Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

OPEN FILE REPORT NO. 87-02-3

SUMMARY OF HYDROGEOLOGIC DATA FROM A TEST WELL (1,725 FT.) DRILLED IN TUCKAHOE STATE PARK, QUEEN ANNE'S COUNTY, MARYLAND

by

David C. Andreasen and Harry J. Hansen

Prepared in cooperation with the
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ABSTRACT

Test well QA-Ef 29 was drilled to a depth of 1,725 feet during the spring of 1986 at the site of a proposed fish (striped bass) hatchery in Tuckahoe State Park, near Queen Anne in southeastern Queen Anne's County, Maryland. The test well demonstrated that the Magothy and upper Patapsco aquifers could produce ground water in sufficient quantity (1 to 1.5 million gallons per day) and of suitable quality to meet the requirements of the hatchery operation.

At the well site the Magothy aquifer consists largely of gray to tannish white, fine to medium grained, occasionally coarse, quartzose sand interbedded with dark gray clayey and organic-rich layers. The upper Patapsco aquifer is characterized by light gray to tan, medium to coarse grained, quartz sand interbedded with tough mottled clays; layers of cemented sandstone occur chiefly within the lowest screened sand.

The pilot hole was converted to a production well by setting five sections of 8-inch diameter well screen from 1,110 feet to 1,120 feet and from 1,135 feet to 1,180 feet in the Magothy aquifer. In the upper Patapsco aquifer screens were set from 1,195 feet to 1,210 feet, 1,230 feet to 1,270 feet, and 1,285 feet to 1,315 feet. A total of 140 feet of screen was set.

The aquifer properties of the combined Magothy and upper Patapsco sands screened in QA-Ef 29 were estimated by a 24-hour pumping (and recovery) test. A constant discharge rate of about 700 gallons per minute resulted in a water-level decline of 164.5 feet from a pre-pumping static water level 62.5 feet below land surface. The 24-hour specific capacity of the well was 4.3 gallons per minute per foot of drawdown with a well efficiency of approximately 70 percent. The transmissivity of the screened sands was 1,585 ft^2/day calculated from water-level data measured during the recovery phase of the test.

Over a 5-week period the static water level in the well fluctuated between about 0.6 and 1.0 foot below sea level and exhibited a close correspondence to changes in barometric pressure. The barometric efficiency of the well was determined to be 39 percent and was used to calculate an approximate aquifer storage coefficient (0.00021). Smaller, semidiurnal variations of less than 0.05 foot were also observed and may be caused by either earth or ocean tides.

The quality of water from the Magothy and upper Patapsco aquifers is generally good. It is low in chloride (2 mg/L) and sulfate (18 mg/L), slightly acidic (pH = 6.2), soft (hardness = 12 mg/L) and relatively low in

dissolved solids (124 mg/L, predominantly sodium bicarbonate). The dissolved iron concentration (0.55 mg/L) is slightly above the recommended level (0.3 mg/L). The water contains no dissolved oxygen. The geothermal gradient was about 1.53°F/100 feet with a well head water temperature of 77°F (25.1°C). For optimum hatchery operation the water must be aerated to provide dissolved oxygen. Aeration may also be an effective treatment for raising the pH due to carbon dioxide degassing and for decreasing dissolved iron concentrations by ferric hydroxide precipitation.

INTRODUCTION

Background

A preliminary study was recently made by James R. Holley and Associates, Inc. (1985) under the direction of the Maryland Department of General Services and the Maryland Tidewater Administration to find the best available site in the State for a new striped bass hatchery. An evaluation of the four proposed sites suggested that a parcel in southeastern Queen Anne's County, located within the boundaries of Tuckahoe State Park, was probably the best available site for the facility. Test well QA-Ef 29 was drilled to obtain site-specific information regarding the aquifers underlying the proposed hatchery site. This information was needed to determine if the aquifers could produce sufficient ground water of suitable quality to meet the requirements of the fish hatchery.

Preliminary plans for the Tuckahoe State Park site required that both surface water from Tuckahoe Creek and ground water be utilized to operate the facility (George Krantz, per. comm.). Surface water would be used to fill the growing-out ponds twice a year during March and July with peak demand over a 20-day period estimated at about 3 million gallons per day (MGD). Peak ground-water usage for hatchery operations would be during a 2-month period, April 15 to June 15, with an estimated pumpage rate of 1 to 1.5 MGD. Additionally, about 0.15 MGD would be required as make-up water for evaporative losses (James R. Holley and Associates, 1985, p. 4).

Constraints on the utilization of aquifers at the site were established by the Maryland Water Resources Administration for management purposes (Robert Miller, per. comm.). The shallower artesian aquifers, such as the Piney Point, Aquia, and to a lesser extent, the Monmouth, are utilized locally for domestic, commercial, and agricultural purposes (tab. 1). In the case of the Aquia aquifer a new, major appropriation in Queen Anne's County was considered inadvisable at this time because of the occurrence of bay-water intrusion in the Kent Island area. Because of these constraints the deeper (>1,100 ft) Magothy and Patapsco aquifers were targeted for testing.

No wells close to the test site pump from the Magothy or Patapsco aquifers. Therefore regional data from Easton and western Queen Anne's County were used to estimate whether pumpage in the 1 to 1.5 MGD range was feasible at the site. The regional data suggested that the Magothy aquifer might sustain excessive drawdowns, if pumped alone at this rate. It was concluded that a multiple-screen completion would be necessary with the Magothy used in conjunction with several upper Patapsco sands. The upper 500 ft of the Patapsco Formation was targeted so that wells deeper than 1,500 ft would not be necessary. The regional data indicated that several sandy units, totaling 50 to 70 ft of cumulative sand footage, probably occurred in the upper 500 ft of the Patapsco Formation. An estimate of their hydraulic properties suggested that these sands probably had the capacity to meet the ground-water requirements of the proposed hatchery.

The pristine nature of the deep aquifers beneath the Tuckahoe State Park site made the presence of toxic contaminants unlikely. The natural quality of the water, with the possible exception of pH and dissolved iron concentration,

Table 1. Generalized subsurface stratigraphy of southeastern Queen Anne's County

ERA	SYSTEM	SERIES	STAGE	GROUP	GEOLOGIC UNIT	LITHOLOGIC CHARACTERISTICS	HYDRO-STRATIGRAPHY	APPROXIMATE THICKNESS (FT.) IN WELL
CENOZOIC	QUATERNARY and TERTIARY	PLEISTOCENE and PLIOCENE (?)	—	COLUMBIA	NOT ASSIGNED	Gravel and sand, composed of poorly sorted, iron-stained quartz, heavily weathered; trace feldspar and layers of orange and gray, tough clay.	Water table aquifer	20
	TERTIARY	MIOCENE	LOWER TO MIDDLE	CHESAPEAKE	CHOPTANK and CALVERT FORMATIONS (Undifferentiated)	Sand and clay, gray, light green and brown, silty to fine grained, quartzose, slightly micaceous, weathered shell beds, moderate calcite cementation, and very low grade brown diatomite.	Chiefly a confining layer but may include minor aquifer (Cheswold)	260
		?	?					
		EOCENE	LOWER TO MIDDLE	PAMUNKEY	PINEY POINT FORMATION	Sand, quartzose, fine to very coarse grained, iron-stained, moderately glauconitic; limonite and/or goethite(?) pellets occasionally very abundant, foraminifera, several silty clay layers, light grayish-green.	Piney Point aquifer generally confined to upper 15 to 20 feet of Formation	120
					NANJEMOY FORMATION	Silty clay, minor percentage of sand, light to dark grayish-green, heavily glauconitic, dark green to black, calcite granules and foraminifera.	Confining layer	160
		PALEOCENE	UPPER		AQUIA FORMATION	Sand, quartzose, iron-stained, moderately glauconitic, medium to very coarse grained, frequent goethite(?) and/or limonite pellets and sandstone, calcite-cemented, fine grained quartz and black, glauconite, forming hard layers interstratified with softer calcareous silt; abundant foraminifera.	Chiefly an aquifer, but lower half contains cemented beds that act as confining layers	190
			LOWER		BRIGHTSEAT and HORNERSTOWN FMS. (UNDIFFERENTIATED)	Clay and sand, dark gray to black, fine grained quartz; glauconitic.	Confining layer	40
MESOZOIC	CRETACEOUS	UPPER	MAESTRICHTIAN	MONMOUTH GROUP		Sand, dark greenish-gray, quartzose, iron-stained, fine to coarse grained, moderately glauconitic, occasional goethite(?) pellets and clay, light gray to dark greenish-gray with glauconite and quartz silt, slightly calcareous.	Aquifer is about 65 feet thick	140
			CAMPANIAN	MATAWAN GROUP		Clay, silty, dark gray to black, quartzose and glauconitic, micaceous, moderately carbonaceous, lignitic, occasional coarse quartz grains.	Chiefly a confining layer but may include a minor aquifer	150
			? SAN-TONIAN	—	MAGOTHY FORMATION	Sand, quartzose, medium to coarse quartz grains, white and gray, some iron-staining and dark micaceous-lignitic clays.	Aquifer may be 25 to 50 feet thick	100
		LOWER	? ALBIAN TO CENOMANIAN (?)	POTOMAC	PATAPSCO FORMATION	Sand, light gray and rose, fine to coarse grained, well sorted, dominantly quartzose, slightly micaceous, lignite, pyrite, occasional weak sideritic(?) cementation; interstratified with clay, mottled (shades of red, brown, gray), tough, lignitic.	Inter-stratified aquifers and confining beds	Not fully penetrated

was believed to be within acceptable limits for hatchery use. The lack of dissolved oxygen in the ground water and well head water temperatures in the 75°F to 80°F range were anticipated and judged not to be serious problems. Consequently, a 1,725-ft test boring was designed to evaluate the potential of the Magothy and upper Patapsco aquifers at the test site with an option to complete it as a production well.

Acknowledgments

The authors appreciate the efforts of Robert Miller of the Maryland Water Resources Administration and George E. Krantz of the Maryland Tidewater Administration during the planning phases of this project. The drilling contract was administered by the Maryland Department of General Services through the efforts of Herbert Belknap and Wallace North. The authors were assisted during the drilling, construction, and testing phases of the project by John Wilson, David Drummond, and Frederick Mack of the Maryland Geological Survey and by Stephen Curtin and Roger Starsoneck of the U.S. Geological Survey. Richard Olsson, of Rutgers University, analyzed selected geologic samples for foraminiferal content. Frederick Mack and John Wilson provided technical reviews of the report. Francis Chapelle of the U.S. Geological Survey commented on the water-quality section. The U.S. Geological Survey provided geophysical logging services and a chemical analysis of the water sample. Donajean Appel and Cynthia Lang-Bachur prepared the manuscript for printing.

DRILLING AND CONSTRUCTION PHASE

Well QA-Ef 29 was drilled at the site of the proposed Tuckahoe State Park Fish Hatchery in Queen Anne's County, Maryland. The site is located approximately one-quarter of a mile north of Queen Anne about 142 ft east of State Route 309 (Lat. 38°55'34"N, Long. 75°57'36"W) (fig. 1).

The well was drilled by Sydnor Hydrodynamics, Inc., of Richmond, Virginia, with a hydraulic rotary rig. Drilling consisted of two phases: First, a 9 7/8-in. pilot hole was drilled and cored to a depth of 1,725 ft[1], followed by geophysical logging of the hole by the U.S. Geological Survey. Second, after an evaluation of the data obtained from the pilot hole, a 14-in. by 8-in. diameter production well (fig. 2) was constructed. The contractor started the pilot hole on April 7, 1986 and completed pump testing the production well on June 28, 1986.

To prevent caving in of surficial deposits, a 22-in. diameter surface casing was installed to a depth of 59 ft. A 10-in. diameter retrievable liner was installed inside of the surface casing to a depth of several feet below the bottom of the surface casing. This reduced the volume of drilling fluid in the surface casing and enhanced the circulation of drill cuttings to the surface. The pilot hole was drilled continuously using a mixture of bentonite, gel additives and fresh, potable water from a nearby well. A proper viscosity and density of drilling fluid was maintained throughout the drilling operation.

Three drill bits were used during the pilot hole drilling phase. They were as follows: (1) a 9 7/8-in. drag bit used from land surface to 750 ft, (2) a 9 7/8-in. drag bit with an offset hole for coring used from 750 ft to 1,302 ft, and (3) a 9 7/8-in. drag bit with a center aligned hole also used for coring from 1,302 ft to 1,725 ft. A wash-out occurred between 508 ft and 526 ft; otherwise the hole was held to a fairly uniform diameter by the drilling fluid (see fig. 6). The drilling averaged about 250 ft/day to 750 ft and then decreased to about 96 ft/day. The slower drilling rate was probably caused by increased circulation time, dulling of drill bits and more resistant strata.

Drill cuttings were collected at 10-ft intervals and at all noticeable changes in lithology from a sample ditch. Drilling fluid was circulated a sufficient length of time after each 10-ft interval to allow the drill cuttings to reach the surface. The geophysical logs and lithologic log correlate well in the section of hole above 700 ft. Cuttings further down the hole became progressively more mixed and a good correlation with the geophysical logs was lost. Field descriptions and driller's logs (Appendix A) were made of the cuttings during the first phase of drilling.

Fourteen cores were taken at selected depths below 750 ft by the wire-line method. The core barrel consisted of a 1 9/16-in. by 18-in., thick walled, split-spoon tube with a combination of sand and clay baskets. Core lengths ranged from 4 in. to 9 in. Lithologic descriptions of cores are

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[1]Depths cited in this report are below land surface unless otherwise stated. Land surface is 61.69 ft above sea level.

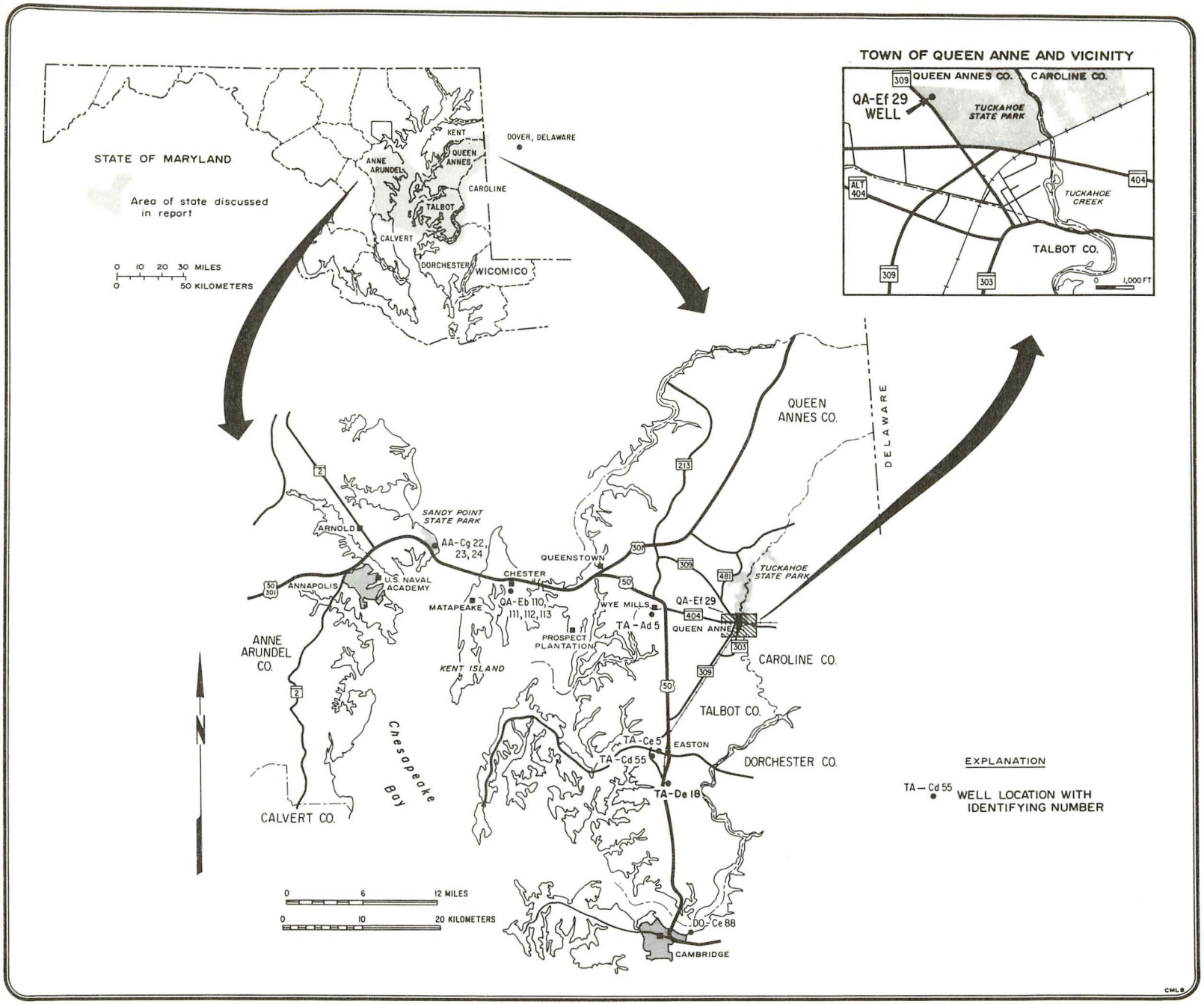

Figure 1. Map locating Tuckahoe State Park and wells cited in report.

