaltic pump; (4) preserved all laboratory samples as required with appropriate acid, and (5) shipped the samples overnight to the analyzing laboratory. The USGS National Field Manual for the Collection of Water-Quality Data (Wilde and others, 1998) documents the methods used in the collection of the ground-water samples.

The USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, analyzed water samples for iron, potassium, silica, magnesium, bromide, sodium, fluoride, manganese, chloride, calcium, sulfate, nitrite plus nitrate, boron, barium, iodide, and Radon-222. Robert Michel (USGS, Menlo Park, California) analyzed water samples for tritium. The Quanterra-Richland Laboratory (Richland, Washington) analyzed water samples for selected radio-chemicals (Radium-226, Radium-228, alpha, gross beta, and Uranium). Laboratory methods are documented in Fishman and Friedman (1989) and are verified for bias, accuracy, and precision with standard-reference materials and by participation in the USGS Office of Water Quality sample-testing program (Maloney and others, 1994; Pritt and Raese, 1995). Appendix B lists all constituents for which water samples were analyzed and provides a brief description of methods that were used by the analyzing laboratory. All water-quality data are stored in the USGS NWIS data base.

At two Aquia aquifer wells, SM Df 61 and SM Df 98, water samples were collected and sent to the Wisconsin State Hygiene Laboratory for analysis of human pathogens. All results were negative for the presence of human pathogens (see Appendix C for list of viral contaminants analyzed).

In addition to the "environmental" water samples mentioned above, quality-control samples were collected to estimate the magnitude of the bias and variability introduced into sampling and analyzing procedures. First, a field blank was collected from well SM Ff 63 and analyzed to determine the bias in the nitrite-plus-nitrate data. Inorganic blank water certified by the USGS National Laboratory in Ocala, Florida, was used to collect a field blank to test for possible nitrate contamination during the collection, shipping, or laboratory analysis of samples. Second, a duplicate sample was collected to check for variability in the water-quality data. The duplicate sample was collected at well SM Ff 63 by use of a sequential method, in which a large churn was filled with ground water from a spigot; as the water was filtered, one Radium-226 sample bottle was filled, then a second (duplicate) Radium-226 sample bottle was filled, then one Radium-228 sample bottle was filled, then a second (duplicate) Radium-228 sample bottle was filled, and so on. Third, the pH, specific conductance, and ANC of the water samples were determined by the laboratory to verify the field-measured values. The percent relative standard deviation (%RSD) was calculated from the duplicate data using the followng equation:

$$\%RSD = 100\left(\frac{\sqrt{(x_1 - x_2)^2/2}}{(x_1 + x_2)/2}\right) ,$$

where:

%RSD	=	the percent relative standard deviation,
x_1	=	the concentration of the ground-water sample, and
x_2	=	is the concentration of the duplicate sample.

The %RSD was less than 5.7 percent for all laboratory-measured constituents except barium (%RSD = 14.6), and bromide (%RSD = 23.0), and the median of the %RSDs for all laboratory-measured constituents was 0.0 percent. The %RSD for all laboratory-measured constituents (less than 5.7%) indicates that the variability introduced by field-collection methods, shipping, and analyzing methods is minimal for all constituents except barium and bromide. The %RSD between field-measured values and laboratory-measured values for pH was less than 1.0 percent, except for well SM Dg 18 (%RSD = 8.7); specific conductance was less than 10 percent, and ANC was less than 1 percent except for well SM Ff 35 (%RSD = 2.7), and well SM Df 61 (%RSD = 6.0).

Cation-anion balances were calculated, as the percent difference between total anions to total cations in milli-equivalents per liter, to ensure that all major ions dissolved in solution were accurately accounted for during analysis. A cation-anion balance of less than 2 percent is considered acceptable (Hem, 1992). The cation-anion balances for all water samples collected from the Piney Point-Nanjemoy

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999*

[no., number; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; E, estimated; –, no data available]

Well identification no.	Building no.	Aquifer	Date	Specific conductance (field) (µS/cm)	pH (field) (standard units)	Air temperature (°C)	Water temperature (°C)	Dissolved oxygen (mg/L)	Calcium (dissolved, mg/L as Ca)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	257	8.0	32.0	17.5	<0.1	22
SM Df 61	524	Aquia	08/03/1999	273	7.9	30.5	17.0	2.5	24
SM Df 98	587	Aquia	08/04/1999	301	8.9	28.5	19.0	2.9	3.4
SM Df 99	2276	Aquia	08/05/1999	309	8.9	29.0	18.5	1.3	2.4
SM Dg 5	651	Aquia	08/04/1999	291	8.7	27.5	19.5	–	3.0
SM Dg 15	523	Aquia	08/04/1999	307	8.9	29.0	19.0	2.9	3.0
SM Dg 18	575	Aquia	08/05/1999	315	8.6	29.0	18.5	4.5	6.7
SM Ff 35	8130	Aquia	08/30/1999	562	8.7	21.5	19.0	<.1	3.5
SM Ff 63	8195	Aquia	08/31/1999	645	8.5	20.5	19.0	<.1	2.6
SM Ff 63 [A]	8195	Aquia	08/31/1999	–	–	–	–	–	2.5
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–	–

A. DUPLICATE
B. NITRATE BLANK

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Magnesium (dissolved, mg/L as Mg)	Sodium (dissolved, mg/L as Na)	Potassium (dissolved, mg/L as K)	ANC (field) (mg/L as $CaCO_3$)	Carbonate (field) (mg/L as CO_3)	Bicarbonate (field) (mg/L as HCO_3)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	11	17	12	140	–	–
SM Df 61	524	Aquia	08/03/1999	12	13	1.0	146	–	–
SM Df 98	587	Aquia	08/04/1999	1.5	62	6.8	155	9	171
SM Df 99	2276	Aquia	08/05/1999	0.97	67	6.0	160	8	179
SM Dg 5	651	Aquia	08/04/1999	1.4	68	6.4	160	6	183
SM Dg 15	523	Aquia	08/04/1999	1.3	72	6.5	168	7	190
SM Dg 18	575	Aquia	08/05/1999	3.0	59	8.9	164	5	189
SM Ff 35	8130	Aquia	08/30/1999	1.6	130	7.8	288	10	332
SM Ff 63	8195	Aquia	08/31/1999	1.5	152	7.8	342	9	398
SM Ff 63 [A]	8195	Aquia	08/31/1999	1.5	152	8.3	–	–	–
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–	–

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Bicarbonate (calculated) (mg/L as HCO_3)	Sulfate (dissolved, mg/L as SO_4)	Chloride (dissolved, mg/L as Cl)	Fluoride (dissolved, mg/L as F)	Silica (dissolved, mg/L as SiO_2)	Dissolved solids sum (mg/L)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	171	7.7	3.8	0.38	53	211
SM Df 61	524	Aquia	08/03/1999	178	5.9	3.0	.37	54	208
SM Df 98	587	Aquia	08/04/1999	–	6.3	1.6	.57	13	193
SM Df 99	2276	Aquia	08/05/1999	–	5.7	1.8	.53	11	191
SM Dg 5	651	Aquia	08/04/1999	–	3.8	2.2	.53	11	193
SM Dg 15	523	Aquia	08/04/1999	–	4.1	2.2	.53	11	202
SM Dg 18	575	Aquia	08/05/1999	–	<0.1	1.5	.41	16	190
SM Ff 35	8130	Aquia	08/30/1999	–	11	1.7	1.3	13	343
SM Ff 63	8195	Aquia	08/31/1999	–	11	1.8	1.8	11	395
SM Ff 63 [A]	8195	Aquia	08/31/1999	–	11	1.8	1.8	11	395
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–	–

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Hardness (calculated) (mg/L as $CaCO_3$)	Nitrite + nitrate (dissolved, mg/L as N)	Barium (dissolved, µg/L as Ba)	Boron (dissolved, µg/L as B)	Bromide dissolved, mg/L as Br)	Iodide (dissolved, mg/L as I)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	100	<0.05	E 0.5	100	0.016	0.006
SM Df 61	524	Aquia	08/03/1999	110	<.05	1.2	80	.021	.006
SM Df 98	587	Aquia	08/04/1999	15	<.05	E 0.47	190	.014	.008
SM Df 99	2276	Aquia	08/05/1999	10	<.05	1.0	200	.015	.007
SM Dg 5	651	Aquia	08/04/1999	13	.082	E 0.94	190	<.01	.005
SM Dg 15	523	Aquia	08/04/1999	13	<.05	E 0.51	190	.011	.006
SM Dg 18	575	Aquia	08/05/1999	29	<.05	1.3	200	<.01	.005
SM Ff 35	8130	Aquia	08/30/1999	15	<.05	2.1	300	.014	.01
SM Ff 63	8195	Aquia	08/31/1999	12	<.05	1.6	400	.018	.013
SM Ff 63 [A]	8195	Aquia	08/31/1999	12	<.05	1.3	390	.025	.012
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	<.05	–	–	–	–

