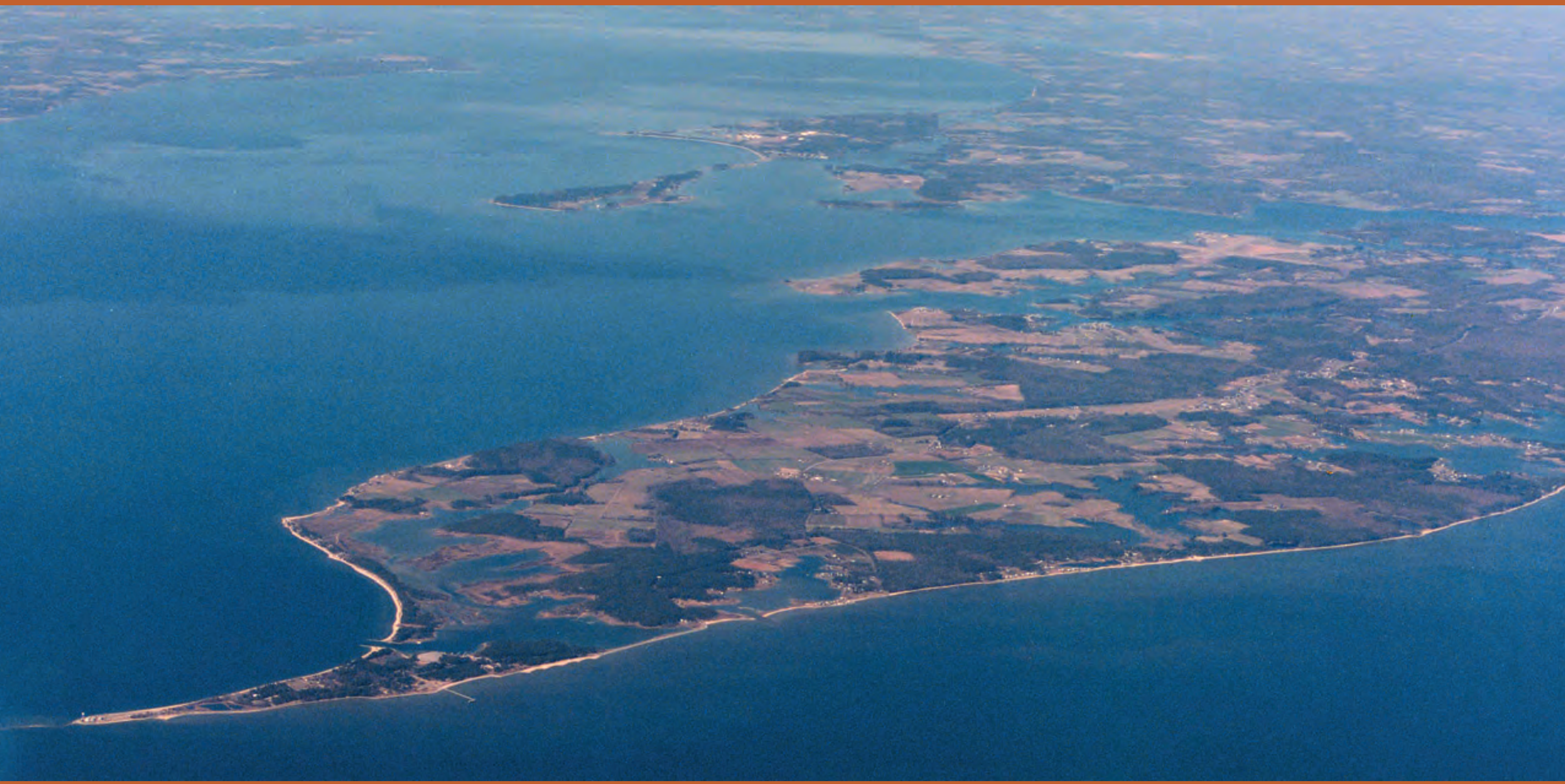
Prepared in cooperation with the
Naval Air Station Patuxent River

# Hydrogeology of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland, 2000–06



Scientific Investigations Report 2006–5266

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

**Cover.** Aerial photograph of the southern tip of St. Marys County. Point Lookout is to the far left.

# Hydrogeology of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland, 2000–06

By Cheryl A. Klohe and Robert T. Kay

Prepared in cooperation with the
Naval Air Station Patuxent River

Scientific Investigations Report 2006–5266

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

**U.S. Department of the Interior**
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS



Suggested citation:
Klohe, C.A., and Kay, R.T., 2007, Hydrogeology of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland, 2000–06: U.S. Geological Survey Scientific Investigations Report 2006–5266, 26 p.

# Contents



# Figures

## Tables

# Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 0.4047 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| gallon (gal) | 3.785 | liter (L) |
| | Flow rate | |
| foot per year (ft/yr) | 0.3048 | meter per year (m/yr) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| gallon per day (gal/d) | 0.003785 | cubic meter per day ($m^3$/d) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3$/s) |
| | Transmissivity* | |
| foot squared per day ($ft^2$/d) | 0.09290 | meter squared per day ($m^2$/d) |

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*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 of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland, 2000–06

By Cheryl A. Klohe and Robert T. Kay

## Abstract

Recent and projected population growth in southern Maryland continues to bring ground-water-quality and quantity issues to the forefront. Lithologic, borehole geophysical, water-level, and water-use data were compiled and interpreted to revise understanding of the hydrogeologic framework of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers in southern Maryland, with emphasis on the Naval Air Station Patuxent River and Webster Outlying Field. Understanding of the hydrogeologic framework for the Upper Patapsco aquifer also has been revised based on the results of aquifer testing and water-quality sampling of two wells.

The Piney Point-Nanjemoy aquifer is 50 to 70 feet thick, with a top altitude of 213 to 260 feet below the North American Vertical Datum of 1988 and a hydraulic conductivity of 2 feet per day at Naval Air Station Patuxent River and Webster Outlying Field. Ground-water withdrawals from the Piney Point-Nanjemoy aquifer have been minimal since 1999 and water levels in the aquifer have not changed substantially since the 1950s. An overall decline of about 2.5 feet has been observed since 1997, however.

The Aquia aquifer is 100 to 145 feet thick, with a top altitude of approximately 450 feet below the North American Vertical Datum of 1988 and a hydraulic conductivity of 6 to 10 feet per day at Naval Air Station Patuxent River. The Aquia aquifer is approximately 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. Water levels in the Aquia aquifer declined in response to increased withdrawals from the aquifer from the early 1940s through about 2000 at Naval Air Station Patuxent River and Webster Outlying Field, but have been generally stable from about 1999 through April 2006.

The Upper Patapsco aquifer at the Naval Air Station Patuxent River and Webster Outlying Field consists of layers of sand interbedded with layers of clay that total over 200 feet in thickness. The top of the aquifer near Naval Air Station Patuxent River and Webster Outlying Field ranges from approximately 620 to 680 feet below the North American Vertical Datum of 1988. The potentiometric surface of the Upper Patapsco aquifer near Naval Air Station Patuxent River and Webster Outlying Field has been declining at a rate of about 2 feet per year for the past several years. Aquifer testing indicates the transmissivity of the aquifer is about 2,100 to 3,900 feet squared per day. Water samples collected from the Upper Patapsco aquifer at Naval Air Station Patuxent River and Webster Outlying Field in 2000 and 2001 met all Federal drinking-water standards.

## Introduction

Development at the Naval Air Station Patuxent River (NASPR) and in the suburban Washington, D.C. area (approximately 50 miles northwest of the air station) has resulted in rapid population growth in southern Maryland, especially in St. Marys, Charles, and Calvert Counties (fig. 1). This population increase has caused an increase in water use, which has been met by increased withdrawals from ground water.

Ground-water withdrawals have resulted in deep cones of depression in water-supply aquifers in parts of southern Maryland. At Lexington Park near NASPR (fig. 1), for example, the potentiometric surface of the Aquia aquifer in 2003 was approximately 100 ft (feet) lower than in 1982 (Curtin and others, 2005a) and the potentiometric surface of the Upper Patapsco aquifer in 2003 was approximately 25 ft lower than in 1990 (Curtin and others, 2005b). Achmad and Hansen (1997) simulated ground-water levels in the Piney Point-Nanjemoy and Aquia aquifers in southern Maryland until the year 2020, estimating future ground-water withdrawals from population projections. The simulations show that the potentiometric surface near Lexington Park could be as low as -95 ft NAVD 88 (North American Vertical Datum of 1988) in the Piney Point-Nanjemoy aquifer, and -235 ft NAVD 88 in the Aquia aquifer. This potentiometric surface is about

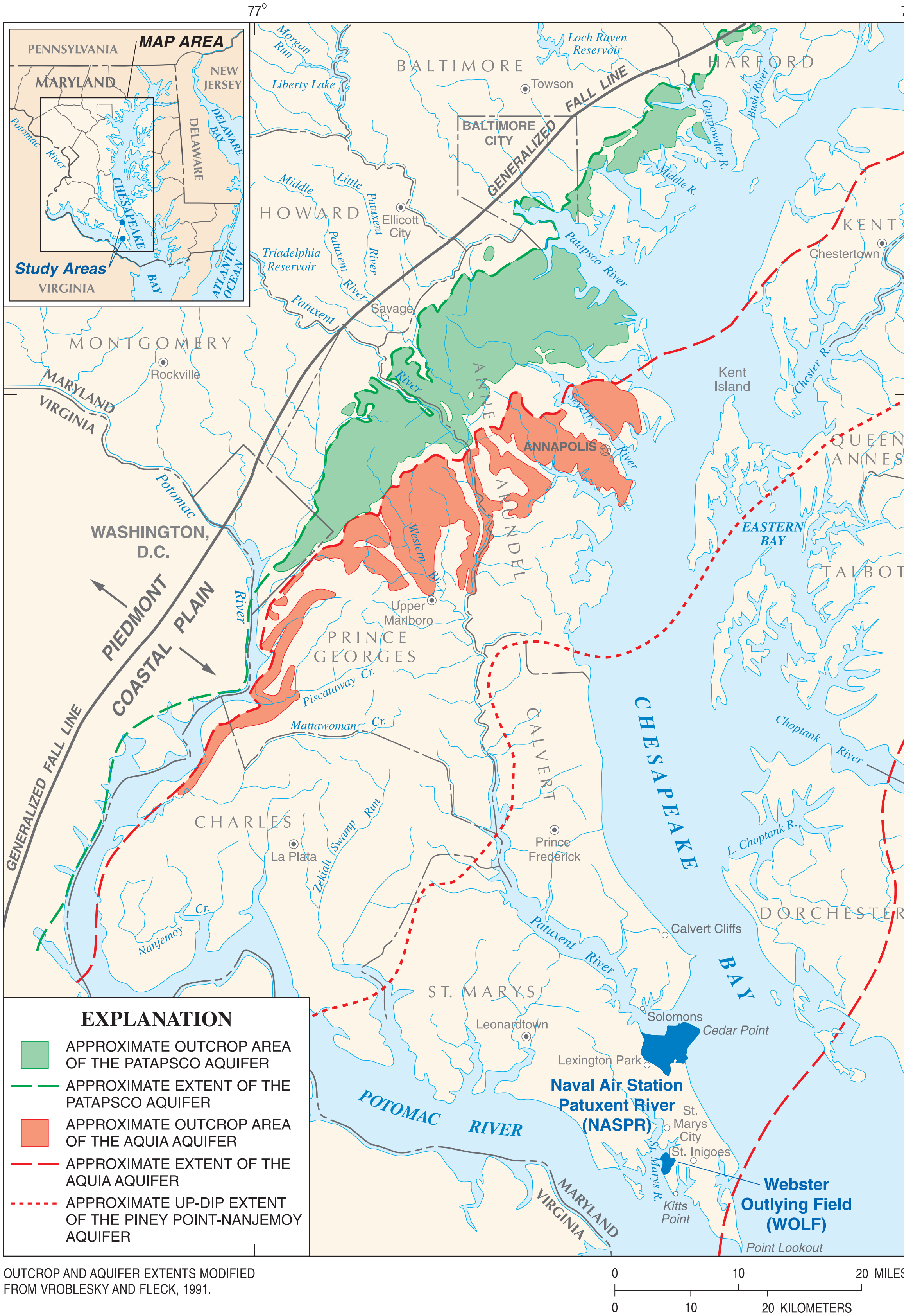



**Figure 1.** Location of Naval Air Station Patuxent River and Webster Outlying Field study areas, approximate outcrop areas of the Aquia and Patapsco aquifers, and approximate up-dip extent of the Piney Point-Nanjemoy aquifer, southern Maryland.

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 near Lexington Park. This potentiometric surface also is about 70 ft lower than that measured in the Piney Point-Nanjemoy aquifer at NASPR during April 2006 and at least 100 ft lower than that measured in the Aquia aquifer at NASPR during April 2006. As a result, many County and State water managers, private citizens, and air station officials are interested in the optimization of water supply from the Piney Point-Nanjemoy, Aquia, and Patapsco aquifers in southern Maryland.

The U.S. Geological Survey (USGS), in cooperation with NASPR, investigated the hydrogeology and water quality of the Piney Point-Nanjemoy and Aquia aquifers in the vicinity of NASPR and Webster Outlying Field (WOLF) (fig. 1) from 1998 through 2000 (Klohe and Feehley, 2001). That investigation was performed to help understand the effects of the water-use practices at NASPR and WOLF on the water resources of the area. Since 2000, the USGS, in cooperation with NASPR, has collected additional data on water levels and water use in the Piney Point-Nanjemoy and Aquia aquifers. In addition, the USGS and NASPR have collected data on water levels and water use from the Upper Patapsco aquifer in the vicinity of NASPR and WOLF, and conducted aquifer tests and water-quality sampling in wells screened in the Upper Patapsco aquifer at NASPR and WOLF. This report presents an update of the data collected from these aquifers in the vicinity of NASPR and WOLF and includes data collected from March 2000 through May 2006.

## Background

NASPR was commissioned in 1943 as part of an effort to centralize U.S. Navy facilities. WOLF, near St. Inigoes, Maryland, serves as an auxiliary landing field for NASPR. Testing and development of aircraft and weaponry at NASPR and WOLF increased during the Korean and Vietnam Wars and continues today. During the 1990s, the Navy began consolidating their technical resources and NASPR became a receiver station as a result of base realignment and closure of other facilities (Naval Air Station Patuxent River, 2000). As a result of this consolidation, the number of personnel at NASPR and WOLF decreased from about 10,000 employees in 1981, to 13,000 in 1996, 18,000 in 1998, and approximately 20,000 in 2006 (James Darcy, Public Affairs Office, Naval Air Station Patuxent River, written commun., 2006).