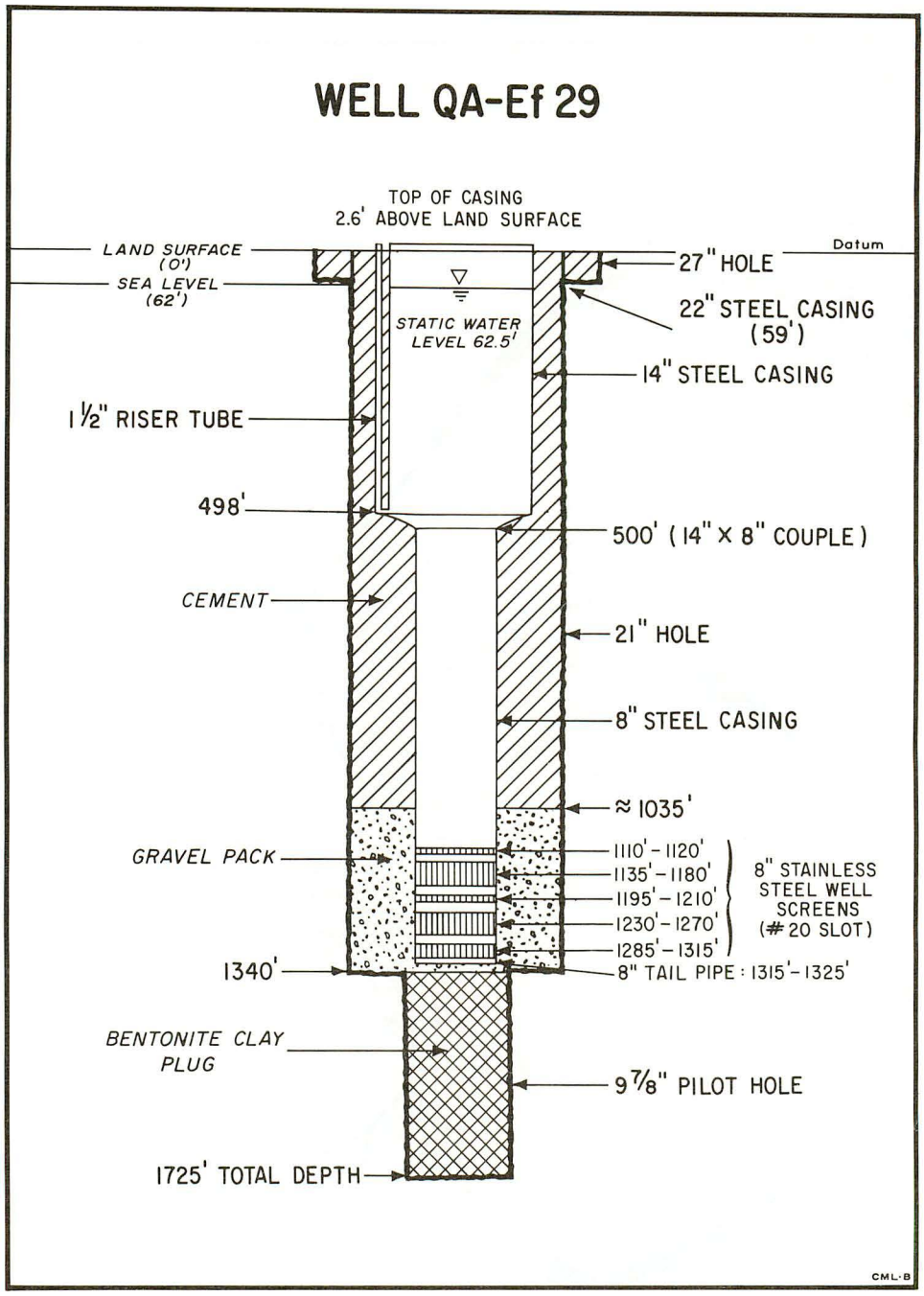

Figure 2. Construction schematic of test boring and well QA-Ef 29.

summarized in Appendix B. A reconstructed lithologic log utilizing field, driller's, and microscopic descriptions along with geophysical logs, core descriptions and drilling rates is contained in Appendix C.

After drilling the pilot hole to 1,725 ft geophysical logs were run in the open hole by the U.S. Geological Survey (Water Resources Division). The suite of logs consisted of a natural gamma radiation log, several electric resistivity logs (6-ft lateral, 16-in. and 64-in. normal, single point), a spontaneous potential log, and a caliper log. The gamma radiation log and the 16-in.-64-in. resistivity log are displayed on cross-section A-A' (pl. 1). Sydnor Hydrodynamics, Inc., ran multi-point electric and natural gamma radiation logs.

The second phase of drilling lasted 14 days and consisted of filling part of the pilot hole below the deepest screenable sand with bentonite clay, then reaming a 21-in. hole to a depth of 1,340 ft. A 21-in. tricone roller bit was used for this portion of drilling. The construction of the well began with the placement of 140 ft of 8-in. diameter wire-wound stainless steel screen, 0.02-in. slot size, between 1,110 ft and 1,315 ft below land surface. Screens were set in five sections, separated by 8-in. diameter steel blanks, with an additional 10-ft length of 8-in. diameter tail pipe attached below the deepest screen. The positions of the screens are detailed in figure 2.

Eight-inch diameter, 40 to 45-ft long sections of steel casing were joint welded and placed from the top of the screens to 500 ft below land surface. To accommodate a high-capacity pump, 14-in. diameter steel casing was installed from land surface to 500 ft. Welded braces were used at every casing joint to insure that the casing was centered in the hole. A 1 1/2-in. diameter riser tube was installed outside the 14-in. casing to facilitate water-level measurements.

Medium grained washed gravel and fresh water were pumped into the annular space from 1,340 ft up to 1,035 ft by means of a tremie pipe (fig. 2). The motion of the water and gravel "slurry" scoured the open hole and helped to remove the mud cake formed by the drilling fluid. This method aided in the development of the well. The well was completed by cementing the annular space from land surface to the top of the gravel pack at about 1,035 ft.

Intermittent development of the well lasted 5 days and consisted of a combination of air lifting and water jetting techniques. Compressed air was forced down the drill stem or riser tube to air-lift drilling mud from the well. Screens and gravel pack were washed using fresh water forced through a high pressure jet and swab device. Water jetting removed drilling mud and formational materials, such as silt or fine sand. If not removed, these fine materials would restrict the flow of water through the gravel pack and screens. During development as much as 300 gallons per minute were air lifted from the well.

REGIONAL HYDROSTRATIGRAPHY

The regional hydrostratigraphic framework is displayed in cross-section A-A' (pl. 1). Cross-section A-A' extends from Sandy Point (AA-Cg 22) in Anne Arundel County to Easton (TA-De 18) in Talbot County. The cross section displays lithostratigraphic (e.g., formation, group), chronostratigraphic (e.g., series, stage), and hydrostratigraphic units[2] (e.g., aquifer) (tab. 1). Lithostratigraphic units are correlated from well-to-well based upon data that is derived from drill cuttings, core samples, and geophysical logs. Chronostratigraphic units are defined by biostratigraphic criteria, chiefly microfossils such as foraminifers and palynomorphs (pollen, spores, plankton) (see Appendix D). Hydrostratigraphic units in the Maryland Coastal Plain consist of one or more sand-dominant formations. These units are defined by their hydraulic conductivity and are mapped using lithostratigraphic criteria. Pumping tests, observation well data, and ground-water modeling analyses are used to determine the hydraulic conductivity of hydrostratigraphic units.

Hydrogeologic and stratigraphic information for the three wells correlated with QA-Ef 29 in cross-section A-A' have been published in the following reports: AA-Cg 22 (Mack and Achmad, 1986); QA-Eb 110 (Mack, 1983); and TA-De 18 (Hansen, 1968; Mack, Webb, and Gardner, 1971)[3]. The stratigraphic interpretations expressed in these reports have been taken into account, but they are not always coincident with the correlations shown in A-A'. In the brief discussion to follow, emphasis is placed on the hydrostratigraphy of the geologic units identified in QA-Ef 29 (tab. 1).

Columbia Aquifer

The Columbia aquifer (Bachman and Wilson, 1984) is a surficial, pebbly sand unit that generally occurs under water-table conditions. The unit is of fluvial origin with deposition initiated in discrete channels that later infilled to form a coalescing sand sheet (Hansen, 1981). The sand sheet is thickest east and south of cross-section A-A' in parts of Caroline, Dorchester and Wicomico Counties. In these areas the Columbia aquifer is a major source of water. At QA-Ef 29 only about 17 ft of aquifer material was logged (Appendix C). Although this interval consists of coarsely textured material, the thin and shallow nature of the aquifer makes it susceptible to dewatering during periods of drought or sustained pumpage; consequently, it is bypassed by high capacity users in this part of Queen Anne's County.

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[2] Lithostratigraphic Unit: A mappable body of rock, identified by lithic characteristics and stratigraphic position, which is prevailingly tabular. (North American Commission on Stratigraphic Nomenclature, 1983, p. 858).
Chronostratigraphic Unit: A body of rock formed during the same time span. (North American Commission on Stratigraphic Nomenclature, 1983, p. 868).
Hydrostratigraphic Unit: A mappable body of rock identified on the basis of its hydraulic conductivity and its boundary discontinuities. (Committee on Hydrostratigraphic Units, 1983, p. 3).

[3] Construction records for these and other wells cited in this report are contained in Appendix E.

Depth to the base of the Columbia Group in QA-Ef 29 is uncertain (Appendix C). The oxidized clays, silts, and fine sands logged between 20 ft and 41 ft may be part of the Columbia. However, these sediments may also represent, at least in part, weathered strata at the top of the subcropping Chesapeake Group.

Cheswold Aquifer

The Cheswold aquifer[4], which occurs as a minor artesian aquifer at Easton (TA-De 18), was recognized at the Tuckahoe State Park test well site between 125 ft and 195 ft. However, as shown on cross-section A-A', the massive sand occurring at Easton has bifurcated into two thinner sands in QA-Ef 29. Additionally, the Cheswold aquifer, which is a fine to medium grained quartzose sand at Easton has become very fine to fine at the Tuckahoe State Park site. At both localities the aquifer contains shell-bearing beds, which may be associated with some secondary calcite cementation. Mack, Webb, and Gardner (1971) estimated a transmissivity value of about 500 ft^2/day for the Cheswold aquifer at Easton.

West of QA-Ef 29 clay, silts and very fine sands dominate the lower part of the Chesapeake Group and the unit is considered a confining bed rather than an aquifer. Westward along A-A', the Chesapeake Group progressively thins as its up-dip edge is bevelled beneath surficial Columbia Group sediments.

Piney Point Aquifer

South and east of cross-section A-A', at localities such as Cambridge, Maryland, and Dover, Delaware, the Piney Point aquifer is a major ground-water source (Williams, 1979). Although recognizable at both Easton and Tuckahoe State Park, the Piney Point sands are thinner and much less productive. Up-dip, the Piney Point Formation thins by truncation as its upper beds are bevelled by more gently dipping strata of the Chesapeake Group. This contact is believed to represent a major regional unconformity with late Eocene and all of the Oligocene missing (about 16.3 million years). However, recent work suggests that previously unrecognized Oligocene beds may be present in the section either as basal Chesapeake Group sediments or within the uppermost strata of the Piney Point (see, for example, Benson, Jordan, and Spoljaric (1985)).

The Piney Point aquifer is a glauconitic, grayish-green, medium to very coarse, quartz sand. The Piney Point is shelly with thin (1 ft) calcite-cemented layers. With increasing depth the Piney Point Formation becomes finer grained and more clayey as it grades into the underlying Nanjemoy Formation, a confining bed. Microfossil data reported by Olsson (see Appendix D) suggest that the contact probably occurs between 400 ft and 440 ft in QA-Ef 29.

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[4]The name Cheswold aquifer was introducted in Maryland by Cushing, Kantrowitz, and Taylor (1973) to describe water-bearing sands in the Calvert Formation (Overbeck and Slaughter, 1958), a unit of the Chesapeake Group.

In the Easton and Tuckahoe State Park areas high capacity wells generally bypass the Piney Point aquifer for deeper aquifers. Transmissivity values along the A-A'traverse are generally less than 500 ft^2/day except in the Wye Mills area where Williams (1979, pl. 5) reports values as high as 1,200 ft^2/day. In wells QA-Ef 29 and TA-De 18 the potentially productive part of the Piney Point is about 15 ft to 20 ft thick and occurs in the upper part of the formation.

Aquia Aquifer

The Aquia aquifer is a major aquifer in the area traversed by cross-section A-A' and can be traced from outcrop at Sandy Point in Anne Arundel County to Easton (pl. 1). The Aquia aquifer is a fossiliferous, glauconitic quartz sand that is medium to very coarse grained in its more productive intervals. In QA-Ef 29 the Aquia section between 622 ft and 710 ft is characterized by frequent occurrences of cemented strata (up to 3 ft thick), particularly in the lower 40 ft. In this interval the quartz, glauconite, and shell clasts of the Aquia have been lithified by a chalky to crystalline, calcareous cement, forming sandstones and coquinas. With pores and vugs plugged by cement this portion of the Aquia Formation is less productive than the upper 60 ft of the unit. At both Easton and Tuckahoe State Park the interval designated the Aquia aquifer is usually restricted to the upper part of the formation. The upper Aquia is a predominantly unconsolidated sand, consisting largely of iron-stained quartz, glauconite (weathered partly to limonite), and leached shell material. Up-dip from QA-Ef 29, at Kent Island (QA-Eb 110), the upper part of the Aquia is also the more productive. In QA-Eb 110 the formation becomes finer grained and clayey with increasing depth. Although intercalated layers of lithified sand and shells occur at Kent Island (D. Drummond, per. comm.), cementation is less common than in the Easton and Tuckahoe State Park areas.

The effect of calcareous cementation on the productivity of the Aquia aquifer is demonstrated by comparing transmissivity values at Easton, where the lower part of the formation is partially cemented, with values at several up-dip localities, where cementation is less pervasive. At Easton transmissivity values ranging from 650 to 1,000 ft^2/day are reported (Mack, Webb, and Gardner, 1971; Chapelle and Drummond, 1983). In contrast at Queenstown and Prospect Plantation, located about 5 to 7 miles east of QA-EB 110, values as high as 5,300 ft^2/day characterize the aquifer (Overbeck and Slaughter, 1958; Chapelle and Drummond, 1983).

Monmouth and Matawan Aquifers

On the upper Delmarva Peninsula there are several sands in the Upper Cretaceous interval that rank as minor aquifers, although in some areas of Queen Anne's and Kent Counties they may be locally important (tab. 1). The foraminiferal data reported by Olsson (see Appendix D) was used to establish a tentative chronostratigraphy for this interval in QA-Ef 29; however, the correlations shown in A-A' (pl. 1) should be considered "working hypotheses" subject to revision as new biostratigraphic data become available.

In QA-Ef 29 the Monmouth aquifer is a quartzose sand, moderately glauconitic with subordinate occurrences of calcareously cemented strata. The electric log recorded a dominantly sandy section between 810 ft and 875 ft; however, the interval between 830 ft and 870 ft, where medium to coarse sands were logged, is probably the most productive zone. Descriptions of drill cuttings and geophysical log data from QA-Eb 110 suggest that equivalent strata at Chester consist largely of muddy, fine sand (pl. 1).