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Iron (dissolved, µg/L as Fe)	Manganese (dissolved, µg/L as Mn)	Alpha radioactive water, (dissolved, pCi/L as TH-230)	Alpha count, 2 sigma, (water, dissolved, pCi/L as TH-230)	Gross beta (dissolved, pCi/L as CS-137)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	<10	<3	<3.0	2.4	13
SM Df 61	524	Aquia	08/03/1999	51	<3	<3.0	2.0	16
SM Df 98	587	Aquia	08/04/1999	E 5.1	<3	<3.0	2.7	11.0
SM Df 99	2276	Aquia	08/05/1999	16	<3	<3.0	2.7	7.0
SM Dg 5	651	Aquia	08/04/1999	<10	<3	<3.0	2.3	8.1
SM Dg 15	523	Aquia	08/04/1999	<10	<3	<3.0	1.9	9.2
SM Dg 18	575	Aquia	08/05/1999	E 9.2	<3	<3.0	2.5	10.0
SM Ff 35	8130	Aquia	08/30/1999	E 8	E 1.9	<3.0	2.1	5.2
SM Ff 63	8195	Aquia	08/31/1999	<10	E 1.2	<3.0	2.4	5.6
SM Ff 63 [A]	8195	Aquia	08/31/1999	10	1.4	<3.0	2.7	5.1
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Beta, 2 sigma, (water, dissolved, pCi/L as CS-137)	Radium-226 (dissolved, planchet count) (pCi/L)	Radium-226, 2 sigma (water, dissolved) (pCi/L)	Radium-228, (dissolved, pCi/L as Ra-228)	Radium-228, 2 sigma, (pCi/L)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	4.5	<0.1	0.054	0.821	0.32
SM Df 61	524	Aquia	08/03/1999	1.7	<.1	.037	.540	.31
SM Df 98	587	Aquia	08/04/1999	1.5	<.1	.052	.498	.29
SM Df 99	2276	Aquia	08/05/1999	1.4	<.1	.037	<1.0	.20
SM Dg 5	651	Aquia	08/04/1999	1.4	<.1	.032	.113	.19
SM Dg 15	523	Aquia	08/04/1999	1.4	<.1	.038	.442	.23
SM Dg 18	575	Aquia	08/05/1999	1.6	<.1	.059	.616	.26
SM Ff 35	8130	Aquia	08/30/1999	4.7	<.1	.034	.359	.30
SM Ff 63	8195	Aquia	08/31/1999	4.8	<.1	.063	.421	.30
SM Ff 63 [A]	8195	Aquia	08/31/1999	4.7	<.1	.051	.901	.35
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–

Table 4. *Concentrations of the major inorganic constituents, selected minor constituents, and radionuclides of ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1999--Continued*

Well identification no.	Building no.	Aquifer	Date	Radon-222 (total) (pCi/L)	Radon-222, 2 sigma, (water whole, total) (pCi/L)	Tritium (pCi/L)	Tritium, 2 sigma (water, whole, total) (pCi/L)	Uranium (natural, dissolved, µg/L as U)	Uranium, natural, 2 sigma, (water, dissolved) (pCi/L)
SM Df 14	532	Piney Point-Nanjemoy	08/05/1999	378	22	4.2	1.0	<1.0	0.2
SM Df 61	524	Aquia	08/03/1999	323	19	<2.5	1.9	<1.0	.1
SM Df 98	587	Aquia	08/04/1999	404	21	<2.5	1.9	<1.0	.1
SM Df 99	2276	Aquia	08/05/1999	415	23	<2.5	1.9	<1.0	.1
SM Dg 5	651	Aquia	08/04/1999	302	19	<2.5	1.9	<1.0	.1
SM Dg 15	523	Aquia	08/04/1999	415	21	<2.5	1.9	<1.0	.1
SM Dg 18	575	Aquia	08/05/1999	331	21	<2.5	1.9	<1.0	.1
SM Ff 35	8130	Aquia	08/30/1999	506	24	<2.5	1.9	<.40	0.0
SM Ff 63	8195	Aquia	08/31/1999	434	22	<2.5	1.9	<.40	0.0
SM Ff 63 [A]	8195	Aquia	08/31/1999	445	22	<2.5	1.9	<.40	0.0
SM Ff 63 [B]	8195	Aquia	08/31/1999	–	–	–	–	–	–

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and Aquia aquifers in 1999 agreed within 1 percent, except those for samples from well SM Df 98 (-2 percent) and well SM Df 61 (-7 percent). The percent difference for well SM Df 61 is most likely due to error in accounting for all the potassium dissolved in the water sample.

The ground-water chemistry of both the Piney Point-Nanjemoy and Aquia aquifers is described on the basis of cations or anions that account for the majority of ions in the samples. In the Aquia aquifer, sodium and bicarbonate account for the majority of dissolved ions in solution. Samples collected recently were compared to values reported in the literature (table 5) to determine if there are any temporal differences in water chemistry. This comparison was especially important for the Piney Point-Nanjemoy sample discussion because only one well screened in the Piney Point-Nanjemoy aquifer was sampled in 1999. Constituent concentrations in the samples collected in 1999 also were compared to average constituent concentrations in saltwater to see if saltwater intrusion is occurring in these aquifers.

Piper diagrams were used as a tool to analyze the similarities and/or differences in the water between the two aquifers, between current and historical values, and between current and average seawater values. Piper diagrams are trilinear diagrams that show concentrations of major cations and anions as percentages of total cations or anions. Water samples that have the same percentage of cations and anions will plot in the same area on the Piper diagram. Samples with different percentages will plot in different areas. In figure 15, the analysis of the water sample from well SM Df 14 (Piney Point-Nanjemoy aquifer sampled in 1999) is plotted as a red triangle. The concentrations of major cations (magnesium, calcium, sodium, and potassium) were summed, and then the percentage of each cation based on the total cations was calculated. The cations are plotted in the left triangle and show that the water sample from well SM Df 14 contains 34 percent sodium plus potassium, 36 percent calcium, and 30 percent magnesium (100 percent total). The same process was used to plot the major anions in the right triangle. The cation and anion percentages were then projected to the diamond part of the plot, which shows the combined percentages of the ions. The sample from the Piney Point-Nanjemoy aquifer (red triangle) had different percentages of ions than all but one of the Aquia aquifer samples (yellow circles) and therefore plotted in a different area of the diagram.

Results of these analyses were also compared to the U.S. Environmental Protection Agency (USEPA) national primary drinking water regulations (table 6) to see if the concentrations of any of the constituents were greater than the maximum contaminant levels (MCLs), the maximum permissible level of a contaminant in water to protect human health, or maximum contaminant level goals (MCLGs), health standards based on the amount of a contaminant in drinking water that will not endanger human health over a lifetime of exposure (U.S. Environmental Protection Agency, 1999a). Results were also compared to the USEPA national secondary drinking water regulations (table 7). These regulations cover contaminants that are considered to be esthetically unpleasant (i.e. causing odor or bad taste) but are not considered to pose health problems (U.S. Environ-mental Protection Agency, 1999b).

Water Quality of the Piney Point-Nanjemoy Aquifer

Water was collected from well SM Df 14, which is screened in the Piney Point-Nanjemoy aquifer. Due to logistical concerns, well SM Df 14 was the only well screened in the Piney Point-Nanjemoy aquifer that could be sampled. The authors determined that the constituent concentrations in the sample from 1999 matched historical values, so the discussion of water quality in the Piney Point-Nanjemoy aquifer could be based on the single sample from well SM Df 14.

The water in the Piney Point-Nanjemoy aquifer is a calcium-magnesium-sodium-bicarbonate water. The water temperature was about 17.5 °C (degrees Celsius), pH was 8.0, specific conductance was 285 µS/cm (microsiemens per centimeter), hardness was 100 mg/L (milligrams per liter) as calcium carbonate, and ANC was 140 mg/L (as calcium carbonate). There was no detectable nitrite plus nitrate. The water contained 22 mg/L of calcium, 11 mg/L of magnesium, 17 mg/L of sodium, 12 mg/L of potassium, 53 mg/L of silica, 100 µg/L (micrograms per liter) of boron, 3.8 mg/L of chloride, and 7.7 mg/L of sulfate.

The Radon-222 value was 378 pCi/L (picocuries per liter). This value is greater than the USEPA proposed MCL of 300 pCi/L, but is less than the alternative maximum contaminant level (AMCL) of 4,000 pCi/L (U.S. Environmental Protection Agency, 1999c). The AMCL is used when a multimedia mitigation program is followed to address radon concentrations in air (U.S. Environmental Protection Agency, 1999c). The radon value is also on the same order of magnitude as other radon concentrations (502 and 719 pCi/L) sampled in the Piney Point-Nanjemoy aquifer in Queen Annes County, Maryland (Smigaj and others, 1999). The tritium concentration was 4.2 pCi/L. The gross beta count was 13 pCi/L (as Cesium 137), Radium-228 was 0.821 ± 0.32 pCi/L, and all other radionuclide values were lower than the detection limits. In the Piney Point-Nanjemoy aquifer, the concentrations of constituents were less than the MCLs, MCLGs, and the secondary drinking-water standards.