## Purpose and Scope

This report describes the hydrogeologic framework of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers at NASPR and WOLF and the surrounding area. Analyses of water levels in the Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers and the relation between water levels and ground-water withdrawals from the aquifers are presented on the basis of data collected from 1943 through 2006. In addition, this report presents the results of aquifer testing and water-quality sampling from two wells screened in the Upper Patapsco aquifer at NASPR and WOLF in 2000 and 2001. The hydrogeology of the area is described on the basis of information from previous reports, State of Maryland permits to drill, 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 are from the USGS National Water Information System (NWIS) database. Ground-water-withdrawal records were obtained from correspondence between the USGS and NASPR in the 1940s, 1950s, and 1970s, and from continuous records kept by the air station from 1989 through April 2006. Ground-water-withdrawal data for southern Maryland were obtained from the USGS State Water-Use Data System (SWUDS) database and the Maryland Department of the Environment (MDE) Regulatory Analysis Management System (RAMS) database.

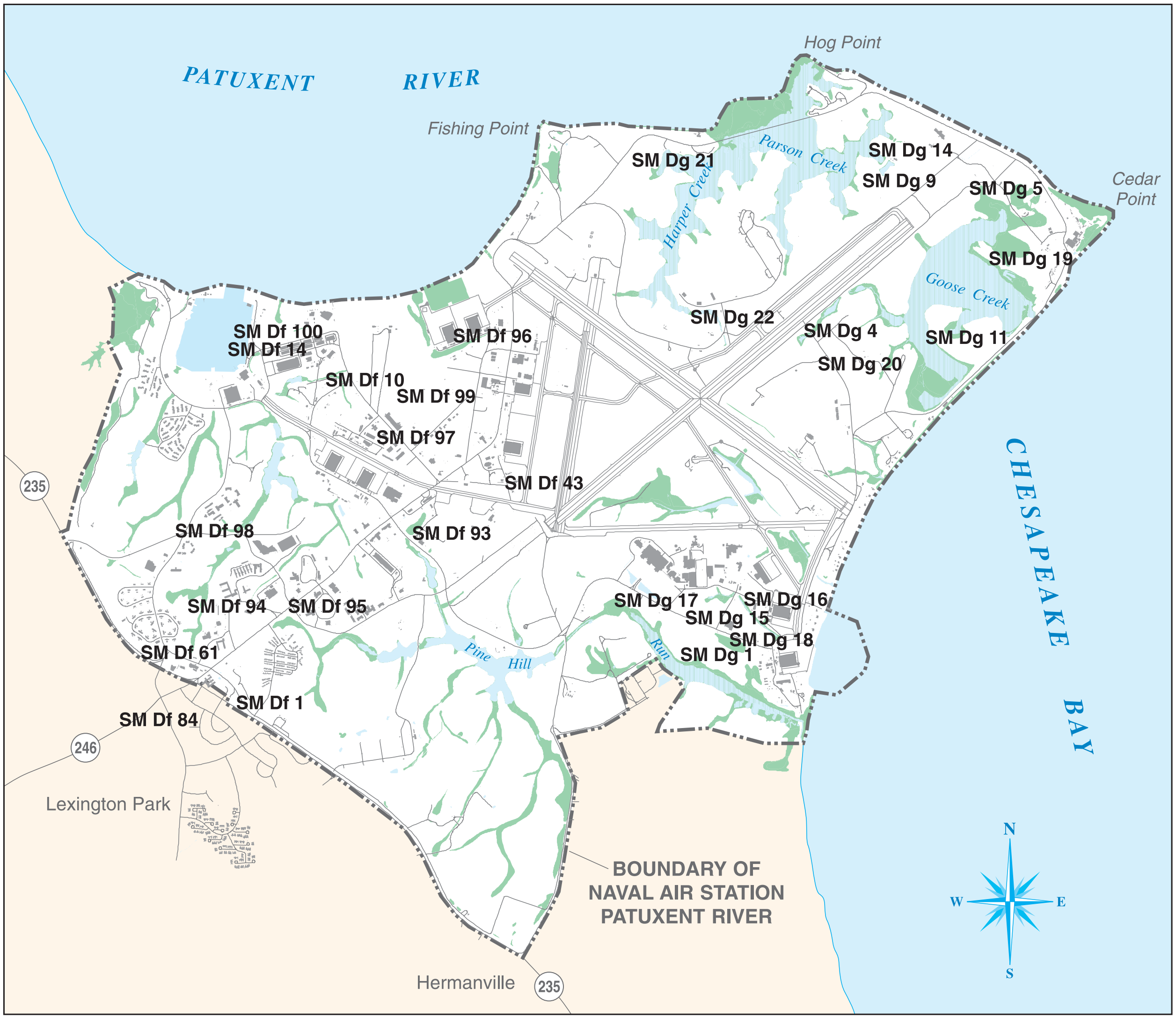
## Study Area and Well-Numbering System

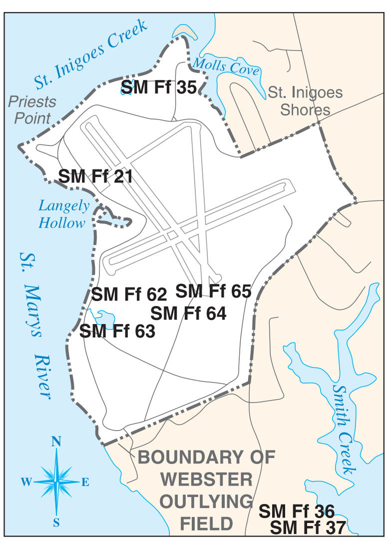
NASPR is in southern Maryland in St. Marys County, southwest of the convergence of the mouth of the Patuxent River and Chesapeake Bay (fig. 1). WOLF is southwest of NASPR, on the St. Marys River near St. Inigoes, Maryland (fig. 1). The locations of the wells discussed in this report are shown in figure 2. Data on well construction is presented in table 1. Most of the wells are production wells, or were production wells that have been abandoned or converted to observation 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 quadrangle, indicated by the last two numbers “14.” The 5-minute quadrangles are designated by uppercase letters from north to south (A through F in St. Marys County), and lowercase letters from west to east (a through h in St. Marys County).

## Previous Investigations

In 1944, the Commanding Officer of NASPR asked the USGS to collect information on the availability of ground water at the naval establishments in the vicinity of Solomons and NASPR (fig. 1). Bennett (1944) compiled available well records, ran brief aquifer tests, and measured static and pumping water levels in some wells. This study provides insight into the hydrogeologic properties of the Piney Point-Nanjemoy and Aquia aquifers and water withdrawals from these aquifers at and near NASPR in the early 1940s.

Since 1982, the USGS has published maps of the potentiometric surface of the Aquia aquifer in southern Maryland. Each year, the maps have shown an increase in the size and depth of the cone of depression in the potentiometric surface of the Aquia aquifer near Lexington Park, Maryland.




**EXPLANATION**

WETLAND

**SM Df 1** WELL IDENTIFIER

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

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

[USGS, U.S. Geological Survey; no., number; NAVD 88, North American Vertical Datum of 1988; --, no data available; n/a, not applicable; geophysical log types - G, Gamma; SP, Spontaneous Potential; R, Resistance; SN, Short Normal; LN, Long Normal]

| USGS well no. | Altitude of land surface (feet above NAVD 88) | Aquifer | Depth of well (feet below land surface) | Well diameter upper-lower (inches) | Screen position (feet below land surface) | Date of construction | State of Maryland well permit no. | Driller |
|---|---|---|---|---|---|---|---|---|
| SM Df 1 | 93 | Aquia | 587 | 8 | 567–587 | 1943 | -- | Washington Pump and Well Co. |
| SM Df 10 | 45 | Aquia | 534 | 8–6 | 514–534 | 1943 | -- | Washington Pump and Well Co. |
| SM Df 14 | 18 | Piney Point-Nanjemoy | 262 | 8 | -- | 1943 | -- | Washington Pump and Well Co. |
| SM Df 43[A] | 39 | Aquia | 553 | 8 | 514–534 | 9/1/1955 | -- | Syndor Pump and Well Co. |
| SM Df 61 | 108 | Aquia | 600 | 8–6 | 580–600 | 1964 | SM-05-5823 | Patuxent Pump and Well Co. |
| SM Df 93 | 41 | Aquia | 567 | 8–6 | 515–565 | 4/7/1994 | SM-92-0358 | A.C. Schultes of Maryland |
| SM Df 94 | 99 | Aquia | 612 | 8–6 | 560–610 | 4/12/1994 | SM-92-0357 | A.C. Schultes of Maryland |
| SM Df 95 | 79 | Aquia | 582 | 8–6 | 530–580 | 4/24/1994 | SM-92-0369 | A.C. Schultes of Maryland |
| SM Df 96 | 8 | Aquia | 539 | 8–6 | 489–539 | 11/10/1994 | SM-93-0036 | A.C. Schultes of Maryland |
| SM Df 97 | 46 | Aquia | 568 | 8–6 | 515–565 | 9/22/1997 | SM 94-0925 | A.C. Schultes of Maryland |
| SM Df 98 | 80 | Aquia | 575 | 8–6 | 525–575 | 12/15/1996 | SM 94-0410 | A.C. Schultes of Maryland |
| SM Df 99 | 44 | Aquia | 600 | 16–8 | 490–600 | 11/8/1994 | SM 92-0642 | Vans Construction Co. |
| SM Df 100 | 20 | Upper Patapsco | 910 | 10–8 | 706–716, 744–754, 835–860, 882–892, 900–905 | 8/4/2000 | SM-94-3113 | A.C. Schultes of Maryland |
| SM Dg 1[A] | 18 | Aquia | 480 | 8 | 460–480 | 1943 | -- | Washington Pump and Well Co. |
| SM Dg 4 | 19 | Piney Point-Nanjemoy | 295 | 2 | 275–295 | 1949 | SM-00-3978 | Washington Pump and Well Co. |
| SM Dg 5 | 21 | Aquia | 494 | 8 | 469–488.5 | 1950 | -- | Washington Pump and Well Co. |
| SM Dg 9[A,B] | 19 | Aquia | 586 | n/a | n/a | 9/1972 | SM-73-0095 | Shannahan Artesian Well Co. |
| SM Dg 11[A] | 9 | Piney Point-Nanjemoy | 290 | 6 | 280–290 | 4/23/1980 | -- | Calvert Well Drilling Co. |
| SM Dg 14 | 18 | Aquia | 542 | 8–6 | 490–540 | 4/22/1994 | SM-92-0370 | A.C. Schultes of Maryland |
| SM Dg 15 | 20 | Aquia | 500 | 8–5 | 450–500 | 12/17/1993 | SM-92-0570 | Patuxent Pump and Well Co. |
| SM Dg 16 | 11 | Aquia | 520 | 8–6 | 470–520 | 11/19/1996 | SM-94-0411 | A.C. Schultes of Maryland |
| SM Dg 17 | 19 | Aquia | 591 | 12–8 | 481–591 | 7/15/1995 | SM-92-0643 | Vans Construction Co. |
| SM Dg 18 | 17 | Aquia | 553 | 8–6 | 503–553 | 10/15/1997 | SM-94-0926 | A.C. Schultes of Maryland |

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

[USGS, U.S. Geological Survey; no., number; NAVD 88, North American Vertical Datum of 1988; --, no data available; n/a, not applicable; geophysical log types - G, Gamma; SP, Spontaneous Potential; R, Resistance; SN, Short Normal; LN, Long Normal]

| USGS well no. | Altitude of land surface (feet above NAVD 88) | Aquifer | Depth of well (feet below land surface) | Well diameter upper-lower (inches) | Screen position (feet below land surface) | Date of construction | State of Maryland well permit no. | Driller |
|---|---|---|---|---|---|---|---|---|
| SM Dg 19 | 9 | Aquia | 532 | 12–8 | 480–510 | 6/23/1988 | SM-81-3345 | Syndor Pump and Well Co. |
| SM Dg 20 | 11 | Piney Point-Nanjemoy | 335 | 4–2 | 325–335 | 2/15/1991 | SM-88-0946 | Watson & Johnson Well Drilling, Inc. |
| SM Dg 21 | 2 | Piney Point-Nanjemoy | 315 | 4 | 295–315 | 6/18/1996 | SM-94-0074 | Southern Well and Recovery Corp. |
| SM Dg 22 | 11 | Piney Point-Nanjemoy | -- | -- | -- | -- | -- | -- |
| SM Ff 21 | 8 | Aquia | 486 | 8 | 464–486 | 8/13/1945 | -- | Washington Pump and Well Co. |
| SM Ff 35 | 4 | Aquia | 537 | 8–4 | 487–537 | 8/8/1975 | SM-73-1496 | A.C. Schultes of Maryland |
| SM Ff 62 | 9 | Aquia | 539 | 8–6 | 486–536 | 2/20/1998 | SM-94-1128 | A.C. Schultes of Maryland |
| SM Ff 63 | 9 | Aquia | 545 | -- | -- | -- | -- | -- |
| SM Ff 64[B] | 9 | Aquia | 534 | -- | -- | -- | -- | -- |
| SM Ff 65 | 9 | Upper Patapsco | 884 | 10–8 | 635–640, 648–658, 689–694, 782–792, 846–856, 864–874 | 8/10/2001 | SM-94-3700 | A.C. Schultes of Maryland |
| Wells outside of Naval Air Station Patuxent River and Webster Outlying Field, Maryland | | | | | | | | |
| SM Ff 36 | 5 | Upper Patapsco | 618 | 8–6 | 594–618 | 10/29/1975 | SM-73-1478 | A. Mirfield |
| SM Ff 37 | 4 | Upper Patapsco | 618 | 4–2 | 594–618 | 8/29/1975 | SM-73-1479 | A. Mirfield |
| SM Df 84 | 108 | Upper Patapsco | 912 | 6–4 | 831–856, 862–867, 897–912 | 1/5/1983 | SM-81-0119 | A.C. Schultes of Maryland |

[A] Well no longer exists.

[B] Test hole.

Chappelle and Drummond (1983) described the Piney Point-Nanjemoy and Aquia aquifers in southern Maryland, but did not include detailed information in the vicinity of NASPR and WOLF. Chappelle 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. Achmad and Hansen (1997) also described 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 Permit rates, Achmad and Hansen's simulations predict that water levels in the Aquia aquifer will average -235 ft from (negative values indicate below) sea level (the vertical datum for sea level is not defined by Achmad and Hansen) by 2020 in NASPR/Lexington Park area. At that pumping rate, the simulated water level in well SM Df 42 at Lexington Park was about -330 ft, which would be within 27 ft of the 80-percent available drawdown management level of -357 ft. The 80-percent regional water management level is calculated as 80 percent of the available drawdown between the top of the aquifer and the pre-pumping potentiometric level and is used by the State of Maryland to determine the amount of discharge a well can be permitted.

