Geology and Ground Water Resources of the Middle Peninsula, Virginia

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NOTE: This is absolutely the very best this report can be copied. The original was not good at all.

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15. Ground-water resources of the Northern Neck Peninsula, Virginia, by Allen Sinnott. 269 p., 2 pls., 10 figs. 200 West Grace St., Richmond, Va. 23220; Natural Resources Bldg., corner of McCormick and Alderman Rds., Charlottesville, Va. 22903.

16. Geology and ground-water resources of the Middle Peninsula, Virginia, by D. J. Cederstrom. 231 p., 9 figs. 200 West Grace St., Richmond, Va. 23220; Natural Resources Bldg., corner of McCormick and Alderman Rds., Charlottesville, Va. 22903.

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Geology and Ground-Water Resources of the Middle Peninsula, Virginia

By

D. J. Cederstrom

Abstract

The Middle Peninsula of eastern Virginia is part of the Coastal Plain province. It extends from the Fall Line to Chesapeake Bay and lies between the Rappahannock River on the north and York and Mattaponi Rivers on the south. Caroline, Essex, Middlesex, King and Queen, Gloucester and Mathews Counties are included in the report. Field work in the area was carried out by several individuals and this report is a synthesis of various data gathered over a period of time. Records of large yield wells drilled in the last several years do much to update the report. The geology is based largely on the writer's interpretation of drillers' logs and well records. Comparison with better controlled geology to the north and south has been helpful in arriving at some degree of accuracy in drawing of stratigraphic boundaries.

The area consists largely of farms and woodlands with scattered small villages and a few large towns. The largest town units are Port Royal, Tappahannock, and Urbanna on the Rappahannock River. Bowling Green lies inland and Mathews lies off Chesapeake Bay.

Manufacturing is not greatly important in the area and is in good part based on lumber products. Sport and commercial fishing

are important locally. Farm crops range widely in economic value from county to county. Commercial production of flowers and bulbs, particularly daffodils, is a unique feature of the Virginia Coastal Plain. A very large duck farm is located below Urbanna. Considerable development of the more desirable river front acreage has been taking place in the last decade, in part as "suburbs" of Urbanna and Tappahannock and in much greater part as summer homes of residents of Richmond, Fredericksburg, and elsewhere. A development consisting of manmade lakes, home sites, camping sites and recreational facilities is being established in Caroline County. A large military reservation, A. P. Hill, is also in Caroline County. The recreation industry is significant, therefore, in the more easterly part of the Middle Peninsula, and will probably increase in importance.

Crystalline rocks crop out in westernmost Caroline County but east of the Fall Line, crystalline rocks and Triassic sandstone lie at progressively greater depths and in Mathews County they are reached at 2,300 feet beneath the cover of Coastal Plain sediments.

Unconsolidated sediments of the Potomac group of Early and Late Cretaceous age rest upon the basement rock. They do not crop out in the area but have been penetrated by wells in central and eastern Caroline County. The deep well in Mathews County penetrates the full section of Potomac sediments. There the Potomac section may be about 900 feet thick and consists of alternating sand and clay beds.

The Mattaponi Formation of Late Cretaceous to Paleocene age consists of alternating sands and clays. The sands are glauconitic or glauconite sands and in many places the clays are highly colored. The maximum thickness may be greater than 500 feet downdip. It is believed to extend nearly to the Fall Zone in Caroline County. The Aquia Formation is a highly glauconitic series of beds of Paleocene age. It is well developed in the Fall Zone area but thins out downdip.

The Nanjemoy Formation of Eocene age is relatively thin in the Fall Zone area but thickens to about 100 feet eastward. However, like the Aquia, it also is truncated eastward by an overlying formation, the Chickahominy, of late Eocene age. It may attain a thickness of more than 125 feet in the eastern part of the Middle Peninsula. The Eocene formations are characteristically glauconitic sands and marls. Thin beds of limestone, commonly cemented shell beds alternating with thin fine glauconitic sand strata, are common. The Paleocene Aquia and Eocene Nanjemoy Formations are exposed along Rappahannock and Mattaponi Rivers but the overlying Chickahominy Formation is known only at depth.

The Late Cretaceous to Eocene beds are transected by the Chesapeake group of marly formations of Miocene age. In central Caroline County the base of the Miocene lies about 100 feet above sea level but in the counties adjacent to the bay the Miocene may extend to more than 400 feet below sea level.

The Columbia group of formations consist of a thin veneer of generally sandy terraces over the entire Coastal Plain.

Few wells develop water from consolidated bedrock beneath the Coastal Plain sediments.

East of the Fall Line water in the Cretaceous to Eocene beds occurs under artesian conditions. Many flowing wells have been constructed along the large rivers and their tributaries as a result of which artesian head is now low and many wells that once flowed must now be pumped. Industrial pumping initiated in more recent years has undoubtedly contributed to the loss of head.

Large quantities of water, 2 to 3 million gallons a day, are available from Mattaponi and Potomac Formations somewhat east of the Fall Zone. However, east of a line drawn from Burhans Wharf on the Rappahannock in lower Middlesex County and southward through western Gloucester County, artesian water is brackish to a greater or lesser degree.

The Nanjemoy and Chickahominy Formations are excellent sources of supply for domestic needs in many places. The Aquia Formation appears to be a very poor aquifer. Miocene sands are developed by wells in those areas adjacent to Chesapeake Bay. In most instances only small supplies are available. Terrace sands yield domestic supplies to thousands of dug wells throughout the Middle Peninsula.

Optimum development of ground water resources is discussed from the point of view of development of maximum hydraulic gradient toward heavily pumping wells thus inducing maximum eastward flow of artesian water and maximum roof leakage. The reservoir capacity of Coastal Plain sediments can be utilized in many places by recharging those sediments when and where excess surface water is available. Storage of fresh water in brackish water sediments is also possible. Recovery of the great volume of recharge received (and now lost to the sea) by terrace formations may be practicable by drainage through recharge wells. Pumping of brackish artesian water for special uses is suggested as a means of diminishing any tendency of the salt water front to move updip.

Deep well water in the easternmost part of the area is somewhat hard but downdip the water is softened by base exchange and a soft sodium bicarbonate water is characteristic of much of the Middle Peninsula. To the east, as noted, this water becomes brackish. In some wells ending in the shallower artesian formations, water is harder than might be otherwise expected, thus suggesting that local recharge through the roof is taking place. Water from Miocene formations is nearly always rather hard whereas that from dug wells ending in terrace sands is soft.

Caroline County lies along the Fall Zone. Bedrock crops out in the westernmost part of the county. Deep sands are fine in the central area, as at Bowling Green and some difficulty has been experienced in developing larger supplies. In the eastern part of the county Coastal Plain sands are thick, and conditions are favorable for developing large supplies. Port Royal and Bowling Green have municipal well water supplies and A. P. Hill Military Reservation is supplied by wells.

There are many domestic artesian wells along the Rappahannock in Essex County (as in Caroline County). Tappahannock has two municipal wells. One yields 200 gpm with 18 feet of drawdown. Several housing developments, a hospital, and a food processing plant are also supplied by wells.

Larger yield wells, up to 1,100 gallons a minute with 50 feet of drawdown, have been drilled at Urbanna, ~~for~~ wells supply the municipality, ~~at~~ a large duck farm downstream and ~~at~~ a few other establishments. Below Burhans Wharf, artesian water is brackish and small supplies are obtained from shallow water table wells ending in Miocene and Pleistocene strata.

No large well water supplies have been developed in King and Queen County but at West Point, adjacent to lower King and Queen, perhaps as much as 30 million ~~gallons of water a day~~ gpd, have been developed for an industrial supply.

In much of Gloucester County, artesian water is somewhat brackish. Gloucester has a municipal ground-water supply in which chloride is 355 milligrams per liter.

Artesian water in Mathews County is brackish and only small supplies are available from Miocene and Pleistocene strata.

Introduction and Acknowledgments

The purpose of this report is to make available information on the ground-water supplies in the Middle Peninsula. The data presented pertain largely to the depths of wells and the strata from which water is obtained, the quantities available and the chemical quality of the water. Where ground water is limited in quantity or saline in chemical character, effort is made to show the practicability of ameliorating potential shortages by artificial recharge.

The investigation of the ground-water resources of the Middle Peninsula in Virginia was begun in the early 1940's as a cooperative project of the Division of Geology of the Virginia Department of Conservation and Economic Development and the U.S. Geological Survey. Work continued intermittently until 1957 and was completed in 1968.

Work was performed initially under direction of the late O. E Meinzer, geologist-in-charge of the Ground Water Branch, U.S. Geological Survey and subsequently under the late A. N. Sayre who succeeded O. E. Meinzer. The work in 1968 was carried out under the general direction of G. E. Ferguson, Regional Hydrologist, Atlantic Coast ~~Section~~ Region, and J. Wyatt Gambrell, District Chief, of the U.S. Geological Survey. Virginia cooperating officials during the earlier years were the late Arthur Bevan and the late William McGill, State Geologists. In 1968, James L. Calver, State Geologist and Commissioner of the Division of Mineral Resources was the cooperating official.

Some field work in the Middle Peninsula was accomplished by the writer during World War II although at that time the greater amount of his work was carried out in the York-James Peninsula. Additional data were collected in the Middle Peninsula counties in succeeding years by Allen Sinnott, who succeeded the writer as geologist-in-charge of cooperative ground water investigations in Virginia, and by his assistant, G. Chase Tibbitts, Jr. The field was briefly visited again by the writer in 1968 at which time a number of significant wells were located and additional water samples were collected.

A little of the information obtained in this study has already been published. Reprint 6 and Circular 3 (Cederstrom, 1943b, 1945b) of the Virginia Geological Survey contain information on several of the deep wells in the Middle Peninsula, although in the present report stratigraphic boundaries have been changed. Bulletins 58 and 68 of the Virginia Geological Survey (Cederstrom, 1943a and 1946a) and a paper published in Economic Geology (Cederstrom, 1946b) deal with the chemical character of typical ground waters in the Middle Peninsula. Data given by Sanford who surveyed the Coastal Plain around 1906 (Bulletin 5 of the Virginia Geological Survey) have been drawn upon to the fullest extent possible.

Data pertaining to a number of wells drilled in ~~recent years~~ the last decade in the Middle Peninsula, records of which are filed with the Virginia Division of Mineral Resources, are included in this report and do much to update the material presented.

This report thus documents and discusses a large number of representative wells in the Middle Peninsula. A fair number of abandoned wells mentioned by Sanford are included because those records confirm the once widespread use of relatively shallow artesian water in some areas or show clearly the presence of brackish water in other areas. Conversely a considerable number of domestic wells drilled in recent years are not included because their records would add little to what is known from the various data at hand.

Most of the analyses of well waters collected during this investigation were analyzed in the laboratories of the U.S. Geological Survey but some few analyses from other sources are also included.

Well drilling firms in and adjacent to the area have furnished well data, either directly to the individuals making investigations or to the Virginia Division of Mineral Resources. In largest part these are Sydnor Hydrodynamics (formerly Sydnor Pump & Well Co.) of Richmond, W. S. and L. R. Reynolds and Bruce Norman of Walkerton, Douglas and Dickenson, Inc., of Warsaw, and Layne Atlantic Co. of Norfolk. Thanks are also due various public officials and many private well owners who have freely given important information.

GEOLOGY

The area included in the Middle Peninsula (fig. 1) is underlain by unconsolidated beds that dip gently seaward and rest upon consolidated bedrock, either Triassic sandstones and shales or granitic rocks. The unconsolidated sediments are of Cretaceous, Paleocene, Eocene, Miocene and Pleistocene age, and consist of a series of alternating sand, clay and marl beds (pl. 1). At Guinea and Ruther Glen, in west-central Caroline County, just east of the Fall Line, unconsolidated sediments are thin and bedrock has been reached in several wells. West of the Fall Line the Coastal Plain sediments have been removed by erosion and bedrock is exposed at the surface but east of the Fall Line the basement rock lies at progressively greater depths and near Mathews the thickness of unconsolidated sediments is 2,300 feet.

Pre-Cretaceous Basement Rock

Triassic System

Bedrock is exposed at the surface in westernmost Caroline County and has been reached by several wells in the west-central part of the county (table 1). It is of particular interest to note that at Bowling Green and Moss Neck (wells 16 and 41, table 2) bedrock is Triassic sandstone rather than granitic rock. A wedge of Triassic strata is shown on the Geologic Map of Virginia near Doswell, Hanover County, 5 miles south of Ruther Glen. Presumably, infaulted Triassic beds may continue northward from there as a narrow band. However, "rock" penetrated at a depth of

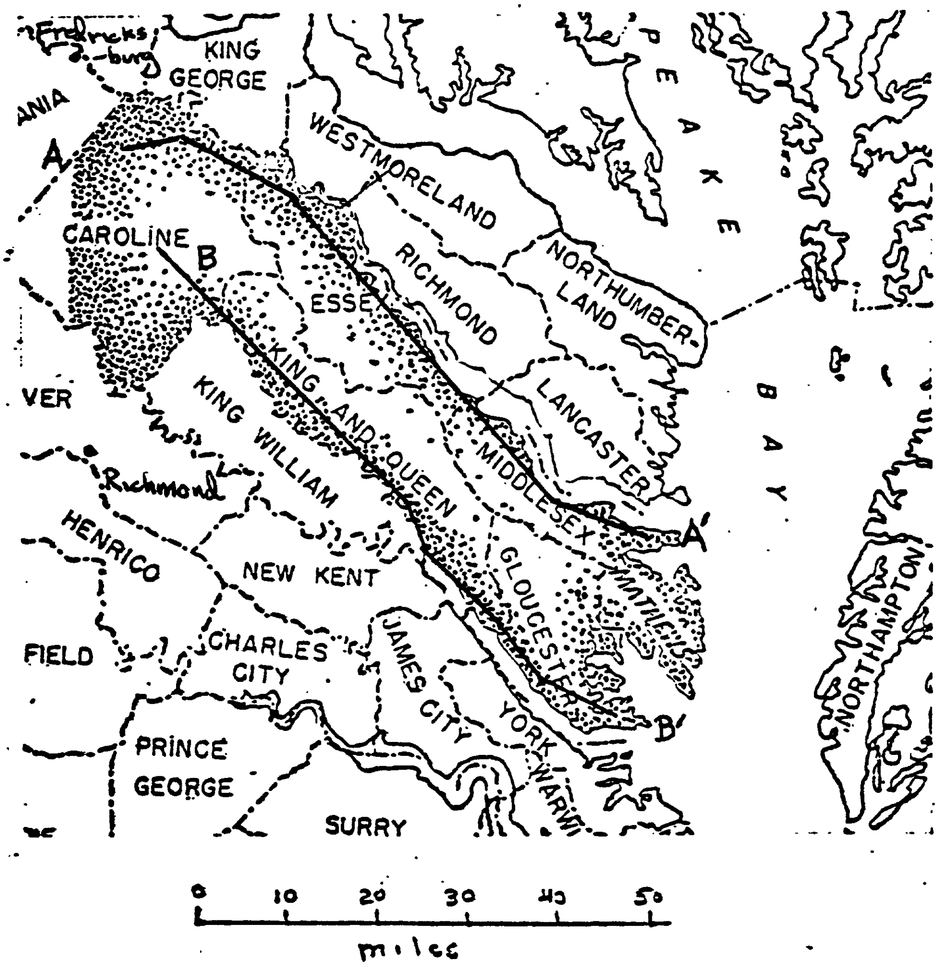

Figure 1. Index map showing location of area and of cross sections given in plate 1.

Scale in miles

0 10 20 30 40 50

1,284 feet at West Point, immediately adjacent to lower King and Queen County, is here tentatively assigned to the Triassic. It cannot be assumed that the Triassic underlies most of the Middle Peninsula. ~~More likely,~~ POSSIBLY Triassic beds occur as a series of somewhat narrow north-south trending bands between irregular areas of crystalline rocks.

Water-Bearing Properties

Consolidated rocks ordinarily yield much smaller quantities of water to wells than those developed in unconsolidated Coastal Plain sediments and will be dealt with briefly here. The average yield of domestic wells in either granitic rocks or sandstones is in the nature of a few gallons a minute. It has been found, however, that in industrialized areas like Richmond, where a maximum effort has been made to develop water from hard rock, some very high yields have been obtained. As much as 300 gpm per well has been obtained from deep wells in granitic rock in the Richmond area (Sanford, 1913, p. 85) where a considerable drawdown has been used, perhaps in excess of 200 feet of drawdown. Several out and out failures are also reported.

In westernmost Caroline County Coastal Plain sediments are thin or absent altogether. Here it may be desirable, when more than minimum quantities of water are needed, to drill at several somewhat widely spaced locations in an attempt to develop water in some quantity. Developers should avail themselves of technical advice in order that wells be located in what appears to be the more favorable sites. Where multiple wells 400 feet deep or more are drilled, an average yield per well of up to 90 gpm might be obtained from granitic rocks and up to 150 gpm from sandstones.

Cretaceous System - Potomac Group

Sediments of the Potomac Group of Early and Late Cretaceous age crop out in the Richmond area south of the Middle Peninsula and in the Fredericksburg area to the north. These sediments consist of alternating lenticular clay and arkosic sand deposits of continental origin. Farther to the east the Potomac sediments are buried beneath a cover of younger sediments and in the Middle Peninsula area have been reached by very few wells. At West Point, adjacent to lower King and Queen County, it is believed that Potomac beds were reached at a depth of 800 feet.

Water-Bearing properties

Wells developed in Potomac sediments near the Fall Zone have not been conspicuously successful in yielding large quantities of water but some miles east of the Fall Zone in the York-James Peninsula (Cederstrom, 1957) and south of James River (Cederstrom, 1945) the Potomac beds have proved to be excellent aquifers. In the Middle Peninsula the few wells that develop large quantities of water, as at Tappahannock, Urbanna, and Walkerton, end in the overlying Mattaponi Formation and little can be said of their potential of Potomac beds in the area in the Peninsula. However, at West Point a well drilled in

1961 developed a million gallons of water a day at 118 feet of drawdown from Potomac beds. It is presumed that Potomac strata of similar water-bearing potential underlie much of the Middle Peninsula from which comparable quantities of water might be obtained from deep wells. However, in most of Gloucester, all of Mathews and in lower Middlesex County, water from Potomac beds is brackish and not suitable for some uses. Near the Fall Line Potomac beds are thin and may pinch out entirely.

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series - Mattaponi Formation

The Mattaponi Formation was established in eastern Virginia on the basis of lithology and micro-fossil study of well cuttings from wells at Colonial Beach and Washington's Birthplace (Cederstrom, 1957, p. 17-21), both of which are located at about 10 miles north of the Middle Peninsula. The beds are described as somewhat glauconitic clays and subordinate sands in the upper portion and highly colored or mottled clays and subordinate sands in the lower portion. The highly colored clays may or may not be glauconitic.

Beds of similar appearance have been logged as far west as Bowling Green. It was noted (p. 20) in the report cited in the preceding paragraph that Foraminifera similar to those found at a depth of 600 feet at Kilmarnock were found in cuttings from the Moss Neck Manor well (41, Table 2), almost as far west as Bowling Green.

At and near Bowling Green the Mattaponi Formation, as tentatively identified by the presence of mottled clays but including underlying sands, extends from a little below sea level to about 125 feet below sea level. Bedrock at Bowling Green is at about 260 feet below sea level. Adopting this interpretation, a thin section of Potomac beds underlies the Mattaponi Formation in western Caroline County and, further, the Mattaponi does extend to the Fall ~~Line~~ Zone area but at such a depth that it should not be expected to be exposed at the surface. Rather, the Mattaponi and underlying Potomac beds lap up against the slope of the bedrock surface and are truncated by the Miocene overlap a very few miles west of Bowling Green.

Mottled clays or highly colored clays marking the Mattaponi Formation have been reported in logs of wells in the Bowling Green area, as already stated, at Walkerton and West Point along the Pamunkey, and at Port Royal, Tappahannock, and Urbanna along the Rappahannock. Glauconitic sands logged at considerable depth in wells at Gloucester and Severn likewise should be assigned to the Mattaponi Formation rather than to the Potomac group.

Drillers' logs at hand are not detailed enough to permit a reasonably accurate stratigraphic separation of the Mattaponi Formation from the overlying and underlying formations in the more easterly part of the area. At West Point mottled clays extend to about 600 feet below sea level. If the underlying 200 foot sandy section is also considered to be part of the Mattaponi, then that formation there is about 640 feet thick.

As shown in cross sections A-A[1] and B-B[1], Figure 21, the upper boundary of the Mattaponi Formation cannot be determined from available data in the eastern part of the area.

Water-Bearing Properties

Sands in the Mattaponi Formation have been penetrated by many wells throughout the six counties covered by this report. However, water in some quantity has been developed from them only in the Bowling Green, Tappahannock, Urbanna, Walkerton, and Gloucester areas. Judging from the slot size of the screens installed, listed in the tables of well records following each county discussion, the sands penetrated are not coarser than medium grain size in most places. Logs also suggest that some of the sands developed are slightly clayey.

A yield of 253 gpm was developed in a well ending in sands of the Mattaponi Formation at Walkerton. At Tappahannock two wells have yields of 200 gpm with drawdown of 28 and 18 feet respectively. Obviously higher yields could be obtained from those wells by increasing the drawdown. In Urbanna a yield from one well is recorded as 1,100 gpm with 50 feet of drawdown; yields of 857, 752, 430, and 205 gpm are also reported in the Urbanna area.

It seems likely that yields of a million gallons a day (about 700 gpm) might be developed in many places in eastern Caroline

County, in all of King and Queen and Essex Counties, and the westerly portions of Gloucester and Middlesex Counties from wells no deeper than 600 feet by installing larger diameter casings (to accommodate large turbine columns) and ample screen, and by utilizing 50 feet or more of the available drawdown. In central Caroline County, the section of Coastal Plain formations is limited and good water-bearing sands are few. In eastern Gloucester and Middlesex Counties and in all of Mathews County, Mattaponi aquifers yield brackish water.

It seems likely that the zone of coarse basal sands of the ~~Mattaponi Formation~~ Potomac Group seen at West Point (pl. 1, B-B^1) has not been reached by any wells east of Port Royal. Hence, even larger quantities of water may be available from properly screened and developed wells along much of the Rappahannock and, of course, in King William and western Gloucester Counties along the York and Mattaponi Rivers from wells about 200 feet deeper than the present wells there. Water from such deeper wells would not be expected to have a chloride content appreciably higher than that characteristic of water from existing wells.

Tertiary System

Paleocene Series - Aquia Formation

Bennett and Collins (1952) showed that the Brightseat Formation in Maryland which underlies the Aquia is of Paleocene age. Loeblich and Tappan (1957 a,b) determined that the overlying typical Aquia itself is of Paleocene age.

Whether or not the Brightseat Formation is in fact equivalent to the upper part of the Mattaponi Formation is yet to be established. To avoid lengthy discussion that would not be fruitful insofar as this paper is concerned, the Virginia pre-Eocene section will be referred to simply, in descending order, as the Paleocene Aquia Formation, as known from microfossils at Aquia Creek (Cushman, 1944), and the Mattaponi Formation of Paleocene to Late Cretaceous age.

The Aquia Formation, as defined at Aquia Creek, appears to thin out eastward from the Fall Zone as it does in the York-James Peninsula (Cederstrom, 1957, p. 24) and may not be present east of Tappahannock. Downdip the upper hundred feet or so of generally glauconitic pre-Miocene sediments become increasingly sandy and contain more and more thin "rock" (shell limestone) strata as the Aquia thins and the overlying Nanjemoy increases in thickness. The lower more marly beds in such sections probably represent the Aquia Formation.

Water-Bearing Properties

As far as can be determined, the Aquia Formation is generally marly and a basal sand is very poorly developed or absent. Hence, the Aquia appears to be essentially nonwater-bearing in the Middle Peninsula area.

Eocene Series - Nanjemoy and Chickahominy Formations

The Nanjemoy Formation of Eocene age with its easily recognized foraminiferal fauna is well developed not far east of the Fall Zone but appears to thin and vanish eastward. As noted above, the typical underlying Aquia Formation (Cushman, 1944) also thins eastward (Cederstrom, 1957, pl. 1).

The upper Eocene Chickahominy Formation, the type locality of which is at Yorktown (Cushman and Cederstrom, 1945, and Cederstrom, 1957, p. 28), does not extend to the Fall Zone. It is present about as far inland as West Point (adjacent to lower King and Queen County) and Tappahannock and thickens to the east from a few feet to more than 100 feet. McLean assigns 100 feet of beds penetrated in the Crisfield well on the Eastern Shore (Sinnott and Tibbitts, 1968, p. 16) to the Chickahominy Formation and considers the Nanjemoy to be absent.

The boundaries of the formations, particularly the Chickahominy-Nanjemoy-Aquia contacts, are tentative and based in large part on interpretations of well logs and comparison with better known geology in the Northern Neck and York-James Peninsula. In the eastern part of the Middle Peninsula, the Chickahominy-Mattaponi contact cannot be determined from existing data.

The lithology of the Nanjemoy and Chickahominy Formations is similar, as far as may be determined from well logs. Both formations are highly glauconitic - sands may be largely glauconite sand or, less commonly, quartz sands containing some glauconite. A feature of the Eocene beds is the presence of thin limestone beds alternating with glauconitic sands. The limestone is a shelly formation in which much secondary deposition of lime has taken place. No regularity in the occurrence of these beds can be discerned. Clays (or marl) strata are present from place to place. These are ordinarily somewhat glauconitic.

Water bearing properties

The Nanjemoy and Chickahominy beds were developed by a great many small diameter flowing wells along the Rappahannock River around the turn of the century. Some few of these are still in use and in more recent years other wells have been drilled to these strata, largely in Middlesex and Essex Counties. There are a number of older wells around King and Queen in the county of that name that obtain water from the Nanjemoy as do a few along upper Gloucester County on York River. Some of these relatively shallow jetted wells supplied canneries along the Rappahannock with their requirements and several small commercial establishments at Tappahannock utilize such wells today. The town of Saluda obtains its municipal supply from Chickahominy beds as do a few schools. However, in largest part, wells tapping the Eocene formations supply water for domestic use.

Miocene Series - Chesapeake Group

Lithologic Character

The Chesapeake group of Miocene formations consist of a series of marl beds with minor interbedded sands. Miocene strata are exposed throughout the area where streams have eroded the overlying terrace formations. In the western part of the area, the base of the Miocene rises above sea level, older beds are exposed along the Rappahannock and Pamunkey Rivers and the Miocene strata are exposed only at the higher elevations along tributary streams. (Downstream the Miocene is exposed also along the two large rivers mentioned.)

