Geology and Ground-Water Resources of the York-James Peninsula, Virginia

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1361

Prepared in cooperation with the Division of Geology, Virginia Department of Conservation and Development

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By D. J. CEDERSTROM

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GEOLOGY AND GROUND-WATER RESOURCES OF THE YORK-JAMES PENINSULA, VIRGINIA

By D. J. Cederstrom

ABSTRACT

The York-James peninsula in eastern Virginia is part of the Coastal Plain province. It extends from the Fall Line to Chesapeake Bay and lies between the James River on the south and the York and Mattaponi Rivers on the north. Central and eastern Henrico County, eastern Hanover County, and all of King William, New Kent, Charles City, James City, York, Warwick and Elizabeth City Counties are included in the report. (The entire counties of Warwick and Elizabeth City have become first-class cities designated Warwick and Hampton, respectively.) Systematic fieldwork was done largely between 1942 and 1947, but many conclusions regarding geology are based on results of studies made as late as 1953. The data used as a basis of discussion consist in large part of well records, well logs, and analyses of water samples. In geological interpretations, much reliance was placed on the writer's studies of foraminiferal content of samples from wells in and adjacent to the area. Data from several special studies and information presented in earlier reports were drawn upon. Some previously held conceptions of Eocene and pre-Eocene stratigraphy have been greatly revised.

The area consists largely of farms and woodland with many small villages and towns and a few large cities. Richmond, West Point, Williamsburg, Yorktown, Newport News, and Fort Monroe are the largest centers of population within the area. The building of ocean vessels at Newport News, production of light and heavy manufactured articles in the Richmond area, and manufacture of paper pulp at West Point are major industries. Appreciable processed food, including frozen seafood, is produced in the area. Activities related to military establishments, particularly at Yorktown, Fort Eustis, and Fort Monroe, continue to be of considerable economic importance. The area has a very heavy tourist trade; Richmond, Williamsburg, Jamestown, Yorktown, and the battlefield parks in Hanover, Henrico, and Charles City Counties are the focal points of interest.

The climate is mild and has a mean annual temperature of about 58° F. The average annual precipitation is 41 inches.

East of the Fall Line the granite basement rock lies at progressively greater depths, and the Coastal Plain sediments, which dip gently seaward, thicken to more than 2,000 feet at Fort Monroe. Westward toward the basement rocks along the Fall Line the sediments are thinner. The Coastal Plain is almost everywhere covered by thin terrace formations.

Unconsolidated sediments of the Potomac group of Early and Late Cretaceous age rest upon the pre-Cambrian granitic basement rock or, in limited areas, upon Triassic consolidated sedimentary rock. Sediments of the Potomac group crop out along the Fall Line and are reached by many wells in that area. Eastward,

few wells reach the sediments of the Potomac group, which is estimated to be over 900 feet thick; a notable exception is the old well at Newport News that was drilled through the entire Potomac section.

A new formational name, the Mattaponi formation, is introduced in this report to include the pre-Wilcox Eocene sediments so widely present as water-bearing formations in the area. It is the writer's opinion that the upper part of the formation is Paleocene in age and that the lower part is Late Cretaceous in age. The type wells are at Washingtons Birthplace and Colonial Beach, Westmoreland County.

The Aquia formation is known only in the Fall Line area. No break in deposition occurs between the upper part of the Mattaponi formation and the overlying Aquia formation of early Eocene age. The basal sand of the Aquia, which represents the shoreline of an advancing sea, becomes progressively older downdip, and is part of the Mattaponi sequence about 30 miles east of the Fall Line.

The Potapaco clay member of the overlying Nanjemoy formation is also of early Eocene age. It appears to truncate the Aquia formation at a low angle.

The Aquia formation and the Potapaco clay member of the Nanjemoy formation wedge out eastward owing to the transgression of the middle Eocene sea.

The Woodstock greensand marl member of the Nanjemoy formation of middle Eocene (Claiborne) age is well formed and extends farther eastward than the underlying lower Eocene formations but it may not extend farther than Williamsburg owing to the transgression of the upper Eocene formations. The Woodstock member is water bearing in places.

The Chickahominy formation of late Eocene (Jackson) age extends only as far inland as Williamsburg, where it is reached at about 300 feet below sea level. It is 80 feet thick at the type well in Yorktown.

In the Fall Line area the Chesapeake group of Miocene age is composed of the basal Calvert formation, the St. Marys formation, and the Yorktown formation. The Yorktown formation is also widely exposed along all the large streams except in the eastern part of the area where it lies below sea level. The Calvert formation is exposed in many places along the Fall Line. The Columbia group of Pleistocene age consists of surficial clays and sands which are widely present beneath the Sunderland, Wicomico, and Pamlico terraces. Recent deposits consist of sand deposited by wind and wave action along Chesapeake Bay and of stream alluvium.

The Coastal Plain sediments dip gently seaward but in addition have been slightly folded along east-west axes. The Eocene section is only moderately thicker in the lower peninsula than it is south of the James River and no pronounced localized depositional basin is recognized. (The deeper glauconitic beds previously assigned to the Eocene are here assigned to the Mattaponi formation of Late Cretaceous to Paleocene age.)

In the Fall Line area small amounts of ground water occur in cracks and fissures in the granitic bedrock. Wells along the Fall Line, particularly around Richmond, obtain water from such fissures.

East of the Fall Line, water in sediments of the Potomac group and the Mattaponi formation occurs under artesian conditions and rises in wells that tap those strata. The wells on low land may flow but those on high ground may have to be pumped. Many flowing wells are located along the large rivers and their tributaries and in such places losses of artesian head have occurred. Water levels have also been affected by industrial pumpage at West Point and at Hopewell, on the south bank of the James River.

Large quantities of water are available from pre-Aquia sands and yields of 2 to 3 mgd (million gallons per day) should be available in many places from properly

constructed wells. In the lower peninsula area, however, these formations yield brackish water.

A few wells near the Fall Line obtain water from the basal sand of the Aquia formation. A large number of small-diameter wells obtain water from sand and shell beds in the Nanjemoy formation in the lower parts of King William and Charles City Counties. In the lower peninsula area a few wells obtain water from the basal Calvert formation of the Chesapeake group or from the Yorktown formation.

Water from granitic rock is generally moderately hard and may contain undesirable amounts of iron. Water from the Cretaceous, Paleocene, and lower Eocene sediments near the Fall Line is soft and is low in mineral content, but eastward it becomes a hard calcium bicarbonate water. East of the hard-water zone is a zone of soft sodium bicarbonate water that has a moderate to high bicarbonate content and in most places contains from 1 to 5 ppm (parts per million) of fluoride. At Williamsburg, Camp Peary, and eastward, chloride is present in objectionable amounts and in the Newport News area the water is useless for most purposes. Water from the Nanjemoy formation has moderate calcium bicarbonate hardness.

An experiment carried out by the writer at Camp Peary showed that it is possible to utilize beds saturated with saline water as a storage reservoir for fresh water.

Water from the Yorktown formation of Miocene age is moderately hard to hard. The hardness is present as calcium bicarbonate. Water from the Pleistocene terrace sands and Recent dune sands generally has a low mineralization but may contain objectionable iron.

Ground water is used for municipal, school, institutional, and domestic supplies in the large towns and villages; in a few places it is used for boiler feed. At West Point large quantities are used in the manufacture of paper pulp, and at Newport News brackish ground water is used for cooling.

Shallow wells in the area are generally dug, but a few of them are driven. Most of the deep wells are jetted wells that are from 2 to 4 inches in diameter and supply domestic or small industrial establishments. Many large-diameter drilled wells supply water to municipalities and industries. A few wells and test holes have been drilled by the rotary method.

Eastern and central Henrico County lies along the Fall Line with Richmond at the western margin of the area discussed. In recent years a number of small municipal supplies have been obtained from wells in granitic rock in the area immediately adjacent to the city. Several deep wells in the county tap beds of the Aquia formation or Potomac group, largely for small municipal supplies, and several hundred gallons per minute per well has been obtained.

In eastern Hanover County a few wells have reached bedrock, which in some places is sandstone of Triassic age. The relatively few deep wells in the county reach sands of the Aquia formation or Potomac group but nowhere have large supplies been developed as yet. The water from artesian beds is moderately hard at Hanover but in the easternmost part of the county it is soft.

King William County extends westward almost to the Fall Line and eastward to the head of the York River. There are a fairly large number of wells in the county, mostly small-diameter wells along the Pamunkey and Mattaponi Rivers and several large-diameter industrial wells at West Point. Most of these obtain water from the Mattaponi formation but several obtain water from the Nanjemoy formation. The water is generally a soft sodium bicarbonate water of good quality.

Few wells have been drilled in New Kent County. Most of these are located along the Pamunkey River, at Providence Forge, and at Boulevard (known also

as Windsor Shades). All the wells are for domestic use and almost all obtain water from the Mattaponi formation. In the lower part of the county a few wells obtain water from the Nanjemoy formation. The water is a soft sodium bicarbonate type.

There are a large number of domestic small-diameter wells in Charles City County along the James and the Chickahominy Rivers. Along the Chickahominy River there are many wells that obtain water from the Nanjemoy formation, but along the James River the source is ordinarily the Mattaponi formation. In the westernmost part of the county units of the Potomac group may lie within the reach of wells of moderate depth. The water obtained from deep wells is of a soft sodium bicarbonate type but the Nanjemoy formation yields slightly hard water.

James City County is on the margin of the zone of high-chloride waters but most deep wells, except those at Williamsburg, yield water in which chloride content is negligible. Most of the wells in the county reach the Mattaponi formation but there are a number in the upper part of the county along the Chickahominy River that obtain water from the Nanjemoy formation. At Jamestown the Chickahominy formation is an inferior water-bearing formation but it is possible that this formation yields water to a few wells at Williamsburg.

Ground-water conditions in York County are known largely from results of deep drilling in the Camp Peary–Yorktown area. In this area the chloride content of water from wells reaching the upper beds of the Mattaponi formation is high, and deeper wells yield water in which the chloride content is notably higher. However, the use of deep-well water was almost entirely discontinued when fresh surface-water supplies became available from the Chickahominy River watershed.

The Calvert formation furnishes water to one well at Yorktown and a few shallow drilled wells obtain water from the Yorktown formation. The water from the shallow Miocene units is somewhat hard but free of excessive chloride.

Pumping tests made at Camp Peary show that the transmissibility of the upper part of the Mattaponi formation there ranges from 30,000 to 80,000 gpd (gallons per day) per foot and has an average value of about 50,000 gpd per foot.

In Warwick County, ground water obtained at Lee Hall for the Newport News and Fort Eustis water systems contained objectionable amounts of chloride. The water was used as a supplement to the Newport News supply in time of drought and as a water supply for Fort Eustis for several years. At Newport News the water obtained from beds in the Mattaponi formation is even higher in chloride content than that at Lee Hall, but even this water has been found worth while for cooling and some industrial purposes. A few shallow drilled or driven wells obtain water from the Yorktown formation in Warwick County.

About 1900 a well at Fort Monroe, Elizabeth City County, was drilled to bedrock. Only high-chloride waters were present in the Coastal Plain sediments so this and other attempts to produce potable water failed. A few shallow wells produce potable water from deposits of the Columbia terrace.

INTRODUCTION AND ACKNOWLEDGMENTS

This report summarizes the results of an investigation of the ground-water resources of the York-James peninsula in Virginia, which was made as a cooperative project of the Division of Geology of the Virginia Department of Conservation and Development, and the U. S. Geological Survey. It was begun under the direction of the late O. E. Meinzer, geologist-in-charge of the Ground Water Branch, U. S.

Geological Survey, and was completed under his successor, A. N. Sayre. The report covers the Coastal Plain province north of the James River and south of the York and Mattaponi Rivers, and includes eastern Hanover and Henrico Counties and King William, New Kent, Charles City, James City, York, Warwick, and Elizabeth City Counties,[1] as shown in figure 1. It includes the cities and towns of Richmond, West Point, Williamsburg, Newport News, and Fort Monroe.

Field work was done immediately preceding and during the early stages of World War II, when local studies were made in connection with obtaining water supplies for Langley Field, Fort Monroe, Newport News, Fort Eustis, the Naval Mine Depot at Yorktown, and Camp Peary. Some systematic field study was made as recently as 1947. As time and funds permitted, studies of foraminiferal content of well cuttings were made in the period 1948–53. The results of these studies have been incorporated in the text.

Some of the information obtained in this study has already been published (see p. 232). Reprint 6 and Circular 3 (Cederstrom, 1943b, 1945b) of the Virginia Geological Survey contain information on a number of deep wells in the area covered by the present report. Bulletins 58, 63, and 68 of the Virginia Geological Survey (Cederstrom, 1943a, 1945a, 1946a) and a paper published in Economic Geology (Cederstrom, 1946b) deal with the chemical character of typical ground waters in the York-James peninsula. A paper on the structural geology of southeastern Virginia, published in the Bulletin of the American Association of Petroleum Geologists (Cederstrom, 1945c), deals in detail with the geology of the area, though the conclusions presented there are revised in the present report. Also included is a study of Foraminifera from wells reaching the Chickahominy formation in the York-James peninsula area (Cushman and Cederstrom, 1945). A summary of an artificial recharge experiment carried out at Camp Peary was published in The Commonwealth (Cederstrom, 1947a).

In addition to information obtained in the field, use was made of previously published data on the Coastal Plain in Virginia, especially the work by Sanford (1913); Darton (1902); Ewing, Crary, and Rutherford (1937); and Miller (1937).

The present report contains analyses of well waters collected during the investigation and analyzed in the laboratories of the U. S. Geological Survey. A few analyses from other sources are also included.

Well drillers in and adjacent to the area furnished a large part of the data on which the hydrologic and geologic interpretations are

[1] The entire counties of Warwick and Elizabeth City have become first-class cities designated Warwick and Hampton, respectively. See sections on these counties for further explanation.

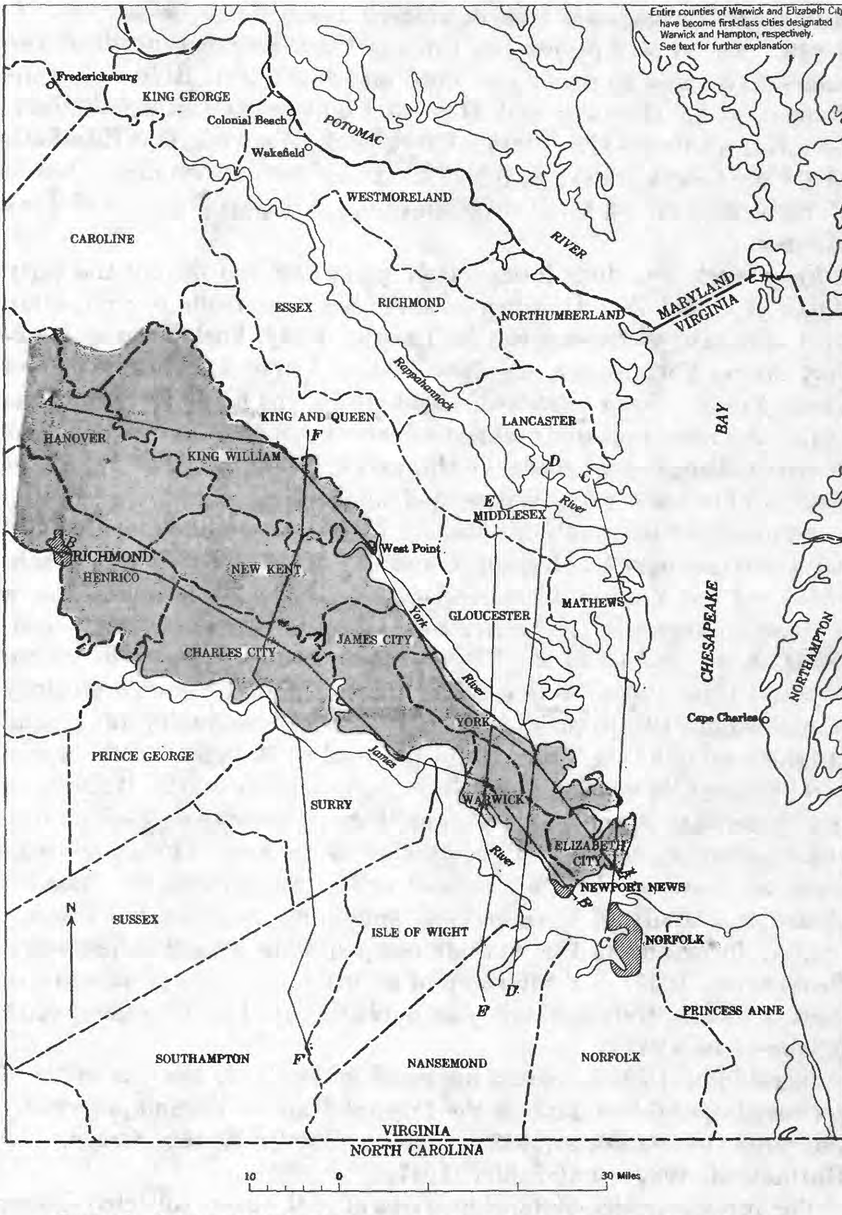

FIGURE 1.—Index map showing location of area and of cross sections given in plates 1 and 5.

based. Acknowledgment is given to O. C. Brenneman of Providence Forge and W. S. Reynolds and Sons of Walkerton. Records for the wells of large capacity were furnished by Sydnor Pump & Well Co., Inc., and the Virginia Machinery & Well Co., Inc., of Richmond, Mitchell's Well & Pump Co. of Petersburg, and the Layne-Atlantic Co. of Norfolk.

The writer is indebted to members of the Virginia Division of Geology for their comments on the manuscript, and to L. W. Youngquist, who visited and located many of the wells in New Kent, Charles City, and King William Counties. Fossils shown in plate 8 were drawn by Patricia and Lawrence Isham, U. S. National Museum.

HISTORICAL SKETCH

The area covered by this report has been the scene of an unusual number of significant historical events. It ranks with Philadelphia and Boston in Colonial and Revolutionary history and with Gettysburg and Bull Run in the Civil War.

The first permanent English settlement in what is now the United States was made at Jamestown in 1607 and the area as far west as Richmond was settled early.

Jamestown was burned in 1675 during the rebellion of Nathaniel Bacon against Governor Berkeley. Williamsburg (Middle Plantation) then became the seat of the Colonial House of Burgesses. It was a seat of political unrest in pre-Revolutionary times.

The York-James peninsula and adjacent area became a scene of conflict during the Revolution, culminating with the defeat of Cornwallis at Yorktown.

During the Civil War McClellan conducted his abortive Peninsula Campaign against Richmond in 1862. Richmond was again besieged when Grant marched from the Rapidan River to the James River in 1864. At Cold Harbor a battle was fought that was equally as bloody as the previous battle of Malvern Hill of McClellan's campaign. With the fall of Petersburg on April 2, 1865, Richmond was evacuated.

During World War I troops were trained at Fort Monroe and Fort Eustis, an air base was established at Langley Field, the Naval Mine Depot was established at Yorktown, and Newport News produced its quota of vessels. In World War II these establishments were reactivated and, in addition, Camp Peary was built for the training of naval construction troops (Seabees), an army bomber base was established at Sandston, and Camp Patrick Henry was built as a staging camp for troops going overseas.

GEOGRAPHY

AREA AND POPULATION

The 1950 area and population of the counties and cities covered in this report as given by Virginia Division of Planning and Economic Development (1951) are given in table 1.

TABLE 1.—*Area and population of counties and independent cities in the York-James Peninsula, 1950*

County or independent city	Area (square miles)	Population
Charles City County	150	4,676
Henrico County	235	57,340
Richmond	39	230,310
Hanover County	466	21,985
King William County	278	7,589
New Kent County	221	3,995
James City County	148	6,317
Williamsburg		6,735
York County	123	11,750
Warwick County	59	39,875
Newport News		42,358
Elizabeth City County	56	55,028
Hampton		5,966
Total	1,775	493,924

INDUSTRY

The industrial development as of 1947 of each of the counties and independent cities is given in table 2.

Manufacturing is localized largely in the Richmond, Newport News, and West Point areas. At Richmond paper and tobacco products are of primary importance but lumber and iron and steel products are also important. At West Point a large pulp mill and a small planing mill form a small industrial center; the building and repair of warships and large commercial vessels at Newport News have been long carried on.

TABLE 2.—*Number of manufacturing establishments and value added by manufacture, by counties and independent cities, 1947*

[Data from Virginia Division of Planning and Economic Development, 1951]

County or independent city	Number of production workers	Number of industrial establishments	Value added by manufacture (dollars)
Charles City County	197	14	363,000
Henrico County	1,348	42	9,492,000
Richmond	24,148	336	205,130,000
Hanover County	705	57	1,923,000
King William County	729	12	------------
New Kent County	1,311	10	575,000
James City County and Williamsburg	188	19	504,000
York County	232	13	498,000
Warwick County	242	22	873,000
Newport News	10,925	28	------------
Elizabeth City County	181	13	414,000
Hampton	231	16	1,167,000
Total	40,437	554	------------

The area is of importance as a tourist center and each year thousands visit the Capitol of the Confederacy, the Rockefeller restorations at Williamsburg, the National Park Service shrines at Jamestown and Yorktown, and the Mariners Museum near Newport News.

Army and Navy installations greatly affected the economy of the area during both world wars; permanent installations, such as Fort Monroe, Langley Field, the Yorktown Naval Mine Depot, and Fort Eustis, still contribute to the economic picture today.

Agriculture is important in the greater Richmond area, where more than $2,000,000 worth of eggs, chickens, and dairy products is produced annually. Elsewhere agriculture is of less importance and lumbering becomes of great relative importance to the sparse rural population.

CLIMATE

Temperature.—The mean annual temperature is 57.9° F at Richmond and 58.9° F at Langley Field, as shown in table 3. A slight ameliorating effect of Chesapeake Bay may be seen in both monthly and mean annual temperatures.

TABLE 3.—*Mean monthly and annual temperatures, in degrees Fahrenheit, at Langley Field and Richmond*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Langley Field	40.5	41.0	47.8	56.0	66.0	74.3	78.4	77.4	71.9	61.3	50.4	42.2	58.9
Richmond	37.9	39.6	47.2	56.6	66.5	74.3	78.5	76.5	70.5	59.6	48.3	39.8	57.9

Precipitation.—The mean annual precipitation ranges from 40.58 inches at Langley Field to 42.02 inches at Richmond, as shown in table 4. At both stations the maximum rainfall is in July and the minimum rainfall is in November.

TABLE 4.—*Mean monthly and annual precipitation, in inches, at Langley Field and Richmond*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Langley Field	2.97	3.34	3.57	2.98	3.39	4.27	5.08	4.53	2.77	2.50	2.13	3.05	40.58
Richmond	3.21	3.17	3.68	3.49	3.79	3.90	4.73	4.42	2.25	2.88	2.21	3.29	42.02

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTER

The area included in the York-James peninsula is underlain by unconsolidated beds that dip gently seaward and rest upon granitic rock. The sediments are of Cretaceous, Paleocene(?), Eocene, Miocene, and Pleistocene age, and consist of a series of alternating sand, clay, and marl beds (pls. 1 and 2). Richmond and Ashland lie along the Fall Line, the belt where Coastal Plain sediments are thin and granitic rock lies close to the surface. In places where the thin cover of sediments has been removed by erosion, the granitic rock is exposed. Eastward the basement rock lies at progressively greater depths and at Fort Monroe the thickness of Coastal Plain stratigraphy sediments is 2,246 feet.

STRATIGRAPHY OF THE COASTAL PLAIN IN VIRGINIA

Until recent years the Coastal Plain sediments have generally been considered to consist of the Potomac group of sand and clay sediments of Early and Late Cretaceous age, unconformably overlain by the Pamunkey group of Eocene sediments. These are in turn unconformably overlain by the Chespeake group of Miocene marls. In Quaternary time the entire area was covered by a thin veneer of terrace deposits. A notable addition to this sequence was recognized at Norfolk where fossiliferous sediments of Late Cretaceous age (Darton, 1902, p. 2) were found.

In recent years it was shown that Upper Cretaceous sediments extend inland as far as Franklin in Southampton County and Lake Prince in Nansemond County (Cederstrom, 1945a, p. 32). An addition to the geologic section, the Chickahominy formation of late Eocene age, was found to be present at Yorktown in York County (Cushman and Cederstrom, 1945).

However, various workers in the field of Coastal Plain stratigraphy, particularly those who had become interested as a result of recent large-scale oil explorations, have decided that some of the old fundamental concepts of Coastal Plain stratigraphy were in need of revision. No effort will be made here to review the various facts and suggestions presented by different workers in adjacent Coastal Plain areas; however, especial attention is given to the exposition by Spangler and Peterson (1950) who have recently studied the Coastal Plain from North Carolina to New Jersey.

Upper Cretaceous sediments have been known at Norfolk since 1902 and recently they were found to extend inland as far west as Franklin (Cederstrom, 1945a, p. 19, 31–32, 52). Upper Cretaceous sediments have not been positively identified in Virginia north of the James River, but, considering the fact that Upper Cretaceous sediments are well known in both Maryland and North Carolina, they might be expected in the Virginia Coastal Plain north of the James River. Although these sediments may not crop out along the Fall Line, it seems more than likely that they should be present under cover at least as far inland as the west shore of Chesapeake Bay.

The writer believes that Upper Cretaceous sediments are present in the subsurface north of the James River (Cederstrom, 1947b,

p. 96–97). It was pointed out that the lower 500 feet of a series of deposits at Fort Monroe, previously assigned to the Eocene (Cederstrom, 1945a, p. 35; 1945c, p. 81–82), are

> non-glauconitic, unfossiliferous and are characterized by thick beds of mottled or brightly colored clays believed to be of Upper Cretaceous age . . . they are widely distributed in the Coastal Plain north of James River and approach the Fall Line in King George and Caroline Counties.

The mottled clay beds north of the James River were later characterized as having dominantly Upper Cretaceous aspect although many forms known from the Paleocene are present near the top of the section (Cederstrom, 1950, p. 97). Fossils of Paleocene age (Midway) were recognized, or at least suspected, south of the James River several years previously by Cushman and Richards (Cederstrom, 1945a, p. 39).

These sediments, characterized lithologically by brightly colored, mottled clays, probably range from Late Cretaceous to Paleocene in age. The relationship of the beds in which Upper Cretaceous and Paleocene fossils were identified south of the James River to comparable beds in the York-James peninsula is shown in plate 5.

The mottled clays in question are widely distributed in the Virginia Coastal Plain north of the James River and are characteristically brightly colored; pink, red, and brown colors being outstanding. In places the beds are entirely unfossiliferous and nonglauconitic, but elsewhere they are highly fossiliferous or contain highly fossiliferous beds and some glauconitic beds. In other places they interfinger with or grade for short distances into highly glauconitic beds of Eocene aspect. These beds will be described in detail below.

The older and rather unsatisfactory concept of geology of the Coastal Plain of Virginia and the relationship of Virginia formations to those of adjacent States were clarified somewhat when it was found possible to accept, almost entirely, Spangler and Peterson's points of view. Their conclusions, based on study over a wide area, closely fit the observed local subsurface geology.

Spangler and Peterson (1950, p. 16–17) note that the Raritan formation of Maryland and Delaware, resting unconformably on the basement crystalline rocks, is, in New Jersey,

> a variable series of continental sands and clays, locally containing marine tongues, and is Upper and Lower Cretaceous in age. . . .
>
> . . . The writers found in examining the Cretaceous outcrops from New Jersey through Delaware and Maryland that the sediments of the Raritan formation of New Jersey were so similar to the combined sediments of the "Raritan" formation and Potomac group of Maryland-Delaware that they were led to believe the two were correlative. It was found in mapping the Potomac group of Lower Cretaceous age that it was necessary to pinch out a considerable thickness of the Lower Cretaceous beds at an unbelieveable rate so that the Upper Cretaceous Raritan formation could be shown in its true relationship in outcrop

and subsurface. This pinch-out of sediments occurred at the Delaware River, the state boundary between New Jersey and Delaware. . . .

It should be mentioned here that the same difficulty occurred at the Virginia-North Carolina state line where the Tuscaloosa, which was considered as Upper Cretaceous, abutted the Potomac group which was considered as Lower Cretaceous. The Tuscaloosa was correlated with the Raritan of New Jersey and both were thought to be younger than the Potomac beds. In mapping southward from Virginia to North Carolina it was necessary to pinch out a great thickness of Lower Cretaceous beds to allow the Tuscaloosa to be shown in its true relationship in outcrop and subsurface.

. . . it is believed from a study of the samples and electric logs that the Tuscaloosa beds are of both Upper and Lower Cretaceous age and should be correlated with the combined Raritan formation and Potomac group of Delaware-Maryland. Faunas in samples from wells in North Carolina make it possible to assign a boundary between these Upper and Lower Cretaceous beds, whereas it is doubtful that this boundary can be determined in the outcrops, for here the sediments of the Tuscaloosa are an almost homogeneous mass of continental sands and clays.

In New Jersey it has been impossible to differentiate these Upper and Lower Cretaceous beds either in the outcrop or the subsurface. Since the Raritan formation of New Jersey is, in reality, a single formation where exposed on the surface, it is treated as such and discussed as an undifferentiated unit. . . .

In describing the Potomac group of Early and Late Cretaceous age in the Delaware-Maryland-Virginia area, Spangler and Peterson (p. 63) note that the lower member of the Virginia Potomac group, the Patuxent formation,

is lithologically inseparable from the Tuscaloosa formation of the Carolinas, [and that] in drawing cross-sections north and south, one must show the beds of the Tuscaloosa formation abutting beds of the Lower [and Upper] Cretaceous Potomac group at the North Carolina–Virginia state line.

These authors consider that the lithologic distinction between the Patapsco formation and the underlying Patuxent formation, both of the Potomac group, is invalid. The contact between them, said to be unconformable, has not been specifically mentioned in the 230 outcrops described in the Virginia literature.

Referring to the basal sequence of Coastal Plain sediments in Maryland, Spangler and Peterson (p. 64) assign the Arundel, Patapsco, and Raritan formations to the Upper Cretaceous and the underlying Patuxent formation to the Lower Cretaceous. Elsewhere the authors note again that the Patuxent formation is considered Early Cretaceous in age and equivalent to the lower part of the Tuscaloosa formation of North Carolina and the lower part of the Raritan formation of New Jersey.

Finally, referring to the James River area of Virginia, concerning a portion of which the present report is written, Spangler and Peterson state (p. 81)—

It is the writers' opinion that more study is needed in this area and that the continental sediments assigned to the Patuxent may contain equivalents of Upper Cretaceous beds that are present at the north and south. Also, it may be found that some of the marine sediments which have been assigned to the Eocene may be the equivalents of the marine, Upper Cretaceous beds on the north and south.

Spangler and Peterson's conclusions were based on a regional study, whereas the writer's conclusions were gained through study of foraminiferal material from well cuttings, and insofar as the geology of the Virginia Coastal Plain is concerned, they are practically identical. In this paper, therefore, it is postulated that Upper Cretaceous and Paleocene units are widespread in the subsurface north of the James River west of Chesapeake Bay. Further, Upper Cretaceous and Paleocene units approach the Fall Line rather closely in the vicinity of Fredericksburg and in that area may grade into continental units at present mapped as Patapsco formation. (Spangler and Peterson regard the Patapsco as Late Cretaceous in age but point out that the Patapsco is not readily distinguished from the Patuxent.)

In discussing the Hornerstown marl of New Jersey, Spangler and Peterson (p. 56) state their belief that the Hornerstown is Midway (Paleocene) in age and

the gradational character from the beds below indicates that deposition was continuous from Cretaceous to Eocene, and the Hornerstown then must represent the Midway or transition beds from Cretaceous to Eocene.

In Virginia, certain fossils, just below typical Eocene units, look more like Paleocene than Upper Cretaceous forms and it appears that the Paleocene may be widely represented in the subsurface, although these beds are not necessarily very thick. As noted above, the sediments generally referred to as the mottled clay sequence are therefore considered to range in age from Late Cretaceous to Paleocene, but with the bulk of the sediments being of Late Cretaceous age. This will be discussed in more detail below.

BASEMENT ROCKS

BASEMENT ROCK SURFACE

Granitic bedrock is exposed in the James River at Richmond and is encountered a few feet above sea level in many wells in and near the city. Bedrock was struck at 280 feet (150 feet below sea level) in a well 3¾ miles southeast of the center of Richmond. The slope of the bedrock surface from Richmond to Old Point Comfort is about 60 feet per mile. At Robinwood, which is 5 miles east-southeast of Richmond, hard rock had not been reached at 500 feet (340 feet below sea level), nor did a wildcat oil well drilled near Sandston (7 miles east of Richmond) in 1917 reach bedrock at a depth of 669 feet (510 feet below sea level).

Bedrock is present at about 150 feet above sea level at Ashland and 100 feet above sea level at Doswell, but it lies below the limit of deep wells drilled in eastern Hanover County (Sanford, 1913, p. 185).

At Curles Neck, along the James River in southern Henrico County, bedrock was struck at 280 feet below sea level (Sanford, 1913, p. 191). At Upper Shirley in western Charles City County, a well struck bedrock at 350 feet (Sanford, 1913, p. 148), probably about 320 feet below sea level. It has been reported (Cederstrom, 1945a, p. 132) that at Howlett House, on the west bank of the James River opposite Curles Neck, bedrock was struck at 260 feet below sea level. These reports suggest that here, a short distance east of the Fall Line, the basement rock surface has a very gentle seaward slope in contrast to the steep slope east of Richmond.

At Mulberry Island, near Fort Eustis, depth to bedrock was determined by geophysical means (Ewing, Crary, and Rutherford, 1937; Miller, 1937) and was found to be 1,300 feet. At Fort Monroe bedrock was reached at 2,246 feet in a well drilled by the U. S. Army in 1902 (Darton, 1902).

GRANITIC ROCK

OCCURRENCE

Granite forms the basement rock throughout the area covered by this report with the exception of part of Hanover County. The rock is massive but in most places it is broken by intersecting fracture planes that are filled with water below the water table. In this report, most of the wells that have been drilled in granitic rock are located in Richmond and vicinity.

WATER-BEARING PROPERTIES

The unpredictable and erratic results of drilling in granite are well illustrated by two wells (72, 73, table 5) drilled in the community of Westbrook near Richmond. One well, 900 feet deep, obtained a yield of 5 gpm (gallons per minute) and a second well, nearby, only 468 feet deep, obtained a yield of 50 gpm. Obviously the poorer well failed to intersect a fissure or series of fissures in the solid rock along which water could be transmitted into the well.

At the Hotel Richmond and at the abattoir (51, 56, table 5) yields of 300 gpm were reported. However, the average yield of wells reaching granitic rock is considerably lower. In arriving at an average, it must be taken into account that some failures are generally unknown and therefore are not included. Thus, the list of wells given by Sanford (1913) may be incomplete and the average yield figure obtained may be somewhat high.

Data were obtained from the Sydnor Pump & Well Co., Inc., on wells drilled near Richmond for a number of small housing projects. These data (table 5) are complete to the extent that all the wells drilled are included in the compilation. According to these data, fourteen 8-inch wells were drilled to an average depth of 293 feet, from which an average yield of 26 gpm was obtained. Furthermore, these wells had a yield of 0.2 gpm per foot of drawdown.

In contrast to the above figures, if the remainder of the list (table 5) of wells reaching granitic rock, most of which are taken from Sanford (1913) is used it would appear that 18 wells were drilled to an average depth of 427 feet, and an average yield of 109 gpm was obtained. This is a misleading appraisal of the situation and a better evaluation would be obtained by using the former group of figures and assuming that moderately deep wells in the granite will generally furnish from 15 to 35 gpm but that much greater or much smaller yields can be expected in some wells.

It is generally believed by drillers that drilling wells in granitic rock to depths greater than 400 feet is not justified unless there has been a continuous increment in yield down to that depth. In other words, if a rock mass is fractured and yields more and more water as the well is deepened, then the well should be continued to about 700 feet or until further gains cease. If, however, the rock is massive and very little water is obtained at a depth of 350 or 400 feet, then the probability of finding fissures at greater depths is small.

Water from granitic rock is generally of good chemical quality and quite palatable; a few of the old wells mentioned by Sanford, however, yielded water that was excessively hard and a few wells in Richmond were obviously contaminated by industrial or other wastes.

TRIASSIC SYSTEM

OCCURRENCE

The bedrock at Ashland is Triassic sandstone, similar to rock cropping out on U. S. Highway 1 where it crosses South Anna River a few miles to the north of Ashland. Triassic bedrock was reached in a deep well at Doswell in north-central Hanover County, according to Sanford (1913, p. 186).

WATER-BEARING PROPERTIES

As near as can be determined, yields comparable to those obtained from granitic rock are obtained from the Triassic formations. Three wells at Ashland, 250, 290, and 374 feet deep, obtained respectively 85, 27, and 45 gpm. At Doswell, one well 192 feet deep obtained only 1½ gpm, but another well 200 feet deep obtained 210 gpm with

92½ feet of drawdown. Two other wells at Doswell, one 174 feet deep and the other 400 feet deep, obtain about 15 gpm each.

At Doswell a sample of water from a well 174 feet deep was found to be a slightly hard calcium- and sodium-bicarbonate type.

CRETACEOUS SYSTEM—POTOMAC GROUP

LITHOLOGIC CHARACTER

Sediments of the Potomac group of Early and Late Cretaceous age crop out along the James River below Richmond and along the Pamunkey River in north-central Hanover County. (See pl. 1 and fig. 1; Va. Geol. Survey, 1928.) These sediments consist of alternating clays and arkosic sand deposits of continental origin. The individual beds generally are not coninuous over wide areas but thin out and give way to beds of some other type. However, where the Potomac is several hundred feet thick there is a good possibility of finding several sand beds, although it may not be possible to predict the exact depth at which these beds will be found.

WATER-BEARING PROPERTIES

A number of wells in the Fall Line area reach the alternating sands and clays of the Potomac group, but east of the Fall Line the Potomac group is buried beneath a thick cover of younger formations and is beyond the reach of all but the deepest wells.

Several wells in eastern Hanover and Henrico Counties obtain water from sands in the Potomac group. Some prolific water-bearing strata are present but little is known of the potential supplies that might be available from these formations in such favorable localities as easternmost Henrico and Hanover Counties, western Charles City County, and New Kent County, where they might be reached at moderate depths. It is believed that a number of excellent wells along the James River in southwestern Charles City County probably obtain water from Lower Cretaceous sands.

In the lower peninsula area, the beds in the Potomac group are generally not important, even though the record at Fort Monroe (8c, table 36) shows they might prove to be as excellent water-bearing beds as beds of the same age south of the James River. In York, James City, Warwick, and Elizabeth City Counties, they are saturated with water that is more or less brackish and of very limited usefulness.

Near the Fall Line, too, the importance of Lower Cretaceous strata diminishes because there the total thickness of unconsolidated sediments is small and, although the water is of generally good quality, the potential yield of deep wells is limited. Several housing projects immediately northeast of Richmond obtain water from Lower Cretaceous sands.

CRETACEOUS TO TERTIARY SYSTEMS

UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

LITHOLOGIC AND PALEONTOLOGIC CHARACTER

In the writer's opinion certain beds occurring in the subsurface of the Virginia Coastal plain north of the James River should be assigned to the Upper Cretaceous and Paleocene series. In 1946 a hole was drilled to a depth of 654 feet at Colonial Beach, on the bank of the Potomac River. The Nanjemoy formation is almost entirely unfossiliferous here but the base of the formation at 194 to 197 feet is marked by the characteristic pink Marlboro clay member. The next 28 feet of dark glauconitic material is assigned to the Aquia formation of Eocene age. Below the base of the Aquia occurs 429 feet of sediments; the top 100 feet is glauconitic to some degree, whereas the remainder consists of brightly colored mottled clays, and gray, blue, red, and purple-brown clays. Below the colored clays is 20 feet of water-bearing sand.

In this well at Colonial Beach, between depths of 250 and 320 feet, a rich foraminiferal fauna occurs that is highly characteristic and appears to have correlatives throughout the Coastal Plain. At the base of the mottled clay member, at a depth of 375 feet, this fauna is present again. The 429 feet of material below the base of the Aquia, characterized in the upper part by mottled clays, is thought by the writer to be of Late Cretaceous to Paleocene age and is here designated the Mattaponi formation. The well at Colonial Beach is considered to be the type well. The log is given below.

Driller's log, municipality of Colonial Beach, Westmoreland County

[Data by Virginia Machinery & Well Co., Inc. Altitude, 20 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	30	30
Chesapeake group (Miocene): Clay, gray, compact	42	72
Nanjemoy formation (Eocene):		
Sand, yellow, clayey	6	78
Gravel	6	84
Boulders, fine sand, gravel	11	95
Clay, black, glauconitic	99	194
Clay, pink	3	197
Aquia formation (Eocene): Marl, dark-olive-green, glauconitic, sandy	28	225
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, black, hard	10	235
Sand, black	15	250
Sand, grayish-green, clayey, glauconitic; Foraminifera	25	275
Clay, dark-olive-green, sandy; Foraminifera	20	295
Sand, dark-gray, running, clayey; Foraminifera	25	320
Clay, mottled, yellowish, red-to-brown, gray; Foraminifera at base	54	374

Driller's log, municipality of Colonial Beach, Westmoreland County—Continued

	Thickness (feet)	Depth (feet)
Mattaponi formation (Upper Cretaceous and Paleocene—Con.		
Sand, fine, gray; water under good head	26	400
Clay, pale-green, silty	10	410
Clay, dark-gray	7	417
Clay, dark-gray, lumps in gray sand	8	425
Clay, dark-gray, and sand	25	450
Clay, tough, gray and brown	110	560
Clay, light-gray	4	564
Clay, red	6	570
Clay, light-brown	10	580
Clay, dark-purplish-brown	10	590
Clay, bright-red	10	600
Clay, light-gray	20	620
Clay, dark-gray	14	634
Sand, water-bearing	20	654

At Washingtons Birthplace, 4 miles southeast of Colonial Beach, a well less than 400 feet deep contains an unusually rich foraminiferal fauna that provides a particularly fine basis for study of the Mattaponi faunal suite and permits easy correlation with strata to the east and southeast.

Two things will be noted in the following log of the well at Washingtons Birthplace: There is no great lithologic difference between

Driller's log, Washingtons Birthplace, Westmoreland County; H. Muse

[Data by Mitchell's Well & Pump Co. Altitude, 20 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, yellow, and sand	20	20
Chesapeake group (Miocene): Marl, gray, sandy	60	80
Nanjemoy formation (Eocene):		
Clay, black, glauconitic	46	126
Clay, light-grayish-green, glauconitic; Foraminifera	93	219
Clay, dull-pink	5	224
Aquia formation (Eocene):		
Sand, glauconitic	6	230
Marl, vivid-green, glauconitic; Foraminifera	22	252
Mattaponi formation (Upper Cretaceous and Paleocene):		
Sand, slightly marly, glauconitic; Foramininifera	4	256
Marl, vivid-green, glauconitic; Foraminifera	34	290
Rock	½	290½
Sand, slightly marly, dark-green, glauconitic; Foraminifera	20	310½
Rock	½	311
Sand, slightly marly, dark-green, glauconitic; Foraminifera	37	348
Clay, dark-yellowish-brown	38	386
Sand, fine, gray; water	10	396

Eocene and pre-Eocene units, and there is little evidence of the brightly colored clay beds found at Colonial Beach. For example, at Colonial Beach mottled clay is present at a depth of 320 feet and should be expected at about 340 feet at Washingtons Birthplace. At Washingtons Birthplace dark-yellowish-brown clay is present at 348 feet.

Foraminifera at 237 feet appear to represent a typical Aquia assemblage; at 254 feet several distinctly different and older forms appear and most typical Aquia forms have disappeared; at 266 feet several more older forms appear but no further sharp differences in faunal content are noted to a depth of 350 feet. Regardless of the ultimate determination of the fossils found in the pre-Aquia units, it is certain that a significant faunal change occurs between 237 and 254 feet. Sediments below 348 feet are unfossiliferous but there is no reason to believe that a formational boundary is passed at that depth.

Because of the faunal content of the well at Washingtons Birthplace, it is designated as the second of two type wells for the Mattaponi formation.

Two wells at Oak Grove (Cederstrom 1945b, p. 17–19), 6 miles south-southwest of Colonial Beach and 5½ miles southwest of Washingtons Birthplace, show the range of variation in the characteristics of the Mattaponi formation. In the Estate Wirtland well about 350 feet of sediments of the Mattaponi formation are tapped. At a depth of 355 feet (about 200 feet below sea level), 119 feet of glauconitic quartz sand is found and below this is 176 feet of yellow to yellowish-brown glauconitic clay. At the base of this sequence 48 feet of white quartz sand is present. In the adjacent Henneson well 60 feet of glauconitic tough pink clay and tough mottled red clay occur near the depth where the yellowish-brown clays are found in the Wirtland well.

At Westmoreland State Park about 3 miles downriver from Washingtons Birthplace, Foraminifera indicate that the top of the Mattaponi formation, as here defined, occurs at a depth of 350 feet or less. The section below 350 feet is characterized by brown, gray, and red clays, mostly dark, but none are mottled. Twelve feet of quartz sand was penetrated at a depth of 617 feet.

At Dahlgren (Cederstrom, 1945b, p. 15), about 3 miles north-northwest of Colonial Beach, the top of the Mattaponi formation is considered to lie at a depth of about 170 feet below sea level. At 272 feet below sea level, 22 feet of reddish-brown clay is present and is underlain by 74 feet of yellow clay. Tough red clay occurs between 402 and 408 feet and yellow clay from 409 to 499 feet below the surface.

Thus, the Mattaponi formation appears to be highly variable in its makeup; it may contain a rich foraminiferal fauna in one locality but this fauna may be extremely meager in adjacent localities. The highly colored clays, commonly mottled, may grade laterally into dark nondescript clays or glauconitic beds in short distances. The upper part of the sequence commonly contains glauconitic beds of an Eocene aspect and in places the highly colored clay beds are glauconitic. It appears that these beds are nearshore marine sediments, subject to considerable variation in short distances.

In the vicinity of Chesapeake Bay, the highly colored strata are apparently less common. However, in a well at Reedville, Northumberland County (Cederstrom, 1945b, p. 28), "brown plastic clay is present, grading through red, yellow, and purple," at depths of from 581 to 660 feet, and "red and brown clay" at 689 to 718 feet is reported. At Burgess Store, Northumberland County, mottled clay is found at a depth of about 500 feet below sea level and extends to a depth of 680 feet and the characteristic Mattaponi fauna, here containing a very high globigerinid content, is found at 550 feet. This fauna has been noted in several wells in the area and is somewhat different from the fauna at Washingtons Birthplace and it may be a deep water facies of the Paleocene part of the Mattaponi formation.

At Moss Neck Manor in Caroline County, the base of the Aquia formation may occur a few feet above sea level. In a well drilled here in 1950, a meager foraminiferal fauna was found about 50 feet below sea level. The rare Foraminifera found appear to be identical with similar Foraminifera found near Kilmarnock, at a depth of more than 600 feet. Regardless of the exact age of the Foraminifera, since they are obviously pre-Eocene, their very presence suggests that these fossiliferous marine pre-Eocene units may crop out along the Fall Line as Moss Neck lies only 4 miles east of the contact of the Aquia with the Patuxent formation as shown on the geologic map of Virginia. The driller indicates that immediately below the blue clay in which the pre-Eocene Foraminifera were found, "tan and white mixed clay" occurs from 135 to 145 feet below sea level, and other beds suggestive of the highly colored Mattaponi formation are found at somewhat greater depths.

On the York-James peninsula, the Mattaponi formation is well preserved at West Point in King William County. In well 26a (table 12) bright mottled clay is first found at 411 feet (129 feet below the base of the Aquia formation) and is reported again at 510 to 568 feet. The predominantly sandy section between 630 and 721 feet may mark the base of the Mattaponi formation. Study of the foraminiferal content indicates that the top of the formation is much higher, however; about 50 feet below sea level. In well 27a (table 12) at West Point, mottled clays are likewise reported to be present. At Cohoke in well 34 (table 12) "hard mottled clay" is reported at

465 feet below sea level. At Walkerton "mixed colored clays" are reported at 280 feet below sea level.

Directly to the south of West Point, characteristic Mattaponi Foraminifera were found in several wells (table 28) at Camp Peary and at Yorktown. At Fort Eustis, not much could be learned regarding the Mattaponi, but at Newport News, the Mattaponi formation appears to be present at 644 feet in well 44 (table 33), if not above that depth. Mottled clays occur at 644 feet and are found to a depth of 786 feet in this well. The sandy zone between 1,013 and 1,082 feet may mark the base of the formation. Attention is called to the presumed Mattaponi section logged between 600 and 900 feet in well 46 (table 33), at Newport News. The upper 130 feet consists of alternating brightly colored clays and glauconite sand, succeeded by 30 feet of mottled red and yellow clay that in turn is underlain by 230 feet of clay or clayey beds, several feet of which is highly colored but apparently lacks glauconite.

Little is gained from perusal of the logs of the old U. S. Army well (8c, table 36) or the Chamberlain Hotel well (9, table 36) at Old Point Comfort even though the former penetrated the entire Mattaponi section. This well will be referred to in a discussion of the Eocene below.

WATER-BEARING PROPERTIES

The mottled clays and basal sands and gravels of the Mattaponi formation have been reached by deep wells at West Point, Yorktown, Fort Eustis, Newport News, and other places. Although its true thickness is uncertain, it is apparent that in the eastern part of the area the succession of colored clays and basal sands underlies much of the area and is capable of furnishing large supplies of water to wells. However, east of Williamsburg, the water obtained is of different degrees of brackishness and its usefulness is limited. The western extent of these beds upstream along the Pamunkey River and the Mattaponi River in King William County, in upper James City County, and in New Kent and Charles City Counties, is less certain, but it is thought that they occur at least as far west as Aylett, Manquin, Providence Forge, and Charles City.

Regardless of the uncertainties concerning the Mattaponi formation, the succession of beds is present in many places and they furnish large supplies of water to wells. At West Point (26a, 27a, 28a, b, c, 29a, 30, table 11), 400 to 1,100 gpm is obtained from each well tapping these beds. Many small-diameter domestic wells that tap these beds in lower King William County yield excellent supplies of water, as at Aylett. A few wells in northern Charles City County may reach the Mattaponi formation. The wells at Dunbar Farm and Waller

Pond near Williamsburg (56, table 22; 22, table 28) and the wells at Camp Peary, Fort Eustis, and Yorktown obtained water from these beds. Three large-diameter wells at Newport News (43, 44, 46, table 32) that furnish water for industrial use also obtain water from deep sands underlying mottled clays.

It is apparent, at least in westernmost James City County, and in eastern Charles City and New Kent Counties, where their presence is reasonably certain, that these beds constitute a great underground reservoir of fresh water which has not yet been tapped by large-yield wells.

Transmissibility.—Several determinations of the transmissibility of the upper sands of the Mattaponi formation were made at Camp Peary. It was found that transmissibility ranged from 22,000 to 85,000 gpd per foot. In the well on which tests were made, from 30 to 50 feet of water-bearing material was developed. These tests are described in detail on pages 162–169.

The water from these beds in the lower peninsula area is too brackish for most uses.

TERTIARY SYSTEM

EOCENE SERIES

Formations of Eocene age crop out along the north bank of the James River in western Charles City County and southeastern Henrico County and along the upper Chickahominy River from the western tip of New Kent County to a point several miles above Aylett (Va. Geol. Survey, 1928). They are mapped along the Pamunkey River from Aylett to and beyond (upstream) the northern borders of King William County. The full thickness of formations of Eocene age in the northern part of the Coastal Plain is said to be about 300 feet (Clark and Miller, 1912, pp. 91–104), but in the area covered by this report no individual outcropping is more than 30 or 40 feet thick.

The top of this group of deposits, as determined from Foraminifera present, is reached in wells at 55 feet above sea level at Bottoms Bridge in eastern Henrico County; at about 150 feet below sea level at West Point; at 210 feet at Camp Peary, York County; 300 feet at Yorktown; 350 feet at Camp Patrick Henry; 400 feet at Newport News; and 600 feet at Fort Monroe. Figure 2, drawn on the contact between the Miocene and Eocene, shows the altitude of the bottom of the Miocene formations relative to sea level.

The total thickness of Eocene strata is about 160 feet at Bottoms Bridge in eastern Henrico County and 110 feet at West Point, and it probably is much greater at Fort Monroe and Newport News.

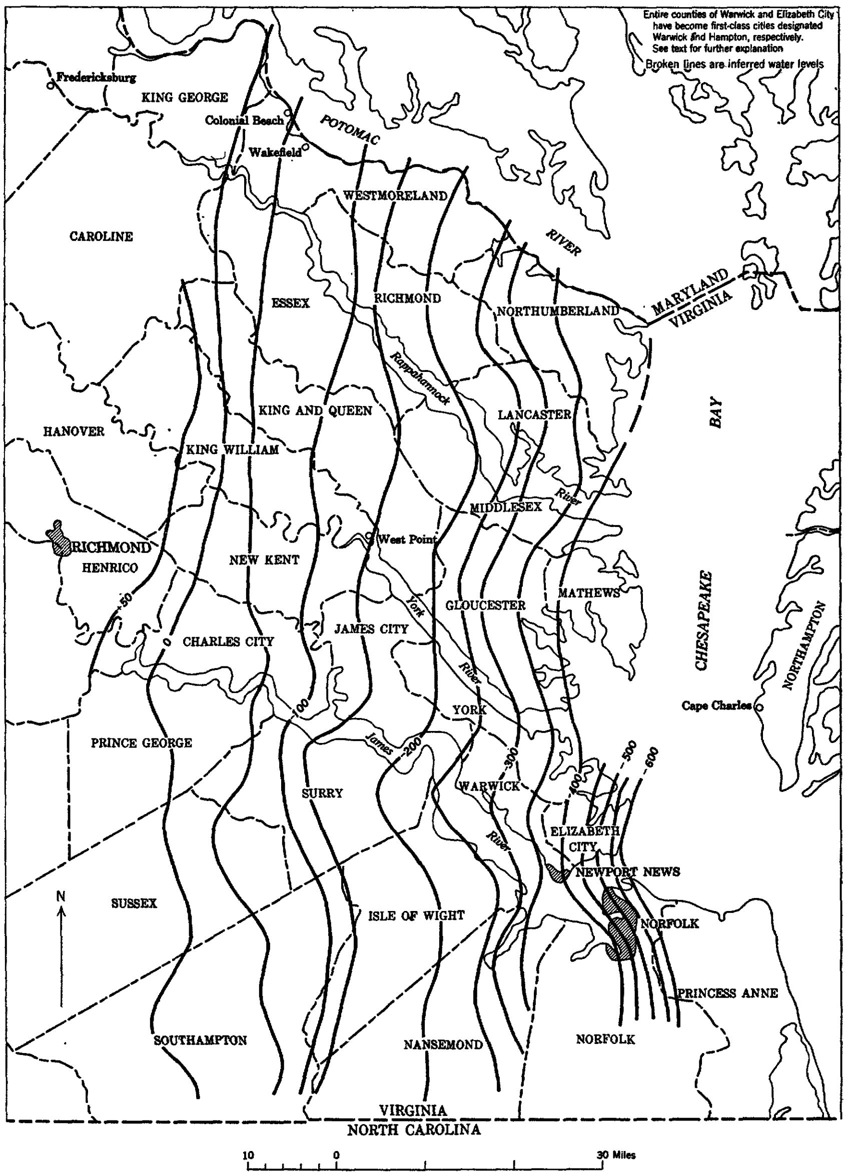

FIGURE 2.—Structural contour map of the base of the Miocene formations.

The deposits consist largely of blue and gray marls or clays, almost everywhere glauconitic to some degree. Interbedded subordinate sands range in composition from glauconite sand to quartz sand containing only a trace of glauconite.

The Pamunkey group of Eocene age, cropping out along the Fall Line in Virginia, has been subdivided (Clark and Miller, 1912, p. 90) into the Aquia and Nanjemoy formations. The Aquia formation (Clark and Miller, 1912, p. 103–104) is of early Eocene age; the lower Potapaco clay member of the Nanjemoy formation is also early Eocene but the upper Woodstock greensand marl member of the Nanjemoy is of middle Eocene age.

The basal Aquia formation, an aquifer that has been tapped by wells at Sandston, Bottoms Bridge, Polegreen, and Mechanicsville, appears to correlate eastward with sands that are overlain by beds containing Foraminifera of the Mattaponi formation. The interpretation adopted here is that this sand represents a shoreline deposit of an advancing Paleocene to Eocene sea and ranges in age from Paleocene to early Eocene. The upper part of the Mattaponi formation and the Aquia formation are deposited as a progressive marine overlap (Malkin and Echols, 1948, p. 252–261) and presumed to be conformable (Lahee, 1949, p. 1901) upon older sediments.

It seems evident (pl. 1) that the lower Eocene (Wilcox) part of the Nanjemoy formation, the Potapaco clay member, truncates the Aquia formation. This relation is shown in section A–A′, plate 1. In King William County, the Aquia thins out eastward, apparently, more rapidly than the overlying Potapaco clay member of the Nanjemoy formation (recognized by the presence of the basal Marlboro clay member).

Thus, the Aquia formation is recognized only in the vicinity of the Fall Line; characteristic Foraminifera have been recognized in wells at Mechanicsville and Bottoms Bridge but the formation probably extends a little distance farther to the east. Downdip, however, the Aquia formation and the lower Eocene Potapaco member of the Nanjemoy formation, as well as the basal pink Marlboro clay member of the Nanjemoy, have been truncated by the transgressive sea of middle Eocene time during which the upper (Claiborne) part of the Nanjemoy formation was deposited. Hence, eastward, the middle Eocene Woodstock member of the Nanjemoy formation generally rests upon beds of the Mattaponi formation.

Foraminifera present in cuttings of deep wells at Yorktown show the presence of upper Eocene units. These strata, which do not crop out along the Fall Line, have been named the Chickahominy formation (Cushman and Cederstrom 1945). The foraminiferal fauna

FOSSILIFEROUS LIMESTONE FROM THE AQUIA FORMATION AT BELVEDERE BEACH

has been described and illustrated by Cushman and Cederstrom (1945, pl. 17).

The upper Eocene Chickahominy formation likewise truncates the older beds and the underlying Nanjemoy formation appears to be thinned in places downdip, as at Jamestown and Camp Peary. So far, however, the writer has not found conclusive evidence that the Chickahominy transgression has removed the Nanjemoy formation entirely at any specific locality in the York-James peninsula.

The Chickahominy formation was subsequently truncated in Miocene time and as a result does not extend much farther west than Jamestown and West Point (pl. 1).

In previous publications (Cederstrom, 1945a, p. 36–37, pl. 1, and 1945c, p. 81–82, figs. 6–7) the Eocene was said to be as much as 800 feet thick. This conclusion was based on the presence of Eocene Foraminifera as reported by Cushman, on the presence of glauconitic sand in sediments thus designated, and by the report of Eocene macrofossils found at 1,440 feet in the old U. S. Army well at Fort Monroe.

The pre-Eocene Mattaponi formation is characteristically glauconitic; the writer is satisfied that the Eocene Foraminifera found at depth in the well cuttings from Fort Monroe are forms first appearing much higher and were washed down. The Eocene macrofossils found at 1,440 feet at Fort Monroe are believed to have fallen from above or to have been improperly labeled when collected. It may be noted that no "rock" layer is reported in well 8c (table 36) in which the fossils are said to have occurred but, on the other hand, a "calcareous rock crust and pebble conglomerate with some wood and shells" is logged between 840 and 850 feet in the Chamberlain Hotel well (9, table 36). This log description is the only one in the two wells that fits the fossiliferous material shown to the writer by L. W. Stephenson.

The thickness of all the Eocene formations in Newport News may be as much as 240 feet, if the macrofossil was taken at that depth. The writer is inclined to believe it may not be much more than 125 feet thick. In any event, granting a thickness of 240 feet, the thickening of the Eocene section is hardly more than moderate.

AQUIA FORMATION

LITHOLOGIC CHARACTER

The Aquia formation consists of glauconite sand and marl beds and a basal quartz sand bed. Consolidated limy beds such as shown in plate 3 are rare. In places the marl beds may be reported as gray or blue clay by the driller but it is thought that such formations are probably glauconitic to some degree also.

At Bottoms Bridge (35, table 6) the formation is 82 feet thick. This well was carefully sampled and the log is accurate. However, if interpretation of logs of wells 19 and 22 (table 9) is correct, the thickness of the Aquia in eastern Hanover County may be as much as 150 feet.

PALEONTOLOGIC CHARACTER

The Foraminifera present in the Aquia section of the well at Bottoms Bridge are typical of the formation (Cushman, 1944). The assemblage at Polegreen (well 28, table 9) is somewhat less typical. The writer has failed to find any good Aquia assemblage in any of the suites of samples from wells in the counties farther to the east, either in the York-James area or northward, and it is concluded that the formation pinches out within 30 miles of the Fall Line, presumably owing to trangression of the early Eocene (Potapaco) sea.

WATER-BEARING PROPERTIES

The Aquia is of limited importance as a water-bearing formation but does furnish moderate supplies of ground water in the area a few miles east of the Fall Line. Municipal supplies are obtained in part from the Aquia at Mechanicsville, Sandston, and Highland Springs.

NANJEMOY FORMATION

LITHOLOGIC CHARACTER

The Nanjemoy formation is of late and middle Eocene age. The higher beds of the Nanjemoy at Windsor Shades (35, table 16) and in lower Charles City County consist of indurated shells, thin "rock" (limestone) streaks, and glauconite and quartz sand mixtures. At the New Kent school, indurated layers and gray sand are reported. A glauconite (black) and quartz sand mixture and thin rock streaks characterize the Nanjemoy at Cumberland Landing; rock layers and gray sand are reported across the river at Cohoke. At West Point the upper beds are largely limestone with many small cavities (coquina) and minor glauconite sand. (The uppermost of these beds may possibly belong to the Chickahominy formation.) "Black and white sand" is reported at Horse Landing on the Mattaponi River, but in the western part of King William County, as in eastern Henrico County, the upper beds of the Nanjemoy grade into marl. Limestone is also present at Williamsburg, but thick limestone beds at Fort Eustis (21, 22, table 33) appear to occur in the Mattaponi formation rather than in the Nanjemoy formation.

The Nanjemoy formation is about 80 feet thick at Bottoms Bridge in western Henrico County, perhaps as much as 130 feet thick at Cohoke, 110 feet thick at West Point, 80(?) feet thick at Providence Forge, 70 feet thick at Charles City, and appears to range from 35 to

60 feet in thickness at Camp Peary. It may be thinner or absent in the lower peninsula area.

Below the more permeable sandy and limestone beds the Nanjemoy consists largely of glauconitic marl. In places the marl is underlain by a pink clay stratum, the Marlboro clay member (Clark and Miller, 1912, p. 103–104). At Bottoms Bridge in western Henrico County, this stratum is 20 feet thick. West of Bottoms Bridge the pink (or red) clay is recognized at Highland Springs, Sandston, and Glendale (24b, 30, 37, table 6), in Henrico County and at Roxbury (1, table 19) in Charles City County. The clay ranges in thickness from 2 to 20 feet in these places. East of Bottoms Bridge a number of rather good well logs show conclusively that the basal pink clay is generally absent in that area. As noted above, the basal pink clay is of early Eocene age and was removed downdip during the middle Eocene transgression.

PALEONTOLOGIC CHARACTER

The Nanjemoy formation has been recognized by the presence of Foraminifera of middle Eocene (Claiborne) age in cuttings from wells at Sandston, Bottoms Bridge, Jamestown, Charles City, Providence Forge, Windsor Shades, Cumberland Landing, Cohoke, West Point, and Camp Peary. There is only a suggestion of the presence of middle Eocene units in samples from wells at Newport News, although admittedly these samples are from a rotary well and hence somewhat poor for foraminiferal studies. The geologic map of Virginia (Va. Geol. Survey, 1928) indicates that the formation is absent westward in many places along the Fall Line, where it was removed by the transgressive Miocene seas. Foraminifera of early Eocene (Wilcox) age, assigned to the lower Potapaco member of the Nanjemoy formation, have been recognized with certainty only at Bottoms Bridge and Polegreen, both localities fairly near the Fall Line.

The Nanjemoy formation is imperfectly known in the lower York-James peninsula. Only a few fossils characteristic of the formation to the west of the lower peninsula can be readily recognized in samples taken from wells at Fort Eustis, Newport News, and Fort Monroe, although contamination by a rich fauna washing down from the Chickahominy formation and Chesapeake group may have badly obscured the relatively lean Nanjemoy fauna below. The Nanjemoy may be absent; certainly the rich characteristic foraminiferal assemblage commonly found to the west is lacking.

WATER-BEARING PROPERTIES

The Nanjemoy formation yields water to a great many domestic wells along the Chickahominy River at Providence Forge and southeastward to the mouth of that river on the James River. (See tables 15 and 18.) These wells are developed in sand beds that lie between limestone strata (rock) or, less commonly, in honeycombed limestone beds.

Northward the higher units of the Nanjemoy are drawn upon to a lesser extent; a well at New Kent School (14, table 15) taps these strata and several wells at farms along the Pamunkey River (17, table 15) probably obtain water from them also. As nearly as can be surmised, well 36 at Cohoke, and well 50 at Manquin (table 11), which are on the King William County side of the Pamunkey River, and well 19 at Horse Landing, and well 21 at Whiteoak Landing (table 11), on the Mattaponi River, also obtain water from the Nanjemoy.