To compare the samples collected in 1999 (table 4) with those collected in the 1940's and 1950's (Chapelle and Drummond, 1983) (table 5), major ions of the samples were plotted on a Piper diagram (fig. 15). The samples plot in the same location on the Piper diagram (fig. 15), indicating that the water chemistry of the Piney Point-Nanjemoy aquifer has not changed during the past 56 years. This would be expected in deep, confined aquifers such as the Piney Point-Nanjemoy aquifer. Achmad and Hansen (1997, p. 76) estimate that the time of travel for water entering the Aquia aquifer is thousands of years, with age dates reported to be greater than 8,500 years (Mignery, 1994). Since the Piney Point-Nanjemoy aquifer is a deep, confined aquifer similar

Table 5. *Historical comparison of major inorganic constituents, and selected minor constituents in ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers, Naval Air Station Patuxent River, Maryland, 1943–62*

[Data taken from Bennett, 1944, for well nos. 1A, 1B, 1C, 2B; data taken from Chapelle and Drummond, 1983, for well nos. SM Df 1, SM Df 3, and SM Dg 1 (table 9), and SM Df 14 (table 10), respectively; no., number; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; n/a, not applicable; –, no data available]

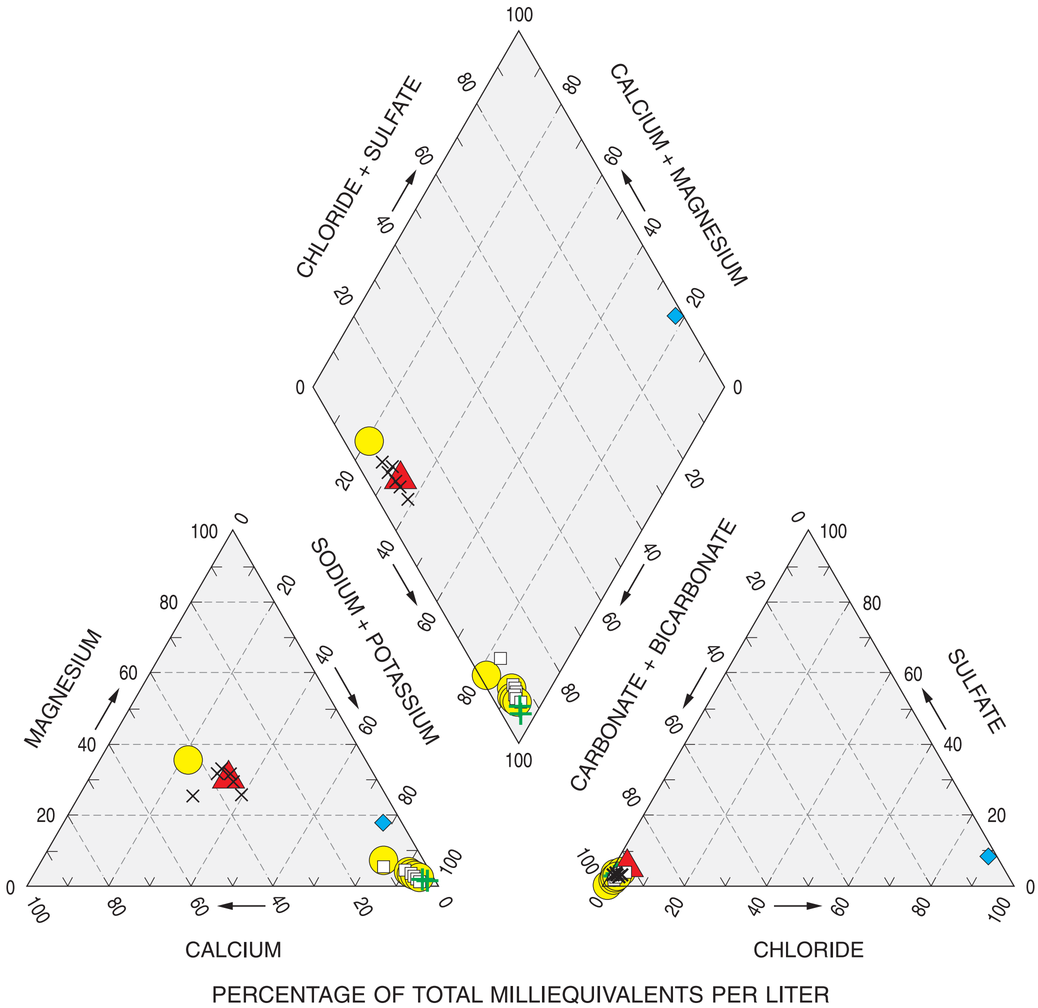
Well identification no.	Aquifer	Date	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Calcium (dissolved, mg/L as Ca)
1A	Aquia	07/22/1943	n/a	8.7	n/a	2.1
1B	Aquia	07/22/1943	n/a	8.7	n/a	0.07
1C	Aquia	07/22/1943	n/a	8.7	n/a	2.9
2B	Piney Point-Nanjemoy	07/22/1943	n/a	7.9	n/a	23
SM Df 1	Aquia	10/29/1951	316	8.5	16.6	2.4
		05/18/1954	336	8.8	18.8	3.0
		03/13/1956	341	8.8	–	2.5
		04/12/1957	342	8.8	–	3.2
		06/02/1958	337	8.0	–	1.7
		08/13/1959	344	8.1	–	3.7
		06/24/1962	344	8.7	–	3.4
SM Df 3	Aquia	10/29/1951	301	8.6	16.6	3.2
		05/18/1954	324	8.9	16.1	2.9
		03/13/1956	323	8.8	–	2.5
		04/09/1957	324	8.9	–	2.7
		06/02/1958	331	8.6	–	2.0
		08/05/1959	331	8.6	–	2.8
		06/24/1962	323	8.4	–	7.5
SM Dg 1	Aquia	11/21/1951	325	8.5	18.8	2.8
		05/20/1954	331	8.4	18.3	3.1
		03/15/1956	326	8.7	–	3.4
		04/09/1957	332	8.7	–	3.5
		06/04/1958	334	7.9	–	2.7
		08/11/1959	334	8.3	–	3.2
SM Df 14	Piney Point-Nanjemoy	11/27/1951	280	8.0	18.3	22
		05/19/1954	279	8.1	17.7	22
		03/20/1956	283	7.9	–	22
		04/12/1957	290	7.8	–	27
		06/09/1958	291	7.7	–	22
		06/24/1962	289	7.8	–	22

Magnesium (dissolved, mg/L as Mg)	Sodium (dissolved, mg/L as Na)	Potassium (dissolved, mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Carbonate (mg/L as CO_3)	Sulfate (dissolved, mg/L as SO_4)	Well identification no.
0.0	n/a	n/a	n/a	15	6.9	1A
2.4	n/a	n/a	n/a	13	6.9	1B
0.5	n/a	n/a	n/a	25	7.1	1C
12	n/a	n/a	n/a	8.9	7.7	2B
1.0	76	9.0	173	n/a	5.5	SM Df 1
1.2	73	6.1	174	n/a	9.6	
0.7	73	7.3	175	n/a	9.4	
0.8	73	6.9	171	n/a	5.8	
0.3	70	7.8	175	n/a	6.0	
1.9	71	6.0	171	n/a	7.6	
0.6	76	7.9	173	n/a	6.4	
0.7	72	9.0	164	n/a	6.5	SM Df 3
1.0	68	5.6	167	n/a	6.6	
0.4	69	6.4	164	n/a	6.6	
0.5	69	6.7	164	n/a	6.0	
1.6	69	6.1	169	n/a	7.0	
0.9	69	9.9	163	n/a	4.3	
2.3	63	7.7	161	n/a	7.0	
1.6	76	7.0	173	n/a	6.0	SM Dg 1
1.2	71	6.3	169	n/a	6.6	
1.0	68	6.7	167	n/a	5.8	
0.7	70	6.7	170	n/a	5.6	
0.3	70	6.4	178	n/a	6.0	
1.2	70	5.7	168	n/a	3.3	
12	17	12	143	n/a	6.8	SM Df 14
12	14	12	143	n/a	7.8	
11	13	12	137	n/a	7.6	
8.7	11	12	139	n/a	6.4	
9.6	20	13	140	n/a	7.2	
11	17	14	141	n/a	6.6	

Table 5. *Historical comparison of major inorganic constituents, and selected minor constituents in ground water from selected wells in the Piney Point-Nanjemoy and Aquia aquifers, Naval Air Station Patuxent River, Maryland, 1943–62--Continued*

Well identification no.	Aquifer	Date	Chloride (dissolved, mg/L as Cl)	Fluoride (dissolved, mg/L as F)	Silica (dissolved, mg/L as SiO_2)	Dissolved solids sum (mg/L)
1A	Aquia	07/22/1943	2.9	n/a	16	234
1B	Aquia	07/22/1943	3.5	n/a	23	226
1C	Aquia	07/22/1943	2.4	n/a	32	194
2B	Piney Point-Nanjemoy	07/22/1943	2.6	n/a	50	224
SM Df 1	Aquia	10/29/1951	2.5	0.5	12	213
		05/18/1954	2.7	0.6	12	–
		03/13/1956	2.5	0.5	13	–
		04/12/1957	2.8	0.6	12	–
		06/02/1958	3.0	0.5	12	–
		08/14/1959	2.5	0.6	12	–
		06/24/1962	2.5	0.2	12	213
SM Df 3	Aquia	10/29/1951	2.8	0.4	12	–
		05/18/1954	3.6	0.5	11	–
		03/13/1956	1.7	0.5	13	–
		04/09/1957	3.0	0.5	13	–
		06/02/1958	3.0	1.4	11	–
		08/05/1959	2.6	1.0	14	–
		06/24/1962	3.5	0.7	18	207
SM Dg 1	Aquia	11/21/1951	4.2	0.4	12	214
		05/20/1954	2.5	0.5	13	–
		03/05/1956	1.8	0.4	12	–
		04/09/1957	2.2	0.5	13	205
		06/04/1958	3.0	0.7	11	209
		08/11/1959	2.2	0.6	12	–
SM Df 14	Piney Point-Nanjemoy	11/27/1951	2.9	0.3	56	215
		05/19/1954	3.8	0.4	48	–
		03/20/1956	1.6	0.3	56	–
		04/12/1957	2.4	0.5	55	–
		06/09/1958	3.0	0.6	50	–
		06/24/1962	3.4	0.0	56	–