Water-bearing properties

Drillers do not report the presence of subordinate sandy beds in the Miocene in most logs of wells in the central and western part of the area. In Gloucester County wells ending in Miocene sand or sand and shell beds range from 50 to 100 feet in depth. In Mathews County there are many wells ranging generally from 110 to 160 feet in depth. In easternmost Middlesex County where some of the land areas are partially surrounded by bay waters and interrupted by tidal streams, water from Miocene beds at 80, 120, and 195 feet is reportedly brackish. This condition is probably also characteristic of some areas in Mathews County that are more or less surrounded by brackish waters. Sanford (1913, p. 222) reports that a 110-foot well at Fitchetts (northwest of Mathews) found water that was too salty to use.

Very small yields have been developed from most wells ending in Miocene strata although at one locality, Ark, in Gloucester County, a yield of 30 gpm was reported and 20 to 30 gpm is reported for several wells in Mathews. The very high yield, 200 gpm, reported at Gwynn Island Coast Guard station, is unique insofar as water from wells in the Miocene is concerned. It seems clear that from place to place quantities of water somewhat greater than that obtained for domestic use can be developed from Miocene strata in the easterly part of the peninsula. The reader is referred to the log of the well at New Point Comfort, Gloucester County, as an illustration of a favorable Miocene section. Here the water-bearing formations are relatively thick but some trouble was encountered with the fine sand. The first well constructed was sand free at a discharge of about 15 gpm but at higher rates of pumping much sand was discharged and the well tended to clog. Such wells could probably be stabilized by installations of an artificial sand pack, as was done with the second well at New Point Comfort, but the volume of water available would be somewhat limited. Pumping an open-end or conventionally screened well with air into a system embodying a sand trap might work successfully but there would be the danger of ground collapse if considerable fine sand were removed from the ground by long continued pumping.

The data at hand also indicate that there is the danger of salt-water intrusion in somewhat shallow wells located near brackish water bodies if somewhat large quantities, say a very few hundred gallons a minute, were pumped over a long period of time. Recharge to Miocene strata is in large part local by slow seepage down through roof material of generally low permeability. Further, the water-bearing strata are probably discontinuous and may not be at ~~any one place~~ of great lateral extent. Hence, upon long continued heavy pumping the limited storage in the fresh water beds will tend to be depleted and its place taken by water from Chesapeake Bay or from brackish water inlets. However, such danger probably exists only in or near the shore in localities where pumping is moderately heavy and continuous. If such wells did become contaminated by brackish water, they would probably freshen again after a period of rest and moderate to heavy rainfall.

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~~ Holocene 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.

Water-bearing Properties

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

Shallow well installations supplying more than domestic needs are almost entirely lacking on the Middle Peninsula, in contrast to the area just east of Richmond where several dairies and schools do develop more than minimum supplies. About 4 or 5 gpm appears to be available to pumps operating several hours or longer each day (Cederstrom, 1957, p. 64). One well east of Richmond drilled in the gravelly terrace beds characteristic of the higher westerly part of the Coastal Plain, has the unusually high yield of 36 gpm. Such results could only be expected where conditions are especially favorable; a coarse sand or gravelly water-bearing stratum of wide extent which holds a rather large volume of water in storage and which is easily susceptible to recharge. Shallow wells penetrating fine grained sediments, either with small catchment areas or located near deeply incised streams or rivers that permit lateral drainage as springs and seeps, will yield poorly except in periods of high rainfall.

The volume of water that might be drawn from shallow wells in wide unbroken terraces several square miles in extent is large. Unfortunately the development of this water would require installation of multiple wells spaced over a wide area and a considerable investment in pumps and connecting pipeline to bring the water to points of use. Infiltration galleries, either open or as intake pipe buried as many feet as practicable below the water table might also be considered. However, except in the eastern end of Middle Peninsula where artesian water is brackish, demands for more than minimum supplies can best be met by drilling deep wells.

Quality of Water

Analyses of samples of water collected from representative deep wells in the Middle Peninsula show that those waters are similar to those present in other parts of the Coastal Plain. These have been described in some detail in Virginia Geological Survey Bulletin 68 and are discussed still further in the literature (Cederstrom, 1946 b).

Briefly, water~~s~~ falling upon the earth along and for a few miles east of the Fall Zone percolates downward to the artesian beds and then moves downdip towards the continental shelf. These waters are slightly acidic due to carbon dioxide absorbed from the air and from dissolved plant acids. Upon entering the ground, ~~rainwaters and snowmelt and rivulets~~ the water percolating eastward ~~flowing eastward from hard-rock areas~~ dissolves limy minerals in the earth material and the water commonly becomes hard within a few miles of the outcrop area although the total amount of mineral matter in solution is quite low.

In very short distances, however, these hard calcium bicarbonate waters come in contact with glauconitic (black) sands or other earth material having the capacity to adsorb the calcium and magnesium content of hard water and liberate sodium to the water in exchange. The water thereby becomes a soft sodic water although its total mineral content is the same, or even somewhat higher than it was originally.

Examples of the hard water of low mineralization have been collected in ~~and near Moss Neck in~~ central Caroline County. However, by the time the underground waters reach Port Royal, the process of base exchange referred to above has become operative and at Port Royal the artesian waters have become soft sodium bicarbonate waters. Still farther eastward the waters become progressively higher in sodium bicarbonate content.

Although contained in a closed artesian system and shut off from a source of atmospheric carbon dioxide and plant acids, either of which are necessary to dissolve carbonate material and generate bicarbonate ions, the bicarbonate nevertheless increases steadily downdip. On the other hand the sulfate concentration, 20 mg/l (milligram per liter) at Bowling Green, decreases and remains negligible.

It was proposed (Cederstrom, 1946 b) that the interaction of the sulfate ion with organic material in the artesian beds generates free carbon dioxide which then (as carbonic acid) acts upon limy material in the sediments to produce calcium bicarbonate which immediately became converted by base exchange to sodium bicarbonate. The relative absence of sulfate and the presence of very high bicarbonate is thus accounted for in waters from artesian wells some distance east of the Fall Zone.

In eastern Caroline, King and Queen and Essex Counties some of the shallower artesian waters are distinctly harder than the deeper artesian waters, lower in bicarbonate and higher in sulfate. These appear to reflect recharge directly downward through the slightly permeable marly roof rocks. Having moved laterally only short distances through the artesian formations, base exchange has not been fully effective and the breakdown of the sulfate and consequent increase in bicarbonate has also lagged.

Still farther downdip deep well waters become brackish. In easternmost Middlesex County, in central and eastern Gloucester County and in all of Mathews County the chloride content of deep well waters is higher than the 5 to 15 mg/1 characteristic of the waters to the west. In easternmost Gloucester County the chloride content of one deep well water is 2,627 mg/1 and in easternmost Middlesex County as much as 1,820 mg/1.

The saline waters in the Virginia Coastal Plain are not derived from present day estuarine or bay waters. Rather, as first proposed by Sanford (p.114), they are the residue of saline waters with which the sediments were once saturated. Up-dip, fresh waters entering at or near the Fall Zone have flushed the formations thoroughly but to the east the flushing process has been incomplete and the waters there are brackish to a greater or lesser degree.

Shallower wells yield water that reflect the character of the formation in which they are found or have passed through. The dug wells developed in the terrace formations throughout the area commonly yield soft water of very low mineral content but if the wells reach the underlying marly beds the water is usually somewhat hard. Jetted wells ending in sands ~~the~~ Miocene underlying the terrace formations yield water ranging from soft to slightly hard (more than 80 mg/l total hardness). Where the shallow wells are contaminated by brackish bay waters, they may yield very hard water.

Optimum Ground Water Development

Water-Bearing ~~Properties~~

Artesian Water

The Coastal Plain Province of Virginia is the one area in the state where ground water in moderate to large quantity can be obtained with ease almost everywhere. In the Middle Peninsula, as elsewhere in the Coastal Plain, only moderate quantities of water can be developed near the Fall Zone. Further, in the lower portion of the Peninsula only brackish water is available from artesian formations. Nevertheless, in an area from Port Royal to Urbanna on the Rappahannock and to the south of that reach, wells may be constructed that will yield 1 mgd (1 million gallons a day) or more practically everywhere.

Use of large quantities of artesian water for industrial ~~use~~ purposes for almost three decades at Franklin and West Point suggests that equally large quantities might be developed in the Middle Peninsula or Northern Neck area where total draft is at present rather small. This indeed may be a practicable and inexpensive source of a large water supply. On the other hand, it is not to be thought that the available water in the Coastal Plain is limitless.

Determination of the amount of water entering Coastal Plain formations is a problem that cannot be completely solved for several reasons. Yet reasonable approaches to the problem do afford an excellent idea of the magnitudes involved that should be considered if an ~~maximum~~ optimum development of artesian water is to be considered. Such developments might be very large local industrial demands (which seem unlikely at the moment), development of large quantities of water for low flow augmentation of Rappahannock or Mattaponi Rivers, or as supplementary supplies for nearby or more distant cities.

Following the methods used by Mack (1966, p. 34; also, Ferris, 1949, p. 236) in Maryland, George Tarver of the U.S. Geological Survey has calculated (written communication, 1969) that roughly 140 mgd could be obtained from artesian formations from a series of closely spaced wells in the area 12 miles east of the Fall Zone from Fredericksburg to Petersburg utilizing a drawdown to the base of the Miocene formations. The Middle Peninsula "share" of this volume would be about 20 to 25 mgd.

Such a determination should be thought of as only helpful rather than absolute. First, the method necessarily assumes that almost all the water flowing eastward in the artesian beds under the assumed hydraulic head can be captured. Because this is mechanically impossible, the figure given would be somewhat high. Second, data on the water-transmitting properties of the artesian beds are only rough approximations. The average transmissibility may be greater than the assumed value of 25,000 gp ft day--it could hardly be smaller. Third, and probably most important, it is not known how much extra water would be transmitted straight downward through the less permeable roof formations when artesian water levels are lowered by heavy pumping. This amount would be large where the roof formation is sandy and smaller where it is marly.

A great deal of detailed data would be necessary before any kind of an answer to the question of roof leakage could be made.

Lastly, it must be borne in mind that in the Coastal Plain where formations are more or less continuous, or at least interconnected, over very wide areas, a deep cone of depression around a heavy pumped well or group of wells will spread widely and draw in water from great distances. If a heavily pumped unit were established at Port Royal, for instance, water would flow to it from intakes to the northwest, west, and southwest and a discharge could be sustained that is much greater than might otherwise be expected.

In brief, the problem, generally speaking, is insoluble from the point of view of the tremendous amount of detailed data needed on the highly variable composition of the geological formations, both the artesian water carriers as well as the overlying roof formations.

Another approach is to consider what is happening in the Virginia Coastal Plain today. Total withdrawal of ~~stream~~ ground water might be as much as 85 mgd, yet as far as is known, no great increase in the hydraulic gradient from the Fall Zone to centers of heavy pumping has taken place. This suggests that the ~~maximum~~ development of artesian water might be several times greater than the present pumpage rather than only twice as much.

~~When all is said and done~~, Undoubtedly the most worthwhile and critical observation to be made is to see what happens to water levels between centers of high discharge and the Fall Zone. On the basis of these observations, reasonably valid conclusions may be drawn to the effect that the great artesian water resource is approaching a certain limit or, conversely, that the limit still lies two or more dimensions beyond present total discharge.

The 20 to 25 mgd figure arrived at above for the Middle Peninsula has a validity only in showing we are not dealing with a inexhaustible resource.

Brackish Water

As mentioned above and as discussed in detail in chapters on Middlesex, Mathews, and Gloucester Counties, artesian beds in the lower Middle Peninsula yield brackish water. The presence of this water not only precludes the possibility of obtaining bounteous supplies of fresh water very cheaply but is a source of danger to heavy pumpers in the adjacent fresh water area. Where heavy continuous fresh water discharge is maintained near the boundary area between the two water types, a cone of depression is created that will spread ~~some distance~~ eastward as well as ~~and a long distance~~ westward and the brackish water will tend to move inland and contaminate the fresh water wells. The spread of a cone tending to induce westward movement of brackish water will depend, among other things, upon the long term sufficiency of fresh water moving in from the Fall Zone area to the wells. With ample fresh water moving eastward, there will be little or no danger of brackish water moving updip.

Two thoughts relative to the brackish water area seem worthwhile. First, brackish water is not valueless for all purposes. It may be used in certain cooling operations or, conversely, its heat may be extracted. Industry may find such cheap water ideal for certain purposes. For example, in Newport News, a gas plant uses brackish water for scrubbing gas. Maintenance of fish, shellfish, or wild duck habitat might be considered through addition of brackish artesian water where such areas are endangered by pollutants or excessive drought. Pure brackish artesian water would be ideal for filling swimming pools that will be constructed in the lower Peninsula area, a section given over in good part to the recreation industry.

Pumping brackish water in quantity would have the effect of lowering the normal hydraulic gradient from the brackish water area toward inland centers of pumping and would thus inhibit the movement of brackish water in that direction. Utilization of brackish water might therefore be encouraged as a means of promoting a modest economic development of the area as well as a step in inhibiting the westward movement of brackish water inland.

Recharge of Brackish Water Strata

An experiment carried out at Camp Peary, near Williamsburg, Va., showed that it is possible to store fresh water in brackish water artesian beds (Cederstrom, 1957, p. 46). Seventeen million

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gallons of water from a surface supply were recharged through a deep well. After a brief interval the well was pumped and it was found that the first half of the recharged water was fresh. With continued pumping the water discharged gradually ~~and~~ took on more and more the character of the formational water.

The practicability of storing very large quantities of fresh water in brackish water formations is being tried out under carefully controlled conditions at Norfolk at this time of writing.

In the lower part of the Middle Peninsula it may be worthwhile to consider the desirability of similarly storing fresh water in the brackish water artesian beds. Fresh water in modest quantities is generally available there from shallow wells. Small quantities might be injected continuously during, say, 9 months of the year to provide a larger supply to be pumped back during the three summer months of much higher demand. It should be pointed out that there are technical problems in the functioning of such a device and it would be best to seek specialized professional advice before carrying out any recharge operation.

In providing larger quantities of water than are now available in the lower peninsula, the alternatives to a deep well recharge operation in the lower peninsula appear to be (1) small surface water reservoirs subject to high evaporation and pollution, in many instances requiring long pipelines to point of use and liable to failure in times of drought, (2) batteries of shallow wells requiring much flat land as well fields, relatively high maintenance costs and, in most instances, considerable investment in pipe hookups and pipeline to point of use or, (3) a trunk line bringing water 30 or 40 miles down the peninsula from a surface or ground-water source serving a number of communities. If the last mentioned arrangement is considered, it would seem that an artesian water source would be the more desirable and by far the most economical in that pure water could be obtained at very low cost at the source and filtration would not be required. At the present stage of technology and anticipated needs of the lower peninsula area in mind, a desalinization plant could hardly be considered in that an acceptable cost to the average consumer could be achieved only where extremely large quantities of water are produced.

Artesian Water Rights and Hydrologic Concepts

The attitude has been taken in some parts of the Coastal Plain that a political subdivision owns the water that lies in the artesian formations beneath that subdivision, presumably based on the concept that artesian water is a static resource not easily replenishable.

Knowing that much water enters the artesian beds along the Fall Zone and that an indeterminate quantity enters by roof leakage, where the shallow water table is higher than the artesian head, and knowing also that water levels decline from west to east, one may conclude that water in the artesian beds is in transit. Water enters the artesian beds in the western part of the Coastal Plain, moves slowly eastward and is discharged by wells, by slow upward leakage through the roof where artesian head is higher than the shallow water table and perhaps moves on out toward the Continental Shelf. A continuous replacement of discharged water is going on.

Darcy's Law shows that the volume of movement eastward depends on (1) the character of the formations, (2) their thickness and, (3) the slope of the water table. The latter factor may be thought of as the pressure head. The first two factors are fixed but the slope of the water table is variable.

Under natural conditions, that is, before the drilling of many wells beginning about 1890, the slope of the water table was very gentle and hence the amount of water moving eastward in the Coastal Plain formations was small. Discharge was ~~probably~~ out to sea or upward through the roof.

With the construction of many hundreds of flowing wells on low ground, artesian water levels were lowered sharply in the vicinity of those well fields. The pressure system was tapped at low levels by these wells (e.g., artesian head may have been 30 feet above sea level and the well outlets at 5 or 10 feet above sea level) and water flowed to these wells from adjacent areas of higher pressure. The combined effect of pressure lowering extended many miles back and in the Fall Zone area water levels may have declined a few inches or more.

By 1920, the total movement of water eastward through the artesian beds was undoubtedly greater than it had been in 1890. Not only do we visualize the discharge of many hundreds of wells, some of which had flows ranging up to 50 to 100 gpm, but we see also from the point of view of hydraulics that the slope of the water table is somewhat steeper; very slightly steeper all along the western Coastal Plain and somewhat more steep in the general area of the flowing wells.

By using more water and increasing the slope of the artesian water levels, an increase in the rate of movement of artesian water had taken place. The slight lowering of water levels in the Fall Zone area had also created that much more space to absorb rain waters falling upon the surface in that area. By this time unrestricted development of flowing wells on low ground had diminished artesian pressures in many areas to the extent that some wells on higher ground no longer flowed. It should be noted, however, that the artesian beds remained just as full of water in 1920 as they were in 1890.

A further large gain in eastward flow of artesian water was accomplished in the period from about 1920 to the present with the construction of many municipal and a few industrial wells. Water levels were lowered locally, sometimes sharply in the immediate vicinity of heavily pumped wells, cones of depression spread widely and the general eastward slope of artesian water levels was increased. With the decline of artesian water levels near heavily pumped wells, many flowing wells ceased to flow, although ample water continued to be available from them by pumps. Regardless of the salvage of water formerly wasted by flowing wells (few of them were equipped with shut-off valves), it is apparent that a very much greater volume of water is being discharged at present than was true in 1920. Briefly, more water was made available by drawing from lower levels (some pump intakes draw water from 50 feet or more below the surface). Only by using more water, accomplished by depressing artesian water levels locally and increasing the eastward artesian pressure slope, was it possible to gain more water.

At present the artesian formations are still as full of water as they were in 1890. ~~Thus,~~ We may conclude from this discussion that the concept that artesian water beneath the land is as static as the land itself is utterly without foundation. The concept that the supply is limited is valid only when we think of total discharge several times greater than the present discharge. Certainly a cone of depression develops around a small flowing well or a group of heavily pumped municipal or industrial wells but this "cost" of lowered head is one of the prices of acquiring additional water.

From a long term point of view, it will be impossible for any individual or political subdivision to "protect" what they consider their own supply. Pumping in adjacent or even somewhat distant areas will slowly draw in artesian water from wherever pressures are high, following the accepted principle that water flows downhill or, in this case, down the pressure slope.

In an Atlantic Coast state a legal ruling was recently made that no new well could be discharged where water levels in any preexisting well would be affected. Obviously, since an increase in gradient is required to bring in additional water, no new wells can be constructed in the Coastal Plain of that State if the ruling is adhered to.

In conclusion, it is suggested that it is a proper function of the state to address itself to the problem of management of ground water in the Coastal Plain. Much more water is available by depressing water levels locally. The effect of lower water levels in individual property owners' wells created by municipal and industrial pumping and the interference of municipal and industrial wells upon each other is presently deserving of much deliberate thought and eventual conclusions based upon the hydrologic, economic, and social factors involved.

Shallow Water

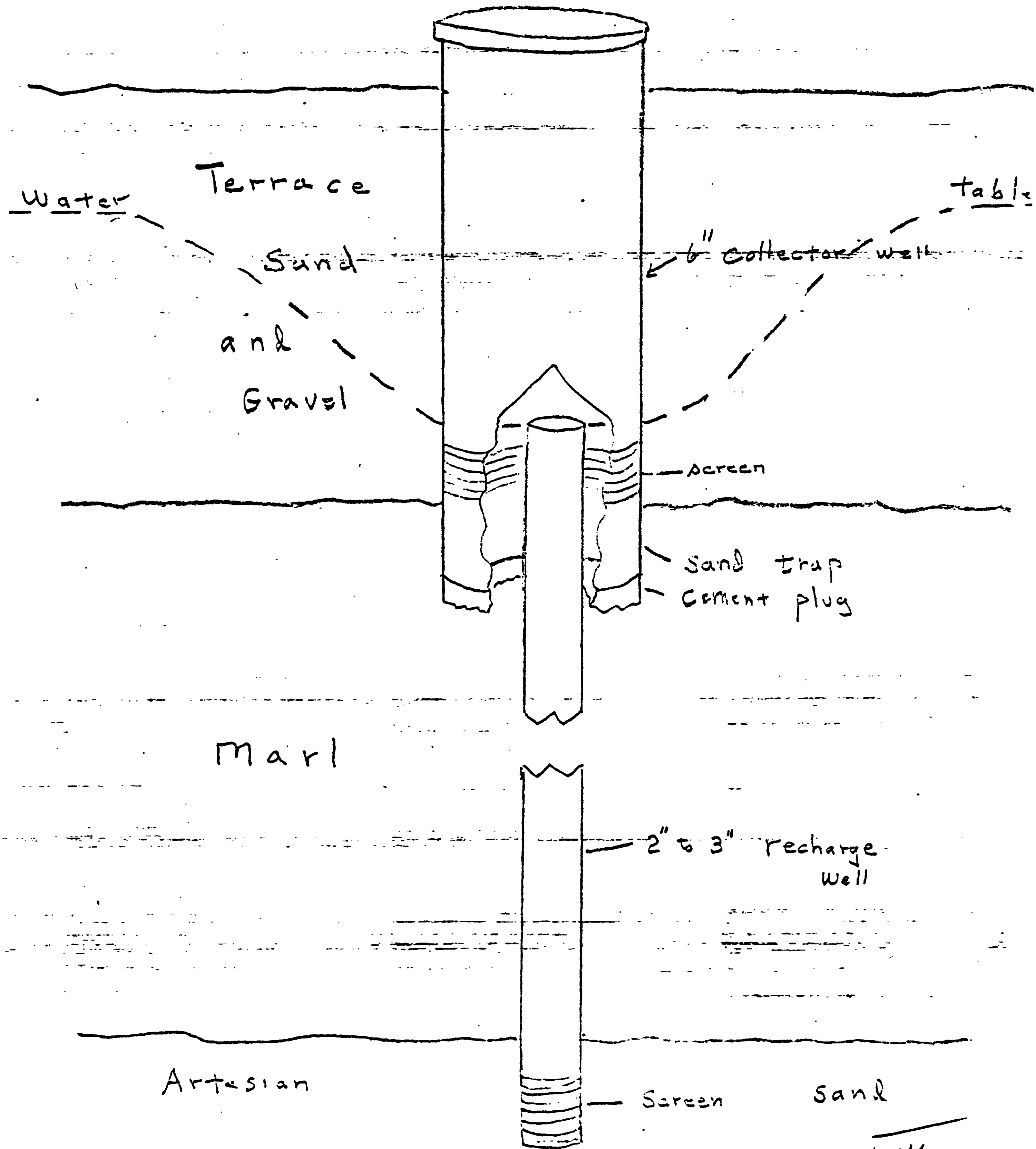
Much of the Middle Peninsula, in fact much of the entire Coastal Plain, is covered by sandy terraces, some of which are a mile or two in length and perhaps a mile or more wide. Such essentially flat sandy areas are subject to rapid recharge and may absorb, on the average, as much as a million gallons of water a day per square mile. The terrace deposits are not very thick, 30 feet being the maximum thickness in most places, and during periods of low rainfall they drain laterally into adjacent streams. Hence, the amount of water available at any one place is rather small and not too great a reliance may be placed on their capacity to supply adequate water in times of drought.

Connecting up a series of shallow wells and delivering the water pumped to some distant point of use would be very expensive and the volume of water delivered would vary greatly from season to season. However, when we consider that the Coastal Plain is roughly 16,000 square miles in area and that a goodly portion of it is covered by terrace formation, perhaps 10,000 square miles, we are dealing with a recharge of 10,000,000,000 gallons a day, a volume that is much too large to be ignored in long range planning.

As stated, capture of this water, in small or large part would be expensive by conventional means. Storage of the captured water would also be a problem.

It seems entirely possible that terrace water could be drained down into the huge artesian water reservoir by means of suitably constructed recharge wells (3.3.2), thus eliminating both the cost of a complex small yield well system and storage facilities. Such proposed recharge wells would consist of two elements; a 6- or 8-inch diameter "shallow" collector well extending to the bottom of the terrace formation, with two or three feet of screen near the bottom, and an inner 2-inch diameter injection well. The inner pipe would rise just above the level of the top of the screen of the outer larger diameter well and would extend down to an appropriate artesian formation where it would terminate in a short screen. Thus, where differences in head exist, water would drain from the terrace sands down into the artesian formation. With the

Figure 2.—Suggested design for drainage-recharge well.



top of the injection well extending slightly above the top of the collector well screen, the water level in the terrace formation could not fall below the screen level, unless influenced by other factors.

Such a device was constructed in Anchorage, Alaska (Cederstrom, ~~and~~ Trainer, and Waller, p. 64). The experience showed that it will be necessary to work out economical construction and development techniques by experimentation but there is no reason to doubt that this can be done.

The water recharged into the artesian beds would help restore artesian pressure head locally, thus lowering costs of pumping from deep wells. In substituting injected terrace water for artesian water moving in from long distances, an addition to the total deep well supply would be gained.

As inferred in the paragraph above, the recharge water would, in effect, be picked up again by a nearby artesian well and used locally or piped to some distant point of use. To be quantitatively significant, multiple recharge wells would be necessary. In many places extra recharge to the terrace formations in which injection wells are sited could be gained by leading spring or stream water flowing from higher terraces across the lower terrace. Assuming the ground was available, normal overland drainage from the terrace in which the well field is located might be inhibited by small earth embankments or by ditching.

The terrace water, under nearly all circumstances, would be an organically pure water in that the formation itself functions as a filter sand. Likewise, upon discharge from the injection well and in migrating to the pickup well, still further filtration of the water would take place. Naturally, in such a proposed scheme, protection of the system from pollutants of all types should be rigorously enforced.

In conclusion, the device could be used simply to maintain artesian head to a greater or lesser degree where head has been lowered by somewhat distant heavy pumping or it could be implemented on a much larger scale for the purpose of adding significantly to the total supply, particularly near centers of heavy pumping.

The device as sketched out above will not function particularly well in introducing fresh water into brackish artesian formations in much of the eastern Middle Peninsula area. A great deal of the land there is low, artesian levels may be as high as the land surface and sufficient head differential is lacking. On high ground drilling 2-inch injection wells to the depth required, 700 feet or more might be both difficult and overly expensive relative to the improvement in quality of water that might be expected.

Logs of Wells

Following each county discussion a number of well logs are given. These are, with few exceptions, drillers' records of formations penetrated and are the basis for most of the discussions of the geology and, with the well records, the basis for conclusions regarding the hydrology. Many of the logs were obtained directly from the driller, others were reconstructed from suites of samples furnished by the driller. Several logs were obtained from files of the Virginia Division of Mineral Resources and a very few were taken from Samuel Sanford's report on the ground-water resources of the Virginia Coastal Plain.