At West Point, yields of about 250 gpm have been obtained from limestone and intercalated sand beds of the Nanjemoy and Chickahominy(?) formations. It seems likely that some of the old wells at Fort Eustis, 367 to 390 feet deep, obtained water from the Nanjemoy formation. In 1914, before great losses in artesian head had taken place, a 3-inch well (14, table 32) had a flow of 110 gpm. (J. Minton, of Smithfield, who drilled the well, stated to the writer that he had a great deal of trouble in jetting through rock layers.) One 10-inch well (15, table 32) drilled in 1918 had a flow of 125 gpm and another (16, table 32) had a flow of 230 gpm.

Elsewhere, the Nanjemoy formation has been tapped by few wells. In places the water-bearing beds grade into fine or clayey sands. In many places larger quantities or a stronger flow (higher head) are wanted and wells are drilled to the underlying Mattaponi formation. In some areas of high ground away from areas of flowing wells, artesian pressure in the Nanjemoy may be considerably higher than that of deeper beds. In a well (8, table 18) south of Providence Forge, the static level of water in the Nanjemoy formation was 53 feet above sea level, whereas, when the same well tapped deeper beds, static level was about 10 feet above sea level. In well 42 (table 15), 2 miles north of Providence Forge, water in a well ending in the Nanjemoy formation stands 58 feet above sea level, whereas, at Providence Forge, water from the same sand is 14 feet above sea level.

CHICKAHOMINY FORMATION

LITHOLOGIC CHARACTER

At Yorktown the Chickahominy formation is made up of blue to dull-brown clay. In most places washed residues of drill cuttings of the Chickahominy formation are highly glauconitic and pyritic and contain very few microscopic shell fragments (pl. 7). At Camp Peary, Lee Hall, and Newport News limestone beds, generally less than 2 feet thick, are intercalated in the clayey strata. In places, the glauconitic content of the clay is sufficiently great to be apparent in the unwashed cuttings. At Fort Eustis and Newport News characteristic Jackson fossils have been recognized, but since the cuttings available for study were from rotary wells not much can be said about the thickness of the Chickahominy formation at these places. However, at Newport News the formation may be as much as 125 feet thick.

PALEONTOLOGIC CHARACTER

The Chickahominy formation (Cushman and Cederstrom, 1945) of late Eocene (Jackson) age, is 80 feet thick at Yorktown, the type locality (pl. 7). It contains a foraminiferal fauna that is plentiful and easily recognized. It appears to be restricted to the lower (eastern) part of the York-James peninsula and has been found in cuttings from Yorktown, Camp Peary, Jamestown, Lee Hall, Newport News, Fort Monroe, and Fort Eustis.

WATER-BEARING PROPERTIES

Although not water bearing at the type well, the Chickahominy formation contains sandy beds of very low permeability at Yorktown (38, 39, table 27) as well as at Camp Patrick Henry, Newport News, and Norfolk. Some of the old wells at Fort Eustis (14, 15, 24, table 32) may have tapped water-bearing sands at the base of the Chickahominy formation. Well 27a (table 22) at Jamestown, tapped "water under low head" in the Chickahominy formation.

MIOCENE SERIES—CHESAPEAKE GROUP

Formations of Miocene age lie unconformably upon Eocene sediments; the eastward dip of these strata is less than that of the underlying strata and westward they transect the Eocene deposits at a lower and lower stratigraphic horizon. In places along the Fall Line, Eocene deposits have been entirely removed in the erosional interval between their deposition and the advance of Miocene seas and in those places Miocene strata may rest upon Cretaceous deposits or even upon granitic bedrock. In the Fall Line area, Miocene deposits may be only a few tens of feet thick in places, but eastward they thicken to 400 feet at Newport News and 600 feet at Fort Monroe.

The base of the Miocene formations lies about 50 feet above sea level at Bottoms Bridge in eastern Henrico County, 150 feet below sea level at West Point, 300 feet below sea level at Yorktown, and 400 feet below sea level at Newport News. The slope of the base of the formations is, therefore, about 8 feet per mile in an eastward direction. Figured in a southeastward direction (Bottoms Bridge to Newport News), the slope is from 4½ to 5 feet per mile.

LITHOLOGIC CHARACTER

The Chesapeake group (Clark and Miller, 1912, p. 126–166) of Miocene age, has been subdivided into the Calvert, Choptank, St. Marys, and Yorktown formations; the basal Calvert formation is a sandy shell marl, the St. Marys formation is largely gray tough clay, and the Yorktown formation is a marly series of strata containing shell, coquina, and sand. The Choptank formation has not been recognized south of the Rappahannock River.

WATER-BEARING PROPERTIES

CALVERT FORMATION

Basal Miocene sands of the Calvert formation yield water to a few wells in the area, mostly around Williamsburg and in upper James City County. (See tables 21 and 27.) The formation yields, at best, only moderate supplies of water and the head is low. Furthermore, in many places the Calvert formation is not sufficiently sandy to yield any water at all—hence, few wells end in this formation.

YORKTOWN FORMATION

A few wells in the area obtain water from the sand and shell beds of the Yorktown formation of Miocene age. Several wells in the vicinity of Williamsburg obtain as much as 10 gpm from these beds. At the Nelson House in Yorktown a well (40, table 27) tapping the Yorktown formation is reported to have yielded 36 gpm, but at the Navy Mine Depot a 10-inch well (33, table 27) ending in the same stratum yielded only 8 gpm.

O. C. Brenneman of Providence Forge has drilled several 2-inch domestic wells in the Yorktown formation in lower York County.

Test holes, drilled in 1942 under the writer's direction adjacent to Big Bethel Reservoir near Langley Field, showed that in this area the Yorktown formation normally contains fine gray sand beds that are poor water-bearing formations. In one test hole no sand beds were found and in another (34, table 32) beds of medium-grained sand and a stratum of sized shell fragments were present, from which 115 gpm was obtained with 81 feet of drawdown.

An excellent well in the Yorktown formation furnished the Wythe Theatre at Newport News with water for air conditioning. Here 120 gpm was obtained with 23 feet of drawdown. Several other attemps to develop water from the same depth in Newport News were only partly successful or were failures.

In the lower peninsula area it is probably worth while, where water is used in quantity, to make test holes to determine the possibility of obtaining water from the Yorktown formation. Where present, it can be produced economically and is of good quality; if sand beds are not present the cost of exploration will have been only moderate.

QUATERNARY SYSTEM

PLEISTOCENE SERIES—COLUMBIA GROUP

LITHOLOGIC CHARACTER

The Quaternary system in the Virginia Coastal Plain is represented chiefly by deposits of sand and clay that mantle the older formations to a height of about 270 feet above sea level, where they have not been removed by erosion. These deposits are collectively called the Columbia group. According to Wentworth (1930), the Pleistocene deposits below an altitude of 100 feet are chiefly marine, whereas those above 100 feet are chiefly alluvial, having been deposited as deltas and flood plains of rivers. Cooke (1931) thinks they were formed in the ocean and estuaries when the sea stood at various heights above its present level. He has recognized marine shorelines at altitudes of about 270, 215, 170, 110, 70, 42, and 25 feet and suspects that there are others that have not yet been detected.

According to Cooke's classification, the deposits that accumulated during these seven stages of high sea level are theoretically divisible into four parts. These four divisions of the Columbia group are separated from one another and from the Recent and pre-Pleistocene deposits by unconformities representing erosion intervals during which sea level stood lower than during the next succeeding stage. It is supposed that the five erosion intervals correspond to glacial stages of the Pleistocene, and that the four divisions of the Columbia group accumulated during interglacial stages (Cooke, 1935).

The oldest division is the Brandywine formation, corresponding to a sea level of 270 feet. The next oldest division includes the Coharie formation (shoreline 215 feet above present sea level) and the Sunderland formation (shoreline 170 feet). The third division includes the Wicomico formation (shoreline 100 feet), the Penholoway formation (shoreline 70 feet), and the Talbot formation (shoreline 42 feet). These three formations presumably are conformable, having been deposited at successively lower stages of sea level. The fourth and youngest division contains the Pamlico formation, whose shoreline stood 25 feet above sea level. The Sunderland, Wicomico, and Pamlico are the most widely distributed formations of the Columbia group in eastern Virginia. The Brandywine and Coharie form narrow bands along the western border of the Coastal Plain; most of the Penholoway and Talbot occupy estuarine reentrants within the older terraces.

The terrace deposits yield water to thousands of shallow dug or driven wells. In the lower part of the peninsula these deposits and the Yorktown formation are almost the only water-bearing units drawn upon because deeper formations yield brackish water.

Although only very small yields are available in many places, there are shallow wells that supply small communities, large dairies, and public schools. It seems apparent that the higher terraces in Henrico and Hanover Counties may generally be depended upon to furnish moderate supplies of water, but eastward the lower terraces are more variable in their lithology and their value as water-bearing formations ranges from nonproductive to fairly good.

WATER-BEARING PROPERTIES

The largest part of the rural population obtains its water from dug or driven wells in the terrace deposits. Practically all these shallow wells have low yields because only a minimum quantity of water is needed; but it seems likely that from 10 to 20 gpm might be available, if needed, where coarse sandy beds underlie broad flat areas. The village of Toano obtains its supply from a dug well about 10 feet in diameter. The Sydnor Pump & Well Co., Inc., of Richmond has pumped 36 gpm from a well drilled to the base of the Pleistocene terrace deposits northeast of Richmond. This 8-inch well is equipped with a strainer and was properly developed by pumping and surging. Generally speaking, the terrace deposits in Hanover and Henrico Counties are reasonably productive nearly everywhere.

Where the terrace formations are fine-grained as is common east of Hanover and Henrico Counties, or where the well site is close to a ravine and the terrace formations drain laterally, low yields may be expected. The possibility of getting moderately large supplies of water from shallow wells in gravelly areas is worthy of more consideration than is generally given.

RECENT SERIES

Recent sediments are present in some places as beach sands along the York River and the James River and also as sand spits and beaches along Chesapeake Bay in Elizabeth City County. These deposits are not important water bearers, but in a few places they may yield a little water to shallow wells.

ARTESIAN WATER LEVELS

Near the Fall Line in Hanover County water in wells tapping artesian beds stands between 50 and 100 feet above sea level. Southward at Sandston and Highland Springs in Henrico County, still relatively near the Fall Line, water in deep wells rises less than 40 feet above sea level; in southeastern Henrico County at the Glendale National Cemetery it rises only 16 feet above sea level. These differences exist because the discharge from the ground by wells in the northern area is negligible whereas to the south water levels are affected by the losses of head resulting from the unrestricted discharge of flowing wells along the James River in Charles City County and by the industrial pumping at Hopewell, directly across the James River from southeastern Henrico County.

In western King William County (65, table 11) water rises more than 30 feet above sea level and, in the vicinity of Manquin, it rises more than 20 feet above sea level. However, from Aylett to West Point on the Mattaponi River and below Manquin on the Pamunkey River, water levels are affected by flowing-well and industrial discharge at Aylett, Walkerton, and West Point. At West Point, near the discharging industrial wells, water levels are below sea level.

From West Point and Providence Forge eastward down the peninsula, water levels are generally between 5 and 10 feet above sea level, although in areas distant from flowing and industrial wells water may rise a few feet higher.

Data given by Sanford show that the original static level of water in deep wells in the lower peninsula area was at least 30 feet above sea level and in the lower reaches of the Mattaponi and Pamunkey Rivers water levels may generally have been about 60 feet above sea level. In the western part of the area water probably did not rise very much higher than it does at present.

The foregoing discussion applies directly to wells ending in the Aquia and Mattaponi formations and formations of Cretaceous age. Shallow wells ending in the Nanjemoy formation are much more variable.

In the flowing-well field from Providence Forge to the mouth of the Chickahominy River, water will rise from 3 to 10 feet above sea level in wells ending in the Nanjemoy formation. However, it has been found that within 2 miles of this area of low artesian pressure water will rise 40 to 60 feet above sea level.

Throughout the area by far the greatest part of the loss of head has resulted from the installation of many flowing wells along the major streams, but recent additional declines have occurred in response to industrial pumping at West Point and Hopewell.

QUALITY OF WATER

WATER FROM GRANITIC ROCKS

Water from granitic rock may contain little or much dissolved mineral matter. A sample from North Rollingwood, Richmond, contained only 67 ppm of dissolved solids, whereas several old analyses published by Sanford (1913, p. 95–96) show that a content of 600 or 700 ppm of dissolved solids is not unusual.

Three of the samples tested (59, 70, and 83, table 7) show 92 ppm or less of dissolved solids. These samples contain a little bicarbonate hardness and silica and not much else. Raw water for North Rollingwood is somewhat corrosive, as might be expected of a water of such low mineral content. This water is passed through marble chips in the storage tank in order to neutralize it before distribution. Water from the old well (56, table 5) at the Richmond abattoir is reported (Sanford, 1913, p. 90) to have been a remarkably good boiler water.

Moderately mineralized water is obtained at Stratford Village in Richmond, at Bonnie Brae in Dumbarton, and at Solomons Store. Hardness, of the carbonate type, is moderate and ranges from 35 to 100 ppm. The remainder of the dissolved mineral matter is sodium bicarbonate. The fluoride content is 1.3 ppm in wells at Stratford Village and Dumbarton but is negligible in the other two wells cited.

Three old analyses given by Sanford indicate that some deep wells (51, 60, 61, table 7) ending in granite yield a highly mineralized water. The hardness of these waters ranges from about 200 to almost 300 ppm. In the sample from the old Richmond Hotel well (51) almost half the 285 ppm of hardness is present as sulfate hardness. A very appreciable sulfate hardness is also present in the Ginter Park well (60). Sanford (1913, p. 92) notes that this water proved unsatisfactory for laundry use. In these wells chloride is somewhat higher than would be expected and it seems likely that bacterial contamination is present.

It is important to note that, so far as information is available, water from wells in granitic rock in the Richmond area is generally low in iron, containing less than 0.5 ppm.

WATER FROM TRIASSIC ROCKS

A sample of water from a deep well (3, table 10) at Doswell in Hanover County is similar to water of moderate mineralization from granitic rocks. The analysis indicates that the water is a slightly hard sodium bicarbonate water containing very little iron and fluoride.

WATER FROM THE CRETACEOUS SYSTEM AND THE PALEOCENE AND EOCENE SERIES

Three types of water are obtained from deep wells that tap the Eocene, Paleocene, and Cretaceous sediments; soft water of low mineral and low bicarbonate content, found along the Fall Line; hard calcium bicarbonate water of moderate to high mineral content, found just east of the Fall Line; and soft sodium bicarbonate water of moderate to high mineral content, found in New Kent and Charles

City Counties and in the lower peninsula (pl. 4*A*). In upper York County and lower James City County the sodium bicarbonate water may contain as much as 500 ppm of chloride and is undesirable for many purposes. In lower York County and in Warwick and Elizabeth City Counties deep wells yield brackish water that is essentially a soft bicarbonate water contaminated by as much as 5 percent of sea water. The areas in which the three types of water are found are not sharply defined but are separated by gradational zones (fig. 3).

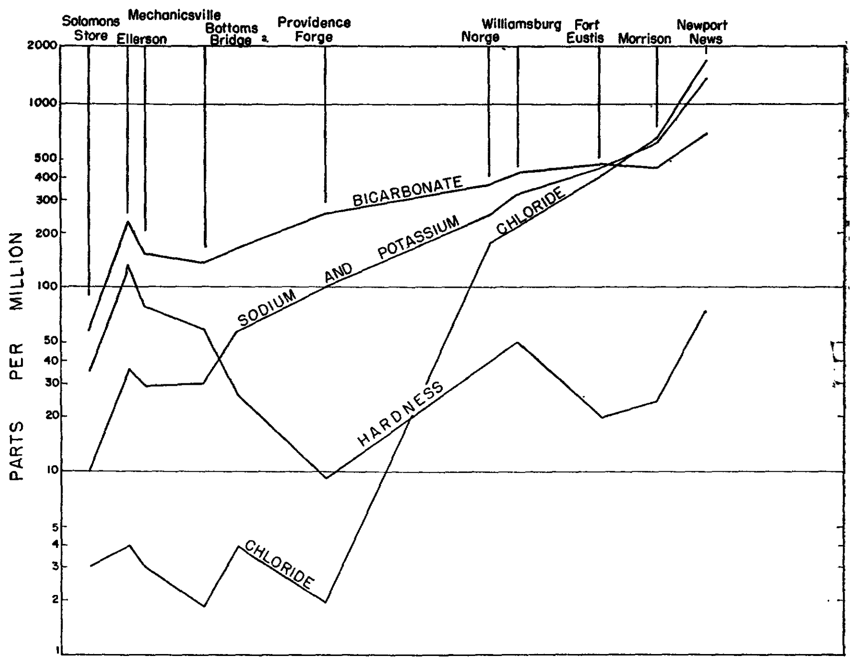

FIGURE 3.—Diagram showing progressive increase in mineralization of Coastal Plain waters east of the Fall Line.

Rain falling upon the surface is practically free of dissolved mineral matter. However, as it percolates through the earth it gains in free carbon dioxide and begins to take into solution small amounts of other constituents of the earth.

Along the Fall Line ground water from sediments of the Coastal Plain has not moved far and has dissolved very little mineral matter from the sediments. However, as it moves eastward the free carbon dioxide in the water reacts with limy sediments and the hardness increases as calcium bicarbonate. Beyond a certain point, however, in eastern Hanover and Henrico Counties in this area, the hard water comes in contact with sediments holding exchangeable sodium, whereupon the calcium in the water is exchanged for sodium from the sediments and the water becomes a soft sodium bicarbonate water. (See fig. 3.) For example, hard water at Glendale National Cemetery (37, table 7) is softened naturally by the time it travels as far east as Malvern Hill (40, table 20). This phenomenon, which is called cation exchange or base exchange (Renick, 1925), insofar as it is effective in the Coastal Plain of Virginia has been discussed in some detail in Bulletins 63 (Cederstrom, 1945a, p. 98–102) and 68 (Cederstrom, 1946a) of the Virginia Geological Survey, and Cederstrom, 1946b. It will suffice to say here that during Eocene, Miocene, and perhaps even Pleistocene times the Coastal Plain sediments were saturated with sea water, and during these times exchangeable sodium was deposited on the clay minerals. Since the last saturation and subsequent flushing out of the sea water, fresh calcium-bearing waters have been passing eastward and gradually converting the sodium clays to calcium clays, with the result that the boundary between calcium and sodium clays (and the boundary between calcium and sodium waters) has moved eastward as far as easternmost Henrico County (pl. 4*A*).

The operation of the base-exchange phenomenon was brought out during the artificial-recharge experiment at Camp Peary. There hard water, poured into sediments previously high in exchangeable sodium, was effectively softened. (See fig. 7.)

The high-chloride water found in the lower York-James peninsula is, as implied above, a mixture of fresh ground water and a small amount of the sea water with which the beds were once saturated. The distribution of the high-chloride waters in the entire Coastal Plain of Virginia is given in Bulletins 58 and 68 (Cederstrom, 1943a, pl. 3; and 1946a) of the Virginia Geological Survey, and origin of the chemical character of this water has been discussed in some detail in the literature (Cederstrom, 1946b, p. 239–244).

SOFT WATER OF LOW MINERAL CONTENT

The zone of soft waters of low mineral content lies along the Fall Line, but no samples of such water in the area covered by this report are at hand. The reader is referred to Bulletin 63 of the Virginia Geological Survey (Cederstrom, 1945a, p. 195) for an example of such water at Stony Creek, south of Petersburg. From Richmond through Ashland and Doswell water obtained from deep wells not reaching bedrock would probably be of this type. Such water would be low in hardness and bicarbonate and other constituents, except free carbon dioxide, iron, and possibly silica. Carbon dioxide might be present in concentrations of as much as 35 ppm making water corrosive, particularly when other mineral constituents are low. Objectionable amounts of iron, as much as 3 or 4 ppm, might also be present. However, in places along the Fall Line, ground water from Coastal Plain sediments is not excessively corrosive and may be quite free of iron.

HARD WATER OF MODERATE MINERAL CONTENT

Hard bicarbonate water of moderate mineral content is found at Hanover, Ellerson, and in several deep wells just east of Richmond. (See tables 7 and 10; pl. 4*A*.) In these waters, hardness ranges from 110 to 180 ppm. The bicarbonate content of the samples at hand ranges from around 150 to 180 ppm. In some of these waters some of the calcium has been replaced by sodium by base exchange. Analysis 17 in table 10 is a good example of a hard water of moderate mineral content. In the three samples in which both calcium and magnesium are determined, the magnesium is about one-third as high as the calcium.

Sulfate is low, generally less than 10 ppm, but a sample from Hanover contained 36 ppm of sulfate. The combined sodium and potassium is less than 30 ppm and chloride is generally less than 5 ppm.

Fluoride is low (pl. 4*B*), generally less than 0.5 ppm, or may be absent altogether. The amounts present are not of significance in relation to either mottling of tooth enamel or reducing the incidence of tooth decay on children (Dean, 1936, p. 1269–1272; 1938, p. 1443–1452).

USE

The water from the hard bicarbonate zone has disadvantages for some domestic uses as it requires the use of more soap than is desirable. Other undesirable constituents, particularly iron, are absent nearly everywhere.

For some industrial uses the hard bicarbonate water may be satisfactory as it comes from the well, but for many purposes, particularly for waters in the higher ranges of hardness, softening is necessary to reduce soap consumption, to eliminate deposition of lime where the water is heated, and to produce a satisfactory ice. Reduction of the amounts of silica and calcium and magnesium bicarbonates is desirable or necessary if the water is to be used in high-pressure boilers.

At Robinwood (23, tables 5 and 7), 2½ miles east of Richmond, ground water must be treated for municipal use. A small system owned and operated by the Sydnor Pump & Well Co., Inc., of Richmond, provides rather elaborate treatment. The water is pumped to an overhead aerator and filtered through charcoal to oxidize the iron in solution and to reduce free carbon dioxide. It then passes into a tank, is chlorinated with calcium hypochlorite, and is softened to a slight extent by precipitation of calcium and magnesium silicates. The water then is filtered through a tank of graded sand and limestone chips, which removes the precipitated iron and decreases the acidity (created by the remaining free carbon dioxide) of the softened water by increasing the hardness slightly, to its original value of 34 ppm.

Samples collected before and after treatment indicate that the iron was reduced from 1.7 to 0.63 ppm. Free carbon dioxide, 7.7 ppm in the untreated water, was not reported in the sample taken after treatment and it is presumed to be negligible in that water. The pH was raised from 7.7 to 8.1.

It is of interest to note that other municipal supplies in the zone of hard water are satisfactory without treatment. At Oak Hill, Sandston, Highland Springs, San Rafael Court in Henrico County, and Mechanicsville in Hanover County, free carbon dioxide is low or entirely negligible and iron is not present in troublesome amounts. The water from Robinwood is an exception because of its high iron content and because it contains almost 2 ppm of fluoride. Waters from both Highland Springs and Robinwood wells are unusual in that the hardness is quite low and they are soft sodium bicarbonate waters rather than hard calcium bicarbonate waters characteristic of the area in which they occur.

SOFT SODIUM BICARBONATE WATER

West of the area of chloride contamination, soft sodium bicarbonate water is obtained from deep wells in eastern Hanover County, in King William, New Kent, and Charles City Counties, in nearly all of James City County, and in the northwestern part of York County (pl. 4*A*).

It was found that the deep wells reaching the Aquia or the Mattaponi formations yield a very soft sodium bicarbonate water and the shallow wells that end in the Nanjemoy yield a sodium bicarbonate water of moderate hardness.

NANJEMOY FORMATION

Slightly hard sodium bicarbonate water is yielded by wells that top the uppermost artesian strata of the Nanjemoy formation in the area outlined above. These wells are from 90 to 150 feet deep along the lower Mattaponi River and the Chickahominy River, but at Norge and Williamsburg, which are on high ground, such wells are from 330 to 350 feet deep. The wells at Williamsburg, however, may draw water from either the Nanjemoy or the Calvert formation, or both.

The bicarbonate content of the water from most of these shallow wells ranges from 125 to 250 ppm except in upper York County and at Williamsburg, where, on the edge of the high-chloride zone, the bicarbonate is much higher. Samples from this area contain 336, 440, and 537 ppm of bicarbonate.

The hardness of samples from wells reaching the Nanjemoy formation ranges from 25 to 100 ppm, present largely as calcium bicarbonate. This is in distinct contrast to the deep wells, which characteristically yield water having a hardness of less than 10 ppm.

In the vicinity of Williamsburg some (but not all) wells about 300 feet deep contain over 100 ppm of chloride, possibly as a result of contamination with water from deeper formations.

Sulfate and other constituents are low. Fluoride ranges from 0 2 to 1.3 ppm in samples analyzed, but most samples contain less than 0.5 ppm of fluoride.

AQUIA AND MATTAPONI FORMATIONS

Soft sodium bicarbonate water is obtained from wells that tap lower Eocene and underlying Coastal Plain beds. In the western part of Charles City County, and in New Kent and King William Counties the water contains from 150 to 200 ppm of bicarbonate, but as it migrates eastward the water gains in bicarbonate content, and in the area from West Point to Williamsburg and Jamestown the bicarbonate content ranges from 350 to 450 ppm.

The hardness of the water from deep wells is rarely greater than 10 ppm, although near the western border of the soft-water province, as at Bottoms Bridge (35, table 7) and Manquin (57, table 14) where base exchange has not yet been completely effective, the water is still very slightly hard.

Fluoride in water from deep wells is somewhat higher than in water from shallow drilled wells but generally does not range above 2.0 ppm. However, in the vicinity of Jamestown two samples analyzed contained respectively 3.4 and 4.4 ppm (pl. 4*B*). These concentrations are great enough to cause the mottling of tooth enamel of children who regularly drink such water (Dean, 1936).

USE

Where the fluoride content exceeds 1.5 ppm, objection may be raised to the use of this water by children for drinking. A municipal water supply may be economically practicable in some areas if obtained from wells, but impracticable because of much greater expense if surface water must be used. In such instances, ground water containing fluoride above the suggested limit (the U. S. Public Health Service recommends an upper limit of 1.5 ppm) might be used for public supply rather than have the community continue to rely on shallow wells easily subject to contamination. Where a high-fluoride water is used for municipal supply it will be desirable to provide children with drinking water from some other source.

Although suitable for many industrial purposes, the untreated soft sodium bicarbonate water is not satisfactory for high-pressure boilers as it may foam and corrode. At the Chesapeake Co. pulp mill at West Point, boiler water has been treated with zeolite-type exchange materials in which sodium in the water is replaced by hydrogen, thus resulting in essentially complete removal of sodium and bicarbonate. A more complete treatment plant for boiler water is now in the process of construction. Not only will sodium and bicarbonate be removed but silica will be precipitated as magnesium silicate and, by a process of ion exchange, chloride, sulfate, and fluoride also will be removed. The dissolved-solids content will be reduced from about 350 ppm to less than 15 ppm.

HIGH-CHLORIDE WATER

The western boundary of the zone of high-chloride water extends as far westward as Toano in upper James City County, southeastward between Jamestown and Williamsburg, and then follows the James River to northeastern Nansemond County (Cederstrom, 1943a, pl. 3). From Toano the boundary passes northeastward near the upper boundary of York and James City Counties (pl. 4*A*).

These high-chloride waters represent a residuum of the sea water with which the sediments were once saturated. Movement of fresh water eastward through the artesian beds has not been sufficiently great to remove completely all the original sea water.

Why the form of the high-chloride water zone has the shape of a wedge is not known, but it is thought that the beds are depressed in this area (Cederstrom, 1943a, p. 13–14) relative to the areas south and north (pl. 5). For example, the Miocene and Eocene contact lies about 400 feet below sea level at Lamberts Point, Norfolk, but is about 600 feet below sea level at Old Point Comfort directly to the north (pl. 5, section C–C′). It rises from there to about 425 feet below sea level at Palmer in Lancaster County, and Byrdton in Northumberland County. A suggestion of a similar trough is seen in section D–D′ (pl. 5) taken from Driver, Nansemond County, across the York-James peninsula to Irvington in Lancaster County. The depression appears to die out inland (pl. 5, sections E–E′ and F–F′).

Probably salt water was flushed least by eastward-moving fresh artesian water in this structural depression because of the difference in specific gravity between the two fluids. Fresh water tends to float on salt water. In the artesian system the movement of water is extremely slow (measured in inches per day), and it seems entirely likely that the eastward-moving fresh water will tend to float above the salt (or, strictly speaking, brackish) water and, in so doing, will tend to be channeled through the highest outlets leading eastward. Here, the structurally high parts of the province are the Northern Neck and the area south of the James River; these are more completely flushed than the intervening structural depression.

Plate 4*A* shows the distribution of the high-chloride waters in the York-James peninsula. As seen in this diagram, the chloride increases from 176 ppm at Norge to 4,500 ppm at Fort Monroe. In general the increase is progressive down the peninsula but it is apparent that along the James River the artesian strata generally yield water of lower chloride content than wells located farther inland or along the York River. This is particularly noticeable near Fort Eustis, where wells along the James River yield water containing as little as 250 ppm of chloride, but wells at Lee Hall and Yorktown yield water in which the chloride is characteristically about 400 ppm; a chloride content of 1,070 ppm was found in one sample. At Newport News the chloride content of deep-well water ranges from 600 to 1,680 ppm, but, as stated above, at Fort Monroe to the east-northeast of Newport News a sample from a deep well was found to contain 4,500 ppm of chloride.

Another factor is the difference in chloride concentration due to differences in depth. In general, samples from the deep wells have a higher chloride content, but it is entirely clear that the degree of permeability of the water-bearing sand beds greatly influences the type of water present in them. Where the strata are less permeable less fresh water has passed through and the flushing action has been less complete; therefore, such beds yield water of higher chloride content than other more permeable beds which may lie deeper. A good example of this is seen in the analyses (42, 43, 46, table 34) from Newport News. A chloride concentration of 1,080 ppm was found at 400 feet, 600 ppm at 813 feet, 690 ppm at 900 feet; and 1,680 ppm of chloride was present in water from well 13 (table 37) at a depth of 820 feet. The excessively high chloride water sample from 400 feet was from a poorly producing stratum. The two samples lowest in chloride are from wells that are rather good producers and are in constant use, and the sample second highest in chloride is from a poor producer.

CHEMICAL CHARACTER

The analysis of water from the well of the Peninsula Dairy at Newport News (42, table 34) is representative of the high-chloride waters found in the lower peninsula. This water contains about 1,500 ppm of dissolved solids, of which the chloride content is 600 ppm. The bicarbonate content of 475 ppm is typical of samples containing 400 to 600 ppm of chloride. Sodium and potassium are high in water from the dairy well, 589 ppm, which is to be expected in view of the high chloride content. The hardness and sulfate are higher than in the chloride-free, soft sodium bicarbonate waters found to the west of Newport News and they reflect the admixture of sea water and fresh artesian water.

In most samples from the lower peninsula the hardness ranges between 15 and 30 ppm and the sulfate, between 40 and 75 ppm. Fluoride is higher here than farther west and is generally between 1.5 and 3.0 ppm.

It has been noted (Foster, 1942) that in these waters there is less magnesium relative to calcium than might be expected in a simple mixture of fresh water and sea water. Further, the hardness is less than might be expected. It is the writer's belief that these differences have occurred largely as a result of base-exchange reactions (Cederstrom, 1946b, p. 239–244).

USE

High-chloride water has a very limited range of usefulness. Where the chloride content is not in excess of 400 ppm the water can be used for municipal supply, although the taste is objectionable to some persons. Water of moderate chloride content has been used for public supply at Williamsburg, Camp Peary, Yorktown, and Fort Eustis. However, low-chloride surface water has supplanted ground water at Camp Peary and Williamsburg and ground water is now used only as a standby supply at Yorktown.

During World War II ground water was pumped into the Lee Hall reservoir, from which the supply for the city of Newport News is taken, to supplement the temporarily failing surface-water supply. It was found that use of small volumes of water containing over 1,000 ppm of chloride was practicable although not desirable, and that use of larger volumes of water containing around 400 ppm of chloride proved successful.

High-chloride ground water is useful for cooling purposes even though it is somewhat corrosive. It is used for this purpose by two firms in Newport News and is used for scrubbing illuminating gas by the Virginia Public Service Co. It is claimed that, in these particular cases at least, the occasional replacement of metal parts necessitated by the use of this water is amply offset by the cheapness of the water itself. Where the water is at high temperatures, the use of stainless steel has proved effective in eliminating the excessive corrosion.

High-chloride water might be satisfactory for most washing purposes. Certain industries might be found where water of this character could be used in processing. The water is totally unfit for boiler use, even low-pressure boilers, and would be very expensive to treat.

WATER FROM THE MIOCENE SERIES

CALVERT FORMATION

Water obtained from the Calvert formation in the vicinity of Williamsburg is low in chloride and has a moderate hardness. In places the hardness, caused by calcium and of the carbonate type, is less than 50 ppm. Water from the Calvert is generally superior to water from the shallower Yorktown formation in that it is softer; it is better than water from the deeper formations of Eocene age in that chloride is negligible. Other constituents are low. Fluoride ranges from 1 to 2 ppm.

Some wells less than 300 feet deep in the Williamsburg area contain a rather high amount of chloride, probably as a result of contamination from deeper strata through old leaky well casings.

A sample of water from the Calvert at Norge has a somewhat greater than average hardness, 65 ppm, but only 0.4 ppm of fluoride, less than in water from the same formation in the Williamsburg area.

YORKTOWN FORMATION

Water from the Yorktown formation ranges in hardness from less than 100 to more than 200 ppm. Hardness is due to the presence of calcium and is of the carbonate type. The bicarbonate content ranges from less than 100 to 150 ppm in the samples analyzed. Other constituents are ordinarily low.

Water from well 59 (table 23) at Norge, in the Yorktown formation, contained excessive iron, 8.1 ppm. Water from a test well (34, table 34) at Big Bethel Reservoir, a few miles from Chesapeake Bay, contained 109 ppm of chloride, and at Hampton Heights Dairy (7c, table 37) water from beds of the Yorktown contains 950 ppm of chloride. This high chloride appears to be confined to the lower peninsula area. Some of the chloride contamination may be due to salt in the air, which drifts inland and is carried into the earth during periods of rainfall, but it seems more likely that most of the chloride is due to lack of complete flushing of the sea water with which the beds were once saturated. The water from the Hampton Heights Dairy is similar to some high-chloride waters from deep artesian beds.

The fluoride content of water from the Yorktown formation is very low, less than 0.5 ppm.

Water from the Yorktown formation generally is considered hard when used for washing purposes. The untreated water leaves a scale in low-pressure boilers and in places the bicarbonate content is higher than is desirable for use in high-pressure boilers. Information on water-quality requirements for boiler use is given by Moore (1940, p. 263).

WATER FROM THE PLEISTOCENE SERIES—COLUMBIA GROUP

Water from shallow wells in the terrace formations is low in mineral content in most places. Total hardness is less than 50 ppm and is generally present as bicarbonate; in water from well 38 at Providence Forge, however, a slight hardness is present partly as sulfate.

Shallow waters contain only a trace of fluoride. Well 89 (table 20), at Holdcroft, yielded water containing 41 ppm of iron after being pumped for 20 minutes with a pitcher pump. This certainly is an excessive iron content. Possibly the sample contained iron oxide sludge that accumulated on the inside of the casing and the iron content of the water in the formation is less. Well 62 at Roxbury has somewhat more than the minimum chloride content generally present. This may possibly represent contamination by organic matter as the well is located inland and sea-water contamination is unlikely. Nitrate is higher than normal (15 ppm) in the spring water from Hanover (20, table 10). It is still higher (30 ppm) in water from well 33 in Henrico County. Both these waters are probably contaminated by drainage from adjacent cultivated land. Safeguarding shallow well supplies is always a problem that must be dealt with by positive action.

The sample from Poquoson High School (47, table 30) is very highly mineralized and represents a gross contamination of naturally occurring ground water by airborne salt spray. The source of the 516 ppm of hardness, however, may be partly ascribed to the limy terrace formations. Most wells in the lowlying easternmost peninsula area would be expected to yield somewhat highly mineralized water, those less protected from sea breezes, as at Poquoson, being the more contaminated. A shallow well at Hampton Heights Dairy (7a, table 37), for instance, a few miles from the open bay, yields water in which the chloride content is only 52 ppm. This water also is rather hard.

Water from shallow wells is generally excellent for most purposes, if protected from pollution and if sufficient quantities can be developed. Iron is a troublesome constituent in some places. Because of its low mineral content and such free carbon dioxide as may be present, the water may be somewhat corrosive. Where contaminated by salt spray, shallow ground water may be of limited usefulness.

WELL CONSTRUCTION

For methods of well construction generally utilized in eastern Virginia see Cederstrom, 1945a, p. 124–129.

Most domestic users find that 2- or 3-inch jetted wells furnish ample water for their purposes, although a few homes or farms have drilled wells as much as 4 or 6 inches in diameter. The majority of rural homes and some large dairies, farms, and schools, however, are supplied from dug wells, some improperly protected from contamination.

Some large farms and estates, several small industrial establishments, institutions, and municipalities are supplied with water from 6- to 10-inch drilled wells. Several large-diameter gravel-packed wells have been drilled in the area.

USE OF WATER

Most wells in the area furnish water for domestic use. These include the many small-diameter wells and the municipal-supply wells at Sandston, Highland Springs, West Point, Yorktown, Fort Eustis, Mechanicsville, Oak Hill, and Robinwood, and several privately owned public-supply wells in and around Richmond.

Water for industrial use is pumped at West Point where it is used for cooling and in the processing of kraft paper. At Newport News rather brackish ground water is used for cooling and for scrubbing illuminating gas.

ARTIFICIAL RECHARGE

Artificial recharge of wells with cold winter water for use in the following hot summer months has now become an accepted and economically proved practice at several industrial plants in the United States, including the Solvay Process plant at Hopewell, Va., (Cederstrom, 1945a, p. 155–156). Cold water is generally obtained from municipal systems in the winter, is allowed to flow down wells into underground strata, and is pumped out again during the succeeding summer months. The cold water gains only a moderate amount of heat while in storage.

A similar practice may be feasible and desirable in the industrial Hampton Roads area in eastern Virginia. However, those parts of the area that might benefit most from artificial recharge are underlain by strata saturated with brackish water. Few deep wells exist in the Norfolk-Newport News regions, and those that are present yield water ranging in chloride content from a few hundred to more than 1,000 ppm. Water of such mineral content, unless greatly diluted with fresh water, is not entirely desirable for air conditioning, because of its corrosiveness, and for other purposes it might be entirely unsatisfactory.

The writer believed that, if fresh water was poured down a well reaching beds saturated with brackish water, a complete mixing of the fresh water with the brackish water would not necessarily result. In the first place, fresh water is less dense than brackish water and would have a tendency to "float" on the heavier water. Furthermore, since the movement of water through the interstices of sandy sediments is extremely slow and turbulence is lacking except in the immediate vicinity of the well screen, the recharge water, regardless of its specific gravity, might tend to push back the ground water, maintaining a rather narrow zone of diffusion between.

Accordingly, in the spring of 1946 such an experiment was started (Cederstrom, 1947a). Detailed information for several idle wells in operating condition at Camp Peary, near Williamsburg, was at hand, and the Public Works Department of the 5th Naval District was requested to allow the proposed experiment to be carried out there. The response was immediate and every possible facility was furnished to make the test run.

THE RECHARGE EXPERIMENT AT CAMP PEARY

Camp Peary, a former training station for Naval Construction Battalions (Seabees), was supplied for about 6 months in the fall and winter of 1942–43 with water from 12 wells, 395 to 500 feet deep. (See p. 172.) The water ranged in chloride content from 260 to 400 ppm and, although potable, was somewhat more mineralized than was considered desirable. There was also the possibility that the chloride content might increase with pumping. Hence, a surface-water supply was made available as soon as practicable.

Surface water was pumped from nearby Waller Pond. Waller Pond itself was fed from local streams and from a takeoff in the pipeline extending from Walker on the Chickahominy River to the Lee Hall reservoir of the Newport News water-supply system.

Although the Navy Department processed Waller Pond water at its filter plant at Camp Peary, the water was purchased from the Federal Works Agency. That agency agreed to release to the Geological Survey the water needed to carry out the recharge experiment. However, as ownership was to pass shortly to the city of Williamsburg, release of water could be granted only so long as Waller Pond was a property of the Federal Works Agency. Subsequently, W. R. Woodbury, town manager of Williamsburg, agreed to furnish the additional amount of water required.

A water meter suitable for the measurement of the amount of water used in recharging and during the subsequent pumping period for the purpose of the experiment was loaned to the Geological Survey through the kindness of the late Eugene Dugger, of the Newport News water commission.

The well recharged at Camp Peary is identified in this report as York County well 11, known locally as D–3 (fig. 15). It is 472 feet deep and 8 inches in diameter. Cook 40-slot screen was placed opposite medium-textured sand strata at 430 to 440 feet and 450 to 475 feet below the surface. This well yielded 305 gpm with a drawdown of 62 feet. The most important factor in the selection of the well was that the water level stood 70 feet below the surface (the elevation of the pump base was 84 feet above sea level), making it possible to build up a pressure head at the well and induce rapid recharge of the water-bearing formation. The chloride content of the water yielded by this well was 340 ppm.

RECHARGE OPERATION

Pipe connections were completed and recharging was begun on April 4, 1946 (fig. 4). Water from the mains was allowed to flow directly through the turbine pump and into the well casing under a pressure of about 35 pounds per square inch. The pump turbines rotated backward at a high rate of speed during this operation. To avoid the possibility of generation of electrical charges, with danger to operators and equipment, the shaft leading from the pump head to the electric motor was disconnected.

Recharge water was under pressure down to the lowest outlet of the turbine column. From that point on, water spilled into an open well casing and that which passed downward into the ground was under only such pressure as was caused by the piling up of water in the well casing, a pressure head measured by the difference between static level and the level of the water in the well during recharge.

The water level in the recharged well gradually rose, as shown by the water levels in adjacent wells (fig. 5), and about May 17 water began flowing out at the pump base at the top of the casing. At this time, the amount of water flowing into the well had fallen from 250,000 gpd (on April 5, the second day of recharging) to about 200,000 gpd.

As the amount of recharge declined, the immediate and natural thought was that the head in the sediments had been built up to such a degree as to reduce the amount of water entering them. However, study of the curves of water levels in wells in the immediate vicinity showed conclusively that recharge was not being retarded by a rise of artesian pressure but rather that recharge was failing in the well itself. In other words, simple clogging was indicated. The artesian head in the vicinity of the recharged well rose more than 4 feet in 5 days, but from then on it declined very slowly, and after May 5 it began to decline rather sharply. (See fig. 5.)

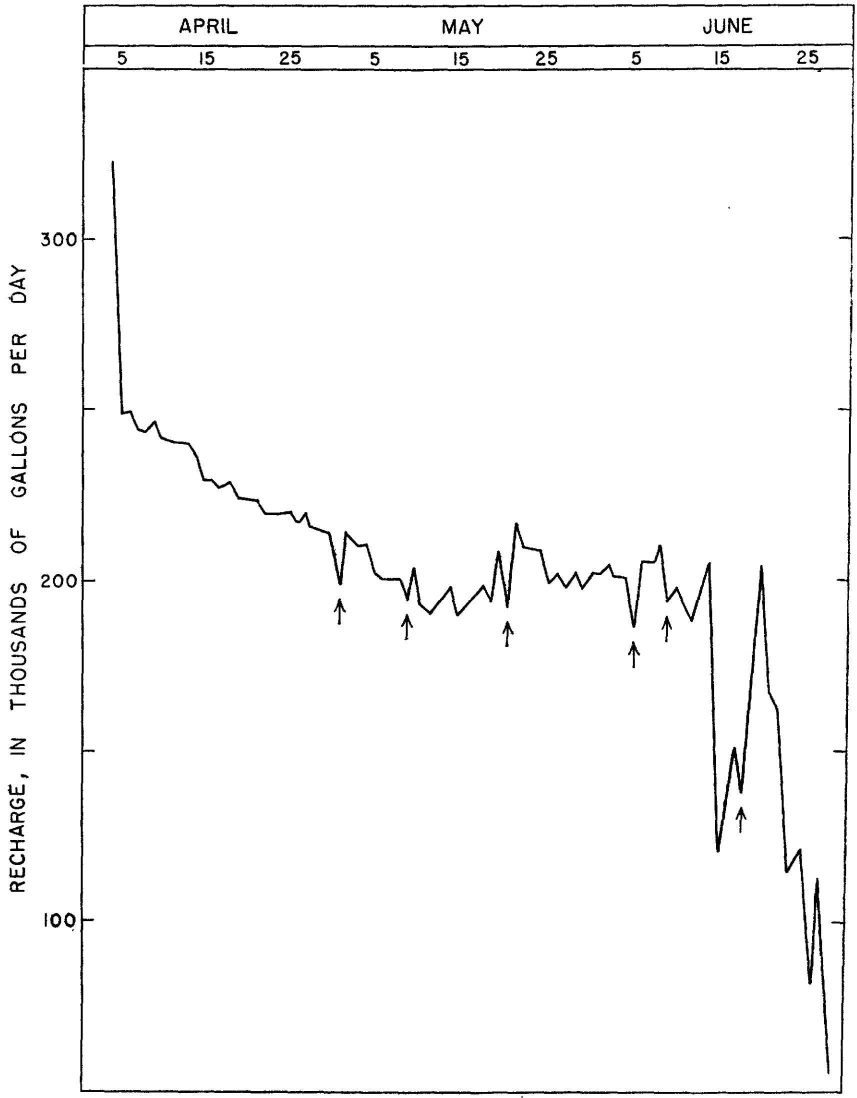

FIGURE 4.—Diagram showing amount of water recharged at Camp Peary, April 4–June 28, 1946. (Arrows indicate brief pumping periods.)

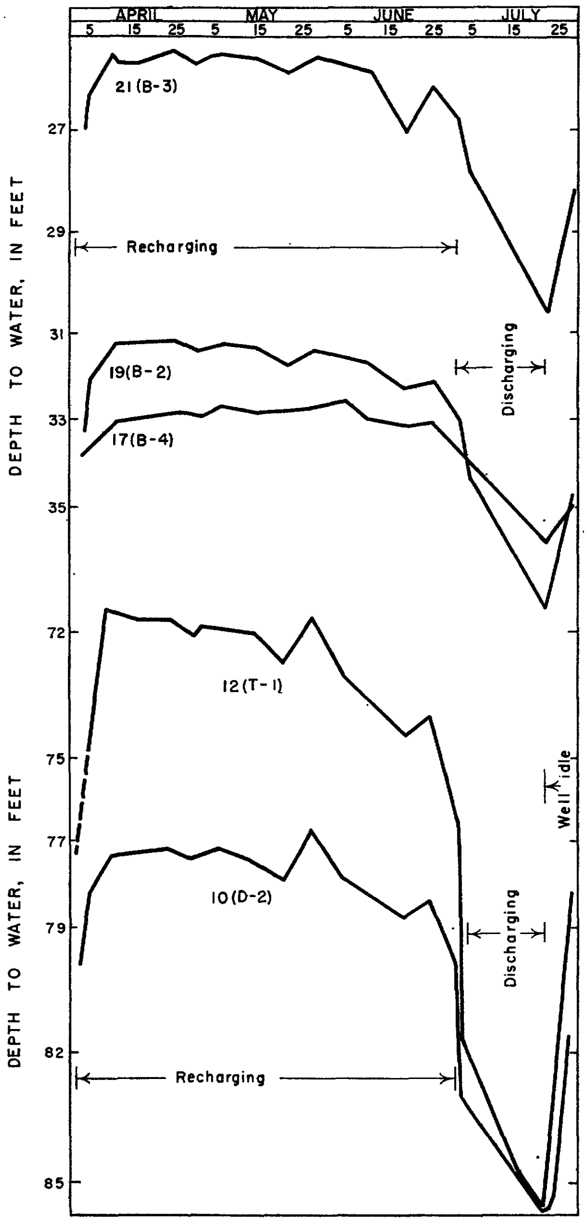

FIGURE 5.—Diagram showing water levels in wells adjacent to well being recharged at Camp Peary (fig. 4). Numbers refer to wells listed in table 27. Numbers in parenthesis are local Camp Peary numbers.

After it was apparent that the recharge well was becoming clogged, it was pumped in an effort to eliminate or decrease the clogging. On May 1 the well was given a 3-minute run; the water discharged was fiery red at first but it cleared and became colorless in that brief run. It seemed apparent that in setting up the recharge experiment, notice had not been taken of the iron rust accumulated in the mains. When the mains were opened and water flowed to the well at a much higher rate than it ordinarily moved in the mains, this accumulation was swept into the well and lodged in the screen and adjacent sediments.

However, only a slight beneficial result was noted from this operation (fig. 4), nor was the 5-minute run made on May 10 particularly helpful. Although the water recharged from May 10 to May 21 seemed to be constant (fig. 4), water levels in the adjacent wells were declining (fig. 5). Some spilling over at the top of the well may have been taking place, and the constant rate of recharge may have been more apparent than real.

On May 21 a longer discharge run was carried out. Discharge was increased to 188 gpm and the pump was then turned off and on six times in an effort to promote backwashing, agitation, and removal of fine material from inside and around the screen. The rate of discharge was then increased to 240 gpm and the well was surged five times. In all, the well was pumped in 11 periods ranging from half a minute to 14 minutes each and a total of almost 15,000 gallons of water was discharged.

During this test run a little red water was discharged at first and bits of iron scale were ejected for a long period. A little fine sand was also brought out, but by the end of the run only traces of sand and almost no iron scale were being brought up.

As a result of this surging operation, the recharge increased from about 179,000 gpd to more than 210,000 gpd and the water levels rose sharply for a short time.

However, clogging set in again, the water levels declined, and the rate of recharge fell off. Short discharge runs on June 5 and June 10 had only a negligible effect and a longer period of pumping and surging on June 19 was helpful for only a day or two. In the latter part of June the rate of recharge declined to less than 100,000 gpd and the water levels in nearby observation wells declined correspondingly.

Packing of sand grains in the vicinity of the well screen took place as the well was recharged, and the diminution in recharge rate may be ascribed in larger part to this effect than to clogging due to the introduction of foreign material. The sand in the formations here is of medium, rather uniform texture; such sand is more difficult to stabilize than a coarse sand or gravel composed of grains of different sizes. This should be taken into account in the selection or construction of wells for recharge purposes.

According to the meter, 17.3 million gallons of water was recharged in the period from April 4 to June 28. However, some waste of water occurred and about 30,000 gallons was pumped out during the recharge period, so that probably slightly less than 17 million gallons was actually added to the underground reservoir.

DISCHARGE OF THE RECHARGED WELL

The recharge well was pumped in the period July 2 through September 21 to determine the extent to which the fresh recharge water had mixed with the slightly brackish ground water. The results of the pumping are shown in figure 6.

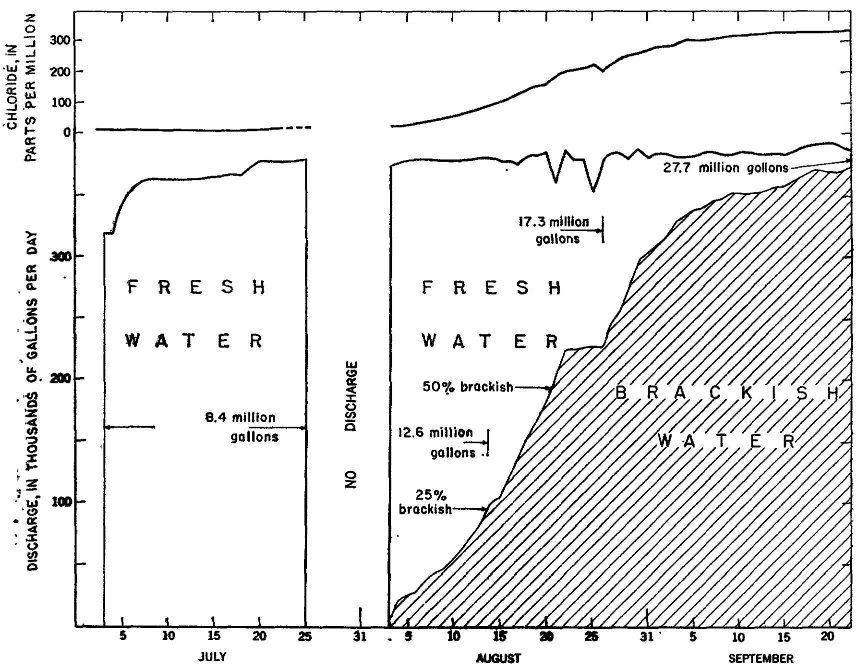

FIGURE 6.—Diagram showing composition and amount of water pumped from well after recharging.

Pumping took place in two periods, from July 2 through July 25 and from August 4 through September 21. The break in continuous pumping was caused by the breakdown of the electric motor. Discharge began at about 325,000 gpd and rose to almost 365,000 gpd in about 5 days. Discharge had increased to 380,000 gpd by the end of the first pumping period, July 25. From August 4 to September 21 the rate of discharge increased very slightly.

At first, the discharged water contained only as much chloride, 10 or 12 ppm, as the fresh recharge water, but during the latter part of the first pumping period, when 8.4 million gallons (an amount of water equivalent to about half the total amount recharged) had been pumped, the chloride content of the water discharged had increased to 20 ppm. Thus, at the end of the first pumping period the brackish water in the water discharged was not quite 3 percent.

In the second pumping period, the chloride content of the water discharged began to increase and by the time a total of 12.6 million gallons of water had been discharged (equivalent to about 75 percent of the total amount recharged) the chloride content was 98 ppm and the water was a mixture of one-fourth ground water and three-fourths recharge water. When 17 million gallons had been pumped (equivalent to the total amount of recharge) the chloride content of the water discharged was 220 ppm. This water was a mixture of about 60 percent ground water and 40 percent fresh water. When about 25 million gallons of water had been discharged the chloride had risen to 340 ppm, and the water was almost entirely ground water.

The pumping data immediately suggest that where fresh water is to be stored in sediments saturated with brackish water, proper operating technique will require adding an excess amount of water the first year. Discharge of only the fresh part of this excess recharge water will leave behind a buffer zone of fresh and brackish water. After recharging in the second and succeeding years it may then be possible to pump a quantity of fresh water nearly equal to the total quantity recharged.

NATURAL SOFTENING OF RECHARGE WATER

A common phenomenon on the Coastal Plain and in some other areas is the softening of ground water by ion exchange. In Virginia, for example, water entering the formations along the Fall Line gradually increases in mineral content and becomes hard as it travels eastward underground. At some distance from the Fall Line, however, the hard water passes over sediments previously saturated by saline waters which are now loaded with exchangeable sodium. As the hard water contacts these sediments, sodium from the sediments is exchanged for calcium and magnesium in the water and the water becomes a soft, high-sodium type (fig. 3).

Camp Peary lies in the zone of soft artesian water and presumably the sediments there are loaded with exchangeable sodium. It was therefore expected that the recharge water, having a hardness of 120 ppm, would be softened after being stored briefly in the ground. Accordingly, samples collected regularly for chloride determination were tested also for hardness.

Two curves are shown in figure 7. The dashed curve shows what the hardness of the pumped water, composed of a varying mixture of fresh water and ground water, would be if no softening action had taken place. This computed hardness, as it is designated, ranges from high, where the discharge water is made up almost entirely of fresh recharge water, to low, where the proportion of soft ground water increases in the discharge.

The actual hardness of the water discharged, as determined by analyses, was very different from the hardness of a simple mixture. The hardness of the water discharged declined sharply to 45 ppm and then more slowly to about 40 ppm, after which it rose to about 70 ppm and then gradually declined again to about 50 ppm.

These departures from the computed hardness of a simple mix are explained as follows: When recharge water is added to the underground reservoir, calcium from the water is absorbed by the sediments, effectively loading them with that element. The recharge water, by the same token, becomes sodic. As the process continues, the sediments become increasingly high in calcium, those nearest the well being the most heavily loaded.

The last portion of recharge water added to the underground reservoir has passed over a limited part of the sediments; these sediments were previously fairly well loaded and cannot absorb much more calcium. Hence, this last portion of water added, which is the first portion pumped out, has been softened only a little; its hardness is only a little less than when it was poured down the well.

However, as recharge water that has migrated some distance from the well is drawn in, the hardness decreases. This water has had an opportunity to pass over sediments that have been relatively less completely loaded with exchangeable calcium and has been greatly softened. As it approaches the well, however, it passes over beds that have just previously been heavily loaded with calcium, and the water is hardened somewhat. As the movement of water continues, the sediments become depleted of their calcium, the totally or nearly totally softened recharge water from perimeter areas is hardened less and less, and the total hardness of the water discharged declines, in this case to as little as 40 ppm.

According to this explanation it would be expected that the hardness would continue to decrease in a regular fashion as the exchangeable calcium deposited on the sediments is gradulaly taken up by the water moving toward the well and the proportion of almost completely soft ground water increases in the discharge mixture. However, coincidental with the discharge of increasing amounts of ground water beginning August 5 (as opposed to "pure" recharge water), the hardness increased again somewhat.

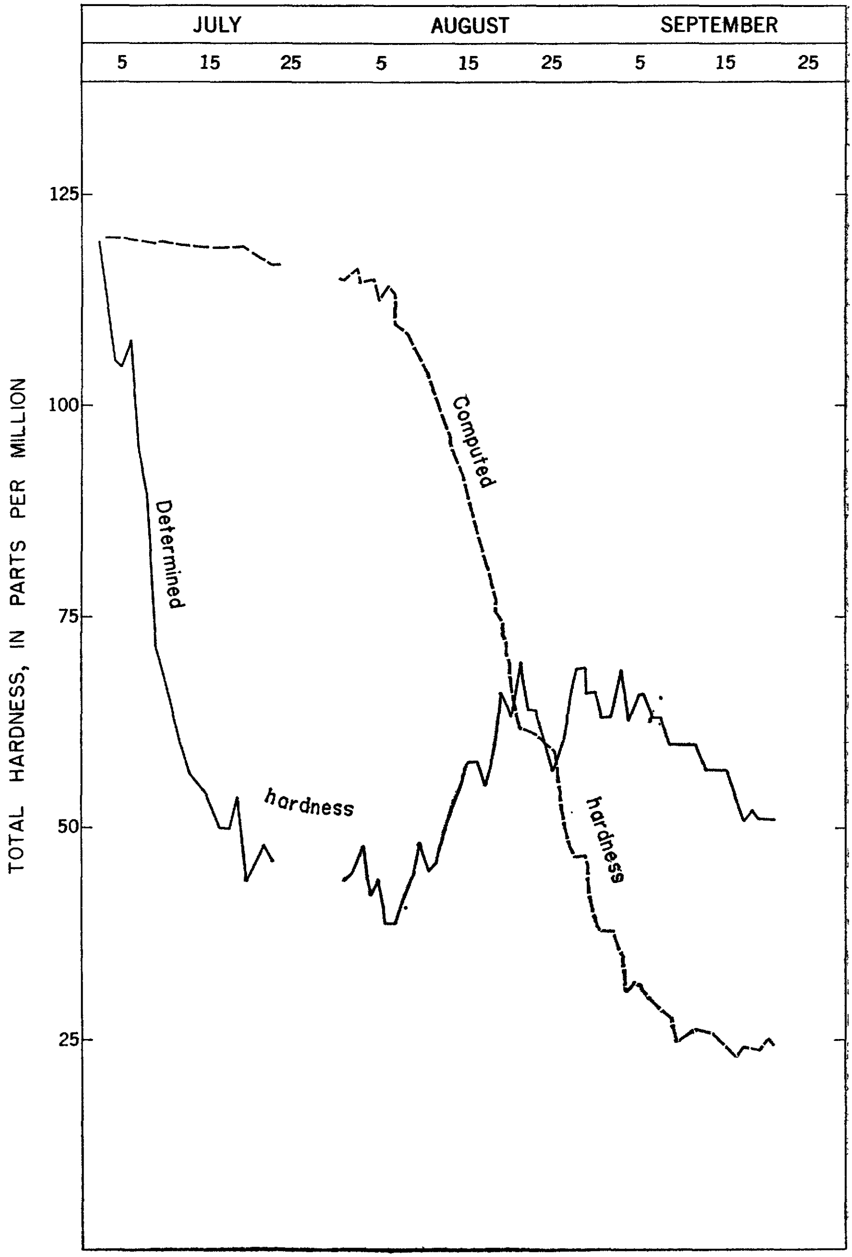

FIGURE 7.—Diagram showing computed and determined hardness of water pumped from recharge well at Camp Peary.

It might appear at first that, if the sediments were in equilibrium with water containing 40 to 45 ppm of hardness from August 1 to August 6, then the soft water passing over them from August 7 to 22 presumably would not be hardened to any greater extent. The observed data, however, indicate that as the native high-sodium ground water becomes a part of the mix, the proportion of sodium in the water rises sharply and the equilibrium shifts toward the retention by the sediments of less calcium and more sodium. After August 5, therefore, as the proportion of sodic ground water increased in the discharge a greater proportion of calcium was liberated from the sediments and the hardness of the discharged water rose from 40 to 70 ppm.

However, when the rate of increase in concentration of sodium in the water discharged began to decrease (after September 5), the rate of liberation of calcium likewise began to decrease. Simultaneously, the hardness of the mix moving toward the well was becoming lower and lower, inasmuch as the recharge-water fraction came from the periphery and was almost completely softened and the ground-water fraction was soft initially. As this water moved toward the well, more and more calcium from the sediments was required to maintain the previous hardness. As the amount of calcium deposited on the sediments by the recharge water was essentially limited in amount, this increasing demand could not be met; continued loss of calcium created a constantly shifting equilibrium and the discharge water became increasingly soft. At the conclusion of the pumping period the hardness of the water discharged was again about 50 ppm.

It is apparent that some calcium from the recharge water still remained in the sediments. Ground water having a hardness of only 10 ppm was originally in equilibrium with the sediments and at the conclusion of the test there was still enough calcium in the sediments to maintain an equilibrium with water containing 50 ppm of calcium.

Each successive period of recharge would undoubtedly result in a small net gain of calcium in the sediments, and in a very few years the amount of natural softening that would take place would be negligible.

SUMMARY OF RECHARGE

The test run at Camp Peary indicates that the storage of fresh water underground in sandy sediments saturated with brackish water is practicable. The following significant facts were brought out by the tests:

1. About 50 percent of the amount of water recharged in this experiment was uncontaminated when pumped out. By allowing a portion of the first run to remain in the ground, it will be possible to pump back

almost all the water recharged in later runs, the proportion of recovery depending on the tolerance to chloride.

2. Clogging of the recharge well due to sand packing probably may be expected, except where the strata are coarse and where the well was highly developed when it was constructed.

3. Foreign material from mains should be prevented from entering the well.

4. Restoring the permeability of a clogged well is difficult; surging for a period of many hours or even days may be necessary. It may be impracticable to do this to any degree of completeness during a recharge run, and it may be found necessary to recharge through two or more wells and to pump all these sufficiently to redevelop them when the water is being recovered.

5. An observation well near the recharge well will be of considerable value; a graph of the water level in the observation well will indicate how much recharge is taking place and whether any decrease in the rate of recharge is due to clogging or the building up of head in the area.

6. Hard water recharged in a soft ground-water area where sediments are susceptible to ion exchange reactions may be softened appreciably, but in a very few years the softening will become negligible unless discharge is greatly in excess of recharge.

Factors to be considered if artificial recharge is to be carried out are:

1. Economic justification; the desirability of water colder than that furnished by public supplies during summer months or by existing wells; the desirability of storing water for certain drier seasons, periods of heavy demand, or emergency use.

2. Favorable water rates; because the cost of artificial recharge is substantial, it may be necessary in many instances that water used for the operation be obtained at a cheaper rate than usual. This can doubtless be arranged in most cities if the water is purchased for recharging in periods of heavy rainfall and during off-peak hours. As the practice of artificial recharge for cooling lowers the demand on city systems during hot, dry periods, when facilities may be taxed to the utmost, favorable rates may be granted more readily than if the water were put to its end use at the time of purchase.

3. Where ground water, either fresh or brackish, is already used successfully for cooling in the summer, artificial recharge will be practicable only if the efficiency of the cooling system is substantially increased by this practice. It is reported that at Hopewell, Va., chemical processes are measurably more efficient where only a small lowering in temperature occurs. Here fresh-water wells normally yielding water at a temperature of 60° F. are recharged during the

winter. A heat gain of 35 percent is reported to occur in the cold recharged water; that is, the process is 65 percent efficient.

4. Where ground water cannot be used at all for cooling because of its corrosiveness or for some other reason based on chemical quality, it may be more economical to use artificially recharged water during the summer months than to use the tepid water supplied by most city systems during this period.

GROUND-WATER RESOURCES

CENTRAL AND EASTERN HENRICO COUNTY

Henrico County, including the independent city of Richmond, has an area of 274 square miles and a population of 287,650, of which 230,310 reside within the city of Richmond (Virginia Division of Planning and Economic Development, 1951). However, this report deals only with that part of the county in the Coastal Plain province, approximately that area lying east of a north-south line drawn through Richmond.