Pumping test data reported by Overbeck and Slaughter (1958) for the Monmouth aquifer in the northern Queen Anne's County - Kent County area suggest a transmissivity of about 650 ft^2/day. Although this aquifer has historically been used at Easton, it is usually screened in wells with multi-aquifer completions and consequently its hydrologic parameters are uncertain (Rasmussen and Slaughter, 1957).

In well QA-Ef 29, the dominantly fine, glauconitic quartz sand between 930 ft and 970 ft is tentatively assigned to the Matawan Group (undivided) based on Olsson's suggestion that these sediments are Campanian in age (see Appendix D). It appears to correlate with a similar sand at Easton, but its relationship with Campanian-age sediments occurring at Kent Island and Sandy Point (pl. 1) is uncertain. The Matawan is a minor aquifer that is used only in special situations, such as at Easton where there are multi-aquifer completions and on northern Kent Island, where the primary aquifer (Aquia) is intruded by bay water.

Magothy Aquifer

The Magothy aquifer in QA-Ef 29 occurs within the lower part of the Magothy Formation and is most productive between 1,135 ft and 1,180 ft. The aquifer grades upward from a medium to coarse grained, lignitic sand to a micaceous, very fine to silty sand, and clay. The contact between the Magothy Formation and the overlying Matawan Group appears to be gradational, but in the absence of comprehensive biostratigraphic data it can only be approximated.

The base of the Magothy Formation is a major, regional unconformity[5]. The contact between the Magothy and the Patapsco Formation is picked at 1,180 ft, where a dense, slow-drilling clay, usually representative of the Potomac Group, first occurs. Because, however, the sediments immediately above this horizon are barren of dateable palynomorphs (plant microfossils), it is possible that the base of the Magothy may be as high as 1,152 ft. This uncertainty often occurs because of the complex distribution of sands and clays within the Patapsco Formation, a nonmarine unit of fluvial to deltaic origin. If the contact is picked solely on the basis of the first dense (or mottled) clay, then inevitably some upper Patapsco sands will be incorrectly included in the basal beds of the Magothy Formation. Defined hydrostratigraphically, however, these beds may be lumped together as the "Magothy aquifer", provided that their sand-on-sand contact results in hydraulic

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[5]At least two, and perhaps three, Upper Cretaceous stages, representing about 10 million years, are absent.

continuity across the unconformity. In practice high capacity wells, like QA-Ef 29, often include the Magothy aquifer in multiple-screen completions of the upper Patapsco sands.

The Magothy Formation represents the depositional product of a major marine transgression and consists of shoreline and shallow-shelf sediments. As such, it is widely distributed on the Coastal Plain. The Magothy Formation is comparatively thin and generally grades upward into fine grained, mid to outer shelf sediments, except in central Anne Arundel County where a thick, apparently fluvial, facies of the Magothy occurs. As might be expected, a high southeasterly trending transmissivity tract (Hansen, 1971, p. 143) characterizes this area where values as high as 12,000 ft^2/day have been reported (Mack and Achmad, 1986, fig. 29). In contrast, the Magothy transmissivity values encountered along the A-A' traverse (pl. 1), which is north of this tract, are considerably less. For example, Mack and Achmad (1986, fig. 29) reported a value of 1,000 ft^2/day at Sandy Point State Park and Rasmussen and Slaughter (1957) reported a value of 1,600 ft^2/day for the Easton area. Because the Magothy aquifer is relatively thin at the Tuckahoe State Park site it was not tested separately, but was instead included in a multiple-screen test of the upper Patapsco aquifer. The Magothy at the Tuckahoe State Park site is a minor aquifer.

It is difficult to generalize about the transmissivity of the Magothy aquifer because of the uncertainty of its lower contact. In places where the Magothy has a sand-on-sand contact with the upper Patapsco Formation values considerably higher than the 1,000 to 1,600 ft^2/day range may occur. For example, at Matapeake on Kent Island, Mack (1983) reports a value of 5,800 ft^2/day.

Patapsco Aquifers

The Patapsco aquifers occur in the upper part of the Potomac Group, a thick sequence of fluvio-deltaic sediments (Hansen, 1969). The Patapsco sediments shown in A-A' (pl. 1) are chiefly interbedded sequences of channel sands (aquifers) and overbank or floodplain sediments (confining beds). In up-dip localities such as Sandy Point (AA-Cg 22) the former predominate with several stacked channel sands forming thick, productive aquifers. Eastward sand percentages decrease as individual sand units become thinner. In well QA-Ef 29 the interval between 1,230 ft and 1,270 ft is a light gray to tan, medium to coarse-grained sand, with trace occurrences of lignite and pyrite. Minor iron staining and thin layers of gray clay were found in the interval. The sands between 1,290 ft and 1,320 ft were logged as finer grained and consisted of alternating intervals of slow and fast drilling, suggesting interbedded layers of unconsolidated and indurated strata. The cementing material appears to be largely siderite (iron carbonate), although the especially hard drilling at 1,302 ft may have been caused by a thin, pyrite (iron sulfide) layer.

Sample recovery was poor from the upper Patapsco sands logged below 1,600 ft. Some cementation of these sands is suggested by the crusty layers logged during drilling and by the sideritic cement noted in the 1,685 ft core. The deeper lower Patapsco aquifer was not penetrated in QA-Ef 29 (see pl. 1).

In general the number and thickness of Patapsco Formation sands decrease down-dip (pl. 1) resulting in a decrease of aquifer transmissivity. For example, at Sandy Point Mack and Achmad (1986, p. 40) report an upper Patapsco transmissivity value of 5,000 ft^2/day for well AA-Cg 24 and an estimated lower Patapsco value in the 2,000 to 3,000 ft^2/day range for well AA-Cg 23. At Chester on Kent Island recovery data from a 24-hour pumping test of well QA-Eb 111 yielded a transmissivity of 1,400 ft^2/day for two sands in the upper Patapsco aquifer. A similar test of well QA-Eb 112 gave a transmissivity of 4,000 ft^2/day for a lower Patapsco aquifer (Mack, 1983). In comparison the combined test of the Magothy aquifer and the uppermost sands of the Patapsco yielded a transmissivity of 1,585 ft^2/day at the Tuckahoe State Park site. The Patapsco aquifers at Easton have not been tested.

Patuxent Aquifer

The Patuxent aquifer occurs at the base of the Potomac Group and consists of a fining-upward sequence of sands and pebbly sands. In general Patuxent transmissivity values decrease down-dip as the sands become thinner and less permeable. In portions of eastern Baltimore County and Anne Arundel County the Patuxent is a major aquifer with transmissivities reported in the 6,000 to 9,000 ft^2/day range (Chapelle, 1985; Mack and Achmad, 1986). However, Patuxent transmissivity values are considerably lower in the down-dip wells displayed on cross-section A-A' (pl. 1); for example, at Sandy Point (AA-Cg 22) and Chester (QA-Eb 110) reported values are in the the 800 to 1,000 ft^2/day range (Mack, 1983; Mack and Achmad, 1986). Beneath the Tuckahoe State Park site a reasonable projection of the Patuxent aquifer places it between about 2,300 ft and 3,100 ft below sea level. At comparable depths beneath Cambridge in Dorchester County, Trapp and others (1984) report transmissivities in the range of 275 to 850 ft^2/day. Decreases in aquifer transmissivity with depth is due in part to a reduction in effective porosity caused by increased overburden pressure. At Cambridge Trapp and others (1984) report aquifer porosity values of less than 30 percent whereas at up-dip localities porosity values of at least 35 percent are typical (Chapelle, 1985). A relatively small change in effective porosity (e.g., 5 percent) can reduce aquifer transmissivity by a factor of two or three for aquifers of comparable thickness (Lynch, 1962, p. 264).

Regional salinity data extrapolated into the area by Lloyd, Larson, and Davis (1985) suggest that at least the lower part of the Patuxent Formation may contain salty water with chlorides greater than 5,000 mg/L. In plate 1 a wedge of salty water is tentatively shown underlying the site of QA-Ef 29 at a depth of about 2,700 ft below sea level.

GEOHYDROLOGY OF THE MAGOTHY AND UPPER PATAPSCO AQUIFERS

The well screen settings in QA-Ef 29 were selected to test potentially productive sands of the Magothy and upper Patapsco aquifers (fig. 2). The three lower well screens, totaling 85 ft in length, are set in the upper Patapsco aquifer from 1,195 ft to 1,210 ft, 1,230 ft to 1,270 ft, and 1,285 ft to 1,315 ft. The Patapsco sands within the screened zones generally consist of "clean", medium to coarse grained quartzose sand, occasionally interbedded with thin layers of siderite (iron carbonate)-cemented sandstone. Tough, varicolored clays separate the sand units. Cumulative thickness of the Patapsco sands approaches 100 ft. No attempt was made to isolate the sands and test them individually.

Two screens in the Magothy aquifer are positioned at 1,110 ft to 1,120 ft, and 1,135 ft to 1,180 ft. Sands screened within these intervals are generally finer grained than the Patapsco sands and are separated by dark grayish, silty clays that are less dense than the clays of the underlying Patapsco Formation. Because the contact between the Magothy Formation and the upper Patapsco Formation is uncertain at this location, the 1,135 ft to 1,180 ft screen may straddle sands of both formations.

Aquifer Test and Hydrologic Properties

A 24-hour pump test was conducted on June 27-28, 1986 at QA-Ef 29 to determine the combined aquifer characteristics of the Magothy and upper Patapsco aquifers. The test consisted of pumping the well continuously at a rate of 700 gallons per minute (gpm) for 24 hours using a diesel-driven turbine pump. At the end of the drawdown phase the pump was shut off to allow for a 24-hour recovery test. Water levels and pumping rates were recorded throughout the test using electric tape and totalizing meters, respectively. The pumping rate varied by about 5 gpm during the test.

A coefficient of transmissivity (T)* of 1,280 ft^2/day was calculated from a semi-log plot relating drawdown to time since pumping began (Cooper and Jacob, 1946) (fig. 3). The absence of an observation well appreciably limits the reliability of the drawdown phase for calculating aquifer parameters because head loss in a pumping well is partly dependent on the effectiveness of its construction and development and on the discharge rate. For this reason the transmissivity obtained from the pumping phase is probably lower than the actual value. Water levels in QA-Ef 29 fell 94 ft after 1 minute of pumpage. The total decline in head measured at the end of the 24-hour test was 164.45 ft. Specific capacity for the well was 4.3 gpm/ft.

A better estimate of aquifer transmissivity can be obtained by measuring water-level recovery after the pump is shut off (fig. 3). The recovery data, plotted as residual drawdown against the ratio of time since pumping began to the time pumping stopped (Driscoll, 1986, p. 257), resulted in a transmissiv-

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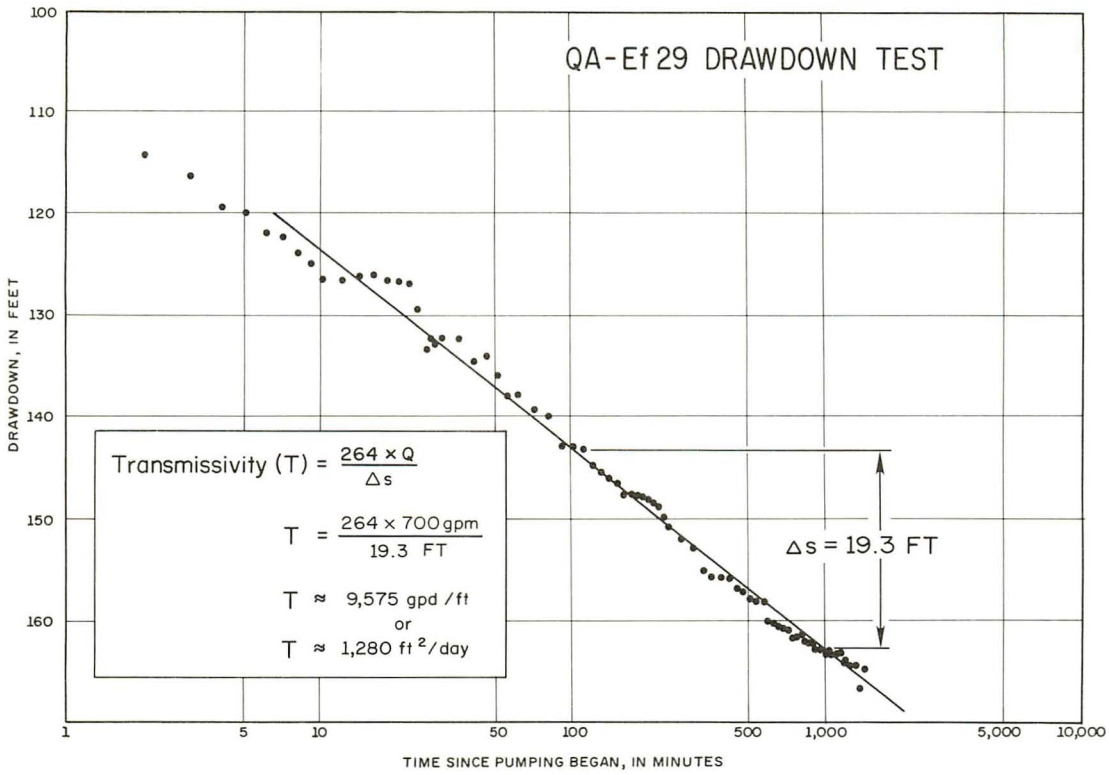
*Coefficient of Transmissivity: Rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972).



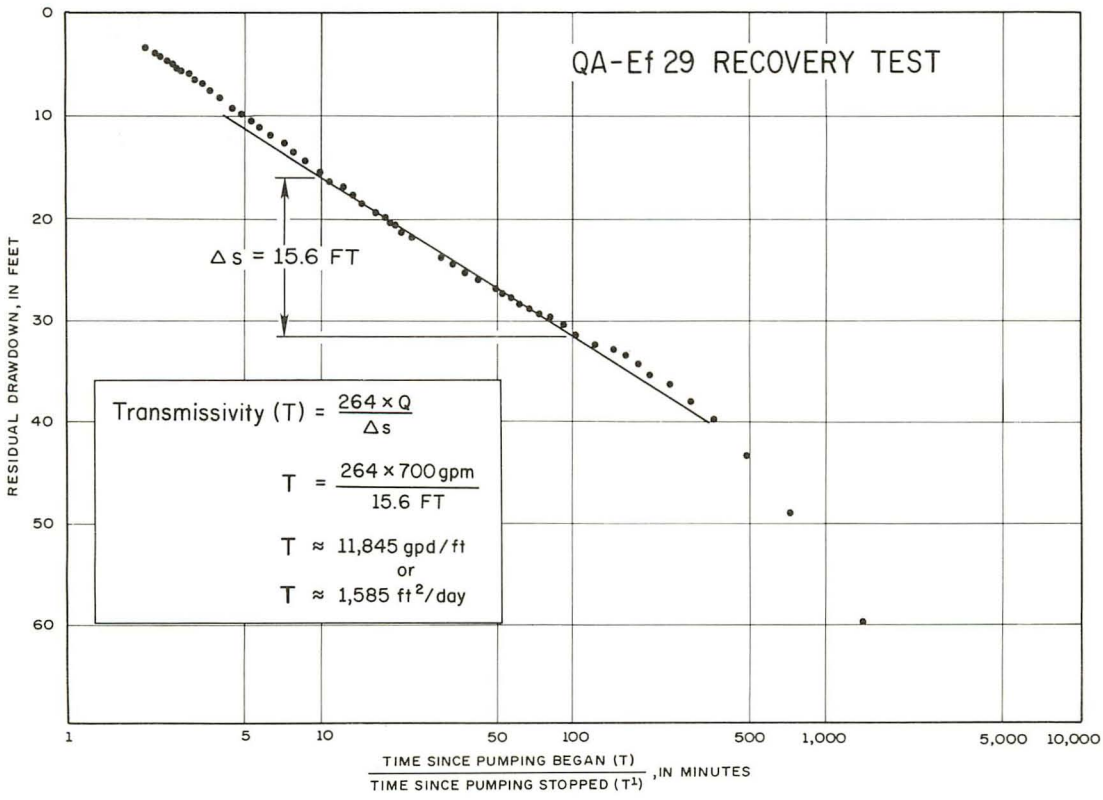


Figure 3. Graphs showing drawdown data, recovery data, and transmissivity calculations for pumping tests of the Magothy-upper Patapsco aquifers.

ity of 1,585 ft^2/day. At the end of the 24-hour recovery test the water level in the well recovered to within 3.4 ft of the original static water level.

