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VIRGINIA CONSERVATION COMMISSION

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

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Geology and Ground-water Resources of the Coastal Plain in Southeastern Virginia

By

D. J. CEDERSTROM

PREPARED IN COOPERATION WITH THE GEOLOGICAL SURVEY OF THE UNITED STATES DEPARTMENT OF THE INTERIOR

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COMMONWEALTH OF VIRGINIA
VIRGINIA GEOLOGICAL SURVEY
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CHARLOTTESVILLE, VA., May 8, 1944.

To the Virginia Conservation Commission:

GENTLEMEN:

I have the honor to transmit for publication as Bulletin 63 of the Virginia Geological Survey, the text and illustrations of a report on *Geology and Ground-water Resources of the Coastal Plain in Southeastern Virginia,* by Mr. D. J. Cederstrom of the Federal Geological Survey.

This report is the third in a series prepared in cooperation with the Federal Geological Survey on the ground-water resources of Virginia. It is based on detailed field and laboratory investigations of the strata and ground waters of Virginia south of James River. Particular attention has been given to the geologic environments which determine the quantity and quality of the ground water available in the district.

The national defense and war programs of the last few years, with the concentration of demands in this district for large supplies of water by military and industrial units and by municipalities with rapidly expanding populations, have resulted in the immediate acquisition of many valuable data from accelerated drilling operations.

This report, therefore, is not only timely for use during the period of the war but also for future industrial and municipal development of ground-water supplies, of which large amounts are available in most parts of the district discussed in this report.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
Virginia Conservation Commission,
Richmond, Virginia, May 9, 1944.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

ERRATA

Page 4 — 3rd line from bottom of page: gallons a minute should read gallons a day.

Page 23 — line 26: Russel's should read Russell's.

Page 24 — line 17: J. R. should read R. J.
line 18: R. D. Russel should read R. D. Russell.

Page 32 — line 4: A. J. should read J. A.

Page 276 — lines 23, 24, and 25 the sentence beginning: Families with children . . . . . , etc., should be rewritten as follows:

Families with children, having a fluoride-free source of drinking water, might find it desirable to use regularly as table water some properly diluted high-fluoride artesian water.

Page 374 — Bibliography, entry no. 92, should read:
Russell, R. J., and Russell, R. D., Mississippi River delta sedimentation: *in* Recent marine sediments, edited by Trask, P. D., Tulsa, Am. Assoc. Petroleum Geologists, pp. 153-177, 1939.

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Geology and Ground-water Resources of the Coastal Plain in Southeastern Virginia

By D. J. CEDERSTROM*

ABSTRACT

The area under consideration is that part of southeastern Virginia lying in the Coastal Plain province. It embraces the area south and west of James River and east of the Fall Zone and includes eastern Chesterfield, Prince George, Sussex, Surry, Southampton, Isle of Wight, Nansemond, Norfolk and Princess Anne counties. Most of the systematic work was done in the period 1937 to 1940, but many valuable data were obtained from 1940 to 1943 when test drilling projects and new large developments were carried out; in particular those at Franklin, Bacons Castle and Lake Prince. The data used as a basis of discussion consist in large part of well records and well logs collected by the writer and analyses of water samples, most of which were made in the laboratories of the U. S. Geological Survey. Data gained in miscellaneous special studies and information presented in earlier reports are also drawn upon.

The area consists largely of farms and woodland throughout which are many small villages and towns and a few large cities. Norfolk, Portsmouth, Suffolk, Hopewell, and Petersburg are the largest cities within the area. The building, repair and servicing of commercial and naval vessels is and has been a major industry in the Hampton Roads area. This activity and activities related to the operation and maintenance of Army camps such as Camp Lee, near Petersburg, the very large Naval Operating Base and Air Station at Norfolk, and the multitude of smaller army and navy airfields, supply depots, training camps and other installations, pertaining to the conduct of the present war overseas or to the coastal defense system, tend to dominate the present scene. The industrial areas owe much of their importance to the production of a variety of chemical products such as cellophane, explosives, fertilizers, and kraft paper, and processed foods and tobacco. Recreational facilities at Virginia Beach, along James River and elsewhere are important to the economy of southeastern Virginia.

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The climate is mild and has a mean annual temperature of about 59°. The annual rainfall is about 46 inches.

East of the Fall Zone the granitic basement rock lies at progressively greater depths, and the Coastal Plain sediments, which dip gently seaward, thicken to more than 2,000 feet, as at Norfolk, but westward the sediments thin out against the basement rocks along the Fall Zone. The Coastal Plain is almost everywhere veneered by thin terrace formations.

The Potomac group of sediments (Lower Cretaceous) lies above the pre-Cambrian granitic basement rock. These sediments are made up of alternating sandy and clayey strata with clays generally predominating. Potomac sediments crop out along the Fall Zone and are reached by hundreds of deep wells throughout the area west of Norfolk. Upper Cretaceous deposits have been found inland at least as far as Franklin but are not known to crop out along the Fall Zone. The gray clays, fine gray sand and brilliant red or variegated clays of these deposits are widely distributed and locally may be more than 200 feet thick. The Pamunkey group of deposits of Eocene age consists of glauconitic sands and marls and includes indurated limy beds in a few places. It crops out along the Fall Zone and is reported in the logs of many deep wells. The deposits are rarely more than 75 feet thick and are thinner in most places. Eocene deposits younger and older than the Pamunkey group may also be present, but only a little is known about them. In the Fall Zone area the Chesapeake group of Miocene age is composed of the basal Calvert formation of fossiliferous blue clay (marl) and subordinate sandy beds, the St. Marys formation of unfossiliferous tough blue clays and the Yorktown formation of highly fossiliferous marls and sands. The Yorktown formation is also widely exposed along all the larger streams except in the eastern part of the area where it lies below sea level. The Columbia group of Pleistocene age consists of surficial clays and sands which are most widely developed on the Sunderland, Wicomico and Pamlico terraces. Recent deposits consist of sands deposited by wind and wave action along the Atlantic Ocean coast and the coastal strip south of the mouth of Chesapeake Bay and west of Cape Henry.

The Coastal Plain sediments dip gently seaward but in addition have been slightly folded along east-west axes. Movements along faults in the basement rock which have been transmitted upward may account for monoclines and reversals of dip seen in a few places and may likewise account for a few faults of small throw observed in Coastal Plain sediments along the Fall Zone.

Ground water occurs in cracks and fissures in granitic bedrock. Many wells along the Fall Zone obtain water from such fissures. The average range of yield is from 10 to 50 gallons a minute, but a few wells yield several hundred gallons of water a minute. From place to place holes drilled into granite have been dry.

East of the Fall Zone, water in sediments of the Potomac group occurs under artesian conditions and rises in wells which penetrate those strata. The wells on low land may flow but those on high ground may have to be pumped. Many flowing wells are located along the large rivers and their tributaries. Losses of from 10 to 30 feet or more of artesian head have occurred since 1900 in flowing well areas, and at present water in flowing well areas rises a maximum of 40 feet above sea level at Branchville and a minimum of about 15 feet above sea level along James River. Water levels in the Coastal Plain area appear to be undergoing a slow persistent overall decline. Potomac strata are recharged along the Fall Zone where they lie at or near the surface. Recharge from rainfall may take place directly, but in most places water percolates through the overlying terrace cover or even through fissured bedrock against which sands of the Potomac group lie. Although the discharge of individual flowing wells is rarely as much as 50 gallons a minute, the aggregate discharge from such wells along James River was about 5 million gallons a day in 1940. Less than a million gallons a day was discharged by flowing wells in Southampton County. Most large-diameter pumped wells have a capacity of from 100 to 300 gallons a minute, but these are run at capacity for only limited periods and the total withdrawal is not great in most places. At Franklin, however, about 8,000,000 gallons a day is pumped continuously, and at Hopewell an average of more than 1,000 gallons a minute is pumped throughout the year.

A few wells at Franklin and possibly elsewhere obtain water from Upper Cretaceous deposits, and a few wells in Surry County obtain water from deposits of the Pamunkey group.

Sands and sandy shell strata of the Chesapeake group supply many small industries in the Norfolk area with water for boiler feed, cooling and general use, and several truck farms near Portsmouth are irrigated with water from shallow wells, also penetrating Miocene deposits. A number of domestic installations elsewhere in Norfolk and Princess Anne counties and along James River in Nansemond, Isle of Wight and Surry counties also use water from Miocene strata. Most rural wells are shallow dug wells in the terrace formations. Generally these are dependable in times of drought for very small supplies.

Water from granitic rock is generally moderately hard and may contain undesirable amounts of iron.

Water from the Cretaceous sediments near the Fall Zone is soft and is low in mineral content, but eastward it becomes a hard calcium bicarbonate water. Still farther to the east the hard water comes in contact with natural base-exchange material and is almost totally softened. This soft water to the east is a sodium bicarbonate water which has a moderate to high bicarbonate content and in most places contains from 2 to 6 parts per million of fluoride. In the area around Norfolk chloride is present in objectionable amounts. Water from Upper Cretaceous and Eocene deposits and basal Miocene beds is similar to water from sediments of the Potomac group.

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

Ground water is used for municipal, school, institutional and domestic supplies in the large towns and villages. It is used for boiler feed and for irrigation in many places in the Norfolk area. At Franklin large quantities are used in the manufacture of kraft paper. At Hopewell ground water is used largely for cooling purposes.

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

Eastern Chesterfield County lies along the Fall Zone and obtains ground water from Cretaceous sands and from the pre-Cambrian granitic bedrock. Several establishments obtain several hundred gallons a minute from wells drilled in granitic bedrock, and smaller supplies are obtained from Coastal Plain sediments. Water from Coastal Plain sands is only slightly mineralized, but water from granitic rock may contain a relatively large amount of dissolved solids.

A few wells in northeastern Dinwiddie County bordering Prince George County obtain water from the pre-Cambrian granitic rock, but throughout Prince George County the relatively few deep wells obtain water from deposits of the Potomac group. At Hopewell an average of about 2,000,000 gallons a minute is pumped during the summer by two industrial concerns but during the winter industrial pumping is at a minimum. At the Solvay Process Company cold surface water is

pumped down large wells in the winter, and in the summer chilled ground water is pumped out. Observation wells in the Hopewell area show that safe yield is not being exceeded. The water from Cretaceous deposits has a fairly low mineralization in the western part of the county but to the east it is rather hard. Water from granitic rock is moderately mineralized.

Deep wells in Sussex County almost everywhere obtain water from Cretaceous deposits, but at Jarratt in northeastern Greensville County, which borders Sussex County on the west, the town is supplied with water by one well penetrating granitic rock. The municipal supplies of Wakefield and Waverly are obtained from Cretaceous strata. Water from Cretaceous deposits in the western part of the county is a soft water of low mineralization; in the central part of the county it is a hard calcium bicarbonate water; and in easternmost Sussex County it is soft sodium bicarbonate water.

In Surry County many flowing wells 2 to 4 inches in diameter are located along James River. These reach Cretaceous strata and furnish a soft sodium bicarbonate type of water. A very few wells obtain water from Eocene deposits. A few shallower wells are developed in the Yorktown formation of the Chesapeake group (Miocene), and several springs issue from outcrops of these strata in deep ravines. The water is a moderately hard calcium bicarbonate water. Two test holes were drilled near Bacons Castle to determine the possibility of obtaining a supplementary supply of 15,000,000 gallons a day for the City of Newport News; the second test hole was converted into a well and thoroughly tested. The well produced 920 gallons a minute with 22 feet of drawdown, and calculations proved that ample ground-water supplies exist in the county.

A very large number of small-diameter jetted wells obtain water for domestic supplies from Cretaceous deposits in Southampton County. Many deep wells at Branchville, Boykins, Courtland and Franklin are flowing wells; very few deep wells are pumped. A deep 10-inch well supplying the town of Franklin is reported to have a yield of about 1,000 gallons a minute. In the central part of the county the water is moderately hard but in the east, as at Courtland and Franklin, it is a soft sodium bicarbonate type of water containing undesirable amounts of fluoride.

Along James River, in Isle of Wight County, a large number of deep jetted domestic wells of small diameter are flowing wells ending in Cretaceous deposits. At Smithfield and Battery Park municipal supplies are obtained from deep wells in Cretaceous strata. The water is a

soft sodium bicarbonate type containing undesirable amounts of fluoride. At Franklin two large-diameter gravel-packed wells at the Chesapeake-Camp Corporation mill supply about 2,500 gallons of water a minute. The water is of excellent quality for the purpose for which it is used. As of January 1, 1944, observation wells in the surrounding area showed that water levels, already affected by industrial pumping, should be expected to decline further although it was not apparent that safe yield was being exceeded.

A number of flowing wells ending in Cretaceous deposits are located between James River and Suffolk in northern Nansemond County. Only a few wells of large diameter are pumped and supply water for industries. During the drought of 1942 a test well 970 feet deep was drilled at Lake Prince with the intention of supplementing the Norfolk City reservoir at that place. In 543 feet of Cretaceous (Potomac group) sediments penetrated, 326 feet of sand was encountered, of which about 300 feet appeared highly permeable. Due to heavy rains the test hole was not converted into a well. Water from the Cretaceous sands is a soft sodium bicarbonate type in which bicarbonate and fluoride may be high. Chloride is negligible except along James River where a maximum of about 100 parts per million is present in several wells. In several places a hard calcium bicarbonate water is obtained from shallow drilled wells which penetrate Miocene deposits (Yorktown formation).

In Norfolk County, Cretaceous strata yield water which contains excessive chloride and is but little used. Many industrial establishments there obtain water for boiler feed and other purposes from Miocene and Pleistocene deposits. Several irrigators pump water from Miocene beds.

In Princess Anne County several wells less than 100 feet deep obtain water from Miocene beds. The water is fairly hard in most places. Still shallower wells obtain water from terrace deposits. Gravelly lenses in the terraces in this county yield more water than is generally developed from terrace deposits elsewhere. A few wells obtain water from dune sand. In both dune sand and terrace formations water may be moderately high in chloride and contain objectionable amounts of iron.

INTRODUCTION

This report presents the results of an investigation of the ground-water resources of the Coastal Plain in Virginia south of James River, which was made by the Geological Survey, United States Department of the Interior, in cooperation with the Geological Survey of the Virginia Conservation Commission. It covers Prince George,

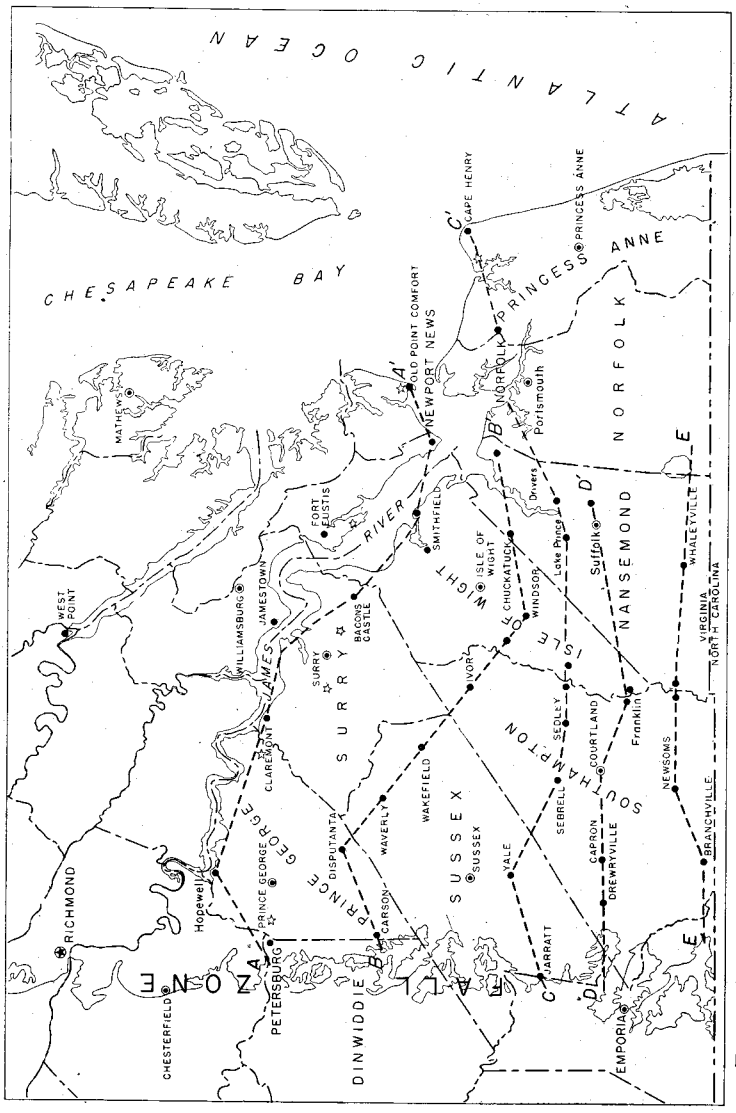


FIGURE 1.—Map of southeastern Virginia, showing counties included in the report and location of the geologic sections on Plate 1.

Sussex, Surry, Southampton, Isle of Wight, Nansemond, Norfolk and Princess Anne counties, eastern Chesterfield County and northeastern Dinwiddie and Greensville counties, as shown in Figure 1. Work in the area was begun in the fall of 1937 under the direction of O. E. Meinzer, Geologist in Charge of the Division of Ground Water, U. S. Geological Survey, and by the fall of 1942 a total of about 13 months had been spent in the field. Bulletin 51-E of the Virginia Geological Survey, which was published in 1939, summarizes the geology and artesian-water resources of Sussex, Southampton and Isle of Wight counties. Circular 1 of the Virginia Geological Survey, published in 1941, summarizes the geology and ground-water resources of the entire area covered by this report, for the purpose of providing information helpful in the interpretation of the well records released at that time. Reprint 6 of the Virginia Geological Survey (1943) presents data on the deep wells which have been drilled in the Coastal Plain province, many of them in southeastern Virginia. Bulletin 58 of the Virginia Geological Survey (1943) is a discussion of the occurrence of high-chloride waters in the central and eastern parts of the Coastal Plain and deals with a large part of the area covered by the present report.

The geologic and hydrologic data presented in this report were obtained from observations made in the field in carrying out a systematic ground-water inventory of southeastern Virginia, in supervising test-drilling projects in that area, from discussions with well owners, engineers or other officials in charge of municipal and industrial water supplies, and from the records furnished by many well drillers.

In addition to information obtained in the field, use was made of previously published data on the Coastal Plain in Virginia, especially the following: Sanford, Samuel, The underground water resources of the Coastal Plain Province in Virginia: Virginia Geol. Survey, Bull. 5, 1912; Darton, N. H., U. S. Geol. Survey Geol. Atlas, Norfolk folio (No. 80), 1902; and Ewing, Maurice, Crary, A. B., Rutherford, H. M., and Miller, Benjamin, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain: Geol. Soc. America Bull., vol. 48, pp. 753-812, 1937.

The present report contains chemical analyses of 137 samples of water collected by the writer and analyzed in the laboratories of the Federal Geological Survey. Most of these analyses were made by Margaret D. Foster and W. M. Noble, but some were made by J. D. Hem and G. J. Petretic. A few water analyses from other sources are also included. A number of chloride and hardness determinations were made in the field by the author.

Several well drillers located within the area covered by this report furnished much of the information upon which the hydrologic and geologic interpretations are based. Some of this information was given from memory, but since each of these drillers has specialized in a limited area, it is felt that their data and observations are of considerable value. They are C. W. Daugherty, of Claremont; P. P. Ellis, of Branchville; the late J. R. McLane, of Franklin; and Jesse Minton and R. W. Sillings, of Smithfield. Written records containing logs of wells and pumping tests have been made available to the writer by Charles F. Cole, of the Virginia Machinery and Well Company, and Garland Sydnor, of the Sydnor Pump and Well Company at Richmond; J. J. Mitchell, of the Mitchells Pump and Well Company at Petersburg; and Paul Schweitzer, of the Layne-Atlantic Company at Norfolk.

The writer is indebted to Dr. Arthur Bevan, State Geologist, Virginia Geological Survey, for suggestions in preparation of the report, and to many members of the Ground-Water Division of the U. S. Geological Survey for suggestions and for critical reading of the manuscript.

The following also deserve thanks for their assistance at various times: Dr. N. H. Darton, whom the writer accompanied on many field trips to various points of geological interest in the Virginia Coastal Plain; W. M. McGill, of the Virginia Geological Survey; Margaret D. Foster, of the Water Resources Laboratory, U. S. Geological Survey; E. S. Shepard, of the Geophysical Laboratory of the Carnegie Institution; H. Trendley Dean, of the U. S. Public Health Service.

Mr. W. R. Jones assisted the writer in the field during the test drilling at Bacons Castle and compiled much of the resultant data. Special thanks are due the Layne-Atlantic Company of Norfolk for their part in making possible extremely valuable pump tests on this project as without their assistance the tests could not have been made.

Miss N. Morris of this office did most of the necessary work on the well cuttings in the preparation of collections of foraminifers for study.

Dr. Horace G. Richards, of the Academy of Natural Sciences of Philadelphia, and Dr. Joseph A. Cushman, of the Federal Geological Survey, made determinations of macrofossils and microfossils collected during the investigation. Their work has made possible determinations of formational boundaries and established the presence of Upper Cretaceous strata a long distance west of previously known occurrences.

GEOGRAPHY

AREA AND POPULATION

The area and population for the counties and cities covered in this report, according to the Sixteenth Census of the United States, are given below:

TABLE 1.—*Area and population of counties and independent cities in southeastern Virginia in 1940*

County or independent city	Area (square miles)	Population	
		Total	Per square mile
Chesterfield County	475	31,183	66
Petersburg	4	30,631	7,656
Prince George County	291	20,905	72
Hopewell	5	8,679	1,736
Sussex County	496	12,485	24
Surry County	280	6,193	22
Southampton County	607	26,442	43
Isle of Wight County	321	13,381	42
Nansemond County	404	22,733	56
Suffolk	2	11,343	5,671
Norfolk County	400	35,828	90
Norfolk	2.8	144,332	51,540
Portsmouth	5	50,745	10,149
South Norfolk	2	8,038	4,019
Princess Anne County	267	19,984	75

INDUSTRY

The industrial development of each of the counties and independent cities is given in the following table:

TABLE 2.—*Number of industrial establishments and value of products, by counties and independent cities in southeastern Virginia*

County or independent city	Date of Census	Number of industrial establishments	Value of products
Chesterfield County	1929	29	5,886,755
Petersburg	1929	71	16,925,382
Greensville County[a]	1939	20	2,696,198
Prince George County and Hopewell	1939	17	31,788,781
Sussex County	1939	19	703,355
Surry County	1939	8	174,306
Southampton County	1939	16	749,698
Isle of Wight County	1939	20	6,433,743
Nansemond County and Suffolk	1939	56	9,698,040
Norfolk County, Norfolk, Portsmouth and South Norfolk	1939	266	91,756,125
Princess Anne County	1939	8	160,470

[a]The greatest part of the manufacturing in Greensville County is carried on in Jarratt and Emporia. These towns adjoin Sussex and Southampton counties respectively.

The construction, repair, loading, unloading, fueling and provisioning of vessels are important in the Hampton Roads area. The Norfolk Navy Yard at Portsmouth is of great importance as a repair base. Large naval vessels dock at the Naval Operating Base at Norfolk and large coaling stations are located at the mouth of Elizabeth River. Norfolk is ordinarily important as a commercial port and ranks twenty-fourth in the list of world ports, based on total registered tonnage.

Manufacturing is almost entirely localized in the area south of Richmond, at Petersburg, Jarratt, Hopewell, Franklin, Suffolk, Norfolk, South Norfolk and Portsmouth. The most important industrial products may be listed as follows: chemicals and chemical products, particularly cellophane, explosives, fertilizers and rayon; processed foods, mostly ham and peanuts; tobacco in various forms; cotton, kraft paper, lumber, cement and leather goods. In addition there are creameries, ice plants, breweries and bottling works in various parts of the area.

Summer resorts, ranging from the highly developed Virginia Beach section on the Atlantic Ocean to small groups of cottages along James River, are normally important to southeastern Virginia.

During the present war, the host of permanent and temporary Army and Navy establishments make their influence strongly felt in practically every county. Camp Lee near Petersburg, the Richmond Supply Depot (Army) between Petersburg and Richmond, the combined Naval Operating Base and Naval Air Station at Norfolk, the Norfolk Navy Yard at Portsmouth, Fort Story at Cape Henry, Camp Pendleton south of Virginia Beach, and many lesser (naval) airfields, supply depots, camps, and minor military installations throughout the eastern half of the area have profoundly altered the normal economic situation in southeastern Virginia.

AGRICULTURE

The rural areas in this part of the Coastal Plain in Virginia are largely agricultural. In most counties somewhat more than one-half of the total acreage is classed as farm land, and the remainder is productive woodland. The main crops are tobacco, cotton, corn, peanuts and hay. Diversified crops are raised on farms in Nansemond, Norfolk and Princess Anne counties, largely for consumption in and about the city of Norfolk. One vegetable cannery is located in northern Nansemond County. Swine are raised and, in

TABLE 3.—*Mean monthly and annual temperatures at U. S. Weather Bureau stations in southeastern Virginia, 1900-1939*

Station	Altitude (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean for year
Richmond	144	38.2	40.2	47.5	56.8	66.6	74.3	78.0	76.5	69.0	59.8	49.8	40.4	58.2
Norfolk	91	41.4	42.3	48.6	56.9	66.4	74.4	78.6	77.2	72.1	61.8	51.5	43.1	59.5

TABLE 4.—*Mean monthly and annual precipitation, in inches, at U. S. Weather Bureau stations in southeastern Virginia*

Station	Altitude (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean for year
Richmond[a]	144	3.11	3.13	3.71	3.50	3.73	3.84	4.49	4.49	3.22	2.92	2.26	3.08	41.48
Hopewell[b]	44	3.01	3.40	4.06	3.42	4.13	4.61	4.56	4.37	3.72	2.83	2.25	3.29	43.65
Runnymeade[c] (Surry County)	50	3.42	4.08	4.61	3.99	4.17	4.97	5.72	4.81	3.44	3.46	2.74	3.46	48.87
Norfolk[d]	91	3.11	3.40	3.87	3.33	3.85	4.29	5.66	5.15	3.61	3.19	2.39	3.38	45.23
Diamond Springs[e] (Princess Anne County)	25	3.49	3.37	3.61	3.23	4.12	5.16	5.68	4.32	3.84	2.89	2.38	4.23	46.23
Cape Henry[f]	20	3.25	3.30	4.02	3.40	3.63	4.09	5.33	4.72	3.32	2.99	2.51	3.45	44.01

[a]Record from 1871 to 1930, inclusive.
[b]Record from 1887 to 1930, inclusive.
[c]Record from 1867 to 1930, inclusive.
[d]Record from 1871 to 1930, inclusive.
[e]Record from 1909 to 1930, inclusive.
[f]Record from 1874 to 1930, inclusive.

every county except Norfolk, their value in 1940 exceeded the value of either dairy or chicken products sold. In general, the value of field crops is half again as much as the total value of swine, dairy and chicken products. Much of the field produce is consumed on the farm and therefore a somewhat larger proportion of the cash income is derived from swine, dairy and poultry than is indicated by the value of these products as compared with field produce.