Hardness (mg/L as $CaCO_3$)	Nitrate (mg/L as NO_3)	Iron, total recoverable (μg/L as Fe)	Manganese dissolved (μg/L as Mn)	Well identification no.
19	0.26	100	0	1A
45	0.3	80	0	1B
28	0.3	0	0	1C
122	0.2	0	0	2B
10	n/a	0	–	SM Df 1
13	n/a	60	0	
9	n/a	270	0	
11	n/a	30	20	
6	n/a	20	0	
17	n/a	10	0	
11	n/a	100	0	
11	n/a	100	–	SM Df 3
11	n/a	50	0	
8	n/a	20	0	
9	n/a	190	20	
12	n/a	0	0	
11	n/a	20	0	
28	n/a	120	0	
14	n/a	0	–	SM Dg 1
13	n/a	70	0	
13	n/a	70	70	
12	n/a	20	0	
8	n/a	30	0	
13	n/a	40	0	
104	n/a	80	–	SM Df 14
104	n/a	40	0	
100	n/a	90	10	
103	n/a	50	0	
94	n/a	100	0	
102	n/a	60	10	



EXPLANATION

- PINEY POINT-NANJEMOY AQUIFER (NAS Patuxent River, 1999)
- AQUIA AQUIFER (NAS Patuxent River, 1999)
- AQUIA AQUIFER (WOLF, 1999)
- PINEY POINT-NANJEMOY AQUIFER (NAS Patuxent River, 1951-1962)
- AQUIA AQUIFER (NAS Patuxent River, 1951-1962)
- COMPOSITION OF SEAWATER (modified from Hem, 1992)

Figure 15. Chemistry of water from selected wells at Naval Air Station (NAS) Patuxent River and Webster Outlying Field (WOLF).

Table 6. *Select national primary drinking-water regulations: contaminants and their respective maximum contaminant level goals (MCLGs), and maximum contaminant levels (MCLs) as regulated by the U.S. Environmental Protection Agency*

[U.S. Environmental Protection Agency, 1999a; MCLG, maximum contaminant level goal; MCL, maximum contaminant level; mg/L, milligrams per liter; pCi/L, picocuries per liter; n/a, not applicable]

NATIONAL PRIMARY DRINKING-WATER REGULATIONS		
Contaminant	**MCLG (mg/L)**	**MCL (mg/L)**
	Inorganic Chemicals	
Barium	2	2
Fluoride	4	4
Nitrate (measured as Nitrogen)	10	10
Nitrite (measured as Nitrogen)	1	1
	Radionuclides	
Gross Beta	n/a	4 millirems per year
Gross Alpha	n/a	15 pCi/L
Radium-226 and -228 combined	n/a	5 pCi/L
	Microorganisms	
Viruses (enteric)	0	n/a

to the Aquia aquifer, the age of ground water in the Piney Point-Nanjemoy aquifer is probably of similar age to ground water in the Aquia aquifer.

Water Quality of the Aquia Aquifer at Naval Air Station Patuxent River

USGS personnel collected water samples from six wells screened in the Aquia aquifer (SM Df 61, SM Df 98, SM Df 99, SM Dg 5, SM Dg 15, and SM Dg 18) at NAS Patuxent River, Maryland, on August 4–5, 1999. The chemistry of the water in well SM Df 61 is more consistent with that of water in the Piney Point-Nanjemoy aquifer than water in the Aquia aquifer. For this reason, water samples collected from well SM Df 61 are discussed separately at the end of this section. The explanation for the non-Aquia

Table 7. *Select secondary drinking-water regulations*

[U.S. Environmental Protection Agency, 1999b; mg/L, milligrams per liter]

NATIONAL SECONDARY DRINKING-WATER REGULATIONS	
Contaminant	**Secondary standard (mg/L)**
Chloride	250
Fluoride	2
Iron	0.3
Manganese	0.05
pH	6.5-8.5
Sulfate	250
Total Dissolved Solids	500

water type will be discussed in a later section.

The Aquia aquifer contains sodium-bicarbonate water, the water temperature is about 19 °C, pH ranges from 8.6 to 8.9, specific conductance ranges from 291 to 315 µS/cm, hardness is 10 to 29 mg/L (as calcium carbonate), and the ANC ranges from 155 to 168 mg/L (as calcium carbonate). Only well SM Dg 5 had a detectable concentration of nitrite plus nitrate with a value of 0.082 mg/L as N. The median concentrations were 67 mg/L of sodium, 3 mg/L of calcium, 1.4 mg/L of magnesium, 6.5 mg/L of potassium, 1.8 mg/L of chloride, 11 mg/L of silica, 4.9 mg/L of sulfate, and 0.53 mg/L of fluoride.

Radon-222 values ranged from 302 to 415 pCi/L, with a median value of 404 pCi/L. This value is greater than the USEPA proposed MCL of 300 pCi/L, but is less than the AMCL of 4,000 pCi/L (U.S. Environmental Protection Agency, 1999c). The radon values are on the same order of magnitude as other radon concentrations sampled from the Aquia aquifer in Anne Arundel and Queen Annes Counties, Maryland (Smigaj and others, 1999) that ranged from 162 to 989 pCi/L, with a median value of 300 pCi/L. Gross Beta values ranged from 8.1 to 11 pCi/L, Radium-228 values ranged from 0.113 ± 0.19 to 0.616 ± 0.26 pCi/L, with a median of 0.442 ± 0.23 pCi/L, and all other radionuclide values were lower than the detection limits.

As with the Piney Point-Nanjemoy water samples, the Aquia aquifer ground-water samples at the NAS Patuxent River were compared to USEPA primary drinking-water MCLs, MCLGs, and national secondary drinking water regulations (tables 6 and 7). Sample concentrations were not greater than the primary drinking-water MCLs or MCLGs. The pH values for the Aquia aquifer at NAS Patuxent River were greater than the secondary drinking-water regulation maximum pH of 8.5.

Comparison of the results of analyses of samples collected in 1999 (table 4) to the analyses of samples collected in the 1940's through the early 1960's (table 5) shows that the concentrations of major constituents in the aquifer have not changed appreciably during the past 56 years. This is common in deep, confined aquifers, where the water is thousands of years old because of long flow paths from areas of recharge to areas of discharge. As noted previously, well SM Df 61 was not included in the discussion of water quality in the Aquia aquifer at NAS Patuxent River, even though the depth and water levels measured in that well are comparable to those of other wells screened in the Aquia aquifer. The chemistry of water at well SM Df 61 (supposedly completed in the Aquia aquifer) is similar to that of water in wells completed in the Piney Point-Nanjemoy aquifer, possibly because (1) the well is screened in both aquifers, or (2) improper/faulty construction is allowing water from the Piney Point-Nanjemoy aquifer to move into the well. A mix-up of sample bottles, and/or sampling of a different well have been ruled out as possible explanations. The screened interval (580 to 600 ft below sea level) noted on the State of Maryland Well Completion Report is consistent with that of other wells screened in the Aquia aquifer. If the well was screened in both aquifers, then the water type would be expected to be a mixture of both water types. In this case, the water is similar to Piney Point-Nanjemoy aquifer water rather than a mixture of both aquifers. It is possible that the well was not properly constructed—Otton (1955, p. 120) reported that there were indications of ground water from the Piney Point-Nanjemoy aquifer possibly leaking into the Aquia aquifer. Otton suggested that this was due to improper construction of Aquia aquifer wells, whereby casing size was reduced through the Piney Point-Nanjemoy aquifer, and that this resulted in vertical movement of ground water through the packers or along the casings of the wells. This would also result in a mixing of waters, however. Further investigation of construction in this well is necessary to determine why the water is not similar to that of the Aquia aquifer. More water samples could be collected from the well, and further examination of the well with a down-hole video camera and/or a caliper log might help determine whether there are construction problems, screened intervals through both aquifers, or a decrease in casing diameter through the Piney Point-Nanjemoy aquifer.

Water Quality of the Aquia Aquifer at Webster Outlying Field

USGS personnel collected water samples from two wells screened in the Aquia aquifer (SM Ff 35 and SM Ff 63) at WOLF on August 30–31, 1999. Although the water in the Aquia aquifer at WOLF is sodium-bicarbonate water, like the water in the Aquia aquifer at NAS Patuxent River, there are observable differences in the chemistry of the water at two facilities. These differences are probably due to chemical reactions between the water and the aquifer matrix that occur as the water moves downgradient from the NAS Patuxent River toward WOLF (Chapelle and Drummond, 1983).

WOLF-Aquia aquifer waters are about 19 °C, the pH is 8.6, specific conductance ranges from 562 to 645 µS/cm, hardness is 12 to 15 mg/L (as calcium carbonate), and the ANC ranges from 288 to 342 mg/L (as calcium carbonate). Neither sample had a detectable concentration of nitrite plus nitrate. The ground water contained about 140 mg/L of sodium, 3 mg/L of calcium, 2 mg/L of magnesium, 8 mg/L of potassium, 2 mg/L of chloride, 12 mg/L of silica, 11 mg/L of sulfate and 1.5 mg/L of fluoride.