Klohe and Feehley (2001) described the hydrogeologic framework, water use, and water quality for the Piney Point-Nanjemoy and Aquia aquifers at NASPR and WOLF. They determined that water withdrawals from the Piney Point-Nanjemoy aquifer have decreased since about 1975 and water levels in the aquifer have been constant since the 1950s. They also determined that water withdrawals from the Aquia aquifer had decreased at NASPR and WOLF since about 1991, but that water levels in the aquifer were still declining in 2000 in response to increased pumping from nearby municipal systems. Water-quality data for both aquifers did not indicate saltwater intrusion.

Drummond (2005) discussed the water use and projected increases in demands on the water supply of Coastal Plain aquifers in Calvert, Charles, and St. Marys Counties, Maryland. Drummond also described two test wells screened in the Upper Patapsco aquifer and four wells screened in the Lower Patapsco aquifer that were constructed between 2001 and 2003. Drummond also simulated projected increases in drawdown in the Coastal Plain aquifers within the three counties, including those at NASPR. Simulations that increased NASPR 2002 withdrawal rates by 10 percent and 20 percent from 2002 to 2030 resulted in a decrease of a few feet in the Lexington Park, Maryland area.

# Hydrogeologic Framework

The Coastal Plain of southern Maryland is underlain by an easterly dipping wedge of sediments composed mainly of unconsolidated clay, silt, sand, and gravel (table 2) (figs. 3 and 4a and 4b). 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, the Aquia aquifer, the lower confining unit, and the Upper Patapsco aquifer (table 2).

## Surficial Aquifer

The uppermost sediments in the study area are Holocene to Pliocene-aged sediments that range from clays and silts to sands and gravels (table 2). These sediments are undifferentiated in the vicinity of NASPR and compose the surficial aquifer. The surficial aquifer ranges in thickness from 10 to 100 ft in the vicinity of NASPR and WOLF. The surficial aquifer is unconfined and was used as a source of water for domestic and agricultural uses in the past (Achmad and Hansen, 1997).

## Upper Confining Unit

Beneath the Holocene to Pliocene-aged sediments lie the clay and silt of the upper part of the Chesapeake Group (undivided) of Miocene age (table 2). These clays and silts are designated as the upper confining unit, which 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 NASPR and WOLF.

## Piney Point-Nanjemoy Aquifer

Below the upper confining bed lie the basal beds of the Chesapeake Group, unnamed Oligocene or Miocene units, the Piney Point Formation, and the upper part of the Nanjemoy Formation (Achmad and Hansen, 1997) (table 2). The basal beds of the Chesapeake Group consist of fine- to medium-grained, yellowish-green to greenish-light gray quartz sand, and are slightly glauconitic with shell fragments, phosphate pebbles, and fine gravel (Achmad and Hansen, 1997). The unnamed Oligocene or Miocene units consist of clayey sands that are brown to olive green, slightly glauconitic, and fossiliferous (Achmad and Hansen, 1997). The Piney Point Formation consists of medium- to coarse-grained, quartz sands that are grayish-green to grayish-white in color, glauconitic, and with calcite cemented beds (Chapelle and Drummond, 1983). The Nanjemoy Formation also is composed of sand that is similar to that of the Piney Point Formation. These four permeable sand units are hydraulically connected and are commonly combined and designated as the Piney Point-Nanjemoy aquifer. The Piney Point-Nanjemoy aquifer underlies the upper confining unit. The elevation of the top of the Piney Point-Nanjemoy aquifer ranges from about -213 ft NAVD 88 in the western part of NASPR, decreasing to

**Table 2.** Hydrogeologic units and corresponding geologic units at Naval Air Station Patuxent River and Webster Outlying Field, Maryland.

<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="10">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="4">Piney Point-Nanjemoy aquifer</td></tr>
<tr><td>Oligocene (?)</td><td>unnamed Oligocene (?) Miocene (?) beds</td></tr>
<tr><td rowspan="3">Eocene</td><td>Piney Point Formation</td></tr>
<tr><td rowspan="2">Nanjemoy Formation</td></tr>
<tr><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 rowspan="4">Cretaceous</td><td rowspan="4">Lower Cretaceous</td><td rowspan="4">Patapsco Formation<br>(of the Potomac Group)</td></tr>
<tr><td>Upper Patapsco aquifer</td></tr>
<tr><td>Confining unit</td></tr>
<tr><td>Undifferentiated aquifers and confining units</td></tr>
</table>

-255 ft NAVD 88 in the eastern part of NASPR, and to about -260 ft NAVD 88 to the southeast at WOLF (Klohe and Feehley, 2001). The aquifer is approximately 50 to 70 ft thick, and has a horizontal hydraulic conductivity (Kh) of approximately 2 ft/d (feet per day) at NASPR and WOLF (Klohe and Feehley, 2001) (figs. 4a and 4b).

The Piney Point-Nanjemoy aquifer is not exposed at the land surface; therefore, recharge to the aquifer occurs by percolation from the overlying upper confining unit. The approximate western (updip) extent of the aquifer in the subsurface in Maryland is along the northern boundaries of Calvert County, and St. Marys County (fig. 1). The eastern (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).

## Middle Confining Unit

The lower part of the Nanjemoy Formation and the Marlboro Clay lie beneath the Piney Point-Nanjemoy aquifer (table 2). 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 clays and silts of the two formations form the middle confining unit (table 2). The thickness of the middle confining unit ranges from 130 to 150 ft in the vicinity of NASPR and WOLF (figs. 4a and 4b).

## Aquia Aquifer

Beneath the middle confining unit lies the Aquia Formation. The greenish-black, quartz sand, glauconite, and lenses of silty clay and shell beds of the Aquia Formation are water-bearing and are designated as the Aquia aquifer (table 2) (Chapelle and Drummond, 1983). The elevation of the top of the Aquia aquifer is approximately -450 ft NAVD 88 beneath NASPR and WOLF (Klohe and Feehley, 2001). The thickness of the Aquia aquifer decreases from about 100 to 145 ft at NASPR to about 50 ft at WOLF (fig. 4b). This trend in thickness is consistent with regional hydrogeologic sections that show the sands of the Aquia Formation nearing

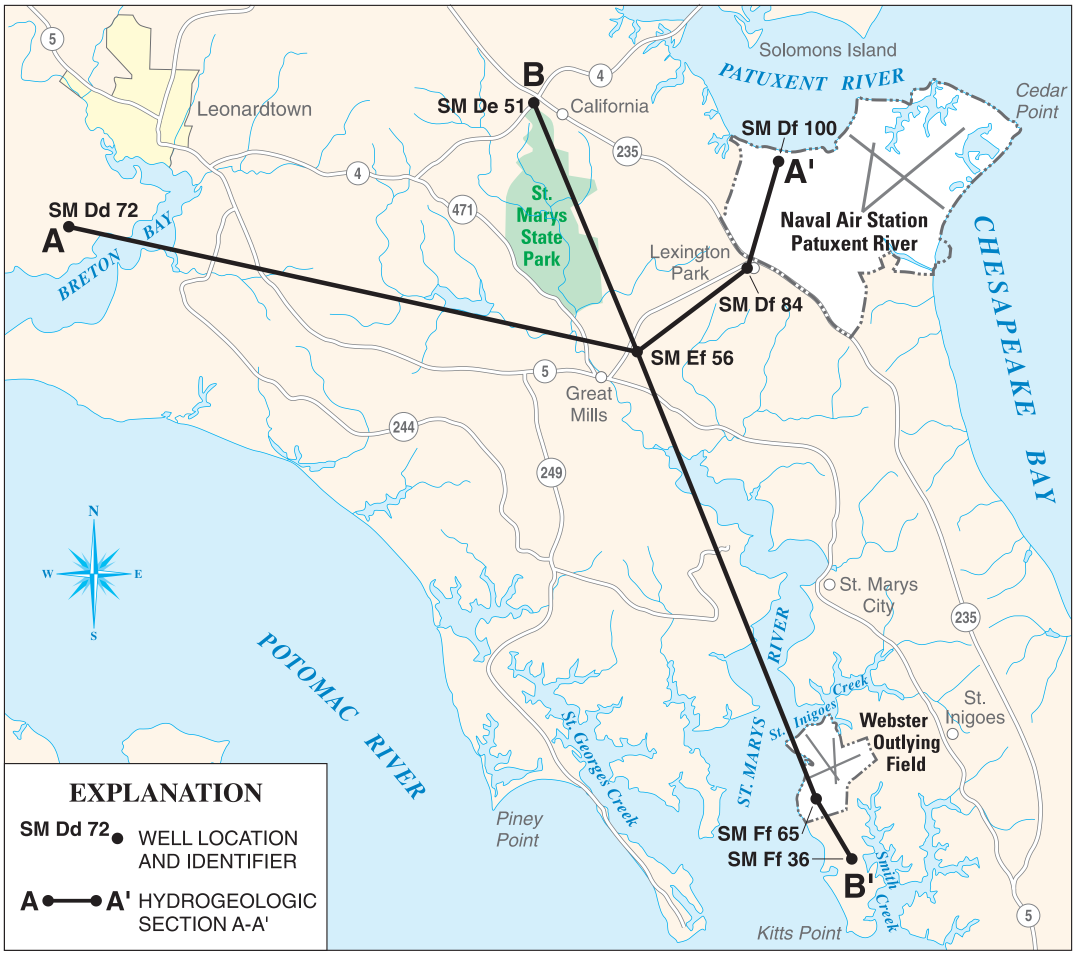



**Figure 3.** Location of wells shown in hydrogeologic sections A-A′ and B-B′ in southern Maryland.

their lateral extent at WOLF (figs. 1 and 4b). As the Aquia Formation continues to the southeast, it becomes thinner, finer-grained, and predominately clayey (Achmad and Hansen, 1997). The Kh of the Aquia aquifer ranges from 6 to 10 ft/d at NASPR and WOLF.

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.

## Lower Confining Unit

The Brightseat Formation is composed of gray clay and fine sand, and the clay beds in the upper part of the Patapsco Formation lie beneath the Aquia aquifer. These clay beds are designated as the lower confining unit (table 2). The lower confining unit is approximately 75 to 175 ft thick in the vicinity of NASPR and WOLF (figs. 4a and 4b).

## Upper Patapsco Aquifer

Sand units in the Patapsco Formation of the Potomac Group lie beneath the lower confining unit. The sand units are interbedded with silt and clay units, making the sand units variable in thickness and location. The sand beds in the upper part of the Patapsco Formation of the Potomac group are designated as the Upper Patapsco aquifer, the deepest hydrogeologic unit of concern in this investigation (table 2). The discontinuity of the interbedded sand and clay layers makes it difficult to determine the bottom of the aquifer; therefore, the bottom of the Upper Patapsco aquifer was not delineated as part of this investigation (figs. 3, 4a and 4b).

From west to east, the altitude of the top of the Upper Patapsco aquifer ranges from -565 ft NAVD 88 at well SM Dd 72 near Leonardtown, Maryland to -660 ft at well SM Df 100 at NASPR (figs. 3 and 4a). From north to south, the altitude of the top of the aquifer ranges from about -687 ft