CLIMATE

TEMPERATURE

The mean annual temperature is 58.2° F. at Richmond and 59.5° F. at Norfolk. Mean temperatures respectively of 38.2° and 41.4° have been recorded in January and mean temperatures of 78.0° and 78.6° in July. A slight ameliorating effect of the ocean may be seen in the mean monthly temperatures at Norfolk as compared with those at Richmond.

PRECIPITATION

The mean annual precipitation in the area ranges from 41.48 inches at Richmond to 48.87 inches at Runnymeade, Surry County, as shown in Table 4. The greatest precipitation occurs in July and

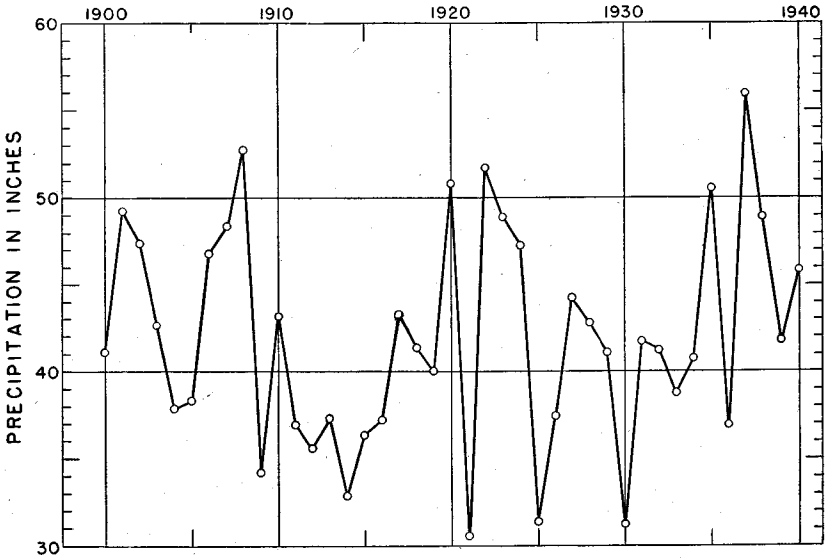


FIGURE 2.—Diagram showing annual precipitation at Richmond, Virginia, for period 1900-1940.

the least in November. At Richmond the average precipitation in July is 4.49 inches while at Runnymeade the average precipitation for July is 5.72 inches. The minimum monthly rainfall for both places is in November, with an average of 2.26 inches at Richmond, and 2.74 inches at Runnymeade.

The precipitation of the region is subject to rather wide variation. Thus at Richmond in the period of 41 years, from 1900 to 1940, there were five years in which the precipitation was less than 35 inches and five in which it exceeded 50 inches, as shown in Figure 2.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTER

The character of the unconsolidated Coastal Plain sediments at the surface has been described in some detail by Clark and Miller.[26]* Information on the geology of the sediments and basal crystalline rock encountered in wells is given by Sanford[93] and Darton[48]. These data have been incorporated with more recent information in the chapters dealing with geology.

Unconsolidated sediments of Cretaceous, Tertiary and Quaternary age lie as a wedge upon the pre-Cambrian basement rock and thicken in an eastward direction, as may be seen in section A-A′ and C-C′, Plate 1. (See also Pl. 2.) The total thickness of sediments at Fort Monroe is 2,240 feet, and at Mathews Court House it is 2,307 feet. Ewing and his associates[60] have presented data to show that the total thickness of sediments 60 miles east of Cape Henry may exceed 12,000 feet.

The Cretaceous, Tertiary and Quaternary sediments in this area have been divided into five large groups: (1) the Potomac group of early Cretaceous age, which rests directly upon the granite basement; (2) sands and clays of late Cretaceous age, recognized previously only from records of two deep borings at Norfolk, but now known to extend a long distance inland, overlie the Potomac deposits; above the Cretaceous groups are (3) the Pamunkey group and younger (?) and older (?) deposits of Eocene age, (4) the Chesapeake group of Miocene age and (5) the Columbia group of Pleistocene age.

Along and near the Fall Zone the Potomac and Pamunkey strata are exposed. Elsewhere only the Chesapeake strata with their veneer of younger terrace sand may be seen, and in Norfolk and Princess Anne counties even the Chesapeake sediments are not exposed above sea level. Upper Cretaceous sediments in Virginia are known only from the records of wells.

GRANITIC BASEMENT ROCK

The counties treated in this paper fall within the Coastal Plain province, an area in which unconsolidated sand, clay, and marl, dipping gently seaward, lie upon a basement of granitic rock, as shown in Plate 1.

The zone in which granite appears at the surface on the western border of the Coastal Plain is known as the Fall Zone. This

*References are listed at the end of the report.

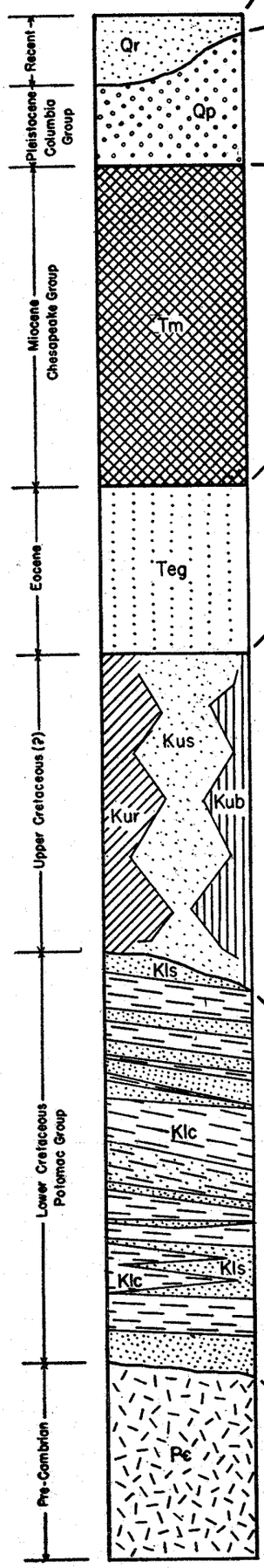
zone extends roughly north and south in Virginia, and passes through Emporia, Stony Creek, Petersburg and Richmond. The granite lies progressively deeper beneath the unconsolidated sediments in an eastward direction. Granite crops out in some stream beds west of Stony Creek and is within 100 feet of the surface in other portions of western Sussex County. It has been encountered in several wells in the vicinity of Petersburg and in eastern Chesterfield County.

BASEMENT ROCK SURFACE

The bedrock surface is an erosional surface that is somewhat irregular. Minor irregularities along the Fall Zone have been discerned from place to place, and what appears to be a major trench in an otherwise undulating surface is indicated by the following information obtained from Mr. J. J. Mitchell. From three to four miles north of Petersburg bedrock is encountered in six wells (34 to 39, Table 13) at about 40 feet above sea level. About eight miles north of Petersburg 2 wells (31, 32) reach sea level and 80 feet below sea level respectively, without encountering hard rock. At Lake Ely well 20 reached a depth of 40 feet below sea level without striking granite. Northward from Kingsland Creek, however, the basement rock is again encountered near sea level, in the deeper wells.

This depression in the bedrock surface between Petersburg and Richmond may be interpreted as a pre-Potomac channel extending east and west. However, it may also mark a westward embayment of one of the nearly horizontal buried terraces cut in bedrock, as shown in section A-A′, Plate 1. A report that at Howlett House, 3 miles east of Chester, bedrock was encountered 260 feet below sea level (well 24, Table 13) indicates that a rock-cut terrace may also be present in this area and the terrace shown in section A-A′ may therefore be of more than local extent.

In the Newport News area depth to bedrock was determined many years ago.[99] At Fort Monroe crystalline rock was encountered at 2,240 feet below sea level. At North End Point, 7 miles north-northeast of Fort Monroe, "hardest kind of stone or granite" was struck at 1,172 feet, but it seems improbable that this was the basement rock. At the Norfolk City pumping station at Waterway or Moores Bridges, a well 1,762 feet deep did not encounter basement rock. In 1929 a test well was drilled by the Elkins Oil and



Geologic Age and Description	Origin	Distribution	Water-bearing Properties
Recent sands and gravels. Maximum thickness known is 140 feet, at Cape Henry.	Deposited by wind and wave action.	Exposed along beaches in Princess Anne and Norfolk counties. Extends below sea level at Cape Henry.	Yields small quantities of water which is generally high in iron content.
The Columbia group of Pleistocene age consists of clays and sands which make up the surficial terraces. Marly strata are present in easternmost terraces only. The average thickness is about 30 feet and the maximum thickness is probably not greater than 60 feet.	The higher and westerly terraces are of continental origin, but the lower easterly terraces are of marine origin.	Exposed at the surface throughout the area.	Excellent water-bearing formation for domestic and small industrial supplies.
The Chesapeake group of Miocene age consists mainly of shell marls, dark-blue or gray clays and subordinate sand or sandy strata. The Yorktown formation is sandy and very fossiliferous. The St. Marys formation consists largely of tough blue or gray clays. The basal Calvert formation is diatomaceous and sandy but is less fossiliferous than the Yorktown formation. The maximum known thickness of the Chesapeake group is 604 feet, at Norfolk.	Deposited in marine waters which may have extended inland some distance west of the present Fall Zone.	Exposed in stream beds except in Norfolk and Princess Anne counties where concealed by younger sediments. The Yorktown and St. Marys formations crop out throughout the central and western area and the Calvert formations crop out along the Fall Zone.	The Yorktown formation is a fairly good water-bearing formation along James River from Norfolk to Surry. Small industrial supplies are developed from it near Norfolk.
Glauconitic strata of the Pamunkey group (Nanjemoy and Aquia formations) of Eocene age. Older and younger Eocene deposits may be included also. It is the "black sand" of the drillers. Consists of glauconite beds, glauconitic sands and marls. Thin indurated beds are common at Franklin. Maximum thickness about 100 feet.	Deposited in marine waters which extended inland at least as far as the present Fall Zone.	Underlies the Miocene formations throughout most of the area. Has limited outcrops along the Fall Zone.	Glauconite sands furnish water to a very few wells in southeastern Virginia. The sand tends to run and clog the well or fails to clear.
Red clay (Kur) correlated with chocolate-brown clay of late Cretaceous age at Franklin. Underlain by glauconite sand at Windsor. Relationship to Upper Cretaceous gray clays uncertain. Maximum thickness about 100 feet.	Deposited in nearshore marine waters, and sediments have a continental aspect. Although the sediments contain marine fossils and are slightly glauconitic in places, they are highly variable in composition and contain bright-colored strata.	Not exposed. Underlies Eocene strata. Distribution patchy but widespread, particularly in Southampton, Isle of Wight, and northern Nansemond counties.	Not a water-bearing formation.
Gray sands (Kus) of late Cretaceous (?) age, recognized at Franklin, in northern Nansemond County and Norfolk. Maximum thickness about 30 feet. Sand slightly glauconitic and may contain indurated layers, as at Norfolk.		Occurs above chocolate-brown clay at Franklin and above gray clays at Drivers. May be quite widely distributed throughout the area but is not recognized.	Yields small supplies of water for domestic purposes. Where known, Upper Cretaceous sands appear to be rather fine and the deposits are not very thick.
Gray or blue clays (Kub) at Drivers and Lake Prince, Nansemond County, and at Norfolk contain Upper Cretaceous fossils. Maximum thickness 55 feet, at Lake Prince.		Gray clays beneath Eocene glauconitic strata at Bacons Castle have been assigned to the Upper Cretaceous, but in some places gray or blue clays at this stratigraphic level are assigned to the Potomac group.	Not a water-bearing formation.
The Potomac group of early Cretaceous age consists of interbedded sands and clays. Sands (Kls) are clean arkosic quartz sands varying in size from fine to coarse gravel. White to gray in color. Individual strata generally are from 5 to 30 feet thick, but strata about 100 feet thick are known. Clays (Klc) of the Potomac group are generally thicker than the associated sands, and thicknesses in excess of 100 feet are not uncommon. Clays become increasingly compact and harder to drill with depth.	Most of the strata occurring in this area are probably of continental origin and are deltaic in character. They were deposited along stream courses, in estuaries, at river mouths, and in bays and lagoons.	Sands and clays of the Potomac group underlie the entire area. Individual strata are generally lenticular and can not be traced for more than a few miles at most. Good exposures are present along James and Appomattox rivers near the Fall Zone, but eastward these strata are concealed by younger formations. East of Norfolk the Potomac strata occur below 770 feet below sea level.	The sands of the Potomac group are an excellent source of water wherever large quantities of water are needed. Along the Fall Zone the Potomac group may contain few or no water-bearing sands and in Norfolk and Princess Anne counties the water yielded is brackish. In intervening areas, however, one-third to one-half of the Potomac strata is generally made up of clean sandy beds and yields of from 1 to 3 million gallons a day are available to properly constructed wells
Pre-Cambrian granite.	Igneous intrusion from great depths.	Exposed along the Fall Zone and has been encountered in some deep wells east of the Fall Zone.	Good water-bearing formation for small yields. A few wells in granite yield more than 100 gallons a minute.

Columnar section giving age, description, origin, distribution and water-bearing properties of formations shown on Plate 1.

Gas Co. at Mathews Court House, about 40 miles directly north of Norfolk. Granite was encountered in this well at 2,300 feet below sea level.

Recently, more detailed data on the Coastal Plain in Virginia have been brought to light by geophysical surveys.[57] Depth to bedrock was determined along a line extending eastward from Petersburg, traversing Prince George, Sussex and Surry counties. The traverse then crossed James River, and other stations were located at Mulberry Island, Hampton and Fort Monroe. Another station, off the line of this traverse, was located near Cape Henry, Princess Anne County.

These data are incorporated in the cross sections accompanying the present report (Pl. 1 and Fig. 1). Section A-A′ was drawn to follow approximately the main traverse from Petersburg to Newport News. The depth to bedrock of 2,900 feet at the Cape Henry station is also shown in section C-C′.

Near the Fall Zone at Petersburg the granite surface slopes eastward 270 feet in the first 4 miles but descends only about 70 feet in the next 5½ miles to the east. From Prince George through Newville to Burrowsville the bedrock surface is reported to be nearly horizontal.

The sharp break in the bedrock slope immediately east of Petersburg is not unique in the Coastal Plain of Virginia. Cady[9] notes that "the record of the wells at Quantico indicates the irregular surface of the rock below the Coastal Plain sediments, for there is a drop of at least 200 feet within a linear distance of less than 500 yards, indicating that there is a steep-sided rock-cut channel beneath the present course of the Potomac River in some places."

A cross section illustrating the bedrock surface near Quantico on the same scale as section A-A′ is shown in Figure 3. It appears that the slope of the bedrock west of Quantico is much steeper than the bedrock slope east of Petersburg. The sharp break in slope at Quantico, to which Cady refers, suggests faulting in the basement rock or a steep pre-Cretaceous erosional scarp.

Darton has observed[a] local eastward-facing scarps in the bedrock surface a few miles east of Washington, D. C.

Still another break in slope on the bedrock surface is seen in section A-A′ from Mercy Seat Church station to Surry station, where bedrock surface inclines moderately steeply seaward. The seaward slope is continued to Mulberry Island and Fort Monroe

[a] Oral communication, January 23, 1940.

(Old Point Comfort), although it varies somewhat from place to place. Even though data are limited and it is recognized that the features described may not be general for the Coastal Plain, the irregularities in the bedrock surface are significant.

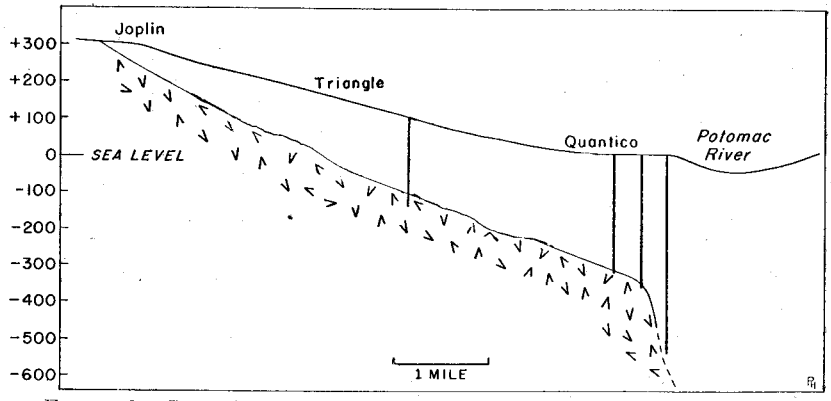


FIGURE 3.—Geologic section showing approximate configuration of basement rock near Quantico, Virginia.

The facts brought out concerning the configuration of the bedrock surface appear to indicate that the following events have taken place: (1) downwarping and submergence of the granitic area, with contemporary accumulation of sediments off shore; (2) cessation of submergence at some stage in Lower Cretaceous time for a period long enough for streams to smooth the bedrock surface east of Petersburg and to create the steep bedrock slope (scarp?) near the western border of the Coastal Plain; and (3) continued submergence and the covering of the flat bedrock surfaces with sediments of the Potomac group.

Certain of the breaks in the slope of the bedrock surface may be due to faulting. It seems logical that the downwarping of a huge crystalline rock mass should be accompanied by at least minor faulting. Sharp breaks, such as the one which exists at Quantico, may have been caused by faulting instead of erosion. Evidence is presented later to show that this portion of the Coastal Plain has undergone at least minor deformation and that a few small faults have occurred along the Fall Zone. Other data[22] seems to indicate that major faulting affected the basement rock and overlying sediments in post-Cretaceous-pre-Eocene times. However, no attempt is made to ascribe all of the bedrock irregularities to faulting.

WATER-BEARING PROPERTIES

The granitic bedrock along the Fall Zone is reached by a number of wells which yield supplies of from a few gallons to more than 300 gallons a minute.

Water probably occurs chiefly in fissures in the granitic rock and in some places in weathered parts of the rock mass, but so far as is known the wells which penetrate the granite in the area covered by the present report derive water from fissures only. Openings occur in the granite in most places along the Fall Zone, and it has been found that in general supplies of 10 to 50 gallons a minute may be obtained by wells penetrating 400 feet of granitic rock. The fissures generally decrease with depth, and 400 feet is generally given as the limit of depth to which a well should be drilled. In a few places large quantities of water have been obtained at greater depth, and it seems likely that where the granite is greatly shattered and yields a moderately good water supply in the first 400 feet, there is a good possibility of encountering further water supplies in fissures at greater depths.

POTOMAC GROUP

LITHOLOGIC CHARACTER

Sediments of the Potomac group are composed mostly of unconsolidated clay, sandy clay and sand, commonly arkosic, in which iron oxide or plant material may be present. (See Pls. 3, 4 and 7.) The deposits are about 1,500 feet thick at Norfolk but thin out to less than 100 feet, or may even be entirely removed by erosion, along the Fall Zone. At Hopewell, about 7 miles east of the Fall Zone, these strata are about 200 feet thick.

Plant and animal fossils found in the Potomac group indicate that these sediments are composed of materials accumulated on the land, in stream beds, along the shore and in shallow bay waters. Because of their manner of deposition the sediments vary greatly and individual beds may thicken, thin or pinch out in short distances. Lateral variation is well illustrated by the marked change in lithology which occurs between test hole no. 1 and test hole no. 2 at Bacons Castle (Pls. 23 and 26). Dependable horizon markers in this series are scarce and of limited areal extent.

The Potomac group has been divided into several formations, two of which, the Patuxent and the Patapsco, are present in Virginia.

Along the Fall Zone the Patuxent formation,[27] at the base of the Potomac group, is predominately a sand, gravel and cobble formation, although interstratified clay beds are present in many places. The associated clay layers are seldom highly colored, and along the Fall Zone tend to be gray, drab, dark-green, or chocolate-colored. Indurated sandy layers are common in this formation along the Fall Zone. It was laid down upon an uneven granite floor and consequently is variable in thickness. In northern Virginia a thickness of about 250 feet is exposed along the Fall Zone and east of the Fall Zone the formation attains a much greater thickness under the cover of younger strata. Clark and Miller[28] describe the Patuxent deposits along James River at Drewrys Bluff, and likewise note the exposures along Appomattox River from Petersburg to City Point (Hopewell). The Patuxent formation is also present along Nottoway River east of Stony Creek.

The Patapsco formation, which uncomformably overlies the Patuxent formation, has not been proved to be present south of Fort Belvoir, Fairfax County. Hence, all the Potomac strata encountered in wells east of the Fall Zone are assigned to the Potomac group, undifferentiated.

Most of the wells obtaining artesian water reach only the uppermost strata of the Potomac group. Hence the description of these strata east of the Fall Zone is based on the logs of the relatively few wells which penetrate a greater-than-average thickness of Cretaceous deposits. These data show that the sediments of the Potomac group in subsurface are made up of beds of clay with abundant interbedded layers and lenses of sand and sandy clay. Drab-bluish or gray clays, such as are characteristic of the Fall Zone area, make up a large proportion of the Cretaceous deposits to the east, but individual beds of clay are rarely more than about 30 or 40 feet thick. Good water-bearing sands free of interstitial clay are present in many places. In many places water-bearing sand contains a little interstitial clay, and in places thin streaks of permeable sand may alternate with streaks of clayey sand or clay. According to local drillers, gravel is common at Branchville, and at Hopewell several strata composed of gravel or gravel and boulders are reported. Gravelly sands are known from deep wells at Franklin, Bacons Castle and Lake Prince (Pls. 24, 25B and 35). Most sands of the Potomac group, however, vary in texture from moderately fine to coarse. The sand is generally a white quartz sand containing subordinate arkosic material. Less commonly arkosic material is abundant, and in many places the sand is gray rather than white. Indurated beds are rare except near or along the Fall Zone, as noted above. Individual

sand beds up to 30 to 40 feet in thickness do not appear to be uncommon and at Branchville a "sand" stratum 110 feet thick is reported. A similarly thick bed, broken by a 3-foot clay stratum, was penetrated in the second test well at Bacons Castle (Pl. 26). A sand stratum 97 feet thick was logged in the Lake Prince test well (Pl. 34) and a stratum 90 feet thick is reported at Franklin (Pl. 32).

At Hopewell the Potomac group is made up of predominantly sandy and gravelly beds. Clay makes up only 22 feet of the 203 feet of strata penetrated. At Sedley (25, Table 30) clay and sandy clay with only minor beds of sand are reported. At Franklin more than half of the first 450 feet of Potomac deposits is quartz sand (Pl. 32) but the next 200 feet are almost entirely clay. At Courtland (141, Table 30) 110 feet of Potomac sediments contains only 25 feet of clay. In a test well (104, Table 40) constructed by the City of Suffolk, 57 feet of good clean sand, 112 feet of clayey sand or sandy clay, and 133 feet of clay were penetrated below a depth of 415 feet. The upper part of these predominantly clayey deposits may be of late Cretaceous age, however. At Lake Prince (Pl. 34) 544 feet of Potomac deposits contained 326 feet of sand and 218 feet of sandy clays and clays. The deep well at Moores Bridges (20, Table 44) penetrated 977 feet of sediments of the Potomac group in which sands, clayey sands and sandy clay predominated.

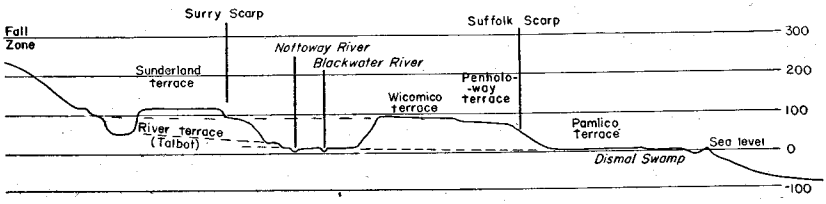


FIGURE 4.—Profile of the Coastal Plain in southeastern Virginia, showing terraces and scarps. (Modified from Figure 7, Virginia Geol. Survey Bull. 32, 1930.)

ORIGIN

Although the Patapsco and Patuxent formations are typical river and estuarine deposits along the Fall Zone, it may be expected that at some point eastward they become marine in character. Darton,[49] however, has called attention to the estuarine character of the sediments in the deep well at Norfolk as denoted by the presence of leaves and wood and the general character of the strata. Other published descriptions of the Potomac group, as found along the Fall Zone, emphasize the presence of continental material in these deposits. To date everything

which has been found in deep well samples indicates that the Potomac sediments are continental in origin.

A recent discussion of the vast Mississippi delta deposits[92] contains a description of those deposits and the means by which they have accumulated. This description, if it does not fit the deposits of the Coastal Plain of Virginia in detail, will probably do so with very slight modifications. The authors point out that "the usual picture of delta structure as a series of top-set, foreset, and bottom-set beds is not supported by evidence in the Mississippi delta. A more correct picture is furnished by a pile of roughly superimposed leaves, in which the veins of the leaves represent natural levees and associated channels and crevasse deposits. Intervein areas represent deposits of the marshes, lakes, and bays, whereas the outer margins of the leaves indicate beaches and bars—the buried ones probably being similar to the shoestring sands of Kansas and Oklahoma. Beyond the fringing bars and beaches occur deposits of the open Gulf. Where advance of the sea over old abandoned sub-delta surfaces has partially destroyed the delta pattern, marine beds, easily recognized by their faunal content, interfinger with the delta complex.

"Delta sedimentation results in a characteristic pattern consisting of: (1) a framework of natural levees, with associated channel and crevasse deposits; (2) within this framework, deposits of the marshes, lakes, and bays; (3) an outer margin of beach and bar deposits and (4) deposits of the open Gulf beyond.