The storage coefficient was estimated by using barometric efficiency in a relationship described by Jacob (1940) (cited in Lohman, 1972, p. 9):

$$S = \theta \gamma b \beta \times \frac{1}{BE} \qquad (1)$$

where

S = storage coefficient;

θ = porosity, as a decimal fraction;

γ = specific weight per unit area, 0.434 lb $in.^{-2}$ ft^{-1};

b = thickness, in ft;

β = reciprocal of the bulk modulus of elasticity of water, 3.3×10^{-6} $in.^2$ lb^{-1}, at ordinary temperatures; and

BE = barometric efficiency of artesian well.

Barometric efficiency (BE) is the ratio of water-level change to atmospheric pressure change. A value of 39 percent was calculated from data obtained from observation well QA-Ef 29 and a barometer located in Annapolis, Maryland (fig. 4). Aquifer porosity was assumed to be 35 percent, a reasonable value for a medium to coarse-grained sand. Total thickness of the aquifers equals 160 ft. The storage coefficient based on these assumptions is computed below.

$$S = \frac{(0.35)\ (0.434)\ (160)\ (3.3 \times 10^{-6})}{(0.39)}$$

$$S = 2.1 \times 10^{-4} = 0.00021$$

where

$\theta = 0.35$;

$\gamma = 0.434$ lb $in.^{-2}$ ft^{-1};

$b = 160$ ft;

$\beta = 3.3 \times 10^{-6}$ $in.^2$ lb^{-1}; and

BE = 0.39.

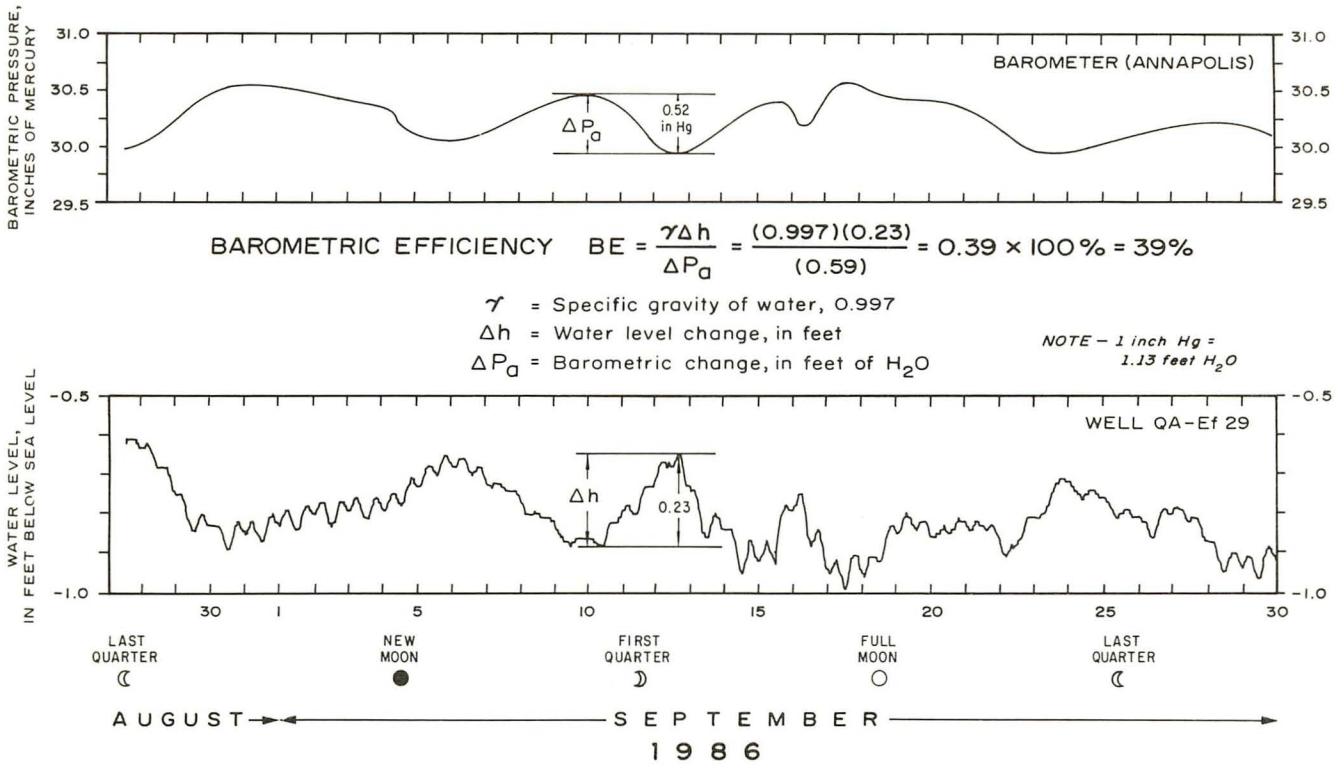


Figure 4. Graphs showing water-level fluctuations in QA-Ef 29, barometric pressure changes in Annapolis, and calculations used to estimate barometric efficiency.

The ratio of actual drawdown after 24 hours of pumping (164.5 ft) to the theoretical drawdown (114.5 ft), resulted in a well efficiency of 69.6 percent. The relationship shown in equation 2 (Ferris and others, 1962, p. 92) was used to estimate the theoretical drawdown:

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S} \qquad (2)$$

where

Q = discharge (700 gpm);

s = drawdown (114.5 ft);

T = transmissivity (11,845 gal/day/ft);

t = time (1 day);

r = effective well radius (0.875 ft); and

S = storage coefficient (0.00021).

Water Levels

The static water level measured in QA-Ef 29 prior to the start of the pump test was 0.81 ft below sea level. Because there are no wells pumping from the Magothy or upper Patapsco aquifers in the vicinity of the test site, this level represents an initial (or prepumping) head condition. The closest major pumpage from the upper Patapsco aquifer occurs approximately 25 miles to the south at Cambridge and 30 miles to the west in Anne Arundel County at the U.S. Naval Academy (Annapolis). The closest significant withdrawals from the Magothy aquifer occur in Easton about 15 miles to the south. Except near pumping centers water levels in the upper Patapsco increase up-dip, toward the west. At Kent Island (QA-Eb 111), for example, the water level measured in the spring of 1986 was 4.06 ft above sea level, while further to the west at Sandy Point (AA-Cg 24), which is closer to the Annapolis and Arnold pumping centers, the water level was -4.94 ft below sea level.

A hydrograph record from August 27 to September 30, 1986 shows the effects of tidal fluctuations and barometric changes on the water level in QA-Ef 29. Water levels recorded during this period vary between about -1.0 ft and -0.6 ft below sea level. Two sets of cyclical fluctuations were seen on the hydrograph. A set of irregular, larger amplitude fluctuations correlate inversely with changes in barometric pressure and are attributed to that factor. Another set of sinusoidal fluctuations are semidiurnal and have amplitudes of less than 0.05 ft. These fluctuations are probably the result of either ocean or earth tides[7] (Todd, 1959, p. 163-169). As Davis and DeWiest (1966, p. 61) point out water-level fluctuations due to earth tides

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[7]Earth tides result from the attraction exerted on the earth's crust by the moon and, to a lesser extent, the sun.

are "generally less than 0.1 ft amplitude" and "show two minima each day which correspond to the moon's upper and lower culminations. The minima are produced by maximum tidal attraction which allows a slight dilation of the aquifer", reducing pressure and causing water levels in wells to decline. Citing Robinson (1939), Todd (1959) has pointed out that regular fluctuations coincide with periods of new and full moon, whereas smaller, irregular fluctuations coincide with periods of first and last quarters of the moon. The small, cyclical fluctuations displayed in the QA-Ef 29 hydrograph tend toward this generalization (fig. 4), but a rigorous evaluation using a synthetic hydrograph corrected for barometric fluctuations was not attempted.

Water Quality

Chemical Analyses and Hydrochemical Facies

Water samples collected 6 hours into the June 27, 1986 pump test of well QA-Ef 29 were analyzed by the Water Resources Division of the U.S. Geological Survey (tab. 2). The water pumped from the Magothy and upper Patapsco aquifers is slightly acidic (pH = 6.18); relatively warm (77°F or 25.1°C); low in chloride (2 mg/L), nitrate (<0.1 mg/L), and sulfate (18 mg/L); soft (12 mg/L); and relatively low in iron (0.547 mg/L) and dissolved solids (124 mg/L). The water at well head contains no dissolved oxygen. Potentially toxic inorganic constituents were either below the detection level (e.g., arsenic, chromium, lead, selenium, tin) or present in only trace concentrations (e.g., aluminum, copper, mercury, zinc). The water was not tested for organic chemicals, such as pesticides or solvents, because the deep aquifers at this site are isolated from potential surface sources of contamination by multiple confining beds.

Although the water is generally of good quality, it will require some treatment in order to meet criteria suggested for the proposed hatchery operation (James R. Holley and Associates, 1983, tab. 1): pH (6.9 to 9.0), hardness (50 to 400 ppm), iron (<0.5 ppm), and dissolved oxygen (80 percent of saturation). The water must be aerated to provide dissolved oxygen. It is possible that aeration may also increase pH due to CO_2 degassing and decrease iron concentrations by ferric hydroxide precipitation. The increase in pH from 6.2 measured in the field to 7.7 measured in the laboratory is probably caused by CO_2 degassing (F. H. Chapelle, written comm.).

Back (1966, p. A1) introduced the term "hydrochemical facies" to denote "the diagnostic chemical character of ground-water solutions occurring in hydrologic systems" (or aquifers). The composition and distribution of hydrochemical facies are a function of the chemical composition of water entering the system, the mineral composition of the lithologic framework, solution kinetics, and regional flow patterns (Fetter, 1980, p. 337-338). Hydrochemical facies are categorized by dominant anions and cations and can be best displayed on a trilinear diagram (fig. 5). The water chemistry of an areally extensive aquifer changes in a generally predictable way along flow paths that extend from outcrop to the deeper subsurface (Back, 1966). For example, ground water from the Magothy and upper Patapsco aquifers changes downgradient from an iron-rich calcium/magnesium sulfate/chloride type at Sandy Point and Kent Island to a sodium bicarbonate type at the Tuckahoe State

Table 2. Chemical analysis of water from the Magothy and upper Patapsco aquifers screened in QA-Ef 29

WELL: QA-Ef 29

ALTITUDE: 62 feet

DEPTH OF WELL SCREENS: (below land surface)
1,110 ft - 1,120 ft
1,135 ft - 1,180 ft
1,195 ft - 1,210 ft
1,230 ft - 1,270 ft
1,285 ft - 1,315 ft

LOCATION: Tuckahoe State Park

AQUIFERS: Magothy aquifer and upper Patapsco aquifer

DATE COLLECTED: June 27, 1986

LABORATORY: U. S. Geological Survey (WRD)
Central Lab (Denver)

Name	Value	Units
Alkalinity, total (field) as $CaCO_3$	79	mg/L
Alkalinity, total (lab) as $CaCO_3$	79	mg/L
Aluminum	10	µg/L
Antimony	<1	µg/L
Arsenic	<1	µg/L
Barium	52	µg/L
Beryllium	<0.5	µg/L
Bromide	0.020	mg/L
Cadmium	<1	µg/L
Calcium	3.2	mg/L
Carbon dioxide	97	mg/L
Carbon, total	2.3	mg/L
Chloride	2.0	mg/L
Chromium	<1	µg/L
Cobalt	<1	µg/L
Copper	6	µg/L
Fluoride	0.2	mg/L
Hardness	12	mg/L
Hardness, noncarbonate	0	mg/L
Iodide	0.002	mg/L
Iron (field)*	120	µg/L
Iron (lab)	547	µg/L
Lead	<5	µg/L
Magnesium	1.0	mg/L

Name	Value	Units
Manganese	21	µg/L
Mercury	0.5	µg/L
Molybdenum	<1	µg/L
Nickel	8	µg/L
Nitrogen, NO_2 + NO_3, as N	<0.10	mg/L
Oxygen (field)	0	mg/L
pH (field)	6.2	units
pH (lab)	7.7	units
Phosphorus, ortho (PO_4) as P	0.27	mg/L
Potassium	5.0	mg/L
Residue, dissolved (calculated sum)	124	mg/L
Selenium	<1	µg/L
Silica	11	mg/L
Silver	<1	µg/L
Sodium, absorption ratio	4.5	
Sodium, dissolved	36	mg/L
Sodium, percent	81	%
Specific conductance (field)	197	µmhos
Specific conductance (lab)	198	µmhos
Strontium	140	µg/L
Sulfate	18	mg/L
Water temperature (field)	25.1	deg. C
Zinc	10	µg/L

IONIC BALANCE

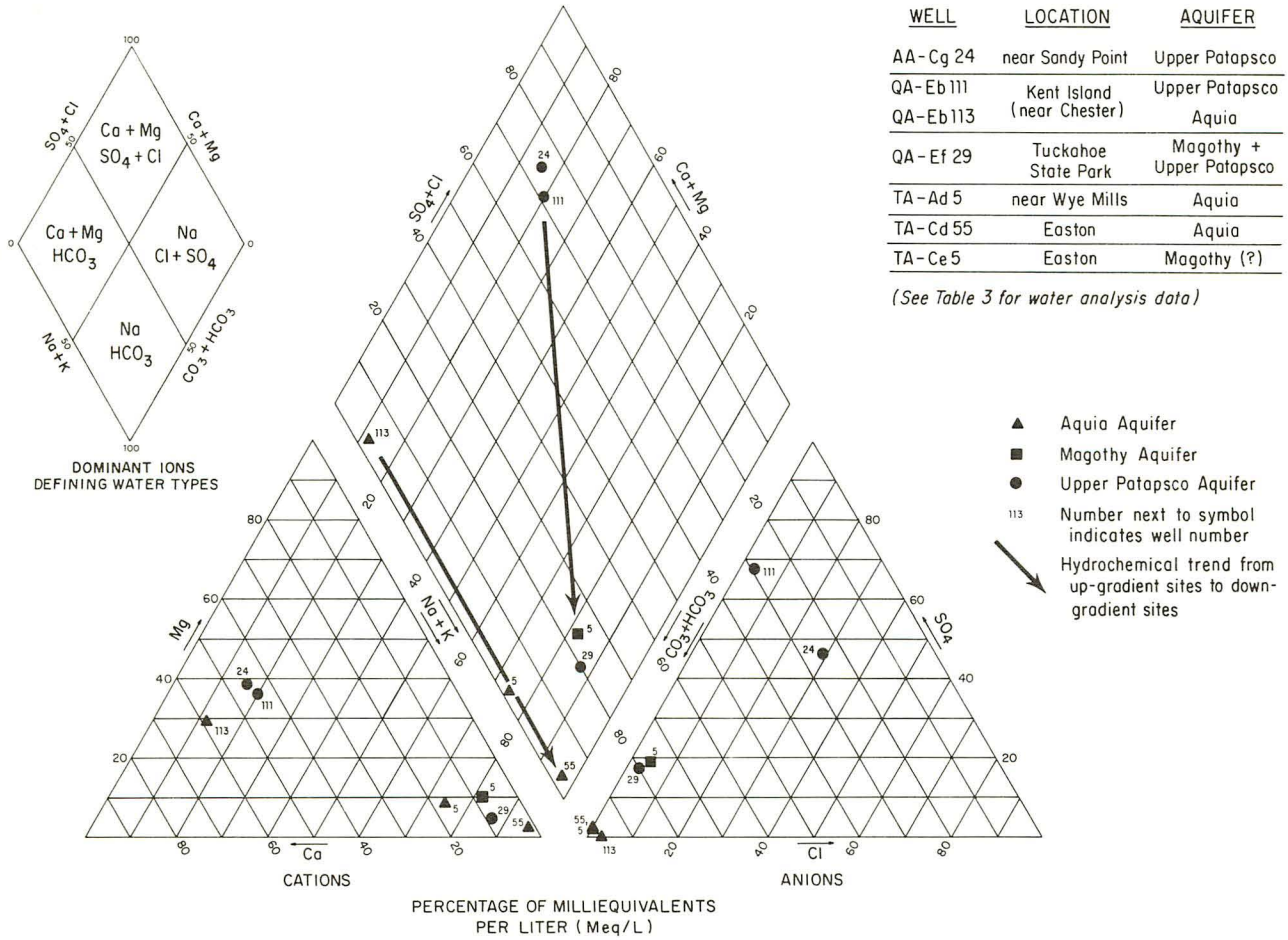
Cations	(mg/L)	(meq/L)
Calcium, dissolved	3.2	.159
Magnesium, dissolved	1.0	.082
Potassium, dissolved	5.0	.127
Sodium, dissolved	36	1.565
Total		1.935

Anions	(mg/L)	(meq/L)
Alkalinity, total (lab) as $CaCO_3$	79	1.578
Chloride, dissolved	2.0	.056
Fluoride, dissolved	0.2	.010
Sulfate, turbidity, dissolved	18	.374
Total		2.020

Percent Difference = -2.13

< constituent is below detection limit
mg/L milligrams per liter
µg/L micrograms per liter
meq/L milliequivalents per liter

*Water sample obtained during air-lift development of well



WELL	LOCATION	AQUIFER
AA-Cg 24	near Sandy Point	Upper Patapsco
QA-Eb 111	Kent Island (near Chester)	Upper Patapsco
QA-Eb 113		Aquia
QA-Ef 29	Tuckahoe State Park	Magothy + Upper Patapsco
TA-Ad 5	near Wye Mills	Aquia
TA-Cd 55	Easton	Aquia
TA-Ce 5	Easton	Magothy (?)