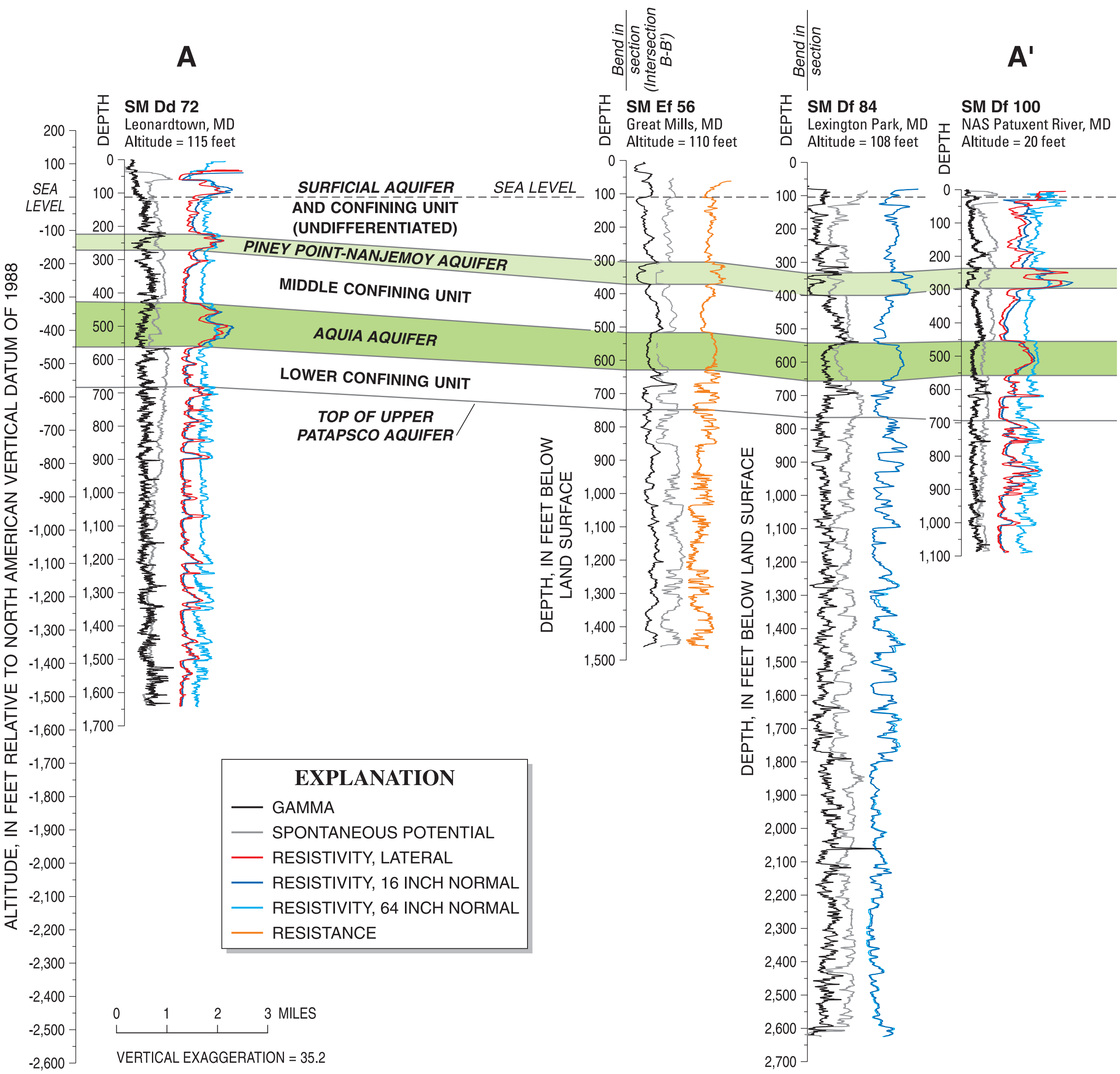



**Figure 4a.** Hydrogeologic section A-A' in St. Marys County, Maryland. (Location of section shown on figure 3.)

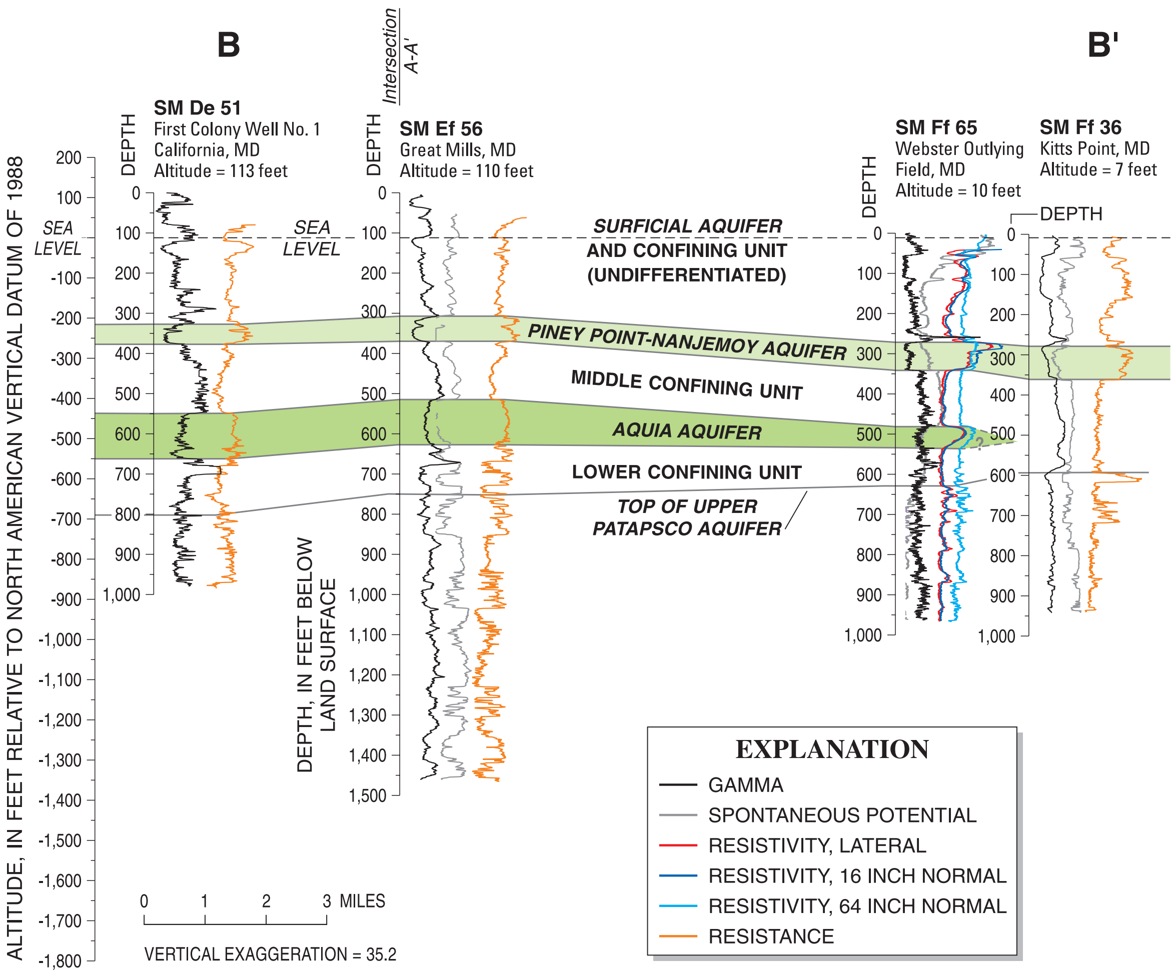



**Figure 4b.** Hydrogeologic section B-B′ in St. Marys County, Maryland. (Location of section shown on figure 3.)

at well SM De 51 in California, Maryland to about -625 ft at WOLF and -600 ft at well SM Ff 36 near Kitts Point, Maryland. Screened intervals for wells SM Ff 65 and SM Df 100 (table 1) indicate the aquifer is approximately 200 to 240 ft thick at NASPR and WOLF, but producing sands are not present throughout the aquifer.

Recharge to the Upper Patapsco aquifer occurs primarily where the Patapsco Formation outcrops subparallel to the Fall Line. In southern Maryland, the outcrop area for the Upper Patapsco aquifer extends from near the boundary with Washington, D.C. northeast to the southern edge of Baltimore.

# Ground-Water Withdrawals and Water Levels

Before 1942, ground-water withdrawals in the area of NASPR and WOLF were restricted to small amounts for domestic use in the town of Solomons, Maryland (Bennett, 1944). Substantial ground-water withdrawal in the vicinity of NASPR and WOLF began in 1942, when these facilities were built. Yearly withdrawal records for NASPR and WOLF 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 with data for that year to calculate the average daily withdrawal. The monthly withdrawal values were either measured with a flow meter or estimated. Data collected since 1988 are considered to be more accurate because complete withdrawal records were collected and furnished by NASPR employees, whereas prior records may not include all withdrawal data.

Average daily withdrawal data from NASPR for the period from 2001 through 2005 indicate that withdrawals during the summer months substantially exceed those for the rest of the year. During 2001–2005, total withdrawals at NASPR averaged about 649,000 gal/d (gallons per day) from January through April, about 826,000 gal/d from May through September, and about 623,000 gal/d from October through December.

Personnel data, furnished by the air station's Public Affairs Office, include the number of military, civilian, contractor, and other employees who worked at NASPR and used its resources. For this report, military personnel data records cover the period from 1962–2006, and total personnel data cover the period from 1981–2006. Personnel data for WOLF were unavailable. The total number of personnel at NASPR increased from 1981 to 2006, with the greatest number of people (about 20,000) working at the station in April 2006. Overall ground-water withdrawals at NASPR decreased during the same period (table 3), as less water was used for industrial and heating applications, and improvements were made in the water-distribution infrastructure (Donald Shaver, Naval Air Station Patuxent River, oral commun., 2000).

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 database. Withdrawal values for large users of the aquifers within a 13-mi (mile) radius of NASPR 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 retrieved from the SWUDS database. The data indicate that total ground-water withdrawals from wells in St. Marys and Calvert Counties near NASPR and WOLF increased from 2.25 Mgal/d (million gallons per day) in 1980 to about 5.0 Mgal/d during most of 1998 through 2004 (table 4). Withdrawals from the Piney Point-Nanjemoy aquifer peaked at about 0.75 Mgal/d in 1992 through 1994, decreased to about 0.35 Mgal/d in 2001 and 2002, and increased to 0.559 Mgal/d in 2004. Withdrawals from the Aquia aquifer typically have been about 4.3 Mgal/d since 1997. Withdrawals from the Upper Patapsco aquifer were less than 0.01 Mgal/d prior to 1995, but consistently increased to 0.35 Mgal/d in 2004. Withdrawals from the Aquia aquifer constituted about 75 to 83 percent of the total withdrawals from 1980 through 1994, increasing to about 88 percent of the total withdrawals from 1997 through 2003 as withdrawals from the Piney Point-Nanjemoy aquifer decreased.

## Piney Point-Nanjemoy Aquifer

The Piney Point-Nanjemoy aquifer began to be used for water supply in the vicinity of NASPR and WOLF in the late 1800s and early 1900s (Chapelle and Drummond, 1983). Utilization of the aquifer was facilitated by its relatively shallow depth and the fact that it was under flowing artesian conditions at Solomons, Leonardtown, and St. Inigoes (Darton, 1896). Substantial ground-water withdrawals 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. Substantial withdrawals from the aquifer also occurred during the same period outside of the air station to support increasing domestic and municipal demands (Chapelle and Drummond 1983).

Limited water withdrawal data for NASPR are available from 1946 through 1975, but the available data indicate that typical withdrawals from the Piney Point-Nanjemoy aquifer were about 70,000 to 108,000 gal/d during this time (table 3). Withdrawals from the Piney Point-Nanjemoy aquifer were less than 100 gal/d from at least 1989 through 1992. There was a large increase in withdrawals from 1993 through 1997. Since 1999, withdrawals from the Piney Point-Nanjemoy aquifer at NASPR have been less than 1,700 gal/d. The lower withdrawals are the result of concerns about excessive water-level declines in the aquifer. There is no record that water has ever been withdrawn from the Piney Point-Nanjemoy aquifer at WOLF.

Withdrawals from the Piney Point-Nanjemoy aquifer have caused water levels in the NASPR and Lexington Park area to decline. Darton (1896) reported Piney Point-Nanjemoy

**Table 3.** Ground-water withdrawal at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 1946–2005.

[-, no data available; data prior to 1989 are intermittent]

| Year | Average daily withdrawal, in gallons per day | | | | | | |
|---|---|---|---|---|---|---|---|
| | Naval Air Station Patuxent River | | | | Webster Outlying Field | | |
| | Piney Point-Nanjemoy aquifer | Aquia aquifer | Upper Patapsco aquifer | Total | Aquia aquifer | Upper Patapsco aquifer | Total |
| 1946 | 47,761 | 1,128,458 | 0 | 1,176,219 | - | 0 | - |
| 1947 | 91,635 | 1,206,427 | 0 | 1,298,062 | - | 0 | - |
| 1948 | 99,895 | 1,313,130 | 0 | 1,413,025 | - | 0 | - |
| 1949 | 67,874 | 1,438,823 | 0 | 1,506,697 | - | 0 | - |
| 1953 | 84,000 | 1,559,000 | 0 | 1,643,000 | - | 0 | - |
| 1954 | 74,000 | 1,414,000 | 0 | 1,488,000 | - | 0 | - |
| 1955 | 73,780 | 1,354,143 | 0 | 1,427,923 | - | 0 | - |
| 1956 | 103,000 | 1,343,340 | 0 | 1,446,340 | - | 0 | - |
| 1970 | 107,868 | 1,249,720 | 0 | 1,357,588 | 14,479 | 0 | 14,479 |
| 1971 | 133,910 | 1,153,838 | 0 | 1,287,748 | 16,945 | 0 | 16,945 |
| 1974 | 75,916 | 1,152,264 | 0 | 1,228,180 | - | 0 | - |
| 1975 | 82,231 | 844,676 | 0 | 926,907 | - | 0 | - |
| 1989 | 93 | 1,038,654 | 0 | 1,038,747 | 73,705 | 0 | 73,705 |
| 1990 | 99 | 938,988 | 0 | 939,087 | 59,225 | 0 | 59,225 |
| 1991 | 99 | 1,118,700 | 0 | 1,118,799 | 78,390 | 0 | 78,390 |
| 1992 | 99 | 797,223 | 0 | 797,322 | 55,774 | 0 | 55,774 |
| 1993 | 55,689 | 808,236 | 0 | 863,925 | 47,799 | 0 | 47,799 |
| 1994 | 178,150 | 812,360 | 0 | 990,510 | 42,627 | 0 | 42,627 |
| 1995 | 43,156 | 748,439 | 0 | 791,595 | 40,245 | 0 | 40,245 |
| 1996 | 45,730 | 697,497 | 0 | 743,227 | 26,498 | 0 | 26,498 |
| 1997 | 58,984 | 754,685 | 0 | 813,669 | 26,498 | 0 | 26,498 |
| 1998 | 1,605 | 831,382 | 0 | 832,987 | 29,536 | 0 | 29,536 |
| 1999 | 24,061 | 832,636 | 0 | 856,697 | 27,666 | 0 | 27,666 |
| 2000 | 888 | 694,786 | 0 | 695,674 | 27,666 | 0 | 27,666 |
| 2001 | 1,392 | 707,274 | 0 | 708,666 | 28,860 | 0 | 28,860 |
| 2002 | 1,336 | 764,935 | 0 | 766,271 | 3,318 | 21,255 | 24,573 |
| 2003 | 1,694 | 674,248 | 37,300 | 713,242 | 5,060 | 28,110 | 33,170 |
| 2004 | 739 | 661,313 | 28,858 | 690,910 | 11,922 | 13,688 | 25,610 |
| 2005 | 714 | 675,266 | 17,518 | 693,498 | 11,507 | 8,621 | 20,128 |

Data Sources:

1946 through 1997: Various U.S. Geological Survey and Naval Air Station Patuxent River documents.

1998 through 2005: Michael Oliver, Naval Air Station Patuxent River, written commun., 2006.

**Table 4.** Ground-water withdrawal from aquifers in parts of St. Marys and Calvert Counties, Maryland, 1980–2004 (Naval Air Station Patuxent River and Webster Outlying Field excluded).

| Year | Average daily withdrawal, in million gallons per day | | | |
|---|---|---|---|---|
| | Piney Point-Nanjemoy aquifer | Aquia aquifer | Upper Patapsco aquifer | Total |
| 1980 | 0.49 | 1.76 | 0.000 | 2.25 |
| 1981 | 0.56 | 1.82 | 0.000 | 2.37 |
| 1982 | 0.58 | 2.06 | 0.000 | 2.63 |
| 1983 | 0.56 | 2.03 | 0.000 | 2.59 |
| 1984 | 0.48 | 2.04 | 0.000 | 2.52 |
| 1985 | 0.67 | 2.13 | 0.000 | 2.80 |
| 1986 | 0.74 | 2.46 | 0.000 | 3.20 |
| 1987 | 0.56 | 2.65 | 0.000 | 3.21 |
| 1988 | 0.58 | 2.67 | 0.000 | 3.25 |
| 1989 | 0.62 | 2.48 | 0.000 | 3.10 |
| 1990 | 0.47 | 2.39 | 0.000 | 2.86 |
| 1991 | 0.51 | 2.85 | 0.000 | 3.36 |
| 1992 | 0.74 | 2.86 | 0.000 | 3.60 |
| 1993 | 0.84 | 3.14 | 0.000 | 3.98 |
| 1994 | 0.71 | 3.40 | 0.004 | 4.11 |
| 1995 | 0.69 | 3.61 | 0.010 | 4.31 |
| 1996 | 0.56 | 3.75 | 0.017 | 4.33 |
| 1997 | 0.55 | 4.09 | 0.025 | 4.66 |
| 1998 | 0.52 | 4.37 | 0.031 | 4.92 |
| 1999 | 0.56 | 4.39 | 0.017 | 4.96 |
| 2000 | 0.45 | 4.22 | 0.140 | 4.81 |
| 2001 | 0.34 | 4.34 | 0.247 | 4.93 |
| 2002 | 0.37 | 5.10 | 0.196 | 5.67 |
| 2003 | 0.47 | 4.53 | 0.169 | 5.17 |
| 2004 | 0.56 | 4.30 | 0.350 | 5.21 |

Data Source:

U.S. Geological Survey State Water-Use Data System, Wendy McPherson, U.S. Geological Survey, written commun., 2006.

aquifer wells flowing 2 to 20 ft above land surface at Solomons, Leonardtown, and St. Inigoes. The wells stopped flowing when pumping caused the ground-water levels to decline in the mid-1940s (Bennett, 1944; Otton, 1955). Otton (1955) also reported the center of a cone of depression in the Piney Point-Nanjemoy aquifer at approximately -20 ft around NASPR by 1951, with the lowest recorded value of -32 ft northwest of well SM Df 43. Williams (1979) reported a water level in the Piney Point-Nanjemoy aquifer of -21 ft near well SM Df 1 in 1976. A 1980 potentiometric surface map of the Piney Point-Nanjemoy aquifer (Chapelle and Drummond, 1983) shows cones of depression around well fields at NASPR and in the Solomons area. The lowest potentiometric levels reported for the Piney Point-Nanjemoy aquifer in 1980 were -23 and -22 ft, near the southwest border of the main facilities at NASPR and the Solomons areas, respectively. Although the potentiometric surface of the Piney Point-Nanjemoy aquifer at WOLF has not been mapped, pumping in the surrounding areas has not led to the formation of an extensive cone of depression as of 2004 (Stephen Curtin, U.S. Geological Survey, written commun., 2006).