All designations of the geological age of formations penetrated were drawn by the writer. Boundaries were generally drawn on the basis of lithology but in a very few instances were based on study of microfossils in samples at hand. In many instances, a comparison with the better known geology to the north and south of Middle Peninsula was helpful.

Economic Data

Economic data pertaining to the various counties have been taken from a series of economic data summaries published by the Division of Planning, Office of Administration, Governor's Office, Richmond, Va.

Caroline County

Caroline is a middle Virginia county lying just southeast of Fredericksburg. The Rappahannock River forms ~~one~~ the northern boundary and the North Anna-Pamunkey Rivers the southern boundary. The area is 529 square miles. The population was 13,381 in 1960 but as of 1968 an increase to about 14,000 seems probable. The largest towns are Bowling Green, with a population of 528 in 1960 and Port Royal with 128 in 1960.

The population was about half rural in 1950 but is estimated to be only 19 percent rural in 1960. This shift is due more to nonagricultural employment outside the county rather than to a major development of industry in the county. Manufacturing of wood products in the county is carried on in several locations of the county and an aluminum product company is located at Milford.

Over 40 percent of farm income was derived from field crops, burley tobacco, soybeans, corn and wheat, about 20 percent each from livestock and dairy products and 10 percent each from poultry and forest products.

A. P. Hill Military Reservation, 120 square miles in area, is located just east of Bowling Green. ~~and adds in some measure to the economic activity within the county.~~

U.S. Highway No. 1 and Interstate 95 cross the western part of the county. U.S. 301 connects Bowling Green with Richmond to the south and passes northeastward to Port Royal, across Rappahannock River and on to Maryland. State Route 2 connects Bowling Green with Fredericksburg.

The Richmond, Fredericksburg and Potomac Railway passes through central Caroline County. Passenger traffic is handled by both Greyhound and Trailways systems.

Geology

~~Caroline County~~

Caroline County is the westernmost of the Middle Peninsula group of counties. Here unconsolidated Coastal Plain sediments lap up upon the older crystalline rocks making up the Piedmont Province. The crystallines are exposed in the westernmost part of the county.

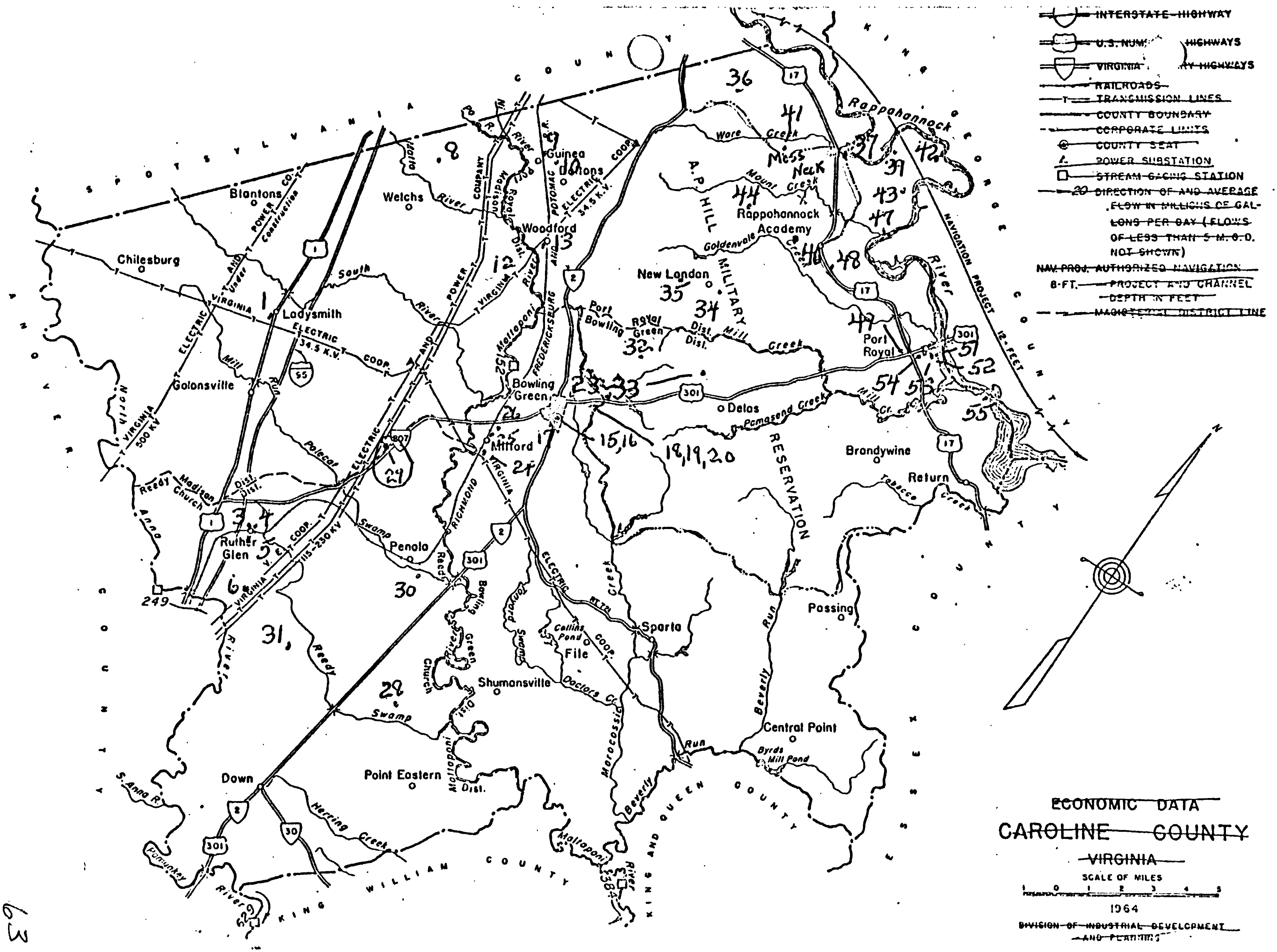
The Geologic Map of Virginia shows that the oldest sediments exposed are those of the Aquia Formation; ~~now considered to~~ be of Paleocene age. These crop out along Rappahannock River in the vicinity of Moss Neck and along the upper Mattaponi in the vicinity of Milford. Sediments of Eocene age, the Nanjemoy Formation, overlie the Aquia Formation and are exposed along the Rappahannock and the Mattaponi. However, throughout the greater part of the county, Miocene marls overlie and mask the older formations and they in turn are obscured to a large degree by a veneer of sandy terrace formations of Pleistocene age.

The Mattaponi Formation of Paleocene and Late Cretaceous age is present below the Aquia Formation in central and eastern Caroline County but is not exposed anywhere in the county. The still older Potomac group of sediments undoubtedly ~~are~~ is present at depth in central and eastern Caroline County but little is known of ~~them~~ it.

Pre-Cretaceous Basement Rock

Triassic System

Basement rocks have been penetrated by several wells in western Caroline County (1-6, 8, 16, 41, table 1 and fig. 3). Records do not show what type of


INTERSTATE HIGHWAY
U.S. NUM HIGHWAYS
VIRGINIA HIGHWAYS
RAILROADS
TRANSMISSION LINES
COUNTY BOUNDARY
CORPORATE LIMITS
COUNTY SEAT
POWER SUBSTATION
STREAM GAGING STATION
20 DIRECTION OF AND AVERAGE FLOW IN MILLIONS OF GALLONS PER DAY (FLOWS OF LESS THAN 5 M.G.D. NOT SHOWN)
NAV. PROJ. AUTHORIZED NAVIGATION
8-FT. PROJECT AND CHANNEL DEPTH IN FEET
MAGISTERIAL DISTRICT LINE
ECONOMIC DATA
CAROLINE COUNTY
VIRGINIA
SCALE OF MILES
1964
DIVISION OF INDUSTRIAL DEVELOPMENT AND PLANNING
SPOTSYLVANIA COUNTY
KING GEORGE COUNTY
ESSEX COUNTY
KING AND QUEEN COUNTY
KING WILLIAM COUNTY
HANOVER COUNTY
Rappahannock River
NAVIGATION PROJECT 12-FEET
A.P. HILL MILITARY RESERVATION
Port Royal
Rappahannock Academy
New London
Delos
Brandywine
Return
Passing
Central Point
Sparta
File
Shumansville
Point Eastern
Down
Bowling Green
Milford
Woodford
Guinea
Welchs
Blantons
Chilesburg
Ladysmith
Golansville
Ruther Glen
Penola
Madison Church
Reedy Church
Byrds Mill Pond
Collins Pond
Mattaponi River
Polecat
Swamp
Reedy
Herring Creek
Beverly Run
Pamunkey
S. Anna R.
North Anna
Ware Creek
Mount Creek
Goldenvale Creek
Mill Creek
Pomasend Creek
Tobacco Creek
South River
Motta River
Morocossic Creek
Doctors Cr.
Tanyard Swamp
Ni River
Po R.
FREDERICKSBURG AND POTOMAC R.R.
RICHMOND
VIRGINIA ELECTRIC AND POWER COMPANY
ELECTRIC COOP. 34.5 K.V.
115-230 KV
VIRGINIA 500 KV
POWER CO. Under Construction
Port Royal Dist.
Madison Dist.
Bowling Green Dist.
Port Royal Dist.
Mattaponi Dist.
Reedy Church Dist.
152
249
384
629
1
2
17
30
55
207
301
N

rock was present in these deep wells. At Ladysmith and Ruther Glen consolidated rock was reached at, respectively, 140 and 115 feet above sea level. At Ladysmith the rock was most likely crystallines of the type exposed at the surface in immediately adjacent westernmost Caroline County, in and around Ruther Glen, the rock is more likely sandstone and shale of Triassic age. "Hard clay" struck at 84 feet in well 6 at Caroline Pines Development, two miles south southeast of Ruther Glen, is interpreted to be soft Triassic shales. "Rock" reported at 270 feet, if accepted, would place bedrock at more than 200 feet below its position at Ruther Glen. This seems unlikely. Triassic rock was penetrated in a deep well at Doswell which lies 5 miles south of Ruther Glen in Hanover County at about 150 feet above sea level (Cederstrom, 1957, p. 78).

Triassic rocks were reached at a depth of 477 feet, 260 feet below sea level, in the old municipal well at Bowling Green. There they consist of a series of alternating sandstones and shales, generally red or brown in color. Granite was encountered in the same well at 1,160 feet, 945 feet below sea level.

The occurrence of bedrock in well 41 at Moss Neck Manor is of more than usual interest in that at least 200 feet of Triassic beds was penetrated by a jet drill. The highly colored "clay" reported by the driller above a depth of 560 feet cannot be definitely assigned to either Triassic or younger Coastal Plain formations on

the basis of the description at hand (see log, 41, table 2).
Hence it is possible that the bedrock surface lies higher at Moss Neck than as shown in plate 1, section A-A'. However, as shown, the bedrock surface lies about 350 feet below sea level at Moss Neck Manor, that is, 90 feet lower than it is at Bowling Green.

Cretaceous System - Potomac Group

Alternating sands and clays of the Potomac group are well exposed north of Fredericksburg but occur only at depth in Caroline County. The white clays and sands listed in the drillers' log of the deep well (16) at Bowling Green between 365 and 477 feet are tentatively assigned to the Potomac Group. However, the boundary between these beds and the overlying more highly colored sediments that are assigned to the Mattaponi Formation cannot be drawn accurately.

The log of the deep well (41) at Moss Neck indicates only that somewhat highly colored clays lie between (probable) bedrock and fairly characteristic Eocene and Paleocene beds. However, it seems likely that beds of the Potomac Group were penetrated in that well. At Sales Corner, the deepest beds penetrated in well 46 are assigned to the Potomac Group. Here they are simply referred to by the driller as "clay" or "alternating sand and clay."

It can hardly be questioned that the Potomac Group of sediments thickens eastward and is several hundred feet thick in eastern Caroline County.

Cretaceous to Tertiary Systems

Upper Cretaceous (and Paleocene Series) - Mattaponi Formation

The Mattaponi Formation of (Paleocene) ~~to~~ ~~Upper~~ Late Cretaceous (and) age, characterized by highly colored mottled clays and glauconitic in places, is believed to be present as far west as Bowling Green. "Mottled blue and red clay" is reported at 15 to 46 feet below sea level ~~in well 22~~ in the USO well (22, table 2) and "red, blue, and yellow clay" is reported at much the same depth in the old CCC camp well (23) $1\frac{1}{2}$ miles east of Bowling Green.

"Yellow sticky clay," is reported in the deep town well ~~log~~ (16, table 2) from 9 to 70 feet below sea level. It may be noted that at Oak Grove, Westmoreland County, fossiliferous glauconitic yellow clay of the Aquia (?) (Paleocene) age was encountered in a well at about 200 feet below sea level. Yellow and yellow brown clays, with older indeterminate fossils (Cederstrom, 1945, p. 17, 1957, p. 19 and Sinnott, 1967), continue ~~there~~ to about 500 feet below sea level. Returning to consideration of the Bowling Green well, yellow clay is reported as deep as 150 feet below sea level, thus suggesting that the Mattaponi Formation is at least 140 feet thick.

At Moss Neck Manor (well 41) which is less than 2 miles east of Bowling Green, "mixed tan and white clay" at 130 feet below sea level should be part of the Mattaponi sequence. why?

In the blue clay stratum (289 to 335 foot depth range) immediately above the "mixed tan and white clay" a meager foraminiferal fauna was found that appears to be similar to the assemblage found at 600 feet near Kilmarnock. Hence the top of the Mattaponi is placed at the base of the "stone" (probably thin limestone and sand strata) at a depth of 289 feet which is 84 feet below sea level.

At Sales Corner, near Rappahannock Academy (well 46), the formation is less distinctive. Blue clay reached at 106 feet below sea level probably represents the Mattaponi Formation.

At Port Royal (well 53) blue clay penetrated at 159 feet below sea level probably marks the top of the Mattaponi Formation. Red clay, penetrated at nearly 200 feet below sea level is certainly Mattaponi. The thickness cannot be assessed on the basis of well logs alone but certainly the "limestone" and underlying white sand is part of the sequence, the minimum thickness then being 121 feet. Inspection of the cross section $A\text{-}A^1$, ~~Figure~~ Plate 1 suggests that the formation is much thicker.

"Tough clay granules of mixed colors, gray, blue, red, rust, white, and brown" is reported (32, Table 2) at Acois Corner, 3½ miles east of Bowling Green, at about 200 feet below sea level. Presumably overlying lithologically less distinctive strata that are reached by the drill at about 86 feet below sea level should also be assigned to the Mattaponi. Similar beds were also reported at Fish Hook Lake (well 35) and Acois Corner (well 32).

The Mattaponi Formation appears to be absent at Ladysmith (well 1). Between Bowling Green and Ladysmith those beds lap up against a bedrock surface that rises somewhat sharply in a westward direction. Whether or not the Mattaponi Formation crops out just above sea level along the Rappahannock in easternmost Spotsylvania County is yet to be determined.

The yellow clay penetrated in a well at Penola (28, table 2) at 195 feet is probably at or near the top of the Mattaponi section.

Tertiary System

Paleocene and Eocene Series - Nanjemoy and Aquia Formations

It is known that the lower unit, the Aquia Formation, is fairly thick along the Fall Zone but thins out downdip (Cederstrom, 1957, p. 24). The overlying Nanjemoy is relatively thin or absent along the Fall Zone but thickens downdip (see cross section A-A^{1}, pl. 1).

The advancing Nanjemoy

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sea eroded the seaward portion of the Aquia beds more deeply than it did where that sea approached its shoreline somewhere west of the Fall Zone. Relatively thick Nanjemoy beds were then deposited upon the Paleocene (Mattaponi-Aquia) surface. In succeeding Miocene time another advancing sea transected the Nanjemoy beds (and any Late Eocene beds that may have overlain the Nanjemoy in Caroline County) but cut more and more deeply as it advanced westward due to a previous slight seaward tilting of the Coastal Plain as a whole.

The base of the Aquia Formation can be estimated with a fair degree of success from well logs at hand but the stratigraphic top of the Nanjemoy (base of the Miocene) is more difficult in this county than elsewhere due to erosion of the higher beds and rather meager descriptions of the formations in some of the well logs at hand. As indicated above, no attempt is made to define the contact between the Nanjemoy and Aquia Formations.

Along Rappahannock River, the Nanjemoy and Aquia Formations crop out the full length of the county. However, at higher elevations back from the river the Nanjemoy is overlain by beds of Miocene age.

At Port Royal the top of the Nanjemoy Formation may extend to about 50 feet above sea level and hence is not determinable from logs of wells there because they are situated on lower ground. The base of the Aquia is considered to be the thin sand penetrated at 193 feet (159 feet below sea level), thus making the combined Nanjemoy-Aquia thickness a little over 200 feet thick. These combined formations (~~the old Pamunkey Group~~ former) are at about their maximum thickness here. The same thickness relationships have been shown to occur in the York-James Peninsula (Cederstrom, 1957, plate 1).

At Sales Corner, a mile west of Rappahannock Academy, well 46 first encountered glauconitic beds at about 60 feet above sea level. The series of glauconitic beds and basal sands continue to about 106 feet below sea level. The combined Nanjemoy and Aquia formations are thus about 164 feet thick. This corresponds reasonably well with findings at Dogue, a few miles to the northwest in King George County (Sinnott, 1967) where inspection of microfossils helped to establish the section with reasonable accuracy.

At Moss Neck Manor (well 41, table 2) slightly west of the Sales Corner locality, the Miocene-Eocene contact is arbitrarily placed at 80 feet above sea level. On that basis the combined Nanjemoy and Aquia Formations are about 160 feet thick.

Elsewhere in the county top of the Eocene is somewhat difficult to recognize from logs at hand. At Bowling Green a stratigraphic break is recorded in the log of well 22 at 80 feet above sea level. This is probably the contact between the Eocene and overlying Miocene beds. The Aquia, and possibly thin overlying Nanjemoy beds, appear to be 95 feet thick here, extending to 15 feet below sea level. Presumably it is at about that level in wells at Howards Corner (33), Acors Corner (32), Eubank Corner (34), and Fish Hook Lake (35).

The base of the Aquia is marked by a "fine black sand" stratum that extends to 76 feet below sea level at Howards Corner. A similar stratum is present at Eubank Corner extends to 56 feet below sea level and at Acors Corner to 62 feet below sea level. In the latter two localities the glauconitic stratum is 89 and 110 feet thick.

At Grace Church (36) the base of the Aquia may be at 5 feet below sea level at the base of "blue clay." At Guinea which is north and about 5 miles west of Bowling Green the base of the Aquia is about 30 feet above sea level. The 31 feet of strata above this level may be safely assigned to the Aquia and it is likely that most or all the overlying 61 feet "tough blue clay" is also Aquia in age. The top of the Aquia, or Nanjemoy if present should be at about 120 feet above sea level here.

Penola is south and slightly west of Bowling Green. The Aquia Formation, if present, cannot be separated from the 125 foot stratum of "blue marl" recorded in the log of well 28.

At Ruther Glen (6) "blue mud" extends to about 80 feet above sea level below which "hard sandy clay" is thought to represent weathered bedrock. Again, differentiation of the "blue mud" cannot be made on the basis of the data at hand.

Water bearing Formations

~~Ground-Water Resources~~

Pre-Cretaceous Basement Rock

Triassic System

Five of the wells that end in basement rock in Caroline County yield from 7 to 35 gpm. It is thought probable that these wells end in the Newark Group ~~Formation~~ of Triassic age. The two wells yielding about 35 gpm (1, 6, table) are around 300 feet deep. It is possible that somewhat larger yields might have been obtained from these wells and from the other wells ending in bedrock if they had been continued to depths of 350 to 450 feet.

The deep well at Bowling Green developed only a little water from the Triassic beds and underlying granitic rocks. At Moss Neck, the Triassic section may not have been adequately tested — or not tested at all — inasmuch as there the jet driller was seeking an unconsolidated sand formation.

Cretaceous System - Potomac Group

As discussed above, the Potomac Group of sediments of Early Cretaceous age have been penetrated by few wells in Caroline County and little can be said of their water-bearing potential except that in the central part of the county, as at Bowling Green, they do not appear to be highly productive.

In eastern Caroline County, several hundred feet of Potomac sediments are almost certainly present. At Port Royal the Powers well (53) is believed to penetrate over 300 feet of Potomac beds. The contact between the Potomac beds and the overlying Mattaponi Formation is placed at 314 feet, below a section of colored clays and a thin limestone stratum. In the Potomac section, as shown in the log, sand is fairly prominent. It seems likely that installation of multiple screens followed by the thorough development possible in a larger diameter well would result in a fairly high yield well. Further, additional sands may be present at even greater depth.

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series - Mattaponi Formation

On A. P. Hill Military Reservation, north and east of the Bowling Green area, several wells (32-35) ending in the lower part of the Mattaponi Formation obtain from 40 to 50 gpm with drawdowns ranging from 32 to 116 feet. The screens in these wells are all 20-slot and it is possible that greater yields might have been obtained there if the sands penetrated were, in fact, medium to coarse sands and screens with wider slots had been used. Several wells in and around Bowling Green (18-20, 22, 23) develop sands higher in the Mattaponi section. One of the town wells (18) yields 75 gpm but the yields of the others are not known.

A number of wells in the Moss Neck-Port Royal area along Rappahannock River end in sands in the Mattaponi Formation. Several wells are around 170 feet deep and are thought to end in the upper part of the Mattaponi Formation but others develop a sand that lies more than 100 feet deeper (see log of wells 46 and 53).

The USGS test well (37) at Moss Neck was jetted to about the same depth below sea level as well 46 at Sales Corner. The 92 feet of Mattaponi section, as shown in the log in Table 2 was sandy to gravelly in largest part — perhaps 60 feet of material could have been developed in a production well. The well was located at an elevation of about 20 feet above sea level and had a flow of 140 gpm. Casing was 3 inches in diameter and extended to 48 feet below the surface. The flow therefore represents the combined yield of all aquifers penetrated.

An old 3-inch well (38) in the Moss Neck area developed 70 gpm at the time it was drilled but it presumably developed water from one stratum only, about two-thirds of the way down the Mattaponi section.

Paleocene Series - Aquia Formation

It is not certain that any wells in Caroline County obtain water from the Aquia Formation.

Pleistocene Series - Columbia ~~Formation~~ Group

A great many rural inhabitants obtain their water supply from dug wells ranging from 25 to 40 feet in depth. The amount of water used is generally very small. In some places numerous head of cattle are also supplied from shallow wells.

At Milford an ice plant (26) obtains its water from a dug well 25 feet deep. The draft is said to be as much as 20 gpm. At Penola a dug well (31) supplies a small cannery and pickle plant. Here reject brines have salinized the supply in the immediate vicinity of the plant.

Quality of Water

Quality - Water

Water in Coastal Plain formations enters those beds in the central and western part of the county but at first has only little opportunity to gain in dissolved mineral content. The entering rainwater and snow melt is slightly acidic due to its carbon dioxide content and, being acidic, takes limy material into solution as it travels eastward and becomes hard. Hardness is present as calcium (and less magnesium) bicarbonate.

As the artesian waters percolate still farther eastward they come in contact with sediments having the capacity to exchange sodium for calcium, as a result of which the hard waters become softened although the total mineral content is essentially unchanged. Port Royal is an example of such a water. This change from hard to soft water is seen in the difference between samples taken from the area of recharge (9, 13, 31, Table 3) and the sample from Port Royal (52). Those near the area of recharge are somewhat hard and, as seen from the high bicarbonate, have already undergone some base exchange. These waters, then, are sodium-calcium bicarbonate waters. At Port Royal deep Coastal Plain water is extremely soft but somewhat high in sodium bicarbonate. As is characteristic of water from artesian aquifers in the Coastal Plain south of Middle Peninsula, the concentration of sulfate does not increase much due to breakdown of that constituent by biochemical action (Cederstrom, 1946, p. 28).

Waters from wells 44 and 48 at Rappahannock Academy are most unusual. Water from artesian aquifers that is both very hard and high in sulfate (162 mg/l in the sample from well 48) are unknown in the York-James Peninsula and in the Coastal Plain south of James River. A sample from Fairview Beach (Sinnott, 1967) from a relatively shallow artesian well is of this type, however, and contains 85 mg/l of sulfate and 270 mg/l of hardness.

It is thought that the hard high sulfate artesian waters may have been derived from local recharge near Rappahannock and Potomac Rivers. In passing through the fairly permeable Eocene beds that crop out for some distance downstream from the Fall Zone, these waters gain more dissolved mineral content than those waters entering older artesian aquifers along the Fall Zone. Having traveled a much shorter distance, they have not had much time to become softened by base exchange nor has the sulfate been broken down by biochemical action.

Most of the waters from deep wells are only moderately mineralized and are excellent for domestic purposes. The harder waters should be quite suitable for irrigation but the very soft sodium-bicarbonate waters present in the lower part of the county are considered quite unsuitable for that purpose. The very hard waters found at Rappahannock Academy are somewhat troublesome in domestic usage.

Only one sample is at hand from a well that obtains water from bedrock (3, Table 3). It is a somewhat hard bicarbonate water. Hardness is 99 mg/l.

Some partial analyses of waters from wells dug in the terrace formations are at hand, but are not given in Table 3 . They range in hardness from 18 to 78 mg/l although only two out of 9 samples have more than 50 mg/1 hardness. Bicarbonate ranges from 8 to 86 mg/1 in samples at hand although it is more commonly less than 50 mg/1. Other constituents are low. A few samples contain as much as 17 mg/1 of nitrate, suggesting that organic pollution may be present.

A sample from a well (31, Table 3) contaminated by waste brines from a pickle plant near Penola contained 1,500 mg/1 of chloride and had a hardness of 216 mg/1.

Table 2 .--Logs of wells in Caroline County, Va. (cont'd)

Well 16, Municipality, Bowling Green
(Log by Sydnor Pump and Well Co.)

Altitude 215 feet (210)

	Thickness (feet)	Depth (feet)
Not described	209	209
Aquia (?) Formation (Paleocene)		
Sand; water	4	213
Mud, blue	3	216
Mattaponi Formation (Paleocene) and Upper Cretaceous)		
Clay, white	8	224
Clay, yellow	2	226
Clay, gray	6	232
Clay, yellow	53	285
Clay, white	17	302
Sandstone; a little water	6	308
Clay, white and yellow interbedded	57	365
Potomac (?) Group (Lower Cretaceous)		
Hardpan	2	367
Sand, water	7	374
Clay, white	1	375
Sand	16	391
Clay, white	3	394
Sand	17	411

Well 16, Municipality, Bowling Green (cont.)