The Radon-222 values ranged from 434 to 506 pCi/L. Gross Beta values were about 5 pCi/L, Radium-228 was about 0.40 ± 0.30 pCi/L, and all other radionuclide values were lower than the detection limits.

As with the other water samples collected in 1999, the chemistry of the samples from the Aquia aquifer at WOLF was compared to USEPA drinking-water MCLs, MCLGs, and secondary drinking-water regulations. Concentrations of constituents in the samples did not exceed the primary MCLs or MCLGs. At well SM Ff 63, the fluoride concentration of 1.8 mg/L is close to, but does not exceed, the secondary drinking-water regulation concentration of 2 mg/L. The pH values were greater than the secondary drinking-water regulation maximum pH of 8.5.

Comparison of Water Types in the Piney Point-Nanjemoy and Aquia Aquifers

The chemistry of the waters in the Piney Point-Nanjemoy and Aquia aquifers differs within the study area. Water in the Piney Point-Nanjemoy aquifer is primarily a calcium-magnesium-sodium-bicarbonate type, and water in the Aquia aquifer is a sodium-bicarbonate type. Water in the Aquia aquifer at NAS Patuxent River can be distinguished from water in the Aquia aquifer at WOLF on the basis of significant differences in specific conductance, ANC, and concentrations of sodium, sulfate, boron, and iodide. The present-day values and the differences in the water types of the two aquifers (table 4) are similar to those of historical water samples reported by Bennett (1944) and Chapelle and Drummond (1983) (table 5). Although not all of the same constituents were analyzed in the 1940's, and some of the methods and/or detection limits may have been different, the unique water types can be identified.

A qualitative comparison of the data in table 4 show that several concentrations of constituents distinguish Piney Point-Nanjemoy ground water from Aquia ground water, and the Aquia ground water at NAS Patuxent River from the Aquia ground water at WOLF. The distinguishable characteristics between the Piney Point-Nanjemoy ground water and the Aquia ground water at the NAS Patuxent River are also supported by the historical data (table 5).

The differences in water chemistry of the aquifers can be summarized as follows:

- The pH of the sample from the Piney Point-Nanjemoy aquifer is slightly less than the pH of representative ground-water samples from the Aquia aquifer (8.0 and 8.9, respectively).
- ANC in the Aquia aquifer at WOLF (300 mg/L) is about twice that in the Aquia aquifer (160 mg/L) and in the Piney Point-Nanjemoy aquifer (140 mg/L) at NAS Patuxent River.
- Specific conductance of the water in the Aquia aquifer at WOLF (600 µS/cm) is almost double the specific conductance in the Piney Point-Nanjemoy aquifer (290 µS/cm) and the Aquia aquifer at NAS Patuxent River (310 µS/cm).
- The concentration of calcium in the sample from the Piney Point-Nanjemoy aquifer (22 mg/L) is about eight times higher than the calcium concentration representative of the Aquia aquifer samples (3 mg/L).
- The concentration of magnesium in the Piney Point-Nanjemoy aquifer (11 mg/L) is also notably different from the concentration of magnesium in the Aquia aquifer, both at NAS Patuxent River and at WOLF (1.5 mg/L).
- The concentration of sodium in the Piney Point-Nanjemoy aquifer (15 mg/L) is one-third lower than the concentration of sodium in the Aquia aquifer at NAS Patuxent River (65 mg/L). The concentration of sodium in the Aquia aquifer at WOLF (140 mg/L) is twice that of the concentration of sodium in the Aquia aquifer at NAS Patuxent River (65 mg/L).

Saltwater Intrusion

Saltwater intrusion can contaminate an aquifer in coastal areas. If the water becomes too brackish, it becomes unusable without treatment. The location of the Piney Point-Nanjemoy and Aquia aquifers puts them at risk for saltwater intrusion as ground-water withdrawals continue. One possible source of saltwater intrusion is downward leakage from the Chesapeake Bay. A second possible source is updip migration of the freshwater/saltwater interface. The following discussion compares constituents in the ground water that indicate the presence of saltwater with concentrations of those constituents in samples collected in 1999.

High total dissolved solids (TDS), high concentrations of sulfate, calcium to magnesium (Ca:Mg) ratios equal to 1.0, sodium to chloride (Na:Cl) ratios equal to 2 (Piper, 1953), and chloride to bromide (Cl:Br) ratios equal to 287.5 can indicate seawater intrusion. Freshwater has less than 1,000 mg/L TDS, brackish waters have 1,000 to 10,000 mg/L TDS, saline waters have 10,000 to 100,000 mg/L TDS, and brines have greater than 100,000 mg/L TDS (Faure, 1991, p. 443). All of the water samples collected in 1999 from both the Piney Point-Nanjemoy and Aquia aquifers were freshwater samples, with a median TDS of 240 mg/L and a maximum TDS of 395 mg/L at well SM Ff 63. Concentrations of sulfate in the samples were less than 15 mg/L. Concentrations of sulfate in seawater are usually greater than 2,000 mg/L (Hem, 1992, p. 205); (Drever, 1988, p. 266). Ratios of Ca:Mg in ground-water samples collected in 1999 were greater than 1.7. For the Piney Point-Nanjemoy aquifer at NAS Patuxent River, the Na:Cl ratio was 4.0; in the Aquia aquifer at NAS Patuxent River, the ratio was 30.0; and at WOLF, the ratio was 12.0. The Cl:Br ratios were close to those of seawater for wells SM Df 14 (237.5), SM Dg 5 (220.0), and SM Dg 15 (200) (table 8).

The presence of connate water, water that is trapped within the sediments as they are deposited, can make an aquifer unsuitable as a source of water supply. In some cases, when the sediments are deposited in a marine environment, the trapped water can be seawater (Faure, 1991, p. 354). The Na:Cl ratios of the water samples collected in this study are higher than ratios commonly found in connate seawater (0.5). Connate water is also indicated by a relative abundance of barium and iodide (24 to 142 mg/L, and 30 to 80 mg/L, respectively) (Piper, 1953). The maximum concentrations of these two constituents in the samples collected in 1999 were only 0.002 mg/L of barium and 0.013 mg/L of iodide (table 8).

Therefore, there is no evidence of saltwater intrusion either from seawater or from connate water at the NAS Patuxent River in either the Piney Point-Nanjemoy aquifer or the Aquia aquifer. At WOLF, the concentrations of sulfate and sodium are higher than at NAS Patuxent River, but are not as high as those typically present in seawater or connate water.

Table 8. *Comparison of average sea water and average connate water to ground-water samples collected in 1999 from the Piney Point-Nanjemoy aquifer, the Aquia aquifer at Naval Air Station Patuxent River, and the Aquia aquifer at Webster Outlying Field, Maryland*

[NAS, Naval Air Station; WOLF, Webster Outlying Field; mg/L, milligrams per liter; <, less than; >, greater than; **E**, estimated; n/a, not applicable]

			AQUIFER		
	Average Sea Water	**Average Connate Water**	**Piney Point-Nanjemoy (1 sample)**	**Aquia at NAS Patuxent River (Range of 5 samples) [A]**	**Aquia at WOLF (2 samples)**
Total dissolved solids (mg/L)	1,000 [B]	n/a	211	190–202	343, 395
Sulfate (mg/L)	2,000 [C, D]	n/a	7.7	<0.1–6.3	11, 11
Calcium : Magnesium (mg/L : mg/L)	1 [E]	n/a	2	2.1–2.4	1.7, 2.2
Sodium : Chloride (mg/L : mg/L)	2 [E]	0.5 [B]	4.5	30.9–39.3	76.5, 84.4
Chloride : Bromide (mg/L : mg/L)	287.5 [F]	n/a	237.5	114–220	100, 121
Barium (mg/L)	n/a	24–142 [E]	**E** 0.5	**E** 0.47–1.3	1.6, 2.1
Iodide (mg/L)	n/a	30–80 [E]	0.006	0.005–0.008	0.010, 0.013

A. Water from well SM Df 61 is not included in “Aquia at NAS Patuxent River” samples because of anomalous chemistry which is discussed in the text.
B. Faure, 1991.
C. Hem, 1992.
D. Drever, 1988.
E. Piper, 1953.
F. Waterloo Hydrologic, 1999.

Summary and Conclusions

The Piney Point-Nanjemoy aquifer and the Aquia aquifer are sources of water supply for the Naval Air Station Patuxent River and Webster Outlying Field in southern Maryland. At Naval Air Station Patuxent River, the top of the Piney Point-Nanjemoy aquifer is 220 to 255 feet below sea level, the thickness is 50 to 70 feet, and the hydraulic conductivity is approximately 2 feet per day. At Webster Outlying Field, the top of the Piney Point-Nanjemoy aquifer is approximately 260 feet below sea level, the thickness is 65 feet, and the hydraulic conductivity is approximately 2 feet per day. At Naval Air Station Patuxent River, the top of the Aquia aquifer is 450 feet below sea level, the thickness is 100 to 145 feet, and the hydraulic conductivity is 6 to 10 feet per day. At Webster Outlying Field, the top of the Aquia aquifer is 470 feet below sea level, the thickness is 50 feet, and the hydraulic conductivity ranges from about 6 to 10 feet per day. Both aquifers are continuous throughout Naval Air Station Patuxent River and Webster Outlying Field, consistent with the regional hydrogeologic framework.