This regional pattern of water levels is consistent with water levels in the Piney Point-Nanjemoy aquifer collected at NASPR by the USGS (fig. 5). The oldest water-level measurement from a well at NASPR screened in the Piney Point-Nanjemoy aquifer was taken from well SM Df 14 in 1944. The water level in 1944 (-26.39 ft NAVD 88) was consistent with measurements taken at this well from 1996 through 1999 (about -24 to -29 ft NAVD 88). Although there is a 52-year gap in the record, these data indicate that the Piney Point-Nanjemoy water levels in the NASPR area did not change appreciably from 1944 through 1999. Well SM Df 14 had a collapsed screen in 2002, so more recent water-level measurements from this well were not analyzed. Water levels measured in wells SM Dg 20, SM Dg 21, and SM Dg 22 at NASPR all showed an overall decline in water levels in the Piney Point-Nanjemoy aquifer from 1998 through 2006 of about 2.5 ft, with water levels measured after May 2002 typically being lower than those measured before that date (fig. 5). This overall rate of decline is about 0.3 ft/yr (feet per year). Water levels in these wells showed some tendency to be lower in late summer than during the rest of the year, which may reflect the effects of seasonal variations on the volume of withdrawals.

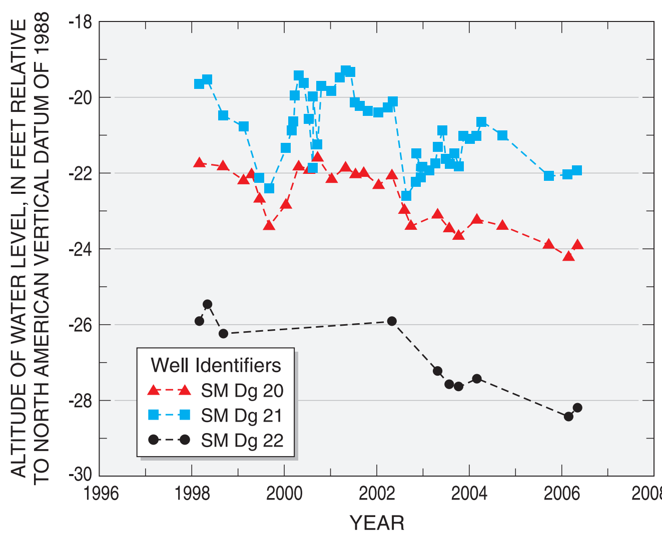



**Figure 5.** Water levels for selected wells screened in the Piney Point-Nanjemoy aquifer at Naval Air Station Patuxent River, Maryland, 1998–2006.

A comparison of trends in water levels in the Piney Point-Nanjemoy aquifer at NASPR with rates of withdrawal from the aquifer at NASPR (table 3) and the surrounding area (table 4) indicates that water levels in the aquifer at NASPR are affected by withdrawals from the aquifer at NASPR. Water levels in well SM Dg 20, and to a lesser degree, well SM Dg 21, were relatively stable in 1998, 2000, and 2001; during this period, pumping from the aquifer at NASPR was about 1,500 gal/d (fig. 5) (table 3). Water levels in wells SM Dg 20 and SM Dg 21 decreased in 1999, when withdrawals from the aquifer at NASPR increased to about 24,000 gal/d (table 3). The decrease in withdrawals from the Piney Point-Nanjemoy aquifer at NASPR from 2002 through 2005 was coupled with an overall trend of decreasing water levels at wells SM Dg 20, SM Dg 21, and SM Dg 22, however, indicating that the stable to slightly increasing withdrawals from the surrounding area (table 4) also may affect water levels in the aquifer at NASPR.

Ground-water levels in wells screened in the Piney Point-Nanjemoy aquifer at NASPR on April 28, 2006 were lower near the middle of the facility at well SM Dg 22 than near the Patuxent River at well SM Dg 21 or the Chesapeake Bay at well SM Dg 20 (fig. 6). A comparison of water levels in these wells with monthly withdrawal totals for each of the wells in southern Maryland indicates that water levels may have been affected by recent pumping from these and other nearby wells at NASPR.

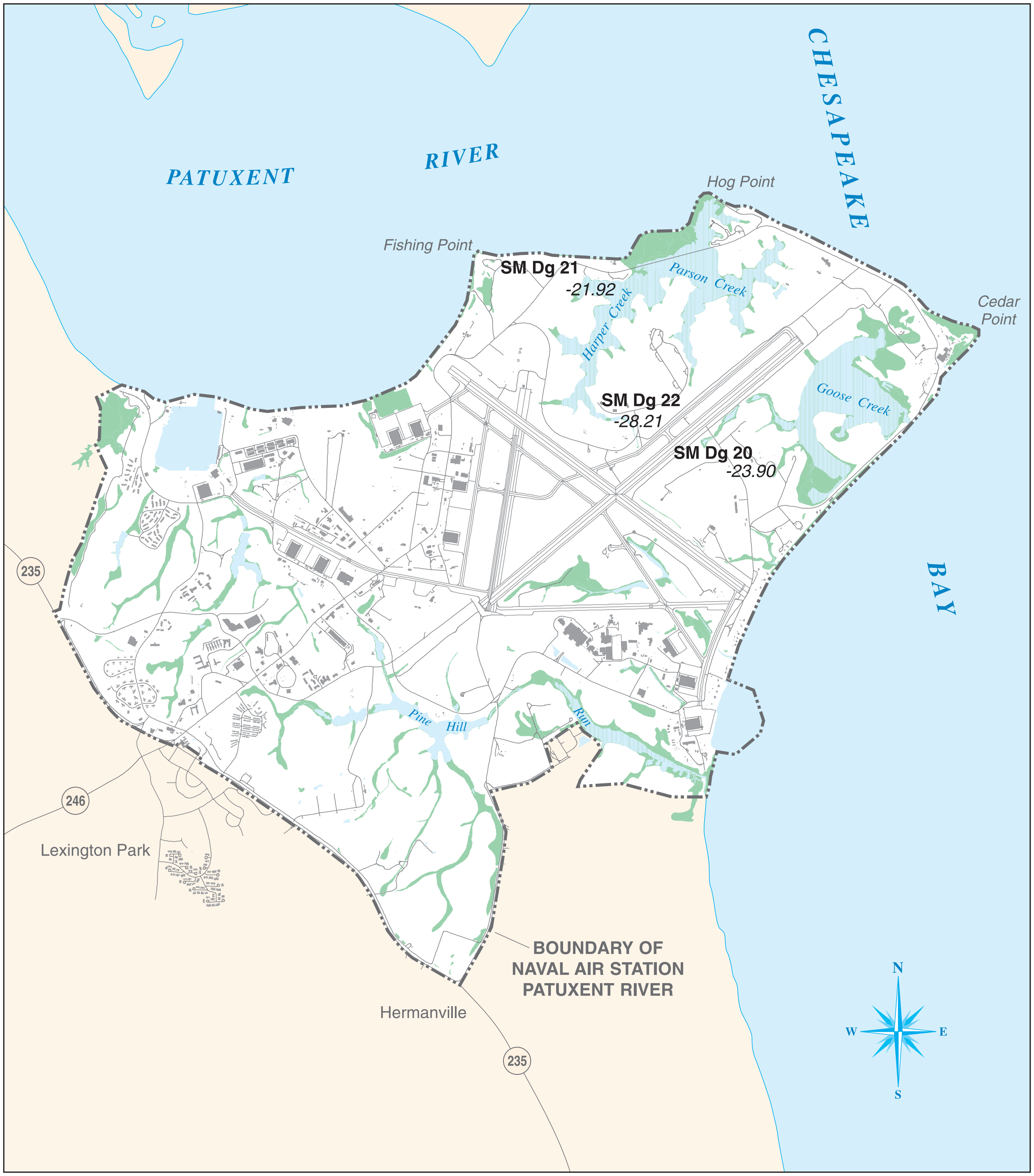
## Aquia Aquifer

Water withdrawals from the Aquia aquifer at NASPR have declined overall through time (table 3). Extrapolation of the historical data indicate that water withdrawals from the Aquia aquifer at NASPR are likely to have exceeded 1.0 Mgal/d from at least 1946 through 1974, and likely were about 1.0 Mgal/d from 1975 through 1991. Withdrawals from the Aquia aquifer at NASPR typically were about 0.8 Mgal/d from 1992 through 1999, and about 0.7 Mgal/d from 2000 through 2005. The Aquia aquifer typically has supplied more than 95 percent of the water used by NASPR.

Water withdrawals from the Aquia aquifer at WOLF also show an overall decrease from 1989 through 2005 (table 3). Extrapolation of the historical data indicate that water withdrawals from the Aquia aquifer may have been less than 20,000 gal/d for much of the period prior to at least 1972. Withdrawals increased sometime between 1971 and 1989, and typically were about 75,000 gal/d from 1989 through 1991. Withdrawals from the Aquia aquifer at WOLF declined from about 56,000 gal/d in 1992 to about 40,000 gal/d in 1995 and were consistently about 28,000 gal/d from 1997 through 2001. Since 2001, withdrawals from the Aquia aquifer at WOLF have been less than 12,000 gal/d, partly because of a shift to pumping from a well drawing from the Upper Patapsco aquifer in 2002. Prior to 2002, all water withdrawals at WOLF were from the Aquia aquifer.

The potentiometric surface of the Aquia aquifer in southern Maryland from 1951–2003 shows a dynamic cone of depression in the Lexington Park-Solomons-NASPR area. This cone formed in an oblong shape around the Lexington Park area, expanding deeper and wider throughout the period of record (Weigle and Webb, 1970; Chapelle and others, 1981; Chapelle and Drummond, 1983; Mack and others, 1983, 1985, 1987, 1989, 1990, 1991, 1992; Curtin and others, 1993a, 1994a, 1995a, 1996a, 1997a, 1999b, 2001a, 2002a, 2003a, 2005a). Otton (1955) prepared the first potentiometric-surface map of the Aquia aquifer in southern Maryland. 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 NASPR-Lexington Park area with levels reported as low as -63 ft along the western boundary of NASPR and -83 ft just outside NASPR in Lexington Park in 1981. Curtin and others (1999a, 2001a, 2002a, 2003a, 2005a) showed an extensive cone of depression in the Aquia aquifer around well fields at Lexington Park and Solomons during periods of measurement in 1997, 1999, 2001, 2002, and 2003. During 2003, the potentiometric surface in the Aquia aquifer was more than -80 ft NAVD 88 in a 60-$mi^2$ (square mile) area surrounding the deepest part of the cone of depression—measured values at NASPR were approximately -120 to -155 ft NAVD 88. The lowest measurement was -156 ft NAVD 88 in Lexington Park, Maryland (Curtin and others, 2005a). Curtin and others (2005b) showed that the potentiometric surface of the Aquia aquifer declined approximately 70 to 100 ft at NASPR from September 1982 to September 2003. Water levels in the aquifer declined more than 80 to 100 ft at Lexington Park, and about 60 ft near St. Marys City, just north of WOLF, during the same period.

Water-level records for wells measured by the USGS at NASPR and WOLF date as far back as the early 1940s for wells SM Df 1 and SM Df 10 screened in the Aquia aquifer, but water levels were not measured on a regular basis until the 1980s. Hydrographs of water levels for which 15 or more years of record exist show a declining trend in Aquia water levels of as much as 137 ft (fig. 7). The trend shows three phases at NASPR. The first phase occurred from about 1943 until no later than 1984, when water levels in wells SM Df 1 and SM Df 10 declined by about 43 to 50 ft, for a typical rate of about 1 ft/yr. The second phase occurred from about 1984 until about 1999, when water levels in the aquifer declined by about an additional 50 to 80 ft, for a typical rate of about 4 ft/yr. The third phase occurred after about 1999, during which water levels in the Aquia aquifer have remained fairly constant. For periods when four or measurements were available from a given well during a year, water levels in the Aquia aquifer at NASPR tended to be lower during the summer months than during the rest of the year, probably in response to seasonal trends in withdrawals.




**EXPLANATION**

WETLAND

**SM Dg 22** WELL IDENTIFIER
*-28.21* (Value in *italics* is altitude of water level, in feet. Datum is North American Vertical Datum of 1988.)

**Figure 6.** Altitude of water levels in the Piney Point-Nanjemoy aquifer on April 28, 2006, Naval Air Station Patuxent River, Maryland.