(See Table 3 for water analysis data)

Figure 5. Trilinear diagram comparing water from QA-Ef 29 with water from other Patapsco, Magothy, and Aquia wells.

Park site (tab. 3; fig. 5). Sodium concentrations increase downgradient as a result of cation-exchange processes with clayey minerals in the aquifer framework; bicarbonate enrichment may occur as a result of dissolution reactions involving either shell material (Chapelle and Knobel, 1985) or silicate minerals, chiefly feldspars and micas (Denver, 1986). The downgradient decrease of dissolved iron associated with the sodium bicarbonate hydrochemical facies is a commonly observed trend in Coastal Plain aquifers. For example, concentrations of dissolved iron, which are as high as 26 mg/L at Sandy Point in Anne Arundel County, have decreased to 0.5 mg/L at well QA-Ef 29 (tab. 3). The mineral pyrite (FeS_2), observed in the core samples, is a possible sink for the iron (Denver, 1986, p. 76). Hem (1985, fig. 14) suggests that the stable form of iron in water similar to the QA-Ef 29 sample (acidic pH, zero dissolved oxygen, sulfur species present) is pyrite.

The comparatively low concentration (124 mg/L) of total dissolved solids in the Magothy and upper Patapsco aquifers sampled in QA-Ef 29 is due to the relatively inert nature of the quartz (SiO_2) sands that dominate the mineral framework of the aquifer. In contrast the Aquia aquifer, which downgradient is also of a sodium bicarbonate type (fig. 5), has appreciably greater total dissolved solids, for example, 517 mg/L at Easton (tab. 3). This reflects the relatively more reactive nature of its mineral framework, particularly shell material (a source of calcium and bicarbonate) and glauconite, which acts as an efficient sodium exchange medium (Chapelle and Drummond, 1983, p. 78).

A useful relationship for estimating the total dissolved solids in ground water is:

$$F = \frac{Ro}{Rw} \qquad (3)$$

where Rw is the resistivity of the water at 77°F, Ro is the resistivity of the water-saturated aquifer at 77°F, and F is the "formation factor" (Keys and MacCary, 1971, p. 41). Ro can be estimated using a deep penetration resistivity log, such as the 64-in. normal log run in QA-Ef 29. Rw* is easily derived provided that the specific conductance of the aquifer water is known. Assuming that the resistivity of the composite water sample collected during the pumping test of QA-Ef 29 is representative of the water in each of the screened aquifers (Rw), the following formation factors (F) can be calculated for two relatively clay-free, unconsolidated sands and one partially cemented, "crusty" sand:

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$$Rw, \text{ in ohm-m (at 77°F)} = \frac{10{,}000}{\text{specific conductance, in } \mu\text{mhos/cm (at 77°F)}}$$

Total Dissolved Solids ≈ 0.6 to 0.75 x specific conductance

Table 3. Water-analysis data for selected wells in Anne Arundel County, Queen Anne's County, and Talbot County

Well Number	Location	Date sample collected	Screen depth, ft.	Cations: Calcium mg/L	Calcium meq/L	Magnesium mg/L	Magnesium meq/L	Potassium mg/L	Potassium meq/L	Sodium mg/L	Sodium meq/L	Anions: Alkalinity (as $CaCO_3$) mg/L	Alkalinity meq/L	Chloride mg/L	Chloride meq/L	Sulfate mg/L	Sulfate meq/L	pH	Dis-solved iron mg/L	Total dis-solved solids mg/L	Specific conductance umhos	Source of data
AQUIA AQUIFER																						
QA-Eb 113	Chester	01/15/80	176-216	43	2.145	13	1.069	5.6	0.143	6.5	0.283	180	3.59	2.5	0.071	0.0	0.0	7.5	0.63	194	345	Mack (1983)
TA-Ad 5	near Wye Mills	09/22/65	429-444	13	0.649	3.8	0.313	9.8	0.251	56	2.436	175	3.491	1.1	0.031	2.4	0.050	7.7	0.1	212	332	Woll (1978)
TA-Cd 55	Easton	12/09/86	575-669	2.6	0.130	2.2	0.181	7.1	0.182	200	8.700	455	9.091	3	0.085	12	0.250	8.4	0.02	517	867	File data
UPPER PATAPSCO AQUIFER																						
AA-Cg 24	near Sandy Point	09/13/78	605-615 648-658	6.0	0.30	3.2	0.26	2.0	0.051	1.3	0.057	9	0.18	7.6	0.21	16.0	0.33	6.0	26	98	140	U.S. Geological Survey (1978)
QA-Ef 29*	Tuckahoe Hatchery site	06/27/86	5 screens 1,110-1,315	3.2	0.16	1.0	0.082	5.0	0.13	36	1.5	79	1.6	2	0.056	18.0	0.37	6.18	0.547	124	198	This report
QA-Eb 111	Chester	02/06/80	955-965 1,030-1,040	7.2	0.36	3.5	0.29	3.1	0.079	1.9	0.08	12	0.24	0.9	0.025	27.0	0.56	6.5	14	75	96	Mack (1983)
MAGOTHY AQUIFER																						
TA-Ce 5	Easton	03/11/49	1,126-1,147	2.4	0.12	2.0	0.164	2.2	0.056	30	1.305	66	1.311	2.5	0.071	15	0.312	7.5	0.38	111	168	Mack, Webb, and Gardner (1971)

*also screened in the Magothy aquifer.

Depth, ft.	Lithology	Ro, ohm-m	Rw, ohm-m	F
1,145-1,150	"clean", uncemented sand	65	50.5	1.3
1,245-1,270	"clean", uncemented sand	95	50.5	1.9
1,285-1,310	partially cemented, "crusty" sand	200	50.5	4.0

As demonstrated above, formation factor can vary appreciably within a hydrostratigraphic unit[9]. Therefore care should be exercised in using the relationship Rw = Ro/F to estimate total dissolved solids. Because the sands logged in QA-Ef 29 between 1,595 ft and 1,710 ft are lithologically similar to the sands analyzed above, their formation factors may also range between 1.3 and 4.0. Below Rw is estimated for a relatively clay-free, unconsolidated sand:

Depth, ft.	F	Ro, ohm-m	Rw, ohm-m	Estimated Total Dissolved Solids (mg/L)
1,610-1,620	2.0	85	42.5	140 to 175

Although the above exercise is clearly only an estimate, it does demonstrate that the deepest sands penetrated in QA-Ef 29 contain fresh water, probably of the sodium bicarbonate type. Based on regional considerations, salty water, if present beneath the Tuckahoe State Park site, is probably restricted to the basal 400 ft of the Coastal Plain (Lloyd, Larson, and Davis, 1985)(pl. 1).

Temperature and Geothermal Gradient

During the pumping test of well QA-Ef 29 the water temperature of samples collected from a tap near the pump head was periodically measured. After 6 hours the water temperature at the well head had stabilized at 25.1°C (77°F). This temperature is an "average" value that results from the mixing of ground water in unknown proportions from the five well screens interset between 1,110 ft and 1,315 ft.

A continuously recorded temperature log was run in the well to measure the local geothermal gradient (fig. 6). Even though the log was run 58 days after cementing the annulus and 41 days after completion of the pumping test thermal equilibrium had not been fully achieved. As noted by Keys and MacCary (1971, p. 106), "Drilling, cementing, and testing disturbs the thermal environment of a borehole and considerable time (up to several years) may be necessary for equilibrium to be attained". Evidence of thermal nonequilibrium in QA-Ef 29 is the small (less than 1.5°F), positive temperature anomaly between about 510 ft and 540 ft. This broadly coincides with a wash-out zone recorded on the caliper log (fig. 6) of the 9 7/8-in. pilot hole between 508

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[9] As a general rule-of-thumb, F increases as porosity (ϕ) decreases ($F = 1/\phi^m$) (Lynch, 1962, p. 201).

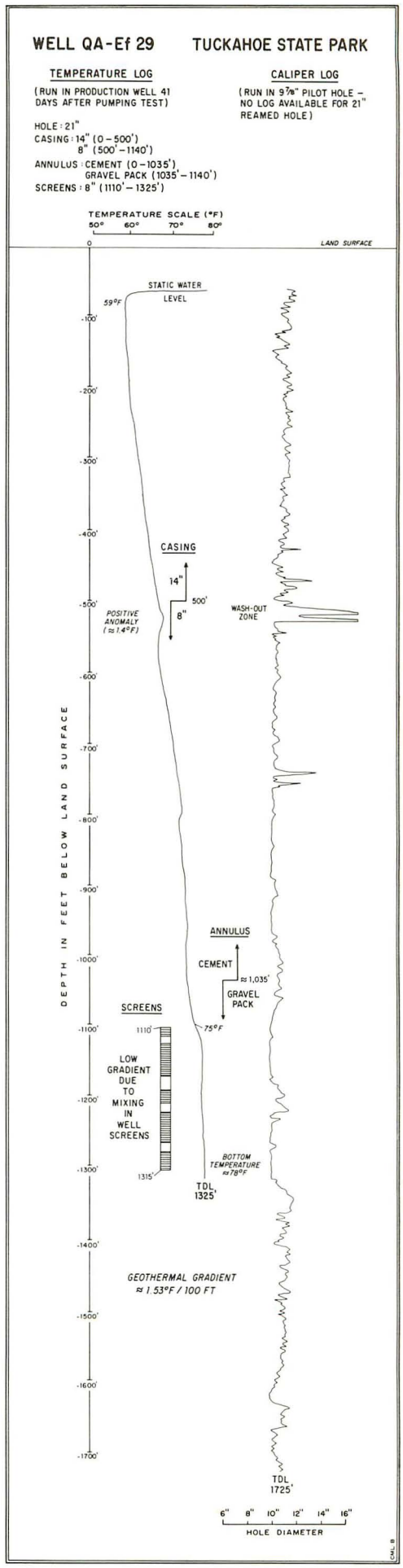

Figure 6. Temperature and caliper logs recorded in QA-Ef 29.

ft and 526 ft (fig. 6) (a caliper log was not run in the 21-in. reamed hole). It is probable that the annular cement surrounding the 8-in. casing in the vicinity of the wash-out zone is thicker than elsewhere in the borehole. This would cause a positive temperature anomaly because setting cement generates a substantial amount of heat that can raise the temperature of adjacent fluids (Folmar, 1959, p. 134). Moltz and Kurt (1979, fig. 4) have calculated that at the casing-grout interface 8 in. of grout can generate a peak temperature increase exceeding 70°F above the normal geothermal temperature. The rate at which this heat is dissipated is dependent on the thermal characteristics of the water-casing-grout-formation system. Apparently sufficient residual heat remained near the grout-filled wash-out zone to produce the anomaly observed in figure 6. On the other hand, the grout-gravel pack interface reported to be at a depth of 1,035 ft is not observable on the temperature log, which shows a normal geothermal gradient through this interval.

The geothermal gradient is interrupted near the base of the upper well screen (1,120 ft) where there is a noticeable change of slope. Opposite the four lower well screens (1,135 ft - 1,315 ft) the log records little rise of temperature with increasing depth suggesting an exchange of water between the lower and upper screens (Mack, Webb, and Gardner, 1971, p. 43). Apparently slightly warmer water is moving upward through this interval, which would indicate that the lower sands open to the well have somewhat higher pressure heads than the upper sands.

The average geothermal gradient in well QA-Ef 29 is about 1.53°F/100 ft, which is within the range normally encountered in deeper Coastal Plain wells (Nathenson and others, 1983, fig. 5). For example, a 2,461 ft well (QA-Eb 110) drilled near Chester on Kent Island has an average gradient of about 1.4°F/100 ft (Mack, 1983), while a well drilled at Cambridge (DO-Ce 88) logged a gradient of 1.51°F/100 ft between 1,002 ft and 3,030 ft (Trapp and others, 1984, p. 17).

CONCLUSIONS

A 1,725-ft deep test boring was drilled at a site in Tuckahoe State Park, southeastern Queen Anne's County, to determine whether the deep Magothy and upper Patapsco aquifers could yield sufficient water (1.0 to 1.5 MGD peak demand) of suitable quality to support the operation of a striped bass hatchery. The test boring demonstrated that the Magothy aquifer was relatively thin at the site, but that several upper Patapsco aquifers were also available for a multiple-screen well completion. As a result, 140 ft of 8-in. diameter screen, divided into five sections, were interset with lengths of blank casing between 1,110 ft and 1,315 ft. The upper two screens (1,110 to 1,120 ft and 1,315 to 1,180 ft) are believed to be in the Magothy aquifer; while the bottom three screens (1,195 to 1,210 ft; 1,230 to 1,270 ft; and 1,285 to 1,315 ft) have been set opposite several upper Patapsco sands.

A 24-hour aquifer test was conducted with a constant pumping rate of about 700 gallons per minute (≈1 million gallons per day). By the end of the test, water levels had drawndown 164.5 ft from an initial static level of 62.5 ft below land surface. The well had a 24-hour specific capacity of 4.3 gallons per minute per foot of drawdown. Analysis of residual drawdown data collected during a 24-hour recovery test suggested a transmissivity of about 1,585 ft^2/day (11,845 gpd/ft), which represents the sum of the five screened sands. A storage coefficient of 0.00021 was calculated using the barometric efficiency (39 percent) of the aquifer.

The water is generally of good quality, but will require some treatment for optimum use in the hatchery. The water must be aerated to provide dissolved oxygen and probably will require treatment to raise pH, decrease dissolved iron concentrations, and increase hardness. The water is soft, with a hardness of 12 mg/L. Chloride (2 mg/L), sulfate (18 mg/L), and total dissolved solids (124 mg/L), occurring chiefly as sodium bicarbonate, are relatively low. The water is slightly acidic (field pH = 6.2) with a dissolved iron concentration of 0.55 mg/L. Potentially toxic constituents were either below the level of detection (e.g., arsenic, chromium, lead, selenium, tin) or present in only trace concentrations (e.g., aluminum, copper, mercury). The temperature of the water at the well head is 77°F (25.1°C).

Potentially productive sands were logged below 1,600 ft in test well QA-Ef 29. These sands have relatively high electric log resistivities, suggesting that they contain fresh water, probably of a sodium bicarbonate type. Assuming a local geothermal gradient of about 1.53°F/100 ft, water temperatures in the 82°F (27.8°C) to 84°F (28.9°C) range may be expected.