Ground-water withdrawal from the Piney Point-Nanjemoy and Aquia aquifers at the Naval Air Station Patuxent River began in 1942. In 2000, an average of 460 gallons per day was pumped from the Piney Point-Nanjemoy aquifer, an average of 742,500 gallons per day was pumped from the Aquia aquifer at the main facilities at Patuxent River, and an average of 28,000 gallons per day was pumped from the Aquia aquifer at Webster Outlying Field. Water levels in the Piney Point-Nanjemoy aquifer at Naval Air Station Patuxent River have remained relatively constant over the past 49 years, at approximately 20 feet below sea level. Ground-water levels have decreased approximately 40 to 80 feet in the Aquia aquifer during the past 15 to 20 years. At the Naval Air Station Patuxent River, water levels were 70 feet below sea level in the Aquia aquifer in 1983, and 115 to 150 feet below sea level in January 2000. At Webster Outlying Field, Aquia aquifer water levels were 37 feet below sea level in 1984, and 80 feet below sea level in December 1999. The decrease in water levels is most likely due to increased withdrawal outside of the air station boundaries in response to growing public water-supply needs in St. Marys and Calvert Counties, Maryland.

Two main types of ground water are present in the study area: calcium-magnesium-sodium-bicarbonate water in the Piney Point-Nanjemoy aquifer, and sodium-bicarbonate water in the Aquia aquifer. Water in the Aquia aquifer can be separated into two sub-types based on significant differences in specific conductance, acid-neutralizing capacity, sodium concentration, sulfate concentration, boron concentration, and iodide concentration observed at Naval Air Station Patuxent River and Webster Outlying Field. No evidence of saltwater intrusion, either from seawater or connate water, was observed in any of the ground-water samples collected in either area.

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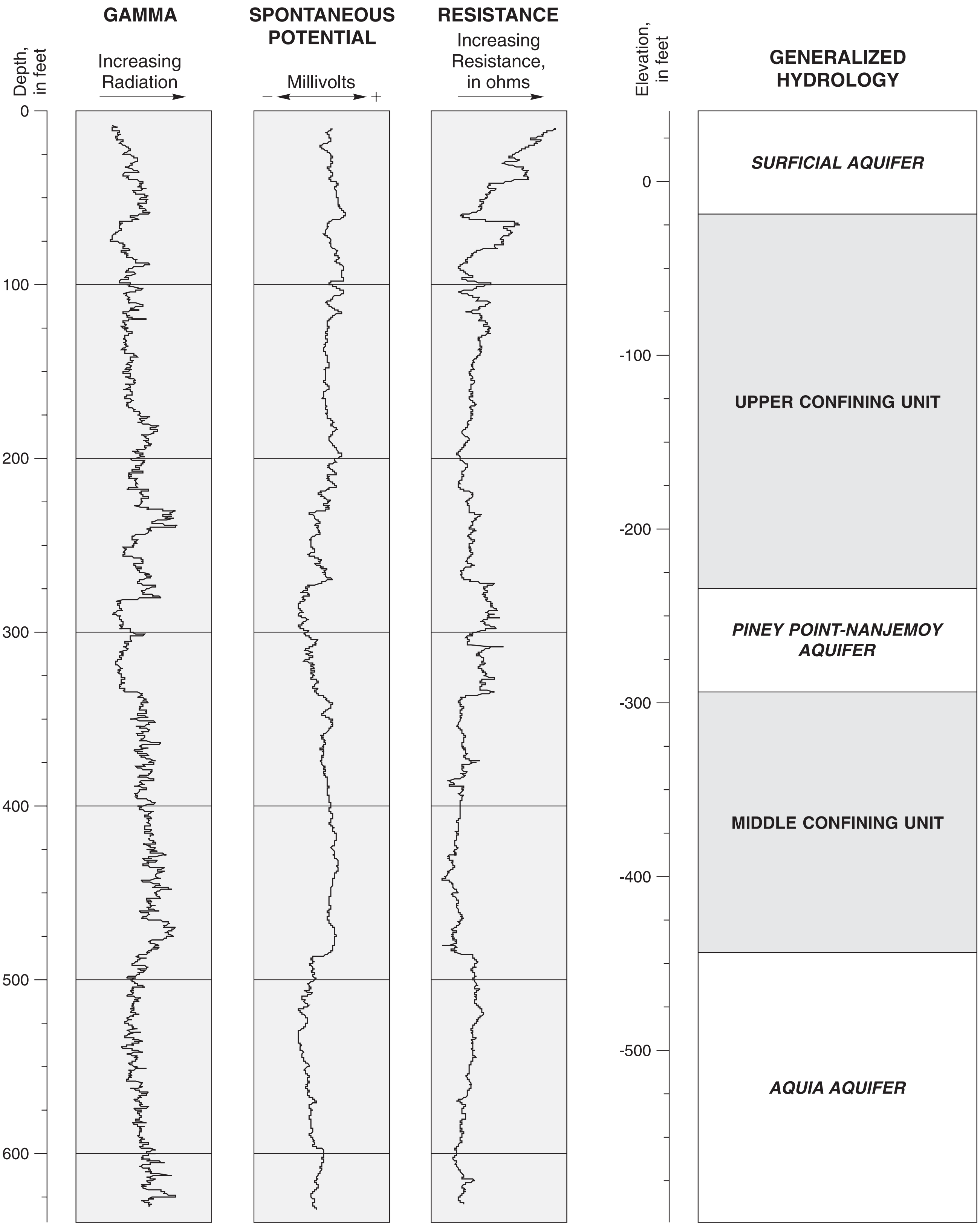
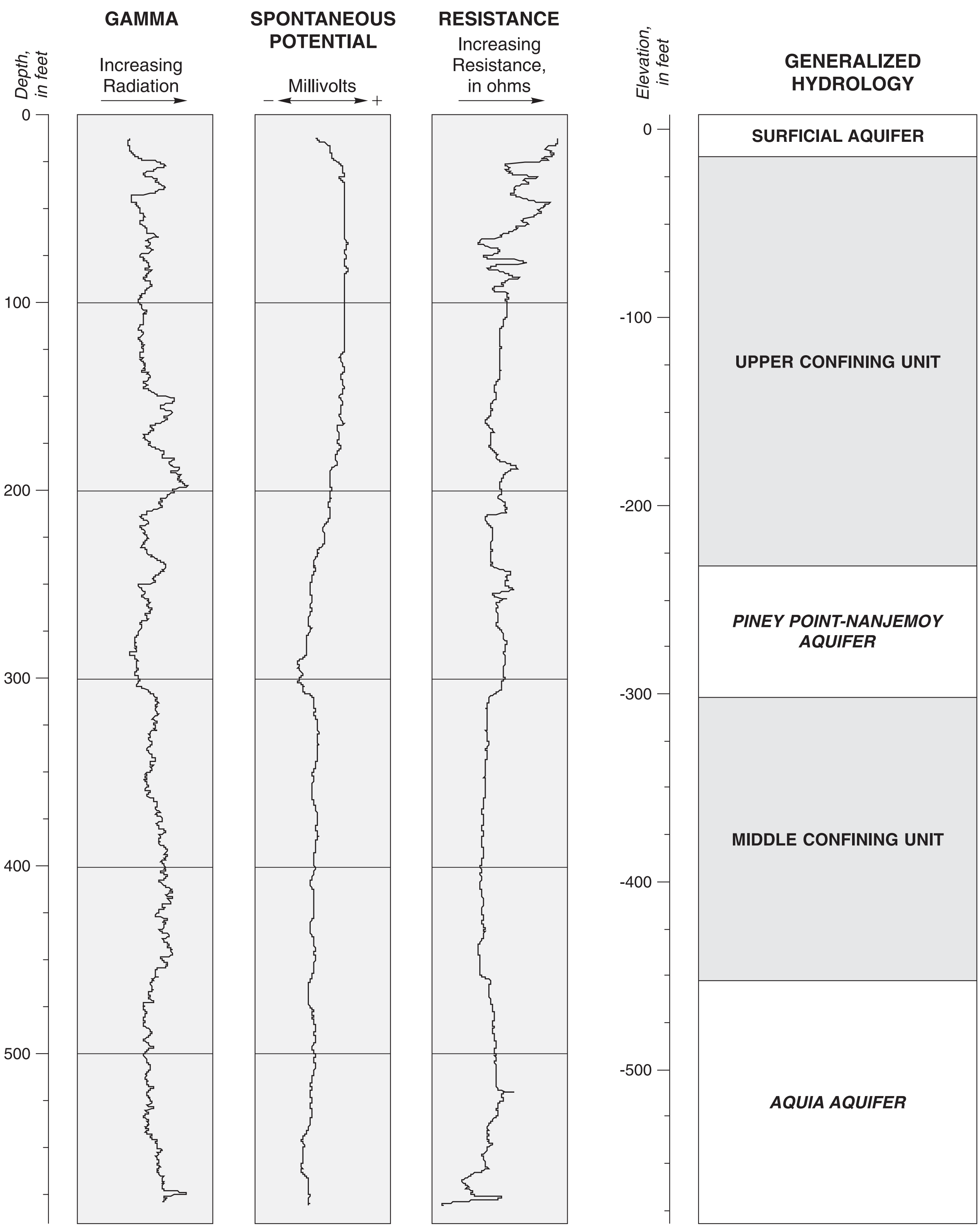
APPENDIXES A THROUGH C FOLLOW