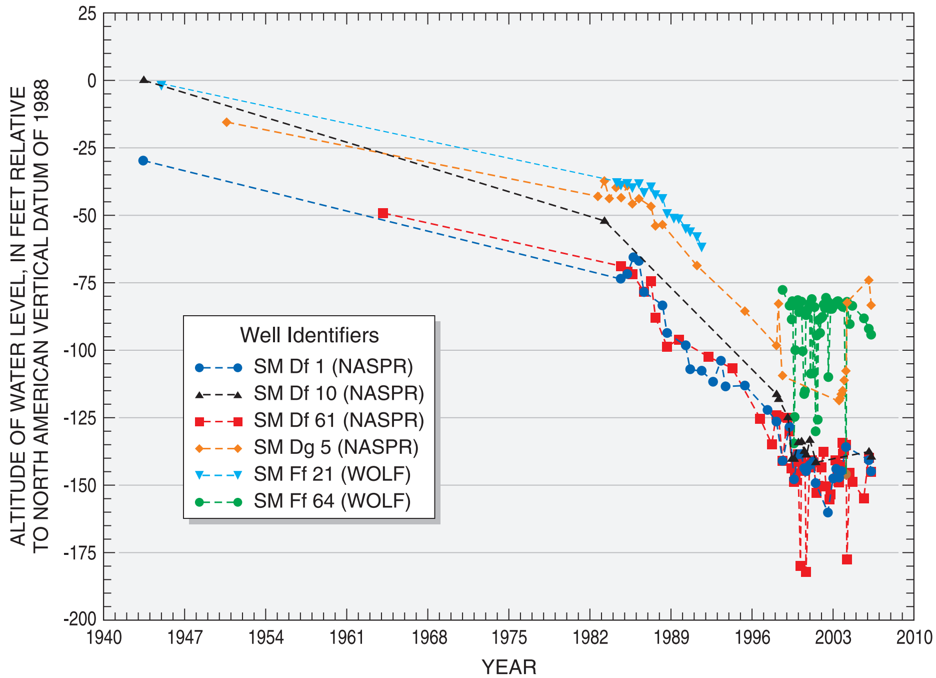



**Figure 7.** Water levels for selected wells screened in the Aquia aquifer at Naval Air Station Patuxent River (NASPR) and Webster Outlying Field (WOLF), Maryland, 1943–2006.

Records for water levels in the Aquia aquifer at WOLF are not as extensive as those at NASPR. The longest water-level record for WOLF is for well SM Ff 64 (1998–2006). Water levels in this well have declined by about 14 ft overall during 8 years of measurement (fig. 7).

A comparison of trends in water levels in the Aquia aquifer at NASPR and WOLF with rates of withdrawal from the aquifer at NASPR and WOLF as well as the surrounding area indicates that water levels in the Aquia aquifer at NASPR and WOLF, although affected by pumping from the bases, also are affected by withdrawals from the aquifer in the surrounding area. The period of the most rapid decline in water levels in the Aquia aquifer at NASPR and WOLF (1984 through 1998 or 1999) corresponds to a period of generally decreasing withdrawals from NASPR and WOLF (table 3), but substantially increasing withdrawals from the surrounding area (table 4). The more recent period of comparatively stable or low rates of decline in water levels in the Aquia aquifer at NASPR and WOLF (1999 or 2000 through April 2006) also corresponds to a period of generally decreasing withdrawals from NASPR and WOLF (table 3), but stable withdrawals from the surrounding area (table 4).

Ground-water levels in wells screened in the Aquia aquifer at NASPR on April 28, 2006 ranged from about -121 ft NAVD 88 at well SM Dg 19 on the eastern side of the facility to about -154 ft NAVD 88 at well SM Df 98 on the western side (fig. 8). These water levels are consistent with a composite cone of depression associated with pumping from the Aquia aquifer in wells located in the western part of NASPR and Lexington Park to the west. The potentiometric level of the Aquia aquifer in well SM Ff 64 at WOLF on April 28, 2006 was about -94 ft NAVD 88.

## Upper Patapsco Aquifer

The Upper Patapsco aquifer is heavily used for water supply in Anne Arundel, Charles, and Prince Georges Counties, Maryland. In St. Marys County, Maryland, the Upper Patapsco was used for water supply by one well at Lexington Park near NASPR and one well at St. Inigoes near WOLF prior to 2002. Due to the declining water levels in the Aquia and, to a lesser extent, the Piney Point-Nanjemoy aquifers, however, NASPR and WOLF began using the Upper Patapsco aquifer as a water-supply source in 2003 and 2002, respectively.

Withdrawals from the Upper Patapsco aquifer at NASPR began in November 2003, when well SM DF 100 began to be pumped. Withdrawals from the Upper Patapsco aquifer at NASPR decreased from 37,300 gal/d in November and December 2003 to about 17,500 gal/d in 2005 (table 3).

Withdrawals from the Upper Patapsco aquifer at WOLF began in January 2002, when well SM Ff 65 began to be pumped. Withdrawals from the Upper Patapsco aquifer at WOLF have declined from more than 21,000 gal/d in 2002 and 2003 to about 8,600 gal/d in 2005 (table 3).

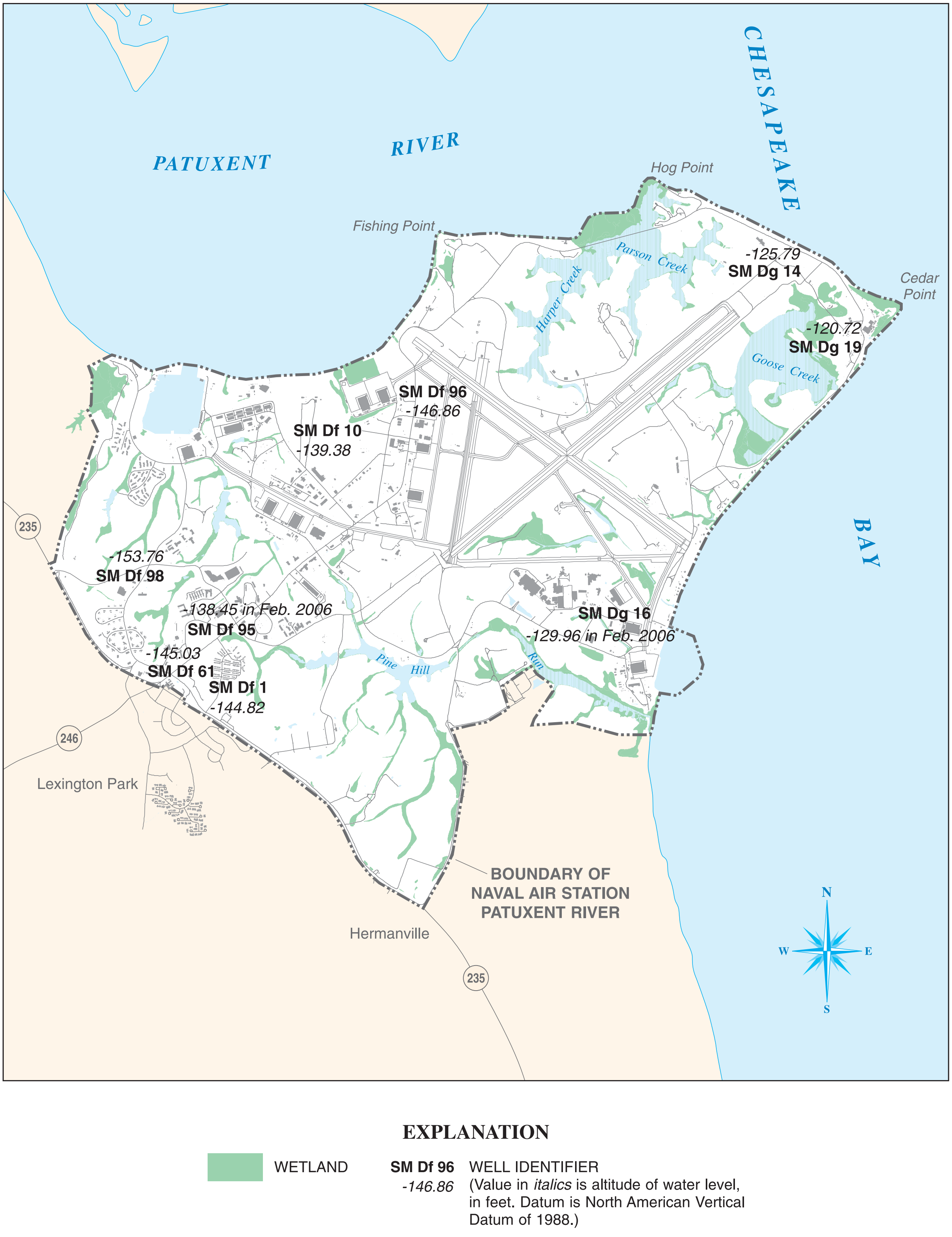



**Figure 8.** Altitude of water levels in the Aquia aquifer on April 28, 2006, Naval Air Station Patuxent River, Maryland.

Maps of the potentiometric surface of the Upper Patapsco aquifer in southern Maryland indicate flow from the recharge area near the outcrop toward the south (Mack and others, 1992; Curtin and others, 1993b, 1994b, 1995b, 1996b, 1997b, 1999c, 2001b, 2002b, 2003b, 2005c; Achmad and Hansen, 2001). Cones of depression were observed around pumping centers in the vicinity of LaPlata and Lexington Park-Kitts Point, Maryland, where the potentiometric level declined as much as 25 ft between 1990 and 2003 (Curtin and others, 2005d).

The longest records of historical potentiometric level data for the Upper Patapsco aquifer in the vicinity of NASPR and WOLF are for well SM Ff 36 (beginning in 1978), located near WOLF at Kitts Point, Maryland and well SM Df 84 (beginning in 1983), located near NASPR in Lexington Park, Maryland (fig. 9). The water-level altitude in well SM Ff 36 declined continuously from -2.25 ft NAVD 88 in November 1978 to -37.53 ft NAVD 88 in February 2006, an overall rate of decline of about 1.3 ft/yr. The water-level altitude in well SM Df 84 declined continuously from about -8 ft NAVD 88 in January 1983 to -47.9 ft NAVD 88 in February 2006, an overall rate of decline of 1.7 ft/yr. The rate of decline has increased through time in both wells. From 1978 through 1984, the rate of decline in well SM Ff 36 was about 0.9 ft/yr, from 1985 through 1996, the rate of decline was about 1.3 ft/yr, and from 1997 to 2006, the rate of decline was about 1.7 ft/yr. From 1983 through 1986, the rate of decline in well SM Df 84 was about 1.2 ft/yr, from 1987 through 1995, the rate of decline was about 1.7 ft/yr, and from 1996 to 2006, the rate of decline was about 2.0 ft/yr. Water-level declines in the Upper Patapsco aquifer at NASPR and WOLF are likely due to a combination of withdrawals from the aquifer in other parts of southern Maryland (beginning in at least 1978), nearby areas in St. Marys and Calvert Counties (beginning in 1995), and at NASPR and WOLF (beginning in 2003 and 2002, respectively). The timing and magnitude of the changes in the rate of water-level decline indicate that current (2006) water levels in the Upper Patapsco aquifer at NASPR and WOLF are declining primarily because of pumping from the aquifer in other parts of southern Maryland, followed by pumping from nearby areas, with pumping at NASPR and WOLF having the least impact. Pumping from both facilities is likely to affect drawdown in the future.

Water levels in well SM Df 100 at NASPR have declined from -37.65 ft in September 2000, shortly after the well was drilled, to -47.83 ft NAVD 88 on April 28, 2006 (figs. 9 and 10). This corresponds to a rate of decline of about 1.8 ft/yr. Water levels in well SM Ff 65 at WOLF have declined from -29.87 ft NAVD 88 in September 2001 to -37.03 ft NAVD 88 on April 28, 2006 (figs. 9 and 10). This corresponds to a rate of decline of about 1.5 ft/yr. These rates of decline are consistent with the recent values for Lexington Park and Kitts Point, and indicate that the rate of decline is slightly higher near NASPR than near WOLF, presumably because withdrawals near NASPR are greater than those near WOLF.

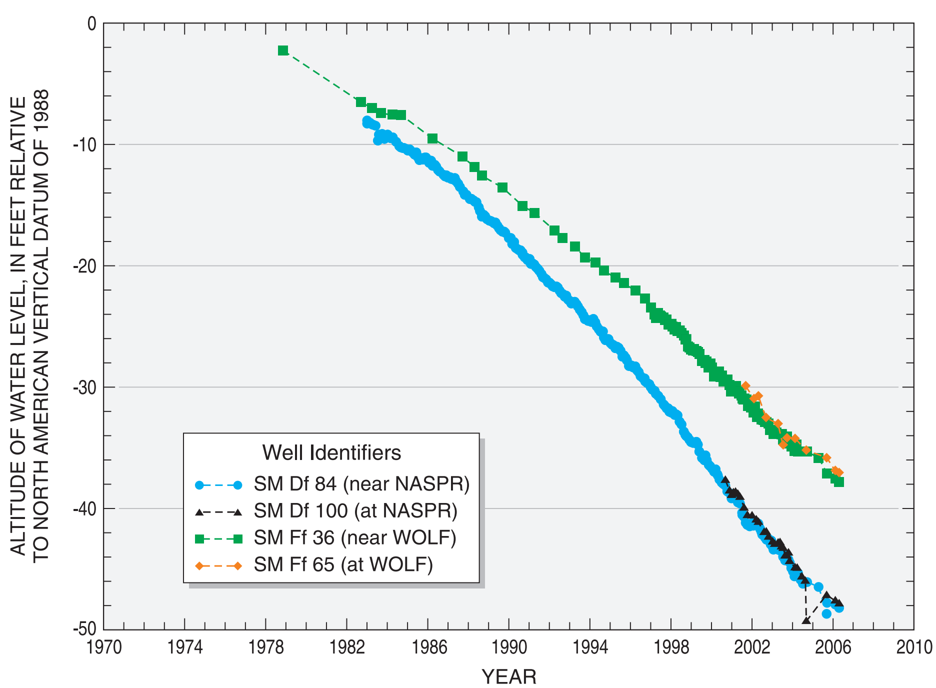
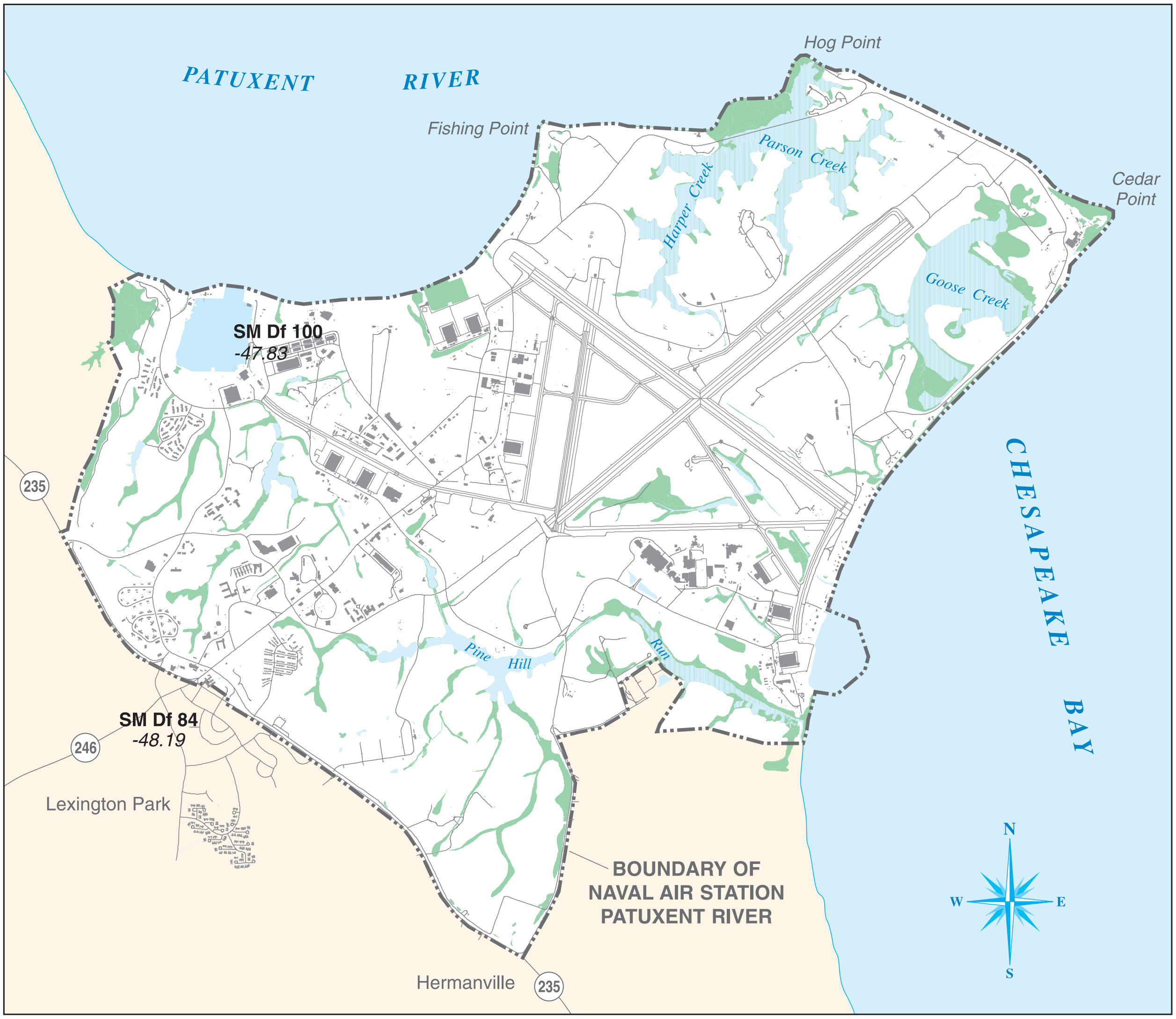
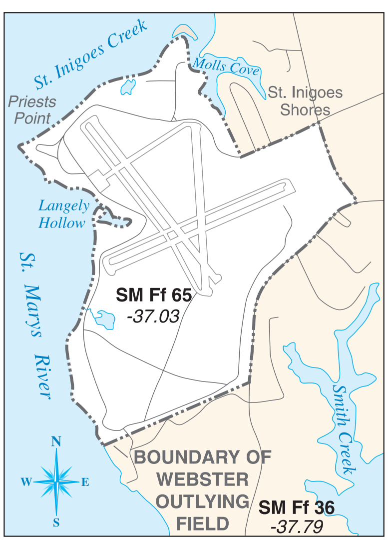