Richmond is the capital of Virginia and of importance also because of its industries including tobacco, food, printing, and paper production. Fabricated metal products, apparel, and chemicals are also significant products of the area. In 1947 the value added to products by manufacture was $205,130,000. During 1947, 24,148 production workers were employed in manufacturing in Richmond. In the county 1,348 people were engaged in manufacturing, largely lumber and basic lumber products, printing and publishing, and stone, clay, and glass products. The value added to products by manufacture was $9,492,000.

Henrico County is a fairly large producer of eggs, chickens, and dairy products. In 1949 their sale (also some horticultural specialties) amounted to $3,158,756.

First settlement in the area began in the "Curles" below Richmond, between 1609 and 1611. A port was established at the head of navigation (Fall Line) in 1637 but it was 1733 before Richmond itself was laid out as a city by William Byrd II. In 1780 the capital was moved to Richmond from Williamsburg.

That part of Henrico County dealt with in this report is well served by railroads. Richmond is an important junction connecting several north-south mainline railroads. The Norfolk-Newport News branch of the Chesapeake and Ohio Railroad passes through Richmond from Charlottesville and a branch of the Southern Railway runs eastward from Richmond to West Point. Richmond (and adjacent Henrico County) is connected with other large cities in Virginia and adjacent States by major highways.

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TOPOGRAPHY

Eastern Henrico County is underlain in large part by broad, flat terraces. These terraces are rather dissected near the James River and there the topography might well be termed rolling, in contrast to the adjacent broad, unbroken terraces somewhat to the north in the vicinity of Sandston. Where the James River is undercutting its banks, cliffs more than 100 feet high are present, and tributaries to the James River have cut ravines with steep banks as much as 50 feet in height.

The greater part of the county is floored by the Sunderland terrace with a maximum altitude of 170 feet. North of Richmond the higher Coharie terrace, with a maximum altitude of 215 feet, is well preserved. In the vicinity of "The Curles", the meanders of the James River in the southeastern part of the county, the low Talbot terrace (maximum altitude 42 feet) is present, and there are small areas where the Penholoway and Wicomico terraces are represented by flat areas 70 and 100 feet above sea level.

GEOLOGY

Granitic basement rock crops out at low altitudes in the vicinity of Richmond and underlies the unconsolidated sediments of the Coastal Plain throughout the eastern part of the county. Generally speaking, the slope of the bedrock surface is inclined gently seaward and depth to bedrock gradually increases eastward.

According to Sanford (1913, p. 17), bedrock was present at about 280 feet below sea level at Curles Neck (40, table 5; fig. 8) in southeastern Henrico County. Taking 50 feet above sea level as the altitude of bedrock at Richmond, it would appear that the slope of the bedrock surface is 23 feet per mile in a southeasterly direction. Rock was not found at 510 feet below sea level near Sandston (27), which is slightly west of a north-south line drawn through Curles Neck, nor at 340 feet below sea level at Robinwood (23), 5 miles east of Richmond.

However, 3¾ miles east of Richmond (47), bedrock lies about 150 feet below sea level and the slope here is about 60 feet per mile.

Thus it is apparent that east of Richmond bedrock lies considerably deeper than it does in the southeastern part of the county. This range in the altitude of the bedrock surface may most likely be ascribed to a pre-Cretaceous erosional channel cut in bedrock; but the possibility of faulting in the bedrock should not be ignored (Cederstrom, 1945a, p. 17).

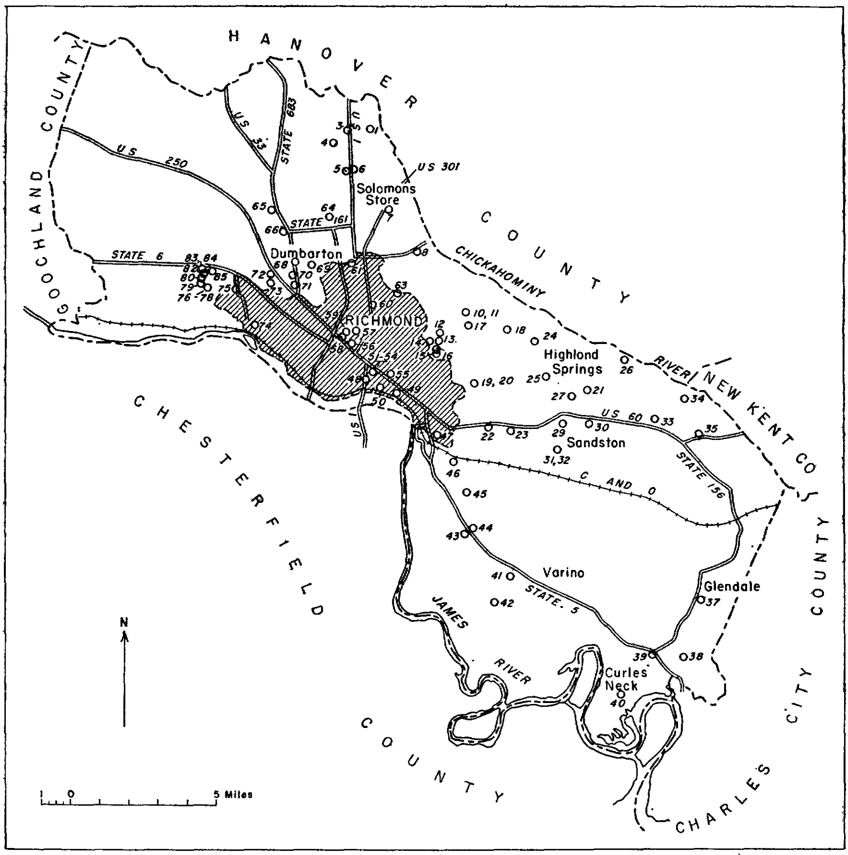

FIGURE 8.—Location of wells in central and eastern Henrico County.

Bedrock is present in several wells (1, 5, table 5; fig. 8) in the vicinity of Solomons Store, north of Richmond. The "sand and rock" reported in the 165-foot well at Oak Hill development (12, table 5) is probably not granitic bedrock but is more likely consolidated Cretaceous units.

Moderate supplies of water are generally obtained from wells tapping bedrock, although failures are known. Yields of 25 to 50 gpm are common and several wells in the granite yield more. A number of small housing projects immediately west and north of the city of Richmond are entirely dependent on water from granitic rock, but in the city most of the industrial concerns and hotels that formerly pumped well water (Sanford, 1913, p. 85–93) no longer do so.

CRETACEOUS SYSTEM—POTOMAC GROUP

Sediments of Early and Late Cretaceous age, the Potomac group, which lie upon the granitic bedrock, crop out along the James River above Curles Neck. They are best displayed, however, at Drewrys Bluff on the west side of the river. These sediments consist of alternating beds of clays and arkosic sands that were deposited by streams. Most of the arkosic sand is somewhat clayey and is relatively impermeable, but clean water-bearing sands are present in some places. In the well (12) at Oak Hill development, referred to above, "sand and rock" is reported. However, consolidated sediments appear to be rare in the Cretaceous.

Along the Fall Line, as in Richmond where granite lies close to the surface and is exposed in some places, the Cretaceous sediments may not be more than 100 feet thick. Few sands are present and these cannot be counted upon to have much lateral extension; in many places no productive water-bearing sands are found. Eastward, however, as at Sandston and Highland Springs, the total thickness of Cretaceous sediments is much greater, there is a better chance of finding several good strata before bedrock is reached, and those that are present seem to be somewhat more persistent over wider areas. In easternmost Henrico County Cretaceous units have not been reached by existing wells; there they might be reached at an estimated depth of 150 feet below sea level.

It is thought that most of the wells along U. S. Highway 360, just northeast of the Richmond city limits, obtain water from Lower Cretaceous units. Generally good yields of excellent water are obtained.

TERTIARY SYSTEM

EOCENE SERIES

The Pamunkey group of sediments of Eocene age overlies the Cretaceous sediments. The upper part of the Pamunkey group is the Nanjemoy formation and the lower part is the Aquia formation. Although these strata crop out along the James River between Richmond and Curles Neck, the exposures are thin, weathered, and covered in part by vegetation; hence the Pamunkey group in Henrico County is best known from logs of wells.

Aquia formation

A well (35, table 5) near Bottoms Bridge, 2 miles east of Sandston, tapped 160 feet of Eocene sediments. These are glauconitic dark clay beds in which subordinate shell zones are present; therefore they are termed marl. The lower 82 feet of the well was in sediments of the Aquia formation, largely glauconitic marls. Foraminifera essentially identical with those found in outcroppings of the Aquia at the

Aquia Creek type section (Cushman, 1944) were found at the top of the Aquia formation at Bottoms Bridge.

The Aquia formation is of particular importance in that it contains water-bearing sands. At Bottoms Bridge 35 feet of medium-grained sand was tapped; at that point the full thickness of the sand had not been explored. This stratum also furnishes water to wells at Glendale, Sandston, and Highland Springs and to a few wells just east of Richmond. However, in the Sandston and Highland Springs municipal wells deeper, presumably Cretaceous units are also drawn upon to obtain a sufficient quantity of water.

Nanjemoy formation

The Nanjemoy formation at Bottoms Bridge is 78 feet thick and contains only one thin rock (limestone) stratum, in distinct contrast to the amount of consolidated material present in the formation in the counties immediately to the east (West Point, well 27, table 12). Furthermore, the formation contains no productive water-bearing sand beds, such as are present along the Chickahominy River. At Bottoms Bridge the Nanjemoy formation includes a 20-foot stratum of red clay at the base (Marlboro clay member).

The basal red or pink clay stratum is a characteristic feature of the Nanjemoy formation; it crops out just below Hopewell on the south bank of the James River (Clark and Miller, 1912, p. 115) and may be traced northward to Glendale (37, table 6) and westward to Highland Springs and Sandston (24b, 27, 30). The Nanjemoy formation apparently does not extend as far west as Richmond but may be represented by pink clay in wells 24b and 30 at Highland Springs and Sandston, east of Richmond.

MIOCENE SERIES

The Chesapeake group of Miocene age overlies and overlaps the Eocene units. In the eastern part of the county it rests upon the Nanjemoy formation but near Richmond the Nanjemoy formation has been eroded and Miocene units may rest upon the Aquia formation. At Chamberlain Heights, just north of Richmond (7, table 5), blue mud, presumably from the Miocene series, rests directly upon granitic bedrock and units of Eocene and Cretaceous age appear to be lacking entirely.

The Chesapeake group consists of the basal Calvert formation, a gray diatomaceous clay; the St. Marys formation, principally clay; and the Yorktown formation, composed of shell marl. Although all three formations are represented, the basal Calvert formation is best known from many exposures along the Fall Line.

The Miocene characteristically is not productive of water in Henrico County.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The entire county is veneered by terrace deposits of the Columbia group. These are stream-laid deposits that slope very gently seaward and are made up largely of yellow clay, sand, and gravel. In the eastern counties the lower terrace deposits have a maximum thickness of about 30 feet, but the higher deposits—the Brandywine formation with a shoreline at 270 feet above sea level, the Coharie formation with a shoreline of 215 feet above sea level, and the Sunderland formation with a shoreline of 170 feet—appear to be generally thicker where not eroded since their deposition. At Bottoms Bridge the terrace deposit appears to be 78 feet thick (35, table 6), but this is thought to be exceptional and may include the weathered (yellow) upper part of Miocene deposits. The maximum thickness of the terrace deposits in most places may be about 50 feet.

The terrace deposits transgress and overlap the older formations. In most places they rest upon Miocene units but locally they rest upon Eocene or Cretaceous deposits. The terrace deposits extend farther west than the underlying Coastal Plain formations and west of Richmond and U. S. Highway 1 they lie directly upon bedrock over wide areas.

The high terraces of the Sunderland and Coharie formations produce some water. Yields of more than 5 to 10 gpm are available in many places to dug wells and in one place over 30 gpm was obtained from a well (13, table 5) drilled to the base of the Sunderland formation.

WATER-BEARING FORMATIONS

GRANITIC BEDROCK

Before the construction of a filter plant by the city of Richmond in 1915, several hotels and a number of industrial concerns in that city obtained water for general use from deep wells tapping bedrock. Apparently most wells obtained moderate supplies of water, as much as 50 gpm, and a few obtained large supplies. (See table 5 and fig. 8.) With the completion of the filter plant and the availability of practically unlimited supplies of clear pure water, most of these wells were abandoned. At present only a few concerns use ground water; one bank, for instance, pumps well water for use with air-conditioning equipment. At a department store the use of wells in air conditioning has recently been abandoned with the change to a system using a cooling tower. The Medical College of Virginia attempted to use well water for air conditioning but found the quantity was insufficient and the temperature of the water obtained increased as warm water was discharged into an adjacent well after use.

At present water from wells tapping the granitic rock is of importance in the Richmond area in supplying a number of small- to moderate-sized housing projects west and north of the city. Most of these water systems are owned and operated by the Sydnor Pump & Well Co., Inc., of Richmond. Each unit generally consists of two wells, each with a small turbine pump ranging in capacity from 10 to 50 gpm, although cylinder pumps are installed in a few. The system also includes a 5,000-gallon pressure storage tank. At Westwood an old elevated tank formerly supplying the community is used. The water is not treated except at North Rollingwood, where the tank contains marble chips to counteract corrosiveness in the water.

The water systems at North Rollingwood, University Heights (Mayo-Trice and Permanesque developments), Spottswood Park, and Westham are interconnected for greater efficiency. Systems at Three-Chopt Court, Westwood, Mayfield, Kildare, and Stratford Village are separate units. North of Dumbarton, Greendale is served by wells of one of the Henrico Sanitary Districts. Just west of Greendale another community, Bonnie Brae, is served by a unit of the Sydnor Pump & Well Co., Inc., as is the community of Chamberlain Heights, about 4½ miles north of the center of Richmond.

In a few places dug wells are continued 10 to 20 feet into granitic rock with good results (Sanford, 1913, p. 190). An unusually deep dug well near Solomons Store (1, table 5) was continued in rock for 18 feet. The total depth of this well is 118 feet.

The well (40) at Curles Neck, which was described in some detail by Sanford (1913, p. 191), still performs to capacity. This well, constructed in 1900, struck granite at 310 feet and was drilled to a total depth of 725 feet. Initial pumping failed to produce more than 10 gpm. The well was later dynamited at various depths in the granite "with complete success" and yielded 100 gpm with very little drawdown. In 1947 the well was being pumped at a rate of about 60 gpm.

CRETACEOUS SYSTEM

Cretaceous units are or have been drawn upon as sources of water in the vicinity of Sandston and Highland Springs. The deepest of several abandoned wells (31, table 5) near Byrd Airport probably reached Cretaceous units. These wells yielded from 150 to 200 gpm each. At Fairfield School in Highland Springs (25) a very thin basal gravel in the Aquia and a thicker Cretaceous gravel were developed. One of the municipal wells (24b) at Highland Springs draws water from coarse sands between 240 and 307 feet. About 35 gpm was obtained, with 15 feet of drawdown.

At Robinwood, near Richmond (23), the drill struck no productive units within 200 feet of Cretaceous sediments.

It seems likely that the several wells along U. S. Highway 360 northeast of Richmond tap Cretaceous sand and gravel beds between

75 and 100 feet below sea level. Good yields are generally available. One well (11) at Glenwood Farms housing project obtained 100 gpm with 20 feet of drawdown. Use of a coarser screen might have increased the efficiency of the well somewhat. At Oak Hill, a well (12) equipped with a slotted casing for a screen produced 300 gpm with 40 feet of drawdown. An even greater yield should be available here with use of a modern commercially fabricated screen. Several wells in southeastern Henrico County, as at Fort Harrison (42), also obtain water from Cretaceous units.

TERTIARY SYSTEM—EOCENE SERIES

The Aquia formation of Eocene age contains a very productive water-bearing sand (more than 35 feet thick at Bottoms Bridge) in eastern and southeastern Henrico County. The bed extends westward to Sandston and Highland Springs, but as the Fall Line is approached the Eocene units thin greatly and in the vicinity of Richmond this bed pinches out.

At Highland Springs and Sandston the municipal-supply wells obtain some water from a gravelly zone that forms the base of the Aquia, but it is likely that Cretaceous units also are tapped here. At Sandston about 200 gpm was obtained with 32 feet of drawdown. The municipal wells at Highland Springs are reported to have capacities of 80 to 160 gpm.

Westward, between Sandston and Richmond, only small amounts of water are available from sand beds of the Aquia formation. At San Rafael Court (22) only 14 gpm was obtained with 30 feet of drawdown. Results of pumping were much the same at Robinwood (23).

QUATERNARY SYSTEM—PLEISTOCENE SERIES

A large number of dug wells obtain small supplies of water from the formations of terrace deposits. These wells furnish more than ample supplies for homes, farms, dairies, schools, and some small business concerns. Shallow wells east of the Fall Line counties characteristically have low yields but in Henrico County some excellent supplies have been obtained from the high terraces.

At Permanesque, just east of the Richmond city limits, a privately owned municipal supply has been developed from wells (80) in terrace deposits. With continuous operation each of two wells yields 5 gpm. Broad, undissected terraces may be expected to yield somewhat more than this where they are underlain by good gravel beds and where modern well construction methods are utilized. East of Sandston a single dug well (33) produces about 4 gpm when operated continuously. At Varina Grove, a modern school with an enrollment of 800 students, which has a cafeteria and complete sanitary facilities, is supplied by one shallow dug well (41). Over 3,000 gpd is used. However, it should be pointed out that here, as at well 33, a 4,000-gallon storage tank is an important part of the system, making available for short periods much larger supplies than can be furnished directly from the well. Available data indicate that the dug well at the Varina Grove school will yield about 7½ gpm. A drilled well (13) at the Montezuma housing project northeast of Richmond obtained a yield of 36 gpm with 11 feet of drawdown. Here the potential shallow-water supply was utilized to the utmost by means of modern drilling techniques and equipment.

R. H. Nelson estimates that the dug well (44) at his dairy in southeastern Henrico County furnishes about 7 gpm. This well is located close to a small valley and may be expected to yield somewhat less than wells located on broad unbroken terraces. At the Midview Farm, a dug well (45) near the middle of such a broad, flat area, easily furnishes ample water for watering a 300-herd dairy, for cooling milk, and for washing purposes.

QUALITY OF WATER

WATER FROM GRANITIC ROCKS

Water that is supplied to small housing projects just outside the city of Richmond, from wells tapping granitic rock (63, 66, 70, 83, table 7), is a soft to fairly soft water of the bicarbonate type, quite satisfactory for all domestic uses. Hardness ranges from 15 to 96 ppm in the four analyses cited. Sulfate, chloride, and nitrate are low. It is of interest to note that a sample from the Bonnie Brae project in Dumbarton (66) and one from Stratford Village (63) both contain 1.3 ppm of fluoride, a constituent generally associated with soft Coastal Plain artesian waters. This is about the maximum amount of fluoride that can be present in water used by children under 10 years of age without causing mottling of teeth (Dean, 1936, p. 156, 177). However, there is evidence (Dean, 1936, p. 1269–1272) that this amount of fluoride, and smaller amounts present in water from wells 70 and 83, may be effective in inhibiting tooth decay.

Analyses published by Sanford (1913, p. 95–96) show that some of the old wells in the city of Richmond yielded water of much greater mineral content. Well 51 yielded water with 702 ppm of dissolved solids and a hardness of 285 ppm, much of which was present as permanent or sulfate hardness. Well 61 had a hardness of 182 ppm, only a little of which was present as sulfate hardness, and a well (60) at Virginia Union University furnished water with 254 ppm of hardness as bicarbonate hardness.

Iron does not appear to be a troublesome constituent in waters from granite in and around Richmond. However, at North Rollingwood the water is somewhat corrosive and marble chips are placed in the storage tank to neutralize the water and prevent the solution of iron from the distribution lines.

WATER FROM THE CRETACEOUS SYSTEM AND EOCENE SERIES

In Henrico County the water obtained from deep wells ending in Coastal Plain sands is rather uniform in quality. A low to moderate hardness which is present as bicarbonate is characteristic. Iron is present in troublesome amounts at Robinwood and in this respect the water is similar to that in many wells on or near the Fall Line.

As discussed in more detail in the general part of this report, water entering Coastal Plain formations near the Fall Line is soft but as it travels eastward it gains in hardness and becomes a fairly hard water (fig. 3). Beyond a certain point, however, the water comes into contact with sediments that act as natural water softeners and it is converted from a hard calcium bicarbonate water to a soft sodium bicarbonate water by the process of base exchange.

In Henrico County the water tends to become harder (35, 37, table 7) as it moves eastward but natural softening by base exchange begins to be effective almost immediately and a regular increase of hardness to a maximum is not evident. Samples at hand in the hard-water zone (23, 24b, 37, table 7) range from 24 to 133 ppm in total hardness. Hardness is present as calcium and bicarbonate. Natural softening does not become completely effective until the water has passed into New Kent and Charles City Counties (pl. 4*A*).

The well at Robinwood (23) yields water that is more mineralized than the average and is a soft sodium bicarbonate water containing relatively large amounts of chloride, sulfate, iron, and fluoride. This water has been softened by base exchange. The municipal well at Highland Springs (24b) yields water that also has been softened by base exchange, but the concentrations of constituents other than sodium and bicarbonate are low.

WATER FROM THE PLEISTOCENE SERIES

Water from shallow terrace deposits is soft and has a very low mineral content. A well at Varina Grove (41) yields water containing almost 1 ppm of iron, but this iron may be dissolved from the pipes through which it passes rather than from the earth, since most shallow waters are at least slightly corrosive.

Water from a shallow well (33) at Savages Station has a very high nitrate content, 30 ppm, suggesting that organic pollution may be present.

Records and logs of wells and chemical analyses of waters for central and eastern Henrico County follow in tables 5, 6, and 7.

TABLE 5.—*Records of wells in central and eastern Henrico County, Va.*

[Type of well: Dg, dug; Dr, drilled; J, jetted. Approximate water level: Water level as of date well drilled. Use of water: Ab, abandoned; B, boiler feed; C, cooling; D, domestic; Irr, irrigation; M, municipal; P, public school; S, stock; T, tourist cabins]

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Remarks
1	1½ miles northeast of Solomons Store	G. S. Hewitt		1907	Dissected terrace.	190	Dg	118	72	−65(?)		D	Granite at 100 feet. Excellent quality of water.
3	do	Ninan Restaurant			Terrace	195	Dr	176	6	−4		T	Suction pump supplies restaurant and 18 cabins.
4a	Longdale	Public School	Sydnor Pump & Well Co., Inc.	1925	do	200	Dr	53	4½		2	Ab	
4b	do	do			do	200	Dg	42		−6 to −40		P	Supplies school cafeteria and 250 students.
5	Solomons Store	Chicks Appliance Co.	C. W. Gentry	1947	do	198	Dr	82	6	−11		D	Rock at 63 feet. See analysis, table 7.
6	do	Solomons Store			do	199	Dg	37				D	
7	3½ miles north of Richmond.	Chamberlain Heights.	Sydnor Pump & Well Co., Inc.	1943	Terrace	190	D	200+				M	Supplies community. Rock at 158 feet.
8	Chickahominy	W. A. Moncure			Dissected terrace.	180	Dg	33				D	Hardly sufficient for very large home.
10	Harvie Rd., off Mechanicsville Turnpike.	Glenwood Farms	Sydnor Pump & Well Co., Inc.	1947	Terrace	185	Dr	270	10	−135	50	M	Drawdown 15 feet.
11	do	do	do	1947	do	190	Dr	290	10	−135	100	M	Drawdown 20 feet. Gravelly sand from 240 to 290 feet.
12	South of Harvie Rd. and Mechanicsville Turnpike.	Oak Hill	Mitchell's Well & Pump Co.	1945	do	165	Dr	291	10	−110	300	M	Drawdown 40 feet. Well finished with slotted pipe. See analysis, table 7.
13	East of Glen Lea School.	Montezuma	Sydnor Pump & Well Co., Inc.	1943	do	170	Dr	48	10	−30	36	M	Drawdown 11 feet. Pumps 30 gpm.
14	Mechanicsville Turnpike.	Glen Lea School			do	158	Dg	25			6	P	Supplies school cafeteria and 300 students.

TABLE 5.—*Records of wells in central and eastern Henrico County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Remarks
15	Mechanicsville Turnpike	Mr. Osterheimer	Sydnor Pump & Well Co., Inc.	1947	Terrace		Dr	236	8	−130	50	D, Irr	Drawdown 40 feet.
16	do	Markow Florist		1947	do	162	Dr	229	8	−130	50	D, Irr	Do.
17	Near Harvie Rd. and Sandy Lane.	Cherry Hill Hatchery.	Virginia Machinery & Well Co., Inc.	1945	Rolling ground.	192	Dr	218	8	−131	50	D, S	Drawdown 56 feet. Finished with #20-slot screen.
18	Creighton and Cedar Forks Rds.	T. V. Earnhardt	Shaw Brothers		Terrace	185	Dr	261	4½	−89	30	D	
19	Ninemile Rd. and Windsor Pl.	Masonic Home	Sydnor Pump & Well Co., Inc.	1936	do	150	Dr	210	8		30	D	
20	do	do	do	1928	Terrace	150	Dr	271	10	−69	100	D	Drawdown 50 feet. Now pumped at 84 gpm.
21	Meadow Rd. and Mechanicsville Turnpike.	J. B. Shaw	Shaw Brothers	1947	do		Dr	265	4½	−120	5	D	Drawdown ½ foot.
22	State Route 60, 1 mile east of city.	San Rafael Court	Sydnor Pump & Well Co., Inc.	1943	do	160	Dr	181	8	−124	14	M	Drawdown 30 feet. 50-slot Johnson screen set at 161 to 171 feet.
23	State Route 60, 2 miles east of city limits.	Robinwood	do	1943	do	165	Dr	196	8			M	Water is treated for acidity. See analysis, table 7.
24a	Highland Springs	Municipality	do		do	172	Dr	250	10			M	
24b	do	do	do		do	172	Dr	307	10			M	See analysis, table 7; see also log, table 6.
25	do	Fairfield school	Virginia Machinery & Well Co., Inc.	1917	Terrace	169	Dr	401	10	−125	35	Ab	Drawndown 15 feet. Gravel developed between 298 and 300 feet and below 395 feet.
26	do	Mr. Lingerfelt			Slope	100	Spring				5	D	
27	Fair Oaks	Mutual Oil and Gas Co.	do	1917	Terrace	163	Dr	669	8			Ab	
29	Sandston	Municipality	Sydnor Pump & Well Co., Inc.	1925	do	166	Dr	272	10	−128	150+	M	Drawdown 32 feet. See log, table 6, and analysis, table 7.

30	do	Seven Pines National Cemetery.	do		do	160	Dr	190	10			D	See log, table 6.
31	Byrd Airport	Seven Pines Foundation Co.	do	1917	do	160	Dr	185–267	10		150–200	Ab	Five wells in area.
32	do	Byrd Airport	do	1942 (?)	do	160	Dr	239	10			M	Water from slightly clayey sand at 226 to 239 feet.
33	Savages Station	Brills Dairy			Rolling ground.	140	Dg	30		—20	3	S, C	Supplies dairy herd of 170 cows. Cools milk. See analysis, table 7.
34	Meadow Rd	W. E. Stevens	Sydnor Pump & Well Co., Inc.		do		Dr	261	4½	—126	15	D	
35	Bottoms Bridge	V. R. Shepherd	O. C. Brenneman	1946	do	162	J	268	3–2	—125		D	See log, table 6, and analysis, table 7.
37	Glendale	National Cemetery	Mitchell's Well & Pump Co.	1936	Terrace	144	Dr	232	8	—128	15	D	Do.
38	do	Methodist Parsonage.	O. C. Brenneman	1945	Dissected terrace.	100	J	190	2			D	
39	Long Bridge and Mill Rds.	Gravel Hill Church			do	140	Dg	26		—18		D	Used for baptismal font.
40	Curles Neck	Curles Neck Farm	F. M. Gould	1900	Terrace	30	Dr	725	8	—26(?)		D,S,C	Granite struck at 310 feet.
41	Varina	Varina Agricultural High School.			Terrace	145	Dg	21		—19	7½	D	Furnishes about 3,000 gpd. No shortage in drought periods. See analysis, table 7.
42	Fort Harrison	National Cemetery	Sydnor Pump & Well Co., Inc.	1933	do	118	Dr	346	6	—50	7½	Ab	See log, table 6. Present well yields irony water at 140 feet.
43	State Route 5 and Schoolhouse Rd.	W. G. Leverty	do		Valley	100	Dr	300	8	—20(?)	12	D	Drawdown over 200 feet. Fills swimming pool.
44	do	R. H. Nelson, Jr			Edge of terrace.	120	Dg	16			7	D, S	Supplies 60 cattle and other farm needs.
45	1 mile east of Varina	Midview Farm			Terrace	156	Dg	31	—26	—26	6	S, C	Supplies dairy of 300 cows. Cools milk. Corrodes galvanized pipes.
47	Darbytown Road and Chesapeake and Ohio RR.	Darbytown Distillery.	Sydnor Pump & Well Co., Inc.		Rolling ground.	140	Dr	500(?)				Ab	Granite struck at 280 feet.
48	500 Spring St., Richmond.	Virginia State Penitentiary.			Valley	115	Dr	248	6		150	Ab	Granite struck at 38 feet.
49	15th and Carey Sts., Richmond.	Kingan & Co		1910	River terrace.	35(?)	Dr	428		—30	70	Ab	Water corrosive. Yield eventually decreased to 18 gpm.
50	8th and Main Sts., Richmond.	Morris Plan Bank					Dr					C	
51	9th & Grace Sts., Richmond.	Hotel Richmond		1905		157	Dr	572	8		300	Ab	Pump set at 250 feet.
52a	8th & Broad Sts., Richmond.	Murphy's Hotel		1904		175	Dr	450	8	—100	50	Ab	Pump set at 390 feet. Water foams and forms scale.

TABLE 5.—*Records of wells in central and eastern Henrico County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Remarks
53	Franklin and Jefferson Sts., Richmond.	Hotel Jefferson		1906		175	Dr	702	8	−100	65	Ab	
53	do	do				180	Dr	445		−60	60	Ab	Rock struck at 118 feet.
54	Broad St., Richmond.	Thalhimers			Terrace	170	Dr	500+			300	Ab	Yield is combined discharge of two wells. Water contained silt.
55	1212 East Broad St., Richmond.	Medical College of Virginia.		1941	Edge of terrace.	150	Dr	765		−100+	50	Ab	Pump set below 500 feet. Temperature 64° to 67° F.
56	Hermitage Rd., Richmond.	Abattoir			Terrace		Dr	400	8		300	Idle	Pump set at 340 feet.
57	1501 Overbrook Rd	Kingan & Co			do	180	Dr	210	8		50	C	Also two other wells of smaller yield.
58	6th & Dinwiddie Sts., Richmond.	Southern Stove Works.		1892	do		Dr	300	6		200	Ab	
59	Richmond Union Stockyard Rd.	Bloomingdale Stock Farm.			do	180	Dr	322	8		25	Ab	Rock struck at 123 feet.
60	Ginter Park, Richmond.	Union Theological Seminary.			do	200	Dr	357	8	−40	166	Ab	
61	Westbrook Community, Richmond.	Westbrook			Edge of terrace.	195	Dr	306	8		50	Ab	Rock struck at 96 feet.
63	Stratford Village Community, Richmond.	Stratford Village	Sydnor Pump & Well Co., Inc.		do	196	Dr		10			M	Rock struck at 149 feet. Overlying material blue clay, slightly sandy at base. See analysis, table 7.
64	1600 Hilliard Rd., Richmond.	Hermitage Club	Virginia Machinery & Well Co., Inc.	1926			Dr	149	8		24	D	Drawdown 120 feet. Flowed ½ gpm.
65	Wistar Rd., Dumbarton.	W. H. Zimmerman	Sydnor Pump & Well Co., Inc.		Terrace			79	4½		40	D	
66	Greendale, near Dumbarton.	Bonnie Brae Community.	do		do	210	Dr		10			M	See analysis, table 7.
68	Staples Mill Rd., Dumbarton.	School	Virginia Machinery & Well Co., Inc.	1926	Valley	190	Dr	325		−8	15	M	

69	2205 Staples Mill Rd., Dumbarton.	R. E. Holland Planning Mill.	Washington Pump & Well Co.	1941		190	Dr	213	8			D, B	Drawdown 60 feet.
70	1 mile south of Dumbarton.	Kildare Community.	Sydnor Pump & Well Co., Inc.		Terrace	205	Dr		10			M	
71	1¼ miles south of Dumbarton.	Mayfield Community.	do				Dr					M	
72	South of Broad St. and west of Libbie Ave.	Westwood Community.	do		Rolling ground.		Dr	900			5	Ab	Rock at 108 feet.
73	do	do	do		do	250	Dr	468	8		50	M	Rock at 118 feet.
74	Three Chopt Rd. and Carey St.	Rest-a-Bit Country Club.	do		Edge of terrace.	210	Dr	172	8	−80	25	D	Drawdown 50 feet.
75	Three Chopt Rd. near Patterson Ave.	Three Chopt Court	do	1947	Slope	270	Dr					M	
76	Westwood Community, Richmond.	Westham	do		Dissected terrace.	240	Dr					M	
77	do	do	do		Stream bank.	190	Dr					M	
78	do	do	do		do	190	Dr					M	
79	Spottswood Park Community, Richmond.	Spottswood Park	do		Dissected terrace.	210	Dr				19	M	
80	University Heights, Richmond.	Permanesque Development.	do		do	230	Dr	Shallow		−25	6	M	Drawdown 20 feet. A second well here of about same depth and yield.
81	Richmond	Fairway Ridge Corporation.	Virginia Machinery & Well Co., Inc.	1923			Dr	499		−20	35	Ab	Drawdown 141 feet.
82	University Heights, Richmond.	Mayo-Trice Development.	Sydnor Pump & Well Co., Inc.		Dissected terrace.	210	Dr	124		−24	20	M	Drawdown 120 feet. Rock struck at 50 feet.
83	State Route 6 and Foxcrest Rd., Richmond.	North Rollingwood	do		do	270	Dr	206	8	−17	35	M	Drawdown 134 feet. Water treated with marble chips. See analysis, table 7.
84	do	do	do		do	240	Dr	201	8	−30	30	M	Drawdown 70 feet.
85	do	Rollingwood	do		Stream bank.	210	Dr	230	8	−20	40	M	Drawdown 100 feet.

TABLE 6.—*Logs of wells in central and eastern Henrico County, Va.*

Well 24b, Highland Springs; Municipality

[Generalized log from samples furnished by Sydnor Pump & Well Co., Inc. Altitude, 172 feet. Some of the sediments above 138 feet may belong to the Nanjemoy formation]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay yellow	38	38
Chesapeake group (Miocene): Clay, sandy, gray	100	138
Nanjemoy formation (Eocene): Clay, gray and pink	5	143
Aquia formation (Eocene):		
Clay, gray	33	176
Sand, coarse; water	11	187
Potomac group (?) (Lower and upper Cretaceous):		
Clay, gray	31	218
Sand, brown	22	240
Gravel, sandy; water	6	246
Silt, clayey	49	295
Sand, gravelly; water	10	305
Sand, coarse	2	307

Well 27, Dean Place (Fair Oaks); Mutual Oil and Gas Co.

[Log by Virginia Machinery & Well Co., Inc. Altitude, 163 feet. Bedrock was not struck. Geologic boundaries based on lithology and comparison with well 30 at Sandston. Some of the blue clay above 110 feet is probably part of the Nanjemoy formation]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): gravel	20	20
Chesapeake group (Miocene): Clay, blue	90	110
Nanjemoy formation (Eocene): Clay, red	20	130
Aquia formation (Eocene):		
Clay, blue	30	160
Clay, blue and green	40	200
Potomac group (?) (Lower and Upper Cretaceous):		
Clay, yellow	20	220
Clay, gray	30	250
Sand and gravel	100	350
Sand, clayey, and gravel	50	400

Well 29, Sandston; Municipality

[Log by Sydnor Pump & Well Co., Inc. Altitude, 166 feet. See also log of well 30]

	Thickness (feet)	Depth (feet)
Undifferentiated:		
Clay, blue	160	160
Clay, blue, coarse gravel; scant water	8	168
Clay, blue	57	225
Gravel, small, and sand; water	39	264
Clay, blue	8	272

TABLE 6.—*Logs of wells in central and eastern Henrico County, Va.*—Continued

Well 30, Sandston; Seven Pines National Cemetery

[Log from samples furnished by Sydnor Pump & Well Co., Inc. Altitude, 160 feet. It seems likely that the lowest 20 or 25 feet of gray clay above the pink clay (Nanjemoy) is also part of the Nanjemoy formation]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, yellow, and sand	58	58
Chesapeake group (Miocene): Clay, gray	77	135
Nanjemoy formation (Eocene): Clay, pink; Foraminifera	8	143
Aquia formation (Eocene):		
Clay, gray; Foraminifera	33	176
Sand, coarse; water	14	190

Well 35, Bottoms Bridge; V. R. Shepherd

[Log by D. J. Cederstrom. Altitude, 162 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand, yellow-to-red, clayey; and clay	40	40
Sand, white; grades down to gravel	10	50
Clay, yellow, sandy	28	78
Chesapeake group (Miocene): Marl, yellow-to-blue; Foraminifera	30	108
Nanjemoy formation (Eocene):		
Marl, slightly glauconitic, blue; Foraminifera	17	125
Marl, glauconitic, contains shells	16	141
Marl, slightly glauconitic	12	153
Clay, gray (rock stratum at 161 feet); Foraminifera	15	168
Clay, red	18	186
Aquia formation (Eocene):		
Clay, gray; Foraminifera	18	204
Clay, glauconitic, gray	6	210
Sand, black; shell zone at top and base	13	223
Rock streak	1	224
Sand, black, and shells; Foraminifera	9	233
Sand, white; water	35	268

Well 37, Glendale; Glendale National Cemetery

[Log by Mitchell's Well & Pump Co. Altitude, 144 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, brown	11	11
Clay, light	9	20
Sand, fine; clay	10	30
Sand, coarse; clay	19	49
Chesapeake group (Miocene):		
Sand and shells	25	74
Marl, blue	22	96
Marl, sandy, blue; with black grit	23	119
Nanjemoy (Eocene):		
Marl, glauconitic	28	147
Marl, glauconitic; contains shells	16	163
Clay, red	11	174
Aquia (Eocene):		
Marl, bluish-gray, sandy	48	222
Gravel; water	10	232

TABLE 6.—*Logs of wells in central and eastern Henrico County, Va.*—Continued

Well 42, Fort Harrison National Cemetery; Varina Grove

[Log from samples furnished by Sydnor Pump & Well Co., Inc. Altitude, 118 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Gravel, hard	20	20
Sand, yellow; clay	5	25
Gravel, yellow	12	37
Sand, yellow; clay	13	50
Chesapeake group (Miocene): Sand, coarse; in hard and soft streaks with gravel and clay; may be weathered Miocene marl	30	80
Potomac group (Lower and Upper Cretaceous):		
Sand, coarse, gray, and gravel; water	18	98
Clay, hard, gray, sandy, and gravel	19	117
Clay, hard, red, sandy, and gravel; some water at 130 ft. and 205 ft	88	205
Clay, hard, gray and brown, sandy	10	215
Rock, hard, red, sand	8	223
Clay, hard; mica	13	236
Clay, hard, red and brown, sandy	4	240
Clay, hard, red, sandy	27	267
Clay, sticky, red	3	270
Clay, hard, red, sandy	35	305
Rock, hard, red	3	308
Rock, streaks, and sandy clay	29	337
No formation given (probably same as above)	9	346

TABLE 7.—*Chemical analyses of waters from wells in central and eastern Henrico County, Va.*

[Analyses in parts per million. Analyst: GWW, G. W. Whetstone; EWL, E. W. Lohr; F & R, Froehling and Robertson Co.; HBS, H. Bently Smith Co.]

	Well no.				
	5	12	22	23	24b
Location	Solomons Store	Oak Hill	San Rafael	Robinwood	Highland Springs
Depth (feet)	182	291	181	196	307
Formation, group, or type	Granite	Potomac group	Aquia formation	Aquia formation	Potomac group
Date	Oct. 14, 1947	Nov. 6, 1947	Dec. 30, 1943	Dec. 30, 1943	Dec. 30, 1943
Silica (SiO_2)	26	26	26		
Iron (Fe)	5.1	.11	.03	1.7	
Calcium (Ca)		25	26		
Magnesium (Mg)		12	11		
Sodium (Na) / Potassium (K)		19	[1] 24		
Bicarbonate (HCO_3)	59	175	177	204	151
Sulfate (SO_4)	3	5.5	13	75	12
Chloride (Cl)	4	2	2.1	69	2
Fluoride (F)	.2	.3	.0	1.9	.3
Nitrate (NO_3)	.2	.2	.0	.4	.1
Dissolved solids		173	183		
Hardness (as $CaCO_3$)	36	112	110	34	24
Free carbon dioxide (CO_2)			.4	7.6	4.0
Analyst	GWW	GWW	EWL	EWL	EWL

	Well no.				
	29	33	35	37	39
Location	Sandston	Savages Station	Bottoms Bridge	Glendale	Gravel Hill
Depth (feet)	272	30	268	232	26
Formation, group, or type	Potomac group	Columbia group	Aquia formation	Aquia formation	Columbia group
Date	Dec. 30, 1943	Oct. 31, 1947	Nov. 4, 1947	Dec. 29, 1943	Nov. 7, 1947
Silica (SiO_2)	44	9.6	16	27	
Iron (Fe)	.03	.03	.18	1.6	0.4
Calcium (Ca)	29	6.8	6.7	32	
Magnesium (Mg)	10	4.5	2.3	13	
Sodium (Na) / Potassium (K)	[1] 22	[1] 14	57	[1] 29	
Bicarbonate (HCO_3)	183	10	164	226	8.0
Sulfate (SO_4)	7.9	3.5	8.1	6.7	1
Chloride (Cl)	2.4	20	4	2.2	12
Fluoride (F)	.0	.2	.4	.3	.0
Nitrate (NO_3)	.1	30	.5	.0	5
Dissolved solids	200	98	167	224	
Hardness (as $CaCO_3$)	114	35	26	133	9
Free carbon dioxide (CO_2)	4.0			1.1	
Analyst	EWL	GWW	GWW	EWL	GWW

[1] Calculated.

TABLE 7.—*Chemical analyses of waters from wells in central and eastern Henrico County, Va.*—Continued

	Well no.				
	40	41	51	59	60
Location	Curles Neck	Varina Grove	Richmond	Richmond	Richmond
Depth (feet)	725	21	572	322	357
Formation, group, or type	Granite	Columbia group	Granite	Granite	Granite
Date	Nov. 7, 1947	Nov. 17, 1947	1904	----------	1905
Silica (SiO_2)	39	----------	28	15	40
Iron (Fe)	.09	0.95	.18	.4	----------
Calcium (Ca)	1.4	----------	68	4.0	82
Magnesium (Mg)	2.0	----------	30	.2	12
Sodium (Na) } Potassium (K)	78	----------		22	7.6
Sodium (Na)			68		
Potassium (K)			29		
Bicarbonate (HCO_3)	142	17	182	50	193
Sulfate (SO_4)	9.7	3	232	12	10
Chloride (Cl)	38	5	63	5.3	35
Fluoride (F)	.1	.0	----------	----------	----------
Nitrate (NO_3)	.2	6.0	----------	----------	68
Dissolved solids	233	----------	702	92	559
Hardness (as $CaCO_3$)	12	12	285	11	254
Free carbon dioxide (CO_2)	----------	----------	----------	----------	----------
Analyst	GWW	GWW	F&R	----------	HBS

	Well no.				
	61	63	66	70	83
Location	Richmond	Stratford Village	Dumbarton	Kildare	North Rollingwood
Depth (feet)	306	----------	----------	----------	206
Formation, group, or type	Granite	Granite	Granite	Granite	Granite
Date	1902	Nov. 4, 1947	Nov. 4, 1947	Nov. 4, 1947	Nov. 4, 1947
Silica (SiO_2)	28	----------	----------	33	26
Iron (Fe)	----------	0.52	0.25	.17	.10
Calcium (Ca)	55	----------	----------	4.4	6.5
Magnesium (Mg)	11	----------	----------	1.0	.6
Sodium (Na)	128	} ----------	----------	4.8	6.7
Potassium (K)	8.5				
Bicarbonate (HCO_3)	174	218	113	18	32
Sulfate (SO_4)	263	9	10	.2	.6
Chloride (Cl)	37	5	3	4	4
Fluoride (F)	----------	1.3	1.3	.2	.1
Nitrate (NO_3)	.18	.1	.1	5.4	.6
Dissolved solids	620	----------	----------	85	67
Hardness (as $CaCO_3$)	182	96	42	15	19
Free carbon dioxide (CO_2)	----------	----------	----------	----------	----------
Analyst	F&R	GWW	GWW	GWW	GWW

EASTERN HANOVER COUNTY

Hanover County has an area of 466 square miles and a population of 21,985 (Virginia Division of Planning and Economic Development, 1951). A small part of the county is a residential area for people working in Richmond, but in most of the county the inhabitants are engaged in the production of dairy, poultry, and forest products. The value of farm products sold in 1949 was $3,277,940. In relative importance the farm products were poultry products, livestock, field crops, dairy products, and vegetables. Three-fifths of the county is wooded, and production of excelsior and other wood products is one of the principal occupations.

U. S. Highway 1, connecting Richmond with Washington, passes northward through Hanover County, as does U. S. Highway 301 connecting Richmond with Baltimore via the Potomac River bridge at Morgantown. Virginia State Route 360 passes northeastward, connecting Richmond with Tappahannock and the Northern Neck peninsula. The main line of the Richmond, Fredericksburg and Potomac Railroad, connecting Richmond with Washington, passes through central Hanover County.

TOPOGRAPHY

Eastern Hanover County consists of two broad, flat or rolling terraces broken by many minor and few major streams. In most places the relief is small but in a few places where the larger streams—the North Anna, the Pamunkey, and the Chickahominy Rivers—are cutting their banks, cliffs from 50 to 100 feet high are present. Although the major streams may lie 100 to 150 feet below the general land surface, narrow intermediate terraces are common and altitude gradations are moderate.

The Coharie terrace, declining from a maximum altitude of about 210 feet along U. S. Highway 1 to about 160 feet in the easternmost part of the county, is widespread. Westward this terrace is only slightly or moderately dissected, but eastward dissection has progressed further and the high terrace level is represented by the flat tops of many low hills.

The Sunderland formation appears to be poorly represented by traces of a 170-foot terrace in a few places along major streams, but the lower Wicomico and Penholoway terraces, with maximum altitudes of respectively 100 and 70 feet above sea level, are better represented by long, rather narrow flats adjacent to the Chickahominy and the Pamunkey Rivers.

Unconsolidated sediments of the Coastal Plain cover eastern Hanover County but thin out in a westerly direction. Along the Fall Line (marked approximately by U. S. Highway 1) the Coastal Plain sediments are very thin and in some places underlying bedrock is exposed.

GEOLOGY

BEDROCK

In the vicinity of Ashland, sandstone of Triassic age is exposed on the banks of the North Anna River and these rocks are reported in logs of deep wells at Ashland itself (9, table 9; fig. 9). These rocks are also present in wells at Doswell, about 10 miles north of Ashland, within 30 feet of the surface. Granite was present in a dug well at a restaurant (15, table 8) along U. S. Highway 1, 3½ miles south of Ashland.

Presumably the Triassic rocks are small blocks moved into position by faulting and it may be expected that the granite is generally present, as in the western part of the county.

CRETACEOUS SYSTEM—POTOMAC GROUP

According to the geologic map of Virginia, the Potomac group of Cretaceous age crops out along the Pamunkey River east of Doswell but these sediments are not exposed at the surface elsewhere in the county. Although Cretaceous units overlie bedrock in most of eastern Hanover County, only a limited part of the Potomac group has been reached by a few wells.

TERTIARY SYSTEM

EOCENE SERIES

The Pamunkey group of Eocene age crops out along the banks of the Pamunkey and the Chickahominy Rivers, from the Fall Line to the easternmost limits of the county, as shown on the geologic map of Virginia. These sediments have been reached by wells at Hanover, Peaks, Mechanicsville, Cold Harbor, and Appersons Store, but not much detail is available on the thickness and character of the beds.

As shown by Clark and Miller (1912, p. 100–101), the Pamunkey group exposed along the larger streams consists of glauconitic clays and marls with interbedded blue clays. In the eastern part of the county (that is, east of U. S. Highway 1) wells tap the basal(?) Eocene sand beds.

Both the lower, or Aquia, formation and the overlying Nanjemoy formation are present in the county; the Nanjemoy formation thins rapidly westward and does not reach the Fall Line, but the Aquia extends all the way to the Fall Line itself in the northern part of the county, although its full thickness there is problematical. (See log of well 22, table 9.) Northeast of Mechanicsville (well 28, table 9) both the Aquia and Nanjemoy formations have been recognized in well cuttings; the combined thickness there is about 125 feet.

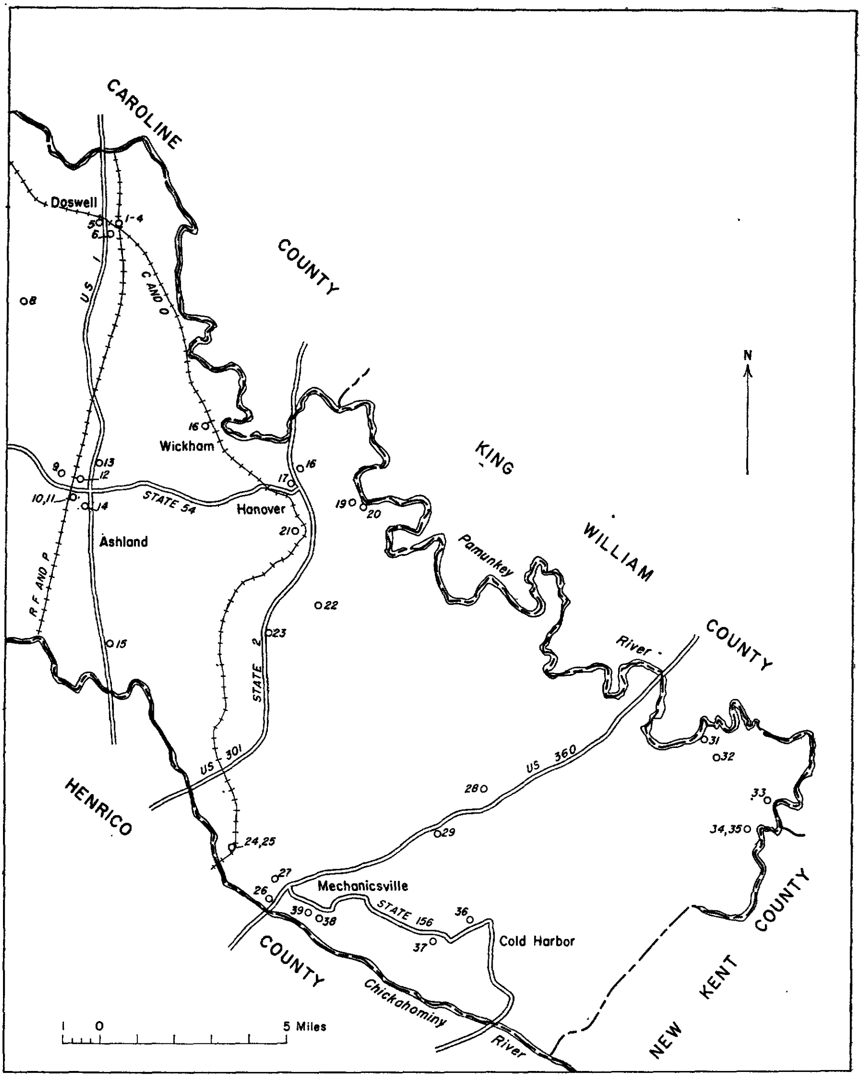

FIGURE 9.—Location of wells in eastern Hanover County.

MIOCENE SERIES

Blue clays of the Chesapeake group of Miocene age overlie the Eocene deposits. These, too, thin to a vanishing point along the Fall Line. Miocene units are exposed in many road cuts and along the banks of many streams.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The eastern part of the county is covered by red and yellow clay and yellow to white quartz sand terrace formations, the Columbia group of Pleistocene age. Near the Fall Line the terrace deposits may reach a thickness of 70 to 80 feet.

WATER-BEARING FORMATIONS

Everywhere along U. S. Highway 1 from Richmond to Doswell the Coastal Plain sediments are thin. In this area and westward it is necessary to continue wells into bedrock in most places in order to obtain more than a minimum supply of water.

BEDROCK

Several wells have obtained water from Triassic bedrock at Ashland. Sanford (1913, p. 195) gives the record of a 365-foot well (9, table 9) at the site of the old Henry Clay Inn which apparently obtained its water supply from a sandstone stratum between 181 and 307 feet. At Randolph-Macon College a well (12, table 8) obtained 27 gpm with 60 feet of drawdown from "gray stone" between 91 and 290 feet. Two municipal wells (10, 11, table 8), drilled about 1910, are reported to be respectively 374 and 250 feet deep and to have yielded 45 and 85 gpm. These wells were abandoned and a supply is now obtained from the nearby South Anna River.

CRETACEOUS SYSTEM

Cretaceous deposits underlie eastern Hanover County, but only a few wells in the county obtain water from these beds. Well 28, near Mechanicsville, well 34 at Eastern View Farm below Old Church, and well 36 at Cold Harbor seemingly obtain water from the same Cretaceous stratum.

There is good reason to believe that large quantities of water might be obtained from wells deeper than those now in use. Cretaceous units are characteristically made up of alternating clay and subordinate sand beds. South of the James River, beds of this age are prolific water bearers. Near the Fall Line, however, Cretaceous units in the aggregate are thin, and permeable sand beds may be thin or lacking. It is thought that the part of Hanover County lying east of a north-south line drawn through Hanover and Mechanicsville is favorable for the development of large supplies of water from deep wells, and that the easternmost part of the county is particularly favorable.

TERTIARY SYSTEM

EOCENE SERIES

Aquia formation

Most deep wells in the county tap basal deposits of the Aquia formation. At Mechanicsville (27, table 8, pl. 1) the sand present at 20 feet below sea level is overlain by glauconite sand. At Hanover, the top of the sand is reached in several wells (17, 18) at 40 feet below sea level. Here have been described deposits of the Aquia (Clark and Miller, 1912, p. 101) on the bank of Pamunkey River, about 50 feet above sea level.

At Hanover (19) 35 gpm was obtained with 70 feet of drawdown. A slightly greater yield, 50 gpm with 83 feet of drawdown, was obtained at nearby Peaks (22). At Mechanicsville (27) 50 gpm with 40 feet of drawndown was developed. The writer believes that the gravelly sand present there would admit a screen of larger slot size than the 30-slot that was used and a greater yield might be obtained.

An unusual well at Ellerson, about 5 miles north-northeast of Richmond, was dug to a total depth of 139 feet and taps the basal sand of the Aquia, which was reached by the municipal well at Mechanicsville. The well at Ellerson is 10 feet in diameter and is entirely curbed with brick. The well is equipped with a turbine pump with a capacity of 30 gpm and supplies water to six families, a florist, a garage, and two other business establishments.

Water levels are high in wells tapping Eocene units in the vicinity of Henrico and Mechanicsville. According to various data, water will rise from 35 to 80 feet above sea level in this area. In the easternmost part of the county water probably will not rise more than about 15 feet above sea level. At Retreat Farm (33) water flows at an elevation of 11 feet above sea level and it seems likely that it will not flow a great deal higher at that place. A few miles downstream, in adjacent New Kent County, water from wells ending in Eocene deposits will rise 8 feet above sea level.

Nanjemoy formation

The Nanjemoy formation lenses out near Hanover and the formation as a whole is thin in eastern Hanover County. There is no indication that these beds are water bearing in Hanover County and it therefore appears that they are largely clays or marls.

MIOCENE SERIES

Apparently neither the basal Calvert nor the Yorktown formation contains water-bearing beds in Hanover County.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The Columbia group of Pleistocene age (terrace deposits) furnishes water to hundreds of domestic driven and dug wells in the county. Several of the dug wells listed in table 8 furnish sufficient water for tourist camps and small dairies. One well (5) supplies water for a sawmill boiler. It appears that the terrace deposits may contain as prolific water-bearing formations here as in Henrico County to the south, although there are no specific data on dug wells in Hanover County showing that more than about 6 gpm is being pumped from any one well. However, the possibility of dug wells furnishing from 10 to 15 gpm should be kept in mind where more than minimum quantities are needed.

Springs that issue from the base of the terrace deposits on the banks of steep ravines are used to a somewhat greater extent in this county than in the other counties and furnish as much as 30 gpm (20). The usefulness of springs is dependent upon their location relative to the point of use of water and in many instances it is found more satisfactory to have a dug well in or near the farmyard than to use one of several springs some distance away.

QUALITY OF WATER

WATER FROM BEDROCK

The sample of water from a well (3, table 10) tapping Triassic bedrock is a fairly soft sodium bicarbonate water, in which calcium bicarbonate hardness is 51 ppm. Iron, fluoride, and other constituents are low.

WATER FROM THE CRETACEOUS TO THE TERTIARY SYSTEMS

Samples from Mechanicsville (26) and Hanover (17, 19) are fairly hard calcium bicarbonate waters, in which hardness ranges from 78 to 180 ppm. Sulfate is higher than average, 36 ppm in one sample (17), and iron is high, 2.6 ppm, in another (19). Fluoride is low in all three samples.

As explained in the general part of this report, Coastal Plain waters upon moving eastward gain in hardness but beyond a certain point become softened by base exchange. Samples from deep wells near Appersons Store (33, 34, table 10; fig. 9) are consequently soft bicarbonate waters in which calcium has been more or less replaced by sodium. At well 33 softening has been only partially effective and the water has a calcium bicarbonate hardness of 24 ppm, but at well 34 the water contains only 3 ppm of hardness. The bicarbonate content of these soft-water samples is about the same as the hard-water samples from farther west, less than 200 ppm.

Other constituents in the soft-water samples are low. The fluoride content of the soft water is less than 1 ppm, about the same as of the hard waters.

WATER FROM THE PLEISTOCENE SERIES

Water from shallow terrace deposits characteristically has a very low mineral content. The sample of spring water from Hanover (20) contains a little hardness, 42 ppm. It also shows evidence of possible organic pollution in that the nitrate content is 15 ppm. Free carbon dioxide in this sample is 19 ppm and it is expected that the water might be somewhat corrosive.

Records and logs of wells and chemical analyses of waters for eastern Hanover County follow in tables 8, 9, and 10.

TABLE 8.—Records of wells in eastern Hanover County, Va.

Type of well: Dg, dug; Dr, drilled; J, jetted. Use of water: Ab, abandoned; B, boiler feed; C, cooling; D, domestic; I, industrial; M, municipal; P, public school; S, stock; T, tourist cabins]

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level: (Feet above (+) or below (−) surface)	Approximate water level: Date of measurement	Approximate yield (gallons per minute)	Use of water	Remarks
1	Near Doswell	Richmond, Fredericksburg and Potomac R.R.			Terrace	55(?)	Dr	327		−3	1910(?)		Ab	Data from Sanford, 1913, p. 308. Triassic rocks tapped.
2	Doswell	do	Mitchell's Well & Pump Co.	1945	do	127	Dr	200	8	−16½	1945	210	I	Drawdown 92½ feet at discharge noted.
3	do	Old Dominion Excelsior Co.	do	1945	do	130	Dr	174	6			15	I	Temperature 59° F. Rock struck at 23 feet.
4	do	Hanover Veneer Co.	do	1945	Slope	140	Dr	400	8			15	B	
5	do	Flippo Sawmill			Terrace	170	Dg	18					B	Supplies 125 hp boiler. Water is slightly corrosive.
6	do	T. F. Flippo	Mitchell's Well & Pump Co.		Slope	160	Dr	192	6	−33	1946	1½	D	Rock struck at 30 feet.
8	2 miles west of Gum Tree.	Mrs. Pemberton	do	1937	Terrace	200	Dr	160	6	−30	1945	25	D	Sandstone struck at 55 feet.
9	Ashland	Henry Clay Inn	Sydnor Pump & Well Co., Inc.	1906	do	220	Dr	365	8				Ab	
10	do	Town		1910	do	220	Dr	374	10			45	Ab	Well became polluted.
11	do	do		1910	do	220	Dr	250	10			85	Ab	
12	do	Randolph-Macon College.	Virginia Machinery & Well Co., Inc.	1918	do	221	Dr	290	10			27	Ab	Rock struck at 91 feet.
13	do	Hanover Service Station.		1937	do	205	Dg	20		−4	1937		D	
14	do	Palm Leaf Cabins		1932	do	205	Dg	24		−7¾	1937		T	
15	3½ miles south of Ashland.	Wigwam Restaurant.			Slope	150	Dg	35		−15	1945	5	T	Granite struck at 28 feet. Well supplies 28 cabins.
16	Wickham	Hickory Hill School.			Terrace	200	Dr	54		−42	1910(?)		Ab	Hard water; has iron taste; from Miocene units.
17	Hanover	Patrick Henry Inn.	C. W. Gentry	1932	do	100	Dr	129	4	−50±	1937		D	

18	do	C. L. Ancarrow	do	1933	do	105	Dr	139	4				D	
19	do	Manual Training School.	Virginia Machinery & Well Co., Inc.	1929	do	80	Dr	152	8	−40	1929	35	D	See analysis, table 10. Drawdown 70 feet at discharge noted.
20	do	do			Edge of terrace.	80	Spring						D	Maximum yield about 30 gpm. See analysis, table 10.
21	Cady	F. V. Baldwin	Virginia Machinery & Well Co., Inc.	1927	Rolling ground.	160	Dr	210	6	−125	1927	10	D	
22	Peaks	Janie Barrett Porter School.	do	1937	Terrace	180	Dr	250	8	−117	1937	50	D	
23	2½ miles south of Hanover.	Hanover Waysides.	Mitchell's Well & Pump Co.		Hilly ground.		Dr	196	6			11	D	
24	Ellerson	Mrs. Blankenship	do	1946	Terrace	124	Dr	142	8	−60	1946	6	D	
25	do	Bradley and Boswell.		1935	Slope	130	Dg	139		−50	1946	30	D, I	
26	Mechanicsville	B. H. Rowe	W. S. Reynolds	1937	Slope	150	J	146	2				D	
27	do	Sydnor Pump & Well Co., Inc.	Sydnor Pump & Well Co., Inc.	1945	Dissected terrace.	190	Dr	260	10	−121	1945	50	M	Drawdown 40 feet.
28	6 miles east-northeast of Mechanicsville.	V. E. Portwood	Mitchell's Well & pump Co.	1948	Terrace	170	Dr	356	6	−130	1948	5	D	Drawdown 38 feet after pumping 5 hours. Open end casing extends to 340 feet.
29	Newman	Battlefield Park High School.		1935	do	195	Dr						P	
31	1½ miles north of Appersons.	P. W. Parker			Cliff	50	Spring					15	S, C	
32	1 mile northeast of Appersons.	Horseshoe Farm			Edge of terrace.	71	Dg	30		−20	1945	15(?)	S, C	
33	2 miles east of Appersons.	Retreat Farm				15	Dr	300(?)	3	+	1945	10	D, S	Yield as flow out of 6 foot standpipe. Temperature 62½° F. See analysis, table 10.
34	2 miles southeast of Appersons	Eastern View Farm.	W. S. Reynolds		Hillside	94	J	366	3	−	1945		D	See analysis, table 10.
35	do	do			Slope	120	Dg	28		−	1945		D, S	Slight iron. Well normally furnishes about 3,000 gpd.
36	Cold Harbor	National Cemetery.	Sydnor Pump & Well Co., Inc.	1932	Rolling ground.	190	Dr	438	8	−	1932		D	See analysis, table 10. Eocene Foraminifera at 255 feet.
37	Gaines Mill	A. E. Goulding			Cliff	120	Spring						D, S	Furnishes water for 50 head of cows.
38	Beaver Dam Creek	B. W. Bruce			Terrace	160	Dg	30		−	1945		D, S	Furnishes water for 40 head of cows.
39		Catlett Farm			Cliff		Spring					10	D, S	

TABLE 9.—*Logs of wells in eastern Hanover County, Va.*

Well 9, Ashland; Henry Clay Inn

[Log from Va. Geol. Survey Bull. 5. Altitude, 220 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Earth	64	64
Newark group (Triassic):		
Rock	117	181
Sandstone	126	307
Shale, soft, brown	58	365

Well 16, Wickham; Hickory Hill Farm

[Log from Va. Geol. Survey Bull. 5. Altitude, 200 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Loam and pebbles	5	5
Clay, red	4	9
Clay, white	10	19
Chesapeake group (Miocene):		
Clay, white and purple	10	29
Clay, dark-bluish-black	8	37
Gravel, blue, and sand	3	40
Sand, blue	2	42
Marl, very hard, full of scallops and clam shells and shark teeth	11	53
Sand, white; water	1	54

Well 19, Hanover; Manual Training School

[Log by Virginia Machinery & Well Co., Inc. Altitude, 80 feet. Dark glauconitic marl is exposed on the nearby Pamunkey River at from 20 to 60 feet above sea level]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, yellow	19	19
Aquia formation (Eocene):		
Earth, blue, fuller's	109	128
Sand; water	24	152

Well 22, Peaks; Janie Barrett Porter School

[Log by Virginia Machinery & Well Co., Inc. Altitude, 180 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, yellow	30	30
Clay, yellow, sandy	10	40
Gravel	10	50
Sand, red, clayey	10	60
Chesapeake group (Miocene): Clay, tough, blue; Miocene Foraminifera at 108 feet	60	120
Aquia formation (Eocene):		
Clay, tough, blue; Aquia Foraminifera at 150 feet	92	212
Clay, hard, white	21	233
Sand	1	234
Clay, white	6	240
Sand and gravel; water	10	250

TABLE 9.—*Logs of wells in eastern Hanover County, Va.*—Continued

Well 28, 6 miles east-northeast of Mechanicsville; V. E. Portwood

[Log by Mitchell's Well & Pump Co. Altitude, 170 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Soil, top, yellow clay	40	40
Chesapeake group (Miocene): Clay, blue	108	148
Nanjemoy formation (Eocene):		
Clay, blue, and shells	22	170
Clay, blue, Foraminifera	5	175
Mud, pink	10	185
Aquia formation (Eocene):		
Mud, blue	15	200
Mud, blue; many Foraminifera	20	220
Mud, blue, and sand; Foraminifera	20	240
Mud, blue, and sand	20	260
Mud, blue, and sand	10	270
Potomac group (Lower and Upper Cretaceous):		
Mud, white, and sand	10	280
Clay, white, and sand	10	290
Clay, yellow, and sand	10	300
Clay, gray, and sand	10	310
Clay, gray, and sand	10	320
Mud, yellow	10	330
Mud, blue, some sand	10	340
Mud, blue, increasing amounts of sand	16	350

TABLE 10.—*Chemical analyses of waters from wells in eastern Hanover County, Va.*

[Analysis in parts per million. Analyst: GWW, G. W. Whetstone; EWL, E. W. Lohr]

	Well no.			
	3	17	19	20
Location	Doswell	Hanover	Hanover	Hanover
Depth (feet)	174	129	154	Spring
Formation, age, group, or type	Triassic age	Aquia formation	Aquia formation	Columbia group
Date	Nov. 6, 1947	Dec. 31, 1943	Dec. 31, 1943	Dec. 31, 1943
Silica (SiO_2)			8.0	
Iron (Fe)	0.39	0.2	2.6	
Calcium (Ca)			41	
Magnesium (Mg)			12	
Sodium (Na) / Potassium (K)			28[1]	
Bicarbonate (HCO_3)	238	220	210	13
Sulfate (SO_4)	10	36	7.7	15
Chloride (Cl)	8	9	23	6
Fluoride (F)	.3	.2	.1	.0
Nitrate (NO_3)	.2	.0	.0	15
Dissolved solids			224	
Hardness (as $CaCO_3$)	51	180	152	42
Free carbon dioxide (CO_2)		.7	.0	19
Analyst	GWW	EWL	EWL	EWL

[1] Calculated.