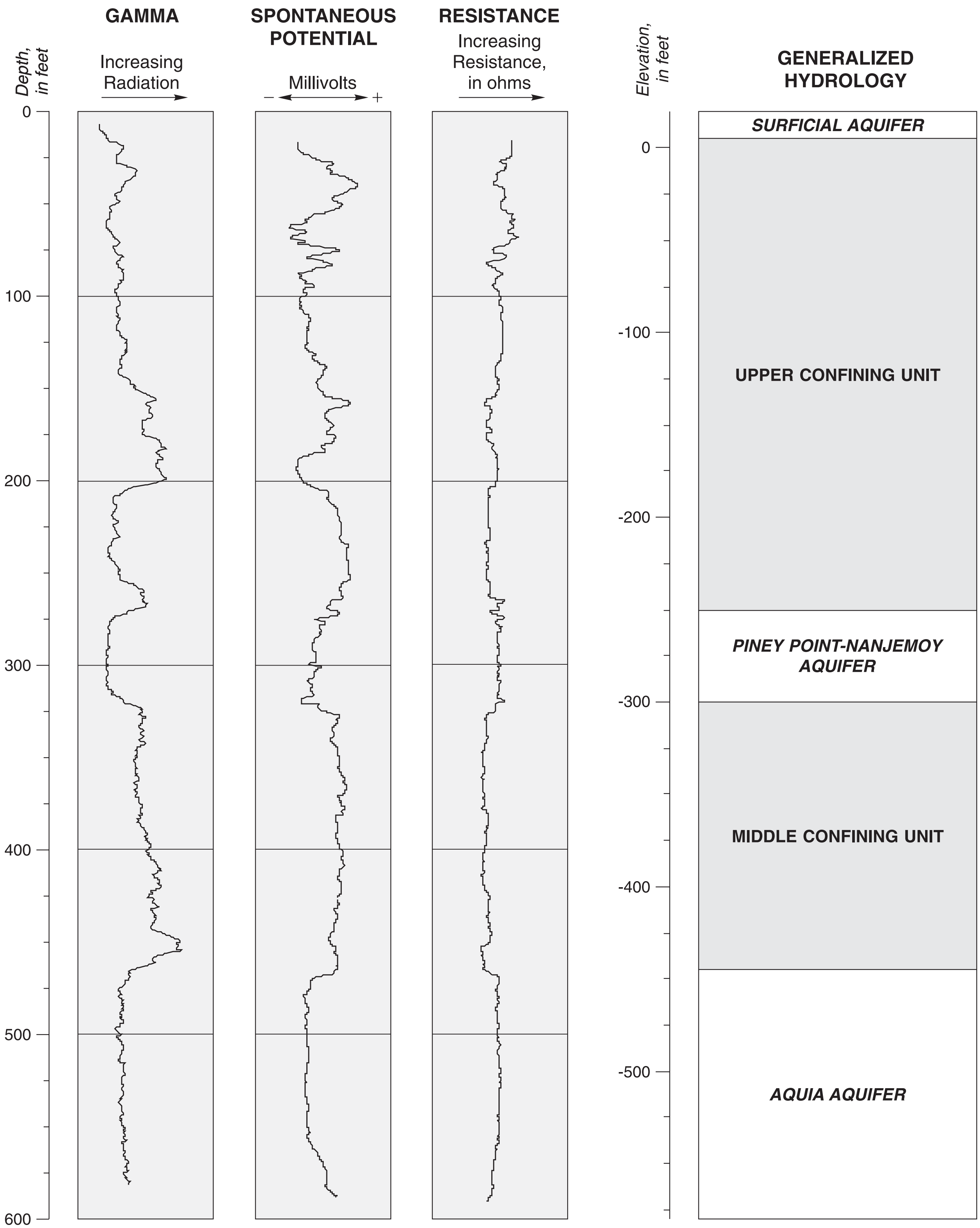
Appendix A1. Geophysical logs with generalized hydrologic units for well SM Df 93



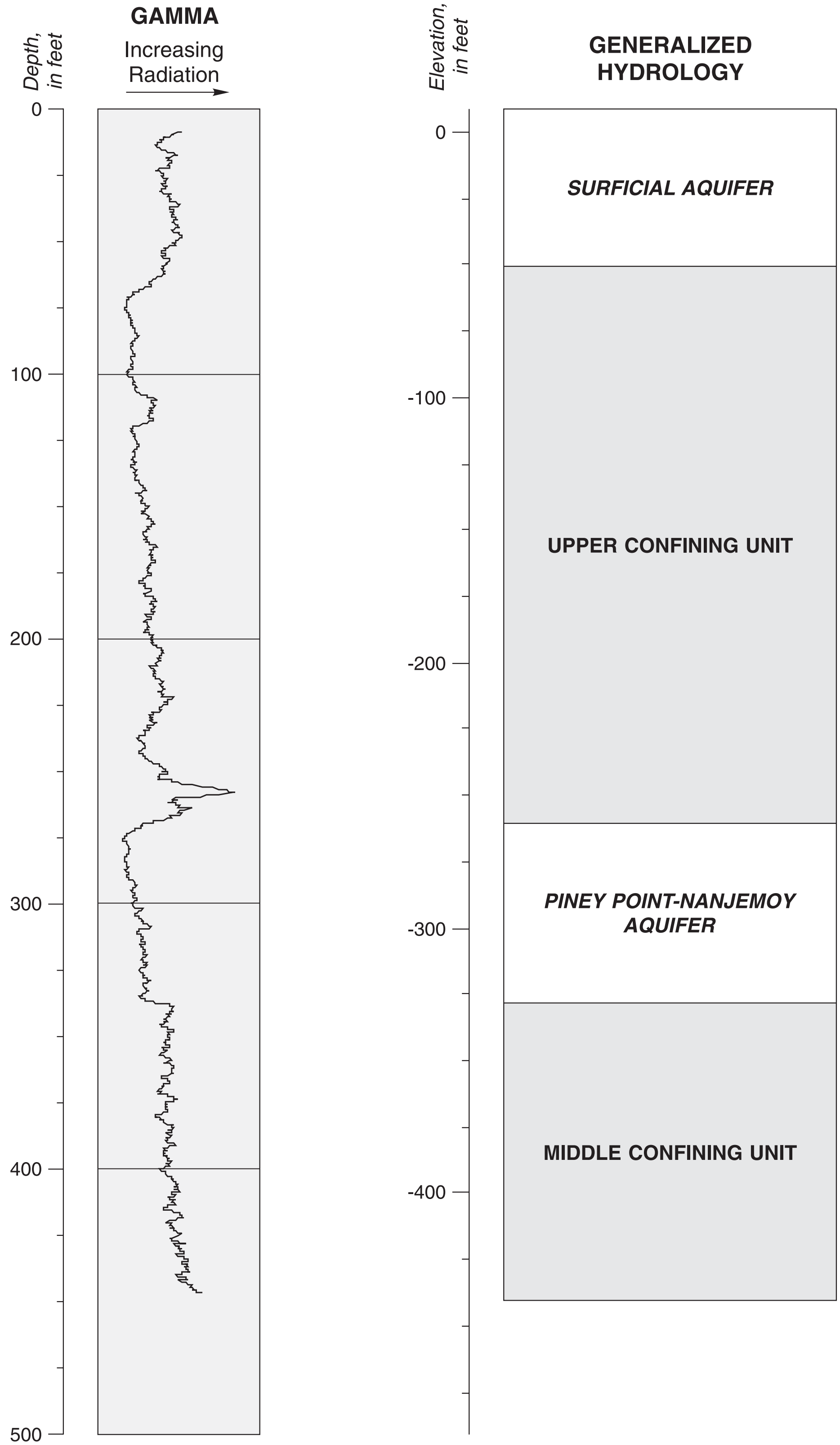
Appendix A2. Geophysical logs with generalized hydrologic units for well SM Df 96