**Figure 9.** Water levels for selected wells screened in the Upper Patapsco aquifer at Naval Air Station Patuxent River (NASPR) and Webster Outlying Field (WOLF), Maryland, 1978–2006.



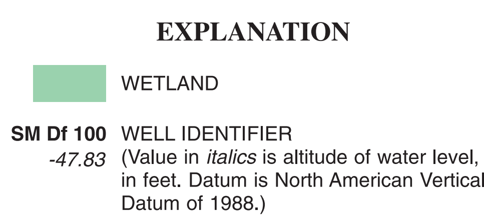




**Figure 10.** Altitude of water levels in the Upper Patapsco aquifer on April 28, 2006, Naval Air Station Patuxent River and Webster Outlying Field, Maryland.

Water levels in the Upper Patapsco aquifer are greater than those in the overlying Aquia aquifer, indicating the potential for flow from the Upper Patapsco aquifer up to the Aquia aquifer in this area (see figures 8 and 10). It is possible, therefore, that the Aquia aquifer receives some recharge from both the Middle and Lower confining units, and that the Upper Patapsco aquifer loses water both to pumping withdrawals and flow to the Middle confining unit. Water levels indicate that flow in the Upper Patapsco aquifer in the vicinity of NASPR and WOLF is from south to north, toward the centers of pumping in southern Maryland.

## Transmissivity of the Upper Patapsco Aquifer

Long-term, constant-discharge aquifer tests were performed in two wells (SM Df 100 and SM Ff 65) screened in the Upper Patapsco aquifer at NASPR and WOLF, respectively. These tests were performed to determine the transmissivity of the aquifer in both areas.

Well SM Df 100 is located in the northwestern part of NASPR (fig. 2). The altitude of land surface at SM Df 100 is about 21 ft NAVD 88 (U.S. Geological Survey, 1974). The well has a diameter of 10 in. (inches) from land surface to a depth of 705 ft, and 8 in. from 705 to 910 ft below land surface (including the screened intervals) (table 1). SM Df 100 is screened in the Upper Patapsco aquifer over the following intervals (ft below land surface): 706 to 716, 744 to 754, 835 to 860, 882 to 892, and 900 to 905, for a total of 60 ft of open interval over a total length of 199 ft.

Well SM Df 100 was pumped at 400 gal/min (gallons per minute) for 96 hours from August 8, 2000 through August 12, 2000. Water levels were measured in well SM Df 100 and in five observation wells (all of which are screened in the Aquia aquifer) for the period of pumping (pumping phase of test), and for 96 hours after pumping terminated (recovery phase of test). The Aquia wells were monitored to see if there was any interaction between the Upper Patapsco aquifer and the Aquia aquifer. Because other production wells in the Aquia were pumped during the test, drawdown due to pumping from well SM Df 100 could not be verified in any of the observation wells screened in the Aquia aquifer. Therefore, the aquifer test data were analyzed using only the data from the pumped well SM Df 100.

Drawdown data from well SM Df 100 were evaluated by use of the straight-line method of Cooper and Jacob (1946) (fig. 11). This technique is used to evaluate the drawdown and recovery data from aquifer testing in a confined aquifer and assumes the aquifer is isotropic, homogeneous, and areally extensive. The technique also assumes that the pumping rate and well loss are constant. Analysis of the data from the pumping and recovery phases of the test indicated transmissivities of about 3,900 and 4,600 ft$^2$/d (feet squared per day), respectively.

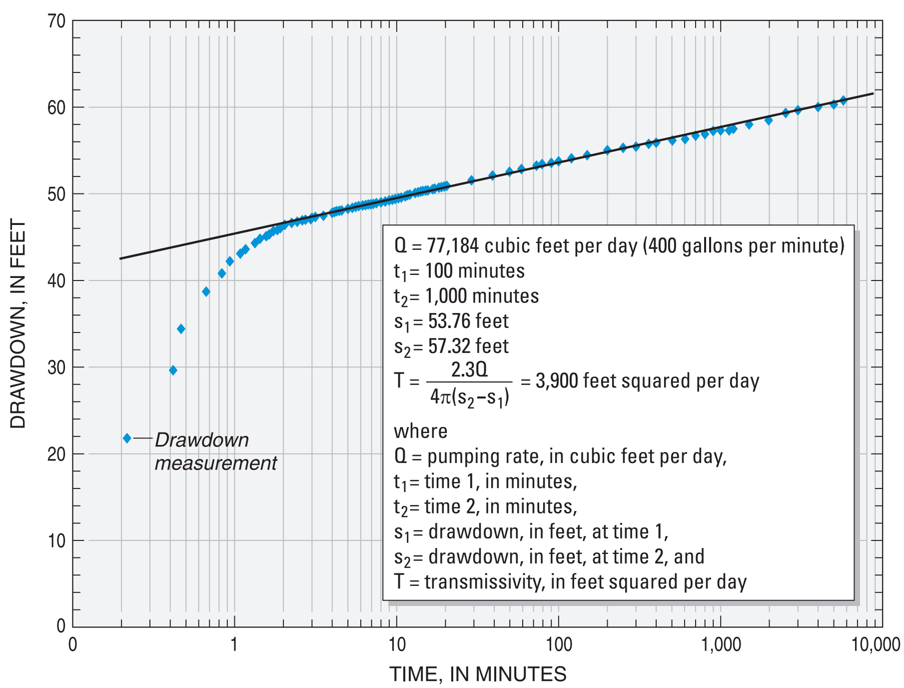



**Figure 11.** Analysis of time-drawdown data for well SM Df 100 at Naval Air Station Patuxent River, Maryland, August 8–12, 2000.

Well SM Ff 65 is located in the south-central part of WOLF (fig. 2). The altitude of land surface at SM Ff 65 is about 10 ft NAVD 88 (U.S. Geological Survey, 1974). The well has a diameter of 10 in. from land surface to a depth of 635 ft, and 8 in. from 635 to 884 ft below land surface (including the screened intervals). SM Ff 65 is screened in the Upper Patapsco aquifer at the following intervals (ft below land surface): 635 to 640, 648 to 658, 689 to 694, 782 to 792, 846 to 856, and 864 to 874, for a total open interval of 50 ft, over a length of 239 ft.

Well SM Ff 65 was pumped at a rate of 375 gal/min for 24 hours on August 6 and 7, 2001. Water levels were monitored in pumped well SM Ff 65 and observation wells SM Ff 36 and SM Ff 37 for the period of pumping and for 24 hours after pumping was terminated. Well SM Ff 36 is screened in the Upper Patapsco aquifer, approximately 1.5 mi south of well SM Ff 65 (fig. 3). Well SM Ff 37 is screened in the Upper Patapsco aquifer near SM Ff 65 (fig. 2). No drawdown was measured in either observation well. Therefore, only the data from pumped well SM Ff 65 were analyzed.

Drawdown data from well SM Ff 65 also were evaluated by use of the technique of Cooper and Jacob (1946) (fig. 12). Analysis of the data from the pumping and recovery phases of the test indicated transmissivities of about 2,100 and 2,800 ft$^2$/d, respectively.

# Ground-Water Quality in the Upper Patapsco Aquifer

Water samples were collected from well SM Df 100 on August 11, 2000, and from well SM Ff 65 on August 7, 2001, near the end of the pumping part of their respective aquifer tests. Water temperature, pH, specific conductance, and acid-neutralizing capacity were measured at the site. Water samples also were sent to the U.S. Geological Survey National Water Quality Laboratory in Denver, Colorado, for analysis of major ions, trace metals, and some radionuclides. A list of all constituents and their corresponding concentrations in the sample is provided in table 5.

The principal cation and anion in both samples are sodium and bicarbonate, respectively. The trace metal concentrations were all below the detection limit except for aluminum, zinc, lithium, molybdenum, strontium, and copper. The concentrations of all constituents were below the national primary drinking water regulation maximum contaminant level as regulated by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1999). Concentrations of all constituents except silica, iron, and radium-228 were greater in well SM Ff 65 than in well DM Df 100. Further characterization of the water quality of the Upper Patapsco aquifer based on these samples is limited because samples were only collected from two wells, only collected once at each well, and were sampled in different years.

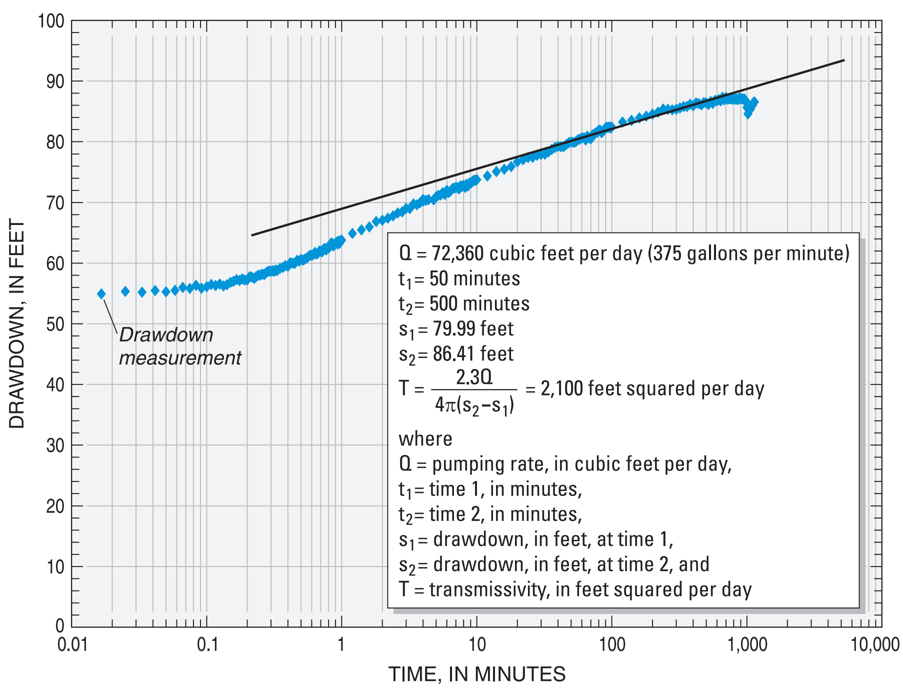



**Figure 12.** Analysis of time-drawdown data for well SM Ff 65 at Webster Outlying Field, Maryland, August 6–7, 2001.

**Table 5.** Concentrations of constituents in ground water from wells SM Df 100 and SM Ff 65 at Naval Air Station Patuxent River and Webster Outlying Field, Maryland, 2000–01.