"The sedimentary load of the Mississippi River (probably more than two million tons per day) is concentrated by deposition in the vicinity of the active passes. This concentration of load results in rapid subsidence, eight feet or more per century. . . . Though land is added in the vicinity of active passes, it is lost to adjacent areas dominated by subsidence. Delta-flank and subdelta-flank depressions thus become sites of marine deposition well inland from positions contemporaneously receiving continental deposits."

It seems to the writer that detailed study of the Potomac group (where logs are available) shows many features analogous to the typical Mississippi delta sedimentation as outlined above, particularly the presence of channel sand deposits and interchannel clayey sediments. Notable differences in the Potomac deposits occur between Hopewell and the Federal Reformatory (21, 1, Table 16). At the former locality excellent water-bearing sands and subordinate clays are present, whereas at the latter locality, 3½ miles to the west, the section is much more clayey and fewer sand strata are present. In the City of Suffolk

test well, 57 feet of sand had been penetrated when the well had reached a depth of 717 feet; at Lake Prince, 5 miles to the northwest, 204 feet of sand had been penetrated at a comparable depth. Other changes in the character of Potomac sediments from place to place may be noted on the cross sections.

It is possible that many seeming lateral variations in Potomac sediments are due to transgressive overlap of Lower Cretaceous deposits by those of late Cretaceous age. However, many marked variations do occur entirely within deposits which are quite certainly of early Cretaceous age.

Therefore, from the available logs, it appears that features of the Potomac strata may be interpreted as deltaic deposition and the description of deltaic deposition in the lower Mississippi River area appears applicable, in part at least, to the southeastern Virginia area. Thick sandy deposits may represent main channelways which have tended to build up their banks and beds by the accumulation of coarser material. On the lower lands on either side of the main channelways, clayey sediments would tend to accumulate, but occasional flooding of these areas would distribute widely a thin blanket of more poorly sorted sand and silt. That submergence of limited areas due to loading has permitted long arms of the sea to reach inland parallel to the main channelways is not yet evident. This hypothesis for means and manner of deposition of Potomac sediments can hardly be considered as new; Sanford and Clark and Miller have offered practically the same idea, though couched in generalities. On the other hand, the application of Russel's findings to what is known of the Potomac deposits from place to place leads to a geological conception which may prove to be of value in predicting the presence of water-bearing strata.

In regard to prediction of water supplies, Sanford[94] states:

"The significance of the disorder of the Patuxent sands to the well driller or geologist is that predictions of striking water at a given place are little better than guess-work unless the records of near-by wells are known. Even then close estimates may be erroneous. Usually the best that can be done is to give the probable depth to a succession of sandy or gravelly beds, some one of which should carry satisfactory supplies."

The writer feels that the "disorder" mentioned by Sanford is overemphasized and that instead of disorder there occurred the deposition of a complex series of strata by variable but definite agencies which tended to create characteristic patterns. The key to the problem lies in the securing of sufficient data to understand the range of variation

within the group and to reconstruct the pattern from one or a few parts in relatively unexplored territory.

Certain rules may therefore be tentatively set forth as guides in the location of water-bearing strata in the Potomac group.

1. Considerable thicknesses of sand, as at Franklin and Lake Prince, may be expected to occur as relatively narrow lenses a few miles wide at most, which grade laterally into sediments containing less sand or none at all. Therefore, excellent series of water-bearing strata at one locality should not be considered as typical of the larger surrounding area until proved.

2. A section containing an alternating series of clay and somewhat subordinate sand beds may be considered to be a delta flank and indicative of a greater thickness of sands in one direction and a lesser thickness of sands in the opposite direction at the same geological horizon. Thus a test hole which shows only relatively few or thin sand beds ought not be considered typical of a very large area.

3. If stream channels in an area tend to be persistent, as J. R. and R. D. Russel suggest, then the first 50 to 100 feet of section is indicative of the character of the section as a whole.

The results of deep drilling at Lake Prince, Suffolk, Bacons Castle, Franklin, Hopewell and Sedley seem to indicate that stream channels are persistent and that the upper portion (the first 50 to 100 feet) of the Potomac deposits is diagnostic of the character of the deposits as a whole. At Bacons Castle and Franklin, however, it appears that the upper several hundred feet of strata of the Potomac group are predominantly sandy whereas deeper strata are predominantly clayey. Such changes in character might be interpreted as due to major stream channel changes which occurred in Cretaceous time.

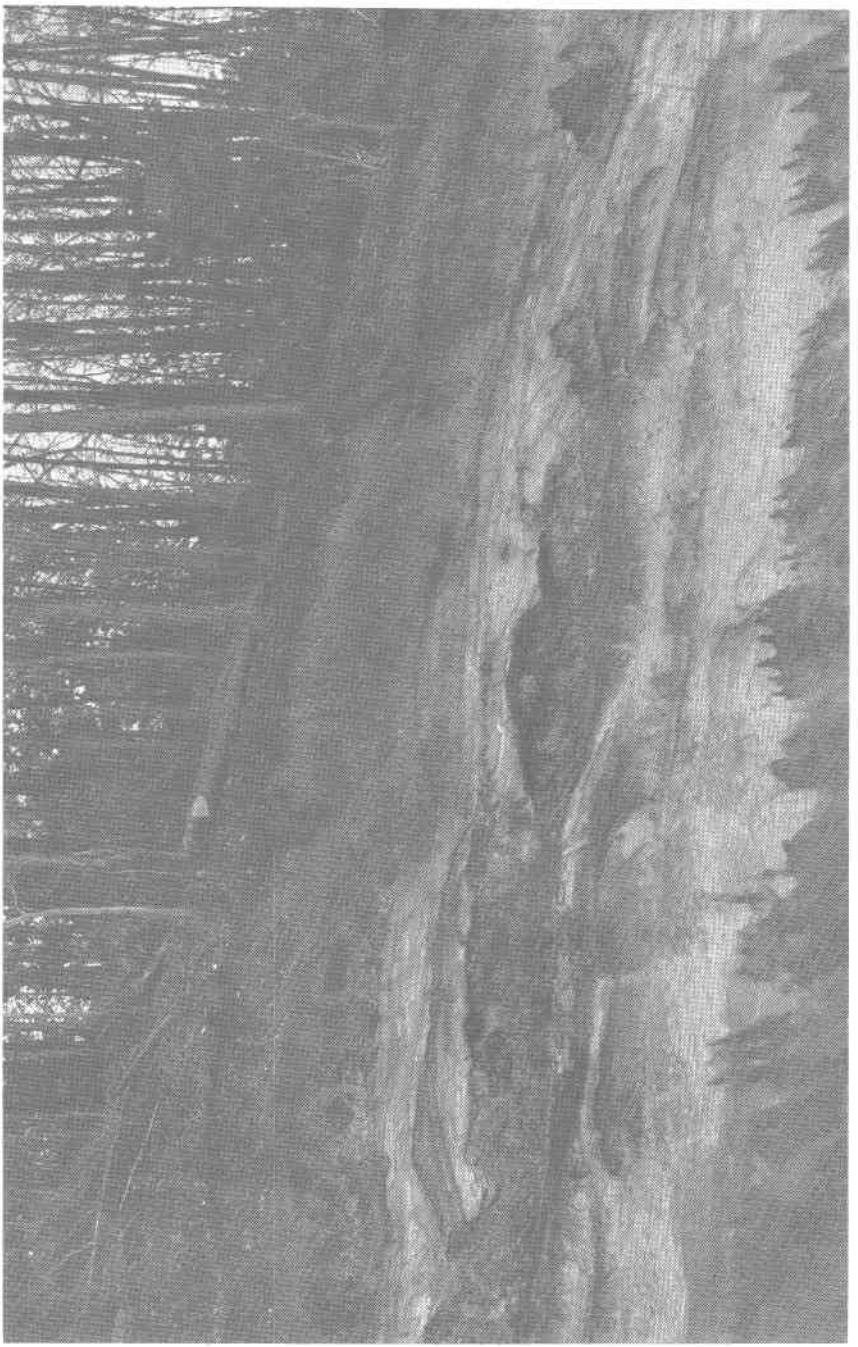
Less is known about the lateral variation of thick sandy strata characteristic of channel deposition. Moderate variation is seen between the two test wells at Bacons Castle (Pls. 23 and 26), which are 3.2 miles apart, and very striking differences are seen between the Lake Prince and City of Suffolk test wells (Pls. 35 and 104, Table 40), which are 5 miles apart. Very little variation in the aggregate thickness of sand is noted in the two closely spaced deep wells at Franklin and the same is true of wells at Hopewell.

The points enumerated above may be of practical value in the development of large supplies of water. In the development of small amounts of water they may for the most part be ignored, because in even the most unfavorable localities thin sands are generally present

Clay and sand in the Potomac group along the Fall zone near Quantico, Virginia. Exposed in cut along U. S. Highway 1.

Clay and sand in the Potomac group along the Fall zone near Quantico, Virginia. Exposed in cut along U. S. Highway 1.

Arkosic sand and included clay masses in Potomac group near Stafford, Virginia. Photograph by U. S. Geological Survey.



Arkosic sand and included clay masses in Potomac group near Stafford, Virginia. Photograph by U. S. Geological Survey.

within the first 100 feet of Potomac strata which yield ample supplies of water for domestic and most small industrial purposes.

WATER-BEARING PROPERTIES

Ample water for domestic and small industrial and public supplies is obtained almost everywhere from wells developed in strata of the Potomac group, except along the Fall Zone, in western Chesterfield, eastern Prince George and eastern Sussex counties, where these strata are thin. East of the Fall Zone large quantities of water are generally available from the Potomac strata. At Hopewell 2,000,000 gallons of water a day have been pumped from the Potomac strata during part of each year since 1924, and one of several test wells at Jarratt obtained a yield of about 300 gallons a minute from these strata. At many places along the Fall Zone the wells do not obtain their water from sands in the Potomac strata but go through them into the underlying granite. It is believed that the practice of drilling into the granite is followed, at least in part, not always because of the lack of sufficient water in the sandy layers but because it is easier to case them off and to finish the well in granite. However, large supplies of water can be obtained in some places from the granite where the overlying sediments are too thin to be a good source of water, and the supplies from the Potomac strata may be augmented by continuing the wells into the granite.

Data of various kinds, such as detailed logs of deep test holes penetrating hundreds of feet of water-bearing sands, pumping records of large-yield wells, close estimates of the aggregate flow of hundreds of small-diameter wells and other information, indicate that in most places in southeastern Virginia yields of 1,000,000 gallons a day or more may be expected from properly constructed wells. A considerable amount of new information bearing on the quantities of water which may be obtained from Coastal Plain sediments has been brought to light in the period from 1940 to 1943. Several test-drilling projects were carried out under supervision of the writer, as part of the cooperative ground-water investigations program in Virginia; in other instances much detailed information has been made available and closely studied and correlated with already known data. In particular, the recent information gained at Franklin, Bacons Castle and Lake Prince in the area south of James River, together with recent data on wells in the York-James Penin-

sula at Ft. Eustis, Lee Hall, Yorktown and Camp Peary, have contributed to a new conception of the large quantities of water available in most places.[16] In 1939 it was believed that a maximum of about 1,000,000 gallons of water a day per well might be obtained in many places in the Coastal Plain and that elsewhere smaller quantities were available. It seems evident now that in most places 1,000,000 gallons a day are available and in many places 2,000,000 or 3,000,00 gallons a day may be obtained. In a few very favorable localities it may be possible to obtain as much as 5 million gallons a day per well.

Favorable though the results of recent deep drilling have been, these results and the encouraging conclusions to which they lead should be accepted with caution. In some places, as at Sedley, thick channel sands may not be present and the quantities of water available in a limited area may be meager. Not a great deal is known of the persistence of thick sand beds which yield copious supplies of water. That they pinch out laterally (usually north and south of a given point) is a fact which is well established, but the distance in which marked thinning may occur is not known. It is also problematical whether the upstream (generally west) or downstream (generally east) extensions of dominant sand strata outside a heavily pumped area may be depended upon to furnish large additional supplies. Records of water-level observations in the Franklin area are encouraging but on the other hand, where only a limited thickness of Coastal Plain strata has been drawn upon, as at Williamsburg, Ft. Eustis, Lee Hall and Camp Peary, it was found that a moderate discharge from several wells exceeded safe yield. Hence, because high-yield wells may be developed in an area, it does not necessarily follow that the wells will continue to have high yields under continuous operating conditions. Consequently, until more quantitative data are available, wide spacing of wells and development of a maximum thickness of sand strata are recommended in large new developments.

Large supplies of water are probably available in the area east of a line drawn southeastward from northeastern Isle of Wight County, but in that area the waters have a high chloride content (Fig. 15) and are generally of poor quality.

UPPER CRETACEOUS DEPOSITS

OCCURRENCE IN HAMPTON ROADS AREA

In late Cretaceous time the sea advanced part way towards the Fall Zone, and in cuttings from the deep wells in Norfolk, marine Upper Cretaceous sands and clays have been recognized.[50] They are about 100 feet thick. Little was known of their occurrence to the west until recently. According to published descriptions, they consist largely of alternating gray sand and clay. Some of the clay is micaceous, and thin consolidated strata are characteristic of the formation.

OCCURRENCE INLAND

LITHOLOGIC EVIDENCE

In studying the logs of wells located throughout the Coastal Plain in Virginia, the writer found it was generally possible to extrapolate the geology of the Fall Zone eastward for ten to twenty miles. Beyond a certain point, however, "abnormalities" were discerned and in many instances the record of the deeper formations penetrated could not be separated into the Potomac, Pamunkey and Chesapeake groups with any feeling of certainty.

Throughout southeastern Virginia a bright-red clay occurs from place to place beneath the characteristic Eocene glauconite sand. It ranges from a few feet to 120 feet in thickness and is extremely erratic in distribution. Bright-colored clays at greater depths in sediments of unquestionable early Cretaceous age are rare. The only stratum exposed along the Fall Zone in any way resembling this bright-red clay in the Eocene of North Carolina[41], Maryland[25], or Virginia[26] is a very thin pink clay stratum which occurs at the base of the Nanjemoy in some places along the Virginia Fall Zone. Mottled clays, some of them predominantly pink, occur in the Eocene section at West Point, King and Queen County, and at Oak Grove, Westmoreland County, but these and the Eocene pink clays exposed along the Fall Zone are pink and not "blood-red" or "brick-red."

It also might be inferred that this red clay stratum is simply a member of the Patapsco formation of early Cretaceous age[11] appearing under cover south of its southernmost known outcrop in northern Virginia. However, as the Patapsco actually thins southward and does not crop out in North Carolina, there is good reason to question its presence in southern Virginia. A further objection to assigning the red clay to the Patapsco formation is that the clay is persistent in the

sense that it appears at a definite horizon in many widely separated localities.

The distribution of the red clay itself and of its probable equivalents shows a persistence over wide areas which is not characteristic of the Lower Cretaceous formations and, on the other hand, these beds are apparently nonglauconitic and therefore probably not Eocene in age. In Maryland Upper Cretaceous formations, the Matawan and Monmouth formations[24] particularly, are persistent although they exhibit marked lateral variations. The more highly glauconitic Upper Cretaceous deposits, such as the Monmouth formation, are distinguished with difficulty from the overlying Eocene deposits. The presence of estuarine and lagoonal facies which have a wide range in lithologic characteristics is recognized, although the deposits as a whole appear to be of marine origin. It is thought that the red clay and associated beds in southeastern Virginia are more similar to known Upper Cretaceous deposits (in Maryland) than to Eocene deposits north of James River in Virginia and hence they are tentatively assigned to the Upper Cretaceous.

Further, recent paleontologic work has demonstrated the presence of Upper Cretaceous strata as far inland as Franklin, although at that locality definite boundaries can not be drawn on the basis of available data.

In some places a chocolate-brown clay stratum, as much as 40 feet thick, lies beneath characteristic Eocene beds of glauconite from which it is separated by a gray water-bearing sand. It seems that this stratum is a correlative of the "blood-red" clay when very recent data on wells in the Franklin-Courtland area are plotted (Fig. 5).

The distribution of the bright-colored clay is as follows: In Branchville and Boykins (section E-E′, Pl. 1), 15 to 100 feet of red clay grades eastward into chocolate-brown clay at Newsoms and South Quay. The red clay is 80 feet thick a few miles south of Capron, but at Capron (section D-D′) it is only about 10 feet thick. It may extend continuously from Capron to a point just west of Courtland. South-southeast of Courtland the red clay is 130 feet thick but thins to 75 feet at Joyners Church (Fig. 5). The red clay at Joyners Church grades into chocolate-brown clay at Franklin (207, Table 30) where it is 85 feet thick. (In a well drilled at the Franklin waterworks in October, 1944 (207b), 86 feet of gray nonglauconitic clay was penetrated at the same depth at which chocolate-brown clay is present in well 207a, a few hundred feet

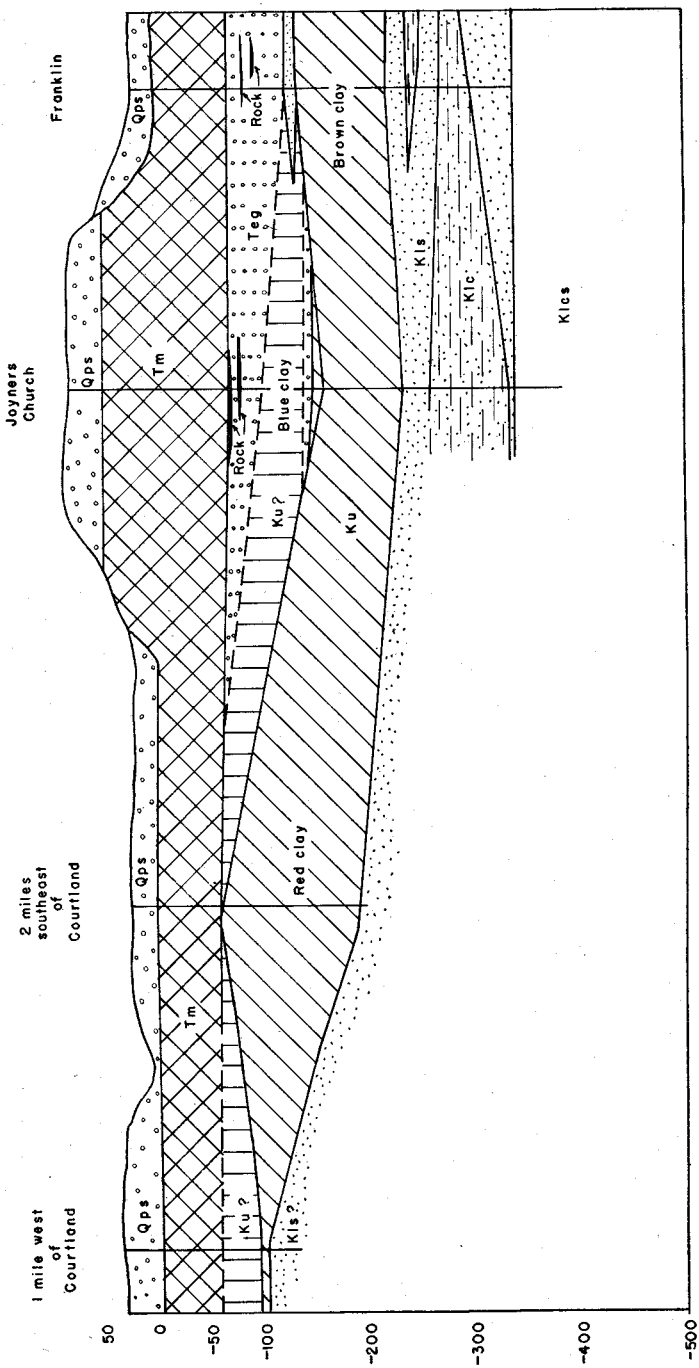


FIGURE 5.—Section showing details of geology in vicinity of Franklin and Courtland, Southampton County. Qps, Pleistocene terrace sand; Tm, Miocene marl; Teg, Eocene glauconite sand; Ku, Upper Cretaceous clay and sand; Kls, Lower Cretaceous sand; Klc, Lower Cretaceous clay.

distant.) Red clay is present at Suffolk in one well (106, Table 40) but appears to be absent in wells 104 and 109.

In section B-B′ a thin red clay stratum is shown to extend almost to the Fall Zone at Disputanta. From Disputanta to Wakefield the stratum is thin and spotty, but at Ivor (2, Table 30) 50 feet of chocolate-brown clay is present. Thinner red clay is found at Windsor, but east of Windsor it thickens to 100 feet at Chuckatuck (8, Table 40) and Drivers (65, Table 40). Chocolate-brown clay is reported in wells 4, 15, and 16, in the vicinity of Claremont (section A-A′), Surry County. At Carrolton, Isle of Wight County (108, Table 35), 47 feet of brown clay overlies 26 feet of red clay.

At Sedley, in east-central Southampton County (well 25, Table 30), a succession of strata 150 feet in thickness, occurring at depths where Potomac strata might be expected (208 to 358 feet below the surface), consists of bright-yellow, pink and red deposits interbedded with more drab sediments which are fossiliferous. The succession is "abnormal" in its bright-colored constituents, in containing fossils, in its several indurated layers, and in its lack of white sands which would be expected if the sediments were of early Cretaceous age. Except for an apparent lack of glauconite and seemingly high content of shells in some beds, these strata are strikingly similar to the Eocene deposits in places north of James River.

Recently at Windsor (144b, Table 35), in central Isle of Wight County, a bed of black glauconite sand was found beneath the red clay. This indicates rather conclusively that the red clay there is either of Eocene or late Cretaceous age and further, the occurrence seems to show that the red clay may be of Eocene age because none of the few positively identified Cretaceous strata are highly glauconitic.

The highly colored succession of deposits at Sedley (section C-C′) referred to above may however be equivalent, at least in part, to the widely distributed Upper Cretaceous (?) red clay. Brightly colored mottled strata at Walters (146, Table 35) are correlated with deposits at Sedley.

At Newsoms (263, Table 30 and section D-D′) and Claremont (4, Table 25, 16, Table 24 and section A-A′) chocolate-brown clay is underlain by indurated strata; elsewhere in Surry County (14, 21, 29 and 80, Table 24) chocolate-colored clay is absent and "rock", respectively 12, 20, 13, and 3 feet thick, underlies glauconite sand directly. Several limy and sandy "rock" strata occur at the base (?) of the brightly colored Upper Cretaceous (?) strata at Sedley.

"Rock" 3 feet in thickness is reported beneath black sand at Morgarts Beach, Isle of Wight County (Table 35). These indurated strata may be of late Cretaceous age. It may be recalled here that the Upper Cretaceous strata described by Darton are characterized by thin indurated layers but, on the other hand, recent studies show that indurated strata are by no means confined to Upper Cretaceous deposits and the possibility that these strata and overlying brightly colored beds may be of Eocene age must be borne in mind pending further information.

The 34-foot stratum of fossiliferous blue clay containing indurated beds which occurs above the succession of bright-colored clays at Sedley is tentatively assigned to the Upper Cretaceous (?) rather than to the Eocene because of the apparent lack of glauconite in it. A like stratum of similar thickness occurs above a variegated clay at Walters, Isle of Wight County, and is also assigned to the Upper Cretaceous (?).

The 184 feet of deposits at Sedley (25, Table 30), described above, is the thickest succession of possible Upper Cretaceous strata thus far mentioned. The base of this series of strata was placed at 358 feet entirely on the basis of lithology, but the underlying 51 feet of green and brown clays assigned to the Potomac group (Lower Cretaceous) are scarcely more similar to Potomac deposits than to those of late Cretaceous age. Three miles south of Franklin (238, Table 30, Section A-A′) 80 feet of black clay and 90 feet of red clay and white clay underlies Upper Cretaceous (?) chocolate-brown clay. At Newsoms (263, Table 30) 151 feet of greenish and yellow clay (cf. Sedley) likewise underlies chocolate-brown clay. The age of these strata is also in doubt, and Upper Cretaceous deposits may form greater thicknesses in these areas than indicated in the logs given in this report.

PALEONTOLOGIC EVIDENCE

Generally neither samples of well cuttings nor fossils occurring in formations encountered in previously existing wells in an area are available for inspection or study when an investigation is made. Hence, it is particularly fortunate that, while a study of southeastern Virginia was being made, several very deep wells were drilled and reasonably complete suites of samples were obtained.

Upper Cretaceous macrofossils, including a species of *Exogyra,* identical with the *Exogyra* found by Darton[49] in the Norfolk City Waterworks well at 715 to 775 feet, were present in well cuttings from

Franklin (161, Isle of Wight County), Lake Prince (80, Nansemond County), and Drivers (37, Nansemond County). These were determined by Horace G. Richards[85] from samples submitted by the writer. Study of foraminifera by A. J. Cushman confirmed the presence of Upper Cretaceous deposits at Lake Prince and Drivers, although not at Franklin, and demonstrated another occurrence of these strata at Rieds Ferry, 3 miles east-southeast of Lake Prince. Particulars of their occurrence are as follows:

At Franklin, the Upper Cretaceous fossils, species of *Exogyra* and *Gryphaea,* were found in a sample taken at 265 feet from well 161, Isle of Wight County. According to available data (Pl. 33) white sand occurs at this depth and it is believed, therefore, that the specimens were carried down in drilling by the rotary method from the dark chocolate-brown clay immediately above, between 200 and 255 feet. The chocolate-brown clay is correlated with the widespread bright-red clay discussed previously (Fig. 5). The deep well drilled for the town of Franklin in 1944 (207b, Southampton County) was sampled by the writer with particular care to a depth of 300 feet. Neither macrofossils nor microfossils of late Cretaceous age were present in material submitted for identification to Horace G. Richards and J. A. Cushman.

At Lake Prince *Exogyra* was found with Miocene and Eocene shells brought up between 460 and 920 feet. This unquestionably was washed down from above. Cushman subsequently found Upper Cretaceous microfossils, *Haplophragmoides* and *Epistomina,* from a sample taken at 375 feet, and these and *Pseudouvigerina* in specimens occurring at 389 feet. Accordingly, sandy gray clay strata from 372 to 427 feet below the surface (Pl. 34) are assigned to the Upper Cretaceous.