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APPENDIXES

Appendix A

Driller's log

Well QA-Ef 29

Description of drill cuttings	Thickness (ft)	Depth (ft) to base
Top soil	1	1
Clay, yellow-gray	13	14
Sand and coarse gravel (up to 1"), with some clay	11	25
Clay, orange	5	30
Clay, gray	15	45
Clay, dark gray, dry	5	50
Clay, brown, with trace mica	20	70
Shells and sand, with some gray clay	6	76
Shells and sand, with some grayish brown clay	34	110
Clay, brown	10	120
Shells and sand, with some gray clay	20	140
Clay, gray, with some silty sand and shells	60	200
Clay, gray, with some silty sand	50	250
Clay, brown-gray, dry	20	270
Sand and shells, with some gray clay	30	300
Clay, green, with black sand	10	310
Sand and gravel, with green clay	5	315
Sand, black, with some green clay	5	320
Clay, green, with fine sand	10	330
Gravel and black sand	45	375
Sand, black	20	395
Clay, grayish green, with silty sand	25	420
Clay, grayish green, with fine sand	80	500
Clay, grayish green	65	565
Sand, blackish brown, with gray clay streaks	25	590
Sand and gravel, black and brown, with gray clay streaks	30	620
Rock, with streaks of clay	50	670
Shells and gray clay	30	700
No description	10	710
Clay, green and shell rock	80	790
Sand, dark grayish blue and gray, with streaks of gravel	10	800
Clay, brown, with dark gray clay flaking from "up-hole"	28	828
Sand, brown	42	870
Clay, brown, sandy	20	890
Clay, gray, sandy	10	900
Clay, light gray	20	920
Clay, dark gray, with black sand	19	939
Shell rock	2	941
Clay, gray, with fine black sand and shells	9	950
Clay, dark gray, with fine sand	35	985
Clay, dark gray, with fine black sand	40	1,025
Clay, dark, with black sand	28	1,053
Shell rock	2	1,055
Clay, soft, gray, with black sand	25	1,080
Shell rock	2	1,082
Clay, dark gray, with black sand	26	1,108
Shell rock, with streaks of hard sand	2	1,110
Clay, sandy, dark gray, with black sand	15	1,125
Sand, fine, dark gray, with trace of clay	13	1,138
Shell rock, hard	2	1,140
Clay, sandy, gray, with black sand	10	1,150
Sand, black and gray, with gray clay	30	1,180
Clay, dark gray	32	1,212
Shell rock	1	1,213
Clay, light gray	7	1,220
Sand and light gray clay	8	1,228
Rock	2	1,230
Shell rock, with fine gray sand	7	1,237
Sand, gray, fine, with clay streaks	20	1,257
Hard sand streaks	2	1,259
Sand, hard, with gray clay streaks	16	1,275
Sand, gray, fine, with trace of gray clay	25	1,300
Rock	2	1,302
Sand, very hard	8	1,310
Clay, gray	5	1,315
Rock and sand, soft	3	1,318
Clay, gray, with soft sand-rock and pyrite	14	1,332
Clay, red and gray	12	1,344
Clay, reddish gray	11	1,355
Sand, with white sandy clay and some red clay	3	1,358
Clay, sandy, white, with some red clay	13	1,371
Shell rock, sandy, with clay streaks	4	1,375

Appendix A - Driller's log - Continued

Description of drill cuttings	Thickness (ft)	Depth (ft) to base
Clay, sandy, gray, streaked with tough clay	15	1,390
Sand	5	1,395
Clay, tough, pink, gray, red and white	20	1,415
Clay, tough, red	15	1,430
Clay, red	47	1,477
Shell rock	1	1,478
Clay, red	12	1,490
Clay, tough, red	35	1,525
Clay, reddish-yellow	5	1,530
Clay, red	55	1,585
Clay, mixed color, with trace of fine sand, sandstone and wood	33	1,618
Clay, tough, mixed colors	12	1,630
Clay, gray and red	10	1,640
Clay, red	15	1,655
Clay, sandy, light gray, with streaks of sand-rock	35	1,690
Clay, mixed colors	5	1,695
Clay, sandy, mixed colors	5	1,700
Clay, red	15	1,715
Rock, soft, yellowish-brown, with mixed color clay	10	1,725

Appendix B

Lithologic descriptions of cores

Well QA-Ef 29

DATUM: LAND SURFACE
LSD: APPROXIMATELY 62.2 FEET

CORE DEPTH (FEET)	VISUAL DESCRIPTION	RECOVERY (INCHES)
750	Sand, glauconitic and quartzose, dark grayish-green, very fine-grained to silty in a dense clayey matrix with trace shell fragments; effervesced in dilute hydrochloric acid (HCL).	5
800	Sand, silty, quartzose, olive-gray, fine to medium-grained; "clean"; with very fine-grained goethite* pellets and glauconite; trace shell fragments; matrix effervesced in HCL.	6
825	Sand, quartzose, yellowish-brown, fine to medium-grained; iron-stained; well sorted, with shell fragments and trace amounts of goethite and botryoidal, olive to dark green glauconite; matrix effervesced in HCL.	6.5
900	Clay, silty; grayish-white; with trace of very fine, quartz sand and blackish carbonaceous(?) grains.	6
925	Sand, very fine to fine-grained, with black to dark green glauconite and clear quartz; light gray, clayey matrix; matrix effervesced in HCL.	7
975	Clay, black; carbonaceous, micaceous (muscovite); irregular partings of yellowish-gray silt; effervesced mildly in HCL.	9
1,075	Silt, clayey to very fine-grained sand; micaceous (muscovite); dark greenish-black; moderately glauconitic; trace of carbonaceous matter; effervesced mildly in HCL.	5
1,125	Sand, quartzose, fine-grained; "clean" and well sorted; light to medium gray; moderately micaceous (muscovite).	6
1,150	Sand, quartzose, "clean", fine to medium-grained, well sorted, dark gray; with trace of lignite, and mica (muscovite).	4
1,225	Sand, quartzose, "clean"; very fine-grained, light grayish-white; trace pyrite; interlaminated with thin, black, carbonaceous clay.	4
1,250	Sand, quartzose, "clean", medium to coarse-grained; well sorted; light gray to white.	4
1,300	Sand, very fine to fine-grained; quartzose; "clean", light gray; weathered pyrite nodule (1 in. diameter) at top of core.	4
1,375	Clay, silty and very fine to fine-grained sand; light gray; slightly micaceous.	4
1,685	Sand with very clayey matrix; quartzose, fine to medium-grained; poorly sorted; several irregularly shaped sideritic(?) granules noted; light brownish-gray weathered to reddish-brown; iron-stained.	7

*$Fe_2O_3 \cdot H_2O$ may occur as goethite (crystalline) or limonite (amorphous). Herein the pelletal form is called "goethite" and the earthy form "limonite", but crystallinity was not determined.

Appendix C

Reconstructed geologic log

Well QA-Ef 29

Lithology	Thickness (ft)	Depth to base (ft)
COLUMBIA GROUP (undivided)		
Top soil	3	3
Clay, tough, light gray and orange, interstratified with well rounded, medium to coarse-grained clear quartz sand	7	10
Gravel (up to 4 cm) and medium to very coarse-grained quartz sand, iron-stained, well rounded, poorly sorted, orangish-tan; trace amounts of white feldspar and minor amounts of clay	10	20
COLUMBIA(?) GROUP and CHESAPEAKE GROUP (undifferentiated)		
Clay, tough, orange, with thin laminates of white silt	7	27
Clay, tough, orange and light gray	4	31
Clay, silty, with some very fine-grained brown quartz sand and minor amounts of coarse-grained clear quartz sand, and micaceous silt	10	41
CHESAPEAKE GROUP		
CHOPTANK(?) FORMATION and CALVERT FORMATION (undifferentiated)		
Clay, silty, grayish-brown, with trace amounts of mica	10	51
Sand, silty, micaceous	10	61
Sand, very silty and clayey, slightly micaceous, dark gray; gamma log indicates more clay than is present in sample	10	71
Shell layer, large well preserved fragments, with minor amounts of fine-grained quartz sand and dark grayish silt	5	76
Clay, silty, calcareous, light gray, slightly micaceous (muscovite); abundant large weathered shell fragments	9	85
Shell layer, composed of large, well preserved shell fragments (up to 2.5 cm) and coarse quartz sand, in a silty calcareous matrix; some shell fragments possess a thin glauconitic coating	10	95
Shell layer, composed of partially weathered coarse shell fragments, some coarse to very coarse-grained quartz sand and small gravel	5	100
Clay, silty, earthy, brown, hard, dry, and slightly micaceous; numerous disc-shaped diatom tests	10	110
Clay, silty, gray, with some very fine-grained clear quartz sand; shell fragments	10	120
Shell layer, large fragments (up to 2 cm) with calcareous cemented fine-grained sandstone	10	130
Clay, silty, green, with abundant shell fragments and trace amounts of mica (muscovite)	10	140
Sand, quartzose, very fine-grained, light gray; interstratified thin shell layers partially cemented by calcite	5	145
Clay, silty, light green, with small amounts of chalky, white, calcareous matter	5	150
Sand, quartzose, light gray, in a silty calcareous matrix; some shell and trace amounts of very fine-grained black quartz sand	10	160
Sand, very clayey, dark green, with minor amounts of very finely divided calcareous granules and shell fragments	10	170
Clay, sandy, light grayish-green, with minor amounts of shell; shell layer at base of interval is composed of large weathered fragments in a sandy clay matrix	10	180
Clay, silty, dark brown, slightly micaceous; shell fragments make up the majority of strata from 187 ft; some shell exteriors bear a thin, bright green rind (possibly glauconite); sand content increases and coarsens toward base of interval	10	190
Silt, brown, with sparse amounts of mica (muscovite), shell fragments, and trace lignite; numerous diatom tests	10	200
Clay, silty, light gray, with very fine-grained quartz sand; shell fragments	15	215
Sand, quartzose, very fine-grained, well sorted, with shell fragments and glauconite	15	230
Clay, silty, glauconitic, light grayish-green, with trace shell	10	240
Clay, silty, dark grayish-green, with dark green glauconite, silt size quartz and mica (muscovite)	10	250
Clay, silty, grayish-brown, with trace amounts of mica	10	260
Clay, silty, grayish-green, with trace amounts of mica	10	270
Clay, silty, dark grayish-green, with very fine-grained quartz sand and minor amounts of shell fragments	10	280
PAMUNKEY GROUP		
PINEY POINT FORMATION		
Shell layer, composed of large weathered fragments, in a silty to medium-grained, light gray quartz sand matrix	10	290
Sand, quartzose, with medium-grained, botryoidal glauconite (partially altered to limonite) loosely cemented in a calcareous matrix; some shell fragments	10	300
Sand and small gravel, medium to coarse-grained, iron-stained; fine-grained botryoidal glauconite (altered to limonite) abundant; shell fragments	10	310
Sand, composed evenly of fine-grained olive green and brown glauconite (partially oxidized), fine to very coarse-grained iron-stained quartz sand and well rounded quartz pebbles (up to 7 mm); goethite[1] pellets and an abundance of moderately weathered shell fragments	10	320
Clay, silty, dark grayish-green, with moderate amounts of fine, iron-stained quartz and black glauconitic sand; limonite nodules, and some coarse, well rounded quartz grains; shell fragments (possibly from "up-hole")	10	330

[1] $Fe_2O_3 \cdot H_2O$ may occur as goethite (crystalline) or limonite (amorphous). Herein the pelletal form is usually called "goethite" and the earthy form "limonite", but actual crystallinity was not determined.

Appendix C - Reconstructed geologic log - Continued

Lithology	Thickness (ft)	Depth to base (ft)
PAMUNKEY GROUP - Continued		
PINEY POINT FORMATION - Continued		
Sand, clayey, composed of medium to coarse-grained, iron-stained quartz, and fine to medium-grained glauconite (altered to limonite); sand grades downward to a light green clay with very fine glauconite	10	340
Sand, predominantly glauconitic; medium to very coarse-grained, iron-stained quartz; some gravel (up to 1 cm); poorly sorted; geophysical log suggests a more clayey or silty bed in upper portion of interval down to 346 ft	10	350
Sand, quartzose, brown, iron-stained, with medium to coarse-grained glauconite (altered to limonite), and goethite pellets; poorly sorted	10	360
Sand, glauconitic, brown, fine-grained, with some botryoidal glauconite, goethite pellets (up to 5 mm), and minor amounts of fine to coarse-grained, iron-stained quartz sand, well rounded to subangular	10	370
Sand, composed evenly of very fine to fine-grained glauconite and clear quartz, well sorted	10	380
Sand, quartzose, with limonite aggregates and fine to medium-grained, dark green to brown glauconite; some coarser quartz grains	10	390
Sand, quartzose, iron-stained and clear, medium to fine-grained, rounded to subangular, with dark to light green glauconite (a minor amount of which is altered to limonite), and fine-grained goethite pellets	10	400
PINEY POINT(?) FORMATION and NANJEMOY(?) FORMATION (undifferentiated)		
Clay, with black glauconite and quartz sand, very fine-grained; abundant foraminifera tests	10	410
Sand, slightly silty, glauconitic and quartzose, dark green, fine-grained, well sorted, with abundant foraminifera tests	10	420
Sand, evenly composed of very fine-grained glauconite and quartz, dark grayish-green, with very fine-grained calcareous granules, and abundant foraminifera tests	10	430
Clay, sandy, very fine to fine-grained quartz, light green	10	440
Silt, composed of dark green glauconite and calcareous granules, dark grayish-green, with abundant foraminifera tests, and trace amounts of mica (muscovite)	10	450
Silt, composed of dark green glauconite and calcareous granules, dark grayish-green, in a chalky calcareous matrix; abundant foraminifera tests	10	460
NANJEMOY FORMATION		
Sand, silty, glauconitic, light green, with moderate amounts of foraminifera tests, and mica (muscovite)	10	470
Sand, silty, quartzose and glauconitic, dark grayish-green, very fine-grained, slightly micaceous	10	480
Clay, silty, dark grayish-green, glauconitic, with silt size quartz and mica (muscovite)	10	490
Silt, clayey, dark green, composed predominantly of glauconite with interspersed quartz; trace mica (muscovite)	10	500
Clay, sandy, silty, green, moderately tough, with minor amounts of quartz and glauconite	10	510
Clay, light green, tough, with sparse amounts of silt size black glauconite (more tough green clay than previous interval)	10	520
Clay, light green, silty, quartzose and glauconitic	10	530
Clay, tough, grayish-green, with very fine-grained glauconite	10	540
Clay, tough, grayish-green	5	545
Clay, silty, glauconitic, very fine-grained, dark green	5	550
Clay, grayish-green, silty, with very fine-grained dark green to black glauconite	10	560
AQUIA FORMATION		
Clay, silty, glauconitic, in a white chalky matrix (560 ft - 565 ft); sand, quartzose, medium-grained, iron-stained, with goethite pellets, and glauconite (altered to limonite) (565 ft - 570 ft)	10	570
Sand, composed of olive green to brown (oxidized) glauconite and iron-stained quartz, medium-grained and well sorted with trace shell (echinoid spines) and thin laminations of clay	10	580
Sand, quartzose, medium to very coarse-grained, poorly sorted, iron-stained, rounded to well rounded, with abundant goethite pellets, and very fine-grained black glauconite and quartz cemented in a hard calcareous matrix; shell fragments (possibly foraminifera *Nodosaria*)	10	590
Sand, and gravel, quartzose, very coarse-grained, iron-stained, rounded to well rounded, poorly sorted, with thin, hard layers of fine-grained glauconite and quartz cemented in a calcareous matrix throughout the interval	10	600
Sand, quartzose, iron-stained, medium to very coarse-grained, poorly sorted, rounded to well rounded, with goethite pellets and some thin, hard zones of very fine, dark green glauconite and quartz sand cemented in a chalky calcareous matrix; some shell (most noticeably foraminifera *Nodosaria*)	10	610
Sand, quartzose, very fine to coarse-grained, iron-stained, well rounded to subangular, poorly sorted, with very fine-grained, olive-green glauconite and glauconite altered to limonite; some shell fragments and thin hard cemented zones as mentioned in previous description	10	620
Sand, quartzose, medium to coarse-grained, poorly sorted, iron-stained, with calcareous concretions and a soft calcareous matrix; very fine-grained olive-green glauconite, iron oxide nodules and shell fragments; dense shell beds appear in several layers, up to 1 ft thick, in the lower half of the interval	10	630
Coquina, interstratified with very fine-grained quartz and glauconitic sand in a chalky calcareous matrix, with loose shell material and hard layers of calcite and calcite cemented sandstone	10	640
Coquina, friable, interbedded with fine-grained quartz sand, loose shell material and thin layers of tough green clay; hard fragments of calcite and trace glauconite	20	660
Coquina, interstratified with loose shell material and hard layers of very fine-grained calcite cemented black glauconite and quartz sand	10	670
Coquina, as above, with the addition of chalky, calcareous aggregates, thin lenses of soft clay and lesser amounts of loose shell material	10	680
Coquina, very friable and soft, with chalky calcareous aggregates and thin lenses of gray clay	10	690