TABLE 10.—*Chemical analyses of water from wells in eastern Hanover County, Va.*—Continued

	Well no.				
	24	26	33	34	36
Location	Ellerson	Mechanicsville	Appersons Store	Appersons Store	Cold Harbor
Depth (feet)	142	146	300(?)	366	438
Formation, age, group, or type	Aquia formation	Aquia formation	Aquia(?) formation	Mattaponi formation	Mattaponi formation
Date	Nov. 7, 1947	Jan. 27, 1944	June 26, 1945	June 26, 1945	June 28, 1946
Silica (SiO_2)	17			32	15
Iron (Fe)	.11	0.23		.64	.08
Calcium (Ca)	30			.7	15
Magnesium (Mg)	14			.2	5.3
Sodium (Na), Potassium (K)	36			76	30
Bicarbonate (HCO_3)	230	153	187	177	136
Sulfate (SO_4)	14	10	10	16	10
Chloride (Cl)	4	3	1	2.8	1.8
Fluoride (F)	.2	.4		.6	.1
Nitrate (NO_3)	.7	.5	.1	.2	.5
Dissolved solids	222			214	154
Hardness (as $CaCO_3$)	132	78	24	3	59
Free carbon dioxide (CO_2)		.23			
Analyst	GWW	EWL	GWW	GWW	GWW

KING WILLIAM COUNTY

King William County lies between the Pamunkey River on the south and the Mattaponi River on the north. The town of West Point lies at the extreme eastern end of the county where the two rivers join to form the York River. The county has an area of 278 square miles and a population of 7,589 of which about 2,000 live in West Point (Virginia Division of Planning and Economic Development, 1951).

The county is entirely agricultural and woodland but a large pulp mill and several smaller lumber and woodworking mills are located at West Point. About 700 persons were employed at these establishments in 1947. Figures on the value added to products by manufacture are not available.

The value of farm products, dairy, livestock, field crops, and poultry products, in that order of importance, was $1,301,393 in 1949.

Eight miles south of King William on the Pamunkey River is the Pamunkey Indian Reservation, where live descendants of the ancient tribe by that name. This reservation is all that remains of the domain of Powhatan who once ruled the tribes of eastern Virginia and Maryland. Nearby is the Mattaponi Indian Reservation.

The major highways traverse King William County. State Route 30 carries much traffic passing through Washington enroute to Newport News and Norfolk. This highway is crossed by U. S. Highway 360 which connects Richmond and Tappahannock. A branch line of the Southern Railway connects West Point with Richmond. Freight service between West Point and Baltimore is also available by water, but the day of regular passenger service to these and other ports is past.

TOPOGRAPHY

Seaward-sloping terraces that are slightly dissected in the eastern part of the county but much more dissected in the central and western parts make up the land surface in King William County. The land surface therefore ranges from rather rough in the west, with a relief of more than 100 feet, to slightly rolling or nearly flat, with very little relief, on the low terrace above West Point.

The Sunderland terrace is widespread and descends from 170 feet in the west to about 130 feet in the east. Remnants of the slightly higher Coharie terrace are present in the extreme western part of the county. The Penholoway terrace, whose maximum altitude is 70 feet, occurs to a more limited extent along the upper reaches of the Mattaponi and Pamunkey Rivers, and the Talbot terrace, with a maximum altitude of 42 feet, occurs along the lower courses of those rivers. The Pamlico terrace, whose maximum altitude is 25 feet, is extensive in the vicinity of West Point.

GEOLOGY

The county is underlain by unconsolidated deposits of Cretaceous, Paleocene, Eocene, Miocene, and Pleistocene age that rest upon a granitic basement rock. Depth to bedrock is unknown but in westernmost King William County it may lie within 400 feet of the surface. At West Point bedrock may be 1,000 feet or more below the surface.

CRETACEOUS SYSTEM—POTOMAC GROUP

Alternating sand and clay beds of the Potomac group of Early and Late Cretaceous age rest upon bedrock but do not crop out and have not been reached by any wells in the county.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

Wells 26a and 34 (table 12 and fig. 10) at West Point and Cohoke, respectively, tap a series of mottled, colored clay and basal sand beds, which are tentatively assigned to the Upper Cretaceous and Paleocene series and designated as the Mattaponi formation. These sediments are separated from the overlying Eocene deposits because of major differences in lithologic character, and the presence of a pre-Aquia foraminiferal fauna that first appears at about 260 feet below sea level at West Point. The included clays are highly colored, they are only slightly glauconitic, and the basal sands are much thicker and coarser than sands in the Eocene deposits. Regardless of their exact geologic

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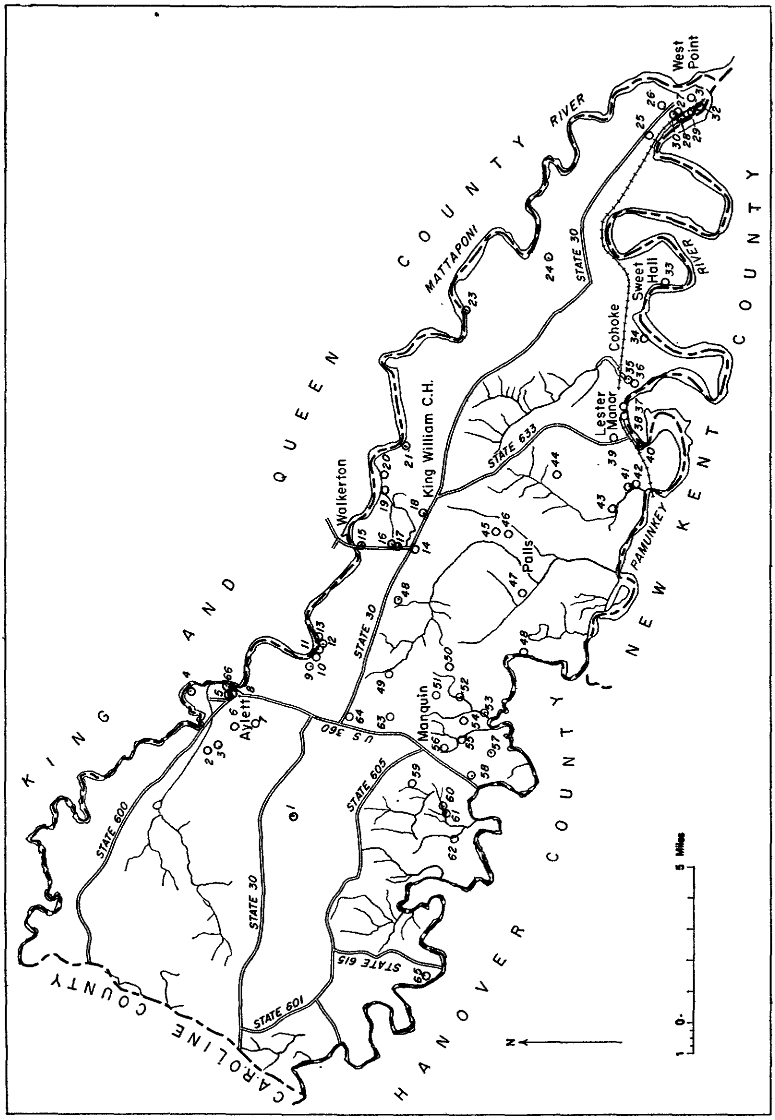

FIGURE 10.—Location of wells in King William County.

age, separation of these beds from the overlying Eocene deposits that are almost invariably highly glauconitic is desirable for the purpose of this report because of the marked differences in water-bearing characteristics of the two units.

The mottled clays are red, blue, and yellow in color and have been termed "rainbow" clay by some drillers. Westward the clays may be entirely one color but, although the mottled colors are lacking, commonly a bright-red color characterizes one or more clay beds beneath the Eocene glauconitic deposits at several localities. Foraminifera typical of the Mattaponi formation have been noted in cuttings from wells as far west as King William, Aylett, and Rumford. Details of their relationship to beds of the underlying Potomac group are uncertain.

TERTIARY SYSTEM

EOCENE SERIES

The Eocene glauconitic deposits are well represented in King William County. Both formations of the Pamunkey group of deposits, the Nanjemoy of middle and early Eocene age and the Aquia of early Eocene age, crop out in the western part of the county along the Pamunkey and Mattaponi Rivers.

Aquia formation

The Aquia formation appears to be absent at West Point and the Nanjemoy formation rests directly upon deposits of the Mattaponi formation. Hence, the Nanjemoy is shown in plate 1 and table 12 to rest directly upon the Mattaponi at that locality.

In the central part of the county the Aquia may be represented in wells 8, 48, and 49 (table 12) but it is thought that not more than 50 or 60 feet of the Aquia may be present. In any event the rich Aquia foraminiferal fauna so well preserved at Bottoms Bridge and well enough represented near Mechanicsville is lacking.

It would appear from study of the logs alone, that the sand beds tapped by well 14 at King William School, well 48 at Grimes Landing, and well 49 at Rumford (table 12), were age correlatives of the basal Aquia sand beds tapped by wells nearer the Fall Line, as at Bottoms Bridge (35, table 6). Foraminifera present seem to preclude this possibility. It is suggested that these deposits represent the advancing shoreline of a Paleocene and Eocene sea and that, in effect, the basal Aquia sand near the Fall Line correlates with the basal Paleocene sand immediately to the east. (See plate 1, section A.)

Nanjemoy Formation

The Nanjemoy formation has been identified from Foraminifera in well cuttings at West Point and at Cohoke (34), King William (14), Rumford (49), and Aylett (8). In the central part of the county these beds consist of blue clay and glauconite sand, but at West Point, Elsing Green, Cohoke, and Sweet Hall, along the Pamunkey River, as in parts of adjacent New Kent County, the upper part of the Nanjemoy formation includes much limestone in which sandy beds are intercalated. These beds are water bearing. In the central and eastern part of the county the limestone beds are rarely present. Limestone is present at 60 feet at Elsing Green, at 78 feet at Cohoke, and at 109 feet at Sweet Hall.

At Cohoke (34, table 12) the red clay at 207 feet is believed to mark the base of the formation at that place and the Nanjemoy is as much as 126 feet thick at that locality. In the central part of the county, at King William and Rumford, the Nanjemoy formation is about 110 feet thick. The basal red or brown clay is also found at Grimes Landing (48) and King William (14).

The brown clay at 260 feet below sea level at West Point (31) probably marks the base of the formation there, and the thickness is, therefore, 109 feet.

MIOCENE SERIES

The Chesapeake group of Miocene age overlies the Eocene deposits and crops out in many places in King William County (Clark and Miller, 1912, p. 138). At West Point, where these beds are less than 150 feet thick, they consist of blue shell marl in which subordinate sand beds are present. The sand beds yield a little water.

At King William (18) and at Walkerton and Stevensville in adjacent King and Queen County, limestone beds have been reported in the Miocene section but these should not be confused with the highly permeable limestone and sand beds occurring in the Nanjemoy formation in the lower part of King William County.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The entire county is covered by the Columbia group of terrace deposits of Pleistocene age. The maximum thickness of these sand and clay beds is about 30 feet. The terrace deposits are important in that they furnish water to shallow dug wells, almost entirely for domestic use.

WATER-BEARING FORMATIONS

CRETACEOUS TO TERTIARY SYSTEMS

UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

Basal sands of the Mattaponi formation are reached by deep large-diameter wells (26a, 27a, 28b, 29a, 30, table 11) at the paper mill at West Point. They are thick permeable quartz sands that furnish large supplies of water. Well 27a was drilled through 150 feet of clayey sand beds at 420 feet, 61 feet of medium- to coarse-grained sand at 539 feet, and 21 feet of medium- to coarse-grained sand at 646 feet. According to the log of well 26a, the full thickness of the deepest sand, between 630 and 721 feet, is about 90 feet, the lower half of which is gravelly. A total of about 4,800 gpm is obtained from these deep strata. (Four shallower wells tapping Nanjemoy beds contribute another 900 gpm.)

Water is used at the mill in the manufacture of kraft paper. Before reaching the pulp mills, however, the water is first used for cooling the condensers of power generators.

Pumping tests indicate that the deeper wells in the mill area yield a million gallons a day or more each. Well 28a, for instance, yielded 790 gpm with less than 72 feet of drawdown. It seems likely that the wells are somewhat closely spaced and that it might have been more desirable to obtain water from farther north. It is probable that practically all the available water in the mill area could be recovered by fewer than the existing 11 wells and that appreciable increases in total supply can be obtained only from wells outside the cone of depression centered at the mill.

Well 34 at Cohoke (see log, table 12) and other wells (37–40a) still farther up the Pamunkey River, at Lester Manor, obtain water from sands of the Mattaponi formation comparable to those found at West Point.

At Walkerton, in adjacent King and Queen County, a prominent quartz sand stratum is present at 365 feet in the well of a canning company. (See log, table 13.) This is correlated with the sandy zone of the Mattaponi at West Point, which is present between 400 and 450 feet, below the mottled variegated clays. (See pl. 1, section A–A′.) This excellent water-bearing stratum is reached in well 59 at Manquin and in wells 5 and 6 upstream at Aylett, where initial flows of 150 and 200 gpm are reported from 3-inch wells.

The stratum tapped at a lesser depth by the King William School well (14) is correlated with the sands tapped by the municipal well (31) at West Point.

As indicated in the cross section A–A′ (pl. 1), the deep sand in well 18 at King William Court House may correlate with the deepest sands now tapped at West Point.

Water will rise as much as 30 feet above sea level in deep wells in the western part of the county but in the central part artesian pressure has been reduced by many open flowing wells along the Pamunkey and Mattaponi Rivers and the artesian head there is about 10 feet above sea level. Around West Point artesian head in both the deep strata and the shallow Nanjemoy units that are tapped in this vicinity are depressed by industrial pumping at the pulp mill and in most places water will not rise as high as 10 feet below sea level.

TERTIARY SYSTEM

EOCENE SERIES

Aquia Formation

The Aquia formation is not water bearing except probably in the westernmost part of the county.

Nanjemoy Formation

Practically all the 300 shallow wells at West Point mentioned by Sanford (1913, p. 210) are now abandoned, but four wells (26b, 27b, 28d, 29b, table 11) ending in the second stratum, 163 to 189 feet deep, at present furnish over 900 gpm at the paper mill. The beds here are a series of honeycombed limestones and intercalated sands that provide an economical source of moderately large supplies of water. Unfortunately, the formation grades laterally into more clayey beds and is not everywhere water bearing.

At Port Richmond, several small domestic or industrial (25) wells draw water from the second (Nanjemoy) sand or shell bed.

Upstream on the Pamunkey River, well 36 at Cohoke and well 33 at Sweet Hall (fig. 10) obtain water from a rock and gray sand stratum between 109 and 123 feet in the Nanjemoy formation. Several wells are located in a similar stratum along the Mattaponi River above West Point. At Whiteoak Landing, which is 15 miles upriver, a 124-foot well (21) is developed in a quartz and glauconite sand in the Nanjemoy.

MIOCENE SERIES

Sanford notes that a number of wells drilled at West Point around 1900 obtained water from Miocene deposits. These are termed the "first sand." However, even in Sanford's time the head of these wells had declined, and most wells in use were drilled to deeper strata. No wells in King William County obtain water from Miocene units today, as far as is known.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

Water from shallow dug or driven wells supplies many rural homes with water but most of the larger farms and business establishments are located on low ground or are adjacent to low ground along the major streams and use water from deep wells.

QUALITY OF WATER

WATER FROM THE UPPER CRETACEOUS, PALEOCENE, AND EOCENE SERIES

Deep wells throughout King William County yield a soft sodium bicarbonate water. In the eastern part of the county (60, 65, table 14) the bicarbonate content is less than 175 ppm. It is slightly higher in another well at Manquin; at Cohoke (35, 36) it is over 200 ppm, and at West Point it ranges from 239 to 458 ppm, the deeper beds yielding water of higher bicarbonate content.

At Manquin, well 60, which is more than 200 feet deep, contains 154 ppm of bicarbonate whereas well 57, which is 350 feet deep and reaches deeper deposits of the Mattaponi formation, yields water containing 197 ppm of bicarbonate. Again, at Cohoke a well (36) ending in the Nanjemoy formation contains slightly less bicarbonate than a well (35) ending in the Mattaponi formation. The water from the Nanjemoy is fairly hard (93 ppm).

At West Point samples taken from wells 28c, 28d, and 29a, apparently are of the same chemical quality, probably because of leakage around well casings from one formation to the other. The sample from the municipal well (31) shows a somewhat greater bicarbonate content than the samples from the wells at the mill—458 ppm as compared to about 345. However, other constituents are about the same.

Chloride, sulfate, and nitrate are low in samples from deep wells throughout the county. Fluoride is less than 1 ppm except at West Point, where it is as much as 3.1 ppm.

At the mill, water from deep wells is extensively treated to remove most of the chemical constitutents. (See p. 40.) Elsewhere, water is used untreated whether for domestic purposes or for boiler feed.

WATER FROM THE PLEISTOCENE SERIES

No samples from shallow wells were collected in King William County. However, it may be assumed that water from terrace deposits is soft water with low mineral content. In few places iron is present in troublesome amounts, and in most places the water is slightly corrosive.

SUMMARY OF GROUND-WATER RESOURCES

Large supplies of water can be obtained from deep strata in practically all of King William County. Strata already tapped by some domestic and small industrial wells may yield hundreds of gallons of water a minute, and deeper strata, now reached only by wells at West Point, should underlie most of the county. It is probable, however, that westernmost King William County is somewhat less favorable as a source of large supplies than the remainder of the county. The quality of water is excellent throughout the county. The water is a soft sodium bicarbonate type admirably suited to many purposes, although not to irrigation. In the westernmost part of the county the water from deep wells may be slightly hard and more suitable for irrigation on that account.

Records and logs of wells and chemical analyses of waters for King William County follow in tables 11, 12, and 14. Table 13 is a log of a well at Walkerton, King and Queen County.

TABLE 11.—*Records of wells in King William County, Va.*

[Type of well: Dg, dug; Dr, drilled; J, jetted; R, rotary. Principal water-bearing formation: A, Aquia; Co, Columbia group; M, Mattaponi; Nj, Nanjemoy. Approximate water level: Water level as of 1943 unless otherwise noted in Remarks column. Use of water: Ab, abandoned; B, boiler feed; D, domestic; I, industrial; M, municipal; P, public school; S, stock]

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing formation	Approximate water level (feet above (+) or below (−) surface	Approximate yield, as flow: Gallons per minute	Approximate yield, as flow: Date of measurement	Use of water	Remarks
1	1 mile southwest of Upshaw.	Brighton Farm			Streambank	122	J	388	2	M	−95			D	343 feet of casing. Water level as of about 1940.
2	Fox Mill	Millwork Corp	W. S. Reynolds		do	15	J	271	2	M	+	125 20	1927 1943	D	
3	½ mile southeast of Fox Mill.	Edge Hill Farm	do		do	12	J	288	3	M	+	5	1943	D	206 feet of casing.
4	1½ miles north of Aylett.	Pine Top Farm	do		Riverbank	3	J	253	2	M	+	20	1943	D, S	253 feet of casing.
5	Aylett	W. G. Pollard	do	1927	River terrace.	3	J	354	3	M	+	200 50	1927 1943	D	Sand at 319 feet. Flowing at about 10 feet above sea level in 1943.
6	do	A. W. Lewis	do	1929	do	3	J	354	3	M	+	150 25	1929 1943	D	Another well of approximately same depth, drilled here in 1951, is listed as No. 66.
7	do	Warsaw Farm	do	1930	Slope	45	J	368	3	M	−13			D	290 feet of casing. See analysis, table 14.
8	do	Tarrant Fox	Bruce Norman	1950	Streambank	35	J	385	4	M				D	See log, table 12.
9	¾ mile south of Aylett Mill.	Rose Sprout Farm	W. S. Reynolds	1930	Swamp	22	J	300	2	M		12	1943	D	253 feet of casing. See log, table 12.
10	1 mile south of Aylett Mill.	Pointers Landing	do		Riverbank	12			2		+	2	1943	D	
11	1¼ miles southeast of Aylett Mill.	W. N. Fitzgerald	do	1932	do	3	J	340+	4	M	+	10	1943	D	Flow measured at 6½ feet above surface.
12	do	Mt. Pisgah Farm	do	1928	do	2	J	344+	2	M	+	40 20	1928 1943	D	340 feet of casing. Water-bearing sand lies below 344 feet.

13	do	Amber Johnson	do		do	3	J	306	1¼	M	+	20	1943	D	
14	½ mile west of King William.	King William School.	Reynolds & Norman.	1949	Terrace	140	J	429	4	M	−			P	See log, table 12.
15	Opposite Walkerton.	J. R. Parker			Swamp	5	J		2		+5	2½	1943	Ab	
16	1¾ miles south of Walkerton.	S. B. Holmes	R. C. Brown	1924	Terrace	139	Dg	30		Co	−			D	Pumps 5 gpm. Has never gone dry.
17	2 miles south of Walkerton.	B. Morris		1941	do	139	Dg	31½		Co	−29			D	
18	King William	Court House	W. S. Reynolds	1932	do	146	J	595	4½–3	M	−			D	
19	Horse Landing	Mr. MacFadden	do	1928	Riverbank	3	J	115	2	Nj	+	15	1943	D	60 feet of casing. Water from glauconitic quartz sand.
20	½ mile east of Horse Landing.	W. Seayright	do		do	3	J	222+	2	M	+	7	1943	D	191 feet of casing. Water from glauconite sand below 222 feet. Flow measured at 4 feet above surface.
21	Whiteoak Landing.	B. C. Garrett	do		Riverbank	2	J	124	2	Nj	+	20	1943	D	72½ feet of casing. Water from glauconite and quartz sand below 124 feet. Flow measured at 6 feet above surface.
23	Wakema	Mrs. Braye			do	3	J		2		+	15	1943	D, S	
24	Custis Pond	Custis Club	W. S. Reynolds		do	4	J	350	3	M	+	20	1943	D	
25	Port Richmond	Westmoreland Sawmill.	O. C. Brenneman	1946	Terrace	20	J	185	2	Nj	−39			B	Water from shell and pebble stratum from 155 to 185 feet. Water level in 1946.
26a	F St., West Point	Chesapeake Corporation.	Layne-Atlantic Co.	1944	Streambank	26	R	763	18.8	M				I	See log, table 12. Yielded 880 gpm with about 180 feet of drawdown. Pumps 837 gpm.
26b	do	do	do	1945	do	26	R	189	8	Nj					Yields 125 gpm with 43 feet of drawdown. Pumps 265 gpm.
27a	19 St., West Point	do	do	1944	Edge of swamp.	10	R	667	18–8	M					See log, table 12. Pumps 571 gpm.
27b	do	do	do	1945	do	10	R	185	8	Nj					Pumps 193 gpm.
28a	16 St., near river, West Point.	do	do	1929	Terrace	10	R	431	18–8	M					Yielded 790 gpm with 72 feet of drawdown. Pumps 572 gpm.
28b	17 St. and A St., West Point.	do	do	1951	do	10	R	699	18–8	M					Yielded 990 gpm with 75 feet of drawdown at end of 3 hours. Pumps 1,157 gpm.
28c	20 St., near river, West Point.	do	Sydnor Pump & Well Co., Inc.	1917	do	10	Dr	335	13–6	M		90	1917	I	Pumps 628 gpm. See analysis, table 14.
28d	19 St., near river, West Point.	do	Layne-Atlantic Co.	1945	do	10	R	164	8	Nj					Pumps 224 gpm.

TABLE 11.—*Records of wells in King William County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing formation	Approximate water level (feet above (+) or below (−) surface	Approximate yield, as flow: Gallons per minute	Approximate yield, as flow: Date of measurement	Use of water	Remarks
29a	13 St., near river, West Point.	Chesapeake Corporation.	Layne-Atlantic Co.	1941	Swamp	5	R	446	18–8	M					Pumps 426 gpm. See analysis, table 14.
29b	do	do	do	1945	do	5	R	163	8	Nj					Pumps 235 gpm.
30	23 St., West Point	do	do	1936	Terrace	10	R	638	12–8	M	−30				Yielded 600 gpm with 130 feet of drawdown. Pumps 518 gpm.
31	West Point	Town	Virginia Machinery & Well Co., Inc.	1936	do	10	D	379	14–10	M	−			M	Pumps 240 gpm. See log, table 12, and analysis, table 14.
32	do	Southern Railway	E. Wilkinson	1899	Terrace	5	J	165	2	Nj	+15	20 7½	1899 1910?	Ab	See analysis, table 14. Water level as of 1899.
33	Sweet Hall	Mr. Vogt	W. S. Reynolds	1946	do	5	J	132	2	Nj				D	See log, table 12.
34	Cohoke	Brick House	do	1946	Stream bottom.	6	J	575	4–3	M				D	542 feet of casing. Yields 18 gpm with 7 feet of drawdown. See log, table 12.
35	do	Cohoke Club	Fetterholf	1920	Millpond	7	J	375	3	M		1½	1943	D	Temperature 61½° F. See analysis, table 14.
36	do	do	do	1915	Millstream	4	J	125	2	Nj		20	1943	D	Temperature 60¾° F. See analysis, table 14.
37	Lester Manor	T. J. Harwell	Sydnor Pump & Well Co., Inc.	1927	Riverbank	9	D	360	6	M	−4			D	
38	do	Mr. Johnson			do	5		350+	3	M		10	1943	D	Temperature 60° F.
39	do	K. H. Dunn	W. S. Reynolds		Terrace	40	J	538	3–2	M	−18			D	Yields 40 gpm with less than 7 feet of drawdown.
40a	do	Club	do	1929	Riverbank	3	J	400	2	M	+	35	1943	D	335 feet of casing.
40b	do	do	do	1929	do	3	J	332	2	M	+	35	1943	D	300 feet of casing.
41	do	Old Town Farm	do	1941	River terrace.	4	J	383+	4	M	+	15	1943	D, S	
42	do	do	do		do	2	J		3		+	10	1943	D, S	

43	do	Williams Ferry Farm.		1928		24	J	398		M	–			D, S	
44	2 miles south-southeast of King William.	A. Noel		1941	Terrace	128	Dg	23		Co	–16			D	
45	2 miles northeast of Palls.	R. K. Glazebrook		1910	do	124	Dg	28		Co	–24			D	
46	do	Wm. Banks			do	122	Dg	17		Co	–12			D	
47	2 miles west of Palls.	John Williams	W. S. Reynolds		do	80	J	220+	3	Nj	–			D	100 feet of casing. Water from black sand below 220 feet.
48	Grimes Landing, Pamunkey River.	Chericoke	Bruce Norman	1950	do	40	J	230	3	M	–			D	See log, table 12.
49	1½ miles southwest of Rumford.	H. V. Shelton	do	1950	Slope	128	J	327	4-3	M	–			D	Do.
50	3 miles east of Manquin.	J. B. Sweet	Sydnor Pump & Well Co., Inc.	1898	Terrace	142	Dr	237	4	Nj	–			D	
51	2 miles southeast of Manquin.	Pampatike Farm	W. S. Reynolds	1930	do	120	J	402	3	M	–			D, S	304 feet of casing.
52	2½ miles southeast of Manquin.	do		1935	Edge of swamp.	5	J	260	2	M	+	1	1943	D, S	
53	3 miles southeast of Manquin.	do	S. H. Fetterholf	1935	do	6	J	260	2	M	+	12	1943	D, S	
54	3 miles south-southeast of Manquin.	The Island	do	1936	River terrace.	5	J	200+	2	M	+	4	1943	D, S	
55	Manquin	E. C. Longest	do	1920	Edge of terrace.	20	J	255	2	M	–			D	Well flowed when drilled.
56	½ mile south of Manquin.	C. B. Chapman	Sydnor Pump & Well Co., Inc.	1896	do	25(?)	Dr	237	6	M	–	6½	1896	D	
57	2½ miles south of Manquin.	Hollyfield Farm	do	1935	Terrace	40	Dr	350	6	M	–			D, S	Pumps about 75 gpm. See analysis, table 14.
58	2½ miles southwest of Manquin.	do	W. S. Reynolds	1926	do	40	J	290	3	M	–20			S	Water level as of 1926.
59	1 mile west-northwest of Manquin.	F. C. Niederhauser	Mitchell's Well & Pump Co.		do	130	Dr	508	6	M	–90			D	See log, table 12.
60	2 miles west-southwest of Manquin.	J. L. Townsend	S. H. Fetterholf	1920	Streambank	20	J	200+	2	A(?)	–	1½	1943	D, S	See analysis, table 14.
61	do	do	do	1925	do	20	J	200+	2	A(?)	–			D, S	Flowed until 1935.
62	3½ miles west-southwest of Manquin.	H. B. Townsend	do	1913	do	10	J	225	2	A(?)	–	10	1943	D, S	
63	1½ miles north of Manquin.	E. L. Longest		1936	Terrace	160	Dg	28		Co	–26			D, S	
64	Sharon Church	King William High School.	Sydnor Pump & Well Co., Inc.	1927	do	162	Dr	585	6	M	–			P	
65	Nelson Bridge	B. O. Atkinson	S. H. Fetterholf	1925	River terrace.	30	J	200(?)	2	A(?)	–	10	1944	D	See analysis, table 14.
66	Aylett	A. W. Lewis, Jr.	Bruce Norman	1951	do	20	J	370	3	M				D	See log, table 12.

TABLE 12.—*Logs of wells in King William County, Va.*

Well 8, Aylett; Tarrant Fox

[Log by W. S. Reynolds. Altitude, 35 feet]

	Thickness (feet)	*Depth (feet)*
Chesapeake group (Miocene): Clay, brown; Foraminifera	50	50
Pamunkey group (Eocene):		
Sand, white, and shells	5	55
Clay, brown; Foraminifera	9	64
Sand, white, and shells	4	68
Stone	1	69
Shells	6	75
Clay, blue	96	171
Stone	1	172
Mattaponi formation (Upper Cretaceous and Paleocene):		
Sand, black	12	184
Clay, blue	6	190
Sand, black	10	200
Clay, blue	50	250
Clay, white, and sand	60	310
Clay, red	40	350
Clay, yellow	10	360
Sand, white	25	385

Well 9, ¾ mile south of Aylett Mill; Rose Sprout Farm

[Log by W. S. Reynolds. Altitude, 22 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Sand	39	39
Pamunkey group (Eocene):		
Clay, blue	93	132
Sand, glauconitic	15	147
Clay, blue	15	162
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue	53	215
Clay, tough (soapstone)	9	224
Clay, lead-gray	56	280
Sand and gravel; water	20	300

Well 14, County School; King William Court House

[Log by W. S. Reynolds. Altitude, 140 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Undescribed	65	65
Chesapeake group (Miocene):		
Clay, blue, sandy	51	116
Clay, blue	11	127
Clay, hard	3	130
Clay, blue	20	150
Clay, brown	40	190

TABLE 12.—*Logs of wells in King William County, Va.*—Continued

Well 14, County School; King William Court House—Continued

	Thickness (feet)	*Depth (feet)*
Nanjemoy formation (Eocene):		
Clay, hard	15	205
Sand, green	2	207
Clay, hard	16	223
Sand, gray	3	226
Clay, brown; Foraminifera	75	301
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, gray	9	310
Clay, red; Foraminifera	18	328
Clay, hard	42	370
Clay, hard	40	410
Sand, white; water	19	429

Well 26a, West Point; Chesapeake Corporation

[Log by Layne-Atlantic Co. Altitude, 26 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Sand and clay	37	37
Chesapeake group (Miocene):		
Marl, glauconitic	60	97
Marl, sandy; contains shells	30	127
Sand and shells; Foraminifera	43	170
Pamunkey group (Nanjemoy formation):		
Sand and shells; Foraminifera	18	188
Coquina and glauconitic sand	13	201
Clay, glauconitic, black	79	280
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, glauconitic, black; Foraminifera	20	308
Sand, glauconitic, and clay streaks	31	339
Clay, glauconitic, sandy; Foraminifera have Cretaceous aspect	31	370
Clay, glauconitic	31	401
Sand, hard; water	10	411
Clay, bright mottled, red predominating; residue is 20 percent glauconite, 80 percent quartz	7	418
Sand, medium grains, compact; water	14	432
Clay, soft	14	446
Sand, hard, and gravel; water	8	454
Clay, glauconitic	56	510
Clay, bright mottled, red predominating; residue is coarse quartz pebbles and scant glauconite	58	568
Sand, compact	17	585
Clay, glauconitic; residue is coarse quartz sand, less glauconite	45	630
Sand, loose; water	16	646
Sand, loose, coarse; water	21	667
Gravel, small; water	54	721
Clay, hard, red; residue is coarse quartz sand and trace of glauconite	42	763

TABLE 12.—*Logs of wells in King William County, Va.*—Continued

Well 27a, West Point; Chesapeake Corporation

[Log by D. J. Cederstrom. Altitude, 10 feet. Nanjemoy and Mattaponi contact approximate. Well drilled by Layne-Atlantic Co.]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, yellow	24	24
Sand, white	4	28
Chesapeake group (Miocene):		
Clay, sandy, blue	46	74
Marl, blue; contains shells	85	159
Nanjemoy formation (Eocene):		
Coquina, in streaks, and slightly glauconitic blue clay	21	180
Coquina, in streaks and glauconite-quartz sand	13	193
Clay, dull-greenish-gray, glauconitic, locally slightly sandy	77	270
Mattaponi formation (Upper Cretaceous and Paleocene):		
Sand, clayey, slightly glauconitic; rock streak at 309 and 420 feet	150	420
Sand, green, clayey, slightly glauconitic, quartz	10	430
Sand, medium-grained, trace of glauconite; rock streak at 435 feet	5	435
Clay; green, sandy, slightly glauconitic; rock streak at 458 feet	23	458
Clay, mottled (blue, red, yellow, green); moderately glauconitic toward the base	81	539
Sand, white; grades from medium grained to coarse grained with depth; rock streak at 600 feet; trace of glauconite; water	61	600
Clay, mottled, blue; very compact from 600 to 609 feet, slightly glauconitic	46	646
Sand, medium- to coarse-grained; quartz, slightly glauconitic clay streaks from 655 to 658 feet; water	21	667

Well 31, West Point; Municipality

[Log by Virginia Machinery & Well Co., Inc. Altitude, 10 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Earth, brown	3	3
Sand, fine, brown	18	21
Chesapeake group (Miocene):		
Clay, light-gray	69	90
Clay, dark-gray	25	115
Sand, shells, and clay	14	129
Clay, green, and hard shells	9	138
Sand, brown	3	141
Clay, green	19	160
Nanjemoy formation (Eocene):		
Clay, shells, and scant green sand	62	222
Clay, gray, sandy	8	230
Clay, gray	30	260
Clay, brown	9	269

TABLE 12.—*Logs of wells in King William County, Va.*—Continued

Well 31, West Point; Municipality—Continued

	Thickness (feet)	Depth (feet)
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, black	11	280
Clay, dark-colored, glauconitic	39	319
Sand, light-gray	27	346
Clay, green	2	348
Sand; water	28	376
Clay	3	379

Well 33, Sweet Hall; Mr. Vogt

[Log by Leonard Reynolds. Altitude, 5 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Sand	48	48
Chesapeake group (Miocene): Clay, blue	39	87
Nanjemoy formation (Eocene):		
Shells and sand	2	89
Clay, blue	20	109
Rock and gray sand; water	23	132

Well 34, Cohoke; W. E. Ruprecht

[Log by Leonard Reynolds. Altitude, 6 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, sandy	23	23
Chesapeake group (Miocene):		
Clay, blue	37	60
Clay, brown	10	70
Sand, white, and soft clay; Foraminifera	8	78
Nanjemoy formation (Eocene):		
Rock	1	79
Clay, hard; Foraminifera	14	93
Clay, hard, and rock	27	120
Sand, gray	½	120½
Clay, hard, brown	9½	130
Clay, blue	15	145
Rock	5	150
Sand, black; Foraminifera	½	150½
Clay, light	54½	205
Clay, red	2	207
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, dark	11	218
Sand, green	3	221
Clay, hard	35	256
Sand, black	1½	257½
Clay, hard	37½	295
Clay, medium hard; Foraminifera at 296 feet	75	370
Sand	½	370½
Clay, hard	4½	375

TABLE 12.—*Logs of wells in King William County, Va.*—Continued

Well 34, Coheke; W. E. Ruprecht—Continued

	Thickness (feet)	Depth (feet)
Mattaponi formation (Upper Cretaceous and Paleocene)—Con.		
Gravel, white, and black sand	51	426
Clay, red	9	435
Clay, tough, red	35	470
Clay, hard, mottled	68	538
Sand, white	----	------
Clay, hard	----	------
Sand, white; water	----	575

Well 48, Grimes Landing; Chericoke

[Log by Bruce Norman. Altitude, 40 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Gravel	4	4
Chesapeake group (Miocene): Clay, red	46	50
Nanjemoy formation (Eocene):		
Clay, blue	85	135
Clay, red	10	145
Aquia formation (Eocene):		
Clay, brown	15	160
Sand, black	4	164
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, brown	46	210
Sand, white	20	230

Well 49, Rumford; H. V. Shelton

[Log by Bruce Norman. Altitude, 128 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, red	20	20
Sand	10	30
Chesapeake group (Miocene):		
Clay, blue	70	100
Clay, brown; Foraminifera	35	135
Nanjemoy formation (Eocene):		
Stone	1	136
Sand, black; Foraminifera	4	140
Clay, blue	10	150
Stone	2	152
Sand, white, and shells	8	160
Stone	1	161
Clay, gray; Foraminifera at 170 feet	39	200
Aquia formation (Eocene):		
Clay, blue	30	230
Sand, black; Foraminifera	5	235
Clay, blue	15	250
Sand, black	5	255
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue	55	310
Sand and shells	17	327

TABLE 12.—*Logs of wells in King William County, Va.*—Continued

Well 56, ½ mile south of Manquin; C. B. Chapman

[Log from Va. Geol. Survey Bull. 5. Altitude, 25(?) feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Loam, clay, and sand	10	10
Undifferenitated:		
Marl and greensand; shells	175	185
Clay, stiff, blue	40	225
Sand, white, micaceous; water	12	237

Well 59, Manquin, F. C. Niederhauser

[Log by Mitchell's Well & Pump Co. Altitude, 130 feet. Geological boundaries inferred]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	22	22
Chesapeake group (Miocene):		
Clay, blue	54	76
Marl, brown, contains shells	44	120
Pamunkey group (Eocene):		
Clay, blue	40	160
Rock	1	161
Clay, gummy, blue	39	200
Clay, white, sandy	60	260
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, white, sandy	165	425
Clay, red	40	465
Sand, white, clayey; water	43	508

Well 66, Aylett; A. W. Lewis, Jr.

[Log by W. S. Reynolds. Altitude, 20 feet]

	Thickness (feet)	*Depth (feet)*
Undescribed	20	20
Chesapeake group (Miocene): Clay, brown; Foraminifera	20	40
Pamunkey group (Eocene):		
Sand, black; Foraminifera	5	45
Clay, blue; Foraminifera	105	150
Sand, brown	10	160
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, brown; Foraminifera	90	250
Clay, red	10	260
Sand, white	110	370

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TABLE 13.—*Log of well 1 at Walkerton, Va.*

Well 1, Walkerton; Taylor & Caldwell, Inc.

[Log by Sydnor Pump & Well Co., Inc. Altitude, 10 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Soil, top	4	4
Sand, white, and gravel	14	18
Chesapeake group (Miocene): Clay, dull-red	46	64
Nanjemoy formation (Eocene):		
Clay and shells, and a little white sand	12	76
Clay, gray; fine sand and some shells	44	120
Clay, dark-brown	20	140
Clay, dark-gray	30	170
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, light-gray	22	192
Sand, black, and mud; water-bearing	57	249
Clay, light-gray	40	289
Clay, blue and gray; mixed (mottled)	3	292
Sand, fine, white; water-bearing	3	295
Clay, mixed-color (mottled)	28	323
Clay, hard, dark (soapstone)	4	327
Clay, mixed-color	38	365
Sand, quartz, white; water	10	375

TABLE 14.—*Chemical analyses of waters from wells in King William County, Va.*

[Analyses in parts per million. Analyst: EWL, E. W. Lohr; MDF, M. D. Foster; LWM, L. W. Miller; HF, H. Froehling]

	Well no.					
	7	28c	28d	29a	31	32
Location	Warsaw Farm	West Point	West Point	West Point	West Point	West Point
Depth (feet)	368	335	162–189	446	379	165
Formation	Mattaponi	Mattaponi	Nanjemoy	Mattaponi	Mattaponi	Nanjemoy
Date	Dec. 31, 1943	Feb. 11, 1941	Feb. 11, 1941	Feb. 11, 1941	Feb. 10, 1941	1904
Silica (SiO_2)			32		21	25
Iron (Fe)					.05	.11
Calcium (Ca)					1.8	4.8
Magnesium (Mg)					.6	4.7
Sodium (Na)					181	213
Potassium (K)					6.6	14
Bicarbonate (HCO_3)	165	343	342	352	458	306
Sulfate (SO_4)	17	8	8	8	12	307(?)
Chloride (Cl)	1	12	11	11	11	6.7
Fluoride (Fl)	.3	1.4	1.4	1.5	3.1	
Nitrate (NO_3)	.1		0		.47	
Dissolved solids					461	927
Hardness (as $CaCO_3$)	4	9	10	9	7.0	31
Analyst	EWL	MDF, LWM	MDF, LWM	MDF, LWM	MDF, LWM	HF

TABLE 14.—*Chemical analyses of waters from wells in King William County, Va.*—Continued

	Well no.				
	35	36	57	60	65
Location	Cohoke	Cohoke	Manquin	Manquin	Nelson Bridge
Depth (feet)	375	125	350	200+	200(?)
Formation	Mattaponi	Nanjemoy	Mattaponi	Aquia(?)	Aquia(?)
Date	Sept. 2, 1943	Sept. 2, 1943	Dec. 30, 1943	Sept. 3, 1943	Dec. 31, 1943
Silica (SiO_2)					
Iron (Fe)					
Calcium (Ca)					
Magnesium (Mg)					
Sodium (Na)			80		
Potassium (K)					
Bicarbonate (HCO_3)	223	203	197	154	162
Sulfate (SO_4)	5	6	16	20	18
Chloride (Cl)	3	3	1	1	10
Fluoride (Fl)	.5	.4	.5	.4	.2
Nitrate (NO_3)	.3	.3	.2	.3	.0
Dissolved solids					
Hardness (as $CaCO_3$)	52	93	6	12	12
Analyst	EWL	EWL	EWL	EWL	EWL

NEW KENT COUNTY

New Kent County lies north of the Chickahominy River and south of the Pamunkey River and the headquarters of the York River. It has an area of 221 square miles and a population, in 1950, of 3,995, or 18.1 persons per square mile (Virginia Division of Planning and Economic Development, 1951). Providence Forge is the largest town in the county. Lumbering is the only industry; the value added by manufacture of products sold in 1947 was $575,000. Farming and dairying are practiced on the low terrace lands bordering the rivers, particularly the Pamunkey River. The value of farm products sold in 1949 was $586,249. In order of relative value, these were field crops, livestock, poultry products, dairy products, and vegetables.

The Chesapeake and Ohio Railroad, with local stations at Mountcastle, Providence Forge, and Lanexa, passes through the southern part of the county. A branch line of the Southern Railway, connecting Richmond with West Point, passes through western New Kent County and crosses the Pamunkey River at Whitehouse.

TOPOGRAPHY

The surface of New Kent County is a rolling upland of moderate relief formed in greatest part by the somewhat dissected Sunderland terrace. The altitude of this terrace descends from about 150 feet above sea level in the western part of the county to about 110 feet above sea level in the eastern part.

The lower Talbot terrace is present to a limited extent along the Pamunkey and the Chickahominy Rivers at about 30 to 35 feet above sea level.

The total relief in the county is about 180 feet and locally a relief of as much as 100 feet is not uncommon.

GEOLOGY

The county is underlain by unconsolidated sediments of Cretaceous, Paleocene, Eocene, Miocene, and Pleistocene age. Depth to bedrock is not known but in the western part of the county bedrock may lie about 350 feet below sea level. In this connection it may be recalled that in southwestern Charles City County bedrock lies about 300 feet below sea level but near Sandston, in Henrico County, bedrock was not reached (27, table 6) at 500 feet below sea level.

Lower Cretaceous sediments may not have been reached by any wells within the county, but Upper Cretaceous to Paleocene units are believed to have been found at Providence Forge and Cumberland Landing. The overlying Eocene units are tapped by many wells. The upper Nanjemoy formation of the Pamunkey group of Eocene age crops out in northwesternmost New Kent County, and the lower Aquia formation is probably present in subsurface, at least in the western part of the county, but it pinches out in central New Kent County. The Chesapeake group of Miocene age crops out in road cuts and along the streambanks from place to place. The entire county is covered by the Columbia group of terrace deposits of Pleistocene age.

CRETACEOUS SYSTEM—POTOMAC GROUP

The Potomac group of Early and Late Cretaceous age may not have been reached by any well within the county but alternating sand and clay beds of this group lie beneath the county at depth and probably constitute an additional source of large water supplies. Beneath the western end of the county, however, these deposits may not be much more than a few hundred feet thick.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

Characteristic Foraminifera of the Mattaponi formation of Late Cretaceous and Paleocene age have been recognized in cuttings from well 12 (table 16; fig. 11) at Cumberland Landing. The formation undoubtedly underlies most of the county, as it has a thickness of over 400 feet at West Point in adjacent King William County, but its westward extent and relationship to the Potomac group of Early and Late Cretaceous age are problematical.

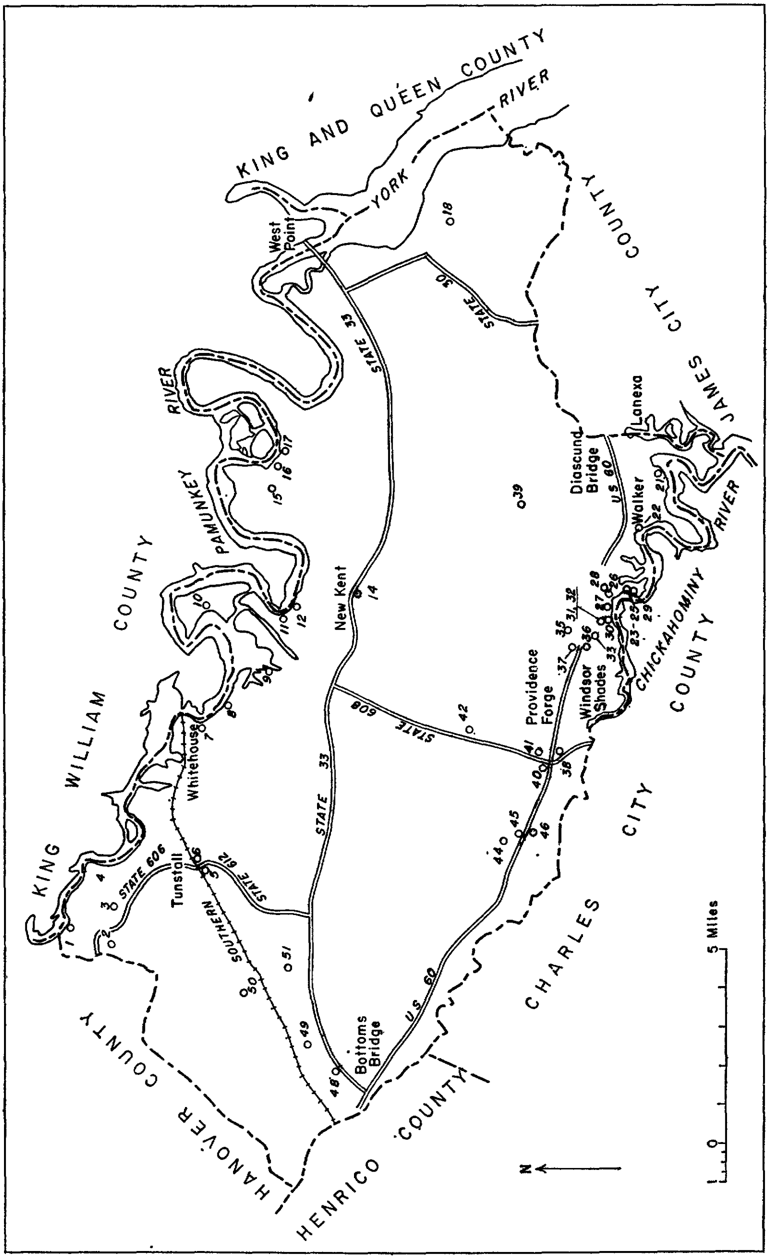


FIGURE 11.—Location of wells in New Kent County.

TERTIARY SYSTEM

EOCENE SERIES

Aquia formation

The basal sand of the Aquia formation furnishes water to a few wells in the western part of the county, as at Quinton(51) but eastward this sand is progressively older and is probably the basal sand of the Paleocene part of the Mattaponi formation. (See plate 1.) Above the basal sand glauconitic marly and sandy beds characterize the Aquia formation.

Nanjemoy formation

The Nanjemoy formation overlies the Aquia formation. At Cumberland Landing these strata consist of very slightly glauconitic light-gray shell marls, underlain by glauconitic marls. At New Kent the higher beds in the Nanjemoy formation are described as fine sands in which a 30-foot stratum of shell rock is present. At Whitehouse the Nanjemoy consists of "rock" and "soft sand rock" underlain by red clay.

At Providence Forge (40, table 16) and Windsor Shades (35) the higher units of the Nanjemoy formation are made up of thin rock strata, shells, and sand, in part glauconitic, whereas the basal Nanjemoy units are glauconitic marls, similar to the Aquia formation. Thirty-one feet of "compact shell" is reported at the Chickahominy River dam, near Walkers.

The pink (Marlboro) clay marking the base of the Nanjemoy formation is recognized at Whitehouse and Quinton and in adjacent counties at Roxbury and Bottoms Bridge. This part of the Nanjemoy formation is early Eocene in age. East of these localities the basal part of the Nanjemoy formation was eroded during the transgression of the middle Eocene sea, along with the Aquia formation.

MIOCENE SERIES

The Chesapeake group of Miocene age consists largely of blue marl overlying the Eocene deposits. It is exposed in many places in road cuts and riverbanks. Thin shell beds and sandy members are present in places. In the western part of the county these formations are very thin or absent but in easternmost New Kent County they range from 150 to 200 feet in thickness. The base of the formations of Miocene age lies at about 50 feet above sea level in western New Kent County but at more than 150 feet below sea level along the York River below West Point.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

Terrace gravels of Pleistocene age, generally not more than 30 feet thick, cover the entire county. These deposits furnish water to many dug or driven wells.

WATER-BEARING FORMATIONS

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

Several wells in New Kent County (11 and 12 at Cumberland Landing, 33 at Windsor Shades, 40 and 41 at Providence Forge, and 44 at Mountcastle) tap sands of the Mattaponi formation of Late Cretaceous and Paleocene age. Little information about the bed is available except that it appears to be an excellent water-bearing stratum. At no place is water pumped in any quantity, although the recently completed 3-inch open-end well at Cumberland Landing furnished about 40 gpm with 13 feet of drawdown.

It is certain that most, if not all, of New Kent County is underlain by prolific water-bearing sands of the Mattaponi formation, and in the western part of the county equally prolific Lower Cretaceous sands may be within reach of fairly deep wells. These beds constitute a vast reservoir of large quantities of water that is almost entirely untouched.

At Providence Forge water rises to about 16 feet above sea level in wells reaching the Aquia formation, but in southeasternmost New Kent County water probably does not rise over 8 or 10 feet above sea level because there much of the original artesian head has been dissipated by open flowing wells along the lower part of the Chickahominy River. Sanford (1913, p. 318–319) reports that well 33 had a head of 32 feet above high tide previous to 1910.

Well 5 at Tunstall, away from the Pamunkey River, flows at an altitude of 20 feet. However, as West Point, an area of heavy industrial discharge, is approached, water levels decline and in that vicinity water in artesian wells rises only to within a few feet of sea level.

TERTIARY SYSTEM

EOCENE SERIES

Aquia formation

The Aquia formation furnishes water to a few wells in the western part of the county.

Nanjemoy formation

The Nanjemoy shell and sand units (see log of well 35, table 16) furnish water to a number of domestic wells in the vicinity of Windsor Shades and to several wells at Providence Forge and Mountcastle, in southern and southeastern New Kent County. These wells generally range from 90 to 135 feet in depth, and the formation is referred to locally as the "first sand." None of these wells pump more than a few gallons a minute although probably yields of as much as 20 or 30 gpm might be obtained if needed.

Although the upper part of the Nanjemoy formation contains good water-bearing units in the southern part of the county, it is quite evident that along the Pamunkey River and in the extreme western part of the county the Nanjemoy formation is much more marly and can rarely be developed as a source of ground water.

The height to which water will rise in wells tapping the Nanjemoy varies considerably from place to place. At Providence Forge water will rise not more than about 15 feet above sea level and near Windsor Shades, where there are many flowing wells, water will rise only about 5 or 6 feet above sea level. However, 2 miles north of Providence Forge water rises in well 42 to about 58 feet above sea level and to about 50 feet above sea level at New Kent. In well 8 in Charles City County, at Sterling Heights which is 3 miles south of Providence Forge, water from the "first sand" rises about 53 feet above sea level. This appears to reflect a low permeability of the formation as a whole; although the water levels may be depressed in places by pumping or discharge of open flowing wells, the effect does not extend over a wide area, and away from areas of discharge water levels are comparatively unaffected.

MIOCENE SERIES

The formations of Miocene age do not contain water-bearing beds in New Kent County, so far as known.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

Water is obtained from shallow dug or driven wells throughout the county, particularly in areas back from the major stream, which supply many homes. Ample supplies for domestic use are obtained from Pleistocene deposits and yields of 5 to 10 gpm appear to be available in some places.

QUALITY OF WATER

WATER FROM THE UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

The water from the Mattaponi formation is more mineralized than water from the shallower Nanjemoy formation. In the vicinity of Providence Forge the "second" and "third" (Mattaponi) sand yields a soft sodium bicarbonate water (37, 41, table 17) in which the bicarbonate content is about 250 ppm—almost twice as much as in water from the "first" (Nanjemoy) sand. At Mountcastle water from the deep well (44) of G. S. Binns is of almost identical character. Other constituents in the samples are low, except fluoride which ranges from 1.1 to 1.5 ppm. In the western part of the county the water is somewhat less mineralized, containing less than 200 ppm of bicarbonate (5, table 17).

Throughout the county water from the Mattaponi formation is excellent for nearly all purposes. However, for high-pressure boilers, and perhaps for other special uses, treatment would be necessary.

WATER FROM THE EOCENE SERIES—NANJEMOY FORMATION

The water from the Nanjemoy formation is a sodium bicarbonate water with a slight to moderate hardness. In southeastern New Kent County, samples (35, 39, table 17) have a total hardness of around 100 ppm, present as bicarbonate hardness. The bicarbonate content is about 125 ppm. In northern New Kent County samples at Potts Landing (17) and Holly Fork (18) are softer but contain about 175 ppm of bicarbonate indicating that these waters have been softened to some extent by base exchange. Fluoride is less than 0.5 ppm. Generally the hardness of water from the Nanjemoy formation is low enough that the water may be termed a fairly soft sodium bicarbonate water.

Like water from the Mattaponi formation, the water from the Nanjemoy is excellent for most purposes. The moderate hardness would make softening necessary, or at least desirable, in places where the water was to be used in some commercial processes, such as laundering or for boiler feed.

SUMMARY OF GROUND-WATER RESOURCES

No wells of large yield have been constructed in New Kent County, but there is reason to believe that several hundred gallons per minute might be developed from sands already reached by a number of domestic wells. Yields in excess of a million gallons per day should certainly be available in central and eastern New Kent County (as at nearby West Point) but in the western part of the county, where the total thickness of sediments may be less than 400 feet, the potential supply may not be quite as great and, until further data become available, individual wells here should not be relied upon to produce more than a maximum of 500 gpm.

Records and logs of wells and chemical analyses of waters for New Kent County follow in tables 15, 16, and 17.

TABLE 15.—*Records of wells in New Kent County, Va.*

[Type of well: Dg, dug; Dr, drilled; Dv, driven; J, jetted. Water level: Yield is given as flow as of date of water-level measurement. Use of water: Ab, abandoned; D, domestic; M, municipal; P, public school; S, stock]

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level: Feet above (+) or below (−) surface	Approximate water level: Date of measurement	Approximate yield (gallons per minute)	Use of water	Temperature (° F.)	Remarks
1	2 miles southeast of Appersons Store.	North Berry Farm		1941	Terrace	34	Dg	22		−19	1946		D,S		Use over 7,000 gpd.
2	1½ miles west of Putneys Mill.	Hampstead Farm	Sydnor Pump & Well Co., Inc.		Hilltop	130	Dg	410	6						Pumped 28 gpm. Much larger yield available.
3	do	W. D. Taylor	S. H. Fetterholf		Terrace	40	J	258	2	−32	1940		D		Pumps black sand.
4	Putneys Mill	Cottage	O. C. Brenneman		do	24	J		2	+	1946	¼	D		Rock reached at 20 feet.
5	Tunstall	D. S. Gardner	S. H. Fetterholf		Slope	20	J	300+	2	+	1946	¼	D		
6	do	H. T. Fauntleroy	do		Terrace	40	J	315	2(?)	−			D		
7	Whitehouse	Southern Railway	P. H. Sweet	1893		5	J	210	1½	−	1946	2	D		Flow as of 1946. See log, table 16.
8	do	Rockyhock Club			Riverbank	12		Spring		+	1946	2	D	59	See analysis, table 17. Spring issues from base of terrace.
9	½ mile southeast of Lily Point.	Richmond Hunt Club.	O. C. Brenneman	1944	Swamp	3	J	190	2	+6	1946	5½	D		Two more wells with smaller flow in swamp nearby.
10	West Island	C. W. Montgomery.	W. S. Reynolds	1927	Marsh	1	J	335	2	+		7	D		
11	Cumberland Landing.	Mr. Brinton	O. C. Brenneman	1943	Riverbank	3	J	310	3	+	1946	4	D, S		
12	do	do	do	1946	Branch	10	J	300	3	−7	1946		D, S		Yielded 40 gpm for 3 hours with 13 feet of drawdown.
14	New Kent	School	Virginia Machinery & Well Co., Inc.	1930	Terrace	140	Dr	246	6	−90	1930		P		Pumped 25 gpm with 55 feet of drawdown.
15	3½ miles northeast of New Kent.	C. P. Crump			do	20	Dg	23		−			D		Ample supply in drought years. Water is slightly corrosive. Contains no iron.
16	4 miles northeast of New Kent.	Dr. Pierson			Edge of swamp.	4	J			+	1946	½	S		

17	Potts Landing	W. G. Gouldman	S. H. Fetterholf		Terrace	17	J	157	2	−7(?)	1946		D,S	60	Seven other wells on farm, 5 of which are about same depth. Greatest flow is 2 gpm at altitude of 3 feet.
18	Holly Forks Pond	Hunt Club	O. C. Brenneman	1946	do	40	J	218	2	−43	1946		D		
20	1¾ miles northeast of Lanexa.	H. C. Taylor		1921		5	J	160	2	+	1943	6	D	59½	
21	½ mile south of Lanexa.	Tom Fletcher	T. P. Binns	1910		2	J	100	2	+	1943	7	D		On island in river. Reportedly flowed 30 gpm in 1910.
22	½ mile southeast of Walker.	Chickahominy Dam.		1920		2	J	241	2	+	1943	1½	Ab	62	
23	1½ miles southeast of Boulevard.	A. T. Howard	D. L. Perkinson	1939	Riverbank	2	J	90	2	+	1943	1½	D		
24	do	do	do	1938	do	2	J	90	2	+	1943	1	D	61½	
25	do	do	do		do	1½	J	90	2	+	1943	1½	D	61¼	
26	do	do		1940	Marsh	2	J	90	2	+	1943	4	D		
27	1 mile southeast of Boulevard.	M. L. Hubbard	O. C. Brenneman	1943		26	J	134	3–2	−21	1943		S	59¼	
28	do	Baptist Church				18	J	135	2	−12	1943		D	58¼	
29	¾ mile southeast of Boulevard.	West End Club		1920		3	J	90	2	+	1943	6	D		
30	do	W. H. Weber	W. H. Weber	1928		2	J	68	2	+	1943	8	D	60½	
31	½ mile southeast of Boulevard.	Carl Weber	do	1929		2	J	68	2	+	1943	7	D		
32	do	W. H. Weber		1850(?)	Terrace	24	Dg	22		−	1943		D	60	
33	do	C. F. D. Weber	Sydnor Pump & Well Co., Inc.	1902		22	Dr	260	4½	+	1902	.52	Ab		Dynamited and ruined when yield decreased in recent years.
35	½ mile northwest of Boulevard.	J. Burnett	O. C. Brenneman	1943		81	J	194	3–2	−75.5	1943		D	59½	See analysis, table 17.
36	½ mile west of Boulevard.	Virginia Game Farm.	do	1942		21	J	137	3	−	1943	D	D, S	59½	
37	do	Chickahominy Club.	T. P. Binns	1908		10	J	230	2	+ −	1942 1943	D	D		Flowed until 1942.
38	Providence Forge	L. H. Anderson	S. H. Fetterholf			30	J	16	1¼	−			D		
39	do	V. E. Jenson	O. C. Brenneman	1937		26	J	110	2	−12	1943		D		Supplies tourist court and restaurant.
40	do	New Kent Tavern	do	1943		28	J	281	2	−12	1943		D		
41	do	O. C. Brenneman	do	1938		34	J	286	2	−18	1943		D		See analysis, table 17.
42	2 miles north of Providence Forge.	Bailey	do			128	J	215	2	−70	1945		D		
44	¼ mile north of Mountcastle.	G. S. Binns	S. H. Fetterholf	1930		54	J	328	2	−	1943		D, S		See analysis, table 17. Referred to locally as sulfur water.
45	Mountcastle	Blaine Harry	O. C. Brenneman	1937		39	J	109	2	−	1943		D		
46	do	L. A. Mead	do	1943		41	J	105	2	−11	1943		D		
48	Bottoms Bridge	Anderson Williams.	do	1944	Terrace remnant.	120	J	250	3–2	−60	1944				
49	Northeast of Bottoms Bridge.	George Washington Spring.			Terrace			Spring		+	1946	30	D		
50	do	Mr. Vandenburg	O. C. Brenneman				J	375	2				D		
51	Quinton		do	1951		150	J	305+					D		

TABLE 16.—*Logs of wells in New Kent County, Va.*

Well 7, Southern Railway, Whitehouse

[Log by P. H. Sweet. Altitude, 5 feet. This is an old record (Darton, 1896), probably given by the owner from memory. Presently available data indicate that the position of the basal clay of the Nanjemoy, as given, is probably too high and should occur about 30 feet lower]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	15	15
Clay, yellow	10	25
Earth, blue, fuller's	40	65
Nanjemoy formation (Eocene):		
Rock strata, several, thin; one stratum was 18 inches thick	5	70
Rock, sandy, soft	25	95
Clay, red	20	115
Aquia (?) formation (Eocene):		
Marl (?), greensand	50	165
Sand, black; water	45	210

Well 12, Cumberland Landing; Mr. Brinton

[Log from samples collected by O. C. Brenneman. Altitude, 10 feet. Base of Nanjemoy determined in part from record at Cohoke, King William County]

	Thickness (feet)	Depth (feet)
No samples	50	50
Calvert formation (Miocene): Marl shell, gray; Foraminifera	20	70
Nanjemoy formation (Eocene):		
Marl, slightly glauconitic, gray; contains shells; Foraminifera	20	90
Marl, slightly glauconitic, gray; contains shells; thin consolidated beds	40	130
Marl, dark, glauconitic; contains shell; Foraminifera	40	170
Sand, black, glauconitic; with minor amount of quartz	30	200
Mattaponi formation (Upper Cretaceous and Paleocene):		
Marl, glauconitic; Foraminifera	25	225
Marl, highly glauconitic, sandy	40	265
Marl, light-brown, glauconitic	10	275
Sand, coarse, white; water	25	300

Well 35, Windsor Shades; J. Burnett

[Log by L. W. Youngquist. Altitude, 81 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Sand, light-colored medium grained; with reddish clay streaks	60	60
Chesapeake group (Miocene):		
Clay, blue	55	115
Clay, hard, blue; with trace of black glauconitic sand	22	137
Shells	5	142
Clay, blue; with trace of black glauconitic sand	9	151

TABLE 16.—*Logs of wells in New Kent County, Va.*—Continued

Well 35, Windsor Shades; J. Burnett—Continued

	Thickness (feet)	Depth (feet)
Nanjemoy formation (Eocene):		
Shells, sand, and small gravel	14	165
Shells, indurated; trace of black glauconitic sand	2	167
Glauconite and quartz sand; water	½	167½
Shells, indurated; minor amount of black glauconitic sand; Foraminifera	1½	169
Glauconite, medium to fine-grained; quartz sand containing a few thin "rock" streaks; water; Foraminifera	15	184
Marl, blue; trace of shells	10	194

Well 40, Providence Forge; New Kent Tavern

[Log by O. C. Brenneman, from memory. Altitude, 28 feet. A few feet of Aquia may be present]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): sand and gravel; with some red clay	30	30
Chesapeake group (Miocene): Sand, blue, and clay	40	70
Nanjemoy formation (Eocene):		
Sand, black, shells, and blue clay; alternating beds with consolidated beds near base; water	40	110
Clay, blue	40	150
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue	50	200
Sand, glauconitic; water	20	220
Clay, red	10	230
Sand, glauconitic, and clay	30	260
Sand, blue and green; small gravel; water	20	280
Gravel, small; water	1	281

Well 51, Quinton

[Log by G. C. Tibbitts, Jr., from samples. Altitude, 150 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, yellow, sandy	70	70
Chesapeake group (Miocene):		
Marl, gray, sandy	10	80
Marl, gray, sandy; contains shells; Foraminifera	65	145
Nanjemoy formation (Eocene):		
Marl, glauconitic; contains shells; Foraminifera	20	165
Sand, yellow, clayey, glauconitic	60	225
Clay, pink, sandy; Foraminifera	20	245
Aquia formation (Eocene):		
Sand, dark, glauconitic quartz	40	285
Sand, light-gray, fine, glauconitic; Foraminifera	20	305

TABLE 17.—*Chemical analyses of waters from wells in New Kent County, Va.*

[Analyses in parts per million. Analyst: GWW, G. W. Whetstone; RBD, R. B. Dale; EWL, E. W. Lohr]

	Well no.			
	5	8	17	18
Location	Tunstall	Whitehouse	Potts Landing	Holly Forks
Depth (feet)	300+	Spring	157	218
Formation or age	Mattaponi formation	Pleistocene age	Nanjemoy formation	Nanjemoy formation
Date	Nov. 4, 1947	June 15, 1946	June 15, 1946	Aug. 15, 1946
Silica (SiO_2)	36	---	---	---
Iron (Fe)	.16	---	---	0.93
Calcium (Ca)	.5	---	---	---
Magnesium (Mg)	1.1	---	---	---
Sodium (Na)	87			
Potassium (K)		---	---	---
Bicarbonate (HCO_3)	189	22	194	163
Sulfate (SO_4)	14	3	5	5
Chloride (Cl)	15	3	2	8
Fluoride (F)	1.4	.20	.16	---
Nitrate (NO_3)	.2	.1	.4	---
Dissolved solids	225	---	---	---
Hardness (as $CaCO_3$)	6	21	42	72
Analyst	GWW	GWW	GWW	GWW

	Well no.			
	33	35	37	38
Location	Windsor Shades	Windsor Shades	Windsor Shades	Providence Forge
Depth (feet)	260	194	230	16
Formation or age	Mattaponi formation	Nanjemoy formation	Mattaponi formation	Pleistocene age
Date	1906	Oct. 27, 1943	Jan. 25, 1944	Jan. 25, 1944
Silica (SiO_2)	23	---	---	---
Iron (Fe)	.08	---	---	---
Calcium (Ca)	2.1	---	---	---
Magnesium (Mg)	.4	---	---	---
Sodium (Na)	---	---	---	---
Potassium (K)	---	---	---	---
Bicarbonate (HCO_3)	290	123	252	18
Sulfate (SO_4)	1.6	10	15	28
Chloride (Cl)	6.5	4	2	29
Fluoride (F)	---	.2	1.2	.0
Nitrate (NO_3)	4.4	---	.2	18
Dissolved solids	60	---	---	---
Hardness (as $CaCO_3$)	9	92	12	62
Analyst	RBD	EWL	EWL	EWL

TABLE 17.—*Chemical analyses of waters from wells in New Kent County, Va.*—Con.