At Drivers, Nansemond County, about 7 miles northeast of Lake Prince, *Exogyra* was found in strata between 373 and 489 feet (37, Table 40). An excellent fauna of foraminifera was found and, according to J. A. Cushman, the sample representing strata from 373 to 452 contains Upper Cretaceous *Gümbelina;* the sample from 480-484 contains *Gümbelitria, Pseudouvigerina* and other Cretaceous forms, and the sample from 484-489 contains Upper Cretaceous *Globotruncana.*

Samples from a depth of 400 to 440 feet from a well at Rieds Ferry were found to contain the following Upper Cretaceous foraminifera: *Gümbelina* at 400, 405, 415 and 440 feet, *Epistomina* at 400, 415 and 440 feet, *Pleurostomella* at 400 feet, and *Haplophragmoides* at 405 feet. The strata in which these forms occur are sandy glauconitic marls.

Neither macrofossils nor microfossils collected from the Bacons Castle test wells were of comparable value in establishing the presence or

absence of Upper Cretaceous deposits there. On the basis of lithologic similarities to the Lake Prince section, gray clay occurring between 325 and 409 feet in well 42a, Surry County (Pl. 23), and gray clay and an underlying thin stratum of marly glauconite sand occurring between 333 and 388 feet in well 42b, Surry County (Pl. 26), are tentatively assigned to the Upper Cretaceous.

According to L. W. Stephenson, the *Exogyra* in the Upper Cretaceous material of Virginia is similar to one found in the base of the Eagle Ford and underlying Lewisville beds in Texas, but since the similarity may be superficial it is undesirable to attempt at this time a definite correlation of the Virginia deposits with those of Texas.

SUMMARY OF DISTRIBUTION

A bright-red clay of a maximum thickness of 120 feet that occurs immediately below Eocene glauconite sands is correlated with a chocolate-brown clayey stratum at Franklin of almost certain late Cretaceous age. Although the bright-red clay is erratic in distribution, it is widely present in southeastern Virginia and occurs within 10 miles of the Fall Zone west of Branchville in Southampton County.

Gray clays occurring at the same stratigraphic level in Nansemond County have been found to be of late Cretaceous age. These clays may extend westward to central Southampton and eastern Surry County. Since the drab clays are similar lithologically to clays of early Cretaceous age, they can be positively identified only where fossiliferous, and hence are probably much more widely distributed than seems apparent at present.

In a few areas, as at Sedley and Newsoms, it is possible that the Upper Cretaceous (?) strata may be thicker and extend to greater depths than indicated by the logs given in this report. The maximum thicknesses may yet prove to be greater than 300 feet but at the time of writing it would appear that the maximum thickness is about 200 feet.

Equivalence with the Matawan formation seems indicated on the basis of lithology, but the evidence of macrofossils seems to point to an equivalence with older Upper Cretaceous formations.

WATER-BEARING PROPERTIES

At Newsoms, South Quay (section A-A′, Pl. 1), Franklin (section D-D′), Burdette (section C-C′), Ivor, and Windsor (section

B-B′) from 5 to 15 feet of water-bearing sand lies between the basal Upper Cretaceous (?) deposit of brightly colored clay and the overlying Eocene deposits of glauconite sand. This white or gray quartz sand is considered to be of late Cretaceous age because it is lenticular and, in that respect, is somewhat more similar to Upper Cretaceous than to Eocene deposits.

In Franklin a number of domestic wells have been sunk to this stratum ("first artesian sand"), but elsewhere only a few wells are developed in it. This stratum is relatively fine in texture and does not yield abundant water.

A "red gravel" encountered at Cypress, Nansemond County, may be of late Cretaceous age. This seems to be a good water-bearing formation. A number of small-diameter flowing wells in northern Nansemond County that are less than 500 feet deep may obtain water from Upper Cretaceous deposits.

In many places prolific water-bearing sands occur directly beneath the bright-colored or gray clay of late Cretaceous age in Nansemond County below a depth of 500 feet. It is not known whether all occurrences of these sands should be assigned to the Lower Cretaceous, but until further data are available these sands below the Upper Cretaceous clays are considered to belong to the Potomac group.

Too little is known of the distribution, both vertical and horizontal, of Upper Cretaceous strata to characterize the water-bearing qualities of the group as a whole.

PAMUNKEY GROUP

LITHOLOGIC CHARACTER

Clark and Miller[30] have described deposits of the Pamunkey group exposed along the Fall Zone as follows:

"The Eocene deposits overlie the Cretaceous formations unconformably and consist largely of greensand marls . . . . In certain places . . . the strata become highly argillaceous, the glauconitic elements largely or entirely disappearing. Infrequently coarse sands and even gravels are found, the latter chiefly toward the base of the deposits and near the ancient shore line. Very commonly, the shells of organisms are so numerous as to form the chief constituent of certain beds, which occasionally become cemented by calcium carbonate to form impure limestones."

This description is generally applicable in the area east of the Fall Zone. Almost everywhere south of James River the Eocene may be designated as glauconitic and deposits made up predominantly of glauconite are reported as "black sand" by the drillers. "Black sand," applied to glauconite sand, quartz-glauconite sand, or to marl containing a high proportion of glauconite, is reported from almost every locality where wells have reached Cretaceous strata. Cursory examination of a number of specimens shows that glauconite grains range in size from medium to extremely fine and range from light-green to dark-green in color. Small grains are irregularly round, but most grains are nodular. Quartz grains occur with glauconite, but south of James River and west of Norfolk the quartz content of Eocene deposits of glauconite sand is generally subordinate. Pyrite has been observed replacing glauconite, and nodular pseudomorphs of pyrite after glauconite have been found.

Fossil shells, mostly mollusks, occur but are generally not particularly abundant in the glauconitic formations. These frequently occur filled with hard masses of white calcite and glauconite grains. Round black phosphate pebbles commonly occur with the glauconite, and phosphatization of a pelecypod shell was noted in a sample from Franklin.

Clark and Miller[31] note that "the great amount of glauconite in the Eocene deposits and the homogeneity of the deposits as a whole, at once separate them from the extremely variable and highly colored sands and clays of the Potomac formations below, and from the blue clays, light-colored sands, and diatomaceous earth beds of the overlying Miocene."

This statement is only partly true; in many places the Eocene deposits of glauconitic sand are found to be sharply distinguished from the underlying Lower Cretaceous and overlying Miocene formations, but elsewhere the absence of "black sand" in drillers' logs may not be indicative of the absence of Eocene formations. It has been pointed out that in some places glauconitic sands of late Cretaceous age underlie the Eocene glauconitic strata, and where this occurs distinction of the boundary between the two formations may not be determinable from drillers' logs.

Recently much data on the Eocene formations north of James River, where these deposits are much thicker, have become available. Logs of strata penetrated in wells at Newport News below a depth of 400 feet (the Miocene-Eocene contact) are given here to show the range in character of these strata.

Partial log of well at Levinson Meat Packing Company, Newport News, Virginia
(Log by Mitchells Pump and Well Co.)
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Undifferentiated (Eocene):		
Blue clay	4	409
Greenish rock	6	415
Blue clay	15	430
Black sand and blue clay	10	440
Blue clay with less black sand	25	465
Black sand and blue clay	10	475
Blue clay with very little black sand	20	495
Blue clay with black sand	85	580
Blue clay	20	600
Red clay	40	640
Blue clay	5	645
Sheets of rock and black sand	15	660
Blue clay and a little black sand	20	680
Red clay	20	700
Brown clay and black sand	10	710
Black and white sand	5	715
Red mud	5	720
Blue mud and black sand	10	730
Yellow and red clay mixture	30	760
Gray clay	37	797
Rock	3	800
Gray clay with mica	20	820
Gray clay	5	825
Green sand	2	827
Yellow clay	8	835
Red clay	11	846
Mixed gray clay and sand	24	870
Red and blue clay	10	880
Fine sand and a little clay	20	900

Partial log of well at gas works, Newport News, Virginia
(Log by D. J. Cederstrom)
Altitude, 12 feet

	Thickness (feet)	Depth (feet)
Undifferentiated (Eocene):		
Medium to fine glauconite-quartz sand, water	22	425
Glauconitic gray clay	145	570
Slightly glauconitic gray clay, drills rather slowly	34	604
Sandy gray clay grading down to hard packed glauconite sand	40	644
Alternating streaks of glauconite sand and quartz sand and soft mottled (pink, brown, green) clay	31	675
Glauconite-quartz sand containing about 35% mottled clay	10	685
Mottled clay containing about 35% glauconite-quartz sand	21	706
Mottled clay with streaks of more sandy clay	31	737
Mottled clay, drills extremely slowly	23	760
Sandy mottled clay	26	786
Gray slightly glauconitic medium quartz sand, water	18	804
Slightly clayey sand	4	808
Medium quartz sand containing very little clay, water	27	835
Sandy clay	2	837
Sand, water	2	839
Slightly sandy green clay	14	853
Clay, drills very slowly	5	858
Gray slightly glauconitic medium sand, water	14	872
Sandy clay	39	911
Loose sand containing thin streaks of clay; good water-bearing formation	18	929
Clayey slightly glauconitic quartz sand	10	939
Clay	9	948
Slightly glauconitic medium quartz sand; water (?)	3	951
Mottled (pink, brown, green) clay	4	955
Medium sand, water	4	959
Slightly glauconitic clayey sand	9	968
Medium sand containing a trace of glauconite and very little clay; water	21	989
Clayey sand	9	998
Loose sand with thin clay streaks, water	12	1010
Hard clay, drills very slowly	3	1013
Gray medium quartz sand, trace of glauconite; water	22	1035
Slightly clayey sand	10	1045
Sand with trace of glauconite; coarse at 1,082 feet; water	37	1082

Many differences in the logs may be more apparent than real; a log of a hydraulic-rotary drilled well is generally less detailed than a log taken when drilling is done by the slower cable-tool method. Colors of strata penetrated are generally masked somewhat in a rotary operation; in logging a cable-tool well colors may be overemphasized. Small amounts of glauconite in sediments may be evident only in thoroughly washed samples or under the microscope and not reported in drillers' logs.

The highly colored clays noted in these logs suggest that some of the red, brown, and variegated clays south of James River now tentatively assigned to the Upper Cretaceous (?) may be of Eocene age. However, when the general absence of glauconitic strata below those clays is considered and when it is recalled that the total thickness of the Eocene formations at the Norfolk Waterworks, Lake Prince and Drivers, has been proved to be less than 100 feet, it would seem that, for the present at least, the evidence favors placement of those strata in the Upper Cretaceous.

Although the data on the Eocene deposits north of James River may not apply to the area south of the river, their wide range in character demonstrates the advisability of keeping in mind the possibility that thick highly colored nonglauconitic beds of Eocene age may have been deposited in relatively restricted channels or troughs in the southern part of the Virginia Coastal Plain.

South of James River thin indurated strata are not uncommon in the glauconite beds and they have been reported at Ivor and Joyners Church in Southampton County and at Smithfield in Isle of Wight County. At Suffolk (104, Table 40) 40 feet of "black rotten rock" is probably indurated glauconitic marl of Eocene age. At the municipal waterworks (207, Table 30) in Franklin "rock" strata 2 feet, 3 feet and ½ foot thick were reported, and at the Camp Manufacturing Co., Franklin, Isle of Wight County (156, Table 35), rock strata 8, 14, and 10 feet thick were penetrated. These beds consist largely of glauconite grains cemented by calcite and appear to have resulted from deposition of lime in permeable glauconitic strata by circulating ground water.

At Joyners Church, 3 miles northwest of Franklin (196, Table 30), 40 feet of blue clay is present below the lowest glauconite stratum; these strata may possibly be of late Cretaceous rather than Eocene age.

At Courtland a thin black clay stratum occurs where the "black sand" might be expected. The age of this stratum is problematical, but it is designated as Eocene in section D-D′, Plate 1.

At Burdette (11a, Table 24) 84 feet of glauconitic strata resemble those of Eocene age. When logs of wells at Walters and Sedley are compared it is apparent that the Eocene at Burdette in part fills a local channel, that the lower portion of the glauconitic strata at Burdette is of late Cretaceous age, or that the Eocene at Walters and Sedley is thicker than given in the logs.

In summary, sediments of the Pamunkey group consist of various combinations of beds of glauconite, glauconite-quartz sands, glauconitic blue marl, indurated limestone, and perhaps also subordinate gray and blue marl or clay containing little or no glauconite. In the western portion of the area the Eocene formations are relatively thin and they are generally reported as "black sand" with or without indurated layers.

PALEONTOLOGIC CHARACTER

Foraminifera of early Eocene age were found at Monogram Farm and Lake Prince, Nansemond County, Bacons Castle (both wells), Surry County, and at Franklin. These are probably the equivalent of the foraminifera of the Aquia formation, according to J. A. Cushman, but the fauna in some ways is more like the Wilcox (Lower Eocene) of Alabama than like the Aquia[45]. Some of the forms also suggest rather strongly the Naheola horizon (Upper Midway, Paleocene). (See log of well 207b, Table 30.)

In this connection special significance may be attached to Richards'[85] notation that a fossil collected by the writer from glauconitic strata in the Franklin Airport well (163, Isle of Wight County) is suggestive that the deposits are of possible Midway age. Since, however, data at hand on the deposits of possible Midway age are meager it is thought best that this problem be deferred until more detailed information becomes available. Hence these lower Eocene deposits are assigned to the Aquia formation.

Fossil evidence throws doubt on the presence of deposits of the Nanjemoy formation in the central and eastern part of the area. The basal pink to white clay of the Nanjemoy formation crops out two miles below Hopewell[35], and glauconitic sands of this formation are

reported elsewhere in that vicinity[69]; hence the formation can not be assumed to be generally absent.

Cushman has recently found that certain Eocene strata contain a rich foraminiferal fauna which is "very different" from that of the Aquia[45], and that it may be Claiborne (Upper Nanjemoy) or even Jackson Eocene. A special study of these foraminifera is now being made.

South of James River fauna of possible Jackson age is found at Monogram Farm, Nansemond County (40). Here very few samples were taken, and characterization of the strata in question can not be made with reasonable certainty. At Yorktown sediments containing the same faunal group are nondescript gray clays. These clays, however, when washed thoroughly in a 150-mesh screen, yield a characteristic residue of glauconite and subordinate quartz sand containing from a trace to 10 per cent of pyrite. A few fish bones and shell fragments are present throughout. The thickness is about 80 feet at Yorktown; there-these strata contrast sharply with older Eocene strata lying immediately below that contain only a little glauconite and are not pyritic.

At Monogram Farm the strata containing Upper (?) Eocene foraminifera, from 315 to 354 feet, are unlike corresponding strata at Yorktown in containing phosphatic pebbles and a rather high amount of quartz. The pebbles and quartz undoubtedly have come down from above. The almost total lack of pyrite is difficult to explain, but the presence of abundant pyrite and Upper (?) Eocene foraminifera in the sample from 354 to 373 feet, which contains older Eocene foraminifera, may be the result of contamination of the older Eocene stratum with Jackson (?) pyritic material from above.

Samples collected by Darton from the Norfolk City Waterworks well were washed and examined by the writer. Residues of samples from 645, 655, 665, 675 and 685 feet were highly glauconitic; the sample from 685 feet was also pyritic. Foraminifera of Jackson (?) age were present at 675 and 685 feet, according to Cushman. The sample from 705 feet was less glauconitic, and older Eocene foraminifera were found at 725 feet. It may be recalled that Darton noted that Upper Cretaceous *Exogyra* appeared at 715 feet or "possibly 700 feet". It would seem that the figure of 715 feet for the base of the Eocene should be taken, and the material from 640 to 685 should be assigned to the Jackson (?) group. Older Eocene foraminifera found at 725 feet were almost certainly washed down from strata between 685 and 715 feet.

It may be recalled that the Castle Hayne marl of North Carolina is of Jackson age.[44] Strata of Jackson age have been recently reported[86] from New Jersey.

Macrofossils found along and near the Fall Zone in southeastern Virginia have been listed in Bulletins 5[35] and 57[69] of the Virginia Geological Survey, and a list of foraminifera from outcrops of the Aquia formation in northeastern Virginia has been recently published.[45]

Eocene macrofossils collected by the writer during this investigation have been identified by Horace G. Richards and are listed in Tables 5, 7, and 9.

THICKNESS AND DISTRIBUTION

Although the Pamunkey strata tend to pinch out towards the Fall Zone, and are overlapped by the Miocene marls, they are well exhibited in places along Appomattox River east of Petersburg, as noted above. A small exposure of these strata is also mapped immediately east of Stony Creek.

As shown in the cross section (Pl. 1), the glauconite beds are generally less than 75 feet thick. They are thin and lenticular in the western and southern parts of the area, and in some places they are entirely absent. It is possible that the Eocene deposits in these areas were originally somewhat thinner than in the northern and eastern areas, but it is believed that south of James River the greatest differences in thicknesses may be ascribed to post-Eocene erosion rather than to shoreward or southward thinning. The marked increase in thickness of strata at Newport News (section A-A′, Plate 1) should be noted. A thickening of these deposits north of James River seems to be general.[22]

The average dip of the strata as determined from the well logs is about 10 feet to the mile although locally dips may be steeper or flatter. It is believed that the dip determined on the base of the Eocene formations in the counties south of James River is probably more nearly the true dip of the immediately underlying Potomac (Lower Cretaceous) sediments than the 30 feet to the mile assigned to those strata by Clark and Miller.[33] However, as has been pointed out, accurate determinations of the dip of the Potomac strata on the basis of the data at hand is difficult because of the lenticular character of those beds.

WATER-BEARING PROPERTIES

Although it is true that in former years the Pamunkey group was an important source of deep water,[95] it seems probable from a study of the well records and logs presented in Sanford's report that some of the wells believed by him to obtain water from Pamunkey strata actually drew water from Cretaceous sediments. Although many wells derive water from Eocene strata in the area north of James River, it is evident that only a few of the wells discussed in this report obtain water from Eocene greensand.

Drillers state that the "black sand" yields a "green water" which has an offensive odor and appearance. Furthermore, the sands are unstable, and tend to "run" and clog the well. Hence, it is the practice of most drillers to go through the glauconite sand and develop water in quartz sands of the underlying Cretaceous strata.

CHESAPEAKE GROUP

LITHOLOGIC CHARACTER

The Chesapeake group of marine deposits of Miocene age overlap the older formations in the Virginia Coastal Plain, and may rest either upon sediments of the Pamunkey or Potomac groups or upon the basement rocks. As a result of this overlap, the Miocene almost everywhere covers the older Eocene and Cretaceous sediments. Due to the wide extent of Pleistocene formations, however, Miocene sediments are generally seen only on the sides of river valleys, or in road cuts.

The Chesapeake group has been subdivided[37, 68, 72] into the Calvert, Choptank, St. Marys and Yorktown formations. The Choptank formation is recognized only in the Northern Neck section of Virginia (Westmoreland and Richmond counties). Mansfield, however, notes that it may possibly be present at Old Point Comfort. The Calvert formation is overlapped by the St. Marys, and both the Calvert and St. Marys (and older strata) are overlapped by the Yorktown formation which extends to the Fall Zone.

The Miocene formations have been described[36] as consisting largely of fine-grained light-colored sand. This may be true along the Fall Zone, but the writer is impressed by the invariable "blue mud", "marl", or "blue clay" reported by well drillers above the

"black sand" of the Pamunkey group throughout the eight counties south of James and Appomattox rivers. It is believed, therefore, that the Miocene formations are more correctly characterized as clayey formations which in most places include considerable sandy and marly material. Such strata may be expected to become more sandy towards an ancient shore line.

Along the Fall Zone the lower part of the Calvert formation is said to be more clayey than the St. Marys and the Yorktown formations, which contain more sand and shell marl. Although conspicuously lacking in detail, most drillers' logs bear out this description in a general way and show that the upper portion of the Miocene deposits is composed of shell marl whereas the lower portion is generally made up of gray or blue clay in which shells are less common. Sands are infrequently reported at the base of the Miocene.

In drilling at Bacons Castle (Pls. 23 and 26) three lithologic units were recognized: the upper sandy shell marl in which drilling progressed rapidly; a middle zone of very tough marl through which drilling progressed very slowly; and a lower zone of sandy shell marl in which drilling was again rapid. A similar zoning of the Miocene strata is characteristic in the Williamsburg-Lee Hall area. The three zones were fairly evident at Lake Prince (Pl. 34), the tough marl being at 194 to 218 feet below the surface. At Franklin (Pl. 33) the lowest sandy zone seems to be lacking.

Most of the strata penetrated are blue or gray and marker beds seem to be generally lacking. At Lake Prince, however, an olive-green sandy marl occurs which appears to have a correlative at Camp Peary, near Williamsburg.

Generally, however, formational boundaries within the Chesapeake group can not be drawn on the basis of available drillers' logs, and the group is largely considered as a unit.

PALEONTOLOGIC CHARACTER

A number of Miocene fossils have been collected from well cuttings and identified by Horace G. Richards. They are listed in Tables 5 to 9 below. It may be noted that in well 42a, Surry County, at Bacons Castle, almost all the material collected came from the strata above 180 feet. In 42b all the material was collected

above 200 feet. Hence it may be expected that the material is largely from the Yorktown formation. The shells collected at Lake Prince were more evenly distributed, but from comparison of the faunal lists it is not apparent that zones lower than those represented in the Bacons Castle wells are represented here. The samples collected at Surry Court House are Miocene in age, but since these were taken from the mud pit their exact position in the geologic section is not known.

The lower boundary of the Miocene formations was confirmed at Franklin, Bacons Castle, Lake Prince, Drivers and Norfolk from foraminifera submitted to J. A. Cushman but special study of the Miocene foraminifera was not made.

Macrofossils found in Miocene sediments cropping out along the Fall Zone and along major streams in southeastern Virginia are listed in Bulletin 5 of the Virginia Geological Survey,[37] and recently the pelecypods found in outcrops have been described and figured by Gardner.[67]

WATER-BEARING PROPERTIES

The Yorktown formation[88] which is exposed at or is near the surface throughout most of Tidewater Virginia "consists of coquina, sand, clay, sandy clay and marl in variable degrees of consolidation. The thickness of the entire formation is not more than 150 feet. The main differences between the Yorktown and the older Miocene formations to the west are the occurrence of coquina, the subordinate amount of sand, and the presence of certain fossil faunas."

At the Lone Star Cement Quarry at Chuckatuck (Pl. 34A) the normal downward succession of quarried material, according to Mr. E. N. Woodward, Superintendent, consists of overburden, red coquina, cemented shell rock, blue shell marl and blue clay (Pl. 31B). The coquina and hard shell rock ("chara") appear to have been subjected to the action of percolating ground water; the coquina appears to represent a zone from which the clay and sandy material have been removed; and the thin layer of hard cemented shell rock below the coquina may represent a zone of secondary deposition of calcium carbonate at the ground-water level. Inasmuch as this material is found below the present water level (at depths of about 12 to 25 feet below the surface), the

leaching action must have taken place at a time of a lower ground-water level.

Material similar to the open-textured "marl" (coquina) quarried at Chuckatuck furnishes water to wells in the Portsmouth area, Norfolk County, and probably elsewhere in Norfolk and Princess Anne counties. Apparently a mixture of fine sand and coarse shell fragments (Pl. 40) is commonly a source of ground water, and in many places in these two counties fine sand and infrequently coarse sand or gravel furnish water to wells. In these counties the lower limit of water-bearing sand and shell strata (presumably all Yorktown formation) is from 150 to 200 feet below the surface. Deeper drilling penetrates only unproductive blue clay beds.

Coquina, uncemented shell beds (Pl. 15) and sand and shell strata furnish water to a number of relatively shallow wells and springs along James River in Surry, Isle of Wight, and Nansemond counties. The material is variable, and although excellent wells of small yield have been constructed in places, other attempts to secure water near by have failed.

Springs issuing from the banks of ravines of James River are utilized in some places. Small impounding basins collect the water, a part of which is lifted by hydraulic ram.

Along James River in Surry County and in central Isle of Wight County a gray or blue water-bearing sand occurs at the base of the Miocene (Calvert? formation). However, wells are generally sunk through this stratum to the better water-bearing beds of the Potomac group, which lie at a relatively shallow depth below.

COLUMBIA GROUP

LITHOLOGIC CHARACTER

The Quaternary system in Virginia is represented chiefly by deposits of sand and clay that mantle the older formations to a height of approximately 270 feet above sea level where they have not been removed by erosion. These deposits are collectively called the Columbia group. According to Wentworth[140] the Pleistocene deposits below 100 feet are chiefly marine, whereas those above 100 feet are chiefly alluvial, having been deposited as deltas

and floodplains of rivers. Cooke [42] thinks they were formed in the ocean and estuaries when the sea stood at various heights above its present level. He has recognized marine shore lines at altitudes of approximately 270, 215, 170, 100, 70, 42, and 25 feet and suspects that there are others that have not yet been detected.

According to Cooke's classification, which is that now used by the United States Geological Survey, the deposits that accumulated during these seven stages of higher sea level are theoretically divisible into four parts. These four divisions of the Columbia group are separated from one another and from the Recent and pre-Pleistocene deposits by disconformities 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.[43]

The oldest division is the Brandywine formation, corresponding to a sea level of 270 feet. The next younger includes the Coharie formation (shore line 215 feet above present sea level) and the Sunderland formation (shore line 170 feet). The third division includes the Wicomico (shore line 100 feet), the Penholoway (shore line 70 feet) and the Talbot (shore line 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 shore line stood 25 feet above sea level. The Sunderland, Wicomico and Pamlico are the most widely distributed formations of the Columbia group in southern Virginia. The Brandywine and Coharie form narrow bands along the western border; most of the Penholoway and Talbot occupy estuarine reentrants within the older terraces.

WATER-BEARING PROPERTIES

These terrace deposits yield water to thousands of shallow dug wells. A few are not to be relied upon in very dry seasons. Water is supplied by some of these wells for sawmill boilers, for which purpose it is generally very suitable on account of its low mineral content. A careful study of such installations shows that

shallow dug or driven wells under favorable conditions supply a maximum of about 2,000 gallons in an 8-hour day, but most of these wells supply less.

The lowest of the terrace deposits, the Pamlico formation, covers the larger portion of Princess Anne and Norfolk counties and parts of Nansemond and Isle of Wight counties. This formation is made up of clayey and sandy material, but it is frequently reported to contain also "blue mud" and "shell marl". It yields water which is generally somewhat harder and of a higher chloride content than water derived from the upland terrace sands. It is extensively drawn upon as a source of water for domestic use.