	Thickness (feet)	Depth (feet)
Clay, white	66	477
Newark Formation (Triassic)		
Sandstone	3	480
Clay, white	20	500
Sand	8	508
Clay, white	25	533
Sandstone, brown	15	548
Sand, red	12	560
Sandstone, brown	295	843
Clay ("shale")	1	844
Sandstone, brown	31	875
Clay ("shale") and interbedded sandstone	63	938
Clay ("shale"), red	2	940
Soapstone	1	941
Sandstone, brown	9	950
Clay ("shale"), red	4	954
Sandstone, gray and red	38	992
Clay ("shale"), sandy	2	994
Sandstone, brown	6	1,000
Sandstone, white, water	3	1,003
Mud	1	1,004
Sandstone, brown, white and gray	84	1,088

Well 16, Municipality, Bowling Green (cont.)

	Thickness (feet)	Depth (feet)
Mud	1	1,089
Sandstone, brown	41	1,130
Clay ("shale"), sandstone, red and brown, interbedded	30	1,160
Pre-Cambrian (?)		
Granite, much less "sandstone"; thin "mud" layers at intervals to 1,402 feet. A dry crevice reported at 1,480 feet and a crevice with some water at 1,509 feet.	390	1,550

Table 2 .--Logs of wells in Caroline County, Va. (cont.)

Well 22, USO House, Bowling Green

Altitude 220 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay and sand, yellow	70	70
Chesapeake Group (Miocene)		
Marl, blue	70	140
Aquia Formation (Paleocene)		
Marl, blue, shells	95	235
Mattaponi Formation (Paleocene) to Upper Cretaceous)		
Clay, mottled blue and red	31	266
Clay	19	285
Silt	30	315
Sand, medium texture; water	40	355

Table 2 .— Logs of wells in Caroline County, Va. (cont.)

Well 28, Dr. I. J. Head, Penola

(Log from Va. Dept. Mineral Resources files)

Altitude 202 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand	25	25
Chesapeake Group (Miocene)		
Clay, yellow	45	70
Undifferentiated		
Marl, blue	125	195
Mattaponi Formation (Paleocene to Upper Cretaceous and) [redacted]		
Clay, yellow	41	236
Clay, brown	29	265
Sand, clay, brown	32	297
Sand, coarse and clay, sandy	11	308

Table 2 .--Logs of wells in Caroline County, Va. (cont.)

Well 32, A. P. Hill Military Reservation, Acois Corner

Altitude 228 feet

	Thickness (feet)	Depth (feet)
Undescribed	61	61
Chesapeake Group (Miocene)		
Clay, blue-gray	81	142
Aquia Formation (Paleocene)		
Sand, glauconite, fine, shell fragments, clayey	110	252
Sand, fine to medium; water?	11	263
Mattaponi Formation (Paleocene to Upper Cretaceous and Cretaceous)		
Clay, tough granules, gray, blue, red, rust, white, and brown	58	321
Undescribed	87	408
Sand, water	22	430

Table 2 .—Logs of wells in Caroline County, Va. (cont.)

Well 33, A. P. Hill Military Reservation, Howards Corner
(Log from Va. Div. Mineral Resources files)

Altitude 203 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, fine	12	12
Sand, medium, some clay	68	80
Chesapeake Group (Miocene)		
Clay, blue-gray	—	—
Nanjemoy (Eocene) and Aquia (Paleocene) Formations		
Clay, blue-gray	—	254
Sand, black, fine	24	315
Mattaponi Formation (Paleocene to Upper Cretaceous and Cretaceous)		
Clay, gray, tough	42	357
Sand, clayey	72	429
Clay, granules, gray, blue, red, rust, white, brown	42	471
Sand, water	52	523
Clay, gray	1	527

Table 2 .--Logs of wells in Caroline County, Va. (cont.)

Well 35, A. P. Hill Military Reservation, Fish Hook Lake

Altitude 225 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, sandy	20	20
Sand, coarse and pea gravel	61	81
Chesapeake Group (Miocene)		
Clay, blue-gray	--	--
Nanjemoy and Aquia Formations (Eocene and Paleocene)		
Clay, blue-gray	--	243
Mattaponi Formation (Paleocene) ~~to~~ Upper Cretaceous and ~~Cretaceous)~~		
Clay, tough, granules, various colors	207	450
Sand, medium, clayey	102	552
Clay, gray	8	558

Table .—Logs of wells in Caroline County, Va. (cont.)

Well 3~~7~~6, ~~Eugene Castles, Grace Church~~
SANTEE FARMS(?)
Altitude 190 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Soil	32	32
Sand, yellow	9	41
Chesapeake Group (Miocene)		
Clay, blue	—	—
Aquia Formation (Paleocene)		
Clay, blue	—	220
Mattaponi Formation (Paleocene ~~to~~ Upper Cretaceous(?) and ~~Cretaceous)~~)		
Clay, hard, and gravel	8	228
Clay, blue	15	243
Clay, brown	22	265
Clay and sand	5	270
Sand and gravel; water	12	282

Table .--Logs of wells in Caroline County, Va. (cont.)

Well 41, T. V. Houser, Moss Neck Manor

Altitude 205 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, yellow	32	32
Chesapeake Group (Miocene)		
Clay, blue	93	125
Nanjemoy and Aquia Formations (Eocene and Paleocene)		
Clay, blue	35	160
Sand and shells	5	165
Clay, blue	97	262
Stone	27	289
Mattaponi Formation (Paleocene and Upper Cretaceous)		
Clay, blue	46	335
Clay, mixed tan and white	10	345
Clay, brown to red	27	372
Undifferentiated		
Clay, hard, tan to red	118	490
Clay, hard, sandy, tan to white	45	535
Clay, red	25	560
Newark ~~Formation~~ (Triassic)		
Clay, hard, tan to yellow	40	600
Stone	4	604

Well 41, T. V. Houser, Moss Neck Manor (cont.)

	Thickness (feet)	Depth (feet)
Hard formation, tan	34	638
Stone, moderately hard	14	652
Soapstone (hard clay?, shale?)	10	662
Hard formation, white	3	665
Stone	20	685
Hard formation, tan	30	715
Sandstone, hard	10	725
Stone, moderately hard to hard	28	753

Table 2 .--Logs of wells in Caroline County, Va. (cont.)

Well 46, A. P. Hill Military Reservation, Sales Corner
(Log by D. J. Cederstrom and L. W. Youngquist)
Altitude ~~190~~ 205 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay and sand	31	31
Chesapeake Group (Miocene)		
Clay, blue	101	132
Nanjemoy and Aquia Formations (Eocene and Paleocene)		
Marl, sandy, glauconitic, scant pyrite, sharks teeth, and phosphatic pebbles	15	147
Shells	¼	147¼
Clay, blue, trace of glauconite	6¾	154
Clay, glauconitic	4	158
Clay, hard	½	158½
Clay, blue, trace of glauconite, a few shells	31½	190
Clay, blue, slightly glauconitic	10	200
Clay, blue, trace of glauconite, a few shells	90	290
Clay, blue, glauconitic	3	293
Sand, quartz, coarse	3	296

Well 46, A. P. Hill Military Reservation, Sales Corner (cont.)

	Thickness (feet)	Depth (feet)
Mattaponi Formation (Paleocene to Upper Cretaceous)		
Clay, blue, trace of glauconite	15	311
Gravel, medium texture, water	23	334
Clay, silty, gray	37	371
Clay, silty, gray to red	18	389
Sand, quartz, fine, water	37	426
Sand, quartz, medium, water	10	436
Potomac (?) Group (Lower Cretaceous)		
Clay	6	442
Clay and sand, alternating	28	450

Table .--Logs of wells in Caroline County, Va. (cont.)

Well 53, W. T. Powers, Port Royal

Altitude 34 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Soil	30	30
Nanjemoy Formation (Eocene)		
Clay, blue ("rock" reported at 51 and at 63 feet in an adjacent well)	70	100
Sand, glauconite	½	100½
Aquia Formation (Paleocene)		
Clay, blue (A thick bed of hard shells 154 to 174 feet and a glauconite bed at 167 feet is reported in adjacent wells.)	92½	193
Sand, white	½	193½
Mattaponi Formation (Paleocene to Upper Cretaceous)		
Clay, blue	46½	240
Clay, red, crumbly	5	245
Clay, brown	24	269
Sand, white	4	273
Clay, compact, sandy	22	295
Limestone	4	299
Sand, white	15	314

Well 53, W. T. Powers, Port Royal (cont.)

	Thickness (feet)	Depth (feet)
Potomac Group (Lower Cretaceous)		
Clay, hard	31	345
Clay, gray, and sand	65	410
Sand, white, and mud	17	427
Clay, brown, grading to red	103	530
Sand, white	15	545
Clay, hard	85	630
Mud, gray, sand, white, gravel	23	653

Essex County

Essex County lies along the south bank of Rappahannock River southeast of Caroline County and wholly within the Coastal Plain Province. It has an area of 258 square miles and a population of 7,776 of whom 1,086 reside in Tappahannock.

Rural farm population declined from 45 percent to 26 percent in the 1950-60 decade and in 1960 agricultural employment accounted for only about 15 percent of the total employment. There are 24 manufacturing establishments in the county, most of which are small and produce lumber or wood products but two rather large fabric plants are located in Tappahannock. Almost two-thirds of the farm income is obtained from sale of field crops, chiefly soybeans, corn and wheat and almost one-third from livestock. The value of standing timber and poultry products sold is about 10 percent of the total farm income.

A number of points of historical interest, largely pertaining to colonial Virginia are found in Essex County, as a result of which there is some tourist trade.

U.S. Highway 17 traverses the county parallel to Rappahannock River connecting Tappahannock with Fredericksburg and U.S. 360 leads into Tappahannock from Richmond and across the bridge at Tappahannock. to the Northern Neck counties. No railroads serve the county but bus service is available. Tappahannock is and has been since early colonial time a river port and the Rappahannock River still serves as an important transportation route for bulk shipping.

A municipal airport is located at Tappahannock.

An accredited college preparatory school for girls is located at Tappahannock.

Geology

Essex County is underlain by unconsolidated deposits of Cretaceous, Paleocene, Eocene, Miocene, and Pleistocene age that rest upon a granitic (?) basement rock. No wells in the county have reached bedrock but, estimating from depths to bedrock in Caroline County and at West Point, it may be as little as 600 feet below sea level in the upper end of the county and about 1,200 feet in the lower part of the county.

Cretaceous System - Potomac Group

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

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series

Mattaponi Formation - Near Tappahannock, highly colored clays and subordinate sands are encountered, (logs of wells 10, 15, 24, and 28, table 5 and fig. 4) at about 200 feet below sea level. These are tentatively assigned to the Mattaponi Formation of Late Cretaceous to Paleocene age.

The late Mr. H. Lyons of Tappahannock stated (oral communication, 1940) that water bearing glauconite ("black") sands are present at 470 to 500 feet at Tappahannock. However, the sand in well 10 at 520 to 540 feet is described as "white sand." If glauconitic beds

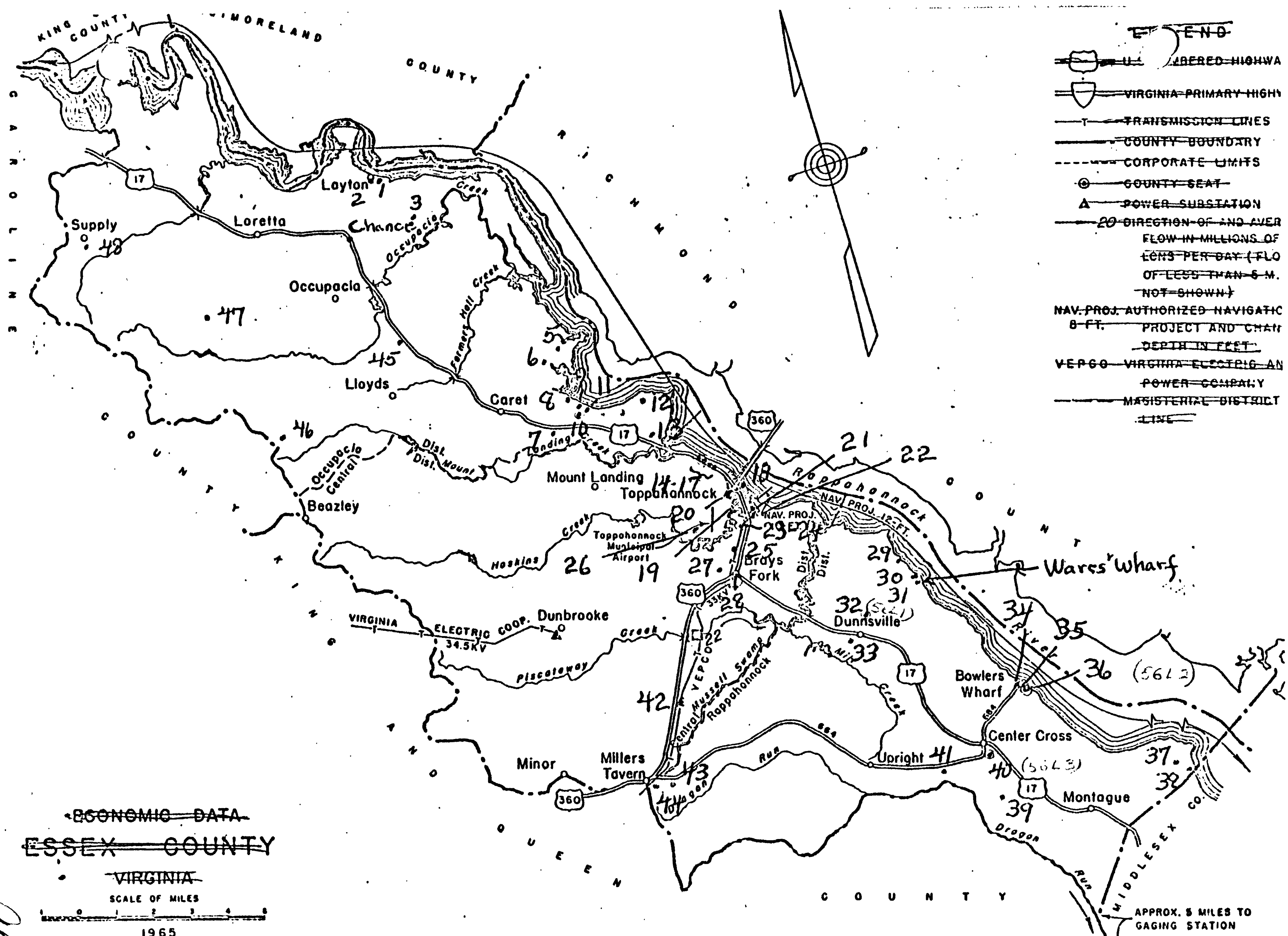


Figure .--Location of wells in Essex County.

are present as noted by Mr. Lyons, then all of the section from 300 to 550 feet at Tappahannock, as noted in the log of well ~~13~~ 10, is probably correctly assigned to the Mattaponi Formation rather than to beds of the Potomac Group.

A 101-foot stratum of ~~B~~black sand is reported to extend to about 370 feet below sea level in the Clanton well (26) at Tappahannock, more than 250 feet below the Miocene-Eocene contact. The lower portion of this stratum ~~(as reported by the driller)~~ should most likely be assigned to the Mattaponi.

~~A more puzzling problem is~~ the brown or red clay penetrated at about 240 feet below sea level (about 150 feet below the Miocene contact) in wells 10, 13, 15, 35, and 36 in and around Tappahannock, [redacted] appears to be too low in the section to be the Marlboro clay Member, the basal member of the Nanjemoy Formation. In any event the Marlboro clay in its typical development is pink rather than brown or red. Hence, it seems ~~more~~ likely that this clay marks the top of the Mattaponi Formation and probably correlative (to the extent that correlations are possible in Coastal Plain sediments) with the first colored clays penetrated at Port Royal upstream.

Downstream from Tappahannock tan and red clays are first penetrated at about ~~300~~ 240 feet below the surface in well ~~43~~ 32a at Dunnsville.

Aquia Formation - The Aquia Formation, [redacted] is [redacted] of Paleocene age. However, Aquia strata containing fossils similar to the outcroppings on Aquia Creek, although of Paleocene age, can be differentiated from the underlying Mattaponi Formation. Studies elsewhere (Cederstrom, 1957) show that the typical Aquia of the outcrop zone thins out downdip. Thus it would be expected that at Tappahannock ~~that~~ the Aquia Formation would not be very thick, perhaps only 10 feet or so, but thicker in the upper part of the county and probably absent a a few miles downstream.

Tertiary System

Eocene Series

Nanjemoy Formation - As shown on the logs, table 5, glauconitic sand (black sand) and clay and intercalated thin rock strata makeup the Nanjemoy Formation of [redacted] Eocene age. These beds are as much as 125 feet thick at Tappahannock. Differentiation of these beds from underlying Aquia beds in upper Essex County is difficult. Below Tappahannock the Nanjemoy probably thins; it may not extend as far eastward as Urbanna.

Chickahominy Formation - The Chickahominy Formation is of Late Eocene age. In this area foraminifera defining this formation were recognized at a depth of 120 feet below sea level in a well at Cat Point Creek, Richmond County, a few miles north-northwest of Tappahannock. The formation thins out updip and does not approach the Fall Zone and it probably is not present in the upper part of the county. The thickness of the Chickahominy in and around Tappahannock is assumed to be 10 or 15 feet. The Chickahominy Formation is certainly present at Wares Wharf and Bowlers Wharf where "black sands" and "black and white sands" are reported immediately below nondescript Miocene marls. It is, therefore, assumed that the Chickahominy Formation is about as thick there as it is in comparable areas in the York-James Peninsula. Thus in lower Essex County, the Chickahominy may be less than 50 feet thick.

Miocene Series

Chesapeake Group —

The Chesapeake Group of Miocene age overlies the Eocene deposits and crops out in many places in Essex County. Along the Rappahannock River it is very thin in the upper end of the county but is about 170 feet thick at the lower end of the county. Beneath high ground back from the river, the Miocene rises much higher above sea level and at Millers Tavern is probably about 300 feet thick.

The Miocene formations are composed largely of blue clay and shell marl and subordinate fine sands.

Quaternary System - Pleistocene Series

Colombia Group—

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 a great many shallow dug wells.

Water Bearing Formations

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series

Mattaponi Formation - Wells deeper than about 300 feet in the vicinity of Tappahannock tap water-bearing sands in the Mattaponi Formation. Wells 14 to 17 end in a sandy section about 370 feet below sea level. A 2½-inch diameter well that furnished water to the town of Tappahannock previous to 1950 is 360 feet deep. The Lumpkin Garage well (24) just south of Tappahannock ends in the same sand stratum high in the Mattaponi Formation as the 360-foot town well, as does the Markam well (28) at Brays Fork two miles southeast of Tappahannock.

At Lobern Acres (25), 2 miles south of Tappahannock, water is obtained from strata a little more than 400 feet below sea level. The same strata are tapped upstream at Laurel Park (11) and Maryfield (13) housing developments.

In well 10 only clay is reported at moderate depths and water is developed from a sand stratum reached at 510 feet below sea level. The newer large diameter town wells (19&20) develop strata at about that depth as does one of the old 3-inch diameter town wells (18) at Tappahannock. The Tidewater Memorial Hospital, 2½ miles south southwest of Tappahannock also obtains water (well 30) from these deep sands.

Sands high in the Mattaponi sequence, somewhat more than 400 feet below sea level, are developed in the John Moncure School well (43) at Millers Tavern. These are also tapped in well 32& at Dunnsville.

Water will rise to 12 feet or so above sea level in the deeper wells in the vicinity of Tappahannock which is much as what might be expected along a major river where artesian pressures have been reduced for more than half a century through unrestricted flow of many wells on low ground. However,

~~Although the height to which water will rise in the deeper artesian wells near Tappahannock is in the nature of 12 feet above~~

sea level, some moderately good flows were obtained from small diameter wells in the middle 1940's. Well 14 developed a flow of 20 gpm and well 9, also near Tappahannock, obtained a flow of 15 gpm. The latter well is at about 9 feet above sea level. Both wells are a little less than 400 feet deep. Well 10, which develops water at 520 to 540 feet obtained a flow of only 5 gpm, perhaps because it is on slightly higher ground. However, it seems likely that to a large degree, the rate of flow from wells located on low ground here (and elsewhere) and from various depths depends greatly upon the character of the formation from which the well obtains water, the degree to which the formation is developed, whether or not a screen was installed and, in the case of old wells, the degree of sand clogging that has taken place through the years.

Some fairly good yields to pumps have been developed in recent years from wells of larger diameter finished with screens. The municipal wells at Tappahannock (19, 20) are reported to yield 200 gpm with, respectively, 18 and 28 feet of drawdown. Obviously the yield of these wells might be increased considerably by installation of high capacity pumps that would utilize more of the available drawdown. At Loubern Acres (25), a yield of 100 gpm was obtained from a well equipped with 20 feet of 3-inch diameter screen. Drawdown in this instance was 51 feet. At Maryfield housing development (13), a yield of 100 gpm with 34 feet of drawdown is reported from a 6-inch well fitted with a 3-inch screen. At the Tidewater Hospital (27) the yield and drawdown were much the same.

A few domestic wells drilled in the last two decades have been equipped with screens and develop small quantities of water. Utilizing greater drawdown, somewhat higher yields could be developed. However, the potential of such wells is severely limited by their small diameter in that on low ground they are restricted to the amount of suction lift available to them and on high ground the yield is even more limited by the capacity of the high lift pump that can be installed.

The upper section of the Mattaponi Formation in the Tappahannock area does not contain as thick or as coarse water-bearing sands as at West Point which lies directly south of the lower end of Essex County. However, the most prolific sands at West Point are first penetrated about 350 feet below the top of the Mattaponi Formation. At Tappahannock it would appear that the deepest wells only begin to reach the zone where thick gravelly beds might be expected. It is likely deeper drilling in the county would penetrate additional permeable sands from which yields up to a million gallons a day (700 gpm) of high quality water per well could be developed.

A number of wells in and near Tappahannock listed by Sanford 1913, (p. 304-7) at the time of his survey in 1906 are 270 to 280 feet deep. Apparently these end in glauconite sands that are present just below the red or brown clay stratum ~~discussed above~~ that is thought to mark the top of the Mattaponi Formation here. None of these wells had large flows although many were located on very low ground. Sanford notes (p. 166) that in one such well the flow was $5\frac{1}{2}$ gpm but it was said to have been 12 gpm initially. Presumably, by 1906 the unrestricted flow of many wells up and down the river had already reduced the artesian head. In a 272-foot well, 1 mile upstream from Tappahannock artesian head was said to be as much as 30 feet above high tide level in 1906. A great many of these wells have fallen into disuse and very few are listed in Table 4 .

Aquia Formation - It is possible that some wells in the upper end of the county have obtained water from the Aquia Formation. The Aquia thins out downdip and it is not certain that the formation extends as far eastward as Tappahannock. Inasmuch as the question is somewhat academic, and fossil evidence to determine stratigraphic boundaries is lacking, all the drilled and jetted wells of moderate depth are considered here to end in the Nanjemoy Formation.

Tertiary System
Eocene Series

Nanjemoy Formation - A few wells ranging in depth from 150 to 250 feet deep develop water from the glauconitic sands in the Nanjemoy Formation of Early and Middle Eocene age.

~~One of the old wells (35) listed by Sanford is that at a packing plant at Bowlers Wharf. It is 165 feet deep and is reported to have had a flow of 49 gpm.~~ In ~~somewhat more recent~~ past years, several wells supplying business establishments at Tappahannock have been constructed that draw water from the Nanjemoy Formation. The 6-inch diameter well (21) at the Virginia Ice and Coal Co. is reported to have yielded 82½ gpm when pumped at the time of its completion in 1930. It was finished with 15 feet of 30-slot brass screen placed between 138 and 150 feet. The permanent pump had a capacity of 60 gpm. The old Wright Lumber Co. well (22) and the well at the former Dr. Pepper bottling plant (23), are of comparable depth and end in the Nanjemoy.

The well supplying Center Cross School (40) and the defunct Mosely Cannery at Millers Tavern (44) also obtain water from ~~Eocene~~ Nanjemoy beds as do a number of domestic wells.

<u>Chickahominy Formation</u> - It is thought that several rather shallow wells at Tappahannock and in the lower end of Essex County may end in the Chickahominy Formation of Late Eocene age. Samples with diagnostic Foraminifera are not available, however.

In a well (36) drilled in 1946 at Bowlers Wharf, "blue" marl is said to extend to 140 feet below the surface, below which is 12 feet of "white sand and shell." This is probably sand in the Chickahominy Formation. Twenty five feet of "rock" lies below this sand and from 177 to 210 feet "black and white sand" of the Nanjemoy (?) Formation was penetrated. The rock stratum from 149 to 167 feet, at Bowlers Wharf, presumed to be the Chickahominy Formation, is described by Sanford (1913, p. 168) as "strata of rock 1 to 9 inches thick and 6 inches to 4 inches apart; blue mud and shells, gray and red sand, and gravel between rocks; increased flow with each sand bed penetrated."

The well described by Sanford (not listed in table 4) was situated at the Garrett and Hunt oyster house on the end of the wharf. It had a flow of 30 ~~gallons a minute~~ gpm at an elevation of about 5 feet above high tide and a head of over 15 feet. The nearby Claybrook and Neal well (35) of about the same depth had a flow of 49 gpm at 12 feet above high tide level.

Miocene Series

It is not apparent that Miocene formations include water bearing sands in Essex County.

Quaternary System

Pleistocene Series

Shallow wells from 10 to 40 feet deep, mostly dug wells, obtain water from the sandy terrace formations of Pleistocene age. A few are deeper. In a great many places the wells are equipped with electric powered pumps but hand pumps and bucket lift are still used from place to place. The shallow wells furnish water for domestic use in homes and in a few small business establishments such as filling stations.

Quality of Water

Water from Mattaponi and Eocene Formations

Water from deep wells in Essex County may be classed as soft sodium bicarbonate waters although there is some real differences in bicarbonate content and total hardness. Those waters with the highest bicarbonate content, 400 to 500 mg/l (1, 2, 18, 41a, Table 6) are invariably very soft with a hardness of less than 20 mg/l. Those waters that have a bicarbonate content ranging from around 120 to 300 mg/l are essentially soft waters although hardness ranges from about 30 to 90 mg/l. The sample from the municipal well at Tappahannock (19) has a low bicarbonate and is almost completely without hardness. In waters described chloride and sulfate are low.

The low bicarbonate somewhat hard waters are ordinarily those from the shallower wells presumably ending in the Eocene Formations whereas the softer but more highly mineralized waters are from the deeper wells ending in the Mattaponi Formation. The same relationship is noted in King and Queen County. Here, it seems likely that some recharge is taking place downward through the "impermeable" marl overlying the uppermost artesian beds. Water from the deeper beds has moved in laterally from the west, has a higher mineral content and has been almost completely softened by base exchange.