	Well no.		
	39	41	44
Location	Providence Forge	Providence Forge	Mountcastle
Depth (feet)	110	286	328
Formation or age	Nanjemoy formation	Mattaponi formation	Mattaponi formation
Date	Dec. 30, 1943	Dec. 30, 1943	Sept. 25, 1943
Silica (SiO_2)	26	33	
Iron (Fe)	.03	.02	
Calcium (Ca)	33	2.0	
Magnesium (Mg)	4.4	1.0	
Sodium (Na) } Potassium (K)	8.7	101	
Bicarbonate (HCO_3)	131	253	230
Sulfate (SO_4)	7.0	15	7
Chloride (Cl)	2.9	1.9	5
Fluoride (F)	.2	1.1	1.5
Nitrate (NO_3)	0	0	0
Dissolved solids	144	279	
Hardness (as $CaCO_3$)	100	9.1	4.5
Analyst	EWL	EWL	EWL

CHARLES CITY COUNTY

Charles City County lies along the James River in the western part of the York-James peninsula. The Chickahominy River forms the eastern and northern boundaries of the county and Henrico County the western boundary.

Charles City County has an area of 150 square miles. The population in 1950 was 4,676, or about 31 persons per square mile (Virginia Division of Planning and Economic Development, 1951). Farming is the principal occupation; the dark soil of the low terraces along the James River is notably the best land and is less subject to frost during the fall and spring days than the adjacent higher land. Farm products sold in 1949 amounted to $714,868; these consisted of field crops, livestock, poultry products, and dairy products, in that order of importance.

The area is heavily wooded and lumbering is an important industry. Value added by manufacture to lumber and basic lumber products was $363,000 in 1947. The slightly brackish waters of the James River yield a variety of fresh- and salt-water fish to a few commercial fishermen.

The Chesapeake and Ohio Railroad, with a local station at Roxbury, crosses the northwestern corner of the county. In addition, the highways and the James River both carry much traffic.

TOPOGRAPHY

Charles City County is made up of rolling terrace lands along the Chickahominy River, where the dissected Sunderland terrace with a maximum altitude of 150 feet has been preserved. In the eastern part of the county between the James and the Chickahominy Rivers, broad undissected terraces less than 40 feet above sea level represent the Talbot formation. In the southern part of the county parallel to the James River, broad undulating areas between 60 and 80 feet above sea level probably represent the terrace of the Wicomico formation.

In a few places where the James River is undercutting its banks there are steep cliffs, but in most places the terrain is subdued. For the most part the county is underlain by moderately dissected terraces, but along the James River, and particularly in the southeastern part of the county near the mouth of the Chickahominy River, there are broad terraces that have been only slightly modified by erosion.

GEOLOGY

BASEMENT ROCK

At Curles Neck, 2 miles west of Shirley in easternmost Henrico County, bedrock was reached at 280 feet below sea level (40, table 5); at Shirley bedrock was reached at 350 feet (Sanford, 1913, p. 148), probably at 325 feet below sea level. Estimating from geophysical soundings made south of the James River (Ewing and others, 1937), it seems likely that bedrock lies more than 800 feet below sea level in southeastern Charles City County.

CRETACEOUS SYSTEM—POTOMAC GROUP

Beds of the Potomac group of Early and Late Cretaceous age have not been reached by deep wells except perhaps in the southwestern part of the county along the James River. Nothing specific is known of the character of the Cretaceous deposits, which underlie the entire county at some depth. (See p. 16.) However, these may be assumed to be prolific water-bearing beds even though almost entirely unexplored to date.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

The Mattaponi formation of Late Cretaceous and Paleocene age extends inland to Charles City County. Diagnostic Foraminifera have been found in cuttings from well 34 (table 19) where the formation probably occurs as high as 70 feet below sea level. The formation may extend almost to the western part of the county. The Mattaponi formation includes some excellent water-bearing sands.

TERTIARY SYSTEM

EOCENE SERIES

The Pamunkey group of Eocene age is reached by many wells in Charles City County. Glauconite sands (black sands) and glauconitic marls seemingly make up the deposits of Eocene age in this county, as elsewhere. The lower of the two formations of the group, the Aquia, is present in western Charles City County (1, 44, table 19; fig. 12) but its presence was not recognized in well 34 at Charles City.

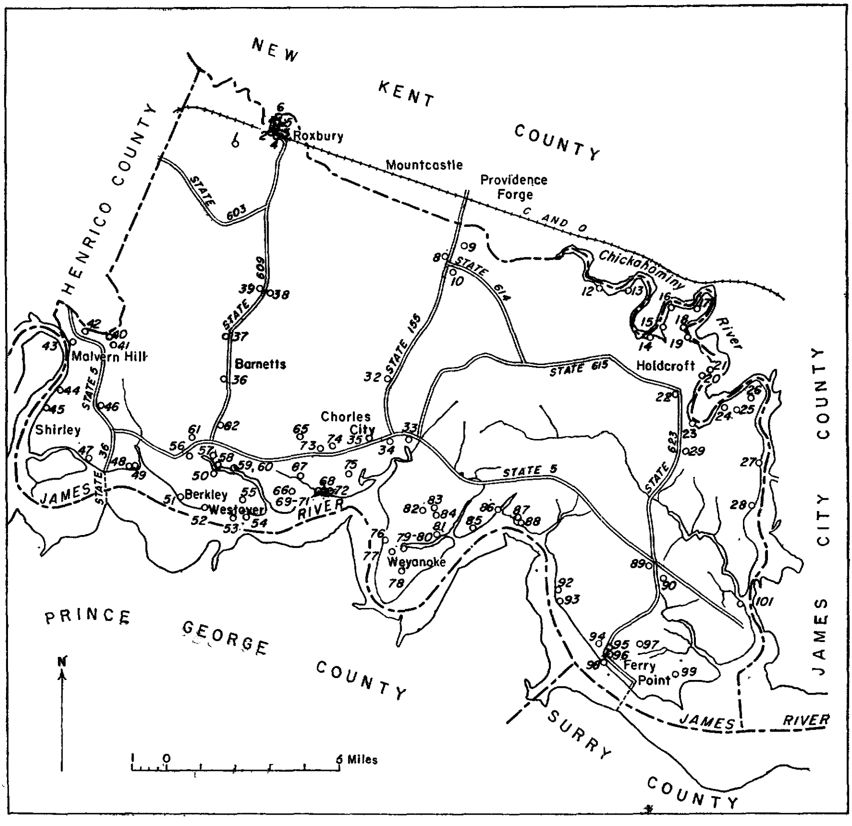


FIGURE 12.—Location of wells in Charles City County.

The pink Marlboro clay member of the Nanjemoy formation marks the base of that formation at Roxbury and is correlated with the similar basal pink or red clay in some wells in Henrico and King William Counties. (A light-brown clay at Charles City is also thought to be the basal Nanjemoy member.) At Roxbury the Nanjemoy formation is 92 feet thick. At Charles City, where the formation extends to 90 feet below sea level, the upper boundary is indeterminate from the samples at hand. The units are slightly glauconitic gray marls, which are not water bearing. Along the lower part of the Chickahominy River, from Providence Forge and eastward, the uppermost Nanjemoy units are sandy and contain rock and shell layers and yield water to many small, relatively shallow jetted wells.

MIOCENE SERIES

The Chesapeake group of Miocene age crops out in many places along the large streams and rivers and has been reached by many wells in northern and eastern Charles City County. It consists largely of blue marl from 50 to 75 feet thick. So far as is known, it does not contain water-bearing beds.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The Columbia group of Pleistocene age (terrace deposits of sand, gravel, and clay) covers the whole of Charles City County. The Chesapeake group, of Miocene age, underlies the sand and gravel cover throughout the entire county except in the southwestern part bordering the James River, where the terrace deposits rest upon formations of the Pamunkey group of Eocene age. The terrace deposits have a maximum thickness of about 30 feet. They furnish water to many dug or driven wells in the county.

WATER-BEARING FORMATIONS

CRETACEOUS SYSTEM—POTOMAC GROUP

Well 53, at Westover (fig. 12), is about 100 feet deeper than most other wells in that area and probably tops pre-Aquia deposits, either Lower and Upper Cretaceous units of the Potomac group or Mattaponi units of Late Cretaceous and Paleocene age. Several other wells in the vicinity that are about 200 feet deep may likewise reach these deposits, but as detailed data are lacking this cannot be stated with certainty.

Small flows are obtained from most of these wells. At Riverview Farm (44) a yield of 60 gpm is obtained by pumping, and it seems evident that larger yields are available.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

In the vicinity of Charles City and eastward along the James River and in a few places elsewhere in the county, mostly along the Chickahominy River, sands of the Mattaponi formation of Late Cretaceous and Paleocene age are developed by wells. At Weyanoke, 3½ miles southeast of Charles City, a 6-inch well (77, table 18) 156 feet deep flows 60 gpm at an elevation of 12 feet above sea level, and a 4-inch well (76) 200 feet deep flows 60 gpm through a 2-inch outlet at an altitude of 8 feet above sea level. Assuming that the well is carefully finished with the proper screen, this well might easily supply from 150 to 200 gpm to a power suction pump.

A 4-inch well (97, table 18) near Sandy Point was drilled in 1905 to a depth of 239 feet below sea level. This well is said to have been the finest well in the county and initially flowed 90 gpm. The flow subsequently diminished and in 1943 it was flowing at a rate of only 7 gpm. Part of the decrease in flow may be due to sanding, as the well was not finished with a screen.

Yields up to a million gallons a day probably could be obtained from properly constructed wells ending in deposits of the Mattaponi.

Water levels in deep wells.—It might be expected that in western Charles City County water levels in wells reaching pre-Eocene strata should be at least 30 or 40 feet above sea level and that in the southeastern part of the county the water levels should be from 15 to 20 feet above sea level. Sanford (1913, p. 302–303), for instance, shows that at Bucklands Landing, near Wilcox Wharf on the James River, water rose 32 feet above high tide, and at Roxbury the water level in a well 280 feet deep was about 40 feet above sea level. At Holdcroft in northeastern Charles City County the initial water level is reported to have been about 26 feet above sea level (29).

Water in deep wells still rises about 30 feet above sea level at Roxbury, but just south of Providence Forge it rises only 20 feet above sea level, and at Holdcroft it will not rise more than about 10 feet above sea level. At Dancing Point, well 99 flowed at 12 feet above sea level in 1943.

In southwestern Charles City County, at well 84 near Shirley, the water level is reported to have been only 9 feet above sea level in 1943; and near Harrisons Point (Hopewell Ferry Landing) water at low tide will not flow over the top of a casing 6 feet above river level. Downriver near Harrisons Landing well 52 flows at 9 feet above sea level.

Although most of the decline of water levels throughout the county may be ascribed to loss of head because of excessive waste of artesian water, in the southwestern part of the county the lowering of water levels may be due to heavy industrial pumping at Hopewell, across the James River.

TERTIARY SYSTEM

EOCENE SERIES

Aquia Formation

A few wells in the vicinity of Malvern Hill and probably also at Roxbury may obtain water from deposits of the Aquia formation (table 18). Only small supplies have been sought. To the east of

Malvern Hill, the Aquia formation thins out, having been largely eroded during later Eocene marine transgressions.

Nanjemoy Formation

Most of the artesian wells in the northern and eastern parts of the county along the Chickahominy River are drilled to the uppermost unit of the Nanjemoy formation of Eocene age, which is reached at 90 to 125 feet below sea level. Beneath 50 to 75 feet of Miocene blue clay containing subordinate shell streaks, there is 10 to 20 feet of coarse shells. Below the shell stratum is a rock stratum from ½ to 1 foot thick made up of black sand, shells, and shell fragments, firmly cemented together by calcium carbonate. This rock stratum is the bed that drillers seek and on which casing is usually set. Beneath this first rock stratum are a number of thinner rock streaks from ½ to 4 inches thick, alternating with strata as much as 2 feet thick composed of a mixture of shells, medium- to coarse-grained sands, and fine gravel, which are water bearing. The driller obtains water by drilling an open hole through 2 to 12 of these layers of sand, shells, and gravel, setting casing on one of the hard strata and pumping out the sandy material beneath, thus creating a cavity below the bottom of the casing. The total thickness of the alternating thin indurated beds and water-bearing sands ranges from 5 to 20 feet. Because excellent flows are obtained from this zone, only a few wells in the area have been drilled deeper. In adjacent parts of New Kent and James City Counties along the Chickahominy River many wells have been drilled to the Nanjemoy strata.

The Nanjemoy water-bearing units do not occur along the James River above the mouth of the Chickahominy River or along the Chickahominy River above Providence Forge but grade westward into fine, silty unproductive marl.

At low altitudes, along streams and swamps, flows from 2-inch wells in the Nanjemoy formation are as much as 10 or 12 gpm.

In a well (14, table 18) 1 mile north of Holdcroft in eastern Charles City County, water rises 8 feet above sea level. In a well (17) 2 miles northeast of Holdcroft, water rises about 6 feet above sea level. Three miles southeast of Holdcroft (24) water in a well 100 feet deep rises 3.8 feet above river level at low tide and 4.6 feet above river level at high tide (river level at mean tide is assumed to be 1 foot above sea level). In southeastern Charles City County it appears that water will not rise higher than 4 feet above sea level in wells drawing upon deposits of the Nanjemoy.

At Mountcastle (46, table 15), in adjacent New Kent County, water in two wells reaching the Nanjemoy is reported to rise 14 and 30 feet, respectively, above sea level; at Sterling Heights (8, table 18) it stood 43 feet above sea level. In the northeastern part of the county the head was initially higher than it was farther east, in James City County, and, in addition, appreciable loss of head has not occurred as it has where there are many unrestricted flowing wells. It is apparent also that the formation as a whole has a low permeability and that loss of head at one locality does not produce marked effects over a wide surrounding territory.

In summary, water excellent for most purposes is available from the Nanjemoy formation at depths of 90 to 125 feet in northern and eastern Charles City County. Small flows from properly constructed wells can be had at altitudes as much as 6 feet above sea level. Both flowing and pumped wells are sources of ample and inexpensive water for domestic purposes but, owing to the limited thickness of water-bearing units, the Nanjemoy formation can hardly be counted upon to yield more than 50 to 100 gpm per well, at the maximum. Furthermore, any large-scale ground-water development drawing heavily upon Nanjemoy strata would result in local depletion of supplies because the permeability of the formation as a whole is poor. Industrial or other large supplies should be obtained from the deeper units.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

Shallow wells from 10 to 50 feet deep obtain water from the terrace formations of Pleistocene age. These provide water for domestic use throughout the county. The majority of these are dug wells but a few wells have been made by driving a sand point. Some shallow wells are equipped with electric or gasoline-powered pumps that deliver up to 10 or 12 gpm for short periods of time. Most wells, however, are fitted with a hand pump or simply a bucket. Although the yield of most shallow wells is probably not more than 2 or 3 gpm, they seldom go dry. Owners report that wells even less than 15 feet in depth rarely fail in the driest weather. Several wells have been in existence for over 100 years and are said to have given satisfactory service since the time they were completed.

QUALITY OF WATER

WATER FROM CRETACEOUS TO TERTIARY SYSTEMS

Analyses of water from the Potomac group and the Mattaponi and Aquia formations in Charles City County (table 20) show that it is a soft sodium bicarbonate water having a maximum hardness of 20 ppm. The bicarbonate content of seven samples ranges from 183 to 298 ppm but one sample from Westover (56) contains 379 ppm of bicarbonate. The eight samples analyzed contain from 2 to 39 ppm of chloride. Only 0.3 ppm of fluoride is present in water from well 80 at Weyanoke, but samples from wells in other parts of the county contain 1.1 to 2.2 ppm.

The quality of water from the Nanjemoy formation was determined from analyses of well waters along the Chickahominy River in Charles City and immediately adjacent James City and New Kent Counties (35, table 17; 6, 13, 17, table 23; 21, 22, table 20). The water is soft to moderately soft; hardness ranges from 21 to 92 ppm in the samples analyzed, most of it caused by calcium and of the carbonate type. Bicarbonate content ranges from 123 to 370 ppm. Since calcium is moderate or very low compared to sodium, most water from the Nanjemoy formation in Charles City County should be classed as of the sodium bicarbonate type with a little calcium. The sodium has replaced calcium by base exchange. (See p. 66.)

Water from the Nanjemoy in and adjacent to Charles City County is low in chloride, generally containing less than 5 ppm. The fluoride content of the waters analyzed ranges from 0.2 to 1.3 ppm. The highest fluoride content was found in water from the easternmost well.

WATER FROM THE PLEISTOCENE SERIES

Water from the terrace formations is reported to be soft, everywhere. The hardness of the two samples analyzed (62, 89, table 20) is, respectively, 36 and 33 ppm. Water from the two shallow wells contained 0.1 and 0.0 ppm of fluoride.

SUMMARY OF GROUND-WATER RESOURCES

Details on the occurrence of water-bearing formations in the deep Paleocene or Cretaceous deposits in Charles City County are lacking and only general conclusions can be reached regarding these deposits. On the basis of data on wells in adjacent areas, particularly Williamsburg, Camp Peary, and West Point, it seems likely, however, that at least several million gallons of water per day might be obtained from properly constructed large-diameter wells in Charles City County. The quality of the water is excellent and it is thought that water from deeper strata in the eastern part of the county probably would not contain objectionable amounts of chloride. Furthermore, owing to the distance from the area of high-chloride water (pl. 4*A*), the chloride content probably would not increase appreciably under heavy pumping. The proximity of deep-water navigation via the James River along the entire southern edge of Charles City County and the excellent ground-water possibilities combine to make this area favorable for industrial development where a large quantity of cheap water is a prime requisite.

Records and logs of wells and chemical analyses of waters for Charles City County follow in tables 18, 19, and 20.

TABLE 18.—*Records of wells in Charles City County, Va.*

[Type of well: Dg, dug; Dr, drilled; Dv, driven; J, jetted. Water-bearing formation: A, Aquia; Co, Columbia group; M, Mattaponi formation; Nj, Nanjemoy formation; P, Potomac group. Approximate water level and approximate yield: Water level and yield as of 1943 unless otherwise noted in Remarks. Use of water: Ab, abandoned; D, domestic; M, municipal; P, public school; S, stock]

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing formation	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Temperature (°F.)	Remarks
1	2 miles southwest of Roxbury.	Roxbury CCC Camp.	Sydnor Pump & Well Co., Inc.	1933	126	Dr	350	6	M	−	------	D	------	See log, table 19.
2	Roxbury	F. S. Bock	S. H. Fetterholf	1898	35	J	250	2	M	−	------	Ab	------	Well now plugged up.
3	do	J. G. McCann	D. L. Perkinson	1930	35	J	186	2	A (?)	−	------	D	------	
4	do	E. V. Marston	do	1942	35	J	283	2	M	−	------	D	------	
5	do	W. D. Wermuth	Tom Walker	1910	39	J	289	2	M	−	------	D	------	
6	do	do	D. L. Perkinson	1941	37	J	194	2	A (?)	−18	------	S	------	Water level as of 1947.
8	2½ miles south of Providence Forge.	Sterling Heights	O. C. Brenneman	1945	90	J	280	2	M	−80	------	M	------	When well was 150 feet deep, water level was 47 feet below surface. Water-level measurement as of 1946.
9	¾ mile south of Providence Forge.	H. C. Sledd	S. H. Fetterholf	1920	22	J	120	2	Nj	−	------	D, S	------	
10	1¼ miles south of Providence Forge.	H. C. Rowan	T. P. Binns	1919	58	J	248	2	M	−	------	D, S	------	
12	2 miles northwest of Holdcroft.	Harwood Estate	do	1915	2	J	105	2	Nj	+	5	D	------	
13	do	do	do	1915	3	J	110	2	Nj	+	2	Ab	------	
14	1 mile north of Holdcroft.	R. E. Graves	do	1916	5	J	90	2	Nj	+8	2	D, S	61	
15	1½ miles northeast of Holdcroft.	J. H. Bocock	do	1920	2	J	110	2	Nj	+	7	D	------	
16	do	do	do	1939	3	J	110	2	Nj	+	3	D	62	
17	2 miles northeast of Holdcroft.	do	do	1902	2	J	110	2	Nj	+6	4	Ab	61½	Height to which water will rise determined to be 4.8 feet above river level.
18	1½ miles northeast of Holdcroft.	do	do	1938	3	J	110	2	Nj	+	2	Ab	------	
19	do	do	do	1930	3	J	110	2	Nj	+	8	D	60	
20	2 miles east of Holdcroft.	T. P. Binns	do	1930	2½	J	240	3	M	+	¼	D	------	
21	do	do	do	1930	2½	J	117	2	Nj	+	4	D	------	See analysis, table 20.
22	do	Walker Potter	do	1933	2	J	110	2	Nj	+	1	D	------	Do.
23	2 miles southeast of Holdcroft.	Frank Curls	do	1922	1½	J	112	2	Nj	+	1	Ab	61	

TABLE 18.—*Records of wells in Charles City County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing formation	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Temperature (°F.)	Remarks
24	3 miles southeast of Holdcroft.	Noland Buck	T. P. Binns	1922	2	J	235	2	M	+6.1	¼	D	63½	See analysis, table 20.
25	do	A. R. Penny	do	1915	1	J	100	2	Nj	+4.8	6	D	61½	Water level listed was at high tide; water level was 3.8 feet at low tide.
26	3½ miles east of Holdcroft.	do	do	1915	1½	J	100	2	Nj	+	3	Ab	61	
27	5 miles southeast of Holdcroft.	K. R. Saunders	do	1943	2	J	118	2	Nj	+	10	D		
28	5½ miles southeast of Holdcroft.	Eagle Bottom Club	do	1925	2	J	120	2	Nj	+	7	D		
29	3 miles southeast of Holdcroft.	N. Walker	H. E. Shimp	1908	28	J	250	2	M	−		Ab		Water reportedly came within 4 feet of land surface when completed.
32	1 mile southwest of Ruthville.	B. McKenney		1943	72	Dg	34		Co	−32		D		
33	Charles City	do	S. H. Fetterholf	1925	6	J	260	2	M	+	4	D	62½	See analysis, table 20.
34	do	School	O. C. Brenneman	1946	45	J	220		M	−		P		See log, table 19.
35	1 mile west of Charles City.	S. W. Beal		1800	43	Dg	35		Co	−25		D, S		
36	Barnetts	A. B. Barnett	S. H. Fetterholf	1930	55	J	241	2	M	−33	3	D, S		See analysis, table 20.
37	1 mile north of Barnetts	M. Green		1909	108	Dg	21		Co	−19		D, S		Never dry.
38	3½ miles northeast of Barnetts.	L. Wallace		1927	114	Dg	14		Co	−12		D, S		
39	do	E. Whitehead		1918	107	Dg	18		Co	−16		D, S		
40	½ mile east of Malvern Hill.	Annie Rathine	D. L. Perkinson	1937	34	J	180	2	P (?)	−		D, S		
41	do	King's Daughters Fresh Air Camp.	T. P. Binns	1936	43	J	160	2	P (?)	−		D		
42	Malvern Hill	Bessie Rathine	D. L. Perkinson	1936	51	J	180	2	P (?)	−		D		
43	do	J. M. Gill	Fisher		42	J	130	4	A (?)	−33	60	D, S		
44	4 miles south of Malvern Hill.	Riverview Farm	Sydnor Pump & Well Co., Inc.	1943	42	D	204	6	P (?)			D, S		See log, table 19.

45	Shirley	Dimmick		1918	2	J	160	4	P (?)	−1½		D		An old deep well here reached bedrock at 325 feet below sea level.
46	1 mile east of Shirley	C. H. Carter		1850	36	Dg	25		Co	−		D, S		
47	Hopewell Ferry Landing	D. L. Perkinson	D. L. Perkinson	1936	6	J	180	2	P	−½(?)		D,S		Will flow occasionally on a very high tide.
48	6 miles west of Westover	R. B. Walton	do	1937	27	J	185	2	P	−		D		Used to fill swimming pool.
49	do	do	do	1935	2	J	180	2	P	−		D		
50	Harrisons Landing	F. B. Jameson	S. H. Fetterholf	1930	51	J	185	3	A	−		D		
51	do	do	D. L. Perkinson	1938	8	J	175	4	P(?)			D		Pumps 40 gpm. Used to fill swimming pool.
52	½ mile west of Westover Post Office.	D. L. Perkinson	do	1936	1	J	186	2	P(?)	+	5	D	62	Flows 2 gpm 9 feet above sea level. See analysis, table 20.
53	Westover	Richard Crane	S. H. Fetterholf	1930	2	J	280	4	P(?)	+	5	Ab	61½	
54	do	do	Sydnor Pump & Well Co., Inc.		3½	Dr		4	P(?)	+	1	Ab	63	
55	do	do	do	1901	15	Dr	139	10	P(?)	+		D,S		Sand 122–130 feet.
56	Roland's Mill	M. Harry	D L. Perkinson	1938	6	J	174	2	Nj(?)		4	D	60½	See analysis, table 20.
57	1½ mile north of Westover.	J. A. Ruffin	S. H. Fetterholf	1927	3	J	200	2	M(?)	+	4	D		
58	do	Westover Parish	do	1927	4	J	200	2	M(?)	+	5	D		
59	do	J. A. Ruffin	do	1924	2	J	200	2	M(?)	+	7	D		
60	do	do	do	1927	4	J	190	2	M(?)	+	2½	D		
61	2 miles southwest of Barnetts.	D. B. Tyler		1929	34	Dg	30		M(?)	−25		D		Never dry.
62	1 mile south of Barnetts	Robert Wyatt		1943	66	Dv	28	1½	Co	−20		D	61	See analysis, table 20.
65	3½ miles west of Charles City.	J. A. Ruffin	D. L. Perkinson	1927	54	J	240	4	Co	−		D,S		
66	1½ miles northeast of Westover.	do		1900	3½	J	200	2	M	+	2	S		
67	2 miles northeast of Westover.	J. L. Parsons		1900	19	J	210	3	M	−		D,S		
68	3 miles southwest of Charles City.	R. B. Saunders	D. L. Perkinson	1928	4	J	197	2	M	−	2	D		
69	do	do			1½	J		3	M	+	10	D,S	62	
70	do	do			4	J		3		+	7	Ab	62	
71	do	do			2	J		3		+	3	D		
72	Wilcox Wharf	Lamar			2	J		3		+	3	Ab		
73	2½ miles west of Charles City.	H. C. Bourne		1915	74	J	240	3	M	−		D,S		Pumps 60 gpm.
74	2 miles west of Charles City.	G. W. McGraw		1908	64	Dg	30		Co	−29		D,S		Went dry in 1941.
75	2 miles southwest of Charles City.	S. A. Mason	Sydnor Pump & Well Co., Inc.	1933	60	Dr	235	6	M	−53		D,S		Pumping 25 gpm. See log, table 19.
76	Weyanoke	Lawrence Lewis, Jr.	do	1939	3	Dr	200	6	M	+	60	D,S		Flow ordinarily shut off.
77	do	Lawrence Lewis	do	1939	12	Dr	156	6	M	+	60	D		Flow ordinarily shut off. Pumps 80 gpm. See log, table 19.
78	do	do	Jewett	1910	7	J	200	2	M	+	½	S	63	
79	do	do	do		11	Dr	210	4	M	+	20	Ab		

TABLE 18.—*Records of wells in Charles City County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing formation	Approximate water level (feet above (+) or below (−) surface)	Approximate yield (gallons per minute)	Use of water	Temperature (°F.)	Remarks
80	Weyanoke	Lawrence Lewis	Jewett	1920	8	Dr	200	4	M	+	60	D,S	61¾	See analysis, table 20.
81	3 miles southeast of Charles City.	L. M. Clark	L. M. Clark	1912	6	J	194	2	M	+	1	D,S	------	
82	2½ miles southeast of Charles City.	A. G. Copland	S. H. Fetterholf	1930	58	J	240	2	M	−	------	D,S	------	
83	do	Riversedge Farm, George Copland.	Jewett	1920	62	Dr	340	4	M	−44	------	D,S	------	
84	do	do		1810	50	Dg	28	------	Co	−	------	D	------	Water contains much iron. Pumps 10 gpm.
85	Milton	A. E. Tate		------	7	J	210	2	M	+	¾	D,S	63½	
86	3½ miles southeast of Charles City.	Sue Tyler	S. H. Fetterholf	1930	5	J	------	2	------	+	12	D	63	
87	Sturgeon Point	Galloway	D. L. Perkinson	------	3	J	185	2	M	+	4	D	63½	
88	do	Eureka Brick Co.		------	6	Dr	210(?)	4	M	+	15	B	------	
89	4 miles south of Holdcroft.	E. H. Peterson		1930	34	B	40	1½	Co	−22	------	D	------	Much iron. See analysis, table 20.
90	4½ miles south of Holdcroft.	R. A. Lampkin		1933	37	B	11	2	Co	−	------	D	------	
92	7¼ miles south of Holdcroft.	Walter Smayfield		------	2	J	190	3	M	+	6	Ab	------	
93	7½ miles south of Holdcroft.	A. W. Boyd	D. L. Perkinson	1939	3	J	190	2	M	+	25	D	63½	See analysis, table 20.
94	8 miles south of Holdcroft.	G. D. C. Garrison	S. H. Fetterholf	1932	10	J	210	2	M	+	2	D	------	Initial flow 27 gpm.
95	do	M. R. Dotson	O. C. Brenneman	1935	8	J	212	2	M	+	3	D,S	63½	
96	do	do	do	1935	8	J	180	2	M	+	¼	D,S	------	
97	8½ miles southeast of Holdcroft.	Stanley Hule	McDermott	1905	11	J	250	4	M	+	7	Ab	65	Reported flowed 90 gpm when completed.
98	Sandy Point	A. L. Smith		1914	12	Dv	20	1½	Co	−	------	D,S	------	Pumps 10 gpm.
99	Dancing Point	K. Ruffin	McDermott	1910	12	J	250	3	M	+	½	S	------	
101	7 miles southeast of Holdcroft.	Peterson	T. P. Binns	1909	3	J	240	2	M	+	1	D	------	Black sand 173–198 feet, sand 270–290 feet. Dancing Point.

TABLE 19.—*Logs of wells in Charles City County, Va.*

Well 1, Roxbury; CCC Camp

[Log from samples furnished by Sydnor Pump & Well Co., Inc. Altitude, 126 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, orange, sandy	35	35
Chesapeake group (Miocene):		
Clay, orange, sandy; shell fragments	17	52
Marl, gray; contains shells	38	90
Marl, gray, silty; Foraminifera	18	108
Marl, gray, sandy; Foraminifera	12	120
Nanjemoy formation (Eocene):		
Marl, gray; trace of glauconite	75	195
Clay, pink	17	212
Aquia(?) formation (Eocene):		
Marl, gray, glauconitic	48	260
Sand, gray quartz	16	276
Undescribed	74	350

Well 34, Charles City; Charles City School

[Log from samples supplied by O. C. Brenneman. Altitude, 45 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Sand, fine, yellow	65	65
Nanjemoy formation (Eocene):		
Marl, slightly glauconitic, gray, sandy; Foraminifera	25	90
Marl, dark, glauconitic; Foraminifera	25	115
Clay, glauconitic, light-brown; Foraminifera	21	136
Mattaponi (?) formation (Upper Cretaceous and Paleocene):		
Marl, dark, highly glauconitic, sandy; Foraminifera	59	195
Sand, white, coarse at base; water	25	220

Well 44, Shirley; Riverview Farm

[Log by Sydnor Pump & Well Co., Inc. Altitude, 42 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, yellow	20	20
Gravel	20	40
Pamunkey group (Eocene):		
Marl, blue	50	90
Sand, compact	10	100
Gravel, coarse, and blue clay	30	130
Potomac group (Lower and Upper Cretaceous):		
Clay, green, sticky	10	140
Gravel, coarse; water (?)	8	148
Clay, green, sandy	34	182
Sand; water	3	185
Sand, coarse; water	10	195
Clay, gray, sandy	9	204

TABLE 19.—*Logs of wells in Charles City County, Va.*—Continued

Well 75, Charles City; S. A. Mason

[Log from samples furnished by Sydnor Pump & Well Co., Inc. Altitude, 60 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Silt, yellow	80	80
Nanjemoy formation (Eocene):		
Clay, gray; trace of glauconite; few limestone fragments; Foraminifera	60	140
Clay, pink; Foraminifera	10	150
Mattaponi(?) formation (Upper Cretaceous and Paleocene):		
Sand, glauconitic	60	210
Sand; water	19	229
Clay, light-yellow	6	235

Well 77, Weyanoke; L. Lewis

[Log by Sydnor Pump & Well Co., Inc. Altitude, 12 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Brown sand	18	18
Gravel	18	36
Undifferentiated:		
Mud, blue	100	136
Mud, brown	16	152
Sand, quartz; trace of glauconite; water	4	156

Table 20.—*Chemical analyses of waters from wells in Charles City County, Va.*

[Analyses in parts per million. Analyst, E. W. Lohr]

	Well no.				
	3	4	21	22	24
Location	Roxbury	Roxbury	Holdcroft	Holdcroft	Holdcroft
Depth (feet)	186	283	117	110	235
Formation or group	Aquia (?) formation	Mattaponi(?) formation	Nanjemoy formation	Nanjemoy formation	Mattaponi formation
Date	Jan. 25, 1944	Jan. 25, 1944	Oct. 28, 193	Oct. 28, 1943	Oct. 28, 1943
Iron (Fe)	----	----	0.55	----	----
Bicarbonate (HCO_3)	260	253	194	190	216
Sulfate (SO_4)	14	13	6	6	15
Chloride (Cl)	2	2	4	4	24
Fluoride (F)	1.2	1.2	.6	.5	1.4
Nitrate (NO_3)	----	.1	.0	.0	.1
Dissolved solids	----	----	----	----	----
Hardness (as $CaCO_3$)	15	12	52	52	15
Free carbon dioxide	1.4	2.5	----	----	----

	Well no.				
	33	36	40	52	56
Location	Charles City	Barnett	Malvern Hill	Westover	Westover
Depth (feet)	260	241	180	186	174
Formation or group	Mattaponi formation	Mattaponi formation	Potomac(?) group	Nanjemoy(?) group	Nanjemoy(?) group
Date	Oct. 10, 1943	Nov. 7, 1943	Jan. 25, 1944	Nov. 7, 1943	Oct. 16, 1943
Iron (Fe)	----	----	----	----	----
Bicarbonate (HCO_3)	270	205	183	298	379
Sulfate (SO_4)	7	10	7	12	10
Chloride (Cl)	12	4	3	30	39
Fluoride (F)	1.8	1.6	.4	1.9	2.0
Nitrate (NO_3)	.0	.1	.4	.0	.0
Dissolved solids	----	----	----	----	----
Hardness (as $CaCO_3$)	12	30	39	16	20
Free carbon dioxide	----	----	2.9	----	----

	Well no.			
	62	80	89	93
Location	Barnetts	Weyanoke	Holdcroft	Holdcroft
Depth (feet)	28	200	40	190
Formation or group	Columbia group	Mattaponi formation	Columbia group	Mattaponi formation
Date	Oct. 15, 1943	Oct. 10, 1943	Nov. 6, 1943	Oct. 11, 1943
Iron (Fe)	0.54	----	41.0	----
Bicarbonate (HCO_3)	36	232	31	219
Sulfate (SO_4)	1	13	1	7
Chloride (Cl)	34	7	19	4
Fluoride (F)	.0	.3	.1	2.2
Nitrate (NO_3)	.0	.0	.0	.0
Dissolved solids	----	----	----	----
Hardness (as $CaCO_3$)	36	12	33	6.0
Free carbon dioxide	----	----	----	----

JAMES CITY COUNTY

James City County stretches across the peninsula from the York River to the James River. At its upper end it is bounded by the Chickahominy River and Diascund Creek flowing into the James River and by the lower part of Ware Creek flowing into the York River. At its lower end, it is bounded by Skiffs Creek flowing into the James River and by Skimino Creek flowing into the York River. Skiffs Creek is considerably farther east than Skimino Creek; the boundary joining these creeks is drawn along the divide in a northwest-southeast direction along the backbone of the peninsula. The county therefore has a relatively long frontage on the James River and a short frontage on the York River.

James City County has a population of 13,052, of which more than half reside in Williamsburg. The area is 148 square miles (Virginia Division of Planning and Economic Development, 1951).

The county produces largely agricultural and lumber products. The value of agricultural products in 1949 was $687,927. Field crops (soybeans and corn), livestock (chiefly hogs), and vegetables were the main products, in that order of importance. The value added by manufactured products, almost entirely lumber products, amounted to $504,000 in 1947.

The first permanent English settlement in this country was at Jamestown in 1607. Jamestown functioned as the capital of the colony until 1699, at which time the capital was moved to Williamsburg (Middle Plantation). It was moved again, to Richmond, in 1780.

The restoration of colonial Williamsburg, begun in 1927, and the Jamestown National Historical Park recall the early colonial history vividly, and, incidentally, provide employment directly or indirectly for a large number of individuals.

The county is served by excellent highways. The Chesapeake and Ohio Railroad, connecting Newport News and Richmond, passes through Williamsburg, Toano, and Norge. A ferry connects Jamestown with Scotland Wharf and points south.

TOPOGRAPHY

That part of the county lying along the divide between the James River and the York River is underlain by the moderately dissected terrace of the Wicomico formation ranging from 130 feet above sea level in the western part of the county to 80 feet above sea level in the eastern part of the county. The lower Pamlico terrace, 10 to 40 feet above sea level, is widespread all along the James River and the mouth of the Chickahominy River; it is hardly present on that part of the county lying along the York River. The remainder of the county consists largely of the dissected terrace of the Wicomico and is consequently rather rugged with high relief in some parts.

GEOLOGY

BEDROCK

Depth to bedrock is not known in James City County but, reasoning from data in surrounding areas, bedrock may lie as little as 600 feet below sea level in the western part of the county and from 1,000 to 1,200 feet in the eastern part of the county.

CRETACEOUS SYSTEM—POTOMAC GROUP

Alternating sand and clay beds of the Potomac group of Early and Late Cretaceous age rest upon bedrock, but so far as is known these have not been reached by the deepest wells in the county.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

The Mattaponi formation of Late Cretaceous and Paleocene age appears to have been reached at a depth of 240 feet below sea level at Jamestown. (See log of well 27a, table 22; fig. 13.) The mottled clays

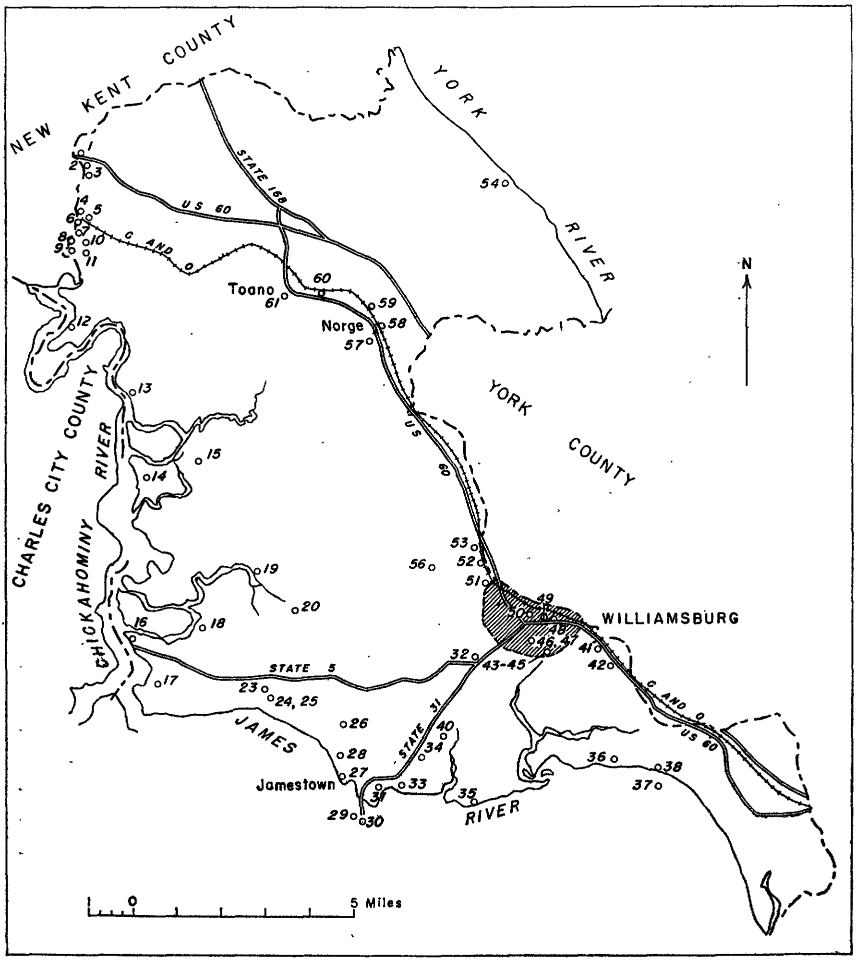


FIGURE 13.—Location of wells in James City County.

found between 660 and 670 feet in well 56 at Dunbar are suggestive of the strata tapped by deep wells at West Point. The beds do not appear to be as prolific water bearers here as they are in lower King William County.

TERTIARY SYSTEM

EOCENE SERIES

Aquia formation

The Aquia formation, of early Eocene age, apparently does not extend as far east as James City County, having been removed during the middle Eocene transgression.

Nanjemoy formation

The Nanjemoy formation of early and middle Eocene age is made up of glauconitic marls and sands. They are not extensive in the eastern part of the county, being only about 25 feet thick at Jamestown where diagnostic Foraminifera were found. The Nanjemoy formation has been thinned by the transgression of the upper Eocene sea.

Along the lower Chickahominy River Nanjemoy units are more or less sandy and yield water to many domestic wells.

Chickahominy formation

Foraminifera present in old cuttings show rather conclusively that the Chickahominy formation (Cushman and Cederstrom, 1945) of late Eocene age is represented at Jamestown in well 27a. At Jamestown the Chickahominy formation is quite sandy, although glauconitic marl beds are also present.

Since the presence of the Chickahominy formation is known from Foraminifera at both Camp Peary and Jamestown, the uppermost Eocene beds at Williamsburg are assigned to the Chickahominy formation rather than to the Nanjemoy formation which they resemble closely. Here, at Williamsburg, the Chickahominy formation is also sandy and commonly contains thin limestone members. In both Williamsburg and Jamestown the Chickahominy formation is an inferior water-bearing formation.

MIOCENE SERIES

The uppermost of the three formations, the Yorktown formation, which is principally shell marl, is exposed along the James River but little is known of the underlying St. Marys and Calvert formations.

As shown in logs of wells at Norge, Dunbar, and Jamestown, the Miocene units consist of dull-gray, blue, or brown clays with intercalated sandy beds. The 135 feet of green sand reported at Norge (57, table 22) is almost certainly a pale-green silt similar to the grayish-green silt present at Camp Peary, rather than a glauconitic sand. At Jamestown (26 and 27a, table 22) the sediments are quite sandy but at Dunbar (56) 20 feet of "soft running formation," probably silt, is the only relatively coarse material in 188 feet of Miocene sediments. At Williamsburg sand and shell of the Calvert formation were reached in well 49 between 254 and 270 feet (164 to 180 below sea level) overlying limestone of Eocene age. It is thought that this bed is present throughout the Williamsburg area.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The older beds are everywhere incompletely covered by the sand and clay deposits of the Columbia group of Pleistocene age, generally less than 40 feet thick. Mr. Hazelwood, a local driller, reports that sand extends from the surface to a depth of 92 feet in one place along Diascund Creek (5). If this is Pleistocene material, it indicates the former existence of a deep channel scoured during one of the glacial stages, at which time sea level stood perhaps 60 or more feet below present sea level, after which the channel filled with sand.

WATER-BEARING FORMATIONS

Only a few large-diameter wells have been drilled in James City County and those are almost all in and around Williamsburg and Jamestown. The greatest number of wells are domestic flowing jetted wells 2 or 3 inches in diameter. These are located along the James and the Chickahominy Rivers and Diascund Creek. The combined flow of these wells is probably not much greater than 100 gpm, but old records show that previous to 1910 the combined flow was perhaps 300 or 400 gpm. The decline of artesian head and the sanding of old wells, particularly those ending in glauconitic or "black" sands, have caused the flow of these wells to diminish to a trickle or to cease altogether.

From shortly before 1906 and up to 1945 water for the municipal supply at Williamsburg was obtained from wells. Now only a few small business establishments (laundry, 49) and homes pump ground water. The Eastern State Hospital at nearby Dunbar, however, is still supplied with ground water. A small municipal supply is obtained from a shallow dug well (61) at Toano.

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

Deep wells (45, 47, 48, and 49, table 21) at Williamsburg, respectively 417, 412, 438, and 416 feet deep, obtain water from the Mattaponi formation of Late Cretaceous and Paleocene age. These are seemingly the same beds tapped at Camp Peary and Fort Eustis.

The well at the college was pumped at a rate of 320 gpm in 1942. The hospital well is reported to have tested at 525 gpm in 1924. An abandoned well (44) at the Eastern State Hospital was drilled in 1912 to a depth of 876 feet but was subsequently blasted at 310 feet, undoubtedly to obtain a less mineralized water.

At Williamsburg water will rise to about 20 feet above sea level in wells reaching deep sands. Data by Sanford (1913, p. 311) indicates that the artesian head there was about 40 feet above sea level around 1910.

At the Dunbar Farm of the Eastern State Hospital, sand beds comparable in depth to those reached by the existing deep wells in Williamsburg are not present and it was necessary to drill deeper there to obtain a ground-water supply (56). Fine- to medium-grained sand beds between 578 and 660 feet below the surface were tapped. The finished well yielded 275 gpm with 40 feet of drawdown.

In the vicinity of Jamestown there are a number of wells ranging in depth from 280 to 320 feet ending in sand beds of the Mattaponi formation. No well in this area now has a large flow although flows of as much as 100 gpm were reported previous to 1920. Water is used only for domestic purposes in this area.

Static head in the Jamestown area is now less than 10 feet above sea level (33). Sanford reports (1913, p. 199) that the Ayers well had a head 28 feet above the surface (38 feet above sea level) previous to 1913; in 1940 water stood a little below the surface—a decline of more than 28 feet.

In well 27a, near Jamestown, water flowed at 30 feet above sea level previous to 1910, but water now stands about 12 feet below the surface in well 27b, which is 33 feet above sea level. A decline of more than 9 feet is indicated. Water levels at Jamestown have been affected by local flowing wells and also by pumping at Fort Eustis, downstream.

A few small flowing wells along the Chickahominy River (11, 12, 18, table 21), which are more than 200 feet deep, tap sand beds in the Mattaponi formation. A 235-foot well (12) is reported to have flowed at 20 feet above sea level in 1910 but water will not rise more than 5 or 6 feet above sea level in deep wells along the Chickahominy River, at present.

TERTIARY SYSTEM

EOCENE SERIES—NANJEMOY FORMATION

From Jamestown to the mouth of the Chickahominy River and along the east bank of the Chickahominy River and Diascund Creek are a number of small-diameter domestic wells (1–10, table 21), generally less than 130 feet deep, which obtain water from basal Miocene or uppermost Eocene deposits; the Nanjemoy deposits seem the likely source of water but sandy Calvert units or a sandy shore phase of the Chickahominy formation may be developed. Critical data on the formations are lacking here. These wells along the rivers are almost all on very low ground and have small flows. Water will rise from 4 to 6 feet above sea level in these shallow jetted wells.

The Nanjemoy formation, presumably, is tapped by well 60 at Toano and well 57 at Norge although it is possible that the sandy zone there should be assigned to the Chickahominy formation rather than the Nanjemoy formation.

UPPER EOCENE TO MIDDLE MIOCENE SERIES—CALVERT AND CHICKAHOMINY FORMATIONS

Several wells in and adjacent to Williamsburg (41, 43, 44, 46, 50, table 21), ranging in depth from 280 to 317 feet, appear to obtain water from the Calvert formation but may also draw from the upper units of the Chickahominy formation. The boundary between the two formations is about 170 to 210 feet below sea level here and most of the wells cited were continued a short distance below this depth. Thus it is not certain that Eocene sands are not tapped also in this zone. In any event, water is available from sandy beds in this range and yields in excess of 100 gpm appear to be available. However, only small quantities are being pumped from this zone at present, at wells 50–53 in York County and at two tourist camps in James City County. Water rises less than 10 feet above sea level in these wells.

Well 27a at Jamestown reached "water under low head" in the Chickahominy formation.

MIOCENE SERIES—YORKTOWN FORMATION

Shallow wells drilled in the Yorktown formation yield small quantities of water. Several of these wells, less than 100 feet deep, are in use, as at Williamsburg (52) and Norge (59, table 21). The water level varies considerably in these wells and stands from 30 to 50 feet below the surface. The Yorktown formation is not constant in character. In places it is not sandy and will produce no water. Elsewhere sand beds at least 20 feet thick certainly yield from 5 to 25 gpm, if not more.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

A large part of the rural population obtains its water entirely from wells dug in the Pleistocene terrace formations. These wells range in depth from 20 to 40 feet and generally are sufficient for small supplies only. Although very important in furnishing domestic supplies, the fact that most large farms and dairies drill to the deeper formations is in itself an indication that the copious supplies generally available to dug wells in Henrico and Hanover Counties are not as easily procured in James City County.

QUALITY OF WATER

WATER FROM UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

At Williamsburg wells about 400 feet deep yield water in which the bicarbonate content is about 435 ppm. The hardness is very low but the chloride content is high. Samples taken from the deep well (47, table 23) at William and Mary College, which was one of the sources of municipal supply for many years, have contained from 215 to 225 ppm of chloride. A sample from the Eastern State Hospital well (45) contained 255 ppm of chloride. Although suitable for many purposes, water from the Mattaponi formation is corrosive when hot and is detrimental to brass or aluminum hot-water heaters and radiators. It is entirely unsuited to boiler use.

Water from wells (27b, 28, 29, 30, 33, 34, table 23) 267 to 376 feet deep at Jamestown is similar in bicarbonate content and hardness to water from deep wells at Williamsburg, but the chloride content in the Jamestown waters is negligible except in well 29. According to an old field analysis by Sanford, chloride here was 57 ppm.

The fluoride content is over 2 ppm in deep well waters at Williamsburg, and at Jamestown it is even higher, ranging from 3.0 to 4.4 ppm.

WATER FROM THE EOCENE SERIES—NANJEMOY FORMATION

The deep lying artesian strata yield a soft bicarbonate type water everywhere in James City County but the relatively shallow wells along the Chickahominy River (6, 13, 17, table 23), which draw upon the Nanjemoy(?) formations, yield a harder water. Hardness in the three samples analyzed ranged from about 80 to 200 ppm and the bicarbonate content ranged from less than 150 to almost 375 ppm. In one sample chloride was relatively high, 36 ppm, but in the other two samples a characteristically low chloride content is evident. Fluoride in these samples ranged from 0.2 to 1.3 ppm.

WATER FROM UPPER EOCENE OR BASAL MIOCENE SERIES—CHICKAHOMINY AND CALVERT FORMATIONS

Several wells in use and a few abandoned wells in and around Williamsburg, which are less than 300 feet deep, obtain water from basal sands of the Calvert formation or the underlying Chickahominy formation. These are wells 41, 43, 44, 46, 50, and 53 in James City County (table 21), and 50, 51, and 53 in York County (table 27). According to available analyses, the chloride content of water from wells 43 and 50 (table 23) ranges from 100 to 125 ppm, but water from well 53 (table 23) at the Williamsburg Tourist Court contains only 7 ppm of chloride. This may indicate a sharp decline of chloride content in a westerly direction, but it seems more likely that at Williamsburg the Chickahominy and Calvert formations may have been contaminated locally by high-chloride water from deeper strata, possibly through leaky casings.

Water from these wells of moderate depth at Williamsburg is otherwise similar to water from the Nanjemoy formation, in that it is a slightly hard sodium bicarbonate water. It may be noted that the bicarbonate content of waters from wells 43 and 50, which have a high chloride content, is almost 400 ppm, whereas in water from well 53, which has a very low chloride content, it is only 268 ppm.

WATER FROM THE MIOCENE SERIES—YORKTOWN FORMATION

Water from shallow wells ending in the Yorktown formation ranges widely in hardness. Well 59 at Norge and well 52 at Williamsburg yield water having hardnesses of 83 and 88 ppm, respectively, largely caused by calcium and of the carbonate type. The bicarbonate content is less than 100 ppm and dissolved solids are also low, less than 125 ppm. Fluoride is negligible, but in the water from the well at Norge the iron content is found to be high, 8.1 ppm.

THE PROBLEM OF HIGH-CHLORIDE WATER

James City County lies partly within the zone of high-chloride water (pl. 4*A*). In the lower part of the county deep wells ending in the Mattaponi formation yield water containing from 100 to 250 ppm of this constituent. Although useful for many purposes, such water is not as desirable as water obtained from shallower, somewhat less productive strata or from deep wells in western James City County, where the chloride content is negligible.

It is of particular importance to recognize that large withdrawals of water in and near the zone of high-chloride water will likely induce further increases in chloride content, which may render the supply totally useless. It is thought that in this zone not more than a million gallons a day should be pumped from deep wells in any limited area, and that where larger withdrawals are planned discharge should be spread over a wide area and observation wells established to detect any change, such as marked lowering of water levels, which might lead toward an increase of chloride content of the water.

SUMMARY OF GROUND-WATER RESOURCES

Ample supplies of soft bicarbonate water for domestic and industrial use are available in James City County. In the western part of the county domestic supplies may be obtained from jetted or drilled wells sunk to about 100 feet below sea level and supplies up to a few hundred gallons per minute may be obtained from wells continued another 100 or 200 feet deeper. In the Jamestown-Williamsburg area, water in large quantity can be obtained only from wells more than 350 feet deep. At Williamsburg such deep wells yield a high-chloride water unfit for some purposes, and only small supplies of a harder, low-chloride water are available from shallow wells. In the vicinity of Jamestown and in all the western part of the county very large supplies of low-chloride water should be available from properly constructed deep wells tapping sands not now reached by existing wells.

Records and logs of wells and chemical analyses of waters for James City County follow in tables 21, 22, and 23.

TABLE 21.—*Records of wells in James City County, Va.*

[Type of well: Dg, dug; Dr, drilled; J, jetted. Water-bearing formation: Ck, Chickahominy formation; Co, Columbia group; Cv, Calvert formation; M, Mattaponi formation; Nj, Nanjemoy formation; Y, Yorktown formation. Yield: Yield as flow in 1943 except as otherwise noted. Use of water: Ab, abandoned; D, domestic; I, industrial; M, municipal; S, stock; T, tourist court]

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Water-bearing formation	Approximate yields (gallons per minute)	Use of water	Chloride content (parts per million)	Temperature (°F.)	Remarks
1	Diascund Bridge	Percy Walls	J. V. Hazelwood	1939	4	J	111	2	Nj	2½	D		59½	Static water level is 2 feet above top of casing which is 4 feet above sea level.
2	do	W. T. Martin	S. H. Fetterholf	1924(?)	20	J	144	2	Nj		D			
3	do	do	do	1930	3	J	124	2	Nj	6	D		59½	
4	1½ miles northwest of Diascund.	J. V. Hazelwood	J. V. Hazelwood		2½	J	115	2	Nj	4			61	Used to supply minnow pond.
5	1½ miles northeast of Diascund.		do	1943	3	J	129	2	Nj	6	D			Sand, 0–92 feet; shells, 92–97 feet; sand and rock, 92–129 feet.
6	do	W. H. Hicks	do	1913	4½	J	128	2	Nj	3	D,S	4	61	Reported flowed 10 feet above sea level in 1913. See analysis, table 23.
7	1¼ miles northwest of Diascund.	Fishing Club	do		4	J	115	2	Nj	5	D		61	
8	do	Cabin	do		3	J	117	2	Nj	5	D		61	
9	1¼ miles west of Diascund.	"Tall Trees" Cabin	do		3½	J	138	2	Nj	6	D		61	
10	1 mile west of Diascund.	Cabin	do		3	J	130	2	Nj	2	D	11	61½	Static water level is 5.3 feet above sea level or 2.3 feet above top of casing.
11	2¼ miles southwest of Diascund.	J. L. Walls			6	J	216	2	M	2	D			See analysis, table 23.
12	do	Walter Martin	T. P. Binns	1910	3	J	235	2	M	2	D			Reportedly flowed out of extended casing 20 feet above high tide in 1940.
13	5 miles south of Diascund.	Menzel Brothers			7	J	117		Nj	10	D	4		See analysis, table 23.
14	do	W. C. Richardson	T. P. Binns	1920	1	J	126	2	Nj	12	Ab		61	Static level is 5.8 feet above sea level or 2.1 feet above top of casing.

See footnotes at end of table.

TABLE 21.—*Records of wells in James City County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Water-bearing formation	Approximate yields (gallons per minute)	Use of water	Chloride content (parts per million)	Temperature (°F.)	Remarks
15	5 miles south of Diascund.	W. C. Richardson	T. P. Binns	1920	11(?)	J	126	2	Nj		D,S			
16	East end of the Chickahominy River bridge.	J. Hofmeyer	do	1938	2	J	125	2	Nj	2½	D		61¼	Will stop flowing on very low tide. Flow 6 gpm during high tide.
17	¼ mile south of the Chickahominy River bridge.	G. T. Brooks	do	1939	2	J	105	2	Nj	4	D	36	60¾	See analysis, table 23.
18	2½ miles west of Warburton Pond.	G. W. Minor	do	1920	2	J	212	2	M	2	D,S		62½	Static level 4.5 feet above sea level in 1943. Level reported 10 feet above sea level in 1920.
19	Warburton Pond	Walter Mercer	do	1915	3	J	130	2	Nj	½	Ab			Originally flowed 7 gpm.
20	1 mile southeast of Warburton Pond.	J. Richardson		1900(?)	79	Dg	30		Co		D,S			
23	3½ miles northwest of Jamestown.	R. H. Jones	T. P. Binns	1939	3½	J	156	2	Nj	6	D	60½		
24	do	do	do	1939	3	J	186	2	Nj(?)	¼	D			
25	do	do	do	1939	3	J	186	2	Nj	¼	D			
26	2½ miles north-northwest of Jamestown.	4-H Camp	O. C. Brenneman	1946	10	J	275	4-2½	M	[a] 37	D			See log, table 22.
27a	2 miles northwest of Jamestown.	R. B. Watts	F. Carman	1906	33	J	320	3	M	[a] ¼	Ab			Chas. Babcock well of Va. Geological Survey Bull. 5, p. 199, 310. See log, table 22.
27b	do	do	Mitchell's Well & Pump Co.	1941	33	Dr	376	6	M		D,S	12		Water level 12 feet below surface 1942. See analysis, table 23.
28	1½ miles northwest of Jamestown.	4-H Club	O. C. Brenneman	1935	4	J	280	2	M	5	D	13	64½	Water from quartz sand. See analysis, table 23.
29	Jamestown	Assoc. Preservation Va. Antiquities.	Sydnor Pump & Well Co., Inc.	1906	5	Dr	267	6	M	[a] 25	Ab	57		Chloride 57 ppm, according to Sanford.
30	do	Raymond Riordan School.	do	1930	5		300		M	[a] 100	Ab	30		See analysis, table 23.
31	½ mile north of Jamestown Island.	G. L. Burleson	C. B. Chapman	1906	15	Dr	310	3	M	[b] 90				Water level 33 feet above sea level in 1918.
32	2½ miles northeast of Jamestown.	Max Rieg	Sydnor Pump & Well Co., Inc.	1940		Dr					D			
33	¾ mile north of Jamestown Island.	L. W. Lane	M. S. Jewett	1915	15	Dr	310		M	[a] 90	D	9.6 7		See analyses, table 23. Water level 33 feet above sea level in 1918.