Fine to medium sands in the Pamlico formation also yield water to many small industrial plants in the Norfolk area. A few wells in these sands have been properly developed, cased, and screened, and in some places water supplies of as much as 40 gallons a minute are obtained. It is believed that comparable yields might be obtained from the higher terraces to the west in some places if wells in these formations were properly developed. Near Diamond Springs, gravelly strata have been quarried and from the shallow pits resulting from these operations (Pl. 37) some ground water has been pumped. According to Mr. Zimmerly of the Virginia Truck Experiment Station, 250 gallons a minute was pumped continuously with slight drawdown from one of these pits for several weeks in the drought of 1942. As far as can be learned, however, gravel seems to be rarely present in the Pamlico formation.

Figure 4 shows that many of the larger rivers traversing the terraced upland have cut down to lower elevations and are bordered by floodplains corresponding to the younger terraces. In Southampton County the upland is in large part formed by the dissected Sunderland and Wicomico terraces at altitudes ranging from 80 to 140 feet. However, flat lands from 20 to 40 feet above sea level in the vicinity of Blackwater and Nottoway rivers represent estuarine reentrants of the Talbot and Pamlico terraces.

The floodplain deposits bordering the large rivers in the western part of the area vary in composition from solid clay to moderately coarse sand. Sandy areas yield abundant supplies of water in many places, and it appears that some of these areas might yield much larger supplies than are now obtained.

RECENT DEPOSITS

LITHOLOGIC CHARACTER

Sand dunes are extensively developed along Chesapeake Bay, from Willoughby Spit to Cape Henry, and southward along the sea coast to the North Carolina line. They attain their greatest development in the area near Cape Henry known as "The Desert", a part of which is set aside as a military reservation. Seashore State Park lies within the strip of sand dunes fronting Lynnhaven Roads.

Although the Recent sands occur as a veneer along the coast in Princess Anne County, data at hand show that in places these sands extend to at least 60 feet below sea level, as at Cape Henry (Fig. 31). These sands were deposited by the cut-and-fill action of ocean currents sweeping northward and slightly westward along the coast in this area. Cape Henry is therefore a sand lens, of unknown maximum thickness and extent, resting upon the older formations. Recent sands forming Willoughby Spit probably also extend below sea level.

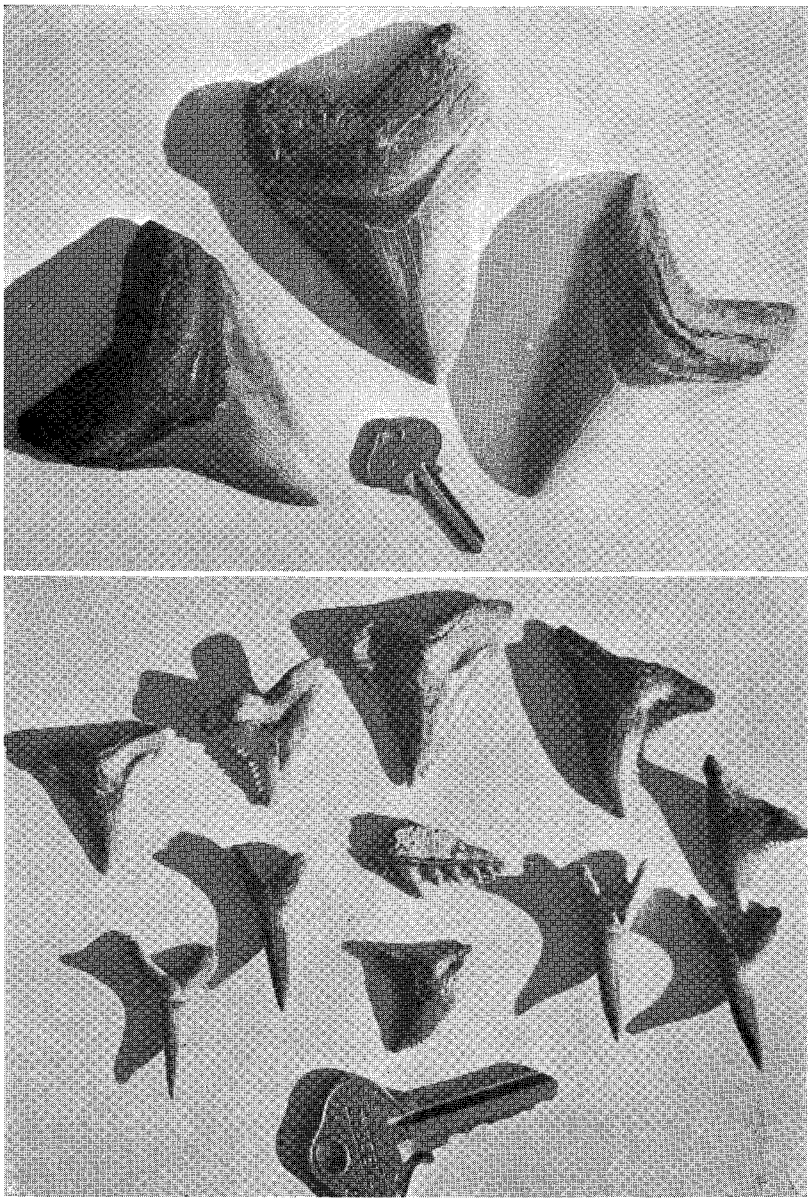
WATER-BEARING PROPERTIES

The white quartz dune sand yields abundant water, and the entire supplies for Fort Story, Dam Neck Lighthouse Station and Seashore State Park have been obtained from it. The water is generally low in chloride, but it may contain objectionable amounts of iron and be slightly colored from plant material.

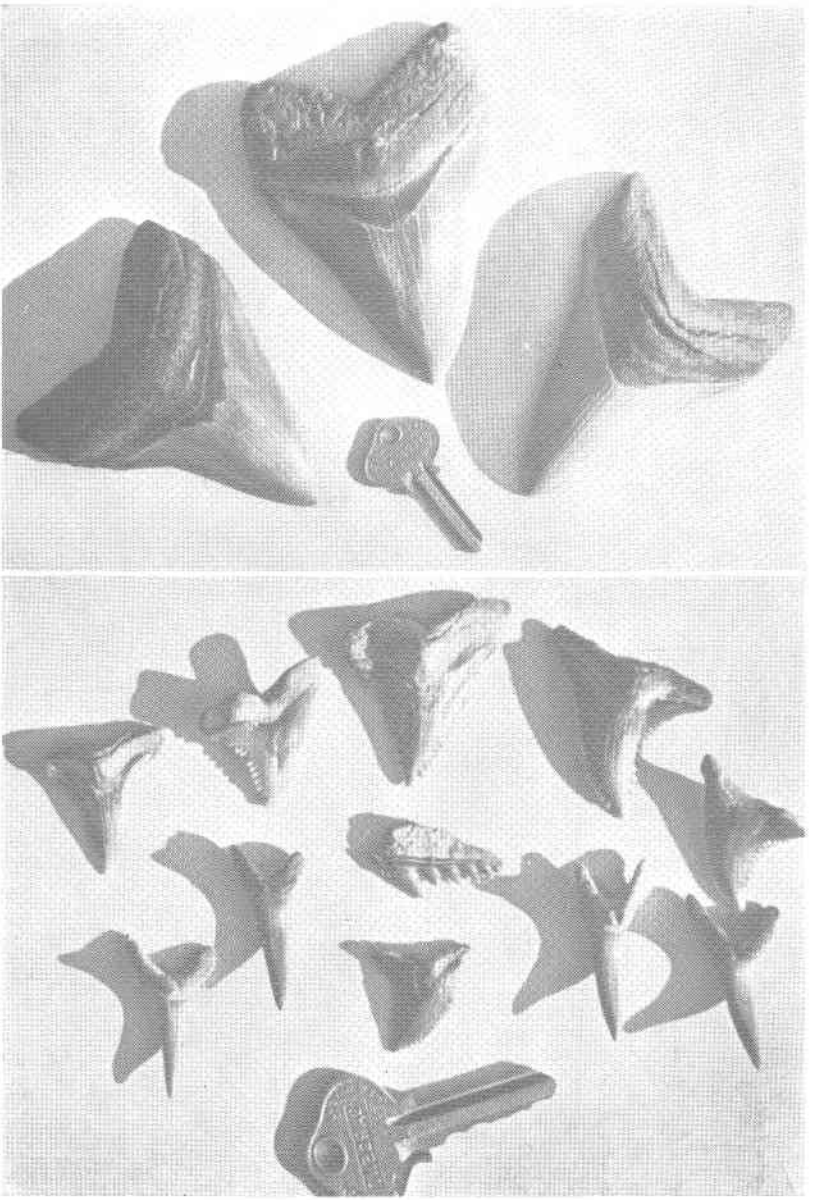
As sluggish swampy streams are characteristic of the entire area, it would appear that the region has suffered recent depression. Consequently no large sandy deposits of the present streams lie above sea or river level. Peaty deposits have been accumulating in the Dismal Swamp, along the courses of Nottoway and Blackwater rivers, and elsewhere.

MACROFOSSILS

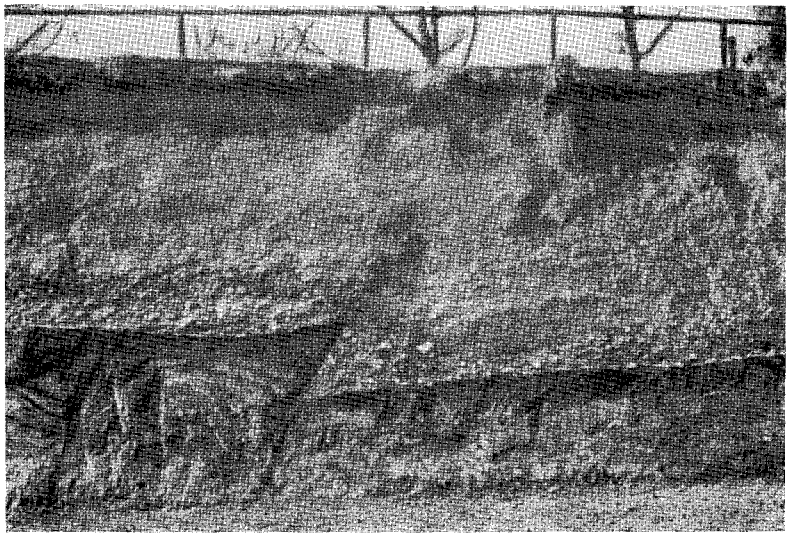
Macrofossils found in well cuttings collected by the writer at Franklin, Surry Court House, Bacons Castle and Lake Prince have been identified by Horace G. Richards and are listed in Tables 5-9, below.



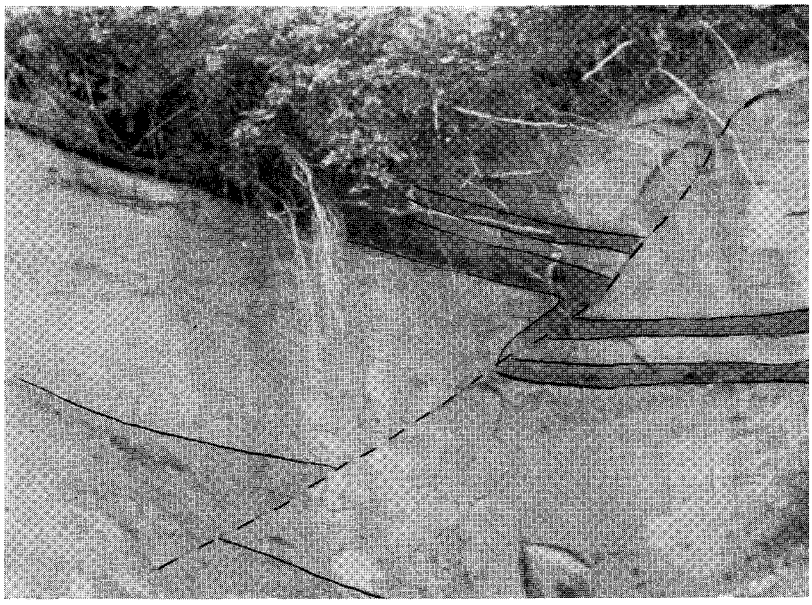
Sharks' teeth from the Yorktown formation. From collection of George C. Barclay.



Sharks' teeth from the Yorktown formation. From collection of George C. Barclay.

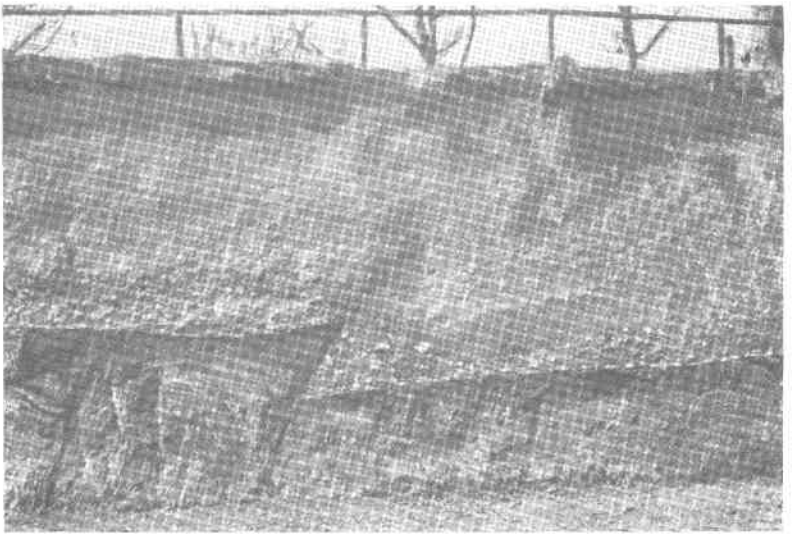


A.

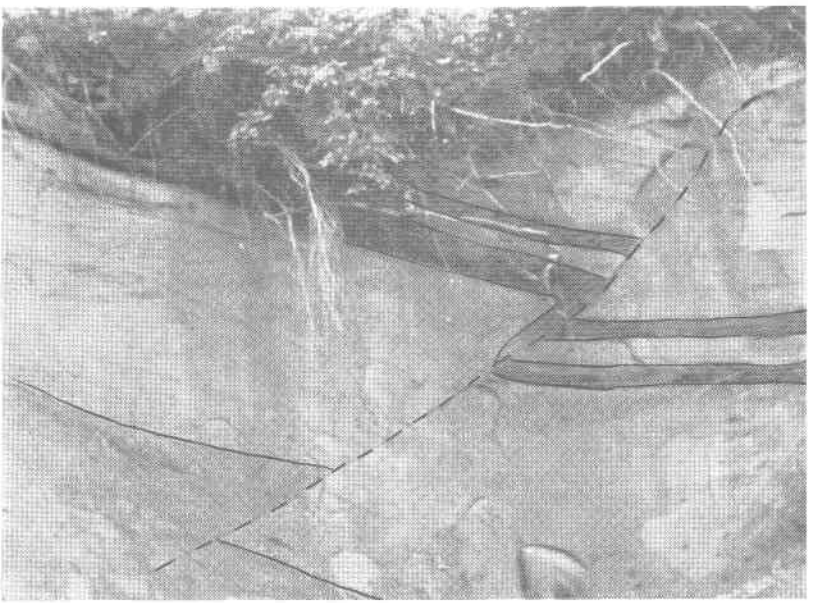


B.

A, Fault in basement rock transmitted upward into Pleistocene terrace gravels, Washington, D. C. Photograph by N. H. Darton; from U. S. Geological Survey Professional Paper 906A. B, Reverse fault in the Potomac group at Drewrys Bluff on James River.



A.



B.

A, Fault in basement rock transmitted upward into Pleistocene terrace gravels, Washington, D. C. Photograph by N. H. Darton; from U. S. Geological Survey Professional Paper 906A. B, Reverse fault in the Potomac group at Drewrys Bluff on James River.

TABLE 5.—*Fossils from wells at Franklin, Virginia*

Well No. [a]		Range (depth, in feet)
	MIOCENE	
	Pelecypoda:	
160	Venericardia granulata Say	106-110
161	Mulinia congesta (Conrad)	265 (washed down)
	EOCENE	
207b	Gryphaeostrea vomer (Morton)	75-138
160	Gryphaeostrea vomer (Morton)	105-145
161	Gryphaeostrea vomer (Morton)	145-210 (washed down?)
161	Ostrea compressirostra Say	161
161	Pecten sp. (fragment)	210 (washed down)
	PALEOCENE (?)	
	Vermes:	
164	Spirulaea meglammeri (Gardner)	100-140
	Pelecypoda:	
164	Pecten n. sp	100–140
	UPPER CRETACEOUS	
	Pelecypoda:	
161	Exogyra sp	265 (washed down)
161	Gryphaea sp	265 (washed down)

[a]See also Fig. 26, Pl. 33, wells 160 and 164, Table 35 and well 207b, Table 30. Well 207b is in Southampton County; others are in Isle of Wight County.

TABLE 6.—*Fossils from well 51, Surry County*[a], *at Surry Court House, Virginia*

MIOCENE

Pelecypoda:
- Venericardia granulata Say
- Mulinia congesta (Conrad)
- Astarte undulata Say
- Astarte exaltata Conrad
- Chama congregata Conrad
- Glycymeris subovata (Say)
- Ostrea compressirostra Say
- Pecten madisonius Say

Gastropoda:
- Crepidula fornicata (Linné)
- Petaloconchus sculpturatum Lea
- Marginella sp. cf. virginiana Conrad

[a]Specimens collected from mud pit. See also Fig. 24 and well 51, Table 25.

TABLE 7.—*Fossils from well 42a*[a], *Surry County, at Bacons Castle, Virginia*

	Range (depth, in feet)
MIOCENE	
Pelecypoda:	
Ostrea sculpturara Conrad	35
Plicatula marginata Say	35
Arca transversa Say	35
Arca improcera Conrad	35
Leda acuata Conrad	35
Astarte concentrica bella Conrad	35– 80
Cardita arata (Conrad)	35–110
Chama congregata Conrad	35-140
Astarte undulata Say	36–160
Mulinia congesta (Conrad)	35–212
Crassinella lunulata Conrad	55
Venericardia granulata Say	55–212
Plicatula gibbosa Conrad	68
Cardium sp	68
Corbula inaequalis Say	68–140
Pecten madisonius Say	80–90
Glycymeris subovata (Say)	80–168
Pecten jeffersonius Say	80–247
Phacoides crenulatus Conrad	90
Pecten eboreus Conrad	90
Astarte cf. A. coheni Conrad	90
Chama corticosa Conrad	120
Teredo fistula H. C. Lea	140
Fissurella redimiculata Say	180
Astarte cuneiformis Conrad	214
Gastropoda:	
Vermetus sculpturatus H. C. Lea	35
Columbella communis Conrad	35– 68
Crepidula fornicata (Linné)	35–100
Calliostoma ruffini H. C. Lea	35–120
Turritella variablis Conrad	55–306
Marginella limatula Conrad	68–161
Turritella plebia Say	80–100
Crepidula convexa Say	90
Lirosoma sulcosa (Conrad)	90
Cochiolepis sp	90
Vermetus graniferus (Say)	90–161
Marginella denticulata Conrad	140
Scaphopoda:	
Dentalium attenuatum Conrad	100–120
Arthropoda:	
Balanus sp	100
EOCENE	
Pelecypoda:	
Terebratula harlani Morton	374 (washed down)

[a]See also Fig. 24 and Pl. 23.

TABLE 8.—*Fossils from well 42b*[a], *Surry County, near Bacons Castle, Virginia*

	Range (depth, in feet)
MIOCENE	
Pelecypoda:	
Leda acuata Conrad	85
Crassinella sp	85
Mulinia lateralis (Say)	85
Glycymeris pectinata (Gmelin)	85–99
Pecten eboreus Conrad	99
Asaphis centenaria Conrad	99
Pecten jeffersonius Say	99
Arca incile Say	99
Astarte concentrica bella Conrad	99
Astarte exaltata Conrad	99
Chama congregata Conrad	99–115
Venericardia granulata Say	99–200
Nucula proxima Say	115
Phacoides anodonta Say	161
Astarte undulata Say	161–200
Venus sp	200
Glycymeris subovata (Say)	200
Modiolus inflatus Tuomey & Holmes	200
Mulinia congesta (Conrad)	218
Gastropoda:	
Turbonilla sp	85
Crepidula fornicata (Linné)	85
Fasciolaria parvula Lea	85
Eupleura caudata (Say)	99
Turritella variabilis Conrad	99–200
Marginella limatula (Conrad)	99
Polinices heros (Say)	99–161
Polinices duplicata Say	161
Vermetus graniferus (Say)	200
Solarium nupera Conrad	200
Marginella bella Conrad	200
Scaphopoda:	
Dentalium attenuatum Conrad	99–288

[a]See also Fig. 24 and Pl. 26.

TABLE 9.—*Fossils from well 80*[a], *Nansemond County, at Lake Prince, Virginia*

	Range (depth, in feet)
MIOCENE[b]	
Pelecypoda:	
Mulinia congesta (Conrad)	35 to 375
Corbula inaequalis Say	35
Phacoides crenulatus (Conrad)	35
Leda acuta Conrad	35
Venericardia granulata Say	35 to 340
Pecten madisonius Say	130
Ostrea compressirostra Say	130 to 285
Yoldia laevis (Say)	130
Astarte undulata Say	250 to 325
Dosinia acetabulum Conrad	250
Venus sp	285
Venericardia granulata Say	300 to 370
Gastropoda:	
Turritella variabilis Conrad	35 to 375
Scaphopoda:	
Cadulus thallus Conrad	35 to 130
Dentalium attenuatum Conrad	250 to 340
Arthropoda:	
Balanus sp	35 to 325
EOCENE	
Pelecypoda:	
Gryphaeostrea vomer (Morton)	460 to 920 (washed down)
Vermes:	
Spirulaea rotula (Morton)	340 and 370
UPPER CRETACEOUS	
Exogyra sp	460 to 920 (washed down)

[a]See also Fig. 28 and Pl. 35.
[b]Miocene forms collected below 295 feet are believed to have been washed down.

DEFORMATION OF COASTAL PLAIN SEDIMENTS

An extensive literature attests to the varied structural features of the Gulf Coastal Plain, and the many workers in that area continue to add to our knowledge of the deformational forces which have been active in that region. Less attention has been given to structural deformation in the Atlantic Coastal Plain, largely because detailed subsurface data have been lacking.

However, a few individuals have brought out the fact that structural deformation has taken place in the Atlantic Coastal Plain. Stephenson[122] has characterized the area as follows:

"In the Atlantic Coastal Plain faults are rare as far south as Georgia and the few that are known are of small throw. However, larger faults may be concealed beneath some of the younger overlapping formations. The Charleston earthquake may have been caused by a movement along an active fault in the underlying basement rocks, and if so, the faulting involved the overlying sediments. Charleston is on the north limb of an area of broad downwarping. Local folding is rare in the Atlantic Coastal Plain."

Stephenson[123] postulated a broad pre-Miocene transverse synclinal axis in Virginia, extending from the vicinity of Stony Creek and Jarratt to the southeastern corner of the state, on the basis of the Miocene overlap which extends farther inland at these localities than it does in northern Virginia or in northern North Carolina.

Mansfield[73] has confirmed the sharp upwarp, first shown by Stephenson, that exists at Wilmington, N. C., 215 miles south of Norfolk, Virginia. Bedrock is encountered at a depth of 2,318 feet at Havelock, N. C., 65 miles north of Wilmington, and at 2,450 feet at Summerville, S. C., about 170 miles southeast of Wilmington. At Wilmington bedrock is encountered at 1,109 feet. The upwarp extends in a west-northwest and east-southeast direction, and data presented point to the fact that warping took place after the deposition of Cretaceous sediments.

From a study of the distribution of Miocene formations, Mansfield[72] showed that during the deposition of the Calvert and St. Marys formations in Virginia and Maryland, the Cape Fear, N. C., area was a land mass undergoing erosion. However, since the Yorktown formation is absent north of the Rappahannock, it is evident that northern Virginia and Maryland were relatively uplifted at the time of the deposition of those strata.

McCarthy[74] studied the Coastal Plain in North Carolina by geophysical methods and found that a magnetically disturbed zone trends roughly parallel to the structural trends of the Piedmont and Appalachian districts and probably represents a folded and perhaps fractured zone.

A minor synclinal structure in the Miocene strata, exposed in the Nomini Cliffs, Westmoreland County, Virginia, and a strong reversal of dip in beds of the Yorktown formation about 2 miles east of Yorktown have been described by Stephenson and others[124].

In the course of systematic study of the water supplies of the Virginia Coastal Plain counties south of James River the writer was fortunate in obtaining many written logs as well as many data given from memory by local drillers. These data supplement the detailed data on wells logged by the writer. Practically all the available data on deep wells have been plotted on Plate 1 and show in detail the distribution and position of Cretaceous and Tertiary sediments. Correlations are difficult in some places, but, in general, enough data on southeastern Virginia are at hand to furnish a reasonably accurate and detailed picture of the subsurface geology.

The most striking geologic feature shown on Plate 1 is perhaps the thickening of the Eocene sediments from Battery Park to Old Point Comfort (section A-A′). The thickening would be even more impressive if sections were taken in a north-south direction;[22] at Lamberts Point and Norfolk City Waterworks, the Eocene formations are respectively 127 and 75 feet thick, whereas at Newport News and Old Point Comfort (Fort Monroe) they are respectively 682+ and 730 feet thick. (The thicknesses given at the localities mentioned are based on a study of washed residues of cuttings from old and recent wells together with determinations of foraminiferal content by J. A. Cushman.)

Thickening of Eocene sediments occurs north of James River at least as far westward as western James City County and possibly farther to the west. It is possible that some thickening occurs along the south bank of James River, but this is not yet evident.

It seems apparent that during Eocene time a basin was forming north of James River, which permitted a much greater thickness of sediments to accumulate there than in the area south of the river. It is thought that this basin was formed by faulting which originated in the bedrock. The southern rim of the basin extends from Hampton Roads northwestward along James River at least as far as Hog Island, Surry County. It is believed that the basin extends still farther west-

ward, but data on borings in the counties east and southeast of Richmond are few and further definition of the rim of the Eocene depositional basin can not be made at this time.