The soft artesian waters in Essex County are excellent for domestic use but may not be satisfactory for some industrial purposes in that they tend to foam in boilers. Because of their high sodium content the very soft high bicarbonate waters are particularly unsuitable for irrigation. The somewhat harder lower bicarbonate waters should be used with care.

Water from Miocene and Pleistocene Formations

A few samples on hand from shallow wells show that water from these wells is generally a soft or fairly soft bicarbonate water. In the examples given in table 6 , hardness ranges from very low, 16 mg/l in water from well 46, to moderately hard, 161 ppm in water from well 48 at Supply. Bicarbonate in the softer water is only 5 mg/l but is 114 mg/l in the harder. However, the range of hardness in water from most wells developed in the Pleistocene terrace formations is between 5 and 60 mg/l and in most instances the hardness of over 20 of the samples taken is generally around 30 to 40 mg/l.

The excessive hardness and high bicarbonate of water from the well at Supply is undoubtedly due to the fact that the well (48) either penetrates sand beds in the underlying Miocene formations or the slightly acidic shallow water in Pleistocene beds comes in contact with limy beds that characterize the underlying Miocene formations. (The pH of the water from well 48 is 5.8 and from well 46 it is 4.9.) The well at Supply is 48 feet deep and probably penetrates Miocene marl in its lower portion and the water from it is hard on that account.

Table 5 .--Logs of wells in Essex County, Va.

Well 10, B. E. Bennett, 1-3/4 miles south-southeast of Jenkins Landing

(Log by W. S. Reynolds)

Altitude 11½ feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, clayey	13	13
Chesapeake Group (Miocene)		
Clay, blue	78	95
Nanjemoy Formation (Eocene)		
Marl, sandy, white; thin rock stratum at base[a]	28	123
Sand, black and white	2	125
Clay with rock streaks	25	150
Aquia (?) Formation (Paleocene)		
Clay, hard	55	205
Mattaponi Formation (Paleocene) ~~to~~ Upper Cretaceous ~~and Cretaceous)~~		
Clay, hard	45	250
Clay, red[b]	22	272
Sand, clayey, gray	30	302
Rock	½	302½
Clay, hard, blue	50½	353
Clay, light to dark brown	62	415
Clay, white to yellow	65	480

Table 6.--Logs of wells in Essex County, Va. (cont.)

Well 10, B. E. Bennett, 1-3/4 miles south-southeast of Jenkins Landing (cont.)

(Log by W. S. Reynolds)

	Thickness (feet)	Depth (feet)
Mattaponi Formation (Paleocene ~~to~~ Upper Cretaceous and ~~Cretaceous~~)		
Clay, hard	25	505
Clay, red to brown	15	520
Sand, white; water	20	540
Clay	10	550

a/ One-half foot of black sand is reported at 97 feet in well ~~10~~ 9.

b/ Soft brown clay is reported at 231 to 265 feet in well ~~10~~ 9 and is underlain by 1½ feet of glauconite sand. ~~Five feet of red clay is reported at 250 feet in well 15 overlying 55 feet of black sand.~~

Table 5 .--Logs of wells in Essex County, Va.

Well 15 , Overton Brooks, Tappahannock
(Log by Leonard Reynolds)

Altitude 5 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, sandy	18	18
Chesapeake Group (Miocene)		
Clay, blue	67	85
Chickahominy (?) Formation (Eocene)		
Shells and gray sand	2½	87½
Clay, blue	11½	99
Shells and sand	1½	100½
Nanjemoy Formation (Eocene)		
Clay and rock	19½	120
Sand, black and gray	1½	121½
Sand, white, and limestone	4	125½
Clay, compact	18½	144
Limestone	½	144½
Clay, hard	18½	163
Limestone	½	163½
Aquia (?) Formation (Paleocene)		
Clay, compact	26½	190
Sand, black	2	192

Table 5 .--Logs of wells in Essex County, Va. (cont.)

Well 15 , Overton Brooks, Tappahannock (cont.)

(Log by Leonard Reynolds)

Altitude 5 feet

	Thickness (feet)	Depth (feet)
Mattaponi Formation (Paleocene ~~to~~ and Upper Cretaceous)		
Clay, compact	58	250
Clay, red	5	255
Sand, black	55	310
Clay, hard	5	315
Limestone, very hard	1	316
Alternating clay and white sand	81	397

Table 5.—Logs of wells in Essex County (cont.)

Well 26, G. Clanton, Tappahannock

(Log from Va. Div. Mineral Resources files)

Altitude 20 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, fine	27	27
Chesapeake Group (Miocene)		
Marl, blue	99	126
Chickahominy Formation (Eocene)		
Rock, hard	4	130
Marl, blue	3	133
Rock, soft	12	145
Nanjemoy Formation (Eocene)		
Sand, black, fine	10	155
Undifferentiated (Eocene to Upper Cretaceous)		
Mud, blue, gummy	130	285
Sand, black	101	386
Sand, white	17	403

?

DOES NOT AGREE WITH WELL 26 IN TABLE 4

Table 5 .--Logs of wells in Essex County, Va.

Well 28, Brays Fork, R. A. Markan, (Triangle Inn)

(Log by Leonard Reynolds)

Altitude 40 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand and clay	32	32
Chesapeake Group (Miocene)		
Clay, blue	82	114
Sand, white, fine	½	114½
Clay, blue	23½	138
Chickahominy Formation (Eocene)		
Limestone	½	138½
Clay, blue	14½	153
Nanjemoy Formation (Eocene)		
Sand, black and white	½	153½
Clay	1½	155
Limestone	1	156
Clay	10	166
Clay, very hard	8	174
Aqu Limestone	1	175
Aquia (Formation (?)) Paleocene		
Clay, hard	32	207
Sand, black	2	209

Table 5 .--Logs of wells in Essex County, Va. (cont.)

Well 28 , Brays Fork, R. A. Markan, (Triangle Inn) (cont.)

(Log by Leonard Reynolds)

Altitude 40 feet

	Thickness (feet)	Depth (feet)
Mattaponi Formation (Paleocene) to Upper Cretaceous and? ~~Cretaceous)~~		--
Clay, blue	63	270
Clay, red brown	7	277
Limestone	1	278
Sand, black	54	332
Limestone	4	336
Clay, hard	41	377
Sand, white	1	378
Clay, hard	10	388
Sand, greenish, muddy	24	412

Table 5. Logs of wells in Essex County (cont.)

Well 32a, Nathan Parker, Dunnsville

(Log from Va. Div. Mineral Resources files)

Altitude 65 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand	30	30
Chesapeake Group (Miocene)		
Clay, blue, and brown	140	170
Chickahominy (?) Formation (Eocene)		
Shells and white sand	6	176
Clay, blue	10	186
Stone, hard	2	188
Clay, blue	6	194
Stone, hard	16	210
Sand, black	20	230
Nanjemoy Formation (Eocene)		
Clay, blue	70	300
Mattaponi Formation (Paleocene) to Upper Cretaceous and ~~Cretaceous)~~		
Clay, tan	50	350
Clay, red	50	400
Sand, white, somewhat clayey	25	425
Clay, white	25	450
Clay, red	50	500
Sand, white	15	515
Clay, yellow	35	550
Sand, white	35	585

Table 5 .--Logs of wells in Essex County, Va.

Well 36 , Bowlers Wharf; R. A. Pitts
(log by Leonard Reynolds)
Altitude, 7 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, yellow	20	20
Chesapeake Group (Miocene)		
Marl, blue	120	140
Chickahominy Formation (Eocene)		
Sand, white, and shell	12	152
Rock	25	177
Nanjemoy (?) Formation (Eocene)		
Sand, black and white; water	33	210

Table 5.- Logs of wells in Essex County (cont.) ~~Essex~~

Well 40, School, Center Cross

(Log from Va. Div. Mineral Resources files)

Altitude 125 feet

	Thickness (feet)	Depth (feet)
Undescribed	90	90
Chesapeake Group (Miocene)		
Clay, blue	157	247
Chickahominy Formation (Eocene)		
Stone, soft	1	248
Shell and white sand	2	250
Stone, hard	1	251
Sand, gray	4	255
Clay, brown	5	260
Shells and white sand	5	265
Stone, soft	10	275
Nanjemoy Formation (Eocene)		
Sand, black	5	280
Stone and sand layers	60	340

Table 6 -Chemical analyses of water from wells in Essex County, Va.

(Analyses in milligrams per liter. ATG, A. T. Grant; MDF, Margaret D. Foster; HBR, H. B. Riffenberg; JL, J. Loudon; AJZ, A. J. Zuchelli.)

	Well no.							
	1	2	18	19 in computer 56 M14	30 in computer 5965	32b	35	37
Location	Layton	Layton	Tappahannock	Tappahannock	Wares Wharf	Dunnsville	Bowlers Wharf	Butylo
Depth (feet)	250	375	515	573	180	390	165	330
Silica (SiO_2)	~~.03~~				38			
Iron (Fe)	.03				.07			
Calcium (Ca)					25			
Magnesium (Mg)					1.1			
Sodium (Na)					93			
Potassium (K)					93			
Bicarbonate (HCO_3)	428	362	404	244	302	198	186	172
Sulfate (SO_4)	16	13	8	15	11	8	7	11
Chloride (Cl)	2.7	2.1	2	1.7	3.3	2	2	3.6
Fluoride (F)	1.5	1.6	2.1	1.5		.6		.7
Nitrate (NO_3)					.48	.6		
Dissolved solids	412	364		255	319			188
Total Hardness (as $CaCO_3$)	18	5	9	1	67	32	72	92
Date	Nov. 1968	Nov. 1968	Feb. 1941	Nov. 1968	July 1918	Aug. 1950	Feb. 1941	Nov. 1968
Analyst	ATG	ATG	MDF	ATG	HBR	JL	MDF	ATG

Table 6 -Chemical analyses of water from wells in Essex County, Va. (cont.)

(Analyses in milligrams per liter. ATG, A. T. Grant; MDF, Margaret D. Foster; HBR, H. B. Riffenberg; JL, J. Loudon, AJZ, A. J. Zuchelli.)

	Well no.										
	41a	41b	45	46	47	48					
Location	Center Cross	Center Cross	Champ-lain	Elevon	Hustle	Supply					
Depth (feet)	410	295	22	40	30	48					
Silica (SiO_2)											
Iron (Fe)	.12										
Calcium (Ca)											
Magnesium (Mg)											
Sodium (Na)											
Potassium (K)											
Bicarbonate (HCO_3)	476	123	44	5	20	114					
Sulfate (SO_4)											
Chloride (Cl)		2.0	4.0	11	2.8	53					
Fluoride (F)			0.0	0	0.2	0.2					
Nitrate (NO_3)		0									
Dissolved solids											
Total Hardness (as $CaCO_3$)	8	87	38	16	15	161					
Date	Apr 1950	March 1954	June 1951	June 1957	July 1951	June 1951					
Analyst	JL	JL	AJZ	AJZ	AJZ	AJZ					

Middlesex County

Middlesex County lies along the south bank of Rappahannock River and, at its eastern end, projects into Chesapeake Bay. The land area is 132 square miles. The population in 1960 was 6,319 of which 512 lived in Urbanna.

Although essentially a rural county only about 15 percent of the working force was employed in agriculture. The number of people employed in manufacturing is not large. However, processing of fresh and frozen seafood is an important industry in and around Urbanna, boatbuilding employs a number of individuals in the eastern end of the county, and lumber is cut in several localities.

Nearly half the total farm income is derived from sale of poultry, chiefly ducks and turkeys, a third of the income from field crops - soybeans, corn, and wheat, and the remainder from dairy products and livestock.

~~An important activity is catering to summer visitors~~ who come to enjoy bathing, boating, and fishing, particularly in the more easterly part of the county.

U.S. Highway 17 leads into Middlesex County from Newport News and passes through Saluda and Urbanna and connects this section with Fredricksburg and other arterial highways. There are no railroads in the county but bus service is available. Bulk freight can be shipped in shallow draught vessels on the Rappahannock River. A small airport is located at Grey's Point, 7 miles northeast of Saluda.

Geology

The county is underlain by unconsolidated sediments of Cretaceous, Paleocene, Eocene, Miocene, and Pleistocene age. It is believed that the Potomac group of Lower Cretaceous sediments has not been reached by any wells in the county. The Mattaponi Formation of Late Cretaceous ~~to~~ and Paleocene age is well developed, ~~but~~ the overlying Aquia Formation of Paleocene age is presumed to be absent. The Nanjemoy Formation of Lower and Middle Eocene age is present and thins eastward, ~~but~~ the Chickahominy Formation of ~~Upper~~ Eocene age thickens to about 140(?) feet in the eastern part of the county (pl. 1, section A-A').

Pre-Cretaceous Basement Rock

Bedrock

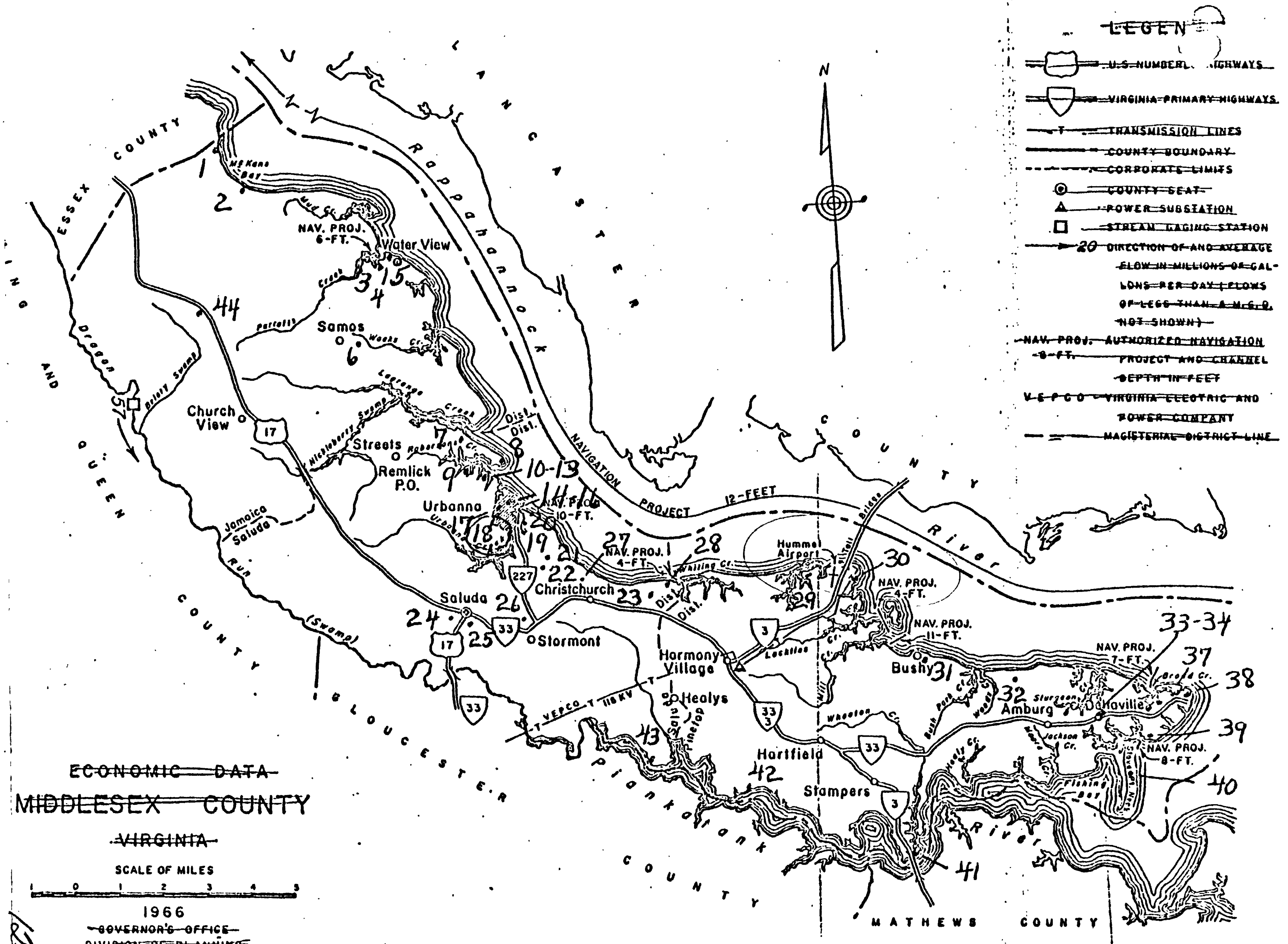
Depth to bedrock in Middlesex County is not known but reasoning from data at West Point and ~~New Point Comfort~~, Mathews ~~County~~, it may be about 1,400 feet in the uppermost end of the county and 2,300 feet in the lowermost part of the county.

Cretaceous ~~to~~ and Tertiary Systems

Mattaponi Formation - The Mattaponi Formation of Upper Cretaceous to Paleocene age is penetrated by several deep wells in and around Urbanna. The higher beds of the Mattaponi Formation are characteristically glauconitic and hence difficult to distinguish from overlying Eocene beds that are glauconitic everywhere. The lower beds in the formation are characterized by highly colored clays and glauconite may or may not be present.

In a well (19) drilled in 1906 for the town of Urbanna (Sanford, 1913, p. 224), it was reported that clay as "red as paint" was penetrated between 522 and 540 feet below the surface. This stratum is underlain by 7 feet of pink and brownish clay. Such beds are typical of the lower part of the Mattaponi Formation. The log of the more recently drilled municipal well (18 see table 8 and fig.) indicates that highly colored clays extend to at least 662 feet below the surface.

According to the log of well 9, the higher beds in the Mattaponi Formation are highly glauconitic. However, the writer feels that perhaps much of the glauconite reported was washed down from higher horizons. Nevertheless, it is likely that the higher beds are glauconitic to some degree, occurring as somewhat glauconitic blue clays and a subordinate glauconitic quartz sands. In the Shannon well (20) the deeper strata are reported to be rather nondescript.



'Figure .--Location of wells in Middlesex County.

Tertiary System

Eocene Series

<u>Nanjemoy Formation</u> - It is thought that the Nanjemoy Formation of Lower and Middle Eocene age may be thin, perhaps 10 to 30 feet thick at Urbanna but thicker upstream and thinner downstream. In any event, it cannot be differentiated from the overlying Chickahominy Formation beds on the basis of logs at hand.

<u>Chickahominy Formation</u> - Foraminifera of Late Eocene age have been identified in samples from several wells in Lancaster County (Sinnott, 1967) which lies on the north side of the Rappahannock River. Hence, there is reason to expect that this formation is present at depth throughout the easterly county.

The Eocene section is characterized by nondescript marl, glauconitic sands and layers of limestone with included thin sandy beds. The Eocene section at Urbanna is thought to be about 120 feet thick, of which the greater part is assigned to the Chickahominy Formation. Updip at the Middlesex-Essex County line the Chickahominy is thinner and the Nanjemoy thicker but the total Eocene thickness is probably much the same as at Urbanna.

The lithology of the sections at Wilton Point (41) and Stove Point (40) nearer the lower end of the county are not very helpful in establishing formational contacts. The base of the Eocene is drawn at the base of a stratum highly characteristic of the Eocene section. The Miocene-Eocene contact was drawn by projection from the area to the west.

Water Bearing Formations

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series

Mattaponi Formation - The old town well (16) at Urbanna described by Sanford was drilled to a depth of 589 feet and developed water initially in a loose sand stratum, 42 feet thick, that was penetrated at 547 feet. This sand lies below the highly colored clays characteristic of the lower part of the Mattaponi Formation. The lower portion of the hole caved but a flow from a sand at 492 to 500 feet continued. The shallower horizon reached in this well was also reached in the G. W. Hurley well (14), the Urbanna Lodge well (17) at the wharf and the Walter Sams well (9). The deepest wells in and around Urbanna, however, are the Shannon well (20) which reached a depth of 650 feet, the 1963 town well (18) 620 feet deep and the Brill Duck Farm wells (21, 22) which are about 650 feet deep.

Upstream at Remlik the several wells at the Lord Mott Canning Co. (11-13) end in the Mattaponi Formation.

Sanford reports (1913, p. 318) that the free flow of the old town well (14), combined with the flow of a shallower well, was 75 gpm in 1906. The Walter Sams well (9) near Remlik, 4-inches in diameter, is said to have had a flow of 72 gpm in 1940.

The 1963 town well (18) is reported to have been pumped at a rate of 430 gpm with only 30 feet of drawdown, having therefore a specific capacity of 14.2 (gallons per foot of drawdown). The Shannon well (20) was pumped at a rate of 205 gpm with 39 feet of drawdown and has a specific capacity of 5.2.

At the Brill Duck Farm, two wells just east of Urbanna (21, 22) and a third well near Burhans Wharf (23), are three of the highest yield wells in the county. Yields are given as 752, 857, and 1100 gpm. When drawdown is taken into account, the efficiencies are, respectively 11.6, 7.7, and 22 ~~gallons~~ gpm per foot of drawdown. The efficiency and maximum yields are a function of the character and thickness of sands penetrated and the amount of screens used. The Shannon well which has a relatively low efficiency has only 25 feet of screen. On the other hand the well of highest yield at Brill Duck Farm (23) does not have as much screen as the well with the lowest efficiency (22). Here, of course, the permeability of the particular sands penetrated rather than their total thickness is the critical factor.

The deep wells at Wilton Point and Stove Point end in the Mattaponi Formation (Section B-B', pl. 1).

Nanjemoy Formation - A few wells in upper Middlesex County, as at Bayport (1 and 2), develop water in a series of thin limestone strata alternating with glauconitic quartz sand penetrated at about 250 to 300 feet below the surface. These sands are thought to be part of the Nanjemoy Formation. In 1906 water would rise as much as 26 feet above sea level in wells of this depth in the upper part of the county (Sanford, 1913, p. 318). No large flows were reported.

Chickahominy Formation - A few wells at Remlik (10), Urbanna (15) and Saluda (25) obtain water from wells 200 to 250 feet below sea level. These probably end in the Chickahominy Formation. At Waterview the formation is described as "sand and shell." Sanford reports that two 1-inch diameter wells 227 feet deep at Urbanna were pumped with a combined yield of 105 gpm.

Wells of moderate depth in the somewhat easterly part of the county may develop water from the Eocene formations. At Greys Point on the Rappahannock the H. M. Jones well (30) is 357 feet deep. In Gloucester County on the south side of the Piankatank River two wells (4, 5, table 13) at Freeport, opposite Healys Mill, are about 330 feet deep. The deeper wells mentioned may end in the Mattaponi Formation but the well at Greys Point and the wells mentioned in Gloucester County are almost certainly developed in the Eocene.

Water from Miocene Deposits

Chesapeake Group - In the lower end of the county, as at Deltaville (34-36), table 7) are many wells that obtain small supplies of water from thin sandy strata of Miocene age. Such wells may be as little as 75 feet deep or, less commonly, as much as 300 feet deep.

In the easternmost part of the county at Stingray Point, six sandy beds are present between 60 and 195 feet but all yield saline water, according to Mr. A. W. Ruark who has drilled many wells in that area. In 1956, Mr. Bruce Norman of Walkerton developed water at 180 feet that was too salty to use[37] and further efforts[38] to a depth of over 700 feet were equally fruitless.

Quaternary System

Water from Pleistocene Deposits

Water in quantities sufficient for household use is obtained from shallow wells throughout the county.

At Stingray Point where Miocene and older formations yield only brackish or saline water, larger quantities of fresh water than that yielded by one shallow well might be developed by pumping several shallow wells as a unit, skimming off fresh water from salty water below. The practicability of an infiltration gallery - a permeable tile or other collecting device laid just below the water table, would be determined by costs involved and ground available. Such a system might yield a few tens of gallons a minute as opposed to the very small yields available to a single dug or driven well.

Quality of Water

Water from the Mattaponi Formation

Water from deep wells in upper and central Middlesex County is a soft sodium bicarbonate type with a very low chloride content. In Remlik (11, table 9) and Urbanna (12, 17, 20) the bicarbonate content of the wells reaching the Mattaponi Formation is around 500 mg/l ~~ranges from 474 to 556 ppm~~ but the concentration of other constituents are low. Fluoride, however, ranges from 2 to 2.6 mg/l ~~ppm~~, slightly more than the 1.5 mg/l ~~ppm~~ considered desirable for public supplies. It is particularly noteworthy that the chloride content of water from the deepest wells is very low.

This type of water is highly satisfactory for domestic and most industrial purposes. Foaming might be troublesome where the water is used for boiler feed. However, because of its high sodium content, it is not suitable for irrigation.

In eastern Middlesex County wells reaching the Mattaponi beds yield a high-chloride water with high sodium-bicarbonate, as shown by the analysis (39, table 9). A sample taken in 1918 from the well at Amburg contained 1,820 mg/l of chloride and 1,051 mg/l of bicarbonate. The high bicarbonate content of the Amburg well water can perhaps be accounted for by solution from the soft glass container upon standing, perhaps for several months.

In 1964, a deep well (40) was drilled at Stove Point Neck in an attempt to find a supply of potable artesian water. Water at a depth of 13 feet, occurring under water table conditions, contained 87 mg/l of chloride. At 51 feet chloride was 710 mg/l and at 120 feet 3,905 mg/l. These waters are probably a mixture of present bay waters and infiltrating rainwater. The first artesian stratum was reached at about 436 feet. Here the water contained 1,395 mg/l of chloride. At 628 feet the water contained 1,847 mg/l of chloride, almost the identical concentration reported in water from the Amburg well.

It may be noted that at Greys Point (29, fig. 5) brackish water was present in a 700 foot well whereas at Burhans Wharf, about 3 miles to the east, water from well 23 contains only 11 mg/l of chloride. On the Piankatank, water from well 42 near Fairfield

Landing has a chloride content of 294 mg/l and a shallower well near Freeport in Gloucester County just upstream has a chloride content of only 30 mg/l. The boundary of the high chloride artesian water zone thus seems well defined.

Water from Eocene (?) Deposits

Wells of intermediate depth, about 300 feet, may yield somewhat mineralized but potable water in the Greys Point - Wilton Point area. However, there are not sufficient data at hand to be more specific in this regard.

The highly mineralized waters from Stove Point Neck and Amburg represent a mixture of fresh water that has migrated down dip from the Fall Zone with old sea water not completely flushed from the formation. Because they were once saturated with sea water the sediments are loaded with exchangeable sodium and waters migrating down dip have exchanged their calcium content for sodium--hence, both the high chloride waters described and the essentially chloride-free waters from around Urbanna are soft sodium bicarbonate waters.

Water from Miocene Deposits

Water from three wells at Deltaville (34-36, table 9) that obtain water from Miocene deposits is somewhat hard, with hardness ranging from 114 to 264 mg/l. Hardness is present as calcium bicarbonate. Chloride is low, as much as 56 mg/l on one sample, but only 7 mg/l in another.