														First analysis for 1918; second analysis for 1941.
34	2¼ miles north of Jamestown Island.	Frank Ayres		1910(?)	15		312	3	M	[a] 79	D	13.5 14		Water level 45 feet above sea level in 1918. See analyses, table 23. First analysis for 1910; second analysis for 1941.
35	2½ miles east of Jamestown.	W. S. Battle		1904	9	Dr	346(?)		M	[a] 10	D,S			
36	½ mile south of Kings Millpond.	Mr. Pough	M. S. Jewett	1912		Dr	400	3	M	[b] 60	D			
37	1½ miles south-southwest of Grove.	E. C. Albert	Sydnor Pump & Well Co., Inc.	1919		Dr	460	10	M	[b] 150	M			Camp Wallace of World War I. Water level reported 46 feet above sea level.
38	1½ miles south-southwest of Grove.	do	do	1919		Dr		10	M					
40		Raymond Piland	Mitchell's Well & Pump Co.	1940	50	Dr	354	8-6	M	[b] 30	M			
41	Williamsburg	Toppings Tourists	do	1938	80	Dr	317		Nj(?)		T			
42	do	Fort McGruder Heights.	do	1940	90	Dr	435	8	M	[ac] 40	M			Water level 81 feet below surface. Well has #20-slot screen.
43	do	Eastern State Hospital.	Sydnor Pump & Well Co., Inc.	1903	80+	Dr	280	8	Cv(?)	[ac] 80	Ab	107		Water level 80 feet below surface. Drawdown 50 feet pumping at 80 gpm. See analysis, table 23.
44	do	do	do	1912	60	Dr	310	3	Ck(?)	[ac] 75	Ab			Water level 30 feet in 1912. This well was originally 876 feet deep but was later opened at 310 feet.
45	do	do	do	1924	60	Dr	417	10-8	M	[ac] 525	M	255		Water level 37 feet. Well has 40 feet of strainer. See analysis, table 23.
46	do	William and Mary College.	do	1910(?)	60	Dr	290	6	Ck(?)	[ac] 60	Ab			Water level 50 feet in 1910(?).
47	do	do	do	1924	60(?)	Dr	412	10-8	M	[c] 200	M	225		Water level 60 feet in 1924. Well has 40 feet of strainer. See analysis, table 23.
48	do	Goodwin Memorial Well No. 1.	do	1935		Dr	438	8	M					Fine (?) sand reached at 397 feet, medium sand at 411 feet, and coarse sand at 427 feet.
49	do	Laundry	do	1936			416	10	M	[ac] 260	I			Water level 69 feet below surface. Pumps about 25,000 gpd. Drawdown 81 feet.

See footnotes at end of table.

TABLE 21.—*Records of wells in James City County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Water-bearing formation	Approximate yields (gallons per minute)	Use of water	Chloride content (parts per million)	Temperature (°F.)	Remarks
50	Williamsburg	G. Vaiden	Sydnor Pump & Well Co., Inc.	1900	60		280		Nj(?)	[a,c] 150	Ab	149		Data from Va. Geol. Survey Bull. 5. Located in back of Governors Palace. See analysis, table 23.
51	½ mile west of Williamsburg.	Varolyn Tourist Court.	Mitchell's Well & Pump Co.	1940	90	Dr	348	4¼	Ck	[a,c] 8½	T	185		Drawdown 18 feet at yield stated. Water level 102 feet below surface. See analysis, table 23.
52	½ mile northwest of Williamsburg.	Open Air Theatre	do	1941	90	Dr	68	6	Y	[a,c] 7½	D	5		Drawdown 29 feet pumping at 7½ gpm. Water level 31 feet below surface.
53	1 mile northwest of Williamsburg.	Williamsburg Tourist Court.	O. C. Brenneman	1944	94	J	310	4	Cv		I	7		See analysis, table 23. Water level 90 feet below surface.
54	Mouth of Taskimas Creek.	Fritz Keck	W. S. Reynolds	1930		J	351	35	M	[a] 35	S,D			Water level 85 feet. Well has 15 feet of #20-slot strainer.
56	Dunbar Farm	Eastern State Hospital.	Virginia Machinery & Well Co., Inc.	1937	60(?)	Dr	670	8–6	M	[a,c] 275	D			Water level 52 feet below surface. Drawdown 40 feet after pumping 275 gpm for 24 hours.
57	Norge	Roseland Farm	Mitchell's Well & Pump Co.	1940	110	Dr	350	4½	Nj(?)	[a,c] 12	D	3		Water level 105 feet. Drawdown 15 feet pumping at 12 gpm. See log, table 22, and analysis, table 23.
58	do	Chesapeake and Ohio Railroad.	Sydnor Pump & Well Co., Inc.	1909	120	Dr	418	10–8	M	[a,c] 110	Ab	176		Water unfit for locomotive boilers. See analysis, table 23.
59	do	do	Virginia Machinery & Well Co., Inc.	1944	100	Dr	88	6	Y	[a,c] 25	D	3		See analysis, table 23.
60	Toano	Cannery	O. C. Brenneman	1947	100	J	228		Cv		I			
61	do	Town			100	Dg	50		Co		M	20		Water is hard. Nitrate is 14 ppm. See analysis, table 23.

[a] Yield at time well was constructed.
[b] Yield in 1918.
[c] Yield by pumping.

TABLE 22.—*Logs of wells in James City County, Va.*

Well 26, Jamestown; 4-H Club

[Log from samples supplied by O. C. Brenneman. Altitude, 10 feet. See log of well 27a, table 22]

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Marl, gray, silty, contains shells	110	110
Marl, fine, gray, sandy	35	145
Chickahominy formation(?) (Eocene):		
Limestone	5	150
Marl, fine, gray, sandy; Foraminifera	20	170
Marl, slightly glauconitic	20	190
Undifferentiated:		
Marl, black, glauconitic	83	273
Sand, white	2	275

TABLE 22.—*Logs of wells in James City County, Va.*—Continued

Well 27a, Jamestown; R. B. Watts

[Log from Va. Geol. Survey Bull. 5. Altitude, 33 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil and red clay	6	6
Sand, reddish; water	10	16
Sand, white, and small gravel; water	39	55
Chesapeake group (Miocene):		
Marl, dark-green, sandy	45	100
Sand, gray	10	110
Marl, contains shells	30	140
Sand, gray; trace of glauconite	10	150
Clay, light-colored	13	163
Chickahominy formation (Eocene):		
Sand, very hard, gray; water under low head	16½	179½
Sand, coarse, gray	2½	182
Quartz, coarse and glauconitic sand; water under low head; Foraminifera	44	226
Nanjemoy formation (Eocene): Mud, blue	25	251
Mattaponi formations (Upper Cretaceous and Paleocene):		
Sand, coarse, black, glauconitic; water	29	280
Sand and shell	9	289
Rock, sand	21	310
Sand, gravelly; water	10	320

Well 51, Williamsburg; Carolyn Tourist Court

[Log by Mitchell's Well & Pump Co. Altitude, 90 feet]

	Thickness (feet)	Depth (feet)
Columbia and Chesapeake groups (Pleistocene and Miocene): Dirt, mud	229	229
Chesapeake group (Miocene): Mud, blue	68	297
Chickahominy formation (Eocene):		
Rock, soft	8	307
Mud, hard, blue, and black sand	41	348

TABLE 22.—*Logs of wells in James City County, Va.*—Continued

Well 53, Williamsburg; Williamsburg Tourist Court

[Log by Sydnor Pump & Well Co., Inc. Altitude, 94 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	35	35
Chesapeake group (Miocene):		
Sand and shells	10	45
Clay, gray	20	65
Sand, hard, and gravel	18	83
Clay, green, sandy	10	93
Clay, greenish, sandy	57	150
Clay, gray	28	178
Clay, green	32	210
Clay, green, and shells	37	247
Sand, clayey	13	260
Clay, hard, sandy	8	268
Chickahominy formation (Eocene):		
Sand, hard, and shells; water	10	278
Sand, coarse, and shells, with some black sand; water	4	282
Sand, black, sticky, and clay	23	305
Nanjemoy formation (Eocene): Sand, black	5	310

Well No. 56, Williamsburg; Dunbar Farm

[Log by Virginia Machinery & Well Co. Inc., Altitude, 60 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, red	40	40
Chesapeake group (Miocene):		
Marl, chocolate-brown	20	60
Marl, blue	40	100
Clay, blue, tough	100	200
Soft running formation (silt?)	20	220
Clay, blue	8	228
Chickahominy and Nanjemoy formations (Eocene):		
Rock, with shells	11	239
Clay, blue; with some sand	11	250
Clay, black, sandy	40	290
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, very tough, blue	30	320
Clay, very tough, chocolate-brown	20	340
Clay, black, sandy	10	350
Sand, gray, clayey	25	375
Clay, tough, white	25	400
Clay, dark-brown, very tough	55	455
Clay, light-colored, sandy	24	479
Clay, blue, sandy	41	520
Soft caving material	1	521
Clay, hard, tough	12	533
Clay, slightly sandy, blue	20	555

TABLE 22.—*Logs of wells in James City County, Va.*—Continued

Well No. 56, Williamsburg; Dunbar Farm—Continued

	Thickness (feet)	Depth (feet)
Mattaponi formation (Upper Cretaceous and Paleocene)—Con.		
Clay, hard, white	10	565
Clay, hard, tough, blue	13	578
Sand; water	2	580
Clay, hard, tough, chocolate-brown	20	600
Clay, sandy, white	8	608
Sand; water	10	618
Clay, sandy, white	10	628
Sand	4	632
Clay, sandy, white	28	660
Clay, hard, tough, blue, chocolate-brown	10	670

Well 57, Norge, Roseland Farm

[Log by Mitchell's Well & Pump Co. Altitude, 110 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, red, sandy	40	40
Chesapeake group (Miocene):		
Sand, yellow, clayey	30	70
Sand, white, clayey	10	80
Sand and shells	15	95
Sand(?), green	135	230
Nanjemoy(?) formation (Eocene):		
Sand and shells	5	235
Sand; water	28	263
Mud	8	271
Rock, white	14	285
Marl, black, contains shells	40	325
Mud, blue	25	350

TABLE 23.—*Chemical analyses of waters from wells in James City County, Va.*

[Analyses in parts per million. Analyst: EWL, E. W. Lohr; MDF, M. D. Foster; LWM, L. W. Miller; ATG, A. T. Geiger; WHT, W. H. Taylor; K, Keystone Chemical Co.; GWW, G. W. Whetstone; F & R, Froehling and Robertson]

	Well no.					
	6	11	13	17	27b	28
Location	Diascund	Diascund	Shipyard Landing	Barretts Ferry	Jamestown	Jamestown
Depth (feet)	128	216	117	105	376	280
Formation or group	Nanjemoy formation	Mattaponi formation	Nanjemoy formation	Nanjemoy formation	Mattaponi formation	Mattaponi formation
Date	Oct. 27, 1943	Feb. 10, 1941	Feb. 7, 1941	Nov. 6, 1943	Dec. 19, 1942	Nov. 6, 1943
Silica (SiO_4)						
Iron (Fe)						
Calcium (Ca)						
Magnesium (Mg)						
Sodium (Na)						
Potassium (K)						
Bicarbonate (HCO_3)	370	366	145	265	302	346
Sulfate (SO_4)	5	15	7	8	5	6
Chloride (Cl)	4	11	4	36	12	13
Fluoride (Fl)	.6	1.7	.2	1.3	4.4	3.2
Nitrate (NO_3)	.0		.0	.0		.0
Dissolved solids						
Hardness (as $CaCO_3$)	60	21	78	21	7.5	6.0
Analyst	EWL	MDF, LWM	MDF, LWM	EWL	EWL	EWL

	Well no.					
	29	30	33	33	34	43
Location	Jamestown	Jamestown	Jamestown	Jamestown	Jamestown	Williamsburg
Depth (feet)	267	300	310	310	312	280
Formation or group	Mattaponi formation	Mattaponi formation	Mattaponi formation	Mattaponi formation	Mattaponi formation	Calvert(?) formation
Date	1906	Mar. 29, 1941	Oct. 18, 1918	Feb. 6, 1941	Feb. 6, 1941	
Silica (SiO_4)						28
Iron (Fe)			0.10			trace
Calcium (Ca)			4.2			8.0
Magnesium (Mg)			6.6			4.3
Sodium (Na)						17
Potassium (K)			149			191
Bicarbonate (HCO_3)	308	319	384	328	341	382
Sulfate (SO_4)		4	7.6	3	4	10
Chloride (Cl)	57	3	9.6	7	14	107
Fluoride (Fl)		3.0		3.6	3.4	
Nitrate (NO_3)			.39			
Dissolved solids			488			553
Hardness (as $CaCO_3$)	3.8	12	38	6	9	38
Analyst		MDF, LWM	ATG	MDF, LWM	MDF, LWM	WHT

TABLE 23.—*Chemical analyses of waters from wells in James City County, Va.*—Con.

	Well no.				
	45	47	50	51	52
Location	Williamsburg	Williamsburg	Williamsburg	Williamsburg	Williamsburg
Depth (feet)	417	412	280	348	68
Formation or group	Mattaponi formation	Mattaponi formation	Nanjemoy(?) formation	Chickahominy formation	Yorktown formation
Date	Feb. 7, 1941	Feb. 7, 1941	1910?	June 15, 1946	June 15, 1946
Silica (SiO_2)	----	----	----	27	18
Iron (Fe)	----	----	----	.08	.12
Calcium (Ca)	----	----	12	10	34
Magnesium (Mg)	----	----	3.7	5.3	.9
Sodium (Na)	----	----	131	239	3.6
Potassium (K)	----	----	----		
Bicarbonate (HCO_3)	434	431	402	336	96
Sulfate (SO_4)	27	23	21	25	10
Chloride (Cl)	255	225	149	185	5.0
Fluoride (Fl)	2.1	2.2	----	1.2	.1
Nitrate (NO_3)	----	----	----	1.0	.1
Dissolved solids	----	----	662	663	122
Hardness (as $CaCO_3$)	15	12	60	47	88
Analyst	MDF, LWM	MDF, LWM	K	GWW	GWW

	Well no.				
	53	57	58	59	61
Location	Williamsburg	Norge	Norge	Norge	Toano
Depth (feet)	310	350	418	88	50
Formation or group	Nanjemoy formation	Nanjemoy(?) formation	Mattaponi formation	Yorktown formation	Columbia group
Date	Nov. 20, 1946	June 15, 1946	1910(?)	June 15, 1946	Nov. 6, 1947
Silica (SiO_2)	----	48	40	11	10
Iron (Fe)	0.06	.08	6	8.1	.03
Calcium (Ca)	----	20	11	32	83
Magnesium (Mg)	----	3.7	3.1	.8	3.9
Sodium (Na)	37	37	252	3.7	14
Potassium (K)					
Bicarbonate (HCO_3)	268	160	365	93	246
Sulfate (SO_4)	8	7.1	39	9.9	12
Chloride (Cl)	7	3.4	176	3.1	20
Fluoride (F)	1.2	.4	----	.1	.0
Nitrate (NO_3)	.6	.2	----	.1	14
Dissolved solids	----	198	718	108	264
Hardness (as $CaCO_3$)	21	65	40	83	223
Analyst	GWW	GWW	F & R	GWW	GWW

YORK COUNTY

York County lies along the south bank of the York River and extends from a point 3 miles east of Norge to a point 8 miles north of Fort Monroe, a distance of about 30 miles. It has an area of 123 square miles and a population of 11,750. Yorktown is the largest town, with a population of 384 (Virginia Division of Planning and Economic Development, 1951).

Farming, lumbering, and fishing are carried on to some extent. The value added by manufactured products, to largely seafood and basic lumber products, in 1947, was $498,000. Value of farm products—field crops, dairy, vegetable, and poultry products—was $287,550 in 1949. A large part of the population is employed in or is indirectly dependent upon the naval and military establishments, the Yorktown Colonial National Historical Park, and businesses catering to the tourist trade. In addition, many residents of the county make their living in Newport News and adjacent urban areas.

Camp Peary, at Magruder, was built in 1942 for the training of naval construction battalions (Seabees) but was later used as a training camp for seamen. The camp was decommissioned in 1946. The Naval Mine Depot and a naval officers training school are at Yorktown; the Penniman Fuel Depot is located at Penniman, partly on the site of the E. I. du Pont de Nemours Co. powder plant that was erected during World War I and subsequently abandoned. Camp Patrick Henry, a staging camp during World War II, is located near Oriana.

The county is served by excellent highways. The Chesapeake and Ohio Railroad, connecting Newport News and Richmond, passes through nearby James City County. Spurs connect Camp Peary, Penniman, and the Naval Mine Depot with the main line.

TOPOGRAPHY

The upper part of York County is rolling country, the maximum altitude is between 80 and 100 feet above sea level. The Wicomico terrace which underlies much of this area is strongly dissected by tributaries to the York River, and the high flat terrace remnants are of limited extent. South of Yorktown the topography changes rather abrupty and the ground is low and flat. A 50-foot (Talbot) terrace has a limited extent at Grafton (5 miles southeast of Yorktown) but the somewhat lower Pamlico terrace, descending gradually from 25 to 10 feet or so, makes up the southeastern part of the county. This terrace also has a limited extent upstream along the York River near Yorktown and Camp Peary.

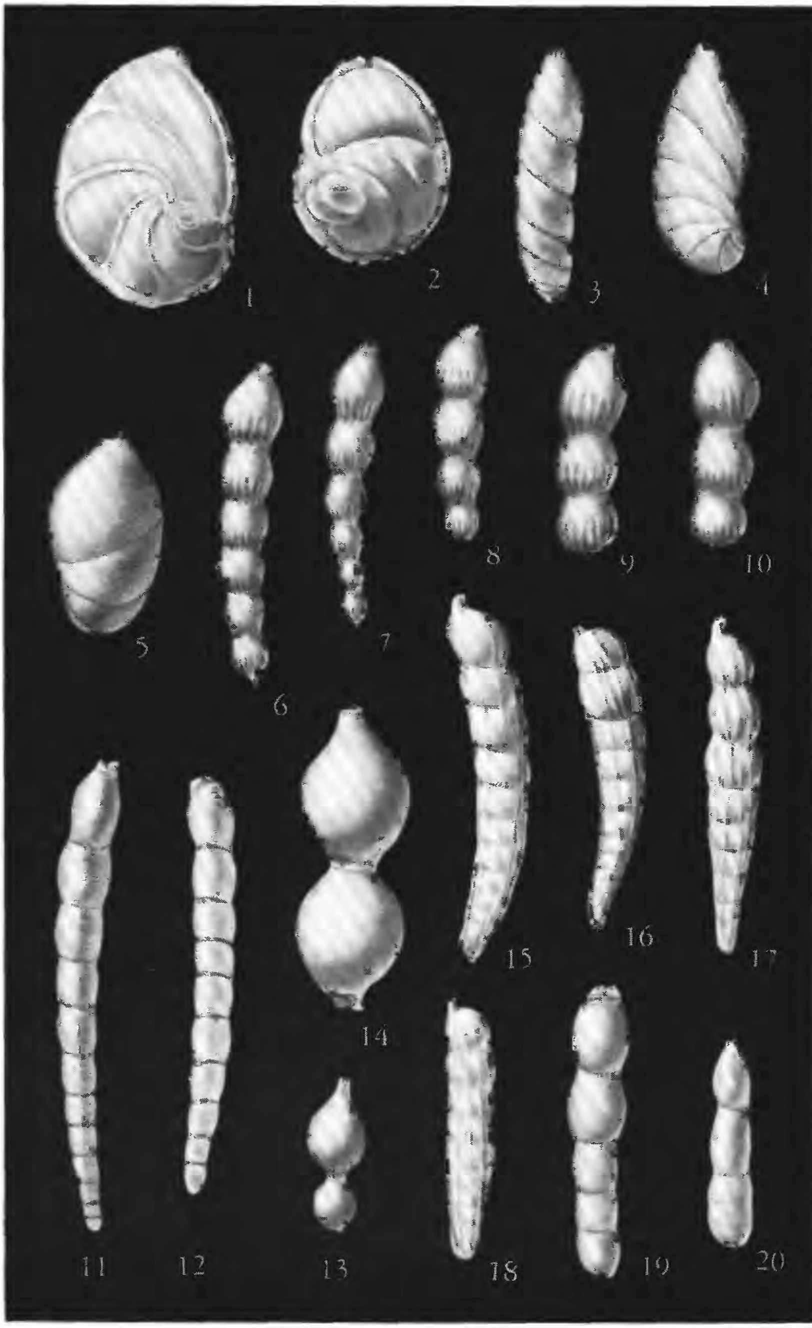
GEOLOGY

BEDROCK

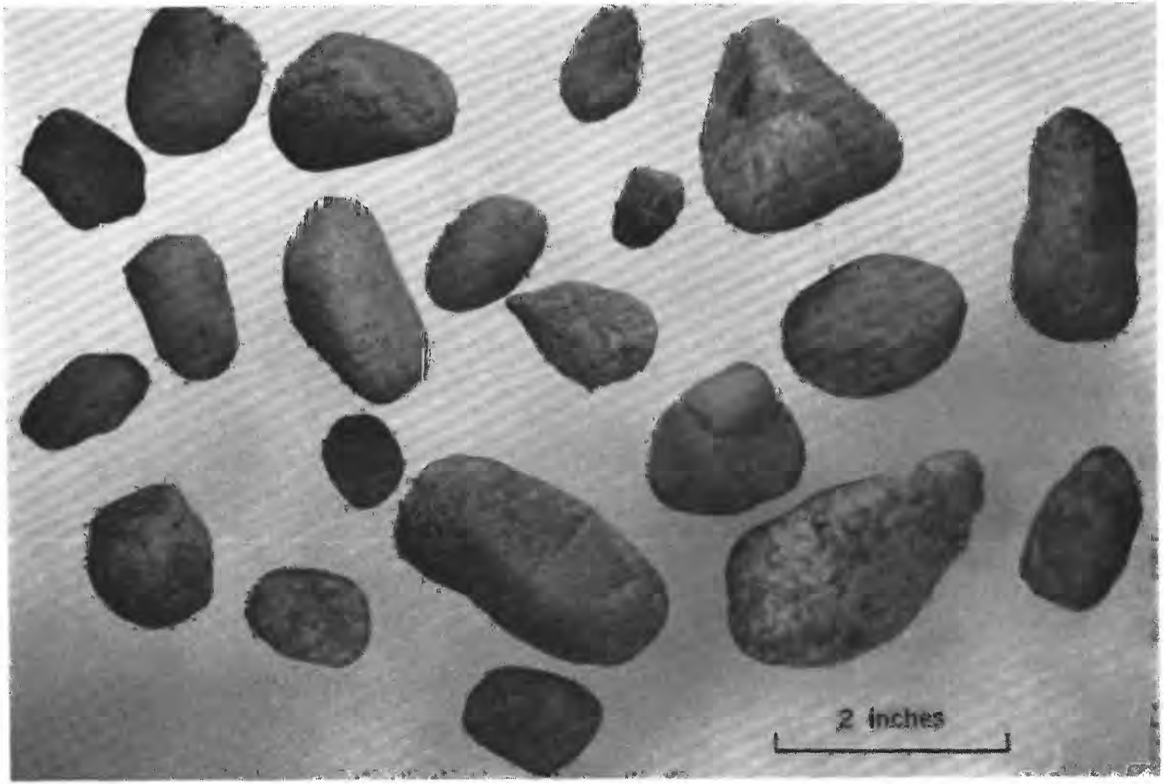
Depth to bedrock is unknown in York County, but from well data and from geophysical soundings made in adjacent areas it is apparent that bedrock may lie at about 1,000 feet below sea level in the upper part of the county and at 2,000 feet in the lower part.

CRETACEOUS SYSTEM—POTOMAC GROUP

Sediments of the Potomac group which rest upon granitic bedrock have not been reached by deep wells in York County.



TYPICAL FORAMINIFERA FROM THE CHICKAHOMINY FORMATION
(After Va. Geol. Survey Bull. 67, plate 2.)



COARSE WATER-BEARING GRAVEL FROM DEEP WELL AT CAMP PEARY

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

Foraminifera of the Mattaponi formation were recognized in cuttings from wells 7 and 10 at Camp Peary about 50 feet above the top of the first prominent water-bearing sand. (See log of well 7, table 28.) The Foraminifera here appear to have a Paleocene aspect, which is not unexpected as only the uppermost part of the formation, presumablyas much as 400 feet thick, was penetrated.

The Mattaponi section penetrated at Camp Peary consists of highly glauconitic marl, gray clay, and water-bearing sand. The bright grass-green clay containing glauconite sand logged in wells 7 and 13 (pl. 6; figs. 14, 15) is of special interest—it is identical in appearance to the green clay strata found at Washingtons Birthplace. (See p. 18.) At Washingtons Birthplace, one such stratum is assigned to the base of the Eocene and the succeeding stratum is assigned to the uppermost part of the Mattaponi formation, as at Camp Peary. In no other localities in the Virginia Coastal Plain have beds of this peculiar appearance been noted by the writer, although perhaps these beds are present at Penniman (24, table 28).

The mottled clays characteristic of the lower part of the Mattaponi section seem to be represented in well 22 (table 28; fig. 16), near Williamsburg, by red and brown "muds."

TERTIARY SYSTEM

EOCENE SERIES

Deposits of Eocene age are reached by wells at Yorktown, Penniman, and Camp Peary. They are reached at 200 feet below sea level at Camp Peary and at 300 feet below sea level at Yorktown (fig. 16). At Camp Peary they consist of highly glauconitic sands ("black sands" of the driller), dark-colored glauconitic clays, and faintly mottled red and gray clays and thin limestone strata and nondescript gray clays (7, 13, 20, table 28; pl. 6). The strata are assigned to the Chickahominy formation of late Eocene (Jackson) age (Cushman and Cederstrom, 1945) and the Nanjemoy formation of early and middle Eocene age.

Nanjemoy Formation

The Nanjemoy formation, the higher part of the Pamunkey group, does not have the typical sandy character of the beds in the vicinity of West Point but it is thought that certain sandy marls and gray clays at Camp Peary should be assigned to this formation. (See wells 7 and 13, table 28.) Typical Nanjemoy Foraminifera were not recognized in cuttings from wells at Yorktown.

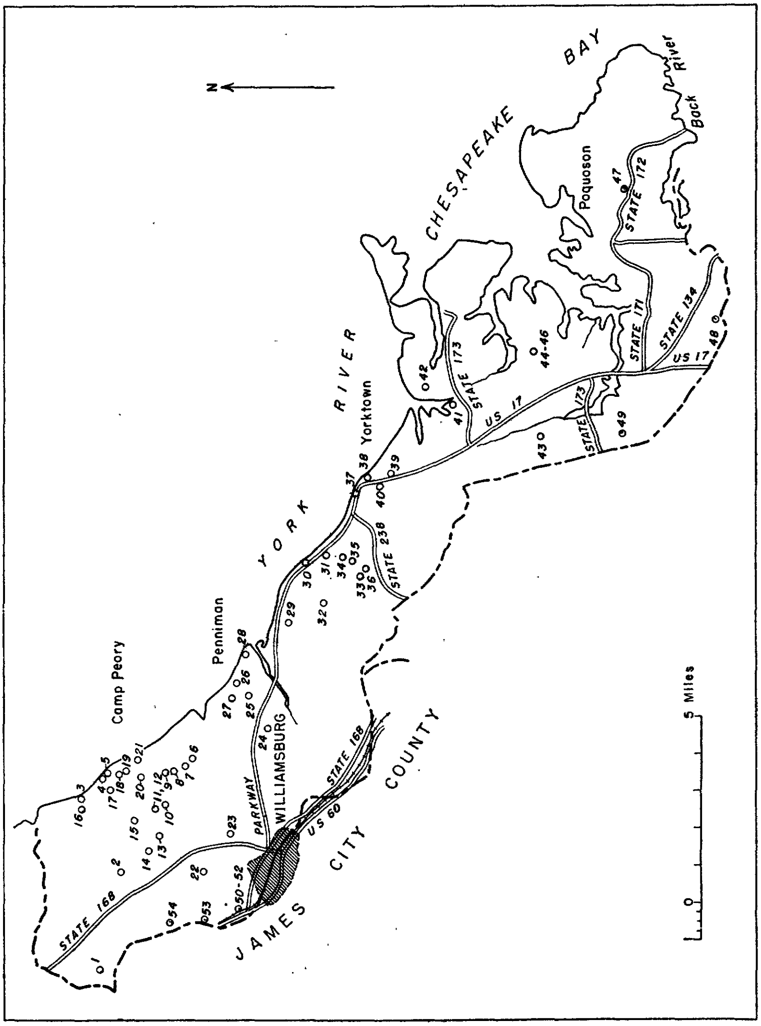


FIGURE 14.—Location of wells in York County.

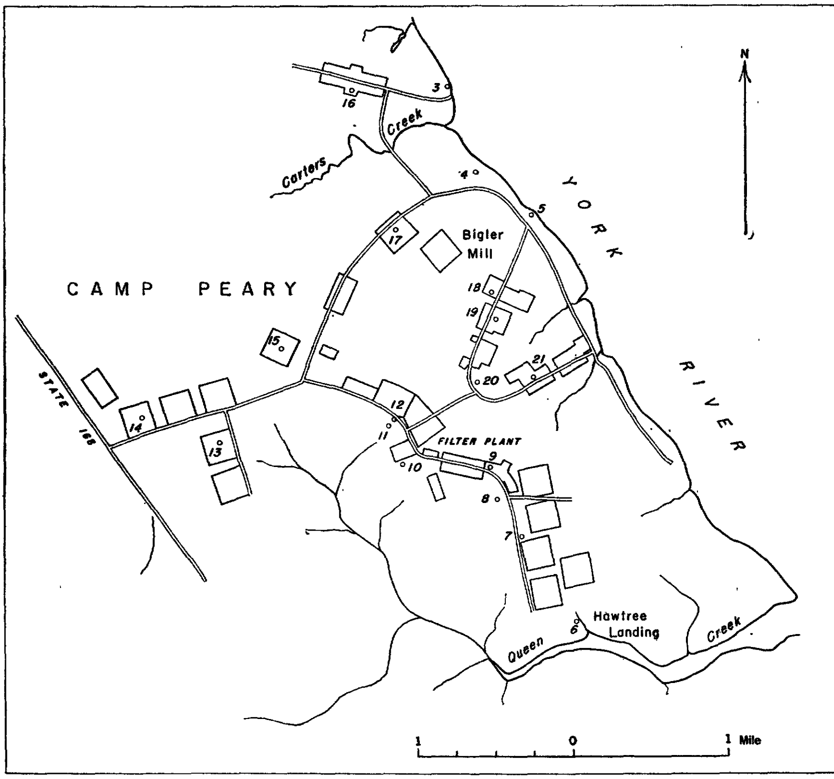


FIGURE 15.—Location of wells at Camp Peary. (Numbers refers to wells listed in table 27.)

Chickahominy Formation

The type locality of the Chickahominy formation (Cushman and Cederstrom, 1945) is Yorktown (35, table 28), at which place the beds are 80 feet thick and consist of highly foraminiferal gray clay beds containing subordinate glauconite and pyrite (pls. 7, 8). These beds are about 35 feet thick at Camp Peary and of the same general character, although in well 7 the beds were more sandy than clayey. The formation probably lenses out in uppermost York County as Chickahominy units are absent in New Kent and King William Counties.

MIOCENE SERIES

Marly beds of the Chesapeake group of formations of Miocene age overlie the Eocene series. The uppermost beds, which make up the Yorktown formation, are exposed in many road cuts and were so named (Clark and Miller, 1906) because of the particularly fine exposures of these strata at Yorktown. The Yorktown deposits have been described in detail in other literature (Clark and Miller, 1912, p. 158; Roberts, 1932, p. 20–23).

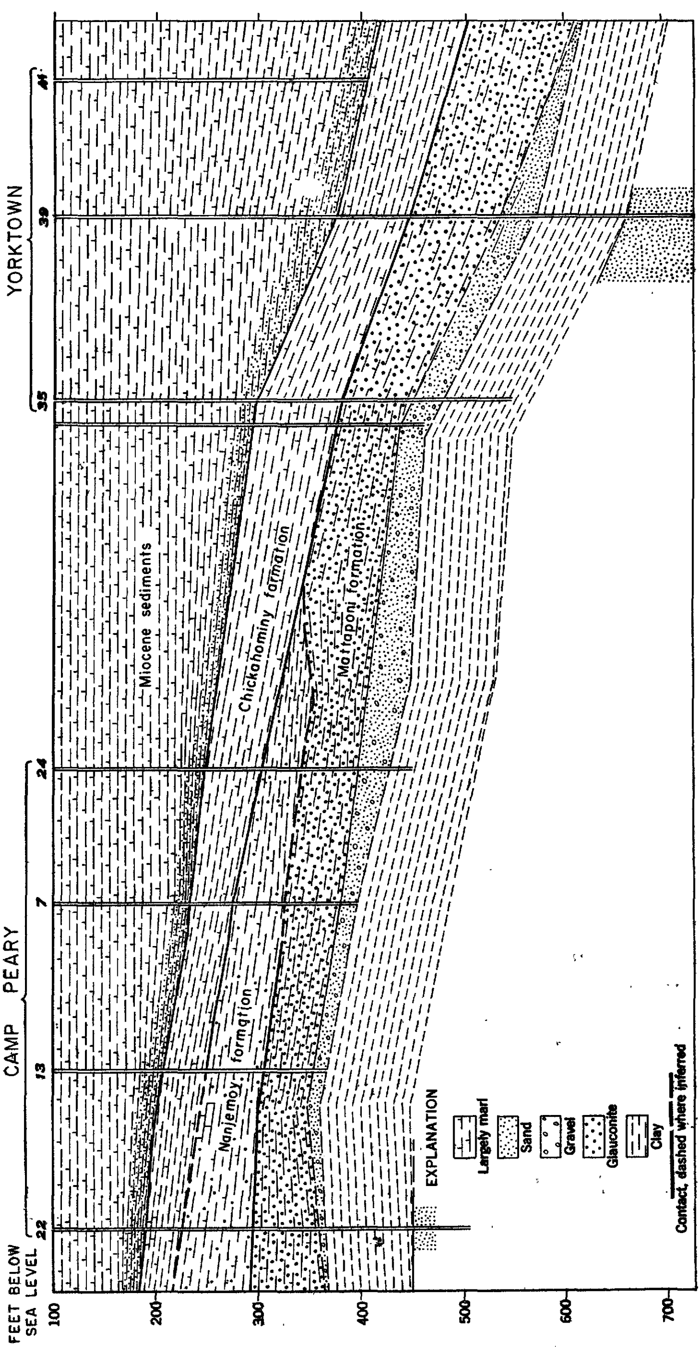


FIGURE 16.—Geologic cross section through wells, upper York County.

The St. Marys and Calvert formations of the Chesapeake group are known from the logs of deep wells at Camp Peary and Yorktown. The Calvert formation is a sandy shell marl (Clark and Miller, 1912, p. 126) that in places is sufficiently permeable to yield small supplies of water to wells. The St. Marys formation is a dark-colored impermeable clay. The Yorktown formation is a shell marl (Clark and Miller, 1912, p. 161–162) containing beds of permeable sands that yield small supplies of water to shallow wells and springs.

Marked changes in foraminiferal content occur at 130 and 270 feet at the Yorktown Naval Mine Depot (35, table 28). These changes may mark the boundaries of the formations of Miocene age. According to such an interpretation (fig. 16), the basal Calvert formation appears to be about 100 feet thick, the St. Marys formation about 140 feet thick, and the uppermost Yorktown formation about 100 feet thick. At the Naval Mine Warfare School (41) the basal Calvert, which appears to thicken to 130 feet, contains a sand member not present at the Naval Mine Depot. At Camp Peary the Yorktown formation appears to be about as thick as at the Naval Mine Depot, but the St. Marys is slightly thinner and the Calvert is about half as thick.

The lower 30 feet of the Calvert formation at the Naval Mine Depot (35) contains in abundance undescribed species of *Uvigerina* (J. S. Cushman, written communication) that have an Eocene rather than a Miocene aspect. However, as a marked lithologic break occurs below these beds and no break is apparent at their upper boundary, they are included with the Calvert in this report.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The Columbia group of Pleistocene age (terrace deposits) lies above the older formations. In the upper part of the county these deposits consist of yellow sand and clay, but in the vicinity of Chesapeake Bay the low terraces are made up of gray marl and fine-grained gray quartz sand. The terrace deposits are generally less than 30 feet thick. They yield meager supplies of water to dug and driven wells.

MUNICIPAL SUPPLIES

The town of Williamsburg (James City County) formerly was served by two deep wells (45, 47, table 21) but since 1946 has used water from Waller Pond in York County. The filtering plant is near the pond; one elevated tank has been erected at the filter plant and a booster pump and elevated tank are located in the town.

Camp Peary was supplied for a short time with ground water from 12 wells in the camp area but upon completion of Waller Pond dam in

1943 a surface-water supply was used. The filter plant is located within the camp.

At Penniman Fuel Depot, well water (25, table 27) is used to some extent but water from surface streams is also used.

At Yorktown Naval Mine Depot three deep wells (32, 34, 37) were in more or less constant use, a spring supply was used constantly, and a small filter plant on a nearby pond also furnished water to the station. The officers training school used water from a spring but depended on deep-well water (41) in periods of heavy demand.

The town of Yorktown has been served by spring and well (39) water. During periods of normal flow the spring is sufficient to supply the park and town areas but during periods of drought, or semidrought, the well water supply also may be drawn upon.

In all these places very large quantities of water are available from deep wells, but the water is more or less mineralized (pl. 4*A*) and is somewhat objectionable to the taste. The deep-well water is particularly unsuitable for boiler use because it foams greatly and is highly corrosive when hot.

WATER-BEARING FORMATIONS

CRETACEOUS TO TERTIARY SYSTEMS—MATTAPONI FORMATION

The Mattaponi formation yields water to many wells in York County; practically all the wells at Camp Peary and Penniman and several wells at Yorktown that are drilled in the upper part of this formation.

Wells 35 and 39 (see log, table 28) were drilled through an appreciable thickness of the Mattaponi formation at Yorktown. These logs show that the formation is sandy and water bearing but there is no suggestion of the mottled colors that characterize the clay in this formation at West Point. However, well 22 at Waller Pond reached highly colored sediments characteristic of the formation in other areas.

Foraminifera characteristic of the Mattaponi formation were recognized in cuttings from well 35 at Yorktown and from several wells at Camp Peary.

All the wells at Camp Peary and Penniman obtain water from a sand bed occurring in the Mattaponi formation about 75 feet below the base of the Chickahominy formation (fig. 16). At Camp Peary this sand lies 320 to 360 feet below sea level, at Penniman about 400 feet above sea level, and at Yorktown 430 to 445 feet below sea level. It ranges from gravel to fine sand with alternating clay streaks; wells near the York River at both Camp Peary and Penniman were much more gravelly than those southwest of the river (pl. 9).

This sand stratum is now known to be discontinuous; it was tapped by wells 32 and 34 at the Naval Mine Depot but when the area between these wells (35, 36) was explored to provide additional water in 1942, no water-bearing sand was found. Water was finally obtained from well 37, near well 34, but at the former site the sand was much finer than at the site of well 34 and considerable difficulty was experienced in development. Fine sand continued to enter the well after initial pumping, and it was twice found necessary to remove the pump and bail out sand lodging in the strainer before the well was put into use. During this process the yield increased greatly.

This sand stratum was not present in well 39, drilled by the Park Service at Yorktown, and was also absent in well 22 at Waller Pond (fig. 16).

YIELDS

The water-bearing stratum at Camp Peary is apparently the same stratum tapped by the municipal well (31, table 12; pl. 1, section A–A′) at West Point. However, the thick permeable basal sands of the Mattaponi formation developed at the Chesapeake Co. mill at West Point (26a, 27a, table 12) have not been reached by wells in York County except perhaps well 39 at Yorktown.

At Camp Peary the specific capacity (yield in gallons per foot of drawdown) of 12 deep wells ranged from 2.7 to 15.6. The two poorest wells yielded only a little more than 200 gpm, whereas the more productive wells yielded from 300 to 710 gpm.

The yields varied according to the thickness and coarseness of the sand strata and, with cable-tool wells, according to the length and slot size of screen installed. In a few instances yields increased appreciably after several months' use as fine sand was removed from the water-bearing strata.

The highest yield, 15.6 gallons per foot of drawdown, was obtained from well 21 (Camp Peary B–3) where 19 feet of gravel and 10 feet of sand were developed. Well 16 (B–6), which tapped 30 feet of coarse gravel, had a specific capacity of 13. This well, although second in efficiency, delivered about 700 gpm, more than any other well at Camp Peary. Well 20 (B–1) was drilled through 40 feet of coarse to gravelly sand. It developed 12 gallons per foot of drawdown.

The lower-yield wells were developed on high ground away from the river, where finer sands were present. Well 15 (B–5), which tapped fine and clayey (?) sand, had a yield of only 2.7 gpm per foot of drawdown. Well 13 (D–6) had an identical specific capacity but the low yield is ascribed to mechanical difficulties rather than to a less-productive stratum. During construction the screen failed to seal properly, causing the collapse of the overlying clay stratum, and the effective sand area opposite the screen was greatly reduced.

A nearby well (14, Camp Peary D-5) that tapped a comparable thickness of gravelly sand yielded 7½ gallons per foot of drawdown.

A study of the data given in table 27 shows that wells utilizing an artificial gravel-pack type of construction were about as efficient as those without such a pack. Where the screens used in the "natural gravel-pack" (cable-tool) wells were not the full length or were not of the optimum slot size, yields were accordingly lower. Well 9 (D-4) undoubtedly would have had a greater yield than 5¾ gallons per foot of drawdown had a more suitable size of screen been used. In the haste to get wells into production at Camp Peary, immediate utilization of any available size and length of screen was regarded as expedient and only rarely was it possible to delay completion of a well in order to install exactly the right size and length of strainer.

Well 32 at Yorktown was drilled in 1918 and when tested in 1941 it yielded 28 gpm per foot of drawdown. Well 34, tapping a fairly coarse sand, yielded only about 4 gpm per foot of drawdown. The yield of this well may be limited by the inflow into the well area through fine sand stringers (the sand is fine or absent in three nearby localities) rather than by the mechanical factors inherent in the well itself.

The desirability of complete development for maximum efficiency was demonstrated when well 37 was being constructed. During the first pump test the yield was only about 80 gpm and much fine sand entered the well. The question arose as to the desirability of using a screen of smaller slot size to keep back the flow of sand; however, it was decided that the No. 30-slot screen would be retained and an effort would be made to draw enough fine sand through the screen to build up a stable gravel pack and increase the yield. Surging and bailing were continued for several days; the yield increased to about 200 gpm and the flow of fine sand ceased. Later a still greater yield was obtained by increasing the drawdown. Had this well been given only routine development, it might have been abandoned as having too low a yield to be of value.

WATER LEVELS AT CAMP PEARY

During the building of Camp Peary in 1941 a water-level observation program was set up before the supply wells were put into operation. The program was continued through the period of use of ground water in order to obtain adequate data concerning possible shortages in supply and correlation between marked lowerings of ground-water levels and possible increases or decreases of chloride.

Water levels of several wells 6, 8, 13, and 20 were measured, as shown in figure 17. Well 20 (B-1) was a producing well and well 6 was used to supply a sawmill with very small quantities of water. Wells 8 (T-2) and 13 (D-6) were not in use.

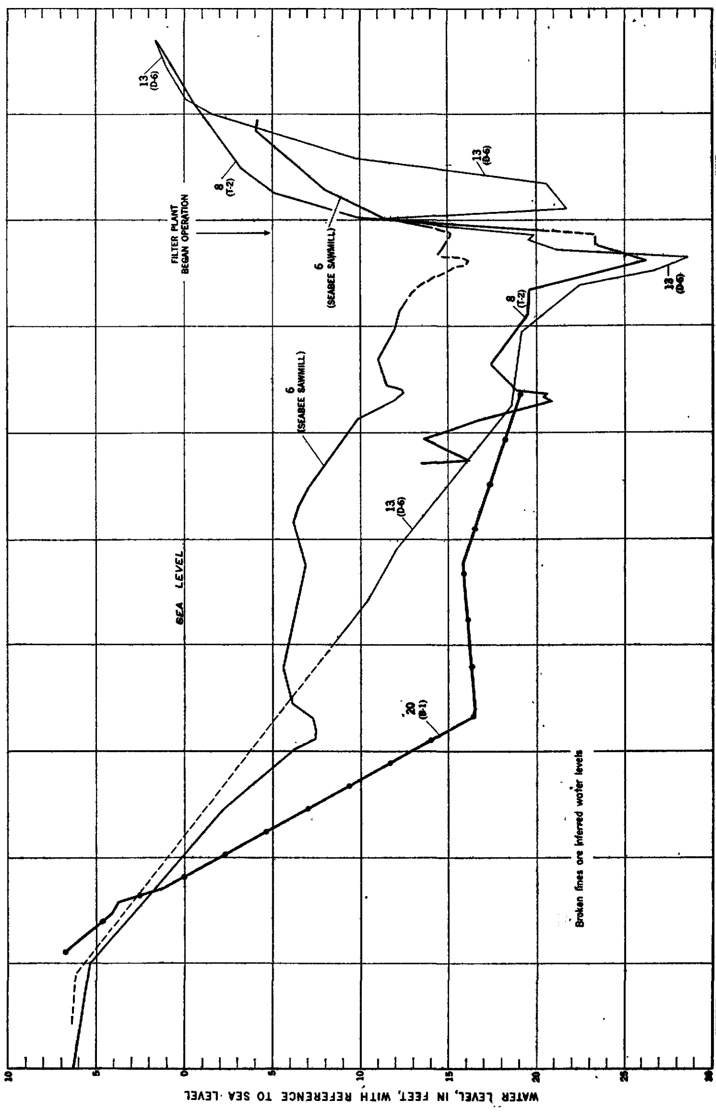


FIGURE 17.—Graph showing fluctuation of water levels in wells at Camp Peary.

The record of the sawmill well 6 is the longest and is based on frequent measurements and showed clearly that water levels continued to decline rapidly from the time the supply wells were first put into operation until they were shut down. The total decline in the sawmill well from October 31, 1942, to May 22, 1943, was 19.8 feet, an average of 2.9 feet per month. The water-level decline was somewhat irregular; wastage of water in December 1942 and January 1943, owing to lack of automatic controls in the supply wells, accelerated the decline temporarily, but in February 1943, when waste of water was eliminated, the graph of the water level began to flatten. The decline from March 4 to May 27, 1943, was accelerated briefly during the period April 4 to 11, owing to the installation of a pump of higher capacity on well 7 and the operation of a new well, CB–3 (not listed), in the Advanced Training area. With resumption of normal distribution of loan on all wells, the water levels rose temporarily.

The water levels in well 20 (B–1) probably represented about the average levels in the center of the zone of depression around the supply wells. The sharp initial decline of water levels before January 3, 1943, was an expected consequence of putting the supply wells into operation. From January 10 to April 13, 1943, the apparent lowering was small, about 2.7 feet, indicating that the cone of depression was continuing to develop slowly.

These records show that the cone of depression around the pumping wells was deepening and expanding up to March 27, 1943; that equilibrium between the amount of water discharged and the amount entering the area was not reached; and further, that there was little, if any, indication that it was being reached.

PUMPING TESTS AT CAMP PEARY

Accurately controlled pumping tests could not be made at Camp Peary when the camp was being built, because of the necessity of putting wells into service immediately upon completion. However, in 1946 a series of tests was made to obtain figures on the coefficients of transmissibility and storage of the sediments, by means of the Theis nonequilibrium formula (Theis, 1935, p. 520). These data were then used to estimate the probable decline of water levels had the camp continued to use ground water as a source of supply.

The coefficient of transmissibility, T is defined (Theis, 1935) as the amount of water, in gallons per day, transmitted through each vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer, under a unit gradient. The coefficient of storage, S, is defined (Theis, 1938) as the volume of water, expressed as a fraction of a cubic foot, released from storage in each vertical column of the aquifer having a base 1 foot square when the water table or other piezometric surface falls 1 foot.

The coefficient of transmissibility was determined by pumping a well at a constant rate and observing the drawdown in an adjacent well. The time and drawdown were then plotted on semilogarithmic paper (fig. 18), with time (t) on the logarithmic scale and drawdown (s) on the arithmetic scale. T, in gallons per day per foot, is then obtained from the variant of the Theis nonequilibrium formula

$$T=\frac{2.303Q}{4\pi\Delta s}$$

(Cooper and Jacob, 1946, p. 528) where Q is the discharge in gallons per day and Δs is the difference in drawdown (or recovery) in feet over one logarithmic cycle (1.03 feet, in fig. 18).

In every instance the recovery of the water level in the observation well after pumping ceased was plotted also and T calculated again. In this operation the recovery used is the difference between the measured water level and the projected drawdown at various stages of recovery from the pumping level at the time the pump was shut off.

The coefficient of storage, S, was determined by using the formula

$$S=\frac{2.25Tt_0}{r^2}$$

(Cooper and Jacob, 1946) where T is expressed in cubic feet per second per foot, t_0 is the time in seconds at which the straight line of the semilogarithmic plot intersects the zero-drawdown line (3.4 minutes or 204 seconds in fig. 18), and r is the distance in feet from the observation well to the pumped well.

Coefficients of transmissibility were computed from records of water levels in seven different observation wells. One of these wells was tested in connection with two different pumping wells and one determination of water levels in the pumping well was made. Eight of the nine different combinations used are shown in table 24. The locations of the wells listed in table 24 are shown on figure 15.

As shown in table 24, the values of transmissibility range from 22,000 to 85,000 gpd per foot. Computations based on a test on well 8 (T–2)

TABLE 24.—*Data on pumping tests at Camp Peary, 1946*

[Camp Peary numbers in parentheses]

Observation well	Pumping well	Transmissibility (gpd per ft)	Coefficient of storage	Remarks
8 (T-2)	9 (D-4)	85,000	1.9×10^{-4}	Drawdown.
10 (D-2)	10 (D-2)	22,000		Do.
10 (D-2)	11 (D-3)	36,000	1.6×10^{-4}	Do.
12 (T-1)	10 (D-2)	41,000	1.0×10^{-4}	Do.
12 (T-1)	11 (D-3)	39,000		Recovery.
19 (B-2)	20 (B-1)	46,000	1.0×10^{-4}	Drawdown.
20 (B-1)	11 (D-3)	50,000	1.0×10^{-4}	Do.
21 (B-3)	20 (B-1)	52,000	1.0×10^{-4}	Do.

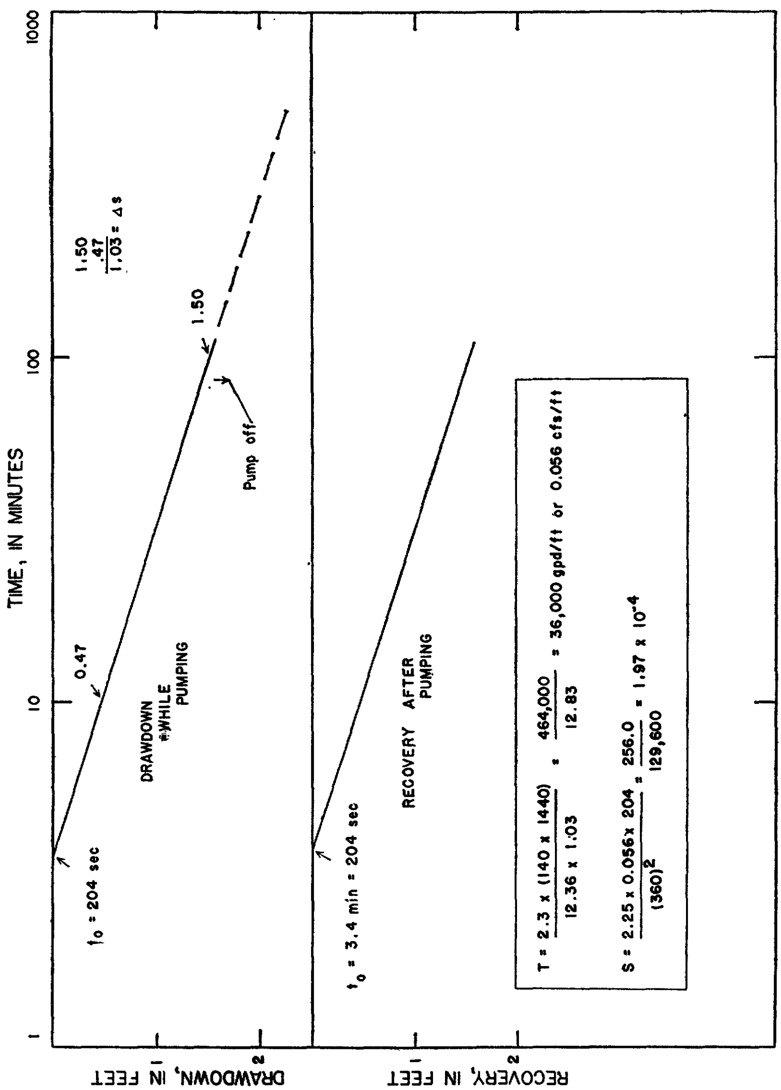


FIGURE 18.—Time-drawdown graph of water levels in well 12 with well 11 pumping, at Camp Peary.

indicate a transmissibility of 85,000 but all other computations give values below 53,000 gpd per foot.

From measurements made on well 10 (D–2) during and after pumping a transmissibility coefficient of 22,000 gpd per foot was obtained, but a higher value, 36,000 gpd per foot, was calculated from measurements made when well 10 was an observation well during and following pumping of well 11 (D–3). Inasmuch as the former test gave, in part, erratic results, the higher transmissibility is considered the correct one.

The results of the test on well 13 (D–6) were not satisfactory. It is possible that water levels during the pumping test were affected by pumping at Williamsburg, about 3 miles distant, and the determinations obtained are not included in table 24.

Drawdown data on observation well 8 with well 9 pumping were analyzed by the Theis nonequilibrium formula. Following standard procedure (Theis, 1935 p. 519; Wenzel, 1942, p. 87; Brown, 1953, p. 851), the drawdown was plotted against r^2/t (r is distance from pumping well to observation well in feet and t is time in minutes) on log-log paper and the well-function type curve superposed. The type curve fitted quite well. The transmissibility checked the results of the straight-line method so it is apparent that locally the transmissibility is higher than average.

Transmissibility reflects local conditions and any one determination is not necessarily indicative of the area as a whole. As the cone of depression widens and covers the surrounding area the thickening or thinning of the water-bearing formations and changes in the degree of sorting and mechanical composition of the sediments will become effective, and after a period of time these differences will be reflected in the observation well; the determined transmissibility will likewise vary and become an "average" value.

In considering the transmissibility of the Camp Peary area as a whole, it seemed likely that an "average" value would be somewhat higher than the 40,000 to 50,000 gpd per foot grouping of actual determinations but not nearly as high as the 85,000 gpd per foot determined for well 8.

Miscellaneous data collected during the artificial recharge experiment at Camp Peary in 1945 (see p. 46) were then examined to ascertain whether these might be used to substantiate the estimated "average" coefficient of transmissibility of 60,000 gpd per foot.

Recovery data obtained during earlier recharge operations were plotted against the logarithms of distance and appeared to be reliable, from the disposition of the plotted points. Utilizing the formula

$$T = \frac{2.303Q}{2\pi\Delta s}$$

(Cooper and Jacob, 1946, p. 527). On April 4 and April 10, respectively 1 and 6 days after recharging had begun, (plotting drawdown against distances to observation wells) values for transmissibility of 70,000 and 63,000 gpd per foot were obtained. On July 9 and July 23, during the subsequent discharge period, figures of 41,000 and 46,000 were obtained by the same method.

Therefore, data at hand seem to indicate that the transmissiblity of the aquifer as a whole is somewhat higher than an arithmetical average of the transmissibilities determined by short-term pumping tests (table 24), and a transmissibility of 50,000 gpd per foot may be a conservative estimate.

In order to compute future declines of water level, an "average" transmissibility of 50,000 gpd per foot and a coefficient of storage of 1.0×10^{-4} was assumed to be characteristic of the Camp Peary area and 8 wells (table 25) were assumed to have pumped a total of about 2,000,000 gpd (2,800 gpm) in the period from November 2, 1942 to February 10, 1943.

The drawdown created by any one well at any distance at any time may be calculated from the nonequilibrium formula (Theis, 1935)

$$s=\frac{114.6Q}{T}W(u)$$

where $W(u)=\int_{1.87r^2S/Tt}^{\infty}\frac{e^{-u}}{u}du$

and $u=\frac{1.87r^2S}{Tt}$

Q is the discharge in gallons per minute, T is the coefficient of transmissibility in gallons per day per foot, t is the time in days, r is the distance in feet to the point at which the drawdown is desired, and S the coefficient of storage. By solving first for u and then determining the value of the integral $W(u)$ from appropriate tables (Wenzel, 1942, p. 89), it is possible to substitute in equation (1) and solve for s (drawdown, in feet).

In considering an 8-well pumping field, the drawdown in each well caused by its own pumping and the interference of each well upon the other 7 must be calculated. Obviously such calculations are time consuming, particularly when different periods are considered. Use was made, therefore, of the graphical method devised by Theis [2] in solving these problems.

[2] Theis, C. V., 1952, Chart for computation of drawdown in wells in vicinity of a discharging well: U. S. Geol. Survey, Water Resources open-file report.

By the end of 100 days, the water level in well 6 was calculated to have declined 16.5 feet, whereas observations made at the time show that the water level in this well had actually declined about 12½ feet. Well 13 (D–6) was calculated to have declined 15 feet in 100 days, whereas observations show the water level had actually declined about 16 feet. It must be noted that at Camp Peary from November 1 to March 1 the discharge had increased irregularly from nothing to about 4 mgd. Considering the approximate data used and the fact that wells were not discharged in the same manner as those on which calculations were based, the check is considered to be excellent.

The computed figures are directly applicable to water levels in observation wells. However, they cannot be applied directly to producing wells because these have an additional drawdown due to entrance losses into the well, which may differ considerably from well to well, even though the coefficient of transmissibility for the area remains constant. Therefore, in these calculations of pumping levels, the entrance losses are added to computed declines. The entrance loss is computed by subtracting the observed drawdown at the end of a pumping period (generally 24 hours) from the calculated decline in water levels one-half foot distant from the pumping well in the same period of time. For instance, it was found that when actually pumping at a rate of 400 gpm, the calculated drawdown in well 7 (D–1) at the end of 1 day was 27.5 feet less than the observed drawdown. This 27.5 feet of difference is considered to be the entrance losses and must be added to all water-level calculations on that particular pumping well. Thus the adjusted decline (100 days, table 25) is the sum of the calculated decline and the screen loss.

Having thus determined the theoretical decline of water levels after 100 days and having adjusted these calculated declines in producing wells for entrance losses ("Adjusted decline, 100 days" in table 25), computations were then made to predict the pumping levels at the end of 5 years. These results are also shown in table 25. It appears that the increase in drawdown from 100 days to 5 years would have been small, from 17½ to 19 feet depending on the location of the well

TABLE 25.—*Calculated decline of water levels in wells at Camp Peary, York County, Va.*

[All water from storage; *T*, 50,000 gpd/ft and *S*, 1.0 x 10^{-4}. Camp Peary numbers in parentheses]

	7 (D-1)	11 (D-3)	9 (D-4)	14 (D-5)	19 (B-2)	21 (B-3)	17 (B-4)	16 (B-6)
Rate of discharge...gpm..	400	300	400	300	300	400	300	400
Entrance losses...feet..	27.5	50.5	49	31.5	13	8	52	13.5
Computed decline in 100 days..feet..	54.3	51.9	57.5	44.4	53.2	58.2	49.8	50
Adjusted decline in 100 days...feet..	81.8	102.4	106.5	75.9	66.2	66.2	101.8	63.5
Computed decline in 5 years...feet..	72.6	70.1	75.6	62.5	71.4	75.8	67.9	68
Adjusted decline in 5 years...feet..	100.1	120.6	124.6	94.0	84.4	83.8	119.9	81.5

and the rate at which it was pumped. It also appears from these data that the camp could have continued to rely upon a ground-water supply during its existence without danger of depletion or diminution of supply, relying only on water from ground storage.

However, as the cone of depression surrounding the pumped wells continues to grow, it will eventually reach the intake area (Fall Line), and lowering of water levels in that area will induce additional recharge. The cone of depression will then cease to expand although it will continue to deepen somewhat. The effect of the additional (induced) recharge can be calculated by setting up a hypothetical image well field at a distance from (west of) the Fall Line equal to the distance of the actual well field (Camp Peary) from the Fall Line. The image wells are considered to be adding water to an infinitely large ground-water reservoir at the same rate as water is being discharged at Camp Peary. The equation is used in the manner in which it was used to compute drawdowns at Camp Peary, except that s represents a rise of water levels due to recharge of the image wells instead of drawdown. The distance used in the formula is 70 miles.

However, it can be shown (Brown, 1953) that in the Theis formula given above, at values of u equal to 0.02 or less, the rate of decline of the image well is linear and, because the pumping well decline has previously arrived at a state of linear rate of progressive drawdown, the effects cancel each other. Solving the equation for t, a figure of about 70 years is obtained as time of stabilization. Table 26 gives the calculated drawdowns.

TABLE 26.—*Effect of image well on water levels at Camp Peary*

Time	Recovery from image well (feet)
100 days	0
5 years	6.4
10 years	9.7
70 years	21.5

The effect of the image well on the producing wells is to decrease the drawdown by 6.4 feet in 5 years. Insofar as the specific problem of water levels at Camp Peary is concerned, we may say that, owing to induced recharge at the outcrop zone, water levels at Camp Peary at the end of 5 years will be about 6 feet higher than those shown in table 25 under "Adjusted pumping level." Water levels will slowly decline for a total of 70 years but the net additional decline from 5 years to 70 years is less than 2 feet. After 70 years, the rate of recovery due to the recharge wells will equal the rate of decline due to the pumping wells and lowering of water levels will cease.

The results of the computations relative to Camp Peary represent the order of magnitude of changes that would occur in the pumping program described. Greater reliance could be given the results if one pumping test of 6 to 12 days' duration were made, and water levels were observed at several surrounding wells. For instance, if well 11 (D–3, fig. 15) was pumped and measurements taken on 14 (D–5), 19 (B–2), 20 (B–1), 12 (T–1), and 8 (T–2) and these data plotted to give time-drawdown and distance-drawdown slopes, determinations could be made which would show the trend toward an "average" transmissibility and furnish several corroborations of results obtained. If water levels in wells were corrected for variations due to tide level and atmospheric pressure, further refinement would be achieved.

TERTIARY SYSTEM

UPPER EOCENE TO BASAL MIOCENE SERIES—CHICKAHOMINY AND CALVERT FORMATIONS

Wells 1, 2, and 54 in the upper part of the county and a few wells near Williamsburg (50, 51, 53) obtain water from uppermost Eocene or basal Miocene deposits. These wells generally do not yield more than 10 or 20 gpm but somewhat larger yields are available in places. However, at other places productive sands in this zone are lacking entirely.

Foraminifera obtained from drill cuttings from a well at the Naval Warfare School (41) show that Calvert fossils are present near the bottom of the hole, but none of the profuse Jackson Foraminifera were found; hence this well and probably also the Park Service well (39) obtain water from basal Miocene strata (fig. 16). Both wells obtain relatively small yields, as compared to wells that tap deeper sand beds. (See table 27.)

MIOCENE SERIES—YORKTOWN FORMATION

Wells.—In the Williamsburg area a well 68 feet deep has been productive (52, table 21). At Yorktown a 102-foot well (40, table 27) at the Nelson House is reported to have yielded 36 gpm. In 1941, at the writer's suggestion, a well (33) was drilled near headquarters at the Naval Mine Depot in an effort to obtain at a comparable depth at least a small amount of water of better chemical character than that obtained from "artesian" strata. The well was drilled to a depth of 168 feet and only about 8 gpm was obtained from a fine gray sand-and-shell stratum 23 feet thick; the well was abandoned. Thirteen jetted 3-inch wells (not shown in table of well records) ranging from 40 to 132 feet in depth, were driven at different sites at the Depot in 1942. Eleven of these yielded from 3 to 4 gpm, one yielded 7 gpm, and one yielded 10 gpm. The two wells of highest yield were respectively 40 and 49 feet deep. The specific capacity of these wells ranged from 0.1 to 0.5 gpm per foot of drawdown.

In the lower part of the county O. C. Brenneman has drilled wells (43–46) for private residences in fine gray sand beds that have small yields. Apparently the strata at a depth of about 100 feet here are fine quartz sand beds identical in character to those reached in the Big Bethel area (48, table 28) described on page 222. The wells here are developed mechanically in the same way as wells in the Nanjemoy formation along the lower Chickahominy River. Casing is set on a thin rock stratum that overlies the water-bearing sand, and during development a quantity of the underlying fine sand is pumped out, presumably creating an open space around the lower end of the casing.