It is of particular interest to note that in North Carolina,[123] "The records seem to verify the opinion of Stephenson that the lower course of Cape Fear River approximately marks the axis of a broad structural uplift, dating from the interval marked by the unconformity between Cretaceous and Tertiary sediments and that the uplifted position has been maintained without marked subsidence until the present time. It also follows that the Great Lake well 2, near Havelock, North Carolina, is located in a downwarped area, for the Cretaceous-Eocene contact shows a relative sinking of the Cretaceous-Eocene erosion surface amounting to nearly 700 feet."

The marked similarity of the Cape Fear area to the Hampton Roads area in Virginia is obvious and suggests that faults of large throw, along which movement began in pre-Eocene time, may be a general feature of the Atlantic Coastal Plain.

A contour map drawn upon the base of the Miocene formations (Fig. 6) bears out in detail the generalization made by Stephenson that transverse structures exist. Several features are apparent. A well-defined ridge extends eastward from northern Southampton County and terminates in a structural nose near Smithfield. The ridge is flanked by marked depressions. The depression paralleling the ridge on the north is well expressed and extends westward from Ft. Eustis through northern Surry County and southern Charles City County. Another structural nose similar to the structure near Smithfield appears to be present north of Jamestown. The depression lying south of the Smithfield nose is well developed south of Smithfield and seems to extend westward to southwestern Sussex County. Details may be added and corrections made in the structural pattern as more data become available.

The Smithfield ridge and its flanking depressions are not contradictory to the syncline postulated by Stephenson, the axis of which tends in much the same direction as the above-mentioned structures, but should be considered as secondary structures upon and probably related to the broad downwarp which has affected the Coastal Plain of southern Virginia.

These east-west structures appear to be post-Eocene, and they may be correlated with the Cape Fear upwarp recognized by Stephenson.

More localized structures have been found at several places, but in most instances critical data on the surrounding area are lacking and

the relation of these local structures to the larger features can not be determined. A sharply defined syncline or partly enclosed basin is present in southwestern Southampton County, the deepest point of which is at Branchville, and a low dome of small extent (as shown in section E-E′, Pl. 1) is present at Boykins.

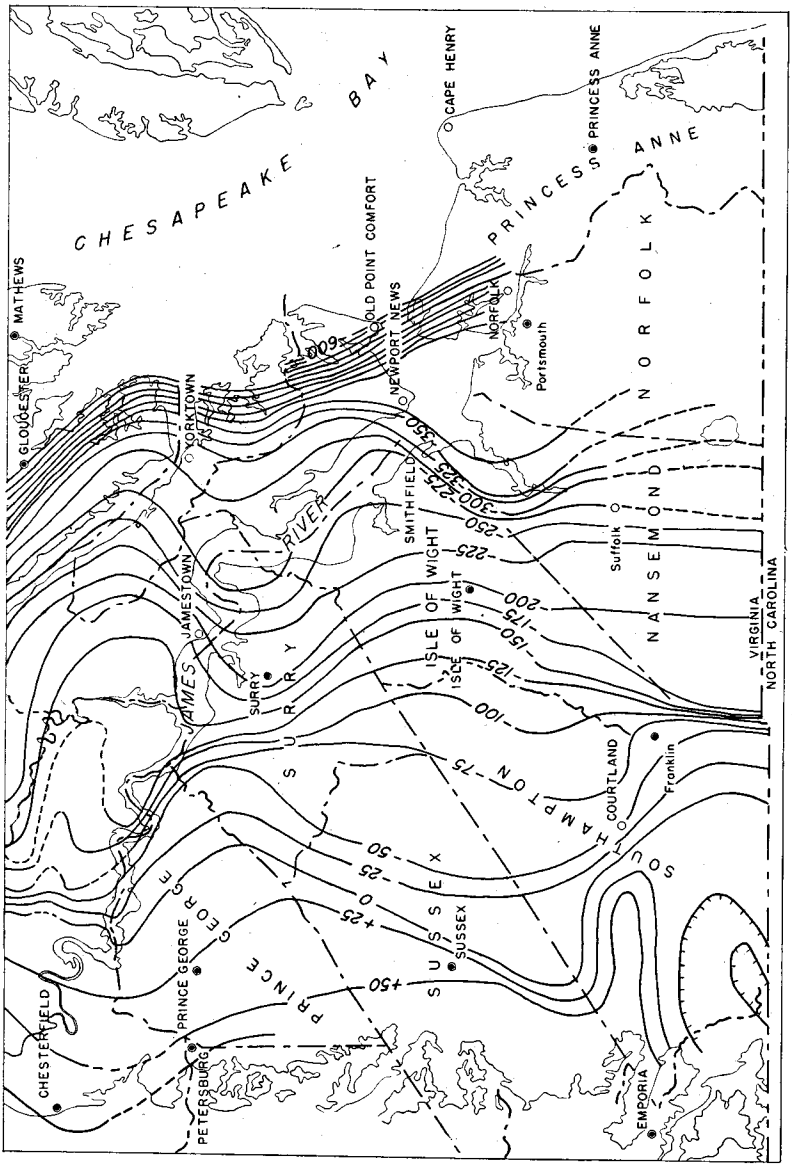
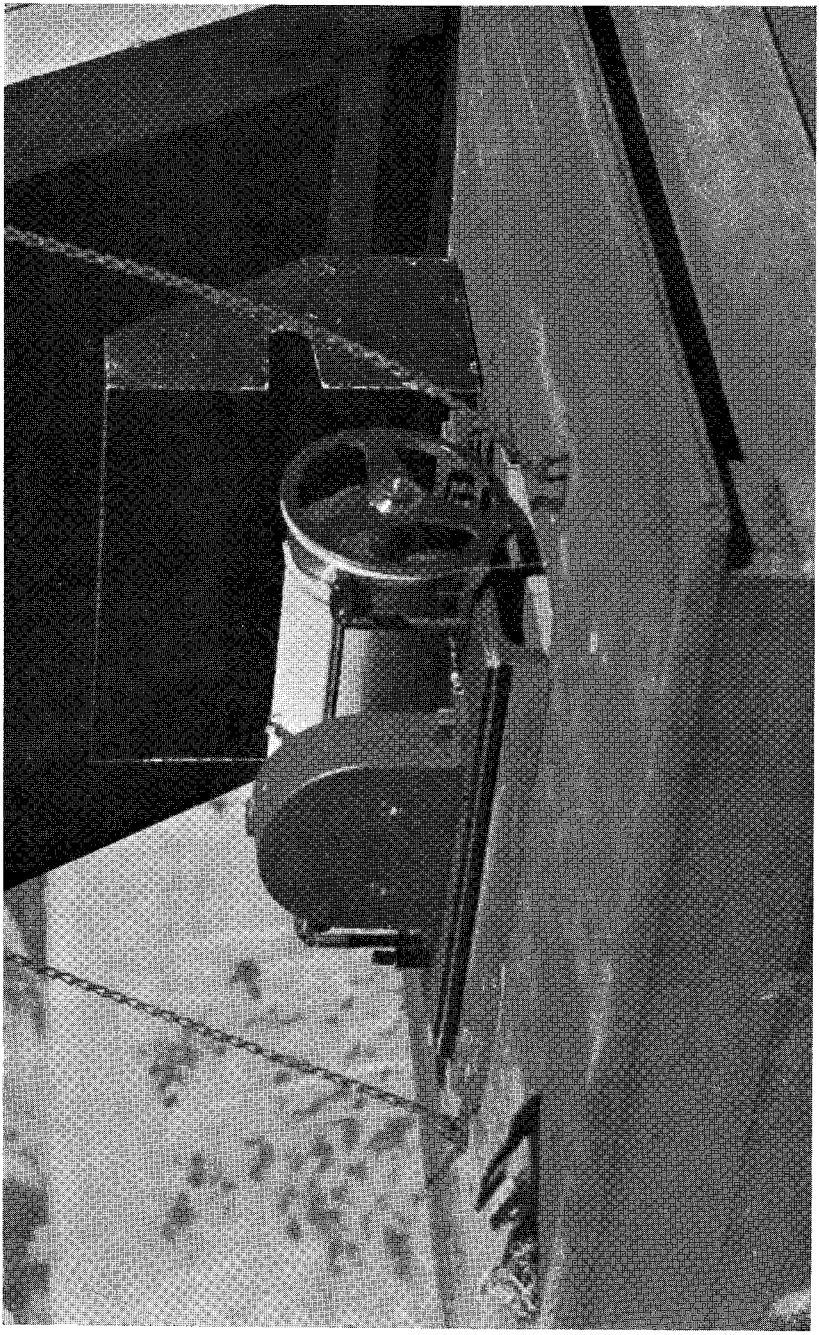


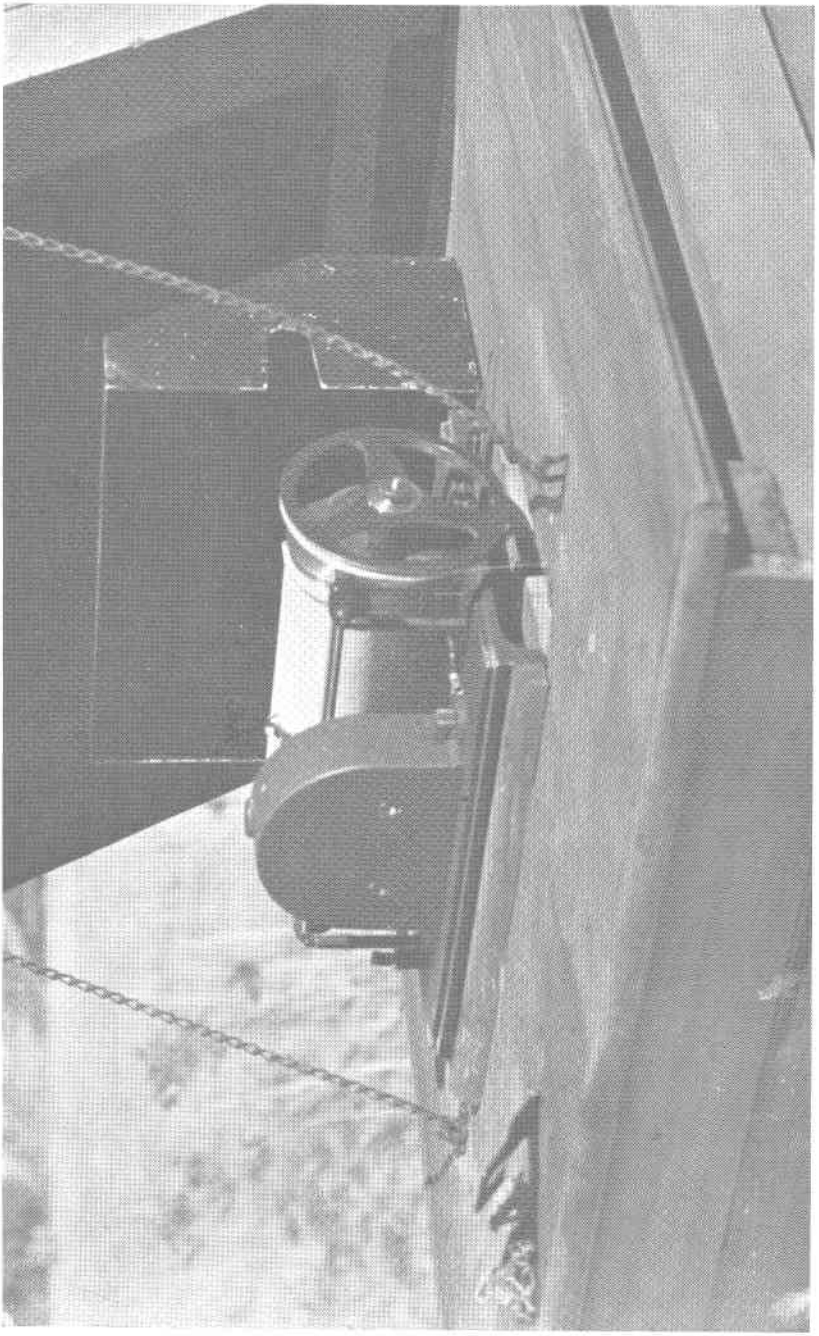
FIGURE 6.—Structural contour map of a part of southeastern Virginia, showing the altitude of the base of the Miocene formations.

Reverse fault in Potomac group along U. S. Route 1 near Quantico, Virginia. Photograph by U. S. Geological Survey.

Reverse fault in Potomac group along U. S. Route 1 near Quantico, Virginia. Photograph by U. S. Geological Survey.



Automatic water-level recorder. Wire cable passes over pulley (right) to float in well. Clock mechanism (left front) controls the pen (center).



Automatic water-level recorder. Wire cable passes over pulley (right) to float in well. Clock mechanism (left front) controls the pen (center).

The geological cross sections (Pl. 1) taken in a general east-west direction reflect the gentle folds plotted in Figure 6. Local steepenings of dip in a seaward direction, alternating with areas in which the beds are almost horizontal, are evident in several sections. The steepening of dip between Burrowsville and Claremont (section A-A′) and from Dwight to Chuckatuck (section B-B′) may be due to compaction of unconsolidated sediments over an uneven basement rock surface rather than to post-Miocene folding.

A definite monocline is present at Franklin, however, and is shown in section D-D′. It appears again in section E-E′, which is taken through a point 4 miles south of Franklin. The base of the Eocene descends 45 feet in half a mile between the Franklin City well and a recent well of the Camp Lumber Company. From Darden's Dairy to South Quay (section E-E′) the base of the Eocene glauconite beds descends 130 feet in 2 miles. The Franklin monocline apparently dies out northward and the eastward dip of formations in northeastern Southampton and central Isle of Wight counties appears to be generally less than 20 feet to the mile.

Clark and Miller[32] point out that peculiar stratigraphic relationships prevail along Appomattox River between Point of Rocks and Petersburg. At Point of Rocks typical Cretaceous strata are well exhibited in the river banks up to an elevation of 80 feet above sea level, but about a mile to the west (up dip) Eocene strata are found a few feet above sea level. The writer visited the locality described and found that strata of the Potomac and Pamunkey groups occur on each side of a large stream about half a mile west of the ocher mine. Time was not available to work out the relationship, but it is apparent that a part of the area west of Point of Rocks is either infolded or infaulted.

From Disputanta to Waverly (section B-B′) the base of the Miocene deposits descends a minimum of 93 feet in 7½ miles in a west-east direction, but at Waverly it rises 11 feet in less than 1 mile eastward. However, the base of the Eocene glauconite beds falls 24 feet in this distance and hence the structure may be due to lensing rather than to deformation.

Compaction of the sediments has undoubtedly contributed to the formation of structures and it is thought that in most places a slight increase in seaward dip of the upper 500 feet of strata may also be attributed to this process.

However, structures such as the Franklin monocline and the Branchville syncline are considered to be too sharply folded to have

resulted from compaction alone and it is suggested that here faulting in the basement rock has created folds in the overlying sediments.

The structures described above have been determined from well data and are shown as folds in the sections of Plate 1. It is possible, however, that some of these are not folds but faults, or folds which change downward into faults.

Post-Cretaceous faults have been observed in the sediments of the Coastal Plain in two localities along the Fall Zone[12]. Both the fault near Triangle, 18 miles north of Fredericksburg, and the fault in the bank of James River at Drewrys Bluff below Richmond are reverse faults (Plates 6B and 7). Near the base of the Chesapeake sediments, 4 miles north-northeast of Petersburg, a small fault was noted trending northwest and dipping 55° SW. In a recent paper on the gravel and sand deposits of eastern Maryland, Darton[52] shows a reverse fault which involves both the basement rock and the overlying terrace formation (Pl. 6A). The sharp break in slope of the bedrock surface at Quantico (Fig. 3) may also indicate faulting.

In conclusion, in southeastern Virginia the geologic history may be summarized as follows: (1) deposition of Lower Cretaceous and Upper Cretaceous sediments; (2) erosion of Upper Cretaceous deposits north of Hampton Roads; (3) formation of a depositional basin, probably by faulting action, north of James River which persisted through Eocene time; (4) uplift of the area as a whole in Oligocene time; (5) subsidence, followed by deposition of Miocene sediments; (6) gentle folding of Coastal Plain sediments in post-Miocene times. The late folding may have originated as settling movements along old faults in the basement rock. Major folds trend east and west but a few, such as the Franklin monocline, may trend north and south. Faulting movements in the basement rock may have been transmitted upward into the unconsolidated sediments for a short distance only but, where the cover is thin, faults of small throw have been observed.

OCCURRENCE OF GROUND WATER

WATER IN GRANITIC BEDROCK

Along the Fall Zone from Richmond to Emporia the granitic bedrock generally yields a moderate supply of water which in places may contain objectionable amounts of iron or hardness. Several domestic, farm, and industrial wells draw upon the fissured bedrock, and yields ranging from a few gallons a minute to several hundred gallons a minute have been obtained. Large yields have been obtained from 4 wells (2, 3, 6, 11, Table 12) developed in the granitic bedrock between Richmond and Petersburg and from a well (134, Table 20) at Jarratt, and more moderate yields have been obtained in a number of other places. However, deep wells in the granite do not always obtain even a moderate supply of water.

Water in the granitic rocks is obtained from fissures, which in some places are absent or very small so that only a meager supply of water may be obtained. At the factory of the U. S. Tobacco Company, near Richmond, a well (2, Table 12) in the granite, 600 feet deep, tested 380 gallons a minute with 93 feet of drawdown after pumping 24 hours. A few hundred yards away a well, 700 feet deep (1, Table 21), at the factory of the American Suppliers Company, developed only 32 gallons a minute with 78 feet of drawdown. A similar situation occurred at the Richmond Deep Water Terminal in Chesterfield County. The first well, more than 400 feet deep, failed to obtain more than a few gallons a minute, but a second well (6, Table 12), located on higher ground a few hundred yards west of the river, yielded 360 gallons a minute with 159 feet of drawdown in a 24-hour pumping test.

The granitic bedrock along the Fall Zone may generally be counted upon to yield from 10 to 50 gallons a minute to wells less than 400 feet deep, and in some places much larger yields may be obtained by drilling deeper. Local drillers believe that if a well 400 feet deep shows, by yielding a moderate supply of water, that the bedrock is fissured, the chances for obtaining a greater supply with greater depth are good. Conversely, if only a meager supply of water is obtained down to 400 feet, the best policy is to abandon the well and drill in another location.

WATER IN THE POTOMAC GROUP[a]

ARTESIAN CONDITIONS

It has been brought out in the discussion above that the sediments of the Coastal Plain consist of the Potomac group of sandy to gravelly

[a] In the discussion of water in the Lower Cretaceous Potomac group a few wells which are sunk to Upper Cretaceous deposits are included.

formations and beds of clay, overlain by glauconite beds of the Pamunkey group and thick beds of impermeable blue clay and marl of the Chesapeake group. These formations dip gently seaward. The water contained in the sandy Potomac strata enters the formations at relatively high elevations along the Fall Zone, travels down the dip and may or may not discharge into the ocean where the sands crop out on the continental shelf several hundred feet below sea level. The movement of ground water is impeded by friction in passing through the water-bearing strata and by the presence of the heavier sea water which must be displaced by fresh water for discharge into the ocean to take place. Clay beds that lie above and below the water-bearing sand layers tend to prevent the escape of fresh water in a vertical direction, and consequently this water is under pressure and will rise in wells. Where the land is low the water may flow, but where the elevation is high the water may rise only part way to the surface.

Figure 7 illustrates these relationships. The height to which the water will rise is called the piezometric level; this is usually below the land surface, but in flowing well areas it is above the sur-

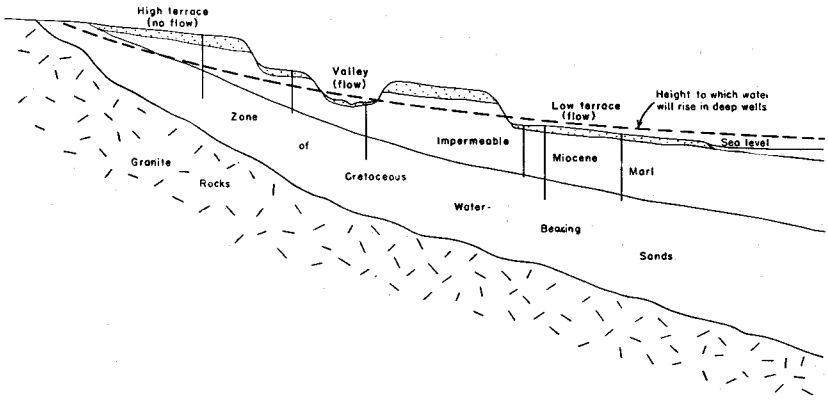


FIGURE 7.—Diagram illustrating relation of flow of artesian wells to topography in the Coastal Plain province of Virginia.

face. If the water discharges beneath the ocean the piezometric surface will slope toward the coast. If the sandy beds are filled with water but do not discharge at their lower ends, the piezometric surface will be horizontal. In southeastern Virginia the piezometric surface slopes towards the sea from Petersburg to Norfolk, but flattens as it approaches the latter area. Information is not at hand on the height to which water will rise east of Norfolk.

ORIGINAL PIEZOMETRIC SURFACE

Study of the data presented by previous workers, together with other data acquired by the writer, indicates the water-level conditions before great losses of head took place following the drilling of many wells.

At Jarratt and Gray, in Sussex County, great losses of head have probably not taken place, since these towns are far removed from areas of heavy withdrawal. Water will rise 149 feet above sea level at Jarratt, which is on the Fall Zone but at Gray, 10 miles farther east, artesian water will rise only about 70 feet above sea level. At Branchville and Arringdale, in western Southampton County, the piezometric levels are reported to have been at about 50 and 71 feet above sea level, respectively. At Sebrell the water level in the well of the Virginian Railroad Co. rose to about 45 feet above sea level in 1907, whereas at Courtland water was reported to flow at a height of 37 feet above sea level in 1910. The area around Courtland, as at Branchville, had probably already suffered some loss of artesian pressure at that date.

Sanford[113] reports that in a well at Coggins Point, Prince George County, drilled in 1903, the water rose more than 30 feet above high tide level.

At Claremont, Surry County, the water rose at least 31 feet above sea level in artesian wells in 1918. In Smithfield, the well of Roy Conklin flowed at 34 feet above sea level in 1914. At the Lamberts Point well in Norfolk, water flowed at about 30 feet above sea level in 1891.

It appears that the original piezometric surface sloped towards the sea, perhaps as much as 2 feet to the mile. Water levels in the vicinity of Jarratt are still high. In the deeply dissected area about Petersburg the water level has always been relatively low. In this area the Appomattox and James rivers trench the sediments of the Coastal Plain deeply and the strata of the Potomac group are exposed at sea level from Petersburg to Hopewell and thence to Richmond. It is believed that this situation has hindered the building up of artesian pressure in the vicinity of these rivers.

Since the slope of the original piezometric surface from Petersburg to Norfolk was probably much less steep than the seaward slope of the piezometric surface from Jarratt to Norfolk, it may be that some of the discharge from eastern Sussex County was originally northward and southward along the Fall Zone. This suggestion is borne out by the existing northward and southward flow from the piezometric high in

western Sussex County. It therefore seems probable that the piezometric slope in a seaward direction has always been slight, with very little submarine or other discharge of deep artesian waters taking place.

Drainage upward may occur through the relatively impermeable marl cap which everywhere overlies the water-bearing sands. Although the permeability of most of the overlying marly material is very low, there may have been enough upward drainage to have created the original gentle seaward slope of the piezometric surface. Such upward drainage can occur only where the piezometric surface is higher than the level of the near-surface water table; otherwise hydrostatic pressure is exerted upon the deep artesian water and recharge of the artesian strata takes place. These relationships are shown in Figure 8.

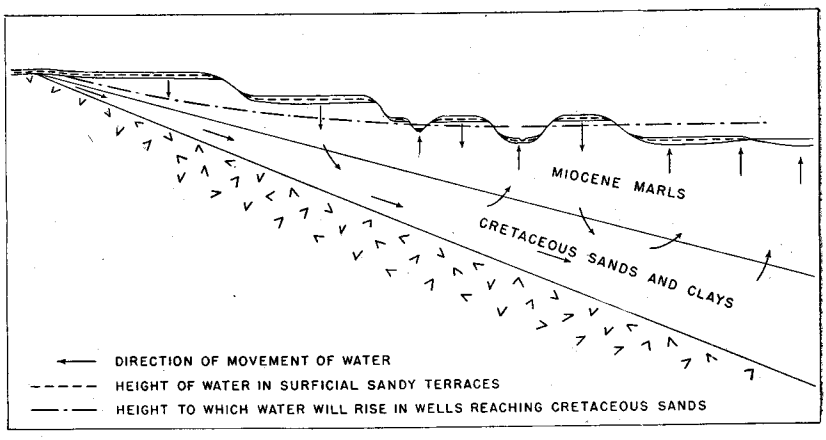


FIGURE 8.—Diagram showing direction of movement of ground water through relatively impermeable marly sediments overlying the deep water-bearing formations.

PRESENT ARTESIAN WATER LEVELS

A decline of the piezometric surface is indicated at every place where comparative records of water levels exist, or where information concerning water levels has been given by residents of the area.

The greatest declines are localized in the areas of heavy withdrawal, along James River, where several hundred flowing wells are located, and at Hopewell and Franklin, where industrial pumping is taking place. Away from areas of heavy withdrawal the decline of water level is less, and at a distance of several miles from areas of heavy withdrawal the loss of head may be quite small. Graphic representation of

the piezometric surface will have the form of inverted cones in the areas of heavy withdrawal. These are spoken of as cones of depression. A contour map of the present piezometric surface is given in Figure 9.