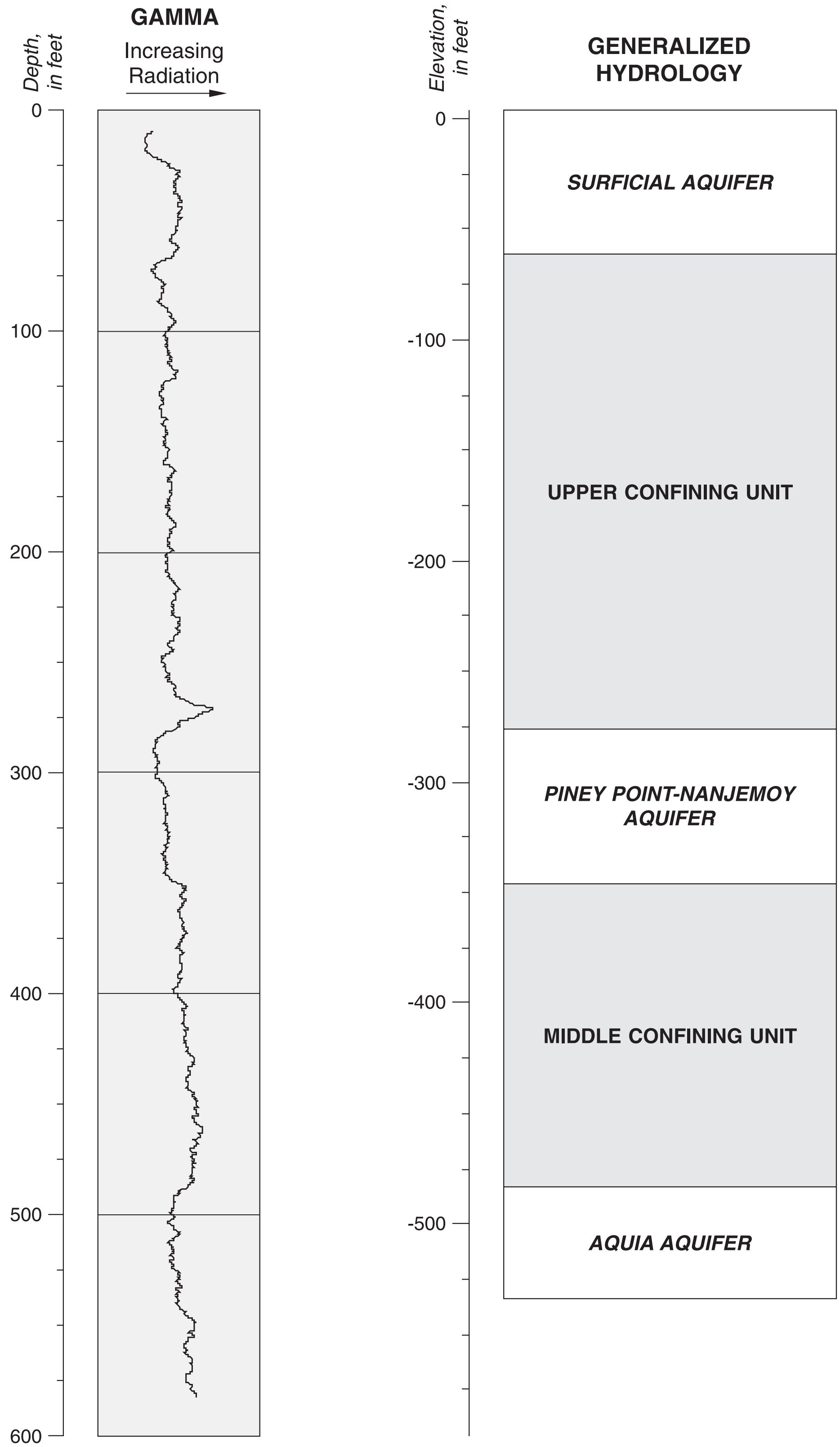
Appendix A3. Geophysical logs with generalized hydrologic units for well SM Dg 9



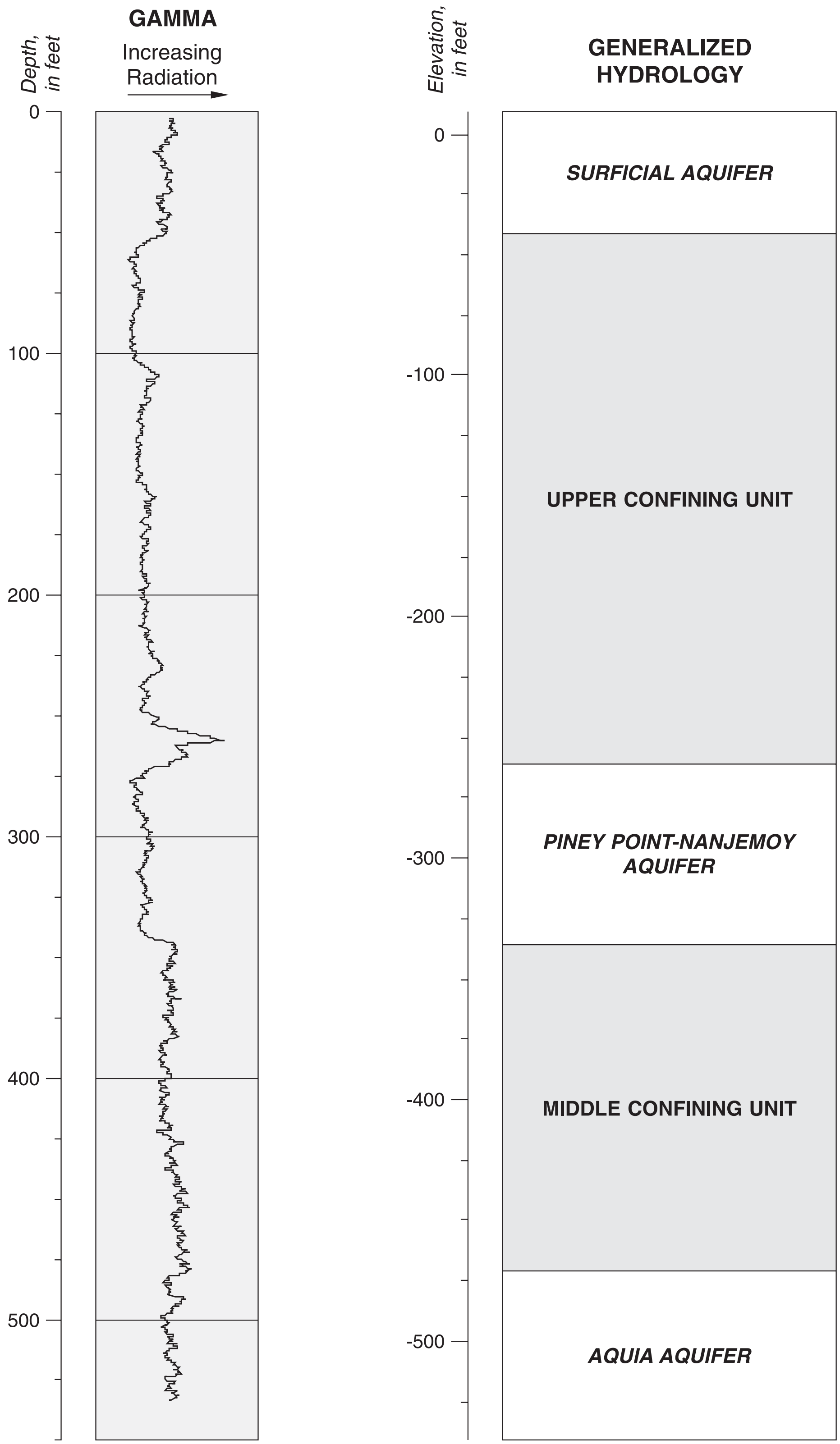
Appendix A4. Geophysical log with generalized hydrologic units for well SM Ff 21
(Depth of casing was 464 feet at time of logging. Obstruction did not allow instrument further down; screened in the Aquia aquifer, 464-486 feet.)



Appendix A5. Geophysical log with generalized hydrologic units for well SM Ff 35
(Depth of casing at time of logging is unknown.)



Appendix A6. Geophysical log with generalized hydrologic units for well SM Ff 64
(Depth of casing was 534 feet at time of logging.)



Appendix B. *Laboratory-analyzed constituents and methods*

[ICP, inductively coupled plasma; IC, ion chromatography; ASF, automated-segmented flow; NWQL, National Water-Quality Laboratory; LC, lab code]

Constituent	Laboratory Method	NWQL Schedule or Lab Code number
Calcium	ICP	1011
Potassium	Atomic Absorption, flame	1011
Sulfate	IC	1011
Chloride	IC	1011
Bromide	Colorimetry	1011
Magnesium	ICP	1011
Silica	ICP	1011
Manganese	ICP	1011
Fluoride	Colorimetry, ion-selective electrode	1011
Iron	ICP	1011
Gross Alpha	Gross Alpha as Thorium-230, by Residue Procedure	456
Gross Beta	Gross Beta as Cesium-137, by Residue Procedure	456
Uranium	Direct laser induced phosphorescence	1385
Tritium	Electrolytic enrichment and liquid scintillation	LC 624
Radium-226	Planchet counting and precipitation	LC 799
Radium-228	Radiochemical separation and beta counting	LC 1364
Radon-222	Liquid scintillation	LC 1369
Nutrients	Colorimetry, ASF, cadmium reduction diazotization	LC 1975
Barium	ICP	LC 641
Boron	ICP	LC 2354
Iodide	Colorimetry, ASF, ceric-arsenious	LC 1202

Appendix C. *Microorganisms and analytical methods for sample analyses from wells SM Df 61 and SM Df 98*

[USEPA, U.S. Environmental Protection Agency; mL, milliliters; °C, degrees Celsius]

Microorganism	Analytical Method
Most Probable Number (MPN) Assay for culturable viruses	USEPA, Information Collection Rule (USEPA 600/R-95/178)
Molecular Assay for virus groups	USEPA 600/R-95/178 [A]
Somatic Coliphage	USEPA 600/R-95/178 [A]
Male-Specific Coliphage	USEPA 600/R-95/178 [A]
Clostridium perfringens	Membrane filtration
Enterococci	Membrane filtration
Escherichia coli (density per 100 mL)	Colilert assay
Fecal *Streptococci* (density per 100 mL)	Membrane filtration at 35 °C for 48 hours
Fecal Coliform (density per 100 mL)	Membrane filtration at 44.5 °C for 24 hours
Total Coliform (density per 100 mL)	Membrane filtration

[A.] U.S. Environmental Protection Agency, 1996.