Springs.—Many springs issue from the Miocene shell marl beds at Yorktown, several of which are used as sources of supply. The Yorktown National Monument captures the flow of two such springs; one, about half a mile south of the monument, yields from 10 to 20 gpm, the amount varying with the local rainfall, and the other, about 1 mile west of the monument, yields more than 22½ gpm. The flow of these springs is piped to a collecting basin and pumped into the system supplying the town. Artesian water is used to supplement this supply.

At the Naval Mine Depot the yield of two springs, totaling about 33 gpm, is likewise collected and used constantly.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

A number of shallow dug or driven wells supply water to homes and farms in York County. Only very small supplies have been developed from the terrace formations in which these wells are sunk. In the vicinity of Yorktown and Camp Peary the terrace is made up of fine silty sand and clay and the yield of driven wells is very meager. During the construction of Camp Peary batteries of wells were driven to provide temporary supplies; these wells yielded very small quantities of water, generally less than 2 gpm. It was also found that existing shallow wells in the surrounding areas generally failed to supply adequate water to homes of naval personnel, and in some instances deep wells were drilled by the Seabees at these places.

GROUND-WATER RECHARGE

In the spring and summer of 1946, well 11 (Camp Peary D–3) was used in an effort to determine the practicability of temporarily storing fresh water in sediments saturated with brackish ground water (Cederstrom, 1947a). Such storage would be desirable where industrial firms or other large consumers could purchase in the winter cold fresh water from city supply systems for use during the subsequent hot summer months for cooling purposes or for necessary large emergency supplies. The experiment was successful and the reader is referred to pages 46–52 where the operation is described in full.

QUALITY OF WATER

WATER FROM THE UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

Deep wells in York County yield a soft sodium bicarbonate water, more or less contaminated by sodium chloride. The chloride content ranges from less than 200 ppm in the upper part of the county to 2,200 ppm at Camp Patrick Henry in lower York County.

At Norge, near the upper end of York County, water from a deep well (58, table 23) drilled for railroad use is reported (Sanford, 1913, p. 348–349) to have contained 176 ppm of chloride. At Camp Peary (see table 29) the chloride content ranges from 260 to 395 ppm, the wells nearer the river having the higher chloride content. At Penniman wells 25 and 26 yield water containing slightly more than 400 ppm, and at the Naval Mine Depot water from wells 32 and 37 contains respectively 522 and 574 ppm of chloride.

A well (39) drilled in the deeper sands of the Mattaponi formation at Yorktown yielded water containing 1,920 ppm of chloride (Roberts, 1932, p. 40). When deeper strata were plugged and the well developed at shallower depth, 420 feet, the chloride was much lower. This well, after a period of idleness, has a chloride content of about 250 ppm, but when in regular use, the chloride content increases to about 400 ppm (Cederstrom, 1943a, p. 16). It seems likely that the old Bectel farm well (28) at Penniman may be deeper than 414 feet and may tap this stratum, as the water from this well contained 985 ppm of chloride, about 450 ppm more than that yielded by the present 10-inch wells.

The bicarbonate content of most samples of water from the Mattaponi formation at Camp Peary and Yorktown ranges between 400 and 500 ppm. Water from well 25 at Penniman contains 632 ppm of bicarbonate and well 38 at Yorktown yields water with 806 ppm although neither of these wells has a higher-than-average chloride content. A sample from 719 feet (well 39) at Yorktown, which contained 1,920 ppm of chloride, also contained 1,446 ppm of bicarbonate.

Fluoride ranges from 1.5 to 2.3 ppm. Sulfate is higher than in chloride-free waters found in the counties to the west of York County. Hardness is also somewhat higher than in water from deep wells in adjacent Charles City and New Kent Counties but rarely exceeds 30 ppm.

The highly mineralized waters present in the deeply buried strata underlying York County represent fresh ground water that has moved in from the west and mixed with salt water with which the sediments were saturated. The origin of the chemical characteristics of these waters has been described in some detail in the literature (Cederstrom, 1946b).

WATER FROM THE UPPER EOCENE TO BASAL MIOCENE SERIES—CHICKAHOMINY AND CALVERT FORMATIONS

Water from the sandy unit in the Chickahominy formation of late Eocene age, or basal Calvert formation of Miocene age at Yorktown (39) is similar to the highly mineralized water in the deeper Mattaponi formation in that place. At Ewell (54) and near Camp Peary (2), however, water from the Chickahominy(?) formation is a soft sodium bicarbonate water with a very low chloride content. Well 50, near Williamsburg, yields water containing 125 ppm of chloride, probably representing local contamination from deeper strata through leaky casings, as other wells of comparable depth nearby yield a very low chloride water.

In the water from wells referred to above, the fluoride content is 1.0 ppm at Ewell, 1.4 and 1.9 ppm near Williamsburg, and 2.4 ppm at Yorktown.

WATER FROM THE MIOCENE SERIES—YORKTOWN FORMATION

Water from the Yorktown formation at Yorktown is a hard calcium bicarbonate water having a bicarbonate hardness of 183 ppm. Fluoride and other constituents are low.

WATER FROM THE PLEISTOCENE SERIES

Water from shallow wells in central and western York County is soft water of low mineral content (52, table 30), but in the eastern end of the county shallow water supplies may be contaminated by salt spray drifting inland. At Poquoson (47), the water from a dug well contains 193 ppm of chloride, attributed to salt-spray contamination, but much of the excessive hardness, 516 ppm, is thought to be of local origin, by solution of the limy marl in the well.

USE OF GROUND WATER

WATER FROM DEEP WELLS

Ground water containing 300 to 400 ppm of chloride was used successfully to supply Camp Peary for 6 months. Water containing 400 to 600 ppm of chloride has been used for drinking and general household purposes at Yorktown but this water was generally diluted with spring water of low chloride content before use.

High-chloride water is unfit for boiler use because it foams and corrodes. It can be used for some cooling purposes as it was at Camp Peary (well 7). For this use it may be only slightly corrosive, except to brass and aluminum when hot. According to local reports, boiling artesian water is very actively corrosive to these metals even under no pressure. However, it may be found that the cost of occasional replacement of corroded metal is small compared to the cheapness of the water. Wells 400 to 500 feet deep yield ground water having a temperature of 65° to 67° F. For cooling purposes the shallow ground water obviously is to be preferred, because it not only is colder but is less corrosive or noncorrosive.

WATER FROM SHALLOW WELLS

Water from the Yorktown formation is hard, requires the use of large amounts of soap, and is difficult to obtain in quantity, but it is generally preferable to water from the deeper formations for drinking purposes and is so used at Yorktown. The more productive Chickahominy or Calvert formations may yield water containing moderate amounts of chloride, as at the Van Arsdale Dairy where it is used for cooling, or that is almost chloride-free, as in upper James City County. Only where these beds yield low-chloride water is this water distinctly preferable to water from deeper beds.

SUMMARY OF GROUND-WATER RESOURCES

Large quantities of water are obtained in York County only from the Mattaponi formation. Unfortunately the water contains undesirable amounts of chloride, ranging from very little in the upper part of the county to very much at the lower end. There is no reason to believe that deeper drilling will produce water of better quality; in fact, it is quite certain that the deeper drilling will yield less desirable water, as was found at Yorktown. The possibility of chloride increase in deep well waters already high in chloride in periods of heavy withdrawal must be considered by potential consumers of large quantities of ground water.

Small quantities of water of better quality are available from shallow wells. The basal Miocene to upper Eocene series is productive in many places. Near Williamsburg and Camp Peary it yields moderate supplies of water containing about 100 ppm of chloride; in the western part of the county it is free of chloride and quite desirable for most purposes.

Small quantities of water are available from the Yorktown formation. Where available it is a hard calcium bicarbonate water which is reasonably suitable for most purposes, but for certain uses, such as commercial laundering, softening would be necessary.

Dug or shallow driven wells yield very little water in most places in York County.

Records and logs of wells and chemical analyses of waters for York County follow in tables 27, 28, 29, and 30.

TABLE 27.—*Records of*

[Type of well: Dg, dug; Dr, drilled; Dv, driven; J, jetted; R, rotary. Yield: Yield as of date of water-
I, industrial; M, municipal;

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)
1	1 mile northeast of Lightfoot.	George Gage	O. C. Brenneman	1946	105	J	287	
2	Oaktree	Mr. Banks	Mitchell's Well & Pump Co.	1941	84	Dr	279	
3	Carter Creek and York River.	R. Marshall	Jewett and McCornic.		30	J	265(?)	3
4	½ mile north of Bigler Mill.	Irving and Thomas.	M. S. Jewett(?)		20	J	367	2
5	Bigler Mill	E. W. Maynard	S. H. Fetterholf	1905	15	J	384	2
6	Hawtree Landing on Queen Creek.	T. R. Daly	M. S. Jewett	1914	9	J	400	3
7	1¾ miles southeast of Magruder.	Camp Peary D-1	Virginia Machinery & Well Co., Inc.	1942	74	Dr	464	10
8	1½ miles east-southeast of Magruder.	Camp Peary T-2	Mitchell's Well & Pump Co.	1942	69	Dr	450	4
9	1¼ miles east-southeast of Magruder.	Camp Peary D-4	do	1942	75	Dr	458	8
10	¾ mile southeast of Magruder.	Camp Peary D-2	Virginia Machinery & Well Co., Inc.	1942	87	Dr	455	10
11	½ mile east-southeast of Magruder.	Camp Peary D-3	do	1942	84	Dr	472	8
12	do	Camp Peary T-1	Mitchell's Well & Pump Co.	1942	85	Dr	444	4
13	¾ mile southwest of Magruder.	Camp Peary D-6	Virginia Machinery & Well Co., Inc.	1943	84	Dr	443	10
14	¾ mile west of Magruder.	Camp Peary D-5	do	1943	80	Dr	440	10
15	⅛ mile north of Magruder.	Camp Peary B-5	Layne-Atlantic Co.	1943	79	R	466	10-8
16	2 miles north of Magruder.	Camp Peary B-6	do	1943	33½	R	426	10-8
17	1 mile northeast of Magruder.	Camp Peary B-4	do	1942	29	R	452	10-8
18	2½ miles southwest of Magruder.	Camp Peary CB-1	Seabees	1942	31	Dr	420	6

See footnotes at end of table.

wells in York County, Va.

level measurement unless otherwise noted. Use of water: Ab, abandoned; C, cooling; D, domestic; P, public school; T, test well]

Screen			Water level		Yield (gallons per minute)	Drawdown		Use of water	Remarks
Setting (feet)	Character of sand	Make and slot size	Feet above (+) or below (−) surface	Date of measurement		Amount (feet)	Duration of test (hours)		
--------	Gray sand	--------	−90	--------	------	------	------	I	Sand is 20 feet thick and underlain by rock.
270-290	Sand and shell	Sawed pipe	−	--------	a 15	------	------	D	See analysis, table 30. Yield as of 1941. Now part of Camp Peary.
--------	--------	--------	−12	1918	------	------	------	Ab	See analysis, table 30. Now part of Camp Peary.
--------	--------	--------	−16	9/42	------	------	------	D	Now part of Camp Peary. Captains' quarters. Well flowed 1½ gpm in 1918.
--------	--------	--------	+10	1906	a 35	------	------	D	Yield as flow in 1918 (?). Now part of Camp Peary.
--------	--------	--------	−3.15	10/31/42	a 120	------	------	D	Reported to have flowed 10 gpm at 20 feet above surface in 1914. Now Seabee sawmill, Camp Peary. Yield as flow at surface in 1918.
438-454 454-464	Gravel	Cook #30 Cook #60	−68	11/1/42	b 300	34½	24	M	See analysis, table 29. Used for air conditioning theater, 1942-46.
440-445	Coarse sand	Cook #30	--------	--------	------	------	------	Ab	Originally site of Doyle & Russel garage, later, Seabee beer garden.
428-458	Coarse sand and gravel	Cook #30	c −82	12/42	b 260 394	63 69	24 48	M	Second test by Seabees in Feb. 1943. See analysis, table 29.
436-455	Coarse sand	Cook #40	c −92	12/5/42	b 240	44	24	M	See analysis, table 29.
430-440 450-475	Medium-grained sand	Cook #40	c −71	11/29/42	b 305	62	24	M	See analysis, table 29. Used in artificial recharge experiment in 1946.
--------	--------	--------	−	--------	------	------	------	Ab	
415-440	Fine sand to gravel	Cook #50	−78	2/2/45	b 222	81½	11	Ab	See log, table 28, analysis, table 29. Yield as of Feb. 12, 1943.
400-429	Coarse sand and gravel	Cook #50	c −87	1/28/43	b 450	60½	24	M	See analysis, table 29.
435-455	Medium-grained to clayey sand	Layne #7	c −86	1/27/43	b 210	76	23	M	Do.
394-424	Gravel	Layne #7	c −34	2/18/43	b 710	55	23	M	Do.
385-400 415-425 435-445	Fine- to coarse-grained sand	Layne #7	c −41	12/29/42	b 352	78⅓	23	M	Do.
--------	--------	--------	--------	--------	------	------	------	Ab(?)	

TABLE 27.—*Records of wells in*

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)
19	¾ miles southwest of Bigler Mill.	Camp Peary B-2	Layne-Atlantic Co.	1942	30	R	414	10-8
20	1 mile southwest of Bigler Mill.	Camp Peary B-1	Washington Pump & Well Co.	1942	41	Dr	418	10-8
21	1 mile south of Bigler Mill.	Camp Peary B-3	Layne-Atlantic Co.	1942	32	R	450	10-8
22	Waller Pond	Village	Mitchell's Pump & Well Co.	1943	10	Dr	467	
23	Queen Creek and Va. Highway 168.	R. W. Mahone	Virginia Machinery & Well Co., Inc.	1940	25	Dr	365	6
24	Penniman	Navy Fuel Depot	do	1942	83	Dr	513	
25	do	do	Virginia Machinery & Well Co., Inc.	1918	28	Dr	485	10-8
26	do	do	do	1918	20+	Dr	535	8
27	do	do	do	1918	20+	Dr	475	8-6
28	do	do	M. S. Jewett (?)		20	J	414	2
29	Yorktown, mouth of Folgates Creek.	Yorktown National Colonial Park.	do	1912	(?)27	J	554	3
30	Below Sandy Point, Yorktown.	do	H. Felterholf	1903	3	J	429	2
31	Near wharf, Yorktown.	Ice Co				Dv	20	2
32	Yorktown	Navy Mine Depot.	Sydnor Pump & Well Co., Inc.	1918	10	Dr	480	10(?)
33	do	do	do	1941	80	Dr	168	10
34	do	do	Virginia Machinery & Well Co., Inc.		27	Dr	470	10-8
35	do	do	do	1942	80	Dr	620	10
36	do	do	do	1942	80	Dr	507	10
37	do	do	do	1943	55	Dr	497	10
38	do	Hotel Corp	do	1927	4	Dr	400	10-8
39	do	Yorktown National Colonial Park.		1931	50(?)	R	772	10
40	do	Nelson House	Sydnor Pump & Well Co., Inc.	1928	60	Dr	102½	8-6.
41	do	Navy Mine Warfare School.	Virginia Machinery & Well Co., Inc.	1943	51	Dr	482	10
42	do		O. C. Brenneman	1944	20	J	86	2
43	Grafton	Convict Camp	do	1944	20	J	85	3-2
44	Dare	Mr. Colonna	do	1944	20	J	80	2
45	do	Mr Green	do	1944	20	J	85	2

See footnotes at end of table.

York County, Va.—Continued

Screen: Setting (feet)	Screen: Character of sand	Screen: Make and slot size	Water level: Feet above (+) or below (—) surface	Water level: Date of measurement	Yield (gallons per minute)	Drawdown: Amount (feet)	Drawdown: Duration of test (hours)	Use of water	Remarks
382–407	Medium-grained sand to gravel	Layne #7	[c]—29½	11/20/42	[b]525	48¾	23	M	See analysis, table 29.
392–422	Small gravel	Cook #60	[c]—36	11/13/42	[b]445	37	3	M	Do.
385–400 425–435 445–450	Gravel	Layne #7	—26	11/2/42	[b]465	29¾	......	M	
....	Hard sand	....	[c]—7½	2/43	[a]50	32½	......	M	Yields as of 1940.
355–365	Coarse sand	Cook #20	—14	1940	[a]60	......	......	D	Driller reports well might produce 300 gpm.
....	Streaks of sand	....	....	....	....	......	......	......	
440–485	....	....	0	8/31/18	[a]140	20	......	......	Nos. 25–27 drilled for du Pont de Nemours. Rehabilitated in 1943. See analysis, table 29.
....	....	....	+	1918	[a]200	15+	......	Ab	Flowed 75 gpm in 1918. See log, table 28.
....	....	....	+	1918	[a]150	28	73	Ab	Slight flow when drilled.
....	....	....	....	....	....	......	......	......	Flowed 76 gpm in 1918. Old Bectel Farm. See analysis, table 29.
....	....	....	0	1918	....	......	......	Ab	Flowed 27 gpm when drilled. See analysis, table 29.
....	....	....	+25	1906	....	......	......	Ab	Flowed less than 1 gpm in 1918.
....	....	....	....	....	....	......	......	I	
....	....	....	+1 (?)	1941	[a]339	12	24	I	Flowed 300 gpm in 1918, according to driller; well would not flow 2 feet above top of casing. See analysis, table 29.
199–122	Fine sand and shell	Johnson #11	—39	1941	[b]8	58	8	Ab	
456–461	Coarse	Cook #30	—19	11/41	[a]315	76	18	D, I	N. M. D. well #2.
461–470	Sand gravel	Cook #40							
None...	....	....	....	....	....	......	......	Ab	Did not reach water-bearing sand. See log, table 28.
None...	....	....	....	....	....	......	......	Ab	Did not reach water-bearing sand.
....	....	Cook #30	....	....	[a]326	......	......	D, I	
363–400	....	....	....	....	[a]250	70	......	Ab	See analysis, table 29.
395–420	....	....	....	....	[a]60	......	......	D	See log, table 28, analysis, table 29.
....	....	....	....	....	[a]36	......	......	D	
....	....	....	—46	....	[a]200	148	......	M	Temperature 65°F.
....	....	....	—10	1944	[a]3	......	......	D	
....	....	....	....	....	[a]4	......	......	D	
....	....	....	—9	1944	[a]2	......	......	D	
....	....	....	—4	1944	[a]4	......	......	D	

TABLE 27.—*Records of wells in*

No.	Location	Owner or user	Driller	Year completed	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)
46	Dare	Mr. Yernerman	O. C. Brenneman	1944	20	J	89	2
47	Jeffs	Poquoson High School.			5	Dg	30	
48	Big Bethel	U. S. Army	Layne-Atlantic Co.	1942	22	J	181	2
49	½ mile east of Williamsburg.	Levinson Subdivision.	Mitchell's Well & Pump Co.	1944	80	Dr	435	6
50	1 mile northwest of Williamsburg.	Van Arsdale Dairy.	O. C. Brenneman	1944	105	J	288	6–4
51	do	do	do	1944	100	J	268	3–2
52	do	do	do	1944	105	J	40	3
53	2½ miles northwest of Williamsburg.	Frozen Food Lockers.	do	1946	85	J	265	4
54	Ewell	Lock-Joint Pipe Co.	Sydnor Pump & Well Co., Inc.	1941	110	Dr	265	4

[a] Reported.
[b] Measured by U. S. Geological Survey.
[c] Water level affected by pumping at Camp Peary which began shortly after Nov. 1, 1942.

York County, Va.—Continued

Screen			Water level		Yield (gallons per minute)	Drawdown		Use of water	Remarks
Setting (feet)	Character of sand	Make and slot size	Feet above (+) or below (−) surface	Date of measurement		Amount (feet)	Duration of test (hours)		
------	------	------	−7	1944	[a] 8			D	
------	------	------	−4	8/40	[b] 2½	16½	6	P	See analysis, table 30.
------	------	------	------	------	------	------	------	I	Only very fine-grained sands reached. See log, table 28.
------	------	------	------	------	------	------	------	------	See log, table 28.
------	Gray sand..	Cook #20	−85	1944	[a] 7½	------	------	D	Temperature 59° F. Well might yield up to 50 gpm, according to owner. See analysis, table 30.
------	------	------	−84	1944	[a] 3	------	------	D	
------	Fine sand...	Open end	−34	1947	[a] 6	------	------	C	Jet pump intake at 38½ feet. Water cools milk and compressor.
------	------	------	−90	1947	[a] 15	------	------	C	Jet pump intake at 110 feet.
------	------	------	------	------	[a] 90	------	------	I	Now abandoned. Water not good for high pressure boilers. See analysis, table 30.

TABLE 28.—*Logs of wells in York County, Va.*

Well 7, Camp Peary; U. S. Navy

[Log by D. J. Cederstrom. Altitude, 74 feet. Camp Peary well D-1, drilled by Virginia Machinery & Well Co., Inc.]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Sand, yellow, clayey	35	35
Chesapeake group (Miocene):		
Clay, yellow, sandy	15	50
Sand, yellow, clayey	10	60
Marl, blue, sandy; contains shells	80	140
Clay, tough, gray; drills slowly	100	240
Clay, greenish-gray	70	310
Chickahominy formation (Eocene):		
Clay, black, glauconitic	35	345
Sand, black, clayey, glauconitic; with small amount of quartz sand	15	360
Nanjemoy formation (Eocene):		
Clay, stiff, gray; with about 20 percent glauconitic and quartz sand	9	369
Clay, soft, gray, glauconitic; a layer of limestone a few inches thick	3	372
Clay, gray; with pink cast	10	382
Mattaponi formation (Upper Cretaceous and Paleocene):		
Sand, jet-black, glauconitic; Foraminifera	3	385
Clay, bright grass-green; contains much glauconitic sand	13	398
Sand, dark, marly, glauconitic; Foraminifera	28	426
Clay, stiff, gray; contains pebbles and gypsum crystals	8	434
Sand, coarse, gray, quartz, and gravel; upper 10 feet has texture of coarse sand, lower 20 feet gravelly, pebbles as much as 2 inches in diameter; trace of glauconite; water	30	464

Well 13, Camp Peary; U. S. Navy

[Log by D. J. Cederstrom. Altitude, 84 feet. Camp Peary well D-6, drilled by Virginia Machinery & Well Co., Inc. H. G. Richards (1947, p. 12) reports *Natica* sp. and *Crassatella* sp., at 385 to 410 feet, and *Gryphaeostrea vomer*, denoting Pamunkey group, at 375 to 379 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, yellow	20	20
Clay, gray	10	30
Chesapeake group (Miocene):		
Marl, bluish; contains shells	60	90
Clay, grayish-green, sandy	25	115
Clay, tough, gray	125	240
Clay, grayish-green, sandy	30	270
Marl, olive-green; contains shells	15	285
Chickahominy formation (Eocene):		
Marl, grayish-green; contains glauconite; turns black on exposure; Foraminifera	33	318
Limestone	¼	318¼
Sand, light-gray, quartz, glauconitic; contains subordinate marl; lower part, more sandy than upper; probably will yield water	21¾	340

TABLE 28.—*Logs of wells in York County, Va.*—Continued

Well 13, Camp Peary; U. S. Navy—Continued

	Thickness (feet)	Depth (feet)
Nanjemoy formation (Eocene):		
Clay, gummy, grayish-green; contains traces of glauconite	20	360
Marl, gummy, brown	2	362
Clay, gummy, gray; contains scant glauconitic sand	18	380
Mattaponi formation (Upper Cretaceous and Paleocene):		
Marl, black, glauconitic	4	384
Clay, vivid-grass-green; contains abundant glauconitic sand; amount of glauconitic sand increases at base; stratum tough and drills slowly	30	414
Gravel; water	3	417
Clay, black; trace of glauconite	2½	419½
Sand, fine, gray; water	3½	423
Clay, black	1	424
Sand, medium-grained, gray; water	12½	436½
Clay, gray	6½	443

Well 20, Camp Peary; U. S. Navy

[Log by D. J. Cederstrom. Altitude, 41 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Clay, red, sandy	10	10
Chesapeake group (Miocene):		
Marl, gray, sandy; with some shells	54	64
Marl, tough, grayish-green	131	195
Marl, brownish-green, somewhat tough	75	270
Chickahominy formation (Eocene):		
Limestone	2	272
Clay, gray; with included sand and pebbles; trace of glauconite	15	287
Limestone, glauconitic	2	289
Marl, moderately hard, greenish; with trace of glauconite	1	290
Clay, gray; with pebbles	15	305
Nanjemoy formation (Eocene):		
Clay, gray	35	340
Sand, white, quartz, coarse; water	4	344
Clay, dull-pinkish; contains a few calcified nodules of glauconitic limestone	2	346
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue	14	360
Sand, black, glauconitic	17	377
Clay, vivid-grass-green; becomes darker at base; glauconitic throughout	15	392
Sand, coarse, gray; water	2	394
Gravel, small; water	28	422
Clay, dark-reddish-purple, becomes gray with depth	12	434

TABLE 28.—*Logs of wells in York County, Va.*—Continued

Well 22, Williamsburg; Waller Pond Housing Development

[Log by Mitchell's Well & Pump Co. Altitude, 10 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Mud, yellow	30	30
Chesapeake group (Miocene):		
Mud, yellow, and sand	30	60
Marl, shells, and mud	30	90
Mud, blue	57	147
Mud, yellow, and shells	23	170
Marl, shells, and sand	28	198
Chickahominy formation (Eocene):		
Rock	5	203
Sand, black, and mud	17	220
Undifferentiated: Marl, hard, blue	120	340
Mattaponi formation (Upper Cretaceous and Paleocene):		
Marl, blue	15	355
Sand and mud, little water	19	374
Mud, very hard, brown; scant sand; no water	34	408
Rock, very hard	7	415
Mud, red	16	431
Mud, brown	29	460
Sand, hard; water	7½	467½

Well 23, Williamsburg; R. W. Mahone

[Log by Virginia Machinery & Well Co., Inc. Altitude, 25 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	50	50
Chesapeake group (Miocene):		
Clay, blue	50	100
Clay, chocolate-colored	102	202
Undifferentiated:		
Marl, blue	103	305
Clay, gray	20	325
Sand, black	21	346
Sand, coarse, and gravel; water	4	350
Sand, coarse; water	15	365

TABLE 28.—*Logs of wells in York County, Va.*—Continued

Well 24, Penniman Fuel Depot, U. S. Navy

[Log by Virginia Machinery & Well Co., Inc. Altitude, 83 feet. Geologic boundaries inferred]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, light-yellow	41	41
Chesapeake group (Miocene):		
Marl, sandy, contains shells	24	65
Marl, blue, contains shells	25	90
Marl, blue, sandy, contains shells	35	125
Sand, gray; water	18	143
Marl, blue, tough	137	280
Marl, blue; contains shells	25	305
Sand, blue; water	20	325
Chickahominy formation (Eocene): Marl, tough	55	380
Undifferentiated: Marl, blue, sandy	20	400
Mattaponi formation (Upper Cretaceous and Paleocene):		
Marl, green	15	415
Marl, green, sandy	20	435
Marl, green, tough	10	445
Marl, blue, sandy	15	460
Marl, blue, gritty	18	478
Clay, sandy, in streaks; water	35	513

Well 26, Penniman Fuel Depot, U. S. Navy

[Log by Virginia Machinery & Well Co., Inc. Altitude, 20 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	30	30
Chesapeake group (Miocene):		
Sand and blue marl	50	80
Mud, blue, sticky	80	160
Undifferentiated: Mud, blue; slightly sandy in places	270	430
Mattaponi formation (Upper Cretaceous and Paleocene):		
Sand, black	10	440
Sand, white, and gravel	25	465
Marl, blue	7	472
Sand, greenish quartz; water	8	480
Mud, dark; little water	15	495
Marl, blue	40	535

TABLE 28.—*Logs of wells in York County, Va.*—Continued

Well 35, Yorktown; Naval Mine Depot

[Log by D. J. Cederstrom from driller's samples. Altitude, 80 feet. Well drilled by Virginia Machinery & Well Co., Inc. This is Naval Mine Depot well 3 referred to in Bull. 67 of the Virginia Geological Survey and the type locality of the Chickahominy formation. See plate 7 for descriptions of residues after washing]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, pink, sandy	40	40
Chesapeake group (Miocene):		
Marl, light-brown, sandy; contains shells	20	60
Marl, tough, gray	10	70
Marl, sandy, gray; contains shells	40	110
Marl, sandy	30	140
Marl, sandy, gray; contains shells	40	180
Marl, very sandy, gray	20	200
Marl, gray	20	220
Marl, light-brown	20	240
Marl, brown, gummy	30	270
Marl, gray, sandy	10	280
Clay, gray, gummy	60	340
Marl, light-gray, sandy	40	380
Chickahominy formation (Eocene): Clay, gummy; light-brown, scant glauconite and pyrite	80	460
Nanjemoy(?) formation (Eocene): Marl, dark-brown, sandy; trace of glauconite; pyrite	20	480
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, gray, sandy; trace of glauconite; rock fragments	40	520
Clay, light-brown, gummy	10	530
Clay, gray, sandy; trace of glauconite; few rock fragments; scant pyrite	90	620

Well 39, Yorktown; Colonial National Monument

[Driller's log. Altitude, 50(?) feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	15	15
Chesapeake group (Miocene):		
Marl, sand, and shells	100	115
Clay, blue	70	185
Shells, hard	7	192
Shells, very hard	3	195
Clay, blue, with hard streaks	161	356
Chickahominy formation (Eocene):		
Sand and shells	44	400
Sand, loose, and shells	25	425
Undifferentiated:		
Clay, blue	149	574
Clay, sandy	28	602
Shells, hard	2	604
Clay, sandy, blue	41	645
Clay, sandy, and shells	60	705
Shell, hard	4	709
Sand and shells; water	63	772

TABLE 28.—*Logs of wells in York County, Va.*—Continued

Well 48, Big Bethel; U. S. Army

[Log by D. J. Cederstrom. Altitude, 22 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, yellow	4	4
Sand, coarse, white	5	9
Clay, sandy, yellow	2½	11½
Chesapeake group (Miocene):		
Clay, blue, silty	38½	50
Clay, silty; with minor amounts of shells	29	79
Sand, quartz, bluish; with minor amount of glauconite; all fairly fine; water-bearing	17	96
Same as above but finer (water-bearing?)	15	111
Silt, compact, clayey	10½	121½
Rock, cemented; with shells	2½	124
Sand, loose, fine; water-bearing	22	146
Shells, hard, streak	2	148
Sand, fine (water-bearing?)	5	153
Rock, shells, hard, and sand	3	156
Sand, silty, very fine and fairly compact at bottom	25	181

Well 49, Williamsburg; J. Levinson Subdivision

[Log by Mitchell's Well & Pump Co. Altitude, 80(?) feet]

	Thickness (feet)	*Depth (feet)*
Chesapeake group (Miocene):		
Clay, blue	95	95
Sand and shell	5	100
Marl, blue	170	270
Undifferentiated:		
Clay, blue [1]	110	380
Clay, yellow	20	400
Clay, green	3	403
Sand, glauconitic; water	15	418
Sand, blue, gray, and white; water	2	420
Sand, clayey; water	15	435

[1] The lowest portion of this stratum should probably be assigned to the Mattaponi formation.

TABLE 29.—*Chemical analyses of waters from wells in Mattaponi formation, York County, Va.*

[Analyses in parts per million. Analyst: EWL, E. W. Lohr; JDB, J. D. Boreman; ATG, A. T. Geiger; F & R, Froehling and Robertson; MDF, M. D. Foster; LWM, L. W. Miller; WMN, W. M. Nobel]

	Well no.			
	7	9	10	11
Location	Camp Peary (D-1)	Camp Peary (D-4)	Camp Peary (D-2)	Camp Peary (D-3)
Depth (feet)	464	458	455	472
Date	Feb. 12, 1943	Dec. 12, 1942	Dec. 4, 1942	Nov. 28, 1942
Silica (SiO_2)	18			
Iron (Fe)	.12			
Calcium (Ca)	5.4			
Magnesium (Mg)	2.5			
Sodium (Na)	433			
Potassium (K)	7.5			
Bicarbonate (HCO_3)	441	457	426	424
Sulfate (SO_4)	54	45	46	35
Chloride (Cl)	395	375	355	345
Fluoride (F)	2.3	2.2	2.1	2.1
Nitrate (NO_3)				
Dissolved solids	1,151			
Hardness (as $CaCO_3$)	24	24	28	21
Analyst	EWL	JDB	JDB	EWL

	Well no.			
	13	14	15	16
Location	Camp Peary (D-6)	Camp Peary (D-5)	Camp Peary (B-5)	Camp Peary (B-6)
Depth (feet)	436	440	466	426
Date	Feb. 12, 1943	Feb. 12, 1943	Jan. 27, 1943	Feb. 12, 1943
Silica (SiO_2)		15		
Iron (Fe)		.37		
Calcium (Ca)		5.2		
Magnesium (Mg)		2.5		
Sodium (Na)		356		
Potassium (K)		9.1		
Bicarbonate (HCO_3)	414	404	404	437
Sulfate (SO_4)	48	40	22	40
Chloride (Cl)	338	305	[1] 142	260
Fluoride (F)	1.5	1.5	1.8	1.6
Nitrate (NO_3)	0	.0		
Dissolved solids		945		
Hardness (as $CaCO_3$)	28	24	28	21
Analyst	EWL	EWL	EWL	EWL

See footnotes at end of table.

TABLE 29.—*Chemical analyses of waters from wells in Mattaponi formation, York County, Va.*—Continued

	Well no.			
	17	19	20	25
Location	Camp Peary (B-4)	Camp Peary (B-2)	Camp Peary (B-1)	Penniman
Depth (feet)	452	414	418	485
Date	Jan. 9, 1943	Nov. 20, 1942	Nov. 13, 1942	Oct. 17, 1918
Silica (SiO_2)				
Iron (Fe)				0.14
Calcium (Ca)				8
Magnesium (Mg)				3.5
Sodium (Na)				478
Potassium (K)				
Bicarbonate (HCO_3)	443	443	440	632
Sulfate (SO_4)	45	60	55	63
Chloride (Cl)	268	365	365	404
Fluoride (F)	1.7	2.1	2.2	
Nitrate (NO_3)				1
Dissolved solids				1,356
Hardness (as $CaCO_3$)	22	32	30	34
Analyst	EWL	EWL	EWL	ATG

	Well no.			
	26	28	29	32
Location	Penniman	Penniman	Folgate Creek	Yorktown
Depth (feet)	535	414 (?)	554	480
Date	Oct. 15, 1942	Feb. 7, 1941	Oct. 17, 1918	Feb. 7, 1941
Silica (SiO_2)				
Iron (Fe)			1.2	
Calcium (Ca)	5.5		8.8	
Magnesium (Mg)	1.3		5.8	
Sodium (Na)			526	
Potassium (K)			14	
Bicarbonate (HCO_3)	391	458	505	454
Sulfate (SO_4)	54	60	61	54
Chloride (Cl)	412	985	524	522
Fluoride (F)	2	2.0		2.3
Nitrate (NO_3)			1.1	
Dissolved solids	1,247		1,474	
Hardness (as $CaCO_3$)		22	46	22
Analyst	F & R	MDF, LWM	ATG	MDF, LWM

	Well no.		
	38	39	39
Location	Yorktown	Yorktown [2]	Yorktown [2]
Depth (feet)	400	719	420
Date	Feb. 8, 1941	Aug. 24, 1931	Aug. 7, 1940
Silica (SiO_2)			24
Iron (Fe)			.79
Calcium (Ca)		30	13
Magnesium (Mg)		20	5.0
Sodium (Na)		490	463
Potassium (K)			14
Bicarbonate (HCO_3)	806	1,446	693
Sulfate (SO_4)	50	184	44
Chloride (Cl)	388	1,920	320
Fluoride (F)	2.0		2.4
Nitrate (NO_3)			1.4
Dissolved solids			1,239
Hardness (as $CaCO_3$)	24	157	53
Analyst	MDF, LWM	MDF	WMN

[1] Subsequently 290 to 300 ppm.
[2] Samples of well 39 at 420 and 719 feet taken before well was completed or drilled to total depth of 772 feet.

TABLE 30.—Chemical analyses of waters from wells in upper Eocene, Miocene, and Pleistocene deposits, York County, Va.

[Analyses in parts per million. Analyst: JDB, J. D. Boreman; MDF, M. D. Foster; LWM, L. W. Miller; WMN, W. M. Noble; GWW, G. W. Whetstone]

	Well no.			
	2	3	39	39a
Location	Oaktree	Carter Creek	Yorktown	Yorktown
Depth (feet)	279	265	420	Spring
Formation or group	Chickahominy(?)	Calvert(?)	Calvert	Yorktown
Date	Dec. 2, 1942	1910	Sept. 7, 1940	Feb. 7, 1940
Silica (SiO_2)		21	24	
Iron (Fe)			.72	
Calcium		7.2	13	
Magnesium (Mg)		2.7	5.0	
Sodium (Na)		185	463	
Potassium (K)		16	14	
Bicarbonate (HCO_3)	400	363	693	221
Sulfate (SO_4)	1	10	44	5
Chloride (Cl)	22	103	320	8
Fluoride (F)	1.9		2.4	.2
Nitrate (NO_3)			1.4	1.8
Dissolved solids			1,239	
Hardness (as $CaCO_3$)	24	29	53	183
Analyst	JDB			MDF, LWM

	Well no.			
	47	50	52	54
Location	Jeffs	Williamsburg	Williamsburg	Ewell
Depth (feet)	30	288	40	265
Formation or group	Columbia	Chickahominy(?)	Columbia	Chickahominy
Date	Aug. 8, 1941	Nov. 6, 1947	Nov. 6, 1947	Dec. 19, 1942
Silica (SiO_2)	18		8.8	
Iron (Fe)	.43	0.06	.02	
Calcium (Ca)	180		2.0	
Magnesium (Mg)	16		1.9	
Sodium (Na)	117		22 (Sodium and potassium)	
Potassium (K)	1.4			
Bicarbonate (HCO_3)	453	326	6.0	223
Sulfate (SO_4)	115	12	1.6	8
Chloride (Cl)	193	125	35	4
Fluoride (F)	.1	1.4	.1	1.0
Nitrate (NO_3)	.10	.6	4.4	
Dissolved solids	814		67	
Hardness (as $CaCO_3$)	516	30	13	26
Analyst	WMN	GWW	GWW	GWW

WARWICK COUNTY[3]

Warwick County and the independent city of Newport News lie along the north bank of the James River and Hampton Roads. The county has an area of 59 square miles and a population (1950) of 81,233 of which 35,875 live outside the city of Newport News (Virginia Division of Planning and Economic Development, 1951). Settled in 1621, Newport News, because of its location, harbor facilities, and shipyards soon became important as a transshipment point for American commerce—a port of entry and departure. Much of the area is agricultural and forest land. The Mariners Museum is located at Morrison. Fort Eustis, established during World War I and rebuilt during World War II, is near Lee Hall.

The aggregate value of dairy and other farm products from Warwick County was $590,736 in 1949; the importance of the area centers about Newport News, where in 1940 over 8,000 people were employed, mostly at the shipyards. Frozen and canned seafoods, woodwork, ship canvas and awning manufacture, apparel, printing and publishing are significant in the local economy. The Chesapeake and Ohio Railroad terminal and ferry terminals connecting the peninsula with Norfolk, Cape Charles, and Washington are important.

TOPOGRAPHY

Most of Warwick County is occupied by the Talbot terrace, the general altitude of which lies between 30 and 40 feet above sea level, the lower altitude characterizing that part of the county near Newport News. In that section there is also some indication of the still lower Pamlico terrace. In the upper end of the county the Sunderland terrace forms a dissected surface generally between 80 and 90 feet above sea level.

GEOLOGY

BASEMENT ROCK

Depth to basement rock was determined by seismic soundings (Ewing and others, 1937) at Fort Eustis and was found to be about 1,300 feet below seal level. Depth to bedrock is not known elsewhere in the county, but, reasoning from data obtained at Fort Monroe, it seems likely that at Newport News it may be about 2,000 feet below sea level.

CRETACEOUS SYSTEM—POTOMAC GROUP

Alternating sand and clay beds of Early and Late Cretaceous age lie upon bedrock and at Newport News they may extend to within about 1,100 feet of the surface. These strata have not been reached,

[3] As of July 1, 1952, the entire county of Warwick and independent city of Newport News became a first-class city designated Warwick.

however, by any well within Warwick County, although they are known from the log of well 8c in adjacent Elizabeth City County.

CRETACEOUS TO TERTIARY SYSTEMS

UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

Brightly colored or mottled clay beds of the Mattaponi formation of Late Cretaceous to Paleocene age are present at a depth of 644 feet, 244 feet below the base of the Miocene, at Newport News (44, table 33). Red clay is present at 640 feet in well 46 but highly colored beds are not present in the Mattaponi formation at Fort Eustis or Skiffs Creek. Between depths of 900 and 1,100 feet the sediments contain more sand beds than clay beds and it is thought that the base of the formation is approached here (pl. 1).

At the Lee Hall Boy Scout Camp (4a, table 32) characteristic Mattaponi Foraminifera are present about 360 feet below sea level and it appears that here 70 to 90 feet of Chickahominy sediments rest directly upon the sediments of the Mattaponi formation. At the Norfolk City Waterworks well, conditions are the same, except that there the Chickahominy formation may be slightly thicker. At Newport News, about midway between Lee Hall and Norfolk City Waterworks, the total Eocene section is thought to be not more than about 125 feet thick.

A prominent coarse to gravelly sand stratum about 150 feet below the base of the Miocene series furnishes water to most of the deep wells in upper part of the county. At Newport News somewhat sandy strata are present 200 to 300 feet below the base of the Miocene series, but the best water-bearing sands occur more than 800 feet below sea level, or 400 feet and more below the base of the Miocene.

TERTIARY SYSTEM

EOCENE SERIES—CHICKAHOMINY FORMATION

The Chickahominy formation of late Eocene age is present at Fort Eustis, Camp Patrick Henry, and Newport News. Chickahominy Foraminifera (Cushman and Cederstrom, 1945) first appear at a depth of about 415 feet below the land surface at Newport News, but the lower limit of this formation is not accurately determinable because samples are rotary-drill cuttings, and because the scant older fauna is intermixed with the rich Chickahominy and the still higher Calvert (Miocene) assemblages. These do not drop out in the deep samples and the older Foraminifera are most difficult to recognize. However, a few small Foraminifera characteristic of the old formations in this area appear at 515 feet; it seems likely, therefore, that the base of the Chickahominy formation is at about 500 feet and that

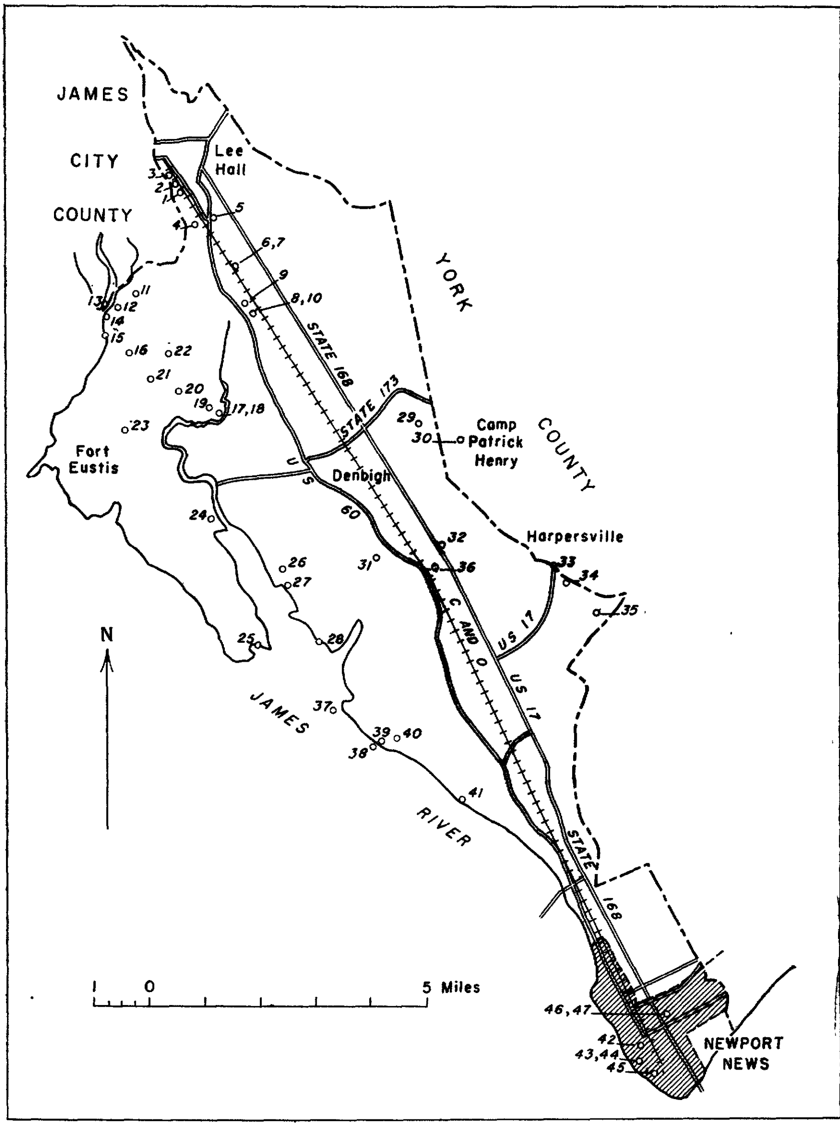


FIGURE 19.—Location of wells in Warwick County. (See footnote 3, p. 189.)

the Eocene formation (including possibly some Nanjemoy formation) is not more than 100 to 125 feet thick at that place.

The same difficulty is found with samples from Fort Eustis. It is entirely certain that the Chickahominy formation is present there; but beyond this all that is known is that these strata are found at about 275 feet below sea level and are probably from 50 to 60 feet thick.

At Camp Patrick Henry the Chickahominy Foraminifera were present in samples taken from depths of 450 to 492 feet in well 30.

MIOCENE SERIES

The Chesapeake group of Miocene age overlies Eocene units and extends to about 270 feet below sea level at Fort Eustis, to about 360 feet below sea level at Camp Patrick Henry, and to about 410 feet below sea level at Newport News.

The basal Calvert formation, perhaps 100 feet thick in the upper part of the county, does not appear to be particularly sandy at either Fort Eustis or Camp Patrick Henry. The St. Marys formation, which lies above the Calvert formation, is made up largely of tough dark marl that is dull olive green, brown, blue, or gray. The uppermost member of the Chesapeake group, the Yorktown formation, consists of blue clay or marl in which subordinate shell, sand, or sand and shell beds are intercalated. The formation is exposed at the surface in many places in streambanks and roadcuts. The thin shell beds generally consist of entire shells, but at Harpersville a lenticular body of small shell fragments was found in a shallow well (34, table 33). This was well sorted and appeared to be a beach deposit. The sands in the Yorktown formation are generally fine in texture and gray in color and yield only small quantities of water to wells.

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The Miocene units are overlain by the Columbia group of Pleistocene age which is composed of sand and yellow clay beds in the upper part of the county and gray sand and marl beds in the lower part of the county. The maximum thickness of these beds is about 30 feet. These yield small supplies of water to dug and driven wells.

MUNICIPAL WATER SUPPLIES

The city of Newport News and most of the suburban and rural areas between Newport News and Lee Hall are supplied by water from the Newport News water system; the main reservoirs are near Lee Hall. To meet the needs of a city where ground water was either difficult to obtain or poor in quality, the first system was completed in 1892, in the Lee Hall area. Harwoods Mill Reservoir to the southeast and Skiffs Creek Reservoir to the west were later added to the system. This system had a normal capacity of about 8 mgd. During World War II, the system was expanded by construction of an additional filter plant at Harwoods Mill and a pipeline to the Chickahominy River dam at Walkers in Charles City County. The system will now furnish more than 15 mgd.

GROUND WATER

Many deep wells have been drilled in Warwick County and large supplies of ground water have been obtained from such wells in the vicinity of Lee Hall and Fort Eustis in the upper part of the county, and in Newport News at the southeastern end of the county. Water from deep wells contains undesirable amounts of chloride, however, and it is therefore of limited usefulness or entirely useless for nearly all purposes. In spite of this condition, ground water has been of great importance in the county because it has satisfied urgent requirements at critical periods of time. It served Fort Eustis during both World Wars and provided the city of Newport News with a much-needed supplementary supply during the drought of 1931–33 and during the early part of the second World War. At Camp Patrick Henry ground water was so brackish that it was used only for a brief time for fire protection. At Newport News the high-chloride water obtained from deep wells has been used successfully for industrial cooling and for scrubbing and cooling illuminating gas.

Dug and driven wells in the Pleistocene terrace deposits supply a number of rural homes and farms.

WATER-BEARING FORMATIONS

In the Fort Eustis–Lee Hall area the Mattaponi formation of Late Cretaceous and Paleocene age contains prolific water-bearing sand beds. Several wells (8, 17, 20, 22, table 33) are developed in a sand about 430 feet below sea level. At Lee Hall (3) a water-bearing sand bed was not reached until a depth of about 500 feet. Water-bearing sand was reached in the two wells at Fort Eustis (21 and 22) at a depth of about 630 feet below sea level. Southward water-bearing sand was found at less than 380 feet below sea level in wells 14 and 15. Whether these are correlative with the sand tapped at 430 feet is uncertain. At Newport News the beds reached at 780 feet in well 44 may correlate with the deep sand tapped at Fort Eustis (pl. 1). At well 46 at a meat-packing plant the upper 400 feet of Mattaponi formation was barren.

At Camp Patrick Henry the upper productive zone was tapped by well 30 but failed to find a water-bearing sand. The sand tapped by well 29 is seemingly a limited lens in the formations of Eocene age.

Water in small amounts is available in places from the Yorktown formation of Miocene age. One attempt to find water-bearing sand in the Chickahominy at Newport News was essentially a failure.

SKIFFS CREEK AND LEE HALL RESERVOIRS

The Newport News supply serves not only Newport News, but Hampton, Phoebus, Buckroe Beach, and much of the area adjacent to those places. In 1941 the supply was obtained from Lee Hall Reservoir and Skiffs Creek Reservoir, located near Lee Hall, and from Harwoods Mill Reservoir to the northeast.

The coincidence of a great increase in population in Newport News as a result of the war and a protracted drought taxed to the utmost the resources of the Newport News Water Commission supply system in the years 1941–42. It was imperative that the available supply, about 8 mgd, be sharply increased to about 15 mgd to care for peak demand in dry seasons. The writer recommended that an area near Bacons Castle in Surry County be explored for ground water and accordingly a test-drilling project was initiated by Newsoms and Aldrich, engineers for the Federal Works Agency, which agency was sponsoring the project. This project (Cederstrom, 1945a, p. 204–213) was abandoned when it was later found that large quantities of water were available from the Chickahominy River at Walkers on the York-James peninsula. Utilization of this source of supply eliminated engineering difficulties inherent in bringing water by pipeline across the James River.

However, before additional water could be brought in the demand upon the existing supplies in the vicinity of Lee Hall became severe and the danger of serious shortage threatened. To alleviate the situation, wells were drilled at Lee Hall and Skiffs Creek and discharged directly into the reservoirs. Although moderately high to high in chloride content, this water was a boon to Newport News water consumers in the winter, spring, and summer of 1942.

Wells had been drilled at both Skiffs Creek and Lee Hall Reservoirs for emergency supplies during drought periods in past years. Wells 6 and 7, drilled in 1912 about half a mile northeast of the filter plant, obtained fairly strong flows, but shortly afterward it was found that the bicarbonate (and chloride?) content of the ground water, mixed with the surface water, caused foaming in railroad locomotives and the wells were plugged. Thus wells (1, 2, table 32) were drilled at Skiffs Creek Reservoir in 1918 and yielded water that had a more moderate chloride content. These wells were used from time to time; well 1 continued to be used in 1941–42.

In the fall of 1941, when the need for water became acute, a well (8) was drilled at the Lee Hall filter plant. Although the water obtained was excessively high in chloride, more than 1,000 ppm, it was used to supplement the surface-water supply. Well 9 was drilled immediately after well 8 was completed; it did not yield quite as much water but the water was lower in chloride, 740 ppm, and this well was used as much as possible in preference to well 8. Well 3 was them constructed at Skiffs Creek; this well had a high yield, and the chloride content of the water was fairly low, 460 ppm. The well furnished the bulk of the water needed until heavy rains in October 1942 replenished the reservoirs.

In January 1943 water became available from a pipeline extending to the Chickahominy River, although the water was not actually used until July 1943, according to the late E. F. Dugger, general manager, Newport News Water Commission.

This system at present supplies not only Newport News but also Camp Patrick Henry and, even more recently, Yorktown Naval Mine Depot. A very small amount of water is supplied to Fort Eustis for making steam and for hospital use. The maximum amount of water supplied by this system during the war was 16.4 mgd.

FORT EUSTIS

SUPPLY WELLS

Fort Eustis was supplied during World War II by wells 19, 20, 21, and 22, located in the central part of the camp area (fig. 19) and alined in a northerly direction. Seven wells, known as the Bailey 1, 2, and 3, Milstead 1 and 2, and Dozier 1 and 2 wells, supplied the camp with water during the first World War. The camp area was abandoned after the war and the wells fell into a state of disrepair. In the fall and winter of 1940–41, while a group of employees of the National Youth Administration were engaged in salvage and cleanup operations, Bailey wells 1 and 3 (11, 13, table 32) were put into service and pumped at a rate of 415 gpm. Milstead well 1 (15) was flowing 2 or 3 gpm. In the spring of 1941, when construction of the present camp was begun, Bailey wells 1 and 3 supplied the camp with water. No attempt was made to use any of the old wells as a source of supply for the new camp and four gravel-packed wells (19–22) were constructed and put into operation late that spring. Milstead well 1 (15), about 2 miles west of the supply wells and near the sewage disposal plant on the James River, was converted into an observation well in the spring of 1941.

GROUND-WATER LEVELS

A decline of ground-water levels began with operation of the Fort Eustis supply wells which furnished 1½ mgd to 1¾ mgd to the camp. In large part the decline was in response to pumping of Skiffs Creek well 1 (1, table 32) of the Newport News Water Commission, at Skiffs Creek, 2 miles north-northeast of the northernmost Fort Eustis supply well. Discharge at a rate of about ¾ mgd was begun in the summer of 1941. Intermittent pumping of 300 to 800 gpm from the well (8) at Lee Hall Reservoir, 1½ miles east of Fort Eustis, started in the fall of 1941. At the end of 1941 a decline of about 2½ feet was registered in the Fort Eustis observation well, 1½ miles southwest of the wells supplying the camp (fig. 20).

Water levels were fairly stable through December 1941, but by March 1942 a decrease of another 2 feet of head was apparent. From March to October the water level declined about 7 feet in response to the beginning of operation of well 3 (Skiffs Creek well 3, a quarter of a mile north of Skiffs Creek well 1), which had a reported yield of about 2 mgd. Well 1 (Skiffs Creek) was shut down at this time.

In the fall of 1942 wells at Skiffs Creek and Lee Hall Reservoirs were shut down and water levels in the observation well at Fort Eustis recovered rapidly. From the last of October to the last of November a gain of about 5 feet was recorded and water stood about 3 feet above sea level. In 1943 the water level fluctuated widely but no further marked recovery was apparent until late in 1943, when the water level rose to about 9 feet above sea level, or about as high as would be expected if no heavy discharge was taking place. The water level fluctuated from 9½ to 11½ feet above sea level in 1944.

VARIATIONS IN CHLORIDE CONTENT

Well 15 (Milstead 1), a well with very meager flow, was sampled in February 1941 and showed no increase in chloride above the sample taken in 1918. There was no apparent increase in chloride content in water from the old Dozier wells (17 and 18).

A sample taken from well 11 (Bailey 1), in August 1940, contained 45 ppm more chloride than a sample taken in 1918. An additional increase of 5 ppm was noted in a sample taken 6 months later (see table 31). At the time samples were taken the well was in use.

Samples from wells 21 and 22 (Layne 2 and 3) were obtained shortly after they were constructed in the spring of 1941. Water from well 21 increased in chloride content, from 445 ppm in April to 485 ppm in December 1941. By May 1942 the chloride had reached a maximum of 502 ppm. There was, therefore, only a slight increase, about 20 ppm, over the initial increase of 35 ppm which took place when the well was put into service. In this respect the well is similar to the Yorktown well, discussed above.

Well 22 showed a gain in chloride content of only 8 ppm when the well was put into service; from September 3, 1941 to May 3, 1942 the chloride increased an additional 28 ppm but declined shortly thereafter.

Well 20 was not sampled until it had been in service for some time, and the chloride content of samples taken shows very little variation.

Well 19, like 20, was not sampled until it had been in service about

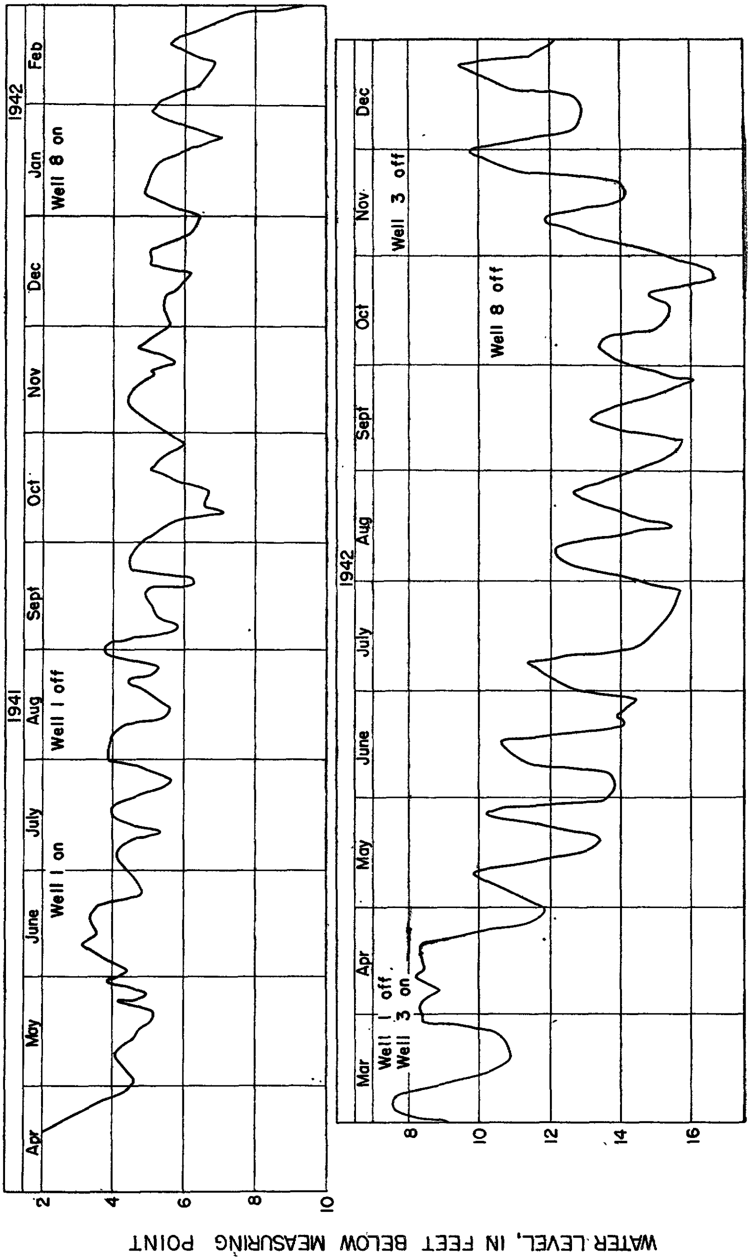


FIGURE 20.—Graph showing effect of pumping on water levels in wells at Fort Eustis.

2 months and the maximum chloride, found by December 23, 1941, 398 ppm, was only 10 ppm more than the minimum found early in September. On May 21, 1942, however, a sample of this water contained 445 ppm of chloride.

Thus it is seen that the chloride content increased with increasing draft in the area in the spring of 1942. However, reference to table 31 shows that further increases were forestalled by spreading the discharge more evenly over a wide area, even though the general piezometric level continued to decline (fig. 20). With the equalization of discharge, the chloride content of water from well 19 decreased immediately to the former normal (?) concentration. Water from well 21 remained high and water from wells 22 and 20, which had shown only a negligible increase in chloride, decreased slightly.

Upon cessation of overpumping and recovery of the piezometric level late in 1942, the chloride content of water from three of the Fort Eustis supply wells continued to be about the same, but by 1944 in water from well 22 it decreased to 20 ppm below the previous known minimum, or about 68 ppm below the previous known maximum.

TABLE 31.—*Chloride content of well water at Fort Eustis, and the well-discharge program*

Date	*Chloride content (ppm)*	*Date*	*Chloride content (ppm)*
Well 11 (Bailey 1)		Well 19 (Layne 1)—Con.	
Oct. 18, 1918	370	(2)	
Aug. 4, 1940	415	May 3, 1942	385
Feb. 6, 1941	420	May 10, 1942	438
(1)		May 21, 1942	445
(2)		(3)	
Mar. 10, 1942	505	June 6, 1942	382
Well 19 (Layne 1)		July 7, 1942	385
Sept. 4, 1941	388	(4)	
(1)		Nov. 2, 1942	385
Nov. 12, 1941	395	Sept. 20, 1943	380
Dec. 23, 1941	398	Nov. 11, 1944	380

1 Fort Eustis supply wells put in operation.
2 Skiffs Creek well put in operation.
3 Total discharge at Fort Eustis equalized.
4 Skiffs Creek well shut down.

YIELDS

Prolific water-bearing sands underlie the Fort Eustis area (see logs of wells 17, 20–22, table 33) and wells there have high yields. According to the available figures on yield as flow and piezometric level in 1918, well 16 (Milstead 2), which presumably tapped only one sand stratum, yielded 230 gpm with 16½ feet of drawdown, or about 14 gpm per foot of drawdown. Well 11 (Bailey 1) furnished 415 gpm to a centrifugal (suction lift) pump as late as 1941.

The large-diameter wells built in 1941 tapped the full thicknesses of the sand beds present and yields are correspondingly high. One well (21) yields only 8½ gpm per foot of drawdown but the other three have yields ranging from 16.8 to 18.3 gpm per foot of drawdown. Well 22, which was tested at the higher rate, 1,340 gpm, is not quite as efficient as well 20 which was pumped at a rate of 1,260 gpm. On the other hand, well 19, which was tested at 800 gpm, is nearly as efficient as the other two, which were pumped at a much higher rate.

The three most efficient wells reached a water-bearing sand about 440 feet below sea level. This is probably the same stratum yielding water in deep wells at the Yorktown Naval Mine Depot and Camp Peary. Well 20, the least efficient of these three, was drilled through only 32 feet of sand whereas the other two wells were drilled through 81 and 97 feet of sand.

Well 21, which had a relatively poor yield, did not find the sand producing water as did the other three wells and was finished in a deeper sand, probably in the Mattaponi formation, below a total depth of 600 feet.

Although tested individually, the four large-diameter wells were never tested simultaneously for any period of time, and the effects on yields of individual wells under such conditions are unknown.

CAMP PATRICK HENRY

Attempts to develop ground-water supplies at Camp Patrick Henry were unsuccessful. In all, three wells were drilled at the order of the contracting firm that was building the camp. Water-bearing sands were not reached by two of these wells (see log of well 30, table 33). The third well (29) yielded 100 gpm but the water contained 2,220 ppm of chloride.

HARPERSVILLE

Shallow test drilling for productive water-bearing beds in the Yorktown formation of Miocene age was carried out in the vicinity of Big Bethel Reservoir in the spring of 1942 with the hope of supplementing the reservoir with well water. Six test holes were drilled; two were in Warwick County, near Harpersville. One well (34) reached 41 feet of sized shell, identical with material present in part of the Norfolk Navy Yard at Portsmouth (Cederstrom 1945a, p. 338). This stratum yielded 115 gallons of water with 81 feet of drawdown in a 48-hour pumping test. Other test holes found only very fine sand or, as in well 35, none at all. Fine gray sand, capable of yielding a few gallons per minute, appears to be characteristic of the Yorktown formation in the lower end of the York-James peninsula. The occurrence of the fragmented shell stratum is rare but the complete absence of fine sand or silty sand is likewise uncommon.

NEWPORT NEWS

Attempts to obtain water from deep wells in Newport News began as early as 1882, when, according to Sanford (1913, p. 10), a well was drilled for the Old Dominion Land Co. to a depth of 582½ feet. A flow of water was obtained at 186 feet from below a rock stratum in the Miocene, and at 422 feet, from sand of late Eocene age, but neither the volume nor the quality of the water is recorded. Presumably the water was unsatisfactory as the well was abandoned at 582½ feet, where the casing broke. In 1906 another unsuccessful well was drilled to a depth of 500 feet.

In 1940 a deep well (46) was drilled for a meat-packing plant. A log (table 33) to a depth of 900 feet affords a good general description of the strata, but it does not indicate the source of the water obtained. According to J. J. Mitchell, the driller, the lowest 100 feet of casing is slotted and the well began to flow when this casing was driven the full depth of the well. A yield of 25 gpm was obtained with 120 feet of drawdown. The water contains 690 ppm of chloride and is very corrosive; in 1945 the entire pump column corroded through and dropped to the bottom of the well. However, the water is reasonably satisfactory for use in air conditioning.