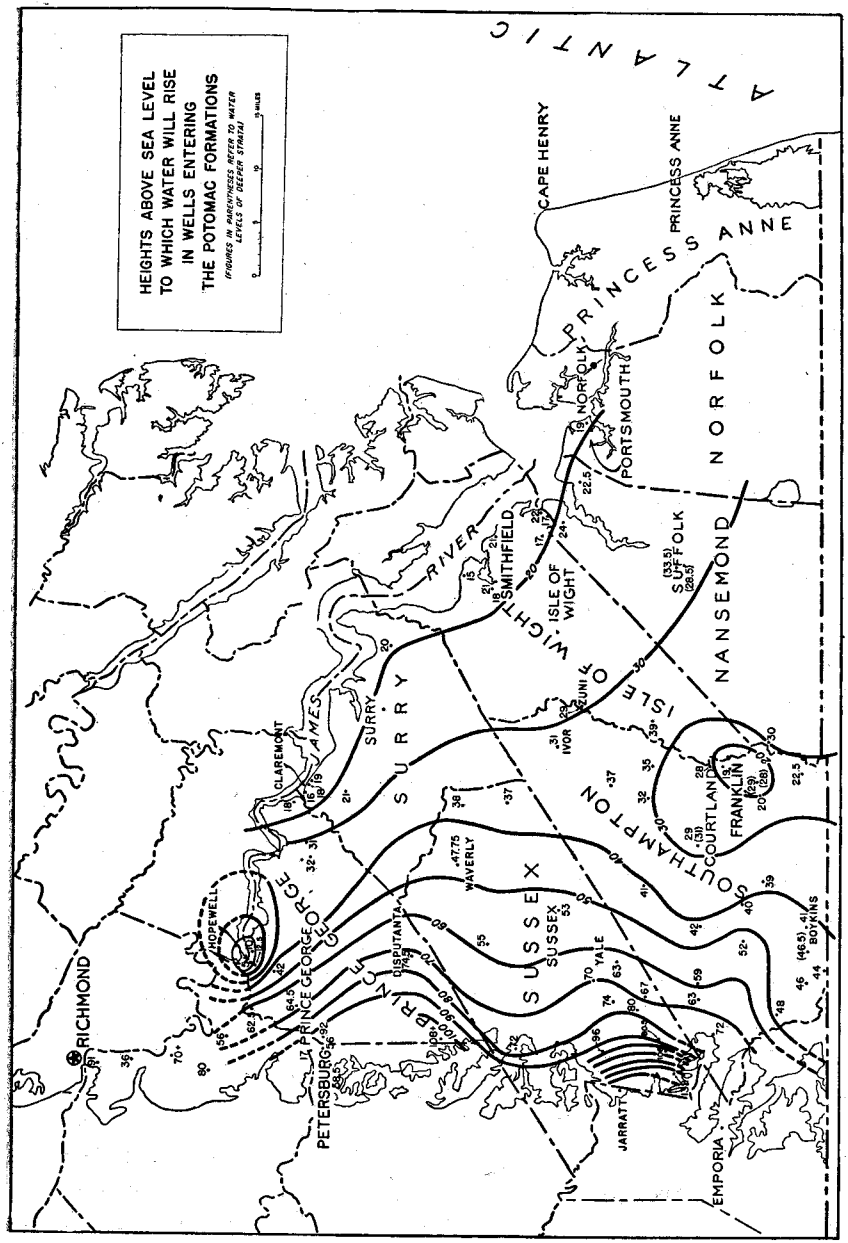


FIGURE 9.—Heights above sea level to which water will rise in wells entering the Potomac formations in the Coastal Plain south of James River. Based on measurements made from 1937 to 1939.

Figure 9 shows that high water levels are found in the western part of the area and that these levels decline in an eastward direction. A well-marked cone of depression is seen at Hopewell. Inasmuch as water flows from regions of high pressure towards regions of low pressure, it is seen that Hopewell is receiving its underground water chiefly from the northwest, and to a lesser degree from other directions. Although data on the water levels in the counties north of James River are not at hand, it seems fairly certain that the piezometric surface is such that some flow to Hopewell from the east and north is taking place.

Another well-marked cone of depression is present in the Courtland-Franklin area. The rise of the piezometric surface outward from Franklin is greatest towards the west. Franklin is therefore receiving its greatest supply of water from the west; but some flow from the north, east and southeast is indicated.

The artesian head at Branchville and at Boykins has not fallen below the general land surface, which is 40 feet above sea level, and a large cone of depression has not been created. However, the regular eastward slope of the piezometric surface has been broken and water is flowing toward Branchville and Boykins from the north and northeast as well as from the west.

The flowing-well field bordering James River and extending from Claremont and Brandon to Norfolk has created an elongated cone of depression lying along the James, which probably includes much of the York-James Peninsula and other territory to the north. The direction of greatest flow is from the southwest into the area, but it also seems probable that water is flowing into the Norfolk region from the south. It is also probable that some water is flowing up dip from the east.

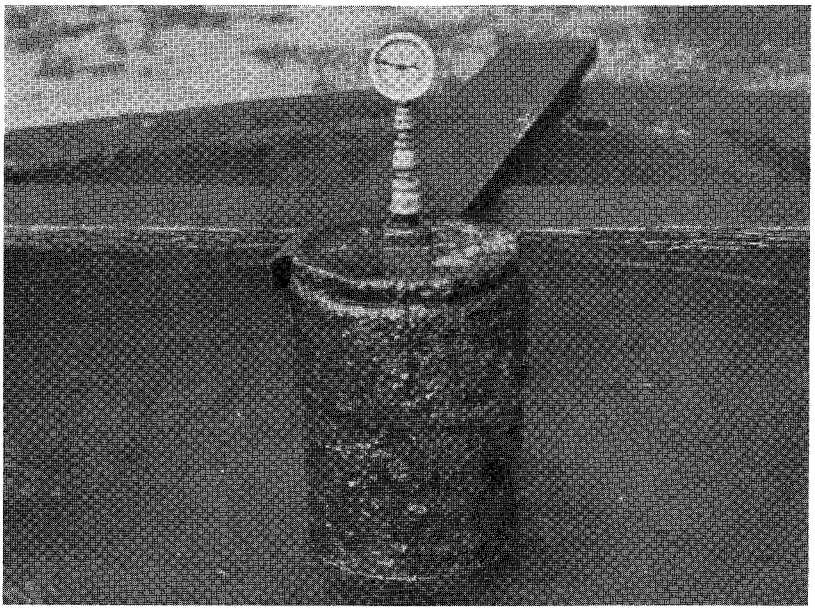
Considering the area as a whole, it will be noted that near the Fall Zone the contours on the piezometric surface are closely spaced, whereas in the central and eastern portions of the area the contours are widely spaced and the hydraulic gradient (slope of the piezometric surface) becomes slight.

This phenomenon is readily explained by considering Darcy's Law, $Q = P\ I\ A$, in which Q equals amount of discharge, P is the permeability, I is the hydraulic gradient, and A is the cross-sectional area through which the discharged water is flowing.

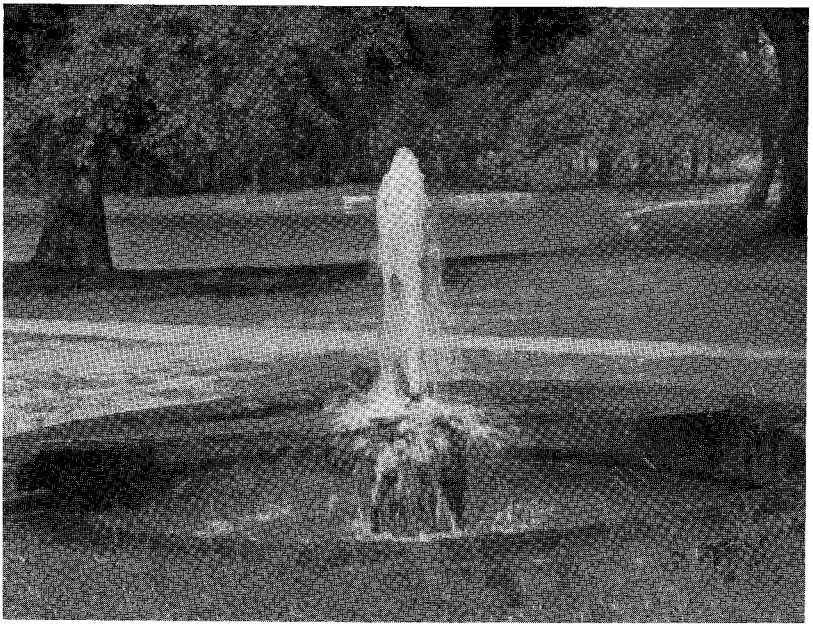
The thickness of the Potomac deposits (A in Darcy's formula) increases in a seaward direction. Therefore since Q and P are constant, I must vary inversely with A, or, as the cross-sectional area increases, the hydraulic gradient decreases. The break in slope of the piezometric surface at Yale, Sussex County, may indicate that there the thickness

Automatic water-level recorder and shelter over well with extended casing at Franklin, Virginia.

Automatic water-level recorder and shelter over well with extended casing at Franklin, Virginia.

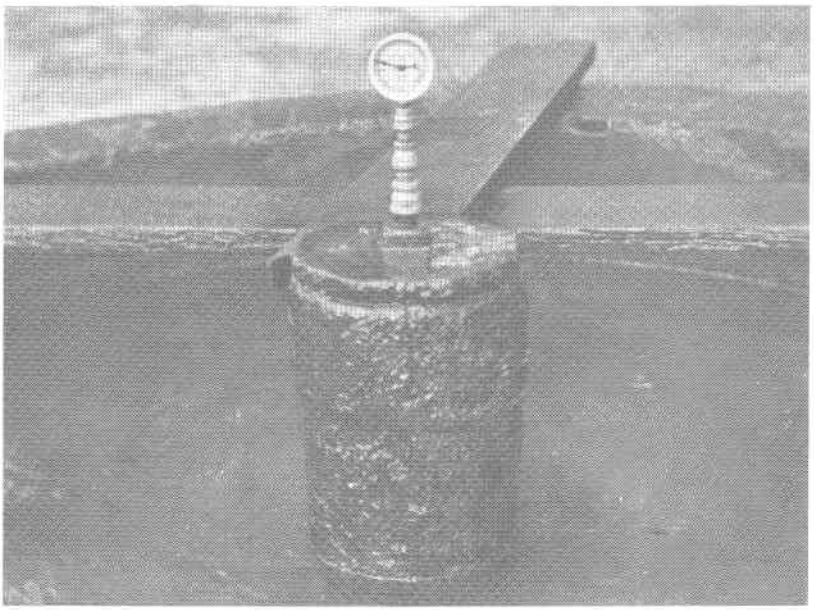


A.



B.

A, Norfolk City Waterworks well shut off and pressure gauge attached to determine height to which water will rise. B, Flowing well at the Norfolk City Waterworks. This well is 1,762 feet deep. It was drilled in 1898.



A.

B.

A, Norfolk City Waterworks well shut off and pressure gauge attached to determine height to which water will rise. B, Flowing well at the Norfolk City Waterworks. This well is 1,762 feet deep. It was drilled in 1898.

of water-bearing sands increases markedly. Some geologic factor is responsible for the thickening, and it is suggested that a bedrock shelf may extend to Yale from Jarratt similar to the shelf shown in section A-A′, Plate 1, extending from Petersburg to Newville, and that east of Yale the bedrock surface slopes more steeply seaward and the Potomac sand deposits thicken accordingly.

Measurements of water levels in artesian wells which were made during field work for the present report are listed in Table 10. Full data on these measurements are given, in order that they may provide other investigators with sufficient information to determine accurately the extent of water level variations which may take place in the future.

RECHARGE OF WATER-BEARING STRATA

The discussion in the foregoing paragraphs of the direction of movement of water in the sandy strata of the Potomac group leads naturally to the question of the sources of the artesian water.

Rain water falling upon the surface along the Fall Zone percolates directly into the Potomac sands or through the overlying terrace sands into the Potomac formations and begins its underground migration in a seaward direction. This zone in which Cretaceous sediments lie at or near the surface and are replenished with water extends through Richmond, Petersburg and Stony Creek to Emporia.

In many places in southeastern Virginia, Miocene marl overlaps the water-bearing formations along the Fall Zone, and surface exposures of the Potomac strata are very limited. However, the marl capping is not entirely impermeable, and it may transmit small amounts of water downward from the overlying terrace deposits, as discussed in a preceding chapter. (See Fig. 8.) It seems logical to expect that, if much water were transmitted downward through the marl capping into the sandy Potomac strata, the water would be hard and contain very little free carbon dioxide. However, most ground water near the Fall Zone has low to moderate hardness, contains important amounts of free carbon dioxide and increases in mineral content toward the east. Hence it would appear that appreciable recharge through the marly cover does not take place, although it is possible that there is a small admixture of hard water moving downward through the marl beds of the Miocene strata with a greater quantity of soft water which has entered the formation through other materials. Although the per-

TABLE 10.—*Measurements of water levels in wells penetrating sand of Cretaceous age*[a]

Well No.	Location	Measuring point	Elevation of M. P. above surface (feet)	Distance to water from M. P. (feet)	Approximate elevation of water level above sea level (feet)	Date measured
		CHESTERFIELD COUNTY				
33	Chester	Top of casing	¼	−104.15	56	10- 6-39
36	Petersburg	Top of casing	¼	−18.04	42	9-22-39
		PRINCE GEORGE COUNTY				
1	Hopewell	Top of casing	¼	−38.96	60+	6-14-39
2	Hopewell	Top of casing	¼	−18.15	63	6-14-39
7	Jefferson Park	Top of casing	¼	−33.29	51	6-14-39
9	Jefferson Park	Top of casing	−4.6	−18.99	65	6- 1-39
				−19.26	63¾	7- 8-39
13	Hopewell	Top of casing	⅛	−41.60	8½	5-29-39
14	Hopewell	Top of casing	3	−36.80	17	5-27-39
15	Hopewell	Top of casing	½	−36.99	14½	5-27-39
16	Hopewell	Top of casing	½	−37.37	14	5-27-39
17	Hopewell	Top of casing	½	−40.18	14	5-27-39
18	Hopewell	Top of casing	½	−43.77	14	5-27-39
23	Hopewell	Top of casing	½	[b]−25.50	−21½	5-27-39
36	Brandon	Surface	0	+3.70	18¾	5-23-39
38	Brandon	Top of casing	−1	−.40	18½	5-26-39
39	Brandon	Surface	0	−1.18	17¼	5-26-39

77	Disputanta	Top of casing	1¼	−40.44	75½	5-22-39
				−40.90	75	11-17-39
				−40.30	75¾	3-19-40
82	Disputanta	Top of casing	2¼	−42.90	73¼	5-22-39

SUSSEX COUNTY

1	Stony Creek	Top of casing	2½	21.35	222	7-26-38
3	Stony Creek	Top of casing	−1½	11.48	177	7-26-38
4	Stony Creek	Top of casing	1	7.59	174	7-26-38
6	Stony Creek	Top of casing	½	4.37	252	7-26-38
9	Peanut	Top of casing	½	10.30	112	7-26-38
11	Stony Creek	Top of casing	5½	23.65	94	7-26-38
14	Huske	Top of casing	2	5.48	83	7-26-38
34	Stony Creek	Top of casing	¼	4.27	72	7-26-38
76	Lambs	Valve seat of pump	¼	13.30	55	7-27-38
80	Waverly	Top of casing	½	70.22	47.8	7-28-38
85	Spring Hill	Inside rim of wide flange at top of casing	½	36.60	38	7-28-38
90	Wakefield	Plug ⅓-foot above 4-inch coupling	1	64.66	35	7-28-38
98	Sussex C. H.	Top of casing	¾	36.65	53	7-27-38
104	Yale	Top of casing	½	51.50	70	7-27-38
110	Yale	Top of casing	1	33.00	62	7-24-38
114	Hilda	Top of casing	¼	46.60	74	7-27-38
115	Gray	Top of casing	½	55.20	67	7-24-38
116	Gray	Top of casing	½	48.70	81	7-24-38
118	Jarratt	Top of casing	⅓	8.98	96	7-26-38
119	Mason	Top of casing	3	42.50	87	7-27-38
121	Bethlehem Church	Top of casing	½	32.94	106	7-26-38
123	Grizzard	Top of casing	¼	20.15	132	7-27-38
129	Jarratt	Top of casing	3	8.97	149	7-26-38

[a]"Well No." refers to corresponding number in tables of well records following each county report. Where the distance to water from the measuring point is expressed to hundredths of a foot the measurement was made by tape. Other measurements were made by pressure gauge. The measuring point (M. P.) is the point above or below which distance to static water level was determined.

[b]Wells Nos. 21 and 24, Table 8, pumping when measurement was taken.

TABLE 10.—*Measurements of water levels in wells penetrating sand of Cretaceous age—Continued*

Well No.	Location	Measuring point	Elevation of M. P. above surface (feet)	Distance to water from M. P. (feet)	Approximate elevation of water level above sea level (feet)	Date measured
		SURRY COUNTY				
2	Claremont	Top of casing	3	+13	18	6-20-39
10	Claremont	Elbow in casing	12	+2	18	6-20-39
40	Bacons Castle	Top of casing	2½	−.13	21	7- 6-39
70	Spring Grove	Top of casing	½	−88.75	22	6-22-39
		SOUTHAMPTON COUNTY				
1	Ivor	Top of casing	1	−54.30	31.0	7- 7-39
16	Baffle	Top of casing	½	−25.43	35½	7-28-38
21	Sedley	Top of casing	½	−60.55	32	7-28-38
26	Vicksville	Top of casing	½	−58.13	32	.....
29	Sebrell	Flange on top of casing	⅓	−21.25	41	7-28-38
35	Joyner	Surface	0	−9.6	45	9-15-37
36	Adams Grove	Top of casing	2½	−14.28	72½	7-27-38
54	Capron	Top of casing	1	−76	42	7-25-38
69	Courtland	Top of casing	2½	−7.30	34½	8-27-37
88	Courtland	Elbow in casing	3½	+1.21	31	8- 1-38
97	Courtland	Elbow in casing	3	+1½	31	8- 1-38
188	Courtland	Elbow in casing	3⅔	+5.23	30	8-18-37
189	Courtland	Elbow in casing	2½	+10	31	7-20-38
228	Franklin	Elbow in casing	4	+5½	17½	7-20-38
229	Franklin	Elbow in casing	5	+7¾	19	7-29-38

239	Franklin	Cement base	0	+2.51	22½	7-29-38
241	Sycamore Church	Elbow in casing	1½	+1	20	7-20-38
259	Capron	Top of casing	½	57±0.3	40	7-25-38
261	Newsoms	Top of casing	½	57.66	38	7-25-38
275	Boykins	Fountain	3	+2	42	7-21-38
358	Branchville	Fountain	3	+6½	46½	7-21-38
359	Branchville	Fountain	½	+9	43	7-21-38
362	Branchville	Fountain	1½	+2	43	7-21-38
368	Zoar School	Fountain	½	31.09	52	7-25-38
369	Little Texas	Fountain	½	37.07	48	7-25-38
370	Hugo	Elbow in casing	¼	+4	42	7-21-38

ISLE OF WIGHT COUNTY

17a	Morgart's Beach	Valve seat in pitcher pump	1	14.98	15	7-30-38
48	Smithfield	Lower end of vertical outlet pipe	2	+15½	22	7-30-38
64	Rescue	Surface	0	0	21	7-30-38
70	Smithfield	Lowest T-joint in casing	2½	Between −1.17 and −2.27	17	11-10-37
76	Smithfield	Outlet on wharf	0	+14½	18	7-30-38
77	Smithfield	Elbow in casing	1½	+11	18	7-30-38
115	Carrollton	Lowest joint in vertical pipe	1	+18½	22	7-30-38
116	Carrollton	Lower joint	1	+14	17	7-30-38
130	Carrollton	Elbow at top of casing	10	+5	17	7-30-38
147	Walters	Elbow in casing	1	+2	39	7-29-38
155	Franklin	Fountain	3½	+4½	24	7-20-38

TABLE 10.—*Measurements of water levels in wells penetrating sand of Cretaceous age—Continued*

Well No.	Location	Measuring point	Elevation of M. P. above surface (feet)	Distance to water from M. P. (feet)	Approximate elevation of water level above sea level (feet)	Date measured
		NANSEMOND COUNTY				
41	Drivers	Top of casing	2½	+12½	20	7-25-39
57	Drivers	Elbow in casing	2½	+13	20½	7-25-39
80	Lake Prince	Top of rotary	4.2	−47.26	19.7	8-20-43
97	South Quay	Pump base	2.35	−2.62	30	7-29-39
104	Suffolk	Outlet at head of gulch 50 feet south of well	16 ft. above high tide	+14½	32½	8- 8-39
105	Suffolk	T-joint	3	+20	27½	7-27-39
		PRINCESS ANNE COUNTY				
24	Moores Bridges	Top of casing	2	+11¼	22	8-12-39

centage of the annual increment to the ground-water reservoir which passes through the marl may be small, the total amount of water thus added may be considerable.

It is believed that much greater recharge of sandy Potomac strata may take place through the underlying fissured bedrock, with which the sandy beds of the Potomac group are in direct contact in many places, as shown in Figure 10. The granitic bedrock

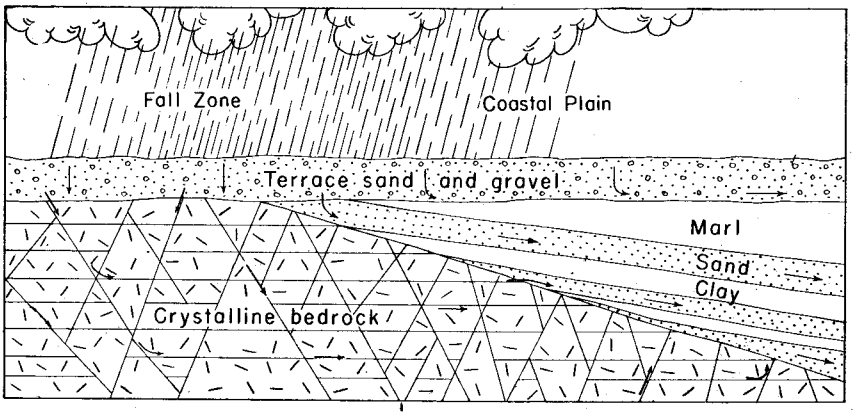


FIGURE 10.—Diagram showing possible mode of recharge of artesian sands through fractured granitic rock.

along the Fall Zone is greatly fissured where exposed, and in only a few places does it fail to yield moderate amounts of water to wells. Furthermore, the granitic rock along the Fall Zone is overlain by terrace formations, 30 feet or more in thickness. These sandy terraces, many square miles in extent, are saturated with water up to a variable distance from the surface and constitute a vast reservoir which might continuously replenish any water draining out of the underlying fissured rock. It is thought therefore that a large part of the recharge of buried water-bearing strata belonging to the Potomac group of sediments may take place in this manner.

OBSERVATION WELLS

A number of observation wells have been selected in the area, in order to determine factors governing recharge and depletion of the water-bearing formations and to furnish current information on the amount of water in underground storage. Water levels in the wells are measured regularly,[76] either weekly by a tape meas-

urement or continuously by an automatic water stage recorder (Pls. 8 and 9).

North of Petersburg.—The record of water levels in well 36, Chesterfield County (Fig. 20), for the period 1940-1942 inclusive (Pl. 11), shows most of the fluctuations which might be expected as a result of normal and abnormal variations in rainfall.

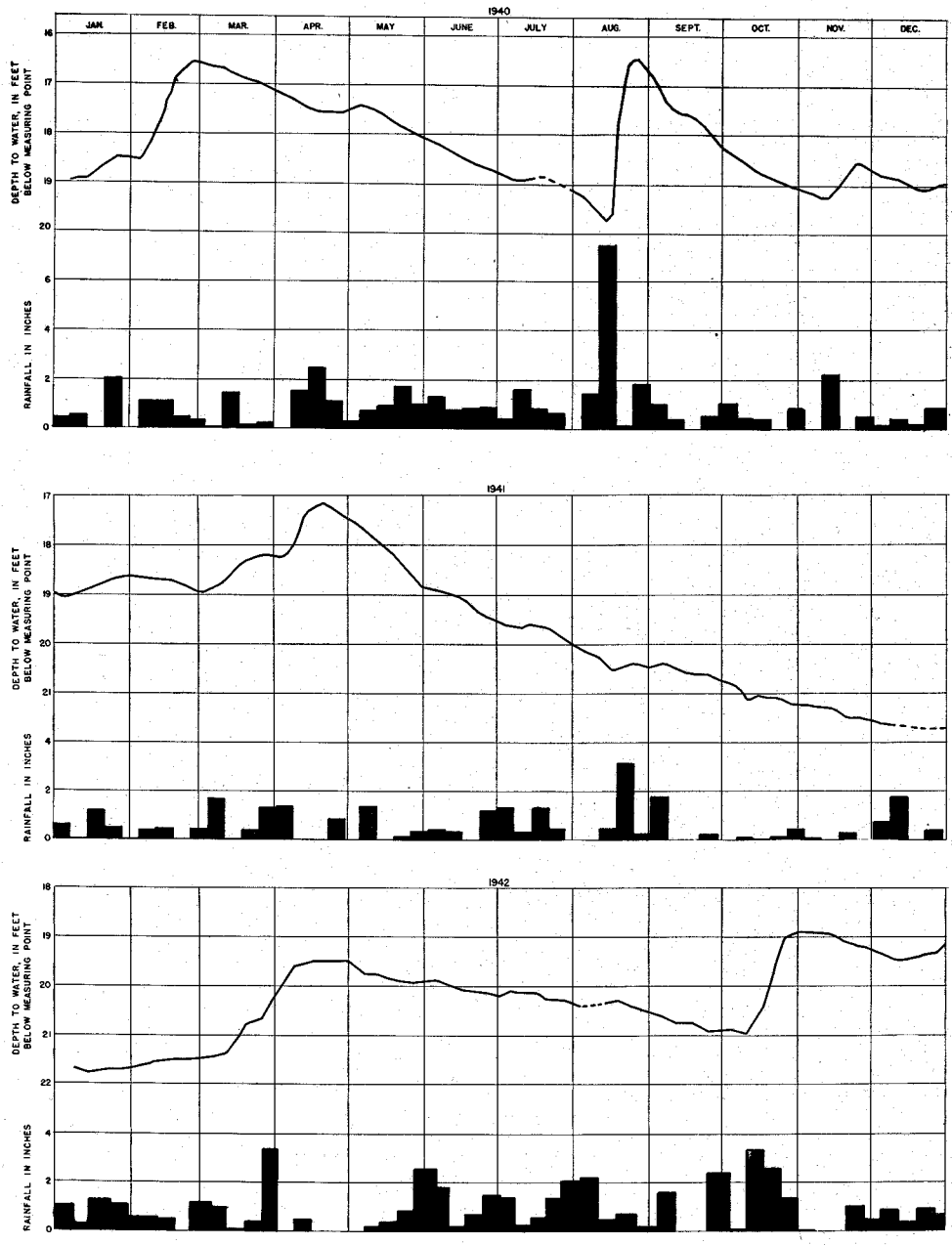
In February, 1940, the water level rose almost 2½ feet as a result of moderate rainfall, but from February 25 to August 13 the water level declined 3.2 feet despite the fact that moderately heavy rains fell from time to time. (On August 6 the total rainfall for the year was only 2.77 inches below normal.) This indicates that in spring and summer the greater part of the precipitation did not reach the zone of saturation but was retained in the zone of soil moisture from which it was dissipated by plant transpiration, but in winter, with plant growth at a minimum, the precipitation had more opportunity to percolate downward into the zone of saturation.