Although somewhat hard, these waters are entirely acceptable for domestic use and, because of their high calcium and low sodium content, they are excellent for irrigation purposes.

Water from Pleistocene Deposits

Water from shallow dug or driven wells has a low hardness and mineralization but where such wells bottom in Miocene marls the soft water derived in largest part or entirely from the terrace formations may become hard. Shallow water characteristically is slightly acidic and where such water comes in contact with limy sediments, calcium bicarbonate is produced.

In low lying areas on the Chesapeake Bay where the only water available is from shallow wells, means of providing larger, more dependable and safer supplies should be considered in view of present heavy summer populations and probable increase in demands.

A trunkline bringing artesian water from a distant source up the peninsula offers an obvious and expensive solution. However, before such a trunkline is justified and constructed, much might be done on a smaller scale through artificial recharge.

Where a central supply point for several villages is to be established, it may be practicable to recharge the deep brackish water artesian formations with fresh water from shallow wells. Much of the recharged fresh water could be pumped back as needed, uncontaminated by the brackish water, as explained in the general part of this report.

Shallow wells in the terrace formations can furnish a modest volume of water but reliance on that water in times of peak demand and low recharge would be both risky and expensive. However, where adequate storage is provided, as in the deep formations, the discharge obtained during long colder month seasons might easily satisfy the peak summer demand. If it be assumed that as little as 50 gpm were pumped from one or two shallow wells continuously and injected in a deep well for 9 months, 150 gpm could be pumped back in the following summer season, a volume sufficient for at least 1,500 people. Actually, since some mixing would take place, the return ratio would not be as favorable as stated. The efficiency to be expected after injection is not determinable at present but there is every reason to believe the device suggested is worth considering. Obviously, a recharge rate of in excess of a hundred gallons a minute would be hoped for. A very few properly constructed shallow wells might supply the amount of water required with ease, most of the time. Economies in operation might be effected by recharging only at times when off peak power rates are available. Inasmuch as recharging would have to be done under some pressure (the artesian head is probably almost as high as the shallow water table), the most efficient operation would require that a maximum recharge rate at minimum head (power cost) be established. On the other hand, slightly higher costs might be accepted in order to recharge a greater volume of water. Since lifting water from a well and pumping to an overhead tank for recharging, might involve as little as 50 feet of pumping head, the power cost would be low--about ~~25¢~~ 1/4 cent per thousand gallons at 1¢ per kilowatt hour.

In some areas, water from the Miocene formations is also available. As noted above, where this is a very hard water, it may not be as desirable for recharging as the softer water from the terrace formations. The compatability of injected water with reference to the deep formations and possible clogging is one of the several aspects of artificial recharging about which little is known.

Assuming that a recharge well was constructed and operated as sketched out above, there is no reason why water from the shallow wells, ending either in the terrace formations or in Miocene beds or both, should not be used in conjunction with water from the recharge well during the peak demand season. The shallow water supply might vary considerably according to recharge received from local rainfall but whether large or small, it could be utilized to the fullest extent possible ~~a maximum~~ and deep well recharged water utilized as makeup.

With respect to artificial recharge, the state of the art is such that specific recommendations cannot be made at this time. The purpose of the discussion given above is to point out the possibilities inherent in this device and the great savings that might be made by providing water locally rather than by trunkline from some distant source. The results of further work in the field of artificial recharge through deep wells will be awaited with interest.

Table 8 .--Logs of wells in Middlesex County, Va.

Well 3 , W. E. Abbott, Waterview
(log by Sydnor Hydrodynamics, Inc.)
Altitude 5 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, yellow, clayey	38	38
Chesapeake Group (Miocene)		
Mud, blue	54	192
Chickahominy Formation (Eocene)		
Sand, shells, mud	12	204
Mud, blue	40	244
Clay, sandy	41	285
Sand, black	5	290
Sand, grey	5	295
Sand, coarse	10	305
Mattaponi Formation (Paleocene to Upper Cretaceous)		
Clay, yellow	6	311

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Table 9.---Logs of wells in Middlesex County, Virginia (Cont.)

Well 4, Mrs. Hazel Glenn, Waterview

(Log by O. C. Brenneman)

Altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, yellow	30	30
Chesapeake Group (Miocene)		
Clay, blue, sandy,	170	200
Chickahominy and Nanjemoy Formations (Eocene)		
Shell and sand; water	40	240
Nanjemoy Formation (Eocene)		
Shell rock formation and black and white sand	55	295

Table 8.—Logs of wells in Middlesex County, Va. (cont.)

Well 6, J. H. Jackson, Samos

Altitude 25 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, yellow	20	20
Sand, coarse	30	50
Chesapeake Group (Miocene)		
Clay, dark	102	152
Sand, fine	8	160
Clay, dark	56	216
Chickahominy Formation (Eocene)		
Sand and shell; water	20	236
Rock and shell	6	240
Sand, clay and shell	15	265
Sand and shell; water	37	302
Rock	4	306
Sand and shell	13	319
Mattaponi Formation (Paleocene to Upper Cretaceous)		
Clay	156	475
Sand	50	550

Table 8 .--Logs of wells in Middlesex County, Virginia (cont.)

Well 7, J. W. Ferguson, Remlik

Altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Subsoil	30	30
Chesapeake Group (Miocene)		
Clay, blue	145	175
Clay, tan, and mud	25	200
Chickahominy and Nanjemoy Formations (Eocene)		
Rock and mud	10	210
Clay, blue to brown	25	235
Continued stone, water (?)	48	283
Sand white; water	7	290

Table 8 .--Logs of wells in Middlesex County, Virginia (cont.)

Well ~~21~~ 9, Walter Sams, Urbanna
(log by Mitchells Pump)
Altitude, 7 feet

	Thickness (feet)	Depth (feet)
Undescribed	40	~~40~~
Chesapeake Group (Miocene)		
Clay, black, and shell	5	45
Clay, blue	125	170
Clay, blue, shell at base	40	210
Chickahominy Formation (Eocene)		
Sand and shell	2	212
Sand and clay	8	220
Rock	2	222
Sand; water	23	245
Sand and rock, alternating	18	263
Sand and shell	5	268
Rock and sand, alternating	16	285
Nanjemoy (?) Formation (Eocene)		
Sand, black and white	15	300
Sand, black	40	340
Mattaponi Formation (Paleocene ~~and~~ Upper Cretaceous and ?) ~~Cretaceous)~~		
Sand, Black	60	400
Sand, black, minor clay	20	420
Sand, black and white	54	474
Sand and gravel, white	13	487

Note: Much of black sand below 340 feet may have washed down from above.

Table 8 .--Logs of wells in Middlesex County, Virginia (cont.)

Well 18, Municipality, Urbanna, ~~Remlik~~

(Log from Va. Div. Mineral Resources files)

Altitude 20 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, fine	43	43
Chesapeake Group (Miocene)		
Clay, green, with shells	37	80
Clay, gray	144	224
Chickahominy and Nanjemoy Formations (Eocene)		
Shell rock, shells, gray and black sand and clay in streaks	73	297
Nanjemoy and Mattaponi Formations (Eocene to Upper Cretaceous)		
Clay, gray, hard	145	442
Clay and black sand, in streaks	12	454
Clay, gray and pink	24	478
Sand, gray	16	494
Clay, mixed colors	34	528
Clay, hard, tough	29	557
Sand, gray, some black	18	575
Clay	7	582
Sand, gray	16	598
Clay	3	601
Sand, gray, coarse	23	624
Clay, red, gray and brown	38	662

Note: In well 16, hard red clay "red as paint" was reported at 522-540 feet below which 7 feet of softer pink and brownish clay was present (Sanford, p. 224, Cederstrom, 1945, p. 3[illegible]).

Table 8 .--Logs of wells in Middlesex County, Va. (cont.)

Well 20 , Mrs. S. L. Shannon, Urbanna

Altitude 15 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand and gravel	21	21
Chesapeake Group (Miocene)		
Clay, gray	207	227
Chickahominy Formation (Eocene)		
Shell and clay, in streaks	23	245
Rock and rock, in streaks	58	303
Clay, green, sand streaks	22	325
Mattaponi Formation (Paleocene to Upper Cretaceous)		
Not described[a]	55	380
Clay, gray	68	448
Sand, gray and brown, and shells	11	459
Clay, gray	16	475
Sand	7	482
Clay[b]	18	500
Sand	6	506
Clay	39	545
Sand	10	555
Clay	13	568
Sand, gray, medium to coarse; water	12	580

Table 8 .--Logs of wells in Middlesex County, Va. (cont.)

Well 20, Mrs. S. L. Shannon, Urbanna (cont.)

~~Altitude feet~~

	Thickness (feet)	Depth (feet)
Mattaponi Formation and (Paleocene) ~~in~~ Upper Cretaceous (cont.)		
Clay, gray	5	585
Sand, gray, clay streaks; water	15	600
Sand, gray	15	615
Clay, sandy	10	625
Sand; water	10	635
Clay, sandy; water	15	650

~~1/ Pink and gray clay at this depth in well 18.~~

2/ "Mixed colored clay" at this depth in well 18.

Table 8 .--Logs of wells in Middlesex County, Virginia (cont.)

Well 75, Town of Saluda, Virginia

(Log by Sydnor Pump & Well Co.)

Altitude 95 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, yellow	30	30
Sand, white	18	48
Chesapeake Group (Miocene)		
Clay, sandy, yellow	12	60
Sand, hard, fine	10	70
Clay, yellow, sandy	4	74
Sand, hard, fine	23	97
Clay, gray, and shells	2	99
Sand, hard, fine, and shells	25	124
Clay, gray	130	254
Clay, gummy, green	24	278
Clay, gray	19	297
Rock, brown	1	298
Clay, gray, and shells	1	299
Chickahominy Formation (Eocene)		
Sand, fairly coarse	16	315
Sand, fine, hard	9	324
Clay, soft, green	6	330

Table 8 .--Logs of wells in Middlesex County, Virginia (cont.)

Well 28 .--R. R. Perritt, Burhans Wharf

Altitude 32 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, brown to white	60	60
Chesapeake Group (Miocene)		
Sand, blue, fine; water	30	90
Sand, yellow	5	95
Marl, blue	133	228
Chickahominy Group (Eocene)		
Clay, gray	80	308
Shell, sand, muddy, hard streaks	44	352
Mattaponi Formation (Paleocene) to Upper Cretaceous)		
Sand, black	13	365
Shell rock	2	367
Sand, black and shell	5	372
Shell rock	3	375
Sand, black and shell	18	393
Clay, gray and black sand	50	443
Clay, gray	62	505
Sand, gray; water	8	513
Shell rock	7	520
Sand, gray; water	4	524
Rock	3	527

Table 8.--Logs of Wells in Middlesex County, Va. (cont.)

Well 40, Stove Point Neck Development

(Log by Sydnor Hydrodynamics, Inc.)

Altitude 5 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, white; water	18	18
Sand and shells; water	4	22
Chesapeake Group (Miocene)		
Clay, blue	31	53
Clay, blue and shells	7	60
Shells, coarse	15	75
Sand and shells; water	8	83
Sand, gray and green, fine; water	36	119
Sand, green, silty and clayey	24	143
Clay, gray	64	207
Sand, gray, silty and clayey	15	222
Clay, gray	16	238
Clay and shells	7	245
Clay, green to gray, silty	65	310
Chickahominy (?) Formation (Eocene)		
Clay, green, silty	20	335
Clay, green	101	436
Sand, black, some shells and clay, sharks teeth; water	21	457
Mattaponi (?) Formation (Paleocene to Upper Cretaceous)		
Clay, green	43	500
Clay, gray, some shells	15	515

Table 8.--Logs of Wells in Middlesex County, Va. (cont.)

Well 40, Stove Point Neck Development (cont.)

	Thickness (feet)	Depth (feet)
~~Undifferentiated~~		
Clay, gray, tough	81	596
Sand (?)	2	598
Clay, gray	29	627
Gray sand, hard, some clay; water	8	635
Gray sand, hard, with mica; water	15	650
Sand, gray, coarse; water	17	667
Sand, gray, fine, some clay	21	688
Sand, gray, coarse; water	8	696
Clay, gray	12	708
Sand, gray, hard; water	14	722
Sand, gray, soft; water	64	786
Sand, clayey	3	789
Clay, gray, hard	3	792

Table 9 .--Logs of wells in Middlesex County, Virginia (cont.)

Well 41, C. Huff, Twiggs Ferry, Wilton Point

(Log from Va. Div. Mineral Resources files)

Altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Subsoil	16	16
Chesapeake Group (Miocene)		
Clay, blue	9	25
Sand and shells	2	27
Clay, blue	18	45
Sand, green, and clay	18	63
Clay, light blue	10	70
Shells	5	75
Stone, soft	15	90
Blue to tan to blue formation	165	255
Soapstone (hard clay)	9	264
Undifferentiated		
Clay, green	151	415
Undescribed	8	423
Stone; some water at 460 feet	37	460
Undescribed; brown clay at 700 feet	240	700

Table 9 -Chemical analyses of water foam wells in Middlesex County, Va.

(Analyses in milligrams per liter. AJZ, A. J. Zuchelli; GWW, G. W. Whetstone; HBR, H. B. Riffenberg; ATG, A. T. Grant; JL, J. Loudon.)

	Well no.									
	3	3	5	11	12	17	20 58K7	23 58J9	25 58J1	31
Location	Jamaica	Water-view	Water-view	Remlik	Remlik	Urbanna	Urbanna	Burhans Wharf	Saluda	Bushey
Depth (feet)	54	311	275	471	535	480	650	~~740~~ 740 ~~527~~	330	22
Silica (SiO_2)		20								
Iron (Fe)		tr								
Calcium (Ca)		7.2								
Magnesium (Mg)		3.7								
Sodium (Na) / Potassium (K)		113								
Bicarbonate (HCO_3)	80	323	325	474	487	485	500	504	319	8
Sulfate (SO_4)		5.5	5	15	19	17	21	26	4	6
Chloride (Cl)	85	2.5	2	6	6.3	6.0	6.0	11.	2	8
Fluoride (F)	0	.9	1.0	2.0	2.6	2.2	2.1	2.6	1.6	.1
Nitrate (NO_3)		.5		0.6		.5			.5	
Dissolved solids		319			465		477	499		
Total Hardness (as $CaCO_3$)	36	33	15	9	3	15	7	4	21	16
Date	May 1951	May 1948	May 1915	May 1948	Nov. 1968	1946	Nov. 1968	Nov. 1968	May 1948	Aug. 1950
Analyst	AJZ	GWW	HBR	GWW	ATG	GWW	ATG	ATG	GWW	JL

(Analyese in milligrams per liter. AJZ, A. J. Zuchelli; GWW, G. W. Whetstone; HBR, H. B. Riffenberg; ATG, A. T. Grant; JL, J. Loudon.)

	Well no.										
	32	34	35	36	37	39	42	44			
Location	Lot	Delta-ville	Delta-ville	Delta-ville	Stingray Point	Amburg	Fair-field Landing	Jamaica			
Depth (feet)	17	75	121	126	16	822 LOJ 6	500(?)	54			
Silica (SiO_2)						In computer. 57					
Iron (Fe)			.31			8.0					
Calcium (Ca)	8.4					9					
Magnesium (Mg)	12					20					
Sodium (Na) } Potassium (K)	79					1,646					
Bicarbonate (HCO_3)	99	176	161	316	0	1,051	496	80			
Sulfate (SO_4)	3.3	2	2	1	10	234	59				
Chloride (Cl)	92	10	7	56	34	1,820	294	85			
Fluoride (F)				.1	.1		3.5	0			
Nitrate (NO_3)	35	1.4	.3	.2		5.0					
Dissolved solids	321					4,308	1,067				
Total Hardness (as $CaCO_3$)	70	129	114	264	56	104	12	36			
Date	June 1918	May 1948	May 1948	Aug. 1950	Aug. 1950	June 1918	Nov. 1968	May 1951			
Analyst	HBR	GWW	GWW	JL	JL	HBR	ATG	AJZ			

King and Queen County

Introduction

King and Queen County is one of the more inland counties of the Coastal Plain. It lies directly south of Middlesex County. The southern boundary is formed by the Mattaponi River and, at the westernmost extent of the county, by Beverly Run. The land area is 230 square miles. The population in 1964 was 5,617.

The population is entirely rural. About one-fourth of the employed persons are engaged in agriculture, forestry, and fishing and about as many are employed in manufacturing. Many of the latter group are employed at West Point in adjacent King William County. With the abandonment of the former cannery at Walkerton, the manufacturing establishments in the county deal exclusively in lumber and basic lumber products.

U.S. Highway 360, connecting Richmond with Tappahannock and Maryland crosses upper King and Queen County. State Highway 14 runs the length of the county and provides access to highways north to Fredericksburg and Washington and southeastward to Newport News via Gloucester County and the bridge to Yorktown.

Geology

Basement Rock

Consolidated rock considered here to be basement rock, has been reached in a well at West Point (fig. 6), at the eastern end of adjacent King William County, at a depth of 1,284 feet, that is, about 1,260 feet below sea level. At Bowling Green it was reached at about 260 feet below sea level. Hence, as shown in Section B-B', plate 1, basement should be perhaps as little as 500 feet below sea level in upper King and Queen County and more than 1,300 feet below sea level at the lower end of the county.

The rock reached in the 1,284 foot well at West Point may be Triassic sandstone although it is possible that the "rock" is a consolidated Cretaceous stratum. However, the rock reported at West Point will fall almost exactly on a line drawn from basement at Bowling Green to basement at Mathews. [redacted] Basement rocks underlying the Tidewater area are more likely largely granite, schist and other metamorphic rocks.

Cretaceous System - -

Potomac Group

A considerable thickness of sediments of the Potomac Group of Early Cretaceous age was penetrated in the deep well at West Point in adjacent King William County. These consist of alternating sand and clay beds. As seen in the cross section, the boundary between the overlying Mattaponi Formation and the Potomac Group is conjectural. It seems likely that the thick sands above a

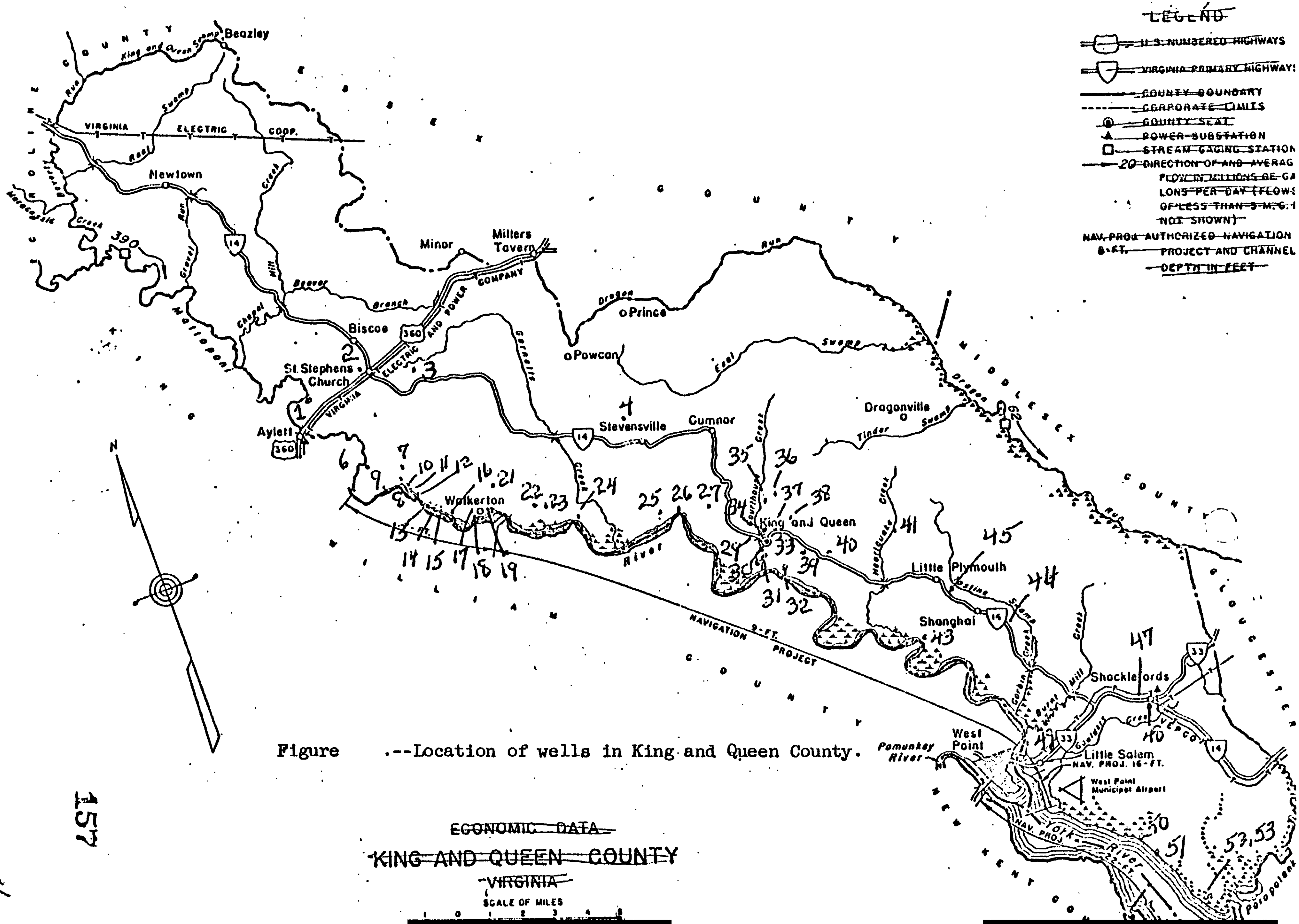

Figure .--Location of wells in King and Queen County.

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depth of 800 feet are basal sands of the Mattaponi Formation rather than Potomac sands. If so, the Potomac section is about 500 feet thick, of which the lower 200 feet is very sandy. The Potomac group underlie all of King and Queen County, ~~they have~~ not been reached by any wells, as far as can be determined.

Cretaceous to Tertiary Systems

Upper Cretaceous to Paleocene Series

Mattaponi Formation: The Mattaponi Formation is of ~~Upper~~ Cretaceous and Paleocene age. It is characterized in its upper portion by glauconitic sands and clays that are not greatly different from overlying Eocene beds in many places. The lower part of the formation is characterized by highly colored, variegated or mottled clays, sometimes termed "rainbow clays" by the driller. These beds are non-glauconitic or only slightly glauconitic. Thick sands occur at the base of the formation at West Point where the Mattaponi section is considered to be about 500 feet thick. The higher beds in the Mattaponi Formation ~~are~~ nondescript clays alternating with glauconitic and quartz sand. ~~These beds~~ and the underlying mottled clays have been penetrated in wells in the Stephensville - Walkerton - St. Stephens Church area in King and Queen County. ~~but wells there penetrate~~ only the uppermost ~~portion~~ of what is considered to be the basal sand section.

<u>Aquia Formation</u>: The Aquia Formation is of Paleocene age but at the type locality on Aquia Creek and for some miles eastward is characterized by a foraminiferal fauna that is different from that of the underlying Paleocene strata. Studies in the York-James Peninsula (Cederstrom, 1957, p. 26) show that the Aquia Formation thins to a vanishing point downdip. It is thought that in King and Queen County it does not extend much farther downstream than Walkerton.

The Aquia is made up of blue clays and minor sand and is highly glauconitic, as are the overlying beds of the Nanjemoy Formation.

Tertiary System
Eocene Series

<u>Nanjemoy Formation</u>: The Nanjemoy Formation of Lower and Middle Eocene age is made up of highly glauconitic sand and marl beds. It is exposed along the Mattaponi River upstream from Aylett but is reached at a depth of about 200 feet below sea level in the eastern end of the county. It is more sandy than the underlying Aquia and commonly has intercalated thin limestone strata. ~~The basal member of the Nanjemoy is~~ A pink to brown clay is present from place to place the base of the Nanj The brown clay reported in the log of well 18a (Table 11) at Walkerton at 120 to 140 feet below the surface is considered to be that distinctive stratum.

The maximum thickness of the Nanjemoy is about 110 feet in this county. In the upper end of the county it may be thinner due to erosion before the overlap of the Miocene formations. In the lower end of the county it is transected by the overlying Chickahominy Formation and there it begins to diminish in thickness.

Chickahominy Formation: Beds of late Eocene age, named the Chickahominy Formation in Virginia, are present only in the easternmost part of the county. Dentalina bevani, a highly diagnostic foraminifer, has been recognized in cuttings from West Point. However, the formation is undoubtedly very thin at West Point and it is not shown in published logs of wells there (Cederstrom, 1957, p. 101-103). "Dirty sand and stone" and "sand and mud" from 243 20 248 feet penetrated in a well at Shackelfords Fork may possibly represent the Chickahominy.

Miocene Series

Chesapeake Group: The Chesapeake Group of formations consists of gray to blue marls and clays and subordinate fine sand beds. Their maximum thickness, beneath high ground, is in the nature of 200 feet. However, on low ground along the Mattaponi River above Aylett, the Miocene strata have been removed by erosion and underlying Eocene beds are exposed at the surface.

Quaternary System

Pleistocene Series

Columbia Group of formations of Pleistocene age occur as terraces capping the older formations (almost entirely Miocene formations) throughout the county. Along streams and rivers erosion has cut through them and only the underlying Miocene beds are present.

The terrace formations are made up of varying degrees of generally yellow clays and quartz sands.

Water Bearing Formations

Lower Cretaceous Series - Potomac Group

Basal sands and gravels of the Potomac group of formations have been penetrated in a well at West Point in adjacent King William County from which 708 gpm was obtained with 118 feet of drawdown. In one well 100 feet of screens were placed from 1,051 to 1,277 feet below the surface, thus indicating an unusually thick section of water-bearing material.

The basal sands and gravels of the Potomac group have not been penetrated in King and Queen County and, in fact, may have been reached by only a few wells anywhere in the Coastal Plain of Virginia north of James River. However, there is every reason to believe that such beds underlie all of King and Queen County. At the upper end of the county they may be thinner but should be as coarse grained. At the lower end of the county they should be thicker although possibly finer grained than at West Point.

It should be noted that the deepest well at West Point yielded water that contained 212 mg/1 of chloride in sharp contrast to wells less than 450 feet deep from which the water contained not more than 12 mg/1 of chloride. Nearer the upper end of King and Queen County water from wells tapping basal Potomac beds should be low in chloride whereas at the extreme lower end of the county, the deep water will probably be more highly mineralized than at West Point.

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series

<u>Mattaponi Formation</u>: About 200 feet of sands and gravels and subordinate clayey beds are considered to mark the base of the Mattaponi Formation at West Point. One well 699 feet deep yields 900 gpm with 75 feet of drawdown (Cederstrom, 1957, p. 97).