Appendix C - Reconstructed geologic log - Continued

Lithology	Thickness (ft)	Depth to base (ft)
PAMUNKEY GROUP - Continued		
AQUIA FORMATION - Continued		
Coquina, as above, with the addition of abundant foraminifera tests; single-point electric log suggests a more clayey lithology from 690 ft - 695 ft	10	700
Clay, silty, light gray, with calcite fragments and minor amounts of shell; geophysical logs suggest a predominantly calcareous or sandy zone which is not fully represented in the drill cuttings	10	710
Clay, silty, light grayish-green, with silt size calcite granules; geophysical logs show a clayey zone in the lower portion of the interval overlain by a calcareous or sandy zone	10	720
Clay, silty, light gray to white, composed largely of foraminifera tests and calcite granules, with some silt size quartz and glauconite; trace amounts of mica (muscovite)	10	730
Clay, grayish-green, composed of very fine-grained glauconite and calcite granules, with abundant foraminifera tests and some hard cemented zones	10	740
Clay, glauconitic, dark green, with minor amounts of fine-grained, iron-stained quartz sand, black to dark green glauconitic sand and shell fragments; multi-point and gamma logs suggest that the sand constituent originates from the upper portion of the interval	10	750
HORNERSTOWN(?) FORMATION and BRIGHTSEAT(?) FORMATION (undifferentiated)		
Clay, very silty, grayish-green, composed in part of aggregated, botryoidal forms of dark green glauconite in a calcareous matrix; minor amounts of very fine-grained, clear quartz sand; some large (up to 1 cm), moderately weathered shell fragments and trace amounts of foraminifera tests	10	760
Clay, sandy, composed of botryoidal to polylobate forms of dark green glauconite, fine to medium-grained, with aggregates of calcareous cemented glauconite and sparse amounts of coarse-grained quartz sand and shell	10	770
Silt, clayey, dark gray, composed of silt size to very fine-grained black glauconite, with some minor amounts of shell debris	10	780
Clay, silty, greenish-gray, composed almost entirely of silt size to fine-grained black glauconite in a clayey matrix, with minor amounts of fine to coarse-grained, iron-stained quartz sand (possibly a contamination from "up-hole")	10	790
MONMOUTH GROUP (undivided)		
Clay, silty, sandy, composed predominantly of silt size, black glauconite in a light to dark gray clayey matrix, with iron-stained, silt size to coarse-grained quartz sand and finely divided shell fragments	10	800
Clay, light to medium gray, glauconitic, with some lenses of medium to fine-grained, brown quartz sand; gradation downward to a fine to medium-grained, well sorted quartz and glauconitic sand; quartz grains are coated lightly with siderite	10	810
Sand, silty, quartzose, fine-grained, iron-stained to clear, and partially aggregated and cemented in a white, chalky, calcareous matrix; trace amounts of goethite pellets	10	820
Sand, quartzose, fine to medium-grained, iron-stained, with some calcareous cemented quartz aggregates, silt size black glauconite and finely fragmented shell debris (foraminifera)	10	830
Sand, quartzose, fine-grained, iron-stained, with some coarse, well rounded grains; minor amounts of dark green to black, silt size glauconite and limonite nodules	10	840
Sand, quartzose and moderately glauconitic, medium to coarse-grained, iron-stained, with well defined agglomerate goethite pellets; glauconite appears dark green and brown (oxidized) and is predominantly fine-grained	10	850
Sand, quartzose and glauconitic (oxidized to limonite), medium to coarse-grained, poorly sorted, with iron staining on quartz grains	10	860
Sand, quartzose, iron-stained, fine to very coarse-grained, poorly sorted, well rounded to subangular grains, with goethite pellets	10	870
Sand, composed of iron-stained quartz and dark green to black glauconite, fine-grained, well sorted	10	880
Sand, glauconitic and quartzose, clean, fine-grained, well sorted	10	890
Sand, silty, clayey, composed of clear and iron-stained quartz and dark green glauconite, very fine to fine-grained	10	900
Clay, silty, light gray, with dark green glauconite and quartz silt, in a calcareous, silty matrix	10	910
Clay, silty, light gray, with dark green glauconite	10	920
Silt, composed of black glauconite in a light to dark gray clayey matrix, with minor amounts of silt size quartz	10	930
MATAWAN(?) GROUP (Note: The contact between the Monmouth Group and Matawan Group is uncertain)		
Sand, silty, clayey, composed of dark olive green to black glauconite and clear quartz, very fine-grained	10	940
Sand, as above, with the addition of a hard shell layer between 940 ft and 943 ft; (geophysical logs show this layer occurring lower in the section)	10	950
Sand, quartzose, fine-grained, iron-stained	10	960
Sand, quartzose, medium-grained, partial iron staining on quartz grains, with very small amounts of glauconite, goethite pellets, and shell	10	970
Clay, sand, carbonaceous, black to dark gray, quartzose, very fine-grained to silt size, with minor amounts of black glauconite and mica (muscovite); geophysical logs show an increase in clay content toward the bottom of the interval	10	980
Clay, silty, black, slightly micaceous, with trace amounts of lignite	10	990
Sand, silty, quartzose, very fine-grained, dark lead gray, with calcareous glauconitic silt and very small amounts of medium-grained quartz sand	10	1,000
Clay, sandy, silty, quartzose, fine to coarse-grained, light to dark gray, lightly carbonaceous, with trace amounts of lignite and shell	10	1,010
Clay, greenish-gray, with sparse amounts of fine to coarse-grained brown and translucent quartz sand	20	1,030
Clay, silty, dark gray, slightly micaceous (muscovite), with some olive green glauconite	30	1,060

Appendix C - Reconstructed geologic log - Continued

Lithology	Thickness (ft)	Depth to base (ft)
MATAWAN(?) GROUP and MAGOTHY(?) FORMATION (undifferentiated)		
Clay, silty, dark greenish-gray, slightly micaceous	20	1,080
Clay, as above, with trace amounts of olive-green glauconite	30	1,110
MAGOTHY FORMATION		
Clay, as above, grading into a sand at base of interval (based on geophysical logs)	10	1,120
Sand, quartzose, very fine-grained, white and gray, grading to a micaceous silt; geophysical logs indicate more clay in interval	10	1,130
Sand, quartzose, medium to very coarse-grained, poorly sorted, tan, white, iron-stained, with some hard, siderite cemented zones and lignite	10	1,140
Sand, quartzose, partially iron-stained, fine-grained, fairly well sorted, with small percentage of very coarse-grained quartz sand; geophysical logs show a clay at base of section	20	1,160
Clay, silty, dark gray to black, carbonaceous, slightly micaceous, with minor amounts of lignite; based on geophysical logs section grades downward to a sand	10	1,170
Clay, silty, dark green; sample not representative - geophysical logs suggest a sand	10	1,180
POTOMAC GROUP		
PATAPSCO(?) FORMATION		
Clay, silty, dark gray, very tough (noticeable rise in drilling fluid pressure), slightly micaceous with trace carbonaceous residue	10	1,190
Clay, moderately hard, silty, dark brownish gray; sample not representative - geophysical logs suggest a sand	10	1,200
Clay, dark brown and black, carbonaceous, with very little silt; geophysical log indicates clay at base of interval only	10	1,210
Clay, light pinkish-gray, black and dark brown, carbonaceous, with thin hard cemented layers at top of interval	10	1,220
Clay, silty, dark gray, slightly micaceous	10	1,230
Sand, quartzose, fine to coarse-grained, clear, opaque, rosey and iron-stained, rounded to subangular, trace pyrite; hard cemented zone at 1,239 ft	10	1,240
Sand, quartzose and feldspathic, fine to very coarse-grained, angular to subangular, with trace amounts of lignite, pyrite and gray clay	10	1,250
Sand, quartzose, clean, medium to coarse-grained, rose, white, gray and clear quartz grains, rounded to subangular, interbedded with tough clay (especially toward bottom of interval)	10	1,260
Sand, quartzose, medium to coarse-grained, clean, light gray to white, well sorted, with some rosey quartz; thin lenses of light gray clay appeared at top of interval	10	1,270
Clay, silty, gray (very poor sample); geophysical log suggests a clay	10	1,280
Sand, quartzose, fine to medium-grained, clean, well sorted, clear and gray with trace amounts of white and gray clay, mica (muscovite), lignite and fine-grained cemented sand nodules	10	1,290
Sand, quartzose, light gray, clean, fine-grained, well sorted, angular to subangular, with trace amounts of pyrite	10	1,300
Sand, quartzose, dark gray, very fine-grained, rounded to subangular, well sorted, slightly micaceous, with trace amounts of lignite; interval contained multiple layers of indurated sandstone with an especially hard zone at 1,302 ft (possibly composed of pyrite)	10	1,310
Sand, silty, light gray, quartzose, very fine-grained, slightly micaceous, with moderate amounts of lignite and trace gray clay	10	1,320
Sand, light gray, quartzose, very fine-grained, clear and iron-stained, well sorted, slightly micaceous, with trace amounts of pyrite	10	1,330
Sand, quartzose, fine-grained, slightly micaceous, with sparse amounts of hematitic clay and yellowish to rose colored spherical sandstone nodules; some intercalated red and gray clay	10	1,340
Clay, red, white, tough	21	1,361
Sand, composed predominantly of very hard, medium to coarse-grained spherical quartz sandstone nodules, yellow and rose, with some thin layers of hard sandstone	14	1,375
Clay, red, and white, with trace amounts of hard lignite	5	1,380
Sand, clayey, silty, gray, quartzose; clay constituent is predominantly red and white, with an especially tough layer at 1,388 ft	10	1,390
Clay, tough, red, white, and pink, with trace amounts of fine-grained sand	10	1,400
Sand, composed of hard, spherical quartz aggregates, very fine-grained, with orange to pink hue	10	1,410
Clay, tough, red, white and gray	60	1,470
Sand (description based on geophysical logs - drill cuttings filled with contaminants from "up-hole")	30	1,500
Clay, tough, red	10	1,510
Clay, tough, reddish-brown	40	1,550
Clay, tough, red, with thin white clay laminations	40	1,590
Clay, silty, variegated, with trace amounts of fine sand, sandstone and lignite	10	1,600
Sandstone, quartzose, hard, with lignite, hematite and pyrite	10	1,610
Sand, silty, quartzose, with some hard, cemented sand zones, light gray to white	5	1,615
Clay, silty, white, variegated	5	1,620
Clay, tough, reddish-orange and white (poor sample - geophysical logs indicate a sand)	10	1,630
Clay, very tough, red, with minor amounts of white and yellow clay; some thin layers of silty sand approximately 3 in. - 6 in. thick; trace amounts of lignite	10	1,640
Sand, reddish-brown, silt size to very fine-grained quartz, in a clayey matrix	10	1,650
Clay, red and gray	10	1,660
Sand, partially indurated; (poor sample; description mostly from geophysical logs)	15	1,675
Clay, red and gray	3	1,678
Sand, medium to coarse-grained, quartzose, with fragments of very hard siderite, also, pyrite and lignite	7	1,685
Clay (poor sample - based mainly on geophysical logs)	5	1,690
Sand, gray, silty, clayey, quartzose, very fine-grained, well sorted, with thin siderite layers interstratified throughout interval	10	1,700
Clay, silty, white, mixed with gray clay and some thin cemented layers, also slightly sandy	10	1,710
Sand, silty, quartzose, very fine-grained, round to subangular grains, reddish-brown; gradation downward to a clay	10	1,720
Clay, hematitic, red, white and yellow, soft, and partially lignitic	5	1,725 (Total Depth)

Described by David Andreasen

Appendix D

Foraminiferal analyses of selected drill cutting intervals*

by Richard K. Olsson

Well QA-Ef 29

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE	SPECIES	
215-220	Light gray to buff, silty, fine to medium sand with shell	Inner to Middle Shelf 50-100 m.	Late Miocene to Middle Pliocene	R**	*Ammonia cf. beccarii*
				F	*Bolivina paula*
				R	*Bolivina striata*
				F	*Buliminella elegantissima*
				C	*Buliminella elongata*
				F	*Elphidium gunteri*
				F	*Florilus atlantica*
				F	*Globigerina apertura****
				X	*Globigerina cf. umbilicata*
				X	*Globigerina praebulloides*
				R	*Globigerina pseudobesa****
				A	*Hanzawaia concentrica*
				R	*Textularia agglutinans*
270-280	Gray silty, medium sand with shell	Inner to Middle Shelf 50-100 m.	Late Miocene to Middle Pliocene	X	*Ammonia cf. beccarii*
				C	*Buliminella elegantissima*
				A	*Buliminella elongata*
				X	*Cibicides lobatulus*
				X	*Cibicides pseudoungerianus*
				A	*Florilus pizzarensis*
				X	*Fursenkoina fusiformis*
				X	*Globigerina apertura****
				X	*Globigerina praebulloides*
				X	*Globigerina woodi****
				A	*Hanzawaia concentrica*
				F	*Spiroplectammina gracilis*
				R	*Textularia agglutinans*
330-340	Brownish-gray, coarse glauconitic sand, weathered pellets	Middle Shelf 65-85 m.	Middle Eocene	X	*Acarinina aspensis*
				R	*Acarinina sp.*
				F	*Alabamina mississippiensis*
				R	*Bolivina huneri*
				X	*Cibicides crassidiscus*
				A	*Cibicidoides pippeni*
				F	*Eponides lotus*
				R	*Florilus spissa*
				X	*Globorotalia possagnoensis****
				X	*Globulina gibba*
				R	*Guembelitria columbiana****
				F	*Gyroidinoides octacameratus*
				X	*Hanzawaia blanpiedi*
				X	*Morozovella spinulosa****
				X	*Pseudohastigerina micra****
				X	*Subbotina linaperta*
				X	*Truncorotaloides rohri****
400-410	Dark gray to green coarse glauconitic sand, weathered pellets	Middle Shelf 85-110 m.	Middle Eocene	R	*Alabamina mississippiensis*
				R	*Bolivina huneri*
				A	*Cibicidoides pippeni*
				R	*Eponides lotus*
				X	*Fissurina orbignyana*
				R	*Globulina gibba*
				R	*Guttulina irregularis*
				X	*Gyroidinoides octacameratus*
				F	*Hanzawaia blanpiedi*
				F	*Kolesnikovella elongata*
				X	*Lenticulina sp.*
				X	*Loxostomum cf. serrula*
				X	*Marginulina hantkeni*
				X	*Melonis planatus*
				R	*Morozovella bullbrooki****
				X	*Morozovella spinuloinflata****
				X	*Nodosaria latejugata*
				X	*Pseudohastigerina micra*
				R	*Pseudohastigerina wilcoxensis*
				R	*Subbotina eocaena*
				R	*Subbotina linaperta*
				F	*Truncorotaloides rohri****
				C	*Turrilina robertsi*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
C = common R = rare
***Diagnostic microfossil

Appendix D - Foraminiferal analyses of selected drill cutting intervals*- Continued

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE	SPECIES	
440-450	Greenish-gray clayey silty medium glauconitic sand	Middle to Outer Shelf 110-160 m.	Lower Eocene	C**	*Acarinina pentacamerata****
				R	*Alabamina mississippiensis*
				X	*Anomalinoides sp. A*
				F	*Bolivina huneri*
				A	*Cibicidoides pippeni*
				X	*Eponides lotus*
				X	*Gaudryina sp.*
				X	*Globulina gibba*
				X	*Guttulina irregularis*
				F	*Gyroidinoides octacameratus*
				R	*Lenticulina sp. 2*
				X	*Loxostomum cf. serrula*
				R	*Marginulopsis mexicana*
				X	*Pseudohastigerina micra*
				A	*Pyramidina subrotundata*
				X	*Siphonina claibornensis*
				X	*Stilostomella aculeata*
				R	*Subbotina eocaena*
				R	*Subbotina linaperta*
				F	*Truncorotaloides rohri*
				F	*Turrilina robertsi*
490-500	Greenish-gray silty medium glauconitic sand	Middle to Outer Shelf 110-160 m.	Lower Eocene	A	*Acarinina sp.*
				X	*Alabamina mississippiensis*
				X	*Anomalinoides acuta*
				F	*Bolivina stuckeyi*
				X	*Cibicidoides cocoaensis gr.*
				R	*Cibicidoides pippeni*
				X	*Eponides lotus*
				R	*Globulina gibba*
				R	*Gyroidinoides octacameratus*
				X	*Hanzawaia mauricensis*
				R	*Kolesnikovella elongata*
				X	*Lenticulina sp.*
				X	*Marginulopsis mexicana*
				R	*Morozovella spinulosa*
				F	*Planorotalites planoconica****
				F	*Pyramidina subrotundata*
				F	*Siphonina claibornensis*
				X	*Stilostomella aculeata*
				R	*Subbotina inaequispira****
				C	*Subbotina linaperta*
				A	*Trifarina wilcoxensis*
				F	*Turrilina robertsi*
540-550	Gray-green greensand	Middle Shelf 100-120 m.	Lower Eocene	F	*Bulimina whitei*
				X	*Cibicidoides cocoaensis gr.*
				X	*Cibicidoides sp. A*
				R	*Epistominella minuta*
				R	*Eponides lotus*
				F	*Fursenkoina sp.*
				X	*Gyroidinoides octacameratus*
				X	*Lagena striata*
				X	*Lenticulina sp.*
				X	*Marginulopsis mexicana*
				X	*Melonis planatus*
				X	*Morozovella formosa****
				F	*Pyramidina subrotundata*
				R	*Siphonina claibornensis*
				R	*Subbotina linaperta*
				F	*Trifarina wilcoxensis*
				F	*Turrilina robertsi*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
C = common R = rare
***Diagnostic microfossil