The extreme rains of mid-August, during which 7.65 inches of rain fell in one week, almost 7 times the normal weekly precipitation in August at Richmond, caused a great rise in the water level in the observation well and from August 13 to August 23 the water level rose 3¼ feet. Obviously much more rain fell at this time than could be taken up by plant transpiration, and much of the rain percolated down through the soil cover to the zone of saturation.

On August 26 the water levels again began to decline, and by November 12 the water level had declined 2.8 feet. From November 12 to December 31, 1940, was a period of light rainfall but a slight gain was recorded because transpiration by plants was negligible in the winter season and the rain and snow which fell in this period had a good opportunity to percolate to the zone of saturation.

Rainfall was subnormal every month in 1941, and the total rainfall deficiency for the year was 15.2 inches. Early in 1941 the water level remained essentially constant, but a gain of almost 1¾ feet took place from March 2 to April 20 in consequence of 5.2 inches of rainfall. Transpiration was probably not great in the early spring period.

The water level in the observation well declined continuously from April 20, 1941, to January 14, 1942, during the drought which affected most of the Atlantic seaboard.[130] The downward trend of



Hydrograph showing rainfall at Richmond and water levels in observation well near Petersburg, 1940-1942.

A flowing well in Nansemond County, Virginia.

A flowing well in Nansemond County, Virginia.

the water level was only temporarily interrupted by moderate rains early in July and again in the last three weeks in August and the first week in September. The net decline in the period was 4.55 feet and on January 14, 1942 the water level was 2.9 feet lower than on January 14, 1940.

Rainfall was slightly above normal in the first quarter of 1942, and by April 15 the water level showed a recovery of 2.35 feet; on that date it was 2.3 feet below the stage of April 15 of the preceding year. The water level declined again in the spring and summer as high transpiration prevented the moderate rains which fell from reaching the zone of saturation. By October 10 the level had declined 1½ feet and was at about the same height as the level of October 10 of the preceding year.

According to rainfall records at Richmond, the drought may be considered to have lasted from January 1941 to October 1942. In this period rainfall was above normal only in January, March, June and August, 1941. The accumulated departure in this period (sum total variation from normal) was —16.3 inches. During most of this period ground-water levels were lower than the levels of corresponding dates in 1940 and in most instances considerably lower.

The drought was broken by a rainfall of 7.38 inches, 4.5 inches above normal, in October, as a result of which the water level rose slightly more than 2 feet from October 10 to October 31. Deficient rainfall in November and December resulted in a small net loss in the last two months of the year and on January 1, 1943, the water level was at approximately the same stage as on January 1, 1940, and 1941.

The water-level curve discussed above shows that moderate rains in winter and early spring will tend to replenish the ground water reservoir quickly, whereas the same amount of rainfall in summer is taken up by plants and generally does not reach the body of underground water.

These records furnish an approximation of the amount of water stored in the ground. The decline of levels indicates that less water is available to wells, and continued decline of the water level in the key well beyond a certain stage shows that in many places in that area, where shallow ground water is a source of supply, water shortages may be expected to occur.

The record is also of importance in an evaluation of probable stream flow in the area in which the well is located. A high

ground-water level indicates that spring-fed streams, rivers and reservoirs will continue to receive an ample inflow of water. A low water level may indicate that springs will decrease markedly in yield and stream and reservoir supplies of water will begin to decrease.

To the east of the Fall Zone water obtained from deep wells occurs under artesian pressure and water levels in wells apparently do not fluctuate in response to short time variations in rainfall. The sands which the wells penetrate are saturated and do not become dewatered in periods of drought. However, artesian pressure varies in response to variations in load of the overlying sediments, such as are caused by changes in river stage at different seasons and by variations in sea tides. Hence high water levels may be recorded in wells near rivers or other large bodies of water at times of flood or unusually high tides, and, conversely, water levels in artesian wells may be several feet lower in dry periods when river stages are low or when a westerly wind forces the water oceanward and causes low water levels in the tidal estuaries.

These variations are not of great importance as far as the purpose of this report is concerned. Variations in artesian head due to lack of recharge along the Fall Zone, to overpumping, or to excessive waste of water by flowing wells are of importance in that these fluctuations show permanent or long-time trends which may be of significance both to individual well owners and to municipalities or large organizations using ground water.

Observation wells at Sebrell and Franklin, Southampton County, and South Quay and Franklin, Isle of Wight County, show that water levels over a wide area are affected by industrial pumping at Franklin. These are discussed in the chapter on Isle of Wight County.

Records of observation wells at Hopewell show mainly the effect of industrial pumping in that city and are discussed in detail in the chapter on Prince George County. It may be mentioned in passing that during the 1939, 1940, and 1941 summer pumping seasons, water levels were generally between 48 and 50 feet below the measuring point in well 13, Prince George County, but during the 1942 pumping season the water level was generally 50 to 52 feet below the measuring point. It is thought that the lower levels characteristic of the 1942 pumping period may be due to deficient recharge along the Fall Zone a few miles to the west,

as a result of the drought which had begun the preceding year, rather than to some other cause.

Wakefield.—Water level measurements have been made since April 7, 1940 on well 90, Sussex County (Fig. 23). From that date to the spring of 1941 depth to water in the well, although subject to short time fluctuations, was generally about 65 feet below the measuring point. In the spring of 1941 the water level declined about 1 foot and remained at about 66 feet below the measuring point. In the spring of 1942 the water level again began to decline and by midsummer, 1942, the water level was 67½ feet below the measuring point. The water level again remained essentially static until the spring of 1943 when a decline of water level again began, and by July 1, 1943 the water level was about 69 feet below the measuring point.

The losses of artesian head recorded in this well are believed to represent a persistent overall decline of the artesian water level throughout the area, due to excessive waste of water by flowing wells along James River. It is not certain why the losses of head each year should occur within a few months in each spring, but these declines may be correlated with the general lack of recharge which is apparently characteristic of the Fall Zone area in spring, when relatively light rains are taken up almost entirely by growing plants and little or no water reaches the zone of saturation. The record of this well, when considered with the record of well 36, Chesterfield County, discussed above, appears to indicate that when water levels along the Fall Zone to the west are high due to abundant rains the amount of discharge by flowing wells is roughly equal to the amount of recharge. When water levels along the Fall Zone are low and recharge of Coastal Plain artesian strata is less, the amount of water discharged by flowing wells exceeds the amount of withdrawal and water levels decline. It will be necessary to have several years additional records, however, to establish the validity of this apparent relationship. It is also possible that heavy industrial pumping at Franklin is contributing to the decline of water level at Wakefield, but records at hand do not cover a sufficiently long period to show whether this is so.

DISCHARGE OF FLOWING WELLS AND WASTE OF ARTESIAN WATER

Flowing wells are found in or near communities located on low ground along the courses of the larger rivers. Branchville and Boykins border on Meherrin River, Courtland lies on the bank of Nottoway River, Zuni on Blackwater River, and Franklin near the junction of Nottoway and Blackwater rivers. The flowing wells in northeastern Prince George County and northern Surry, Isle of Wight, Nansemond (Pl. 12), and Norfolk counties lie along the shore of James River or its tributaries. Very few flowing wells are located on the smaller tributaries a few miles distant from these large streams.

The initial yield of the flowing wells is considerably diminished in most localities due to loss of artesian head brought about by the excessive waste of water. In Branchville most wells yield about 3 gallons a minute although one 4-inch well flows 25 gallons a minute. The average flow of domestic wells at Courtland and at Franklin respectively was about 4 and 8 gallons a minute in 1938. Along the James River, where many wells are located only a few feet above sea level, the average yield in 1939 was about 19 gallons a minute.

The amount of water discharged by flowing wells in 1938 is estimated as follows: 90,000 gallons a day in the Branchville area; 250,000 gallons a day at Courtland; 360,000 gallons a day at Franklin[a]; and about 5,000,000 gallons a day along the south bank of James River[b]. More than three-fourths of the water is wasted through unchecked flows or in the operation of hydraulic rams (Pl. 14).

The loss of artesian head throughout the area has already been noted and it has been pointed out that cones of depression have formed in the flowing-well areas. This loss of artesian head is thought sufficient to account for the greater part of dimunition of yield noted in most places (Pl. 13). However, it has been found in some places that wells have partially filled up with fine sand and have yielded less water or entirely ceased to flow on that account. It is the common belief in this part of Virginia that flowing wells require no screens and that the constant flow of water is sufficient to carry away any fine sand which might other-

[a] As of 1937. Does not include flow from municipal wells, which is entirely recovered and which is included with estimates of pumped water in this area, nor the flow from a few industrial wells in nonpumping periods.

[b] In 1939.

wise lodge in the lower portion of the casing. This belief is not entirely justified, however. Well 55, Nansemond County, had a constant flow of 40 gallons a minute or more, but when a pump was installed and set in operation a large quantity of sand was brought up. The well threw sand for several weeks, and the owner, Mr. Earl Eberwine, stated that the well has continued to yield a little sand.

Well 59, Nansemond County, has had a similar history. The natural flow was at first delivered into the home at an elevation about 23½ feet above sea level. The yield decreased and eventually ceased. A new and lower outlet was made, and a strong flow of water with considerable sand was obtained. The flow of sand ceased after several days. Still later a pump was installed (which installation, however, does not interfere with the natural flow except when the pump is actually in operation), and again a large quantity of sand was pumped in the first few days of use. The owner, Mr. J. C. Mathews, stated that after the pumping of sand, the yield of the well appeared to increase somewhat. At Courtland several weak flowing wells have had their yield increased by jetting out the sand which had partly filled the casing.

The construction of deep artesian wells began a little before 1900 in southeastern Virginia, and by 1910 several men were established in the area as drillers. In those early years a flowing well was always sought; strong artesian head was present in many places and the natural pressure delivered water directly to the user. In addition to the convenience offered by flowing wells, the value of an uncontaminated water supply was early recognized; the statement has been made many times to the writer that the acquisition of an artesian well definitely put an end to a variety of illnesses, especially typhoid fever. For one reason and another, the idea gradually became firmly implanted that flowing artesian water was purer and tasted better than water from the same horizon in a pumped well. Furthermore, cheap power for dependable and easily operated pumps was not available in many places at that time. Hence, some wells drilled in those early days were branded as "failures" because they did not flow, and even today a well which ceases to flow is sometimes said to be "ruined," despite the fact that it may furnish a good yield by pumping.

It is a common belief here, as in other areas of artesian flow, that the restriction of flow of a well will cause it to cease flowing. The fact that some wells whose flows have diminished or ceased

are found to be partly sanded lends weight to this belief. But wells may sand up even before they suffer great diminution of yield. Conversely, several wells which have entirely ceased to flow have been found not to be clogged by sand. As most flowing wells are not equipped with strainers it seems probable that a great many of the flowing wells might become sanded a short time after their construction.

Water from well 38b, at Hog Island, Surry County, has been piped into the home and when not in use the flow is entirely shut off. This well has not suffered any diminution of yield since its construction in 1933. Many other instances are known where the flow of wells has been totally shut off for short periods with no observable effect and it is believed that in most instances the restriction of flow can not be shown to have any appreciable effect on the flow of wells; those which tend to become sanded, do so whether they flow strongly or not. A few wells may, however, suffer diminution of yield if their flow is suddenly restricted.

As mentioned above, many individuals believe that the restriction of flow will cause a well to cease flowing; and many believe that water from a flowing well tastes better and is purer than water from a pumped well. Furthermore, the combined effect of many small unchecked flows is not considered as particularly detrimental, and it is generally believed that some one large well in an area of declining artesian pressures is the main cause of loss of head. Lastly, the substitution of a pump for a hydraulic ram, although inevitable in many places, is an added expense and is deferred as long as possible. As a result, the necessary concerted action in well regulation by nearly all residents in an area is impossible to attain.

The aggregate discharge of many small wells, as noted above, is by no means inconsiderable in many areas. Little is done to restrict free flows to a nominal discharge, and hydraulic rams, which make inefficient use of rather large amounts of water, generally deliver more water than is needed; many such installations are so devised that the ram takes as little as one-third of the total flow and rejects the remainder through an overflow pipe (Pl. 14).

The expense involved in changing over to a pumped supply is a reasonable objection. Probably a majority of flowing wells are now equipped with hydraulic rams which deliver water directly to the point of use, or to an elevated tank for temporary storage, and

which give good service. In a few localities electric power is not available and gasoline-powered pumps would have to be used. These are not only relatively expensive but inconvenient to operate.

The loss of artesian pressure in the flowing-well areas is of significance and it can be shown that this loss of head might have an important effect on the ultimate development of large supplies of water for industrial or other uses. If several large properly spaced wells were constructed along the James near the center of the flowing-well field, each one of which was capable of pumping 1,000,000 gallons a day, in a comparatively short time a deeper cone of depression would develop around the pumped wells, and most of the flowing wells would cease to flow. However, a large part of the water which is now being wasted by the flowing wells would then be available to the pumped wells. After several years of heavy pumping a new cone would be established whose extent would greatly exceed the limits of the present cone of depression and the effects of the present cone of depression would no longer be manifest.

However, flowing wells have not been discharging merely recharge water which enters the formation along the Fall Zone, but have also been wasting the water which has been liberated from storage in the sediments in consequence of decreased artesian pressure. The amount of water thus liberated is considerable and represents a net loss of large amounts of water to any future consumer. Although it is evident that large amounts of water may be obtained in a great many places in southeastern Virginia, the cost of securing that water is now somewhat greater than it would have been had not great losses of head occurred.

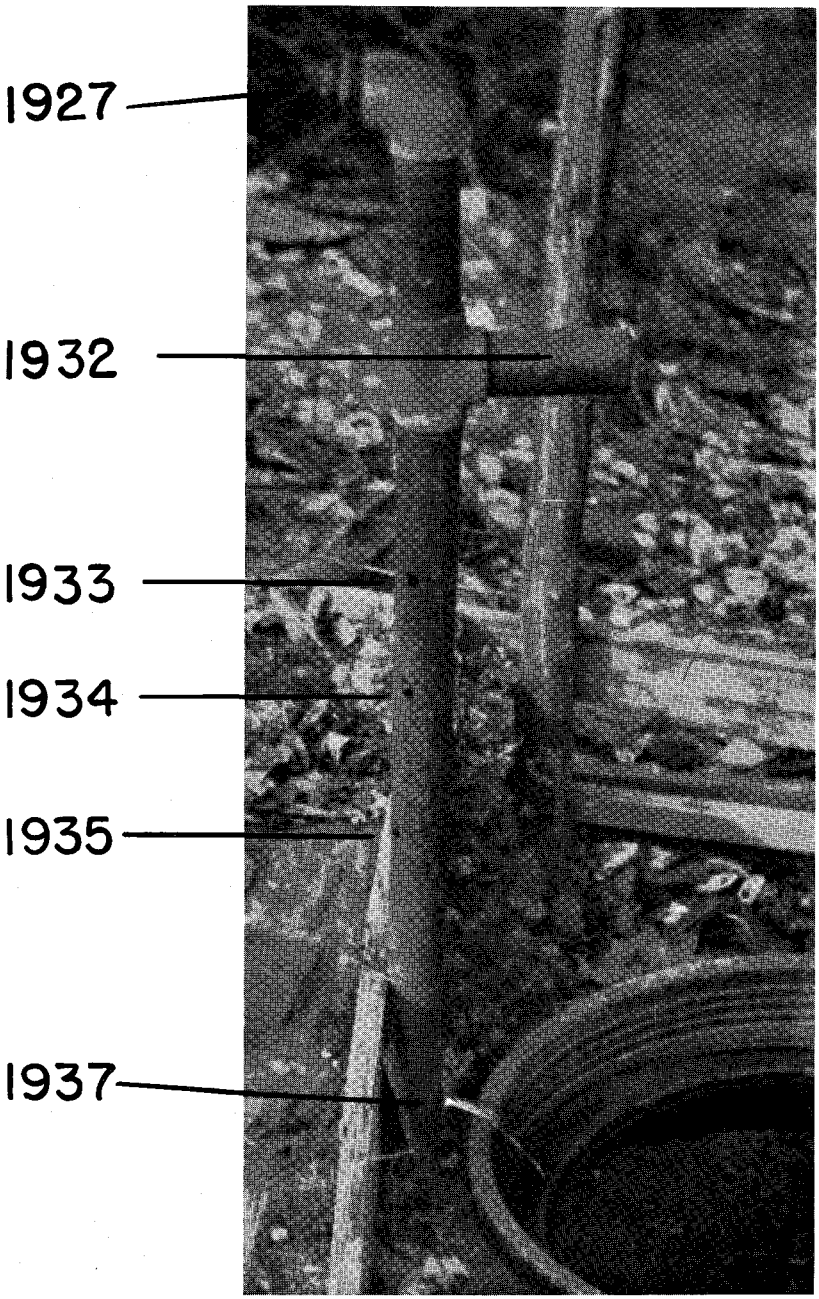
The amount of water released from storage may be roughly estimated by assuming that the over-all loss of head in an area 25 miles wide bordering James River, and extending from Claremont to Norfolk, has been a minimum of 20 feet, applying a factor of compressibility of .001 to the volume of water-bearing beds. Calculation shows that a minimum of over 5 billion gallons of water has been released from storage which is not replaced by incoming water from recharge. The amount of water thus needlessly discharged is equivalent to 1,000 gallons a minute pumped continuously for a period of almost a year. The amount of water thus liberated from storage is not very great, as water is used today in some large industries, but it is a quantity which has been irretrievably and unnecessarily wasted. The unrestricted use of flowing wells is therefore harmful to individual well owners, and in

some measure, to future consumers of large amounts of water. In 1912 Sanford[98] stated:

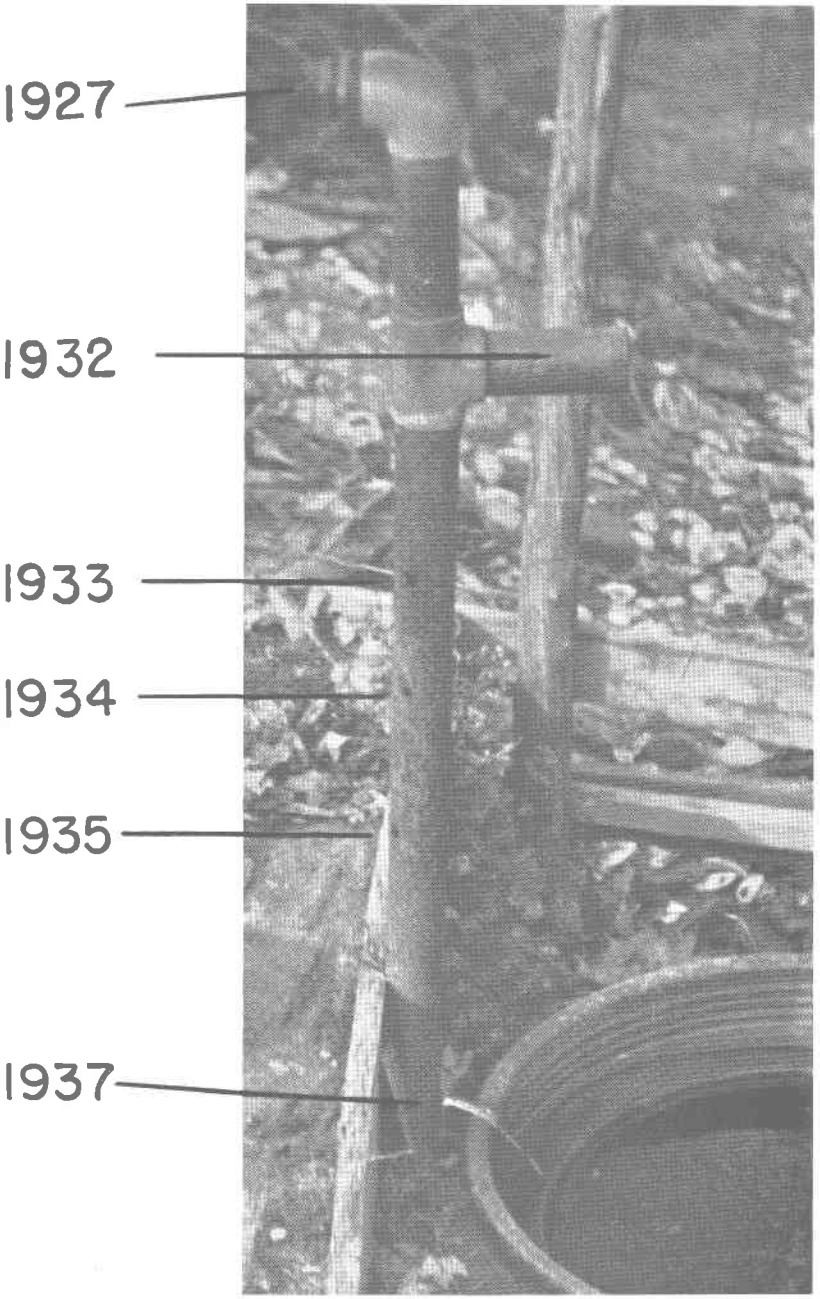
"The artesian supplies obtainable under the greater part of the region investigated are so abundant that their conservation and even their most advantageous development have received little attention. The situation at West Point and at Colonial Beach, where hundreds of wells no longer flow, depriving owners of advantages that in the aggregate have a large money value, shows that conservation can not be neglected. While such severe restrictions on the use of underground water as some states have imposed are not required, there is already need for local regulation. Waste is unnecessary and may work public injury. Where many wells have been driven those on low ground need not be allowed by unrestricted flow to diminish or cut off the flow of wells on higher ground. Neither is it right that the static level of the water in an underground reservoir should be lowered to the detriment of innocent parties by the insufficient casing of new wells or by the neglect of old wells. The casing of wells at wharves may be damaged by accident or corrosion, allowing a part or the whole of the flow to escape below tide level. It is obviously unjust to permit this where it means loss to other property owners, and where it can be prevented by the simple expedient of plugging the well. It is true that . . . there are undeveloped sands that can furnish plenty of water, and the depletion of all the sands is a remote contingency, but this does not alter the essential injustice of permitting the impairment of an important natural resource, and the depreciation of private property by carelessness and neglect, especially when preventive measures are simple and inexpensive. Sooner or later the fact that the interests of the public are superior to those of any individual will be so generally recognized that unnecessary waste will not be tolerated."

Although legal measures toward restoring artesian head by control of flowing wells has been recently carried out with a high degree of success in New Mexico and North Dakota[61, 120] where water is important for irrigation, it has not yet been fully and generally realized in Virginia that by lack of regulation considerable cost and needless inconvenience are brought upon a host of water users who must install pumps, change from one type of pump to another or return to unsanitary open wells for water supply because they lack funds to provide a pump for artesian water. Conservation might be brought about by plugging wild[a] wells, restricting the flow of others to actual use, limit-

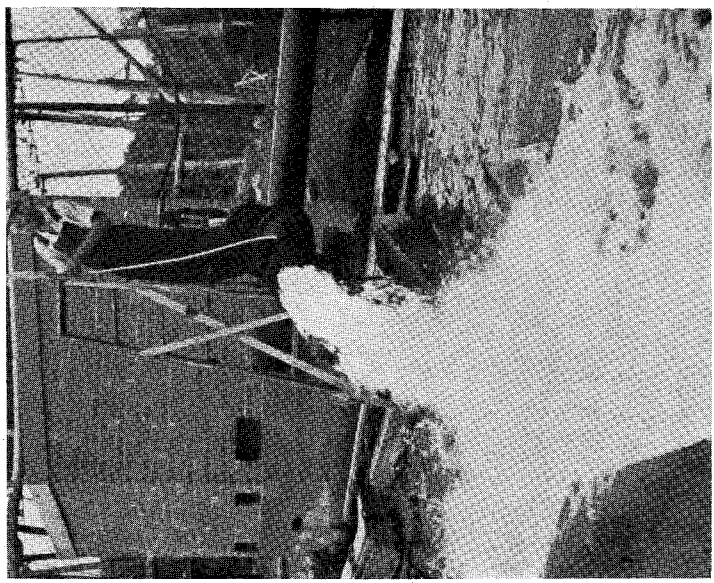
[a] A wild well is one on an abandoned farm or inaccessible place whose water is being totally wasted.



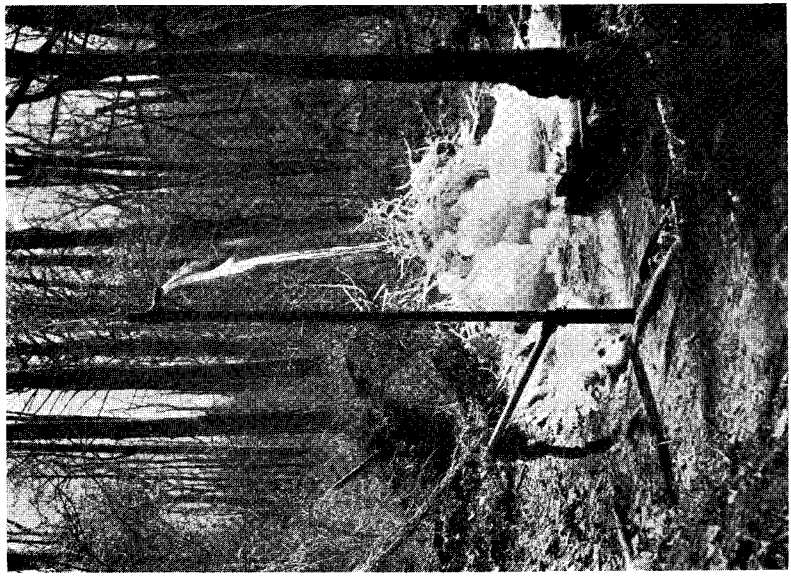
Well with casing perforated at successively lower points in order to maintain a flow as artesian pressure declines; Isle of Wight County.