In King and Queen County wells more than 350 feet deep near Aylett (1), Walkerton (22, 18, 19, and 21) and Stevensville (4) and at Roane below West Point (52) penetrate the upper portion of the basal Mattaponi sands referred to above.

The largest flow from any deep well in the county (11, Table 10) was 35 gpm as of about 1906 (Sanford, 1913, p. 203). Well 18b at Walkerton, drilled in 1926, had a flow of 45 gpm and well 18c, drilled in 1939, flowed 30 gpm and yielded 150 gpm to a suction pump. Both wells 18b and 18c are 3 inches in diameter and are equipped with screens, the latter having had 10 feet of #40 slot screen installed. However, it may be noted that a 3-inch well drilled in 1927 near Aylett in adjacent King William County is reported to have had a flow of 200 gpm at about 10 feet above sea level at the time it was drilled and another 3-inch well drilled nearby in 1939, also tapping basal Mattaponi sands, had a flow of 150 gpm (Cederstrom, 1957, p. 96).

The pumped well of highest yield in the county (18d) is that drilled for the now defunct cannery at Walkerton. This well is equipped with 40 feet of screen and yielded 253 gpm with 139 feet of drawdown. The slot sizes of the screen installed (25- and 30-slot) suggests that the water-bearing sand is a medium-grained sand.

As noted, very high yields have been obtained at West Point and initial flows of small diameter artesian wells of limited depth in upper King and Queen and King William Counties are fairly impressive. Therefore, it seems obvious that large yields should be available from properly constructed and developed deep wells penetrating the Mattaponi Formation and Potomac Group throughout practically all of King and Queen County.

At the time of Sanford's survey, around 1906, the height to which water in the deep artesian beds would rise was 35 feet or so above high tide level, in the central part of the county. In 1943 it rose 15 feet above sea level at Walkerton.

A larger number of wells (23, 12-16, and 6-10) and in quartz or quartz and glauconite sands higher in the Mattaponi section at depths generally ranging from 225 to 285 feet. These are located along the Mattaponi River from Aylett to Walkerton.

No large flows have been reported from these wells. The maximum reported (well 16) was 20 gpm but most of the wells had a much smaller flow. The artesian head in wells in this depth range appears to be about the same as in the deeper wells. Presumably good yields, say in the nature of 100 gpm, could be obtained from some or many of these wells were they of somewhat larger diameter than 2 inches and equipped with screens.

Tertiary System

Paleocene Series

Aquia Formation: It is not certain that any wells in the county end in the Aquia Formation. (See Section B-B[1], pl. 1).

Eocene Series

Nanjemoy Formation: Twelve wells (32, 42, 29, 30, 34-41) at King and Queen Court House and at least one at Mantapeke (25) and at Little Plymouth (43) end in sands of the Nanjemoy Formation at a depth of about 150 feet below sea level. The sands are glauconitic to some degree or, in places, all glauconite, sand, fine in texture and commonly thin. The artesian head was never as high as ~~there~~ in deeper wells, only about 23 feet above river level, and flows were generally small. Sanford mentions an old well at King and Queen Court House (38, Table 10), 216 feet deep and drilled in 1889, that had a small flow at an elevation of 23 feet above high tide but which, in 1906, had lost head to the extent that it had to be pumped. The greatest flow reported in 1943 from Nanjemoy beds was 12 gpm (well 32) but well 416 was said to have been pumped at a rate of 20 gpm. Because of the low head, sands in the Nanjemoy are not developed by wells in many places. However, the formation appears to be an excellent and economical source of water for domestic use and could probably be developed in other parts of the county.

Chickahominy Formation: Many of the old wells mentioned by Sanford (1913, p. 210) 110 to 120 feet deep at West Point end just about where thin beds of the Chickahominy Formation would be expected to be found. The well (50) at Gressitt, according to Sanford (p. 310) ends in rock at 206 feet. This appears to be the thin limestone and sand sequence characteristic of the Chickahominy elsewhere. The old wells at Roane (53) and Belleview (51) are of much the same depth.

Chesapeake Group — Miocene Series

No wells are known to end in Miocene formations in King and Queen County, nor in the adjacent more highly developed West Point area.

Quaternary System
Pleistocene Series

Throughout the county are many wells up to about 40 feet deep that obtain water from the terrace sands. Only quantities sufficient for domestic use have been developed as far as is known.

Quality of Water

Water from the Mattaponi Formation

Water from jetted and drilled wells in King and Queen County are soft sodium bicarbonate waters. Two samples from deep wells in the Mattaponi Formation, 18c (table 12) at Walkerton and at St. Stephens Church have a rather low bicarbonate, respectively, 215 and 163 mg/1. However, just upstream from Walkerton, water from wells ending in the uppermost part of that formation (11, 16), have around 400 mg/1 of bicarbonate. In well at the Fish Hatchery (4) that developed deep Mattaponi sands also has a low bicarbonate content, 224 mg/l.

Water from the Nanjemoy and Chickahominy (?) Formations

Wells 29, 40, 44, and in the Nanjemoy Formation or (possibly) the Chickahominy Formation. These are fairly soft sodium bicarbonate waters in which bicarbonate ranges from 190 to 241 mg/1. Although considered fairly soft, the hardness of these waters is in distinct contrast to waters from the Mattaponi Formation and ranges from 56 to 93 mg/1 in those samples. The water from well 47 in the easternmost part of the county, has a hardness of only 18 mg/1 and a somewhat higher bicarbonate than the other three. The relationship suggests a not too distant source of recharge. Samples from the first three wells mentioned have undergone less base exchange than samples from greater depth and have gained only moderately in bicarbonate. The water from well 47 has traveled farther, is softer and has gained somewhat in bicarbonate.

Water from Pleistocene Deposits

Partial analysis of 23 samples of water from shallow wells shows that hardness ranges from 7 to 103 mg/l although most samples range in hardness from 20 to 45 mg/l. Most shallow well water is, therefore, fairly soft. The hardness is present as bicarbonate; other constituents are low. The analysis of water from well 35 is typical.

Where shallow wells penetrate marl beneath the sandy terrace formations, very slightly acidic shallow water may react with lime in the marl and become fairly hard.

Table 12.—Logs of Wells in King and Queen County, Va.

Well 3, Civilian Conservation Corps, St. Stephens Church
(Log from files of Va. Div. Mineral Resources)

Altitude ~~192~~ 170 (?) feet

	Thickness (feet)	Depth (feet)
Not described	65	65
Chesapeake Group (Miocene)		
Marl, blue	165	230
Nanjemoy Formation (Eocene)		
Rock	10	240
Marl, some fine sand	15	255
Marl, blue	15	270
Rock	5	275
Undifferentiated (Eocene to Paleocene)		
Marl, blue	67	342
Sand, pepper and salt	6	348
Rock, shelly, not hard	3	351
Sand, black, and rock strata	10	361

Table 12 .--Logs of Wells in King and Queen County, Va. (cont.)

Well 4, Fish Hatchery, Stevensville

Altitude 70 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Subsoil	17	17
Chesapeake Group (Miocene)		
Clay, blue	103	120
Clay, green	20	140
Nanjemoy Formation (Eocene)		
Sand, white	2	142
Stone strata	33	175
Sand, black	5	180
Sand, gray	2	182
Clay, blue	13	195
Aquia (?) Formation (Paleocene)		
Stone	2	197
Clay, blue	13	210
Mud, black	20	230
Clay, blue	35	265
Mattaponi Formation (Paleocene) ~~to~~ (Upper Cretaceous) and		
Clay, red	5	275
Clay, blue	15	290
Clay, hard, green	5	295
Clay, gray, glauconitic	40	335
Stone, shelly	3	338

Table 12.— (cont.)

Well 4

	Thickness (feet)	Depth (feet)
Mattaponi Formation (cont'd.)		
Clay, blue, soft	12	350
Sand, white, clayey	14	364
Clay, red, soft	6	370
Clay, mottled	60	430
Sand, white	35	465

Table 12.- Logs of Wells in King and Queen County (Cont.)

Well 18a, Taylor and Caldwell Cannery, Walkerton
(log by Sydnor ~~Pump & Well Co~~) Hydrodynamics, Inc.)
altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Topsoil	4	4
Sand and gravel	14	18
Chesapeake Group (Miocene)		
Clay, light brown	46	64
Nanjemoy Formation (Eocene)		
Clay, shells, sandy	56	120
Clay, dark brown	20	140
Aquia (?) Formation (Paleocene)		
Clay, dark gray	52	192
Mattaponi Formation (Paleocene) ~~to~~ (Upper Cretaceous and ?) ~~Cretaceous)~~		
Sand, black, muddy	57	249
Clay, gray	43	292 u
Sand, white; water	3	295
Clay, mixed colors	47	342
Sand and gravel; water	4	346
Mud, sand, gravel, colored clay	10	356
Sand and gravel; water	5	361
Sand and gravel, clayey; water	16	377
Sand; water	13	390

Table 12 .--Logs of wells in King and Queen County, Va. (cont.)

Well 31, King and Queen Court House; King and Queen County School Board

(Log by W. S. Reynolds)

Altitude, ~~25~~ 20 feet

	Thickness (feet)	Depth (feet)
Columbia and Chesapeake Group (Pleistocene and Miocene)		
Top soil, clay, and sand	50	50
Chesapeake Group (Miocene)		
Clay, blue	60	110
Nanjemoy Formation (Eocene) and Aquia (?) Formation (Paleocene)		
Clay, brown	15	125
Sand and shells	5	130
Clay, hard	1	131
Clay, brown	12	143
Clay, hard	1	144
Shells	6	150
Gray sand	5	155
Clay, hard	60	215
Mattaponi Formation (Upper Cretaceous and Paleocene)		
Black sand (water)	10	225

Table 12 .--Logs of wells in King and Queen County, Va. (cont.)

Well 48, E. R. Rilee, Shackelfords Fork

(Log by Reynolds & Norman)

Altitude, 100 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand and shells	100	100
Chesapeake Group (Miocene)		
Clay, blue	143	243
Chickahominy Formation (Eocene)		
Sand and stone, dirty	2	245
Sand and mud	13	258
Nanjemoy Formation (Eocene)		
Clay, blue	17	275
Continued stone	31	306
Clay, blue and sand, glauconitic	14	320

Table 12 -Chemical analyses of water from wells in King and Queen County, Va.

(Analyses in milligrams per liter. SK, S. Kaputska; EWL, E. W. Lohr; AJZ, A. J. Zuchelli; GWW, G. W. Whetstone; AIG, A.I. Grant.

	Well no.										
	4	5	11	16	18c	29	40	42	44	48 Put in Computer	48
Location	Stevensville	St. Stephens Church	Near Walkerton	Near Walkerton	Walkerton	King and Queen	Truhart	Little Plymouth	Shanghai ~~Eloom~~	Shackelfords Fork	Shacklefords Fork
Depth (feet)	465	517	170	214 Put in computer	365	145	216	35	285	320	320
Silica (SiO_2)	55K1			17	32			13		23	
Iron (Fe)	.18			.02	.01			.01		.14	.10
Calcium (Ca)				3.8	.6			20		4.8	
Magnesium (Mg)	4 ~~32~~			1.6	.5			7.2		1.4	
Sodium (Na)				160	88			15		94	
Potassium (K)				~~160~~	~~83~~			9.5		~~94~~	
Bicarbonate (HCO_3)	224	163	432	413	215	205	200	36	190	251	248
Sulfate (SO_4)	17		13	14	11	7		6.7		7.6	6.2
Chloride (Cl)	1.7	1.6	2	4.0	2.2	3	3.2	30	2.8	2.5	2.3
Fluoride (F)	1.5		2.3	2.2	1.7	.4		.1	0.8	1.0	1.1
Nitrate (NO_3)			.8	.0	.0	.0	.8	53	1.0	1.0	
Dissolved solids	268			404	242			192		267	251
Total Hardness (as $CaCO_3$)	6	10	21	16	3.6	69	93	80	56	18	18
Date	not in computer No Date	Feb. 1954	Aug. 1943	Dec. 1943	Dec. 1943	Sept. 1943	July 1951	Apr. 1952	July 1951	May 1948	Nov. 1968
Analyst		SFK	EWL	EWL	EWL	EWL	AJZ	SFK	AJZ	GWW	AIG

Gloucester County

Gloucester County lies between York River on the south and the Piankatank on the north. The southeastern portion of the county borders on Mobjack Bay which opens directly into Chesapeake Bay. The land area is 225 square miles. The population in 1965 was 13,082. Gloucester has been the only heavily populated ~~area~~ locality but in recent years marked increases in population have taken place in the Gloucester Point area.

Although a rural county, only about 8 percent of the work force was employed in agriculture. The processing of fresh or frozen seafood is an important industry, as is lumbering. Fiberglass boats are manufactured at Gloucester and some boatbuilding is carried on elsewhere.

Over half the farm income is derived from sale of field crops, chiefly soybeans and corn, a fifth from sale of hogs. About 13 percent of the farm income was obtained largely from sale of daffodils, both plants and bulbs. Poultry products accounted for about 10 percent of the farm income and dairy products about 2½ percent of the total.

In addition to the commercial activities mentioned, Gloucester County also enjoys a modest trade catering to summer vacationers, fishermen and tourists visiting points of historical interest.

U.S. Highway 17 passes through the county and connects Gloucester with Newport News to the south via the George P. Coleman Memorial Bridge to Yorktown and with Fredericksburg to the northwest.

There are no railroads in the county but bus service is available to Washington, Norfolk, and Richmond.

There is no large port in Gloucester County but at West Point, 32 miles distant from Gloucester, is a port that serves ocean-going vessels as well as a railroad.

Geology

Bedrock

Bedrock was reached in a well at Mathews C. H. at 2,300 feet below sea level and at West Point at 1,257 feet below sea level. Hence, in western Gloucester County, bedrock may be about 1,600 feet below sea level and about 2,000 feet below in the eastern part of the county.

Cretaceous System - Potomac Group

The Potomac Group consists of alternating strata of clay and sand of Early Cretaceous age. These beds underlie Gloucester County but have not been reached by any wells in the county. As shown in Section B-B[1], ~~Figure~~, the Potomac sediments might be reached at about 950 feet below sea level at Gloucester C. H. (Court House.

Cretaceous to Tertiary Systems

Upper Cretaceous and Paleocene Series

Mattaponi Formation: The Mattaponi Formation is of ~~Upper~~ Late Cretaceous ~~to~~ and Paleocene ~~in~~ age. It is ordinarily characterized by mottled clays in its lower portion and by rather highly glauconitic clays in its upper part.

The boundary between the underlying Potomac beds and the Mattaponi Formations is problematical in Gloucester County.

The well at Gloucester C. H. (3) does not penetrate the full section of the Mattaponi Formation and in any event, the boundary between the Mattaponi and overlying Chickahominy Formation is highly uncertain. The deeper strata there are largely dark glauconitic clays and subordinate glauconitic sands. The well is finished in a quartz sand and gravel lying a few feet below a quartz-glauconitic sand.

The log of the well at Severn (26, Table 14) was given to Samuel Sanford (p. 180) in 1907 from memory by the owner several years after construction of that well. This log is almost valueless for stratigraphic correlation purposes although the mention of 35 feet of pea-sized gravel at 575 to 610 feet, fairly high in the Mattaponi section, is of particular interest.

At Newport News, directly south of Severn in Gloucester County, mottled clays are reported at a depth of 951 to 955 feet, below which the sequence is sandy to a depth of 1,082 feet (Cederstrom, 1957, p. 212). The base of the Mattaponi may be at much the same depth in Severn. However, the highly colored clays typical of the Mattaponi have not been reported in the few logs at hand of deep wells in Gloucester County. Well 18 in Gloucester County at Roanes, a bit west of Severn, reached the "principal aquifer" at 850 feet and was continued to a depth of 981 feet (Sanford, p. 308). This suggests, at least, the sandy zone that is present in the basal part of the Mattaponi at West Point.

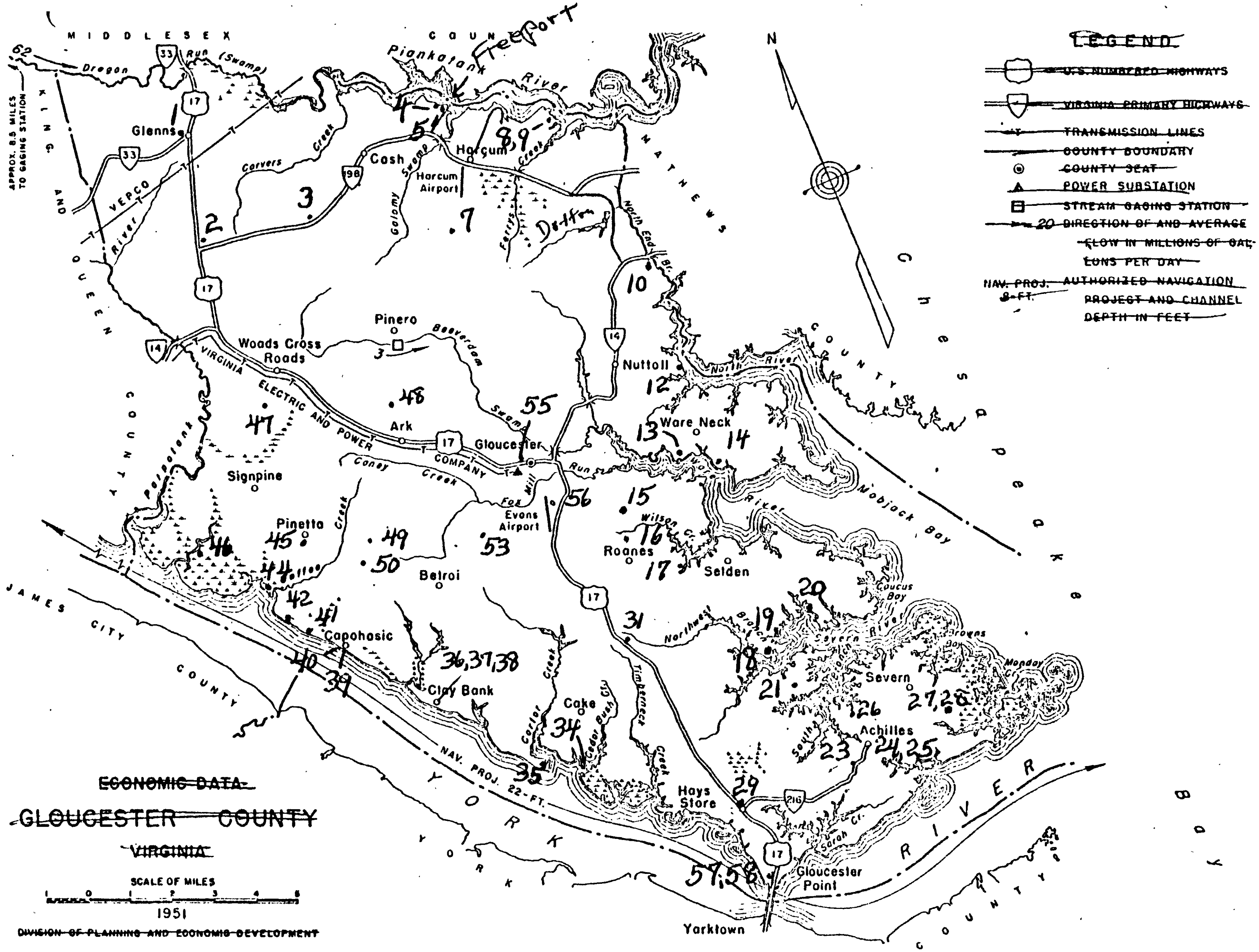


Figure .--Location of wells in Gloucester County.

Eocene Series

Nanjemoy Formation: The Nanjemoy Formation of early and Middle Eocene age is probably present in western Gloucester County but thins eastward and may be absent east of Capahosic. The Nanjemoy is made up of highly glauconitic clays and sands with occasional very thin limestone strata.

Chickahominy Formation: A few feet of late Eocene sediments are present at West Point. The formation thickens eastward and probably makes up most of the Eocene section in central and eastern Gloucester County. Reasoning from data available on the York-James Peninsula to the south, it seems likely that the Chickahominy Formation is 100 to 120 feet thick in central and eastern Gloucester County. The well (42) at Capahosic penetrates 60 feet of pre-Miocene sediments. These are all assigned to the Chickahominy. They consist of alternating clays and sands, in part glauconitic. A "hard bed of shells" near the base of the section may be coquina, ordinarily termed "limestone" in other logs. The yellow clay reported is unusual. One of the other rare reports of yellow clay is at Newport News where "sand and yellow mud" is logged at 450 to 500 feet and "yellow clay" at 500 to 525 feet (Cederstrom, 1957, p. 229). There the yellow sediments occur in the lower part of the Eocene section and in the immediately underlying Mattaponi(?) Formation.

Wells 4 and 5 at Freeport on the Piankatank may also develop water from the Chickahominy Formation.

The contact between the Miocene formations and the underlying Eocene formation would appear to be at 387 feet (317 feet below sea level) at Gloucester C. H., but projection of the probable contact from the west suggests, rather, that the contact should be higher, perhaps much higher. A similar difficulty is seen in trying to use the Severn log for stratigraphic correlation. Hence, it seems better to leave the stratigraphy of this area an open question at this time.

Water Bearing Formations

Cretaceous System

Lower Cretaceous Series - Potomac Group

The Potomac Group of clays and prolific water bearing sands are present beneath Gloucester County at depth but are not reached by any wells. However, water from the Potomac Group may be expected to range from brackish to saline inasmuch as water from basal Potomac beds updip at West Point contains 212 ~~ppm~~ mg/l of chloride.

Cretaceous to Tertiary Systems

Upper Cretaceous to Paleocene Series

Mattaponi Formation: A rather large number of wells in Gloucester County have been drilled to aquifers in the Mattaponi Formation. However, only two ever approached the base of the formation. These were drilled in 1905 at Eagle Point Plantation to 981 (or 900) and 1,004 feet, respectively (Sanford, 1913, p. 179, 308) but failed to get either a strong flow or fresh water. The well of lesser depth (18) is listed in table 13.

The well at Gloucester C. H. (55) penetrated 14 feet of coarse sand and gravel at 730 feet below sea level, well down in the Mattaponi section. A thick stratum of fine glauconite sand is present a few feet above the coarse sand. The old well at Gloucester Point (58), 694 feet deep, and one at Naxera (19), 716 feet deep, end in much the same horizon.

A somewhat persistent stratum appears to be present a little higher in the section. It was reached in well 26 at Severn at a depth of 575 feet. Wells 35 at Oliver Landing, 25a and 26 near Achilles and 21 at Glass may all end in the same stratum. Wells somewhat deeper than 400 feet (24, 34, 36, 37, 44) may end in another water-bearing sand high in the Mattaponi sequence.

The largest flow reported is from well 36 at Claybank, 460 feet deep, which had a flow of 35 gpm in 1918. Well 19 at Roanes, 716 feet deep had a flow of 52 gpm in 1906 and 10 gpm in 1941.

The artesian head in wells ending in the Mattaponi Formation was a maximum of about 35 feet above sea level at the time of Sanford's canvass in 1906. In 1945 water would rise to only about 3 feet above sea level at Claybank in a well (37) 440 feet deep.

As inferred above, no large quantities of water have been developed from the Mattaponi Formation and lacking data on the thickness and grain size of the aquifers, no reasonable estimate can be made of how much water might be developed in a single well anywhere. It seems likely that aquifers comparable to those at West Point should be present in the western part of the county and where such aquifers are present are properly screened and developed, several hundreds of gallons a minute should be available. In the eastern part of the county the deep formations yield water too mineralized for most uses.

Miocene Series

Chesapeake Group of Formations: ~~Due~~ Owing to the depth at which artesian beds lie and the inferior quality of water to be obtained from them in the central and eastern parts of the county, many homeowners have had somewhat shallow wells drilled for their supply. These wells are commonly 2 inches in diameter and range from 50 to 110 feet deep. Water is developed from fine sand or a mixture of fine sand and shells. Ordinarily not more than a few gallons a minute, ample for a household, has been developed from most wells in the Miocene strata but near Ark, northeast of Gloucester, a well (48) 80 feet deep is reported to yield about 30 gpm. At Bena a 6-inch well (23), screened at 54 to 65 feet and from 70 to 80 feet yields 23 gpm with 26 feet of drawdown. This is about as much as may be expected from wells ending in Miocene beds and, in fact, many wells, even though properly screened and developed, yield much less, roughly from 3 to 10 gpm.

The well near Roanes (17) is of particular interest in that water is obtained from a depth of 265 feet, well down in the Miocene section. Further, it was reported to have had a small flow. The shallower wells in Miocene beds all occur under water table rather than artesian conditions.

The reader is referred to the general section of this report for a fuller discussion of the water-bearing potential of the Miocene formations.

Quaternary System

Pleistocene Series

<u>Columbia Group</u>: Throughout the county are a large number of dug wells and fewer driven wells ranging in depth from as little as 10 to about 35 feet. These obtain household supplies from the surficial terrace deposits.

An ice plant (57) near Gloucester ~~G. H.~~ Point obtains about 9 gpm from a battery of 7 shallow driven wells 15 to 15 to 16 feet deep. Water is obtained from a white sand stratum lying beneath a marl bed.

Quality of Water

Water from Mattaponi and Chickahominy Formations

Water from deep wells in Gloucester County is generally rather highly mineralized. Wells along York River at Allmondsville and Capahosic (40, 41, table 15), yield water containing only from 50 to 70 mg/l of chloride but a short distance downstream, two others (34, 36, 38) at Claybank and Olivers Landing yield water containing as much as 440 and 470 mg/l chloride. All these waters are soft sodium-bicarbonate waters in which the bicarbonate ranges from 432 to 541 mg/l. Sulfate is fairly low, 12 to 58 mg/l.

The wells yielding water with the lower chloride are upstream, but they are also somewhat shallower than the downstream wells. It is advisable that any attempt to develop larger supplies should be made at as shallow a depth as possible along the whole reach of Gloucester County along York River. It seems probable that the deeper the well and the farther downstream, the greater will be the likelihood of developing a highly mineralized water.

At Freeport on the Piankatank the water from the 330-foot well (4) is of much the same character as these along upper York River. Chloride in the Freeport well water is only around 30 mg/1 although bicarbonate is somewhat higher, around 700 mg/1. An adjacent well (5) yields water that is almost identical in chemical character and is thought to be of about the same depth although it was reported to be much deeper. It may be noted that directly across the Piankatank, a 500 (?) foot well at Woodstock Farm yields water containing 294 mg/1 of chloride (42, table 9 and fig. 5).

The municipal well (55) at Gloucester C. H. extends to 740 feet below sea level and taps a deeper aquifer than the wells mentioned above. Chloride is 355 mg/1, somewhat less than in water from wells 34 and 36 at Claybank but bicarbonate is higher, 742 mg/1. This is the most mineralized water used for public supply in the Middle Peninsula and probably in all of Tidewater Virginia.