Appendix D - Foraminiferal analyses of selected drill cutting intervals*- Continued

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE		SPECIES
600-610	Yellowish-brown medium to very coarse glauconitic sand weathered	Middle Shelf 75-100 m.	Upper Paleocene Zone P4	R**	*Acarinina aquiensis*
				X	*Acarinina wilcoxensis*
				R	*Alabamina midwayensis*
				X	*Anomalinoides pseudowelleri*
				R	*Bolivinopsis emmendorferi*
				X	*Chiloguembelina wilcoxensis*
				A	*Cibicides marylandicus*
				F	*Cibicidoides alleni*
				X	*Dentalina sp.*
				X	*Eponides plummerae*
				X	*Fursenkoina sp. 2*
				C	*Gavelinella compressa*
				A	*Gavelinella neelyi*
				X	*Guttulina hantkeni*
				X	*Morozovella aequa*
				X	*Morozovella occlusa****
				X	*Planorotalites pseudomenardii****
				X	*Planorotalites sp.*
				X	*Polymorphina cf. frondea*
				R	*Spiroplectammina wilcoxensis*
				X	*Stilostomella aculeata*
				X	*Subbotina linaperta*
				X	*Subbotina velascoensis****
				R	*Trifarina wilcoxensis*
				F	*Turrilina robertsi*
640-650	Light gray to white silty clayey glauconitic calcareous sand	Middle Shelf 75-100 m.	Upper Paleocene Zone P4	X	*Acarinina primitiva*
				X	*Acarinina soldadoensis*
				R	*Alabamina midwayensis*
				A	*Cibicides marylandicus*
				F	*Cibicidoides alleni*
				C	*Eponides plummerae*
				C	*Gavelinella compressa*
				A	*Gavelinella neelyi*
				X	*Gavelinella sp.*
				X	*Gavelinella umbonifera*
				X	*Globulina gibba*
				X	*Spiroplectammina cf. wilcoxensis*
				X	*Spiroplectammina spectabilis*
				X	*Subbotina velascoensis****
				R	*Turrilina robertsi*
690-700	Light gray glauconitic calcareous sand and silt	Middle to Outer Shelf 100-150 m.	Upper Paleocene Zone P4	X	*Acarinina cf. gravelli*
				F	*Acarinina esnaensis*
				X	*Acarinina mckannai****
				X	*Acarinina primitiva*
				C	*Alabamina midwayensis*
				R	*Allomorphina halli*
				C	*Bulimina pseudocacumenata*
				X	*Bulimina quadrata*
				F	*Cibicides marylandicus*
				F	*Cibicidoides alleni*
				C	*Cibicidoides succedens*
				X	*Dentalina colei*
				R	*Epistominella minuta*
				F	*Eponides plummerae*
				X	*Gaudryina aissana*
				X	*Gavelinella cf. beccariiformis*
				C	*Gavelinella compressa*
				F	*Gavelinella danica*
				A	*Gavelinella neelyi*
				R	*Gavelinella umbonifera*
				R	*Globulina gibba*
				R	*Guttulina hantkeni*
				X	*Lagena hornerstownensis*
				R	*Lenticulina cf. rancocasensis*
				X	*Marginulina sp.*
				X	*Marginulinopsis tuberculata*
				X	*Morozovella subbotinae*
				X	*Nodosaria pseudoaculeata*
				X	*Osangularia plummerae*
				X	*Planorotalites cf. imitata*
				X	*Rectonodosaria tenuistriata*
				X	*Spiroplectammina wilcoxensis*
				F	*Subbotina linaperta*
				X	*Subbotina triangularis*
				X	*Subbotina velascoensis****
				F	*Tappanina selmensis*
				R	*Trifarina wilcoxensis*
				F	*Turrilina robertsi*
				X	*Vaginulinopsis longiforma*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
C = common R = rare
***Diagnostic microfossil

Appendix D - Foraminiferal analyses of selected drill cutting intervals*- Continued

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE		SPECIES
720-730	Light gray glauconitic calcareous sand and silt	Middle to Outer Shelf 100-150 m.	Upper Paleocene Zone P4	F**	*Acarinina aquiensis*
				R	*Acarinina esnaensis*
				R	*Acarinina mckannai****
				R	*Alabamina midwayensis*
				X	*Allomorphina halli*
				A	*Bolivinopsis emmendorferi*
				A	*Bulimina pseudocacumenata*
				R	*Bulimina quadrata*
				A	*Cibicides marylandicus*
				C	*Cibicidoides alleni*
				R	*Cibicidoides succedens*
				A	*Epistominella minuta*
				X	*Eponides plummerae*
				R	*Gavelinella compressa*
				R	*Gavelinella danica*
				X	*Gavelinella umbonifera*
				R	*Globulina gibba*
				R	*Guttulina hantkeni*
				X	*Gyroidinoides cf. globosus*
				X	*Lagena hornerstownensis*
				X	*Lenticulina cf. rancocasensis*
				X	*Lenticulina degolyeri*
				X	*Marginulinopsis tuberculata*
				X	*Morozovella apanthesma*
				X	*Nodosaria latejugata*
				X	*Nodosaria pseudoaculeata*
				X	*Nodosaria toulmini*
				X	*Planorotalites pseudomenardii****
				X	*Pseudouvigerina triangularis*
				X	*Pullenia cf. eocenica*
				X	*Pulsiphonina prima*
				X	*Pyramidina sp. A*
				X	*Rosalina ystadiensis*
				R	*Subbotina linaperta*
				R	*Subbotina triangularis*
				R	*Subbotina velascoensis****
				F	*Tappanina selmensis*
				X	*Trifarina wilcoxensis*
				X	*Vaginulinopsis longiforma*
750	Grayish-green clayey silty greensand	Middle to Outer Shelf 100-150 m.	Upper Paleocene Zone P4	X	*Acarinina acarinina*
				X	*Acarinina pseudotopilensis*
				X	*Acarinina soldadoensis angulosa*
				X	*Alabamina midwayensis*
				X	*Allomorphina halli*
				X	*Anomalinoides acuta*
				X	*Bolivinita sp.*
				A	*Bolivinopsis emmendorferi*
				X	*Bulimina midwayensis*
				C	*Bulimina pseudocacumenata*
				X	*Bulimina quadrata*
				X	*Cassidulina cf. globosa*
				X	*Chiloguembelina wilcoxensis*
				F	*Cibicides marylandicus*
				X	*Cibicidoides alleni*
				F	*Cibicidoides succedens*
				X	*Dentalina budensis*
				C	*Epistominella minuta*
				X	*Eponides plummerae*
				X	*Florilus florinensis*
				X	*Gavelinella danica*
				X	*Gavelinella neelyi*
				R	*Gyroidinoides globosus*
				X	*Gyroidinoides octacameratus*
				F	*Hanzawaia mauricensis*
				X	*Kolesnikovella elongata*
				X	*Lagena fenestrissima*
				X	*Lagena multicostata*
				X	*Lagena sp. A*
				X	*Lenticulina sp.*
				X	*Marginulina sp.*
				X	*Morozovella acuta****
				X	*Morozovella acutispira****
				X	*Morozovella aequa*
				X	*Morozovella apanthesma*
				X	*Morozovella formosa gracilis*
				X	*Nodosarella irregularis*
				X	*Osangularia plummerae*
				R	*Pararotalia inconspicua*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
C = common R = rare
***Diagnostic microfossil

Appendix D - Foraminiferal analyses of selected drill cutting intervals* - Continued

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE		SPECIES
750 Cont'd	Grayish-green clayey silty greensand	Middle to Outer Shelf 100-150 m.	Upper Paleocene Zone P4	X**	*Planorotalit es chapmani*
				X	*Planorotalites imitata****
				X	*Planorotalites laevigata****
				X	*Planorotalites pseudomenardii****
				X	*Polymorphinids*
				X	*Pseudohastigerina wilcoxensis*
				X	*Pullenia quinqueloba*
				X	*Pulsiphonina prima*
				X	*Pyramidina sp. A*
				X	*Quadrimorphina allomorphinoides*
				X	*Rectonodosaria tenuistriata*
				R	*Siphonina claibornensis*
				X	*Spiroplectammina wilcoxensis*
				X	*Stilostomella aculeata*
				X	*Subbotina linaperta*
				X	*Subbotina triangularis*
				X	*Subbotina velascoensis****
				F	*Tappanina selmensis*
				X	*Tritaxia midwayensis*
				R	*Turrilina robertsi*
				X	*Uvigerina elongata*
				X	*Valvulineria texana*
800	Brown medium to coarse glauconitic sand weathered pellets	Inner to Middle Shelf 50-100 m.	Upper Maestrichtian Globotruncana Ganesseri Zone	R	*Anomalinoides highlandicus*
				R	*Anomalinoides sp. B*
				R	*Cibicides harperi*
				R	*Globigerinelloides multispina****
				R	*Globotruncana gansseri****
				R	*Globotruncana subcircumnodifer****
				R	*Globotruncana tricarinata****
				R	*Globulina gibba*
				R	*Gyroidinoides imitata*
				C	*Heterohelix striata*
				R	*Praebulimina carseyae*
				R	*Pseudouvigerina seligi*
				R	*Pullenia americana*
				R	*Pulsiphonina prima*
				R	*Rugoglobigerina reicheli****
				R	*Tappanina selmensis*
925	Dark gray green medium to coarse glauconitic sand	Outer Shelf 100-150 m.	Upper Campanian	A	*Archeoglobigerina cretacea****
				R	*Arenobulimina subspherica*
				F	*Cibicides harperi*
				R	*Gaudryina stephensoni*
				F	*Gavelinella compressa*
				F	*Gavelinella nelsoni*
				R	*Gavelinella pinguis*
				A	*Globigerinelloides prairiehillens*
				R	*Globorotalites micheliniana*
				R	*Globotruncana bulloides****
				R	*Globotruncana fornicata****
				R	*Globotruncana tricarinata****
				F	*Globulina gibba*
				F	*Gyroidinoides cretacea*
				F	*Hedbergella cf. planispira****
				A	*Heterohelix striata*
				R	*Lenticulina pseudosecans*
				F	*Loxostomum eleyi*
				F	*Neobulimina spinosa*
				R	*Nodosaria latejugata*
				F	*Praebulimina aspera*
				R	*Pseudouvigerina cretacea*
				R	*Pullenia jarvisi*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
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***Diagnostic microfossil

Appendix D - Foraminiferal analyses of selected drill cutting intervals*- Continued

DEPTH* (FT)	LITHOLOGIC DESCRIPTION	PALEOENVIRONMENT	BIOSTRATIGRAPHIC ZONE	SPECIES	
975	Dark gray to black sandy silty clay	Inner Shelf 50-100 m.	Campanian	R**	*Archeoglobigerina cretacea****
				R	*Cibicides harperi*
				R	*Eggerella cf. trochoides*
				R	*Gavelinella compressa*
				F	*Gavelinella henbesti*
				R	*Globotruncana bulloides****
				R	*Globotruncana fornicata****
				R	*Gyroidinoides cretacea*
				R	*Heterohelix striata*
				R	*Lenticulina cf. tricarinella*
				F	*Lenticulina pondi*
				F	*Lenticulina pseudosecans*
				R	*Saracenaria saratogana*
				R	*Valvulineria depressa*
1,075	Gray clayey fine to medium sand, weathered pellets	Inner Shelf 50-100 m.	Campanian-Santonian	R	*Archeoglobigerina blowi****
				R	*Archeoglobigerina cretacea****
				R	*Cibicides sp. A*
				R	*Gaudryina laevigata*
				R	*Gavelinella compressa*
				R	*Gavelinella henbesti*
				R	*Gavelinella nelsoni*
				R	*Globulina gibba*
				R	*Gyroidinoides cretacea*
				R	*Heterohelix striata*
				R	*Lenticulina pseudosecans*
				F	*Pseudogaudryinella capitosa*
1,125	Gray medium sand slightly glauconitic	Inner Shelf?	Cretaceous	R	*Gavelinella henbesti*
				R	*Gavelinella pinguis*
				R	*Lenticulina sp. 2*
				R	*Neobulimina spinosa*
				R	*Praebulimina carseyae*
				R	*Tappanina selmensis*

*Drill cuttings from 110-120 ft to 720-730 ft.; cores 750 ft to 1,125 ft.

**A = abundant F = few X = very rare
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***Diagnostic microfossil

Appendix E - Record of wells and test holes used in this report

Well Number	State permit number	Owner	Drilling contractor	Altitude of land surface (ft)	Date drilled	Depth hole (ft)	Depth well (ft)	Diameter of well screen (in.)	Screen settings (ft)	Aquifer	Static water level (ft)**	Pumping test data: Date measured	Yield (gpm)	Draw-down (ft)	Specific capacity (gpm/ft)
AA-Cg 22	AA-73-8606	U.S. Geological Survey	Sydnor Hydrodynamics	12.6	1978	1,862	1,760	4	1,735-1,755	Patuxent	-3.66	09/25/78	30	125.81	0.24
AA-Cg 23	AA-73-8959	U.S. Geological Survey	Sydnor Hydrodynamics	12.6	1978	1,000	986	4	968-978	Lower Patapsco	-6.34	09/19/78	35	79	0.44
AA-Cg 24	AA-73-8960	U.S. Geological Survey	Sydnor Hydrodynamics	12.7	1978	670	664	4	605-615 648-658	Upper Patapsco	-11.73	09/12/78	150	29	5.17
QA-Eb 110	QA-73-2979	U.S. Geological Survey	A. C. Schultes & Son, Inc.	14	1980	2,547	2,485	4	2,413-2,423 2,465-2,475	Patuxent	+4.06	09/16/80	6.7	2.24	3.0
QA-Eb 111	QA-73-3122	U.S. Geological Survey	A. C. Schultes & Son, Inc.	14	1979	1,056	1,050	4	955-965 1,030-1,040	Upper Patapsco	-10.44	02/05/80	65	20.46	3.2
QA-Eb 112	QA-73-3123	U.S. Geological Survey	A. C. Schultes & Son, Inc.	14	1980	1,711	1,709	4	1,652-1,662 1,692-1,702	Lower Patapsco	-8.7	02/13/80	64	48.34	1.3
QA-Eb 113	QA-73-3172	U.S. Geological Survey	A. C. Schultes & Son, Inc.	12	1979	220	216	6	176-216	Aquia	-16.1	11/15/79	10	8	1.2
QA-Ef 29	QA-81-1593	Md. Dept. of Natural Resources	Sydnor Hydrodynamics	61.7	1986	1,725	1,325	8	1,110-1,120 1,135-1,180 1,195-1,210 1,230-1,270 1,285-1,315	Upper Patapsco and Magothy	-62.50	07/11/86	700	164.45	4.25
TA-Ad 5	TA-65-0037	Schluderberg-Kurdle Co.	Shannahan Artesian Well Co.	54	1964	444	444	2	429-444	Aquia	-56	11/64	16	7	2.3
TA-Cd 55	TA-71-0080	Easton Util. Commission	Shannahan Artesian Well Co.	21	1971	669	669	8	575-669	Aquia	-41	1/71	530	181	2.9
TA-Ce 5	TA-00-2261	Easton Util. Commission	American Drilling Co.	30	1947	1,188	1,148	12	1,126-1,147	Magothy(?)	-8	01/18/49	415	59	7.0
TA-De 18*	TA-66-0007	U.S. Geological Survey	Shannahan Artesian Well Co.	40	1965	1,493	-	-	-	-	-	-	-	-	-

*Test boring not completed as well.
**Measured from land surface.