In 1944 two deep wells (42 and 43), were drilled. Well 42 reached a 93-foot stratum of coarse sand at 720 feet, in the Mattaponi formation. This well yielded 262 gpm with 120 feet of drawdown. Although somewhat corrosive to the warm metal surfaces which it cools, the use of ground water is considered economically desirable at the dairy. Repairs to corrosive metal have been minimized by using as much stainless steel as practicable.

In well 43 an attempt was made to obtain water from sand beds of late Eocene age just below a depth of 400 feet in the hope of finding a less brackish water, but as the volume was low and the chloride high another well (44) was drilled, which tapped water from sands of the Mattaponi formation between 786 and 893 feet below the surface. Well 44 was quite productive and yielded 400 gpm. The water is used for cooling and scrubbing gas.

Many attempts have been made to obtain water from shallow Miocene strata in the city of Newport News, but here, as near Big Bethel Reservoir, strata differ greatly from place to place and, in general, results are disappointing. In well 45 a sand stratum was found at a depth of about 140 feet, from which a yield of 20 gpm was obtained although attempts to find water-bearing beds in adjacent areas were fruitless. These fairly shallow strata are worth exploring in Newport News, although the chances are against rather than for obtaining a moderate supply; any water obtained in this area is particularly valuable to consumers.

SHALLOW WELLS IN RURAL AREAS

Various reports are at hand on the yields of shallow wells. At one dairy a 4-inch well (32) supplies water for a herd of more than 80 cows, in addition to water used for cooling milk and for cleaning purposes. The owner states that the well furnishes 30 gpm, but this figure seems high. On the other hand, at another dairy four 2-inch wells (26) are required to furnish about 6,000 gpd.

Two shallow drilled wells (47) are reported to yield respectively 30 and 20 gpm from a sand and shell bed reached at about 25 feet below the surface. A yield of 25 gpm is also reported from well 36 near Denbigh, which is about 40 feet deep and possibly tops the uppermost shell beds of the Yorktown formation.

Although the reported yields may be high, it is apparent that in some places reasonably large yields may be obtained from properly constructed shallow wells. The occurrence of fine silty sand in the lower peninsula area is common and in such places shallow wells will have very low yields; however, the available records indicate the desirability of considering the potentialities of shallow deposits in Warwick County when small or moderate supplies of water are needed.

QUALITY OF WATER

WATER FROM DEEP WELLS

It has been brought out that the chloride content of water from deep wells is the critical mineral constituent affecting the usefulness of the water. The Public Health Service specifies 250 ppm as the maximum amount permissible in drinking water used on interstate carriers; nevertheless, in Warwick County water containing more than 250 ppm of chloride has been used fairly satisfactorily. (Also, the Public Health Service limit formerly was 500 ppm.)

In the upper part of the county along the James River the chloride content may be as low as 200 to 250 ppm, but inland (north) and farther down the peninsula the chloride content is progressively greater (fig. 3; pl. 4*A*). At Fort Eustis the main supply wells, located somewhat inland from the James River, have a chloride content ranging from 385 to 500 ppm. Still farther inland at Lee Hall Reservoir, the chloride content of one well was found to be over 1,000 ppm. At Camp Patrick Henry, a few miles above Newport News but midway between the York and the James Rivers, ground water contained 2,200 ppm of chloride.

At Newport News the chloride content of well water is seemingly a function of the permeability of the sediments, the less permeable sediments being the less flushed of their content of sea water with which they were once saturated, and hence having a high chloride content. The more permeable sands, through which fresh water from the west

TABLE 32.—*Records of wells*

[Type of well: Dg, dug; Dr, drilled; Dv, driven; J, jetted. Yield: Yield as of date water level is noted, I, industrial; M, municipal; Obs,

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well
1	Skiffs Creek Reservoir.	Newport News	Sydnor Pump & Well Co., Inc.	1918	Riverbank	10	Dr
2	do	do	do	1918		10	Dr
3	do	do	do	1942		20	Dr
4	¼ mile southwest of Lee Hall.	S. R. Curtis	J. Minton	1916	Stream bottom.	10	J
4a	Lee Hall	Boy Scout Camp	O. C. Brenneman	1947	Terrace	70	J
5	do	Clements				45	
6	Lee Hall Reservoir	Newport News	M. S. Jewett	1912	Streambank	17	J
7	do	do	do	1912	do	17	J
8	do	do	Sydnor Pump & Well Co., Inc.	1941	do	15	Dr
9	do	do		1941	do	15	Dr
10	do	do	Layne-Atlantic Co.	1931	do	15	R
11	Fort Eustis	U. S. Army	Sydnor Pump & Well Co., Inc.	1918	do	6	Dr
12	do	do	do	1918	Terrace	20	Dr
13	do	do	do	1918	Streambank	6(?)	Dr
14	do	do	J. Minton	1914	do	8	J
15	do	do	Sydnor Pump & Well Co., Inc.	1918	Stream bottom.	7	Dr
16	do	do	do	1918	do	6	Dr
17	do	do	do	1918	do	7	Dr
18	do	do	do	1918	do	13	Dr
19	do	do	Layne-Atlantic Co.	1941	Terrace	28.13	R
20	do	do	do	1941	do	31.13	R
21	do	do	do	1941	do	34.0	R
22	do	do	do	1941	do	37.1	R
23	Mulberry Island	do	Sydnor Pump & Well Co., Inc.	1942	do	10	Dr
24	do	do	do	1918	River bottom.	6	Dr
25	Curtis Point	do	H. E. Shimp	1904	Shore	5	J
26	Mohea	L. A. Burkholder	Owner		Terrace	29	Dg
27	do	A. M. Miller	J. Minton	1928	Streambank	20	J

See footnote at end of table.

in Warwick County, Va.

unless otherwise stated in Remarks. Use of water: Ab, abandoned; B, boiler feed; C, cooling; D, domestic; observation well; T, test well]

Depth of well (feet)	Diameter of well (inches)	Principal water-bearing zone: Depth to top of bed (feet)	Principal water-bearing zone: Thickness (feet)	Approximate water level (feet above (+) or below (−) surface)	Date of measurement	Yield (gallons per minute)	Use of water	Chloride content (parts per million)	Remarks
525	10	------	------	------	------	500	Ab	410–440	See analysis, table 34.
550	10	------	------	------	------	[a] 200	Ab	488	The combined pumping yield of wells 1 and 2 was reported to be over 1,000 gpm in 1940. See analysis, table 34.
526	10	478 482 500	4 18 20	−	1942	1,300	Ab	460	See log, table 33. Drawdown 95 feet.
560	3	560	------	+	1918	[a] 35	D	------	
540	4–2	480	------	−60	1947	15	D	------	
575	3	------	------	−	1918	------	D	------	
525	6	------	------	+18	1912	[a] 150	Ab	790 (wells 525 ft, 6 in. and 525 ft, 3 in.)	
525	3	------	------	+	1912	[a] 80	Ab		
470	10	444	------	−	1941	400	M	690	See log, table 33. See analysis, table 34.
457	10	435	15	−11	1941	500	M	1,050	Used as little as possible because of high chloride content. See analysis, table 34.
690	10	------	------	------	------	778	Ab	800 at 522 ft. 790 at 690 ft.	Yield as of 1931. 24 hour test.
515	10	------	------	+	1941	415	------	370–420	Bailey 1. Supplied construction workers with water in 1941. Temperature 68° F. Yield as of 1941.
------	10	------	------	------	------	------	Ab	------	Bailey 2.
450(?)	10	------	------	------	------	------	------	202	Bailey 3. Supplied small construction group with water in 1940. See analysis, table 34.
390	3	332	8	+	1914	[a] 110	Ab	------	
367	10–8	367	------	+19½ +7½	1918 1941	[a] 125 [a] 2	Obs	250	Milstead 1. Located near sewage disposal plant. Top of extended casing 14.50 feet above sea level. Used as U. S. Geol. Survey observation well. Temperature 66° F. See analyses, table 34.
370	10–8	------	------	+16½ +5	1918 1940	[a] 230 [a] 50	------ Ab	------ 268	Milstead 2. See analysis, table 34.
447	4½	437	10	+19½	1918	[a] 77	Ab	390	See analysis, table 34. Dozier 1. Chloride as of 1918. See log, table 33.
454	6	------	------	+ +	1918 1941	[a] 192 5	Ab	392	See analysis, table 34. Dozier 2. Chloride as of 1941. Temperature 65°F.
498	18–8	442	32	−13½	1941	800	M	385	See analysis, table 34. Layne 1. Drawdown 47½ feet in 10 hour test.
543	18–8	462	81	−20	1941	1,260	M	440	Drawdown 69 feet in 10-hour test. Layne 4. See log, table 33, analysis, table 34.
692	18–8	600 660	40 22	−18	1941	708	M	491	Drawdown 84 feet in 10-hour test. Layne 2. See log, table 33; analysis, table 34.
550	18–8	475	97	−20¼	1941	1,340	M	408	Drawdown 78½ feet in 10-hour test. Layne 3. See log, table 33; analysis, table 34.
465	8–6	415	50+	−5	1942	75	M	------	Drawdown less than 14 feet in 72-hour test. See log, table 33.
417	8–6	387	30	------	------	250	------	216	Yield as of 1918. See analysis, table 34.
363	2–1	------	------	+	1918	[a] 2	Ab	244	See analysis, table 34.
16–25	------	------	------	−	------	------	D	------	Four wells needed to supply about 6,000 gpd. Slight iron.
510	3	------	------	+	------	[a] 20	D	360	See analysis, table 34.

TABLE 32.—*Records of wells*

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well
28	Menchville	Newport News	Layne-Atlantic Co.	1932	Terrace	35	R
29	Camp Patrick Henry.	U. S. Army	Sydnor Pump & Well Co., Inc.	1942	do	30	Dr
30	do	do	Virginia Machinery & Well Co., Inc.	1942	do	30	Dr
31	2 miles south of Denbigh.	C. P. Yoder	J. Minton	1935	Slope	30	Dr
32	2½ miles east-southeast of Denbigh.	Yoder Dairy	Hostetter		Terrace	31	Dv
33	½ mile west of Harpersville.	Big Bethel Reservoir.	Layne-Atlantic Co.	1942		30	J
34	¼ mile west of Harpersville.	do	do	1942	Terrace	30	R
35	½ mile east of Harpersville.	do	do	1942	do	30	R
36	2½ miles east-southeast of Denbigh.	Rountree Lumber		1937	do	31	Dv
37	1 mile above Blunt Point.	J. E. Lamphier	J. Minton	1935	Shore	5	J
38	½ mile below Blunt Point.	James River Country Club.	do	1935	Riverbank	4	J
39	do	do	E. W. Sault		Terrace	43	Dv
40	do	do	J. Minton	1931	Streambank	12	J
41	Watts Creek	Mariner's Museum.	do	1930 (?)	do	6	J
42	Newport News	Peninsula Dairy	Layne-Atlantic Co.	1944	Terrace	10	R
43	do	Virginia Public Service Co.	do	1944	do	8	R
44	do	do	do	1944	do	12	R
45	12 St. and Jefferson Ave., Newport News.	Waterfront Lumber Co.	Mitchell's Well & Pump Co.	1940	do	10	Dr
46	Newport News	Levinson Meat Packing Co.	do	1940	do	8	Dr
47	do	do	do	1940	do		Dr

[a] Yield as flow.

in Warwick County, Va.

Depth of well (feet)	Diameter of well (inches)	Principal water-bearing zone		Approximate water level (feet above (+) or below (−) surface)	Date of measurement	Yield (gallons per minute)	Use of water	Chloride content (parts per million)	Remarks
		Depth to top of bed (feet)	Thickness (feet)						
485	6-4	362	63	−2	------	------	D	350	
492	------	425 442	13 8	−34	1942	100	------	2,200	Drawdown 110 feet in 8-hour test. See log, table 33.
554	10	------	------	------	------	------	------	------	See log, table 33. No water-bearing sand.
517	2	------	------	+	------	[a] 20	D	455	
29	4	------	------	−	------	30	D, C	------	Water is 50 feet.
180	3	59	51	------	------	------	T	------	See log, table 33.
165	18-8	54 95	41 22	−9	1942	115	T	109	Drawdown 81 feet in 48-hour test. See log, table 33; analysis, table 34.
180	------	------	------	------	------	------	T	------	No water-bearing strata.
40(?)	3	------	------	−	------	25	B	------	Water is hard.
400+	2	------	------	+	1940	------	D	368	
738	3	------	------	+	1941	[a] 26	D	495	See analysis, table 34. Used for swimming pool.
43	1¼	------	------	−	1940	10	D	------	Supplies clubhouse.
732	3	------	------	+	1940	[a] 25	D	755	Supplies fish pond. Set analysis, table 34.
1,000	3	640	------	------	------	[a] 12	Ab	660	Drawdown 120 feet. See analysis, table 34.
813	------	720	93	0	1944	262	C	600	Cools milk after pasteurization. Somewhat corrosive. See analysis, table 34.
708	18-8	401	62	+	1944	6	Ab	1,080	Flows ½ gpm. Drawdown 160 feet when pumping 6 gpm.
1,082	18-8	786 808 858 911 968 998 1,013 1,045	18 27 14 18 21 12 22 37	+	1944	400	------	------	Casing and screens extend to 893 feet. Flowed 100 gpm. See log, table 33.
140	6-4	------	------	−	1940	20	I	------	
900	6	------	------	+	1940	25	C	690	Drawdown 120 feet in 3-hour pumping test. See log, table 33; analysis, table 34.
37	8	20	3	−6	1940	30	D	------	Two wells. Water has bad odor.

has passed in greater quantity, have a low chloride content. A chloride concentration of 1,080 ppm was found at 400 feet; 600 ppm at 720–813 feet; 1,680 ppm at 820 feet; and 690 ppm at 900 feet. The two samples of low chloride content are from the better producing wells. Ordinarily it may be assumed that the deeper the stratum the higher the chloride content (compare wells 19–22 at Fort Eustis, table 34), but it is certain that in eastern Virginia the factor of permeability must also be taken into account.

The chloride in these samples is balanced largely by sodium, as other cations are low. In addition, there is a fairly high bicarbonate content. The bicarbonate content generally ranges from 400 to 500 ppm except in those samples which have an excessively high chloride content, as at Camp Patrick Henry where the water contains 724 ppm of bicarbonate. Exceptions are found, however, as in the sample (24) from Mulberry Island, which contains 621 ppm of bicarbonate and only 216 ppm of chloride.

Hardness is generally low, less than 30 ppm, but samples with very high chloride content (29, 43) may be quite hard.

Fluoride ranges from 0.9 to 3.0 ppm but the greater number of samples contain more than 2.0 ppm.

Sulfate in these samples is generally high as compared to water from counties to the west, this again being an indication of the marine origin of the chloride present. The amount of sulfate is generally less than 60 ppm but in a few places is higher, and in samples with very high chloride content it is more than 100 ppm. The sample from Camp Patrick Henry contains 300 ppm of sulfate.

The high-chloride waters of eastern Virginia are not simple mixtures of fresh and marine waters but are waters that have undergone certain chemical changes, largely base-exchange reactions, as fresh ground water from the west diluted the marine water in the sediments. The origin and chemistry of these waters have been described in some detail in the literature (Cederstrom, 1946b).

WATER FROM SHALLOW WELLS

The one sample (34, table 34) at hand from the Yorktown formation is a hard calcium bicarbonate water with a moderate chloride content, around 109 ppm. Fluoride and sulfate are low. A commercial analysis at hand shows that water from the 43-foot well at the James River Country Club (39) has a very low mineral content (less than 90 ppm of dissolved solids) and a chloride content of 7 ppm. The 140-foot well at the Waterfront Lumber Co. (45) yields water with a chloride content of 25 ppm. Total hardness is 96 ppm.

Records and logs of well and chemical analyses of waters for Warwick County are given in tables 32, 33, and 34.

TABLE 33.—*Logs of wells in Warwick County, Va.*

Well 3, Lee Hall (Skiffs Creek); Newport News Water Commission

[Log by Sydnor Pump & Well Co., Inc. Altitude, 10(?) feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Soil	1	1
Clay, hard, yellow	7	8
Clay, yellow, sandy	12	20
Chesapeake group (Miocene):		
Clay, yellow, soft	10	30
Clay, gray, and shells	26	56
Shells, hard, and sand	5	61
Clay, gray, sand, and shells	29	90
Clay, gray, and fine shells	62	152
Clay, sticky, gray	58	210
Clay, gummy, gray	50	260
Clay, gummy, green	26	286
Chickahominy formation (Eocene):		
Rock and green clay	1	287
Clay, sticky, green	4	291
Rock, soft	½	291½
Clay, gummy, green	34½	326
Mattaponi formation (Upper Cretaceous and Paleocene):		
Rock, soft	1	327
Clay, tough, gray	49	376
Rock, soft	5	381
Clay, tough, gummy, gray	13	394
Rock, soft	1	395
Clay, very tough, gray	11	406
Rock, soft	1	407
Clay, tough, gray	13	420
Clay, hard, sandy, gray	16	436
Clay, very sticky, brown	4	440
Clay, sticky, sandy, gray	20	460
Clay, sandy, gray	7	467
Sand, hard, fine	1	468
Clay, black sandy	10	478
Sand, fairly fine	4	482
Sand, coarse; water	18	500
Sand, medium coarse; water	20	520
Clay, fine, sandy	6½	526½

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 8, Lee Hall Reservoir; Newport News Water Commission

[Log by Sydnor Pump & Well Co., Inc. Altitude, 15 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, hard, yellow	6	6
Clay, tough	6	12
Sand and boulders	3	15
Chesapeake group (Miocene):		
Clay, gray	10	25
Clay, gray, and shells	26	51
Sand, clay, shells	8	59
Clay, gray, and shells	31	90
Clay, hard, and shells	3	93
Clay, gray, and shells	81	174
Clay, gray, sticky	56	230
Clay, gummy, gray	20	250
Clay, green, gummy	30	280
Clay, gray	22	302
Chickahominy formation (Eocene):		
Rock	1	303
Clay, green, sand, shale	7	310
Rock, soft	½	310½
Clay, green, and sand	11½	322
Clay, tough, sticky, green	18	340
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, tough, gummy, gray	70	410
Clay, sticky, gray	34	444
Sand, quartz; streak of clay at 462½ to 463½ feet; water	26	470

Well 17, Fort Eustis; U. S. Army

[Log by Sydnor Pump & Well Co., Inc. Altitude, 7 feet. The sediments from 281 to 437 feet probably consist of about 40 feet of Chickahominy and 116 feet of Mattaponi formation deposits]

	Thickness (feet)	*Depth (feet)*
Chesapeake group (Miocene):		
Sand, light-brown, fine, and shell fragments	106	106
Clay, brown, and shells; large shells nearly 1 inch thick at 260 feet	175	281
Undifferentiated (Eocene):		
Sand, black	156	437
Sand, coarse, light-colored, and gravel; many subangular pebbles as much as 2 inches in diameter; water	10	447

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 20, Lee Hall; Fort Eustis

[Log by Layne-Atlantic Co. Altitude, 31 feet. Sediments from 300 to 460 feet probably consist of about 40 feet of Chickahominy formation underlain by 120 feet of Mattaponi formation]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, red, sandy	30	30
Sand, blue, and clay	7	37
Chesapeake group (Miocene):		
Marl, sandy, blue; contains shells	128	165
Clay, blue	120	285
Marl, blue; contains shells	15	300
Undifferentiated:		
Marl, sandy, blue; contains shells	15	315
Marl, gray; contains shells	145	460
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, tough, brown	2	462
Sand; water	81	543

Well 21, Lee Hall; Fort Eustis

[Log by Layne-Atlantic Co. Altitude, 34 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, sandy, red	18	18
Sand, white, and clay	20	38
Chesapeake group (Miocene):		
Clay, blue, sandy	18	56
Sand, blue, and shells	15	71
Marl, sandy, blue; contains shells	15	86
Clay, sandy, blue	50	136
Marl; contains shells	44	180
Clay, tough, blue; Foraminifera	116	296
Chickahominy formation (Eocene): Clay, blue; Foraminifera	59	355
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, tough, blue	31	386
Clay, sandy, blue	91	477
Limestone, glauconitic	62	539
Clay, blue	11	550
Clay, sandy	50	600
Sand	40	640
Sand, clayey	20	660
Sand; water	22	682
Clay	10	692

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 22, Lee Hall; Fort Eustis

[Log by Layne-Atlantic Co. Altitude, 37 feet. Chickahominy formation may be thinner than indicated below]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, red, sandy	20	20
Sand, blue, clayey	10	30
Chesapeake group (Miocene):		
Marl, sandy; contains shells	77	107
Marl; contains shells	167	274
Clay, tough, blue	37	311
Chicakahominy formation (Eocene):		
Sand and shells	20	331
Clay, sandy, blue	52	383
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, tough, blue	8	391
Clay, sandy, blue	49	440
Limestone, glauconitic, and blue marl	13	453
Sand; water	97	550

Well 23, Mulberry Island Rifle Range; U. S. Army

[Log by Sydnor Pump & Well Co., Inc. Altitude, 10 feet]

	Thickness (feet)	*Depth (feet)*
Undescribed	324	324
Mattaponi formation (Upper Cretaceous and Paleocene):		
Limestone, glauconitic	15	339
Clay, gray	43	382
Sand, gray	11	393
Clay, hard, blue	13	406
Sand, clayey	9	415
Sand, coarse, gray, micaceous; water	50+	465+

Well 29, Camp Patrick Henry; U. S. Army

[Log by Sydnor Pump & Well Co., Inc. Altitude, 30 feet]

	Thickness (feet)	*Depth (feet)*
Undescribed	390	390
Chickahominy formation (Eocene):		
Clay, gray; with scant glauconite	35	425
Sand, quartz, medium-grained, gray; with minor amount of glauconite; water	13	438
Clay, greenish-gray, sandy	4	442
Sand, quartz, medium-grained; with minor amount of glauconite; water	8	450
Mattaponi(?) formation (Upper Cretaceous and Paleocene):		
Clay, greenish-gray	42	492

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 30, Camp Patrick Henry; U. S. Army

[Log by Virginia Machinery & Well Co., Inc. Altitude, 30 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene):		
Clay, blue and yellow	5	5
Gravel, large	3	8
Mud, yellow	4	12
Chesapeake group (Miocene):		
Marl, contains shells, light-blue, sandy	33	45
Marl, light-blue; contains shells	155	200
Marl, light-blue	180	380
Chickahominy formation (Eocene): Marl, black, glauconitic	50	430
Mattaponi(?) formation (Upper Cretaceous and Paleocene): Clay, greenish-gray	124	554

Well 33, Big Bethel Reservoir; U. S. Army

[Log by D. J. Cederstrom. Altitude, 30 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Sand	20	20
Chesapeake group (Miocene): Marl, blue, rich in shells at several horizons; thin rock layers at 127, 174, and 180 feet	160	180

Well 34, Big Bethel Reservoir; U. S. Army

[Log by D. J. Cederstrom. Altitude, 30 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	30	30
Chesapeake group (Miocene):		
Sand, yellow, and shells	10	40
Clay, bluish, sandy; with minor amount of shells	14	54
Shells; sized fragments to ¼ inch in diameter; minor amount of sand, no clay; water	41	95
Sand, fine; small percentage of glauconite and shells; water	22	117
Clay, blue	4	121
Silt, with minor amount of clay	24	145
Clay, blue	20	165

Well 44, Newport News; Virginia Public Service Co.

[Log by Layne-Atlantic Co. and D. J. Cederstrom. Altitude, 12 feet. Well drilled by the Layne-Atlantic Co. Foraminifera determined by J. A. Cushman. Log at 372 feet from cuttings collected by the Layne-Atlantic Co.; below 372 feet the well was logged by the writer]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow, sandy	34	34
Chesapeake group (Miocene):		
Sand, fine, clayey	30	64
Marl, very sandy, gray; contains shells	32	96
Sand, fine, gray	30	126
Marl, slightly sandy, gray; contains shells	30	156
Marl, sandy, gray; contains shells	10	166
Sand and shells	24	190
Clay, sandy, gray	30	220
Marl; contains shells	30	250

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 44, Newport News; Virginia Public Service Co.—Continued

	Thickness (feet)	Depth (feee)
Clay, dark-gray	92	342
Clay, tough, gray	30	372
Clay, slightly glauconitic, gray	31	403
Chickahominy formation (Eocene):		
Sand, medium- to fine-grained glauconitic, quartz; water	22	425
Clay, glauconitic, gray	78	503
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, glauconitic, gray	67	570
Clay, slightly glauconitic, gray; drills rather slowly	34	604
Clay, sandy, gray; grades down to hard-packed glauconitic sand	40	644
Glauconite with alternating streaks of quartz sand and soft mottled (pink, brown, green) clay	31	675
Sand, glauconitic quartz; contains about 35 percent mottled clay	10	685
Clay, mottled; contains about 35 percent glauconitic quartz sand	21	706
Clay, mottled; with streaks of more sandy clay	31	737
Clay, mottled; drills very slowly	23	760
Clay, sandy, mottled	26	786
Sand, quartz, medium-grained, gray, slightly glauconitic; water	18	804
Sand, slightly clayey	4	808
Sand, quartz, medium-grained; contains very little clay; water	27	835
Clay, sandy	2	837
Sand; water	2	839
Clay, slightly sandy, green	14	853
Clay; drills very slowly	5	858
Sand, gray, slightly glauconitic, medium-grained; water	14	872
Clay, sandy	39	911
Sand, loose; contains thin streaks of clay; good water-bearing formation	18	929
Sand, quartz, clayey, slightly glauconitic	10	939
Clay	9	948
Sand, quartz, slightly glauconitic medium-grained; water (?)	3	951
Clay, mottled (pink, brown, green)	4	955
Sand, medium-grained; water	4	959
Sand, clayey, slightly glauconitic	9	968
Sand, medium-grained; contains traces of glauconite and clay; water	21	989
Sand, clayey	9	998
Sand, loose; with thin clay streaks; water	12	1,010
Clay, hard; drills very slowly	3	1,013
Sand, quartz, gray, medium-grained; trace of glauconite; water	22	1,035
Sand, slightly clayey	10	1,045
Sand; trace of glauconite, coarse at 1,082 feet; water	37	1,082

TABLE 33.—*Logs of wells in Warwick County, Va.*—Continued

Well 46. Newport News; Levinson Meat Packing Co.

[Log by Mitchell's Well & Pump Co. Altitude, 8 feet]

	Thickness (feet)	*Depth (feet)*
Columbia group (Pleistocene): Clay, yellow	20	20
Chesapeake group (Miocene):		
Clay, blue	65	85
Clay, shells, and sand	15	90
Clay, blue	30	120
Sand, fine	5	125
Clay, blue	250	375
Clay, green	30	405
Clay, blue	4	409
Chickahominy formation (Eocene):		
Rock, greenish	6	415
Clay, blue	15	430
Sand, black, and blue clay	10	440
Clay, blue; with small amount of black sand	25	465
Sand, black, and blue clay	10	475
Clay, blue; with scant black sand	20	495
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue; with scant black sand	85	580
Clay, blue	20	600
Clay, red	40	640
Clay, blue	5	645
Rock, and black sand; in sheets	15	660
Clay, blue, and scant black sand	20	680
Clay, red	20	700
Clay, brown, and black sand	10	710
Sand, black and white	5	715
Mud, red	5	720
Mud, blue, and black sand	10	730
Clay, mottled, red and yellow	30	760
Clay, gray	37	797
Rock	3	800
Clay, gray; with mica	20	820
Clay, gray	5	825
Sand, green	2	827
Clay, yellow	8	835
Clay, red	11	846
Clay, sandy, gray	24	870
Clay, red and blue	10	880
Sand, fine, and a little clay	20	900

TABLE 34.—*Chemical analyses of waters from wells in Warwick County, Va.*

[Analyses in parts per million. Analyst: MDF, M. D. Foster; WMN, W. M. Noble; LWM, L. W. Miller; JDB, J. D. Boreman; HBR, H. B. Riffenberg; EWL, E. W. Lohr; GWW, G. W. Whetstone; DMD, D. M. Derrick. See also table 32]

	Well no.				
	1	2	8	8	9
Location	Skiffs Creek	Skiffs Creek	Lee Hall	Lee Hall	Lee Hall
Depth (feet)	525	550	470	475	457
Formation	Mattaponi	Mattaponi	Mattaponi	Mattaponi	Mattaponi
Date	Nov. 22, 1941	Aug. 5, 1940	Nov. 21, 1941	Feb. 18, 1942	Feb. 18, 1942
Silica (SiO_2)					
Iron (Fe)					
Calcium (Ca)					
Magnesium (Mg)					
Sodium (Na)					
Potassium (K)					
Bicarbonate (HCO_3)	457	452	546	542	504
Sulfate (SO_4)	64	56	112	140	68
Chloride (Cl)	410	448	1,050	1,065	690
Fluoride (F)	2.0	2.6	1.4	1.8	2.4
Nitrate (NO_3)					
Carbon dioxide (CO_2)		5.8			
Hardness (as $CaCO_3$)	15	14	40	48	24
Dissolved solids					
Analyst	MDF	MDF, WMN	MDF	MDF	MDF

	Well no.				
	11	11	13	15	15
Location	Fort Eustis	Fort Eustis	Fort Eustis	Fort Eustis	Fort Eustis
Depth (feet)	515	515	450(?)	367	367
Formation	Mattaponi	Mattaponi	Mattaponi	Mattaponi	Mattaponi
Date	Oct. 18, 1918	Aug. 4, 1940	Feb. 6, 1941	Oct. 18, 1918	Feb. 6, 1941
Silica (SiO_2)					
Iron (Fe)	0.15			0.15	
Calcium (Ca)	5.4			5.4	
Magnesium (Mg)	3.6			4.4	
Sodium (Na)	421				
Potassium (K)	12				
Bicarbonate (HCO_3)	495	430	419	463	436
Sulfate (SO_4)	49	48	22	36	30
Chloride (Cl)	370	415	202	250	250
Fluoride (F)		2.6	2.8		2.8
Nitrate (NO_3)	.26			Trace	
Dissolved solids	1,191			949	
Hardness (as $CaCO_3$)	28	21	10	32	12
Carbon dioxide (CO_2)		5.8			
Analyst		MDF, WMN	MDF, LWM	MDF	MDF, LWM

TABLE 34.—*Chemical analyses of waters from wells in Warwick County, Va.*—Con.

	Well no.				
	16	17	18	19	20
Location	Fort Eustis	Fort Eustis	Fort Eustis	Fort Eustis	Fort Eustis
Depth (feet)	370	447	454	498	543
Formation	Mattaponi	Mattaponi	Mattaponi	Mattaponi	Mattaponi
Date	Feb. 6, 1941	Oct. 15, 1918	Feb. 6, 1941	July 7, 1942	July 7, 1942
Silica (SiO_2)				17	17
Iron (Fe)		Trace		.04	.06
Calcium (Ca)		4		4.6	4.8
Magnesium (Mg)		4.2		2.2	2.6
Sodium (Na)		} 521		434	473
Potassium (K)				8.7	9.0
Bicarbonate (HCO_3)	433	638	469	464	471
Sulfate (SO_4)	27	81	46	56	60
Chloride (Cl)	268	390	392	385	440
Fluoride (F)	3.0		2.8	2.8	2.9
Nitrate (NO_3)		Trace		.3	.3
Dissolved solids		1,442		1,152	1,252
Hardness (as $CaCO_3$)	10	27	15	20	22
Carbon dioxide (CO_2)					
Analyst	MDF, LWM	JDB	MDF, LWM	JDB	JDB

	Well no.				
	21	22	24	25	27
Location	Fort Eustis	Fort Eustis	Mulberry Island	Curtis Point	Mohea
Depth (feet)	692	550	417	363	510
Formation	Mattaponi	Mattaponi	Mattaponi	Mattaponi	Mattaponi
Date	July 7, 1942	July 7, 1942	Oct. 15, 1918	1910	Feb. 26, 1942
Silica (SiO_2)	22	17		18	
Iron (Fe)	3.8	.21	Trace	.12	
Calcium (Ca)	5.2	4.5	4.0	7.2	
Magnesium (Mg)	2.3	2.3	4.5	1.2	
Sodium (Na)	489	454	} 390	350	
Potassium (K)	8.0	9.0			
Bicarbonate (HCO_3)	443	475	621	540	436
Sulfate (SO_4)	50	56	58	32	52
Chloride (Cl)	491	408	216	244	360
Fluoride (F)	2.2	2.9			2.8
Nitrate (NO_3)	.7	.8	Trace		
Dissolved solids	1,305	1,201	1,130		
Hardness (as $CaCO_3$)	22	20	28	23	18
Carbon dioxide (CO_2)					
Analyst	JDB	JDB	HBR	HBR	MDF

TABLE 34.—*Chemical analyses of waters from wells in Warwick County, Va.*—Con.

	Well no. 29	Well no. 31	Well no. 34	Well no. 38	Well no. 40
Location	Camp Patrick Henry	Denbigh	Harpersville	Morrison	Morrison
Depth (feet)	492	517	165	738	732
Formation	Chickahominy	Mattaponi	Yorktown	Mattaponi	Mattaponi
Date	Oct. 16, 1942	Feb. 25, 1942	Mar. 21, 1942	Aug. 5, 1940	Aug. 6, 1940
Silica (SiO_2)					
Iron (Fe)	18				
Calcium (Ca)					
Magnesium (Mg)					
Sodium (Na)					
Potassium (K)					
Bicarbonate (HCO_3)	724	490	242	456	398
Sulfate (SO_4)	300	52	8	56	60
Chloride (Cl)	2,200	455	109	495	755
Fluoride (F)	.9	3.0	.4	2.6	1.7
Nitrate (NO_3)			1.6		
Dissolved solids					
Hardness (as $CaCO_3$)	240	15	200	18	12
Carbon dioxide (CO_2)				6.8	
Analyst	EWL	MDF	MDF	MDF, WMN	MDF, WMN

	Well no. 41	Well no. 42	Well no. 43	Well no. 46
Location	Mariners Museum	Newport News	Newport News	Newport News
Depth (feet)	1,000	813	401-463	900
Formation	Mattaponi	Mattaponi	Chickahominy	Mattaponi
Date	Feb. 26, 1942	Aug. 13, 1946	May 31, 1944	Dec. 12, 1940
Silica (SiO_2)		16		
Iron (Fe)		.09		
Calcium (Ca)		5.8		
Magnesium (Mg)		3.3		
Sodium (Na) and Potassium (K)		589		
Bicarbonate (HCO_3)	452	475	1,184	614
Sulfate (SO_4)	52	65	135	75
Chloride (Cl)	660	600	1,080	690
Fluoride (F)	2.2	2.0	1.2	1.2
Nitrate (NO_3)		.5	.6	
Dissolved solids	1,650	1,510		
Hardness (as $CaCO_3$)	24	28	144	22
Carbon dioxide (CO_2)			1.4	
Analyst	MDF	GWW	DMD	MDF, LWM

ELIZABETH CITY COUNTY[4]

Elizabeth City County fronts Chesapeake Bay at the eastern end of the York-James Peninsula. The area is 56 square miles and has a population of 60,994 (Virginia Division of Planning and Economic Development, 1951). Urban communities are Buckroe Beach, Fort Monroe, Phoebus, and independent city of Hampton. A smaller center of population in the northern part of this small county surrounds Langley Field, where the Army Air Forces and the National Advisory Committee on Aeronautics have extensive installations.

The value added to products by manufacture in 1947 was $1,581,000, more than two-thirds of which is credited to Hampton. Lumber products come from the rural areas and packaged seafoods from Hampton. Some farms and dairies are in the county; the value of farm products (poultry, dairy, and horticultural specialties) was $539,537 in 1949. Fishing is the livelihood of a few individuals, and a brisk business in furnishing vacation amusements and services is done in the summer season at Buckroe Beach.

TOPOGRAPHY

The entire county is low and flat, rising less than 20 feet above sea level, except in a small strip along the northwestern boundary with Warwick County, where it approaches an altitude of 30 feet. This terrace is identified as the Pamlico terrace.

The area is broken by swampy sluggish tidal streams and small bays. Marine erosion and deposition have been effective and have created a wide sandy beach along Chesapeake Bay, extending from the tip of the North End Point to Buckroe Beach on the mainland and still farther southward to make the spit, on the hook of which Fort Monroe is located, at Old Point Comfort. In the vicinity of Hampton Roads to the south erosion has been most effective; the fairly smooth coast is characterized by poor beaches.

GEOLOGY

The main aspects of the geology of Elizabeth City County have been known since 1902, when Folio 80 of the U. S. Geological Survey was published (Darton, 1902); in it the results of deep drilling for fresh water at Fort Monroe were discussed. Although the deep holes drilled by the Army and subsequent efforts (Cederstrom, 1943b) to obtain fresh water by deep drilling in the lower peninsula have proved fruitless, the information thus gained has served as a geologic guidepost for the entire Virginia Coastal Plain.

[4] As of July 1, 1952, the entire county of Elizabeth City County and the independent city of Hampton became a first-class city designated Hampton.

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GRANITIC BEDROCK

The granitic rock forming the basement on which the unconsolidated coastal plain sediments rest was struck at 2,246 feet below the surface at Fort Monroe (8c, table 35, fig. 21). Only one other well in the eastern part of the Virginia Coastal Plain, at Mathews, has been drilled to basement rock.

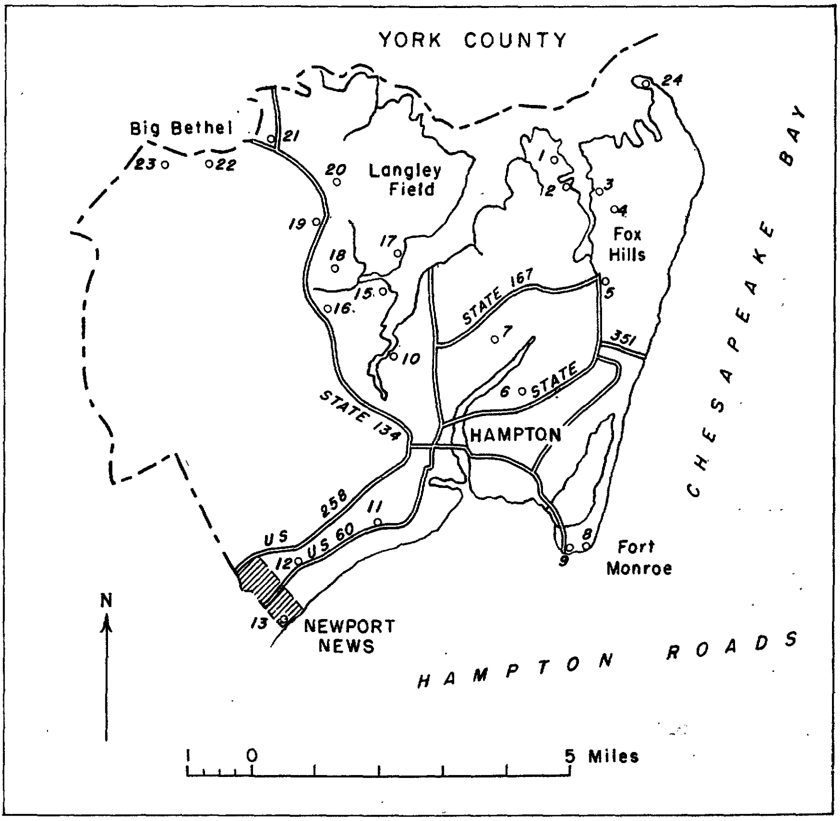

FIGURE 21.—Location of wells in Elizabeth City County. (See footnote 4, p. 217.)

CRETACEOUS SYSTEM—POTOMAC GROUP

According to Darton, Cretaceous sediments, presumably the Potomac group, extend from a depth of 900 feet to basement rock at Fort Monroe. In this report they are considered to extend from about 1,300 feet to basement rock. The sediments contain many productive water-bearing beds but the water obtained from them is brackish.

CRETACEOUS TO TERTIARY SYSTEMS

UPPER CRETACEOUS AND PALEOCENE SERIES—MATTAPONI FORMATION

Units of Late Cretaceous age have been identified at Norfolk (Darton, 1902) and elsewhere (Cederstrom, 1945a, p. 27–33; Richards, 1947) south of the James River. Darton indicated that these beds are present at Fort Monroe, although he had no paleontologic evidence.

The series of mottled clays and basal sandy sediments that are widely distributed in eastern Virginia, named the Mattaponi formation in this report, of Late Cretaceous and Paleocene age, are considered to extend from about 700 to about 1,300 feet below the surface at Newport News. The coarse sand, gravel, and boulders reported between 1,255 and 1,320 feet at Fort Monroe (see log of well 8c, table 36) seemingly mark the base of the Mattaponi formation there.

The sands of the Mattaponi formation are prolific water bearers in eastern Virginia. However, in the lower end of the peninsula the water obtained from these beds is brackish.

TERTIARY SYSTEM

EOCENE SERIES

Eocene sediments, largely glauconite sands, glauconitic marls, and subordinate quartz sand, lie at depths between 610 feet and about 850 feet at Fort Monroe.

The writer believes that both the Aquia formation and most or all of the Nanjemoy formation are absent here, having been removed by the transgressive late Eocene sea.

The Chickahominy formation is 80 feet thick at Yorktown. It is thought to be not more than 125 feet thick at Fort Monroe. However, in the absence of a suite of uncontaminated samples from depths in question, not much can be said definitely about the formation in the lower peninsula area. The Chickahominy is at best a poor water-bearing formation in this area.

MIOCENE SERIES

The Chesapeake group of Miocene age extends from a depth of 40 or 50 feet to 600 feet below the surface at Fort Monroe. It consists of shell marls, clays, fine silts, and subordinate sand beds.

The basal Calvert formation, which is ordinarily somewhat sandy, yields water in some places, but no wells are developed in this stratum in Elizabeth City County.

The Yorktown formation contains sand lenses that yield water. However, the occurrence of these lenses is very spotty, and in Elizabeth City County the formation is more often barren than productive.

The St. Marys formation, which lies between the basal Calvert and the upper Yorktown formations, is made up largely of clays (Clark and Miller, 1912, p. 158) and is not water bearing.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

Terrace deposits of Pleistocene age form the surface of the county everywhere. These are fine gray and white silts and sands and gray shell marls. In most places small quantities of water may be obtained from shallow dug or driven wells in these deposits.

RECENT SERIES

It is of interest to note the thickness of Recent deposits at the North End Point sand spit (24, table 36). Here sands at the surface extend to a depth of 75 feet as a result of cut and fill action of marine currents and the spit is comparable in thickness to Cape Henry (Cederstrom, 1945a, p. 360). At more inland localities, the surficial deposits of Recent and Pleistocene age are ordinarily less than 30 feet thick.

MUNICIPAL WATER SUPPLIES

In most of Elizabeth City County ground water contains some chloride and the water is unsuitable for many or nearly all purposes. In a few places moderate supplies of fresh water are available, 5 to 50 gpm per well, but beds furnishing such supplies are lenticular and cannot be relied upon throughout any particular area. Shallow wells yield small to moderate quantities of fresh water over large areas, but they are not considered desirable in urban localities because they are easily subject to organic contamination. Hence, municipal systems were developed early to provide urban and many rural areas with dependable water supplies.

Big Bethel Reservoir, about 3 miles west of Langley Field, is owned by the U. S. Government and serves Langley Field and Fort Monroe. The filtration plant has a normal capacity of 2 mgd.

Suburbs east of Newport News, Hampton, Phoebus, Buckroe Beach, and Fox Hills and adjacent rural areas are supplied by the Newport News water system. (See p. 200.)

WATER-BEARING FORMATIONS

CRETACEOUS TO TERTIARY SYSTEMS—LOWER CRETACEOUS TO EOCENE SERIES

The deep wells in Elizabeth City County are important in that they provided valuable geologic and hydrologic information at a very early date. Unfortunately, these wells produced only brackish water.

According to Darton (1896, p. 167), the first attempt to obtain water at Fort Monroe was made in 1845, when a well was drilled there to a depth of 168 feet. In 1869 a government-sponsored well reached a depth of 907 feet. A flow of "very saline water" was obtained at 599 feet from gray sand (basal Miocene), with a head of about 14 feet above sea level.

In 1886 a deep hole was drilled at North End Point, about 7 miles north-northeast of Fort Monroe. There is no record of the quality of the water obtained and the quantity (as flow?) was meager. The log has been preserved (24, table 36) and is of particular interest; many layers of "hard sandstone" are reported below 926 feet and the "hardest kind of stone or granite" was found at 1,170 feet, which caused abandonment of the well at 1,172 feet. Darton states (1896 p. 172) that "the nature of the rock was surmised only from its hardness." It is the writer's opinion that the "rock" is neither sandstone nor granite, but probably is limestone. The thick limestone beds at Fort Eustis, as observed in wells 21 and 23 (table 33), may be recalled. The consolidated strata at North End Point are more likely Paleocene than Eocene in age, as they are at Fort Eustis.

In 1896 another effort was made to obtain potable water from depth at Hotel Chamberlain, immediately adjacent to Fort Monroe. This well reached a depth of 945 feet. The well was flowing when visited by Sanford in the early 1900's, and he was moved to remark "the well gives a rather small flow of the saltiest and most mineralized water yielded by any flowing well in the Norfolk–Newport News area." An analysis made in 1906 (Sanford, 1913, p. 350) indicates that the chloride content of the water was 4,978 ppm.

A final attempt to find fresh water at Fort Monroe was made in 1902. This well (8c), begun at an altitude of 3 feet above sea level, was sunk to a depth of 2,251 feet. The drill struck granitic bedrock at a depth of 2,246 feet.

The well was not properly tested for either volume or quality of the water but the records of sand and gravel beds found indicate that large quantities should be available at several horizons. Water samples obtained at 1,317 and 2,128 feet were "very salty."

In recent years several deep holes have been drilled in Elizabeth City County and at adjacent Newport News (42, 43, 44, 46, table 32; 13, table 35), and data on quantities of water available from the water-bearing beds have been obtained. However, all water obtained had been somewhat brackish.

Although logs of deep wells mentioned in the preceding paragraphs show that sand and gravel beds that may be expected to yield fairly large quantities of water occur from place to place below a depth of 600 feet, the water available is brackish and unfit for most purposes. Hence, no further discussion of these beds will be included here.

Very few wells in the county obtain water from the Yorktown formation of Miocene age. A well (7c) 178 feet deep at the Hampton Heights Dairy obtains about 12 gpm. A somewhat shallower well at that place failed to obtain more than a minimum quantity of water. The well (12) at Wythe Theatre is of especial interest. Here 120 gpm was obtained with 23 feet of drawdown. More than 100 gpm is pumped for air conditioning. It is not certain that all the water is obtained from Miocene deposits as screens are placed as high as 30 to 50 feet.

Three test holes (22, 23, table 35; 48, table 28) drilled to depths of less than 200 feet near Big Bethel Reservoir under the writer's direction for Army officials at Fort Monroe found only fine water-bearing sands. A hole drilled half a mile west of Harpersville (33, table 32), in Warwick County, found slightly coarser material but another hole drilled still nearer Harpersville (35, table 32) found only blue mud to a depth of 180 feet. However, in this same exploratory program, a well drilled a quarter of a mile west of Harpersville (34, table 33) struck medium-grained sand and a stratum of sorted shell, which yielded 115 gpm with 81 feet of drawdown.

The Big Bethel drilling project illustrates the variability of the Miocene series in the lower peninsula area. Briefly, in a few places moderate supplies of water are available but elsewhere even small supplies are obtained with difficulty.

At the wind tunnel of the National Advisory Committee on Aeronautics at Langley Field a determined effort was made in 1942 to obtain a small quantity of water for air conditioning. A shell and fine sand bed was found between 134 and 194 feet, which yielded 18 gpm to a turbine pump. The well failed to stabilize and continued to produce much fine sand after several days of pumping, and it was therefore abandoned.

Such a well might possibly be stabilized by using an artificial pack of medium- or coarse-grained sand (not gravel) around the screen. Mr. O. C. Brenneman of Providence Forge maintains that this type of fine sand stratum can be brought into production by seating an open-end casing on an overlying hard clay or limestone stratum and pumping to create a cavity in the fine sand beneath that stratum. The extent to which this technique might be effective in large-diameter wells intended to produce a maximum supply of water is problematic, however. In general, a shallow fine sand stratum, producing 30 to 50 gpm of water and sand, can be pumped at a lesser rate and produce perhaps 10 or 15 gpm of clear sand-free water.

Strata similar to those at Big Bethel and Langley Field are in use or have been used as sources of supply at a few other places in the county (1, 4, table 35). A stratum at 178 feet furnishes about 12 gpm for cooling purposes at the Hampton Heights Dairy (7c).

QUATERNARY SYSTEM—PLEISTOCENE SERIES

The shallow terrace formations are believed to be productive of rather small quantities of water in most places. A number of homes and small farms obtain sufficient water from shallow driven or dug wells. At several places yields from 5 to 15 gpm are reported, but it is thought that this is a rather optimistic estimate based upon intermittent operations. However, at the Bloxom Nursery a shell "marl" stratum consisting entirely of shells (hence a shell bed) yields 40 gpm to a dug well (5). This is comparable to results obtained from shallow shell strata in the vicinity of Norfolk (Cederstrom, 1945a, p. 337), where Pleistocene and Miocene deposits furnish small-diameter wells with enough water for irrigation.

QUALITY OF WATER

WATER FROM THE CRETACEOUS TO TERTIARY SYSTEMS

Water from deep wells is brackish and represents a mixture of fresh water, which has migrated from the west, and sea water, with which the sediments were once completely saturated. The maximum chloride content noted was 4,978 ppm, from a deep well at Hotel Chamberlain. On the other hand, water from a deep well at the Peninsula Dairy, in nearby Newport News, contained only 600 ppm of chloride. It is entirely probable that the range in chloride content is great and at any particular spot waters from different depths would differ in chloride content, depending in part upon the permeability of the sediments. However, there is no basis for believing that a stratum at any depth would yield water that is essentially free of or very low in chloride.

WATER FROM THE MIOCENE SERIES

Water from wells in Miocene deposits less than 200 feet deep may be expected to contain moderate amounts of chloride but not in such quantities as to preclude its usefulness for many purposes.

Water from Miocene beds in Warwick County just west of Big Bethel Reservoir (34, table 34) is a hard calcium bicarbonate water containing 109 ppm of chloride. The sulfate content is low, 8 ppm, and only 0.4 ppm of fluoride is noted.

At the Hampton Heights Dairy (7c, table 37) water from a depth of 178 feet contains 950 ppm of chloride. Other constituents are characteristic of salt-water contamination; hardness is 231 ppm, sulfate is 119 ppm, and fluoride is low. The water is used for air conditioning.

This water, like water from deep wells in the area, appears to represent a mixture of a little sea water with which the sediments were once contaminated and normal ground water that has moved in from the west.

WATER FROM THE PLEISTOCENE SERIES

The quality of water from shallow wells varies according to the nearness of the locality to the sea. Where sandy deposits lie close to salt-water bodies contamination from the present sea occurs. A sample (3) from a dug well near Fox Hills contained 715 ppm of chloride and had other characteristics of sea-water contamination. Although fresh water tends to float on salt water, mixing due to constant tide movements occurs, particularly near the shore, and skimming of fresh water does not seem possible. In any event, the water in this community has always been regarded as unfit for drinking.

At Bloxoms Corner, which is somewhat inland, shallow wells (5) yield a moderately hard calcium bicarbonate water practically free of chloride.

At Buxton Hospital several shallow driven wells near the shore yielded fresh water at first but upon continuous operation they became salty. It is to be expected that such shallow wells that become salted will freshen after a period of rest, during which time a fresh-water lens has opportunity to form again over the salt water. Salting of shallow wells is best avoided by sinking the wells no more than a few feet below the water table, and by pumping at a moderate rate from several widely spaced wells rather than from only one well.

TABLE 35.—*Records of wells in Elizabeth City County, Va.*

[Type of well: Dg, dug; Dr, drilled; Dv, driven; J, jetted. Use of water: Ab, abandoned; C, cooling; D, domestic; Irr, irrigation; S, stock]

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level (feet above (+) or below (−) surface)	Chloride content (parts per million)	Use of water	Remarks
1	Near Stony Point	Sergt. Spencer	Budd Wyatt		Terrace	3	J	120	2	−		D	Yields 10 gpm.
2	do	G. Cosby			do	3	J	79	2	−		D	Water is hard. Yields 5 gpm.
3	Fox Hills	F. B. Johnson			do	4	Dg	20		−8	715	D	Water is brackish. Water level 1 foot below surface at high tide.
4	do	High School	Budd Wyatt		do	4	J	120	3	−7		Ab	Yielded more than 10 gpm.
5	Bloxoms Corners	N. E. Bloxom	Owner		do	6	Dg	10		−	26	Irr	Yields up to 40 gpm from a shell bed. See analysis, table 37.
6	East bank of Hampton Creek.	Bayview Dairy			do	11	J	30	2½	−3 to −8		S, C	Yields 10 to 15 gpm, from a shell bed.
7a	1 mile northeast of Hampton.	Hampton Heights Dairy.			do	10	Dg	18		−	52	Ab	Yields a maximum of 15 gpm. See analysis, table 37.
7b	do	do	Layne-Atlantic Co.		do	8	J	120	2	−		Ab	Yields 2 gpm by suction, 3½ gpm with 60 feet of cylinder.
7c	do	do	Sydnor Pump & Well Co., Inc.		do	8	Dr	178	8		950	C	See analysis, table 37.
8a	Old Point Comfort	Fort Monroe		1845	do			168				Ab	
8b	do	do		1869	do	3		907				Ab	Water at 599 feet is salty.
8c	do	do		1902	do	3	J	2,254	15–9			Ab	Rock at 2,240 feet. Water at 1,317 and 2,128 feet very salty. See log, table 36.
9	do	Hotel Chamberlain		1896	do	4	J	945	4		4,978		See log, table 36.
10	1 mile north of Hampton.	Seldon Dairy			do	4	Dg	15		−		S, C	Furnishes about 7,000 gpd.
11	1 mile southwest of Hampton.	LeMack Nursery	Owner		do	11	Dv	16		−		Irr	
12	½ mile east of Newport News.	Wythe Theatre	Mitchell's Well & Pump Co.		do	12	Dr	138	8	−	54	C	Strainer at 30 to 50 feet and 74 to 79 feet, slotted pipe from 100 to 140 feet. See analysis, table 37.

TABLE 35.—*Records of wells in Elizabeth City County, Va.*—Continued

No.	Location	Owner or user	Driller	Year completed	Topographic situation	Approximate altitude above sea level (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Approximate water level (feet above (+) or below (−) surface)	Chloride content (parts per million)	Use of water	Remarks
13	Newport News	Buxton Hospital	do		do	11	Dr	820	8	+2	1,620	Ab	See analysis, table 37; log, table 36.
15	2 miles northwest of Hampton.	Tide Mill Farm			do	8	Dg	13		−8½		S	Water level on Aug. 3, 1940.
16	do	Seldon Dairy			do	10	Dg	20		−6½		S, C	Supplies small dairy. Yields about 5 gpm.
17	2½ miles northwest of Hampton.	Hampton School Farm			do	5	Dg	20		−1 to −4		S	Supplies a maximum of 5,000 gpd.
18	South of Langley Field.	H. W. Parker			do	12	Dr	6		−6		D	Water is hard. Water level on Aug. 2, 1940.
19	West of Langley Field.	H. F. Collier			do	10	Dg	22		−5		D	Yield poor.
20	Langley Field	NAAC	Sydnor Pump & Well Co., Inc.		do	10	Dr	184	8			Ab	About 18 gpm obtained, but well failed to clear of fine-grained sand.
22	Big Bethel	U. S. Army	Layne-Atlantic Co.	1942	do	20	J	150	2			Ab	Only fine sands present.
23	do	do	do	1942	do	20	J	125	2			Ab	Only fine sands present. See log, table 36.
24	North End Point	Fish Factory	R. H. Milligan	1896	Sand spit	3(?)	J	1,172	3			Ab	See log, table 36.

TABLE 36.—*Logs of wells in Elizabeth City County, Va.*

Well 8c, Fort Monroe; U. S. Army

[Log from U. S. Geol. Survey Geol. Atlas, folio 8. Altitude, 3 feet. Chickahominy formation may not be much more than 100 feet thick]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene): Sand	50	50
Chesapeake group (Miocene):		
Clay	40	90
Sand, gray	40	130
Clay	30	160
Sand	25	185
Clay, sandy	25	210
Clay	30	240
Sand	15	255
Rock and boulders	20	275
Sand; water	20	295
Clay	230	525
Clay and sand; Foraminifera	85	610
Chickahominy formation (Eocene):		
Sand and boulders; water	30	640
Clay, glauconitic and pyritic; Foraminifera	200	840
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay and gravel	80	920
Sand, gravel, and boulders	25	945
Clay	35	980
Sand; water	5	985
Clay	105	1, 090
Boulders	5	1, 095
Sand and clay	30	1, 125
Boulders	5	1, 130
Sand and clay; residue contains 3 percent glauconite	20	1, 150
Sandstone	5	1, 155
Sand and clay; trace of glauconite	25	1, 180
Clay and small gravel; residue contains about 20 percent glauconite	20	1, 200
Sand	18	1, 218
Sand and clay	2	1, 220
Hard sand	30	1, 250
Sand, with some clay and boulders	5	1, 255
Sand, gravel, and boulders	65	1, 320
Potomac group (Lower and Upper Cretaceous):		
Sand and clay	45	1, 365
Sand, mostly coarse; with some clay	70	1, 435
Clay, red; and sand	5	1, 440
Sand, coarse; water	98	1, 538
Clay	20	1, 558
Clay and sand	17	1, 575
Sand, coarse	45	1, 620
Sand and clay; water at 1,630 feet	100	1, 720
Sand and boulders	10	1, 730
Clay	20	1, 750
Sand	50	1, 800

TABLE 36.—*Logs of wells in Elizabeth City County, Va.*—Continued

Well 8c, Fort Monroe; U. S. Army—Continued

	Thickness (feet)	Depth (feet)
Potomac group (Lower and Upper Cretaceous)—Continued		
Sand and clay	20	1,820
Sand and pebbles	10	1,830
Clay and white sand	50	1,880
Sand with minor amount of clay; water at 1,915 and 1,945 feet	120	2,000
Sand, coarse	60	2,060
Clay	5	2,065
Sand, coarse	115	2,180
Clay	66	2,246
Precambrian(?): Rock, crystalline	8	2,254

Well 9, Old Point Comfort; Hotel Chamberlain

[Log from Va. Geol. Survey Bull. 5. Altitude, 4 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand, surface	10	10
Sand, with minute fragments of shell	20	30
Chesapeak group (Miocene):		
Sand, dark-gray; spines of sea urchins plentiful	10	40
Sand, light in color	10	50
Clay, sandy; with Miocene shells	10	60
Clay, greenish, sandy	30	90
Clay, sandy; with Miocene shells	10	100
Clay, greenish, sandy; a few shells	20	120
Clay, greenish, sandy; with shells in great number	10	130
Sand, fine, dark-gray; spines of sea urchins plentiful	30	160
Clay, dark-brown, sandy; with shells	20	180
Clay, dark-green; with marine shells, of Miocene age, at 190, 200, 270 feet	100	280
Clay, dark-green; with more sand, but without shells	60	340
Clay, dark-green; not as sandy, still without shells	190	530
Clay, dark-bluish-green, diatomaceous	30	560
Clay, dark, not diatomaceous	30	590
Clay, dark-brownish, sandy	20	610
Chickahominy formation (Eocene):		
Sand, greenish, clayey; with a large admixture of glauconite grains	50	660
Clay, greenish, sandy; with glauconite	50	710
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, brown, sandy	90	800
Sand, gray; mixture of glauconite and pure quartz grains	20	820
Sand, brown, clayey; also contains a mixture of glauconite and quartz sands	20	840
Conglomerate, calcareous rock crust, and pebble; with some wood and shells	10	850
Clay, dark, sandy, micaceous	55	905
Sand, fine, gray	15	920
Gravel, coarse; water-bearing	25	945

TABLE 36.—*Logs of wells in Elizabeth City County, Va.*—Continued

Well 13, Newport News; Buxton Hospital

[Log by Mitchell's Well and Pump Co. Altitude, 11 feet]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, yellow	5	5
Clay, yellow, and shells	5	10
Chesapeake group (Miocene):		
Sand, yellow, and shells	25	35
Sand, gray, and shells	35	70
Clay, blue, and shells	20	90
Mud, gray, shells, sand	30	120
Mud, gray, and sand	114	234
Marl rock (shell)	1	235
Mud, gray, sand, shells	25	260
Clay, blue	40	300
Clay, sticky, blue	100	400
Undifferentiated (Eocene):		
Clay, blue	50	450
Sand and yellow mud	50	500
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, yellow	25	525
Mud with scant black sand	25	550
Clay, brown	50	600
Sand, black, and clay	25	625
Clay, black	32	657
Clay, blue	13	670
Sand, fine, black and white	10	680
Clay, brown	40	720
Clay, black	20	740
Sand, black, and mud	15	755
Sand, black and white; water	35	790
Sand, white; water	30	820

Well 23, Big Bethel Reservoir; U. S. Army

[Log by D. J. Cederstrom. Altitude, 20 feet. Test hole, drilled by the Layne-Atlantic Co.]

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay, yellow	4	4
Sand, white, coarse	5	9
Sand, white, clayey	2	11
Chesapeake group (Miocene):		
Clay, blue, silty; with minor amount of shells	68	79
Sand, fine, glauconitic; quartz, with minor amount of shell streaks; glauconite content up to 20 percent; water	17	96
Sand, very fine, glauconitic; quartz, with few shells	15	111
Sand or silt, packed very fine; with clay content increasing with depth	14	125

Well 24, North End Point

[Log from U. S. Geol. Survey Bull. 158. Altitude, 3(?) feet]

	Thickness (feet)	*Depth (feet)*
Quaternary (Recent): Sand, white, and gravel	75	75
Chesapeake group (Miocene):		
Clay, blue	5	80
Sand, white	20	100
Sand, thin layers, and blue clay	30	130
Sand, blue or gray	25	155
Quicksand	10	165
Sand, hard, white	5	170
Sand, loose, white	15	185
Marl, black	2	187
Sand, white, and marl	62	249
Rock	1	250
Clay, blue	17	267
Stone	1	268
Sand, hard	7	275
Clay, blue, with thin marl layers	255	530
Clay, hard, blue	70	600
Chickahominy formation (Eocene):		
Quicksand	18	618
Stone or boulder	2	620
Sand, white	5	625
Sand, yellow	1	626
Clay and sand mixed	69	695
Gravel and clay	1	696
Mattaponi formation (Upper Cretaceous and Paleocene):		
Clay, blue, hard and soft layers	44	740
Clay, very hard	8	748
Clay, soft, blue	165	913
Clay, hard, blue	7	920
Sand, coarse	6	926
Sandstone	13	939
Sandstone, hard	16	955
Sand, hard; with few gravels	18	973
Sandstone, hard	27	1,000
Sandstone; with two veins of gravel and some water	7	1,007
Sand and sandstone, alternate layers of 3 to 4 ft thick	8	1,015
Sand and sandstone, alternate layers of 3 to 15 ft thick	65	1,080
Sand, very hard, white	20	1,100
Sandstone	55	1,155
Sandstone, red	5	1,160
Sandstone, hard (boulder zone?)	10	1,170
Hardest kind of stone or granite; here drill rods broke and work was abandoned (boulder zone?)	2	1,172

TABLE 37.—*Chemical analyses of waters from wells in Elizabeth City County, Va.*

[Analyses in parts per million. Analyst: GWW, G. W. Whetstone; WHT, W. H. Taylor; WMN, W. M. Noble; MDF, M. D. Foster]

	Well no.			
	3	5	7a	7c
Location	Fox Hills	Bloxoms Corner	Hampton Heights	Hampton Heights
Depth (feet)	20	10	18	178
Formation or group	Columbia group	Columbia group	Columbia group	Yorktown formation
Date	Nov. 5, 1947	Nov. 5, 1947	Nov. 5, 1947	Nov. 5, 1947
Silica (SiO_2)			8.6	14
Iron (Fe)	0.74	0.15	.1	.04
Calcium (Ca)			67	58
Magnesium (Mg)			4.3	21
Sodium (Na) Potassium (K)			32	804
Bicarbonate (HCO_3)	134	93	176	625
Sulfate (SO_4)	160	.1	29	119
Chloride (Cl)	715	26	52	950
Fluoride (F)	.2	.0	.2	.6
Nitrate (NO_3)	.4	.1	8.0	1.6
Dissolved solids			321	2,280
Hardness (as $CaCO_3$)	360	81	185	231
Analyst	GWW	GWW	GWW	GWW

	Well no.		
	9	12	13
Location	Fort Monroe	Newport News	Newport News
Depth (feet)	945	138	820
Formation or group	Mattaponi formation	Columbia group and Yorktown formation	Mattaponi formation
Date	1896	Aug. 6, 1940	Aug. 5, 1940
Silica (SiO_2)	14	42	
Iron (Fe)	16	19	
Calcium (Ca)	97	26	
Magnesium (Mg)	44	9.0	
Sodium (Na)	3,268	61	
Potassium (K)	87	4.3	
Bicarbonate (HCO_3)	433	163	686
Sulfate (SO_4)	265	24	80
Chloride (Cl)	4,978	54	1,680
Fluoride (F)		.1	.9
Nitrate (NO_3)		.6	
Dissolved solids	9,248	306	
Hardness (as $CaCO_3$)		102	76
Analyst	WHT	WMN	MDF

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