The old 694-foot well (58) at Gloucester Point, yields water in which chloride is about the same concentration as at Claybank, about 430 mg/1, but bicarbonate is higher, around 800 mg/1. At Maxera (northwest of Selden) the chloride content is much higher; 1,700 mg/1 in water from a 716-foot well (19) and 1,090 mg/1 (Sanford, p. 353) in water from a 981-foot well (18). Bicarbonate is not as high as in waters as might be expected but sulfate ranges up to 155 ppm. This suggests that the high bicarbonate ground water has been "diluted" with a little of the sea water with which the sediments were once saturated.

A 615-foot well (25a) also in eastern Gloucester County at Achilles, yields water in which chloride content is 1,350 ppm and a 450-foot well (24) there (Sanford, p. 306) yielded water with 1,540 mg/l of chloride. Offhand, it might be thought that ~~a~~ the latter well ~~of this depth~~ would yield a somewhat less highly mineralized water. The highest chloride content found in deep well water in the county, 2,500 mg/l, is from a 610-foot well (26) at Severn (Sanford, p. 351). It is a hard water, as contrasted with other deep well waters already discussed. Here, too, sulfate is high but bicarbonate is only moderately high.

Soft waters of moderately low chloride and high bicarbonate content are satisfactory for most domestic uses but unsuitable for some industrial uses, particularly boiler feed. High chloride waters are useful for only special purposes or as a source of water for desalinization devices. As such, however, they would be more economical to treat than more saline waters from the adjacent bay.

Although the low chloride waters are excellent for domestic use and many industrial uses they, like higher chloride waters from deeper wells, are undesirable for irrigation use on account of their low calcium and high sodium content.

Water from Miocene Deposits

Water from Miocene deposits (14, 16, 17, 20, 28, 49, 53a) is characteristically somewhat hard. Total hardness in samples at hand ranges from 200 to 400 mg/l and is present as calcium bicarbonate. In the sample collected from the well at Maryus (28, table 15) sulfate is fairly high, 110 mg/l, but in other samples sulfate is generally less than 20 mg/l. Chloride is low in samples analyzed with the exception of a water from Naxera (20) in which the concentration of that constituent is 316 mg/l. This well is near the shore and may be contaminated by bay waters.

Because the concentration of calcium is high relative to sodium, water from Miocene aquifers is excellent for irrigation. The problem in using such water for that purpose is the development of sufficient quantities rather than the quality of the water itself.

Water from Pleistocene Deposits

Water from shallow wells ranges from soft (2, 9, 25b) to fairly hard (27, 57), the hardness being present largely as calcium bicarbonate. The chloride content ranges 20 to 60 ppm in most samples. Inasmuch as total mineralization is low in most instances, most departures from that norm may be due in largest part to a slight contamination by sodium chloride, originating as salt spray carried over the land.

The sample from Mayus (27) may show the effect of contamination by salt spray, but inasmuch as nitrate is 87 mg/l the high chloride content may perhaps be due to contamination by organic material rather than by salt spray.

Most waters from shallow wells are susceptible to contamination by organic material and in the other three samples taken, nitrate ranges from 10 to 28 mg/l.

Inasmuch as the artesian water at Gloucester C.H. and Gloucester Point is relatively high in chloride, it would be desirable to point out some method of improving the quality of that water if it were possible. The only solution that suggests itself, aside from bringing in water some distance by trunkline from the ~~east,~~ west is blending with properly protected shallow water supplies, injection of shallow water into deep wells, or both.

Shallow well water can be made available only in modest quantity in the area of Gloucester C.H. a bank of shallow wells in the Gloucester C.H. - Ark area might produce enough water to be worth pumping to Gloucester C.H. and blending with the water from the present city supply. Utilizing methods outlined in the general part of this report and recharging the deep formation by small diameter wells in a shallow well field on the high ground northwest of the city might be done but the principal gain would be in a slightly higher pressure head. Recharged water would move so slowly in the artesian beds from the recharge point to the city well under the existing low hydraulic gradient, that it would probably be many years before any of that water had a dilution effect on the formational water now drawn upon. The better use of any shallow ground water that might be developed would be, as stated above, to blend it with the presently used supply. Were larger quantities of shallow water available it might be worthwhile to consider recharging the somewhat brackish water formation through an injection well in the immediate vicinity of the supply well.

The subject of artificial recharge of brackish water wells is discussed in some detail in the chapter on Mathews County.

The situation at Gloucester Point is much the same as at Gloucester C.H. Deep wells there yield a high chloride water and shallow water supplies are available in reasonable quantity only at some distance from the point of greatest demand.

Table 14.—Logs of wells in Gloucester County

Well 8, Dr. Stanley Grey, Hell Neck[1]

(Log from Bull. V, Va. Geol. Survey)

Altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand; water	15	15
Clay	15	30
Sand	4	34
Chesapeake Group (Miocene)		
Marl, sandy, blue; water at 42 to 46 ft.	201	235
Sand; small flow of water	2	237
Undifferentiated		
Marl	148	385
Rock, soft; ½ gpm water at 415 ft.	30	415

1/ R. J. Bristow well of Sanford (p. 179)

Table 14.—Logs of wells in Gloucester County, Virginia (Cont.)

Well 23, Theodore Pratt, Bena
(Log by Sydnor Hydrodynamics, Inc.)
Altitude 10 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Topsoil	1	1
Clay, yellow	3	4
Sand, yellow, fine	12	16
Sand and clay	3	19
Chesapeake Group (Miocene)		
Clay, blue, few shells	9	28
Mud, blue and shells	15	43
Clay, blue	11	54
Shells, hard	7	61
Sand, muddy, and shells	31	92
Clay, blue	13	105

Table 14 .--Logs of wells in Gloucester County, Virginia (cont.)

Well 26, J. M. Shackelford, Severn
(log from Bull. V, Va. Geol. Survey)
Altitude 8 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay	1	1
Sand, white	6	7
Sand, yellow to red; water	1	8
Chesapeake Group (Miocene)		
Marl, shells	10	18
Sand, gray; water	6	24
Marl, sandy	46	70
Undifferentiated		
Marl, blue, a few shells	355	425
Sand, black; water under low head	15	450
Mud, dark or green cast	135	575
Sand, black, in hard layers; water under low head	55	610
Gravel, pebbles the size of wheat grains; water under strong head	?	?

Table 14 .--Logs of wells in Gloucester County, Virginia (cont.)

Well 42, Mrs. M. D. Nunnally, Capahosic
(Log by Sydnor ~~Pump & Well Company)~~ Hydrodynamics, Inc.)
Altitude 25 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, yellow	8	8
Clay, yellow sandy and white sand	7	15
Sand and gravel, coarse	10	25
Sand, fine white	27	52
Chesapeake Group (Miocene)		
Sand, black and mud, few shells	51	103
Clay, dark blue	35	138
Clay, blue	38	176
Sand, fine white, few shells and brown rock	4	180
Clay, dark green	35	215
Chickahominy Formation (Eocene)		
Sand, fine	9	224
Sand, medium coarse	10	234
Sand and shells	3	237
Mud, yellow	2	239
Sand, muddy and shells	7	246
Mud, gray	4	250
Mud, gray and fine black sand	4	254
Shells,,hard bed	13	267
Clay, black sand and fine beach sand	8	275

Table 14 .--Logs of wells in Gloucester County, Virginia (cont.)

Well 46, R. C. Coleman, Signpine

Altitude 3 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand, yellow	33	33
Chesapeake Group (Miocene)		
Marl, blue	155	188
Chickahominy Formation (Eocene)		
Sand; water	9½	208½
Shell rock, hard	1½	210
Sand; water	1	211

Table 15.-Chemical analyses of waters from wells in Gloucester County, Va. (cont.)

	Well no.										
	49	53a	53b	55	57	58	58				
Location	Sassa-fras	Bellamy	Bellamy	Gloucester	Gloucester Point	Gloucester Point	Gloucester Point				
Depth (feet)	80	60	18	815	12-16	694	694				
Silica (SiO_2)				16		30					
Iron (Fe)				.01		0					
Calcium (Ca)				1.4		1.2					
Magnesium (Mg)				.7		6.4					
Sodium (Na)				538		619					
Potassium (K)											
Bicarbonate (HCO_3)	180	306	4	742	166	881	780				
Sulfate (SO_4)	11	1	4	59	3	48	30				
Chloride (Cl)	6	8	32	355	10	424	432				
Fluoride (F)	.1	.0	.0	2.2	.1		1.2				
Nitrate (NO_3)	.2	.2	24	1.0	.8	1					
Dissolved solids	331	485	176	1340	312	1618					
Total Hardness (as $CaCO_3$)	168	288	60	6	158	29	30				
Date	Aug. 1950	Aug. 1950	Aug. 1950	May 1948	Aug. 1950	June 1918	Feb. 1941				
Analyst	JL	JL	JL	GWW	JL	HBR	MDF &WM				

Mathews County

Introduction

Mathews County lies on Chesapeake Bay with the Piankatank River forming the northern boundary and with Mobjack Bay and North End Branch forming most of the western boundary. The area is 87 square miles. The population in 1964 was 6,836.

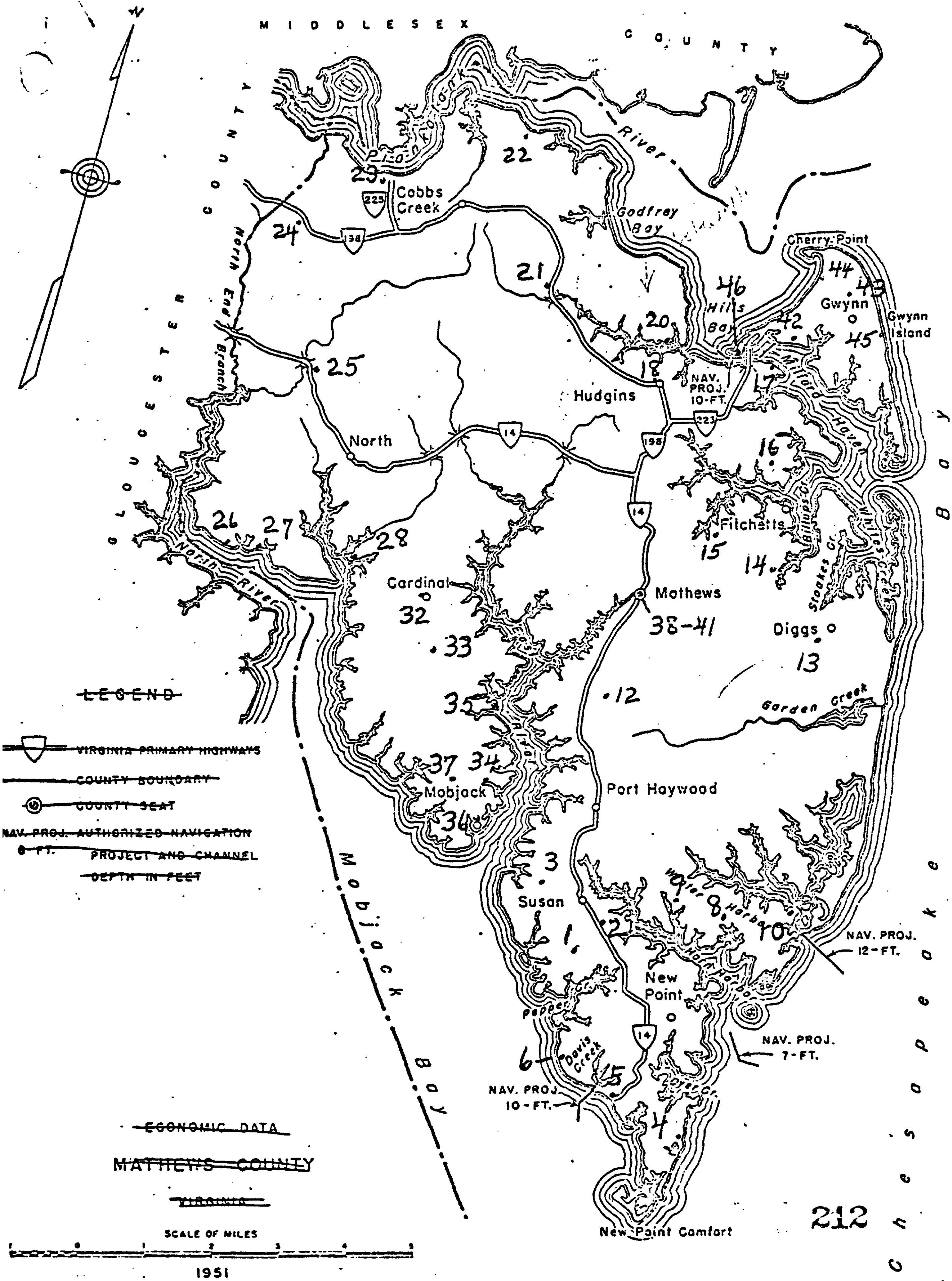
Agriculture is engaged in largely as a part-time activity in Mathews County, but wood lot cuttings add appreciably to the farm income. Commercial fishing provides employment for the greatest number of Mathews men and sport fishing by visiting fishermen brings additional income to the county. There is some local employment in seafood packing establishments and a few persons find work in sawmills.

Geology

Consideration of the geology of Mathews County hinges upon the log of the deep well at Mathews Court House (39, table 17 and fig. 8). That well penetrated the complete section of Coastal Plain sediments and entered bedrock at a depth of 2,307 feet. This is the only record showing the thickness and character of the Pre-Miocene formations in Mathews County. Unfortunately, few samples are available and the description of the formations is not sufficiently detailed to define the limits of the various geologic units.

Sediments of the Potomac Group of Early Cretaceous age are penetrated in this well, extending perhaps from a depth of 1,670 feet to basement rock at 2,307 feet. The boundary is drawn on the basis

Figure .--Location of wells in Mathews County.



of a possible correlation between basal Mattaponi sands at West Point and a thick sand at Mathews. The section is made up of alternating sand and clay beds, with clay predominating.

The sediments from 1,670 feet up to as much as 300 feet are assigned to the Mattaponi Formation of Late Cretaceous and Paleocene age and to the Chickahominy Formation of Late Eocene age. These beds consist of sands, glauconitic in part, alternating with clay. Mottled highly colored clays characteristic of the Mattaponi Formation are not reported but may be present. A record of "shale" (actually clay) without further qualification neither confirms nor denys the presence of those characteristic beds.

The upper part of the section must be assigned to the Chesapeake Group of marly formations of Miocene age. Reports of a thick sand bed within the Miocene (at 100 to 200 feet) is not quite believable.

Summing up, this well was drilled by the rotary method and bears all the earmarks of a careless job of logging. Some of the thick sands reported may reflect much washing out of loose sands and, in general, little confidence can be placed in the detailed notations made.

The 300 (?) feet of Miocene beds, overlain by 30 to 40 feet of sandy terrace formations of Pleistocene age, are seemingly more sandy than in the area to the west where the Miocene is ordinarily logged as "marl" or "blue clay."

Water Bearing Formations

Cretaceous to Tertiary System

Upper Cretaceous to Eocene Series

"Salt water and sand" is reported at 1,910 and 1,945 feet in the log of well 39 at Mathews. The 817-foot well at Mathews (38), sampled in 1918 yielded water in which the chloride content was 156 mg/l. Water from the Billups well (28) which is only 596 feet deep contained 550 mg/l of chloride when sampled in 1918 and 1941. This anomaly might be explained as due to greater permeability and hence better circulation in the deeper stratum. However, it is possible that the relatively low chloride water is leaking from a stratum up in the Miocene rather than far depth. As brought out in Virginia Geological Survey Bulletins 58 and 68, Mathews County lies in the zone of brackish artesian water and there is no reason to expect that fresh water will be obtained from wells ending in pre-Miocene formations.

It is pointed out that there is every reason to believe that large quantities of brackish water are available from deep-lying sandy beds in Mathews County. Brackish water is useful for some industrial purposes and other specialized needs as brought out in the introductory chapter of this report.

Miocene Series

That portion of Chesapeake Group of Miocene formations within reach of relatively shallow jetted or driven wells consists of alternating beds of marl, and silt or sand in which shells are commonly present.

The Miocene sandy beds yield water readily to wells, most of which range from 50 to 150 feet in depth. Yields of up to 25 gpm have been reported from place to place.

Much of the sandy material is fine grained (silty) and trouble has been experienced where attempts have been made to develop more than a modest yield. At the New Point Comfort Army installation, the first well constructed (4a) initially yielded about 15 gpm of sand-free water but at a later date when a valve was inadvertently opened to a higher discharge, the well sanded up. The second well (4b) was gravel packed (more likely, sand packed) and yielded 25 gpm of sand-free water.

Reports of yields of 25 gpm from 2-inch unscreened wells seem somewhat optimistic. It seems likely, in view of the experience at New Point Comfort, that many open-end, 2-inch wells would be liable to rapid sand clogging if pumped at that rate for even a short time.

The well (37) at the Coast Guard Station on Gwynn Island is of particular interest in that it has a reported yield of 200 gpm with 49 feet of drawdown. There is no reason to believe that yields of this nature might not be developed in Mathews County where the aquifer is gravel. Gravel, as opposed to sand and silt, is thought to be present in only a few places in the county, although coarse sand may be more widely distributed.

Quaternary System

Pleistocene Series

There are a great many very shallow dug or driven wells in the county that supply rural inhabitants with water. Not much can be said about them except that they are reported to be reliable sources of water even in times of drought.

Quality of Water

Water from Pre-Miocene Deposits

There is justification for discussing the quality of water from deep wells in Mathews County from the point of view that such water might conceivable be developed for some special purpose, as noted in the introductory section of this report. Further, there are no fresh water streams in the county that might be developed to supply large demands and if large supplies were to be developed by treatment of locally available water, brackish water would be more economical to treat than adjacent saline bay waters.

The sample taken from the 817-foot well (38, table 19) at Mathews is a slightly hard sodium-bicarbonate water in which the chloride content is 156 mg/l. The chloride content is surprisingly low and it is possible that under steady pumping conditions, the chloride content of the water would increase. At Yorktown, Virginia, a deep well (Cederstrom, 1943, p. 16), upon pumping at a rate of 118 ~~mg/l~~ gpm, yielded water initially containing only 248 mg/l. After a short time, however, the chloride content rose to 440 mg/l.

After a period of rest the chloride content reverted to its former lower concentration. The Mathews well might respond similarly under pumping conditions if the water is entering the well at a depth of about 800 feet rather than leaking in from a stratum low in the Miocene section.

The samples taken from the Billups well (28) at North, 568 feet deep, are very much the type that would be expected from deep wells ending in pre-Miocene aquifers in Mathews County. It is a very slightly hard sodium-bicarbonate water in which the chloride content is 530 mg/l. The high chloride content of deep well waters represents a residuum of sea water with which the sediments were once saturated that have not been completely flushed out.

Because of the high sodium and low calcium content and high total dissolved solids, waters from deep wells in Mathews County are unsuitable for irrigation use.

Water from Miocene Deposits

Water from Miocene deposits is characteristically a hard calcium bicarbonate type in which the chloride content is low or fairly low. The hardness of four samples taken from wells ending in Miocene beds (4a, 16, 40, 41) ranges from 136 to 279 ~~ppm~~ mg/l but water from a fifth well (10) contained only 27 ~~ppm~~ mg/l of hardness. Comparison of the analyses of the soft water (10) with an otherwise similar hard water (16) shows that the softer water has been softened by natural base exchange. The sample from well 41 is a hard water containing 268 ~~ppm~~ mg/l of hardness. In this water the bicarbonate (in equivalents per million) is a little greater than the total hardness and, therefore, it has also been softened to some degree by base exchange.

The chloride in water from Miocene beds ranges from 10 ~~ppm~~ mg/l in well 4a to 136 ~~ppm~~ mg/l, in well 40. The water containing 136 ~~ppm~~ mg/l of chloride is also high in bicarbonate, 640 ~~ppm~~ mg/l, and on that account may not be as pleasant tasting as water of lesser mineral content.

The chloride content of Miocene waters may be sea water remaining in those marine beds that has not been completely flushed out by infiltrating rain and snow melt. On the other hand, Mathews County is bordered by saline bay waters and there is every reason to believe that salt spray has added much or all of the sodium chloride present in Miocene (and Pleistocene) well waters.

The hardness of most waters from Miocene beds will result in high soap consumption where the water is used for washing purposes and the high bicarbonate content of some of the waters may render it unsatisfactory for boiler feed. Hard calcium bicarbonate waters are highly suitable for irrigation purposes. As pointed out, not all water from wells ending in the Miocene yield water of this type. The Hudgins well water (10) has a high sodium-bicarbonate content relative to the calcium bicarbonate present and would be considered undesirable for irrigation use, although being soft, it would be highly satisfactory for domestic uses.

Water from Pleistocene Deposits

The four samples of water from shallow wells have a rather low mineral content. Water from well 43 is hard, the total hardness being 210 mg/l, water from well 25 is moderately hard, and at Susan (3) the well water is soft and contains only 30 mg/l of hardness. In all three instances hardness is present largely as bicarbonate hardness. Hardness is likely a function of the relative presence or absence of shell material in the surficial sediments. Chloride is 196 mg/l in water from well ~~6~~ 43 on Gwynn Island; this well is only 6 feet deep and the chloride content ~~and~~ undoubtedly ~~originated as~~ is derived from salt spray blown over the land.

Table 17.--Logs of wells in Mathews County, Virginia (cont'd)

Well 4a, U.S. Army, New Point Comfort

(log by D. J. Cederstrom)

Altitude, 3 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Top soil	1	1
Sand and clay, hard	3	4
Chesapeake Group (Miocene)		
Clay, soft blue sandy	59	63
Clay, hard blue silty, with some shells	7	70
Sand and clay, hard blue silty, with some shells	5	75
Sand and clay, softer, blue silty	8	83
Sand, green silty	7	90
Sand, gray silty	30	120
Sand, gray silty, few shells	16	136
Sand and shell, hard	14	150
Shell rock	20	170
Sand, gray silty	5	175

Table 17 .--Logs of wells in Mathews County, Virginia (cont.)

Well ~~7~~ 6, Dr. J. H. Scherer, Dutchman's Point
(Log by Sydnor ~~Pump & Well Company~~ Hydrodynamics, Inc.)

Altitude 5 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Clay, sandy	15	15
Chesapeake Group (Miocene)		
Marl, blue	50	65
Shells with sand	35	100
Marl, blue	50	150
Shells with sand	15	165
Sand with shell	10	175

Table 51 .--Logs of wells in Mathews County, Virginia (cont)

Well 39, Elkins Oil and Gas Co., Mathews

Altitude 7 feet

	Thickness (feet)	Depth (feet)
Columbia Group (Pleistocene)		
Sand surface soil	5	5
Sand	78	83
Chesapeake Group (Miocene)		
Sand and shell	16	99
Shell	1	100
Sand and shell	100	200
Shale[1]	10	210
Sand	20	230
Undifferentiated		
Shale, gummy	170	400
Shale, sticky	90	490
Driller reports sand; cored sample is gray shell marl containing minor glauconite, fish bones and pyrite	10	500
Sand and gravel	60	560
Sand, shell, and boulders	30	590
Shale, sandy	5	595
Gumbo	205	800
Shale	10	810
Shale, gummy	55	865

Table 17 .--Logs of wells in Mathews County, Virginia (cont.)

Well , Elkins Oil and Gas Co., Mathews (cont.)

	Thickness (feet)	Depth (feet)
Sand, green glauconitic-quartz	7	872
Sand, hard, and pyrites	1	873
Sand, green	5	878
Sand	3	881
Gumbo	14	895
Sand, coarse glauconitic-quartz	7	902
Sand	8	910
Gumbo	7	917
Sand	118	1035
Shale	15	1050
Sand	35	1085
Shale	5	1090
Shale and sand	20	1110
Driller reports sand; core is light green glauconite in limey matrix	12	1122
Gumbo	38	1160
Sand	15	1175
Gumbo	40	1215
Shell and black sand	5	1220
Shale, sandy, and shell	60	1280
Gumbo	54	1334
Sand	1	1335
Sand, trace of glauconite	75	1410

Table 17 .--Logs of wells in Mathews County, Virginia (cont.)

Well , Elkins Oil and Gas Co., Mathews (cont.)

	Thickness (feet)	Depth (feet)
Shale	78	1488
Sand	2	1490
Gumbo, red	62	1552
Sand	118	1670
Shale, red, sticky	10	1680
Sand	125	1805
Shale	65	1870
Sand; salt water	40	1910
Sand	20	1930
Shale	15	1945
Sand; salt water	5	1950
Sand	75	2025
Shale	40	2065
Sand	20	2085
Sand and gravel	90	2175
Sand	35	2210
Chalk, sandy	16	2236
Sand and shale	4	2240
Sand and gravel	67	2307
Pre-Cambrian (?)		
Rock	6	2313
Red and green rock	5	2318
Broken rock and shale	2	2320
Granite	5	2325

Table 18 -Chemical analyses of water from wells in Mathews County, Va.

(Analyses in milligrams per liter. JL, J. Loudon; GWW, G. W. Whetstone; HBR, H. B. Riffenberg.)

	Well no.											
	3	4a	10	16	25	28	28	33	38	40	41	43
Location	Susan	New Point Comfort	Sarah ~~Hudgins~~	Redart	James Store	North	North	Miles Store	Mathews	Mathews	Mathews	Gwynn Island
Depth (feet)	8	152 60G1	120	115 60H3	20	568	565	10	817 60H2	120	127	6
		pu?		In computer					In computer			
Silica (SiO_2)			48									
Iron (Fe)			tr									
Calcium (Ca)			5.2	28		8.4			17			
Magnesium (Mg)			3.5	16		8.3			20			
Sodium (Na) Potassium (K)			75	35		711			351			
Bicarbonate (HCO_3)	10	270	183	193	92	917	824	67	800	640	388	24
Sulfate (SO_4)	14	10	6.1	13	25	65	50	32	9.5	1	1	12
Chloride (Cl)	4	93	10	28	38	550	552	156	156	136	36	196
Fluoride (F)							1.0			.2	.1	.2
Nitrate (NO_3)	2.2	0	.41	1.0	11	1.2		4.2	tr		.4	3.8
Dissolved solids			255	266		1881			1090			
Total Hardness (as $CaCO_3$)	30	279	27	136	120	55	39	90	124	255	268	210
Date	Feb. 1949	June 1943	June 1918	June 1918	Feb. 1949	June 1918	Feb. 1941	Feb. 1949	June 1918	Feb. 1949	Aug. 1950	Aug. 1950
Analyst	JL GWW	EWL	HBR	HBR	JL GWW	HBR	MDF LWM	JL GWW	HBR	JL	JL	JL

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