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; na, not analyzed; µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; $CaCO_3$, calcium carbonate; $CO_3^{2-}$, carbonate; $HCO_3^-$, bicarbonate]

| Constituent | Well SM Df 100 | Well SM Ff 65 | Units |
|---|---|---|---|
| Specific conductance, field | 238 | 508 | µS/cm |
| Specific conductance, lab | 260 | 538 | µS/cm |
| pH field | 8.4 | 8.5 | standard units |
| Calcium (dissolved) | .39 | 0.8 | mg/L |
| Magnesium (dissolved) | .2 | 0.388 | mg/L |
| Sodium (dissolved) | 56.3 | 127 | mg/L |
| Potassium (dissolved) | 2.3 | 4.11 | mg/L |
| Acid-neutralizing capacity, field titration | 127 | 285 | mg/L as $CaCO_3$ |
| Acid-neutralizing capacity, laboratory titration | 177 | 277 | mg/L as $CaCO_3$ |
| Carbonate, field | na | 7.3 | mg/L as $CO_3^{2-}$ |
| Bicarbonate | 155 | 332 | mg/L as $HCO_3^-$ |
| Sulfate (dissolved) | 4.6 | 12.5 | mg/L |
| Chloride (dissolved) | 1.7 | 2.1 | mg/L |
| Fluoride (dissolved) | .4 | 0.8 | mg/L |
| Silica (dissolved) | 12.6 | 12.1 | mg/L |
| Barium (dissolved) | 6.7 | 12.4 | µg/L |
| Boron (total) | na | 318 | µg/L |
| Bromide (dissolved) | 0.02 | 0.04 | mg/L |
| Iron (dissolved) | 50 | 30 | µg/L |
| Manganese (dissolved) | 9 | 11.3 | µg/L |
| Nitrate + nitrite (dissolved) | <0.1 | na | mg/L |
| Radium-228, (dissolved, pCi/L as Ra-228) | <1.00 | .725 | pCi/L |
| Radium-228, 2 sigma, (pCi/L) | 0.38 | 0.33 | pCi/L |
| Uranium (natural, dissolved) | <.02 | < 0.02 | µg/L |
| Cyanide | <0.01 | na | mg/L |
| Mercury | <0.01 | na | µg/L |
| Aluminum | na | 4 | µg/L |
| Beryllium | <2 | <0.6 | µg/L |
| Nickel | <50 | <0.06 | µg/L |
| Arsenic | <1 | <0.2 | µg/L |
| Chromium | <1 | <0.8 | µg/L |
| Thallium | <1.0 | <0.4 | µg/L |
| Cadmium | <1.0 | <0.04 | µg/L |
| Antimony | <1.0 | <0.05 | µg/L |
| Selenium | <1.0 | <0.3 | µg/L |
| Lead | <1.0 | <0.08 | µg/L |
| Zinc | <20 | 3 | µg/L |
| Lithium | na | 4.8 | µg/L |
| Molybdenum | na | 2.4 | µg/L |
| Cobalt | na | <0.2 | µg/L |
| Silver | na | <1.0 | µg/L |
| Strontium | na | 16.5 | µg/L |
| Vanadium | na | <0.2 | µg/L |
| Copper | na | 0.3 | µg/L |

## Summary and Conclusions

Ground-water withdrawals have resulted in deep cones of depression in aquifers used for water supply in parts of southern Maryland. Recent and projected population growth in southern Maryland is likely to exacerbate decreases in the potentiometric surfaces of these aquifers. As a result, the U.S. Geological Survey (USGS), in cooperation with Naval Air Station Patuxent River (NASPR), has conducted an ongoing investigation of the hydrogeology and water quality of the Piney Point-Nanjemoy and Aquia aquifers in the vicinity of NASPR and Webster Outlying Field (WOLF). Lithologic, borehole geophysical, water-level, and water-use data were compiled and interpreted to revise understanding of the hydrogeologic framework of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers in southern Maryland, with emphasis on the Naval Air Station Patuxent River and WOLF. Understanding of the hydrogeologic framework for the Upper Patapsco aquifer also has been revised based on the results of aquifer testing and water-quality sampling of two wells.

The Piney Point-Nanjemoy aquifer is 50 to 70 feet thick, with a top altitude of -213 to -260 feet from the North American Vertical Datum of 1988 (NAVD 88) and a horizontal hydraulic conductivity of 2 feet per day at NASPR and WOLF. The Aquia aquifer is 50 to 145 feet thick, with a top altitude of -450 feet NAVD 88 and a hydraulic conductivity of 6 to 10 feet per day at NASPR and WOLF. The Upper Patapsco aquifer at the NASPR and WOLF consists of layers of sand interbedded with layers of clay that total over 200 feet in thickness. The altitude of the top of the Upper Patapsco aquifer is approximately -625 to -660 feet NAVD 88 at NASPR and WOLF.

The Piney Point-Nanjemoy, Aquia, and Upper Patapsco aquifers are sources of water supply for the NASPR and WOLF, as well as for nearby municipalities and industries in southern Maryland. Ground-water withdrawals from the Piney Point-Nanjemoy and Aquia aquifers at the NASPR and WOLF (Aquia aquifer only) began in 1942. Ground-water withdrawals from the Upper Patapsco aquifer at WOLF and NASPR began in 2002 and 2003, respectively. In 2005, about 710 gallons per day were pumped from the Piney Point-Nanjemoy aquifer, about 657,000 gallons per day were pumped from the Aquia aquifer, and about 17,500 gallons per day were pumped from the Upper Patapsco aquifer at NASPR. About 11,500 gallons per day were withdrawn from the Aquia aquifer and about 8,600 gallons per day were withdrawn from the Upper Patapsco aquifer at WOLF in 2005.

Water levels in the Piney Point-Nanjemoy aquifer at NASPR have not changed substantially during the past 52 years, and are approximately -20 feet NAVD 88. Water levels may have shown an overall decrease of about 2.5 ft from 1998 through April 2006. Water levels in the Piney Point-Nanjemoy aquifer at NASPR appear to be affected by pumping withdrawals at the facility and perhaps in the surrounding area.

Water levels in the Aquia aquifer decreased as much as 136 feet from 1943 through April 2006 at the NASPR and WOLF. The rate of decrease was greatest from about 1984 through 1999, when water levels declined about 4 feet per year. Water levels in the Aquia aquifer have remained stable overall since about 2000. In April 2006, water levels in the Aquia aquifer ranged from about -154 ft NAVD 88 in the western part of NASPR to about -121 ft in the eastern part. Water levels in the Aquia aquifer in April 2006 were about -92 ft NAVD 88 at WOLF. Water levels in the Aquia aquifer at the NASPR and WOLF appear to be affected by pumping at these facilities and in the surrounding area.

Water levels in the Upper Patapsco aquifer in the vicinity of NASPR and WOLF declined from about 1.3 to 1.7 feet per year overall between 1978 and April 2006. The rate of decline has increased through time from about 0.9 to 1.6 feet per year during 1978 through 1984, to about 1.7 to 2.0 feet per year from 1997 to April 2006. The rate of decline was greater in the vicinity of NASPR and WOLF. Water levels in the Upper Patapsco aquifer at NASPR and WOLF appear to be affected primarily by pumping throughout southern Maryland, although pumping at the facilities is likely to affect future drawdown.

Aquifer testing at two wells screened in the Upper Patapsco aquifer indicates the transmissivity of the aquifer is about 2,100 to 4,600 feet squared per day at NASPR and WOLF. Aquifer transmissivity appears to be lower at WOLF than at NASPR. Water samples collected from these wells near the end of the pumping part of their respective aquifer tests in 2000 and 2001 indicate the water in the Upper Patapasco aquifer at NASPR and WOLF is a sodium-bicarbonate type.

## Acknowledgments

The authors thank the personnel at NASPR 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 U.S. Geological Survey employees who assisted in field data collection.

## References Cited

Achmad, G., and Hansen, H.J., 1997, Hydrogeology, model simulation, and water-supply potential of the Aquia and Piney Point-Nanjemoy aquifers in Calvert and St. Marys Counties, Maryland: Maryland Geological Survey Report of Investigations No. 64, 197 p.

Achmad, G., and Hansen, H.J., 2001, Ground-water levels and pumpage trends in the major coastal plain aquifers of southern Maryland between 1970 and 1996: Maryland Geological Survey Open-File Report No. 00-02-12, 150 p.

Bennett, R.R., 1944, Ground-water resources at the Naval establishments in the Solomons-Patuxent River area, Maryland: U.S. Geological Survey Open-File Report, 35 p.

Chapelle, F.H., and Drummond, D.D., 1983, Hydrogeology, digital simulation, and geochemistry of the Aquia and Piney Point-Nanjemoy Aquifer System in Southern Maryland: Maryland Geological Survey Report of Investigations No. 38, 100 p.

Chapelle, F.H., Drummond, D.D., and Curley, T., 1981, Map showing the potentiometric surface of the Aquia aquifer, May 19–23, 1980: U.S. Geological Survey Open-File Report 81–416, 1 p.

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526–534.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1993a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1991: U.S. Geological Survey Open-File Report 93–652, 1 p.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1993b, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September 1991: U.S. Geological Survey Open-File Report 93–654, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1994a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1993: U.S. Geological Survey Open-File Report 94–390, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1994b, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September 1993: U.S. Geological Survey Open-File Report 94–392, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1995a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1994: U.S. Geological Survey Open-File Report 95–743, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1995b, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September 1994: U.S. Geological Survey Open-File Report 95–745, 1 p.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1996a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1995: U.S. Geological Survey Open-File Report 96–620, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1996b, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September 1995: U.S. Geological Survey Open-File Report 96–622, 1 p.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1997a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September–October 1996: U.S. Geological Survey Open-File Report 97–788, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1997b, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September–October 1996: U.S. Geological Survey Open-File Report 97–790, 1 p.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1999a, The difference between the potentiometric surfaces of the Aquia aquifer, September 1982 and September 1997 in Southern Maryland: U.S. Geological Survey Open-File Report 99–81, 1 p.

Curtin, S.E., Andreasen, D.C., and Mack, F.K., 1999b, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1997: U.S. Geological Survey Open-File Report 99–82, 1 p.

Curtin, S.E., Mack, F.K., and Andreasen, D.C., 1999c, Potentiometric surface of the Upper Patpasco aquifer in Southern Maryland, September 1997: U.S. Geological Survey Open-File Report 99–85, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2001a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1999: U.S. Geological Survey Open-File Report 01–204, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2001b, Potentiometric surface of the Upper Patapsco aquifer in Southern Maryland, September 1999: U.S. Geological Survey Open-File Report 01–208, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2002a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 2001: U.S. Geological Survey Open-File Report 02–442, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2002b, Potentiometric surface of the Upper Patapsco aquifer in Southern Maryland, September 2001: U.S. Geological Survey Open-File Report 02–446, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2003a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 2002: U.S. Geological Survey Open-File Report 03–255, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2003b, Potentiometric surface of the Upper Patapsco aquifer in Southern Maryland, September 2002: U.S. Geological Survey Open-File Report 03–257, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2005a, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 2003: U.S. Geological Survey Open-File Report 2005–1004, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2005b, The difference between the potentiometric surfaces of the Aquia aquifer, September 1982 and September 2003 in Southern Maryland: U.S. Geological Survey Open-File Report 2005–1005, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2005c, Potentiometric surface of the Upper Patapsco aquifer in Southern Maryland, September 2003: U.S. Geological Survey Open-File Report 2005–1008, 1 p.

Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 2005d, The difference between the potentiometric surfaces of the Upper Patapsco aquifer, September 1990 and September 2003 in Southern Maryland: U.S. Geological Survey Open-File Report 2005–1009, 1 p.

Darton, N.H., 1896, Artesian well prospects in the Atlantic Coastal Plain region: U.S. Geological Survey Bulletin 138, 232 p.

Drummond, D.D., 2005, Water-supply potential of the Coastal Plain aquifers in Calvert, Charles, and St. Mary's Counties, Maryland, with emphasis on the Upper Patapsco and Lower Patapsco aquifers: Maryland Geological Survey Administrative Report, June 2005, 70 p.

Klohe, C.A., and Feehley, C.E., 2001, 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: U.S. Geological Survey Water-Resources Investigations Report 01–4029, 51 p.

Mack, F.K., Andreasen, D.C., Curtin, S.E., and Wheeler, J.C., 1987, Potentiometric surface of the Aquia aquifer in Southern Maryland during the fall of 1986: U.S. Geological Survey Water-Resources Investigations Report 87–4214, 1 p.

Mack, F.K., Andreasen, D.C., Curtin, S.E., and Wheeler, J.C., 1989, Potentiometric surface of the Aquia aquifer in Southern Maryland during the fall of 1987: U.S. Geological Survey Water-Resources Investigations Report 89–4012, 1 p.

Mack, F.K., Andreasen, D.C., Curtin, S.E., and Wheeler, J.C., 1990, Potentiometric surface of the Aquia aquifer in Southern Maryland during September 1998: U.S. Geological Survey Water-Resources Investigations Report 90–4037, 1 p.

Mack, F.K., Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 1991, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1989: U.S. Geological Survey Water-Resources Investigations Report 91–4094, 1 p.

Mack, F.K., Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 1992, Potentiometric surface of the Aquia aquifer in Southern Maryland, September 1990: U.S. Geological Survey Open-File Report 92–459, 1 p.

Mack, F.K., Wheeler, J.C., and Curtin, S.E., 1983, Preliminary map showing the potentiometric surface of the Aquia aquifer in Southern Maryland, September 1982: U.S. Geological Survey Open-File Report 83–929, 1 p.

Mack, F.K., Wheeler, J.C., Curtin, S.E., and Andreasen, D.C., 1985, Preliminary map showing the potentiometric surface of the Aquia aquifer in Southern Maryland, September 1984: U.S. Geological Survey Water-Resources Investigations Report 85–4338, 1 p.

Mack, F.K., Wheeler, J.C., Curtin, S.E., Andreasen, D.C., and Wheeler, J.C., 1992, Potentiometric surface of the Upper Patapsco aquifer in Southern Maryland, September 1990: U.S. Geological Survey Open-File Report 92–461, 1 p.

Naval Air Station Patuxent River, Naval Air Station History: accessed December 4, 2000, at URL *http://nas.nawcad.navy.mil*

Otton, E.G., 1955, Ground-water resources of the Southern Maryland Coastal Plain: Maryland Department of Geology, Mines, and Water Resources Bulletin 15, 347 p.

U.S. Environmental Protection Agency, 1999, Code of Federal Regulations 40, Part 141—National Primary Drinking Water Regulations: Washington, D.C., Office of the Federal Register, [variously paged.]

U.S. Geological Survey, 1974, Solomons Island Quadrangle, Maryland: U.S. Geological Survey Topographic Quadrangle Map 5760 IV SW, scale 1:24,000, 1 sheet.

Vroblesky, D.A., and Fleck, W.B., 1991, Hydrogeologic framework of the Coastal Plain of Maryland, Delaware, and the District of Columbia: U.S. Geological Survey Professional Paper 1404–E, 45 p.

Weigle, J.M., and Webb, W.E., 1970, Southern Maryland records of selected wells, water levels and chemical analyses of water: Maryland Geological Survey Basic Data Report No. 4, 48 p.

Williams, J.F., III, 1979, Simulated changes in water level in the Piney Point Aquifer in Maryland: Maryland Geological Survey Report of Investigations No. 31, 49 p.

Prepared by Publishing Service Centers 3 and 1.
Edited by Valerie M. Gaine.
Graphics by Timothy W. Auer.
Layout by Ann Marie Squillacci.

For additional information, contact:
Director, MD-DE-DC Water Science Center
U.S. Geological Survey
8987 Yellow Brick Road
Baltimore, MD 21237

or visit our Web site at:
http://md.water.usgs.gov

Klohe, C.A. and Kay, R.T.—**Hydrogeology of the Piney Point-Nanjemoy, Aquia, and Upper Patapsco Aquifers, Naval Air Station Patuxent River and Webster Outlying Field, St. Marys County, Maryland, 2000–06**—USGS Scientific Investigations Report 2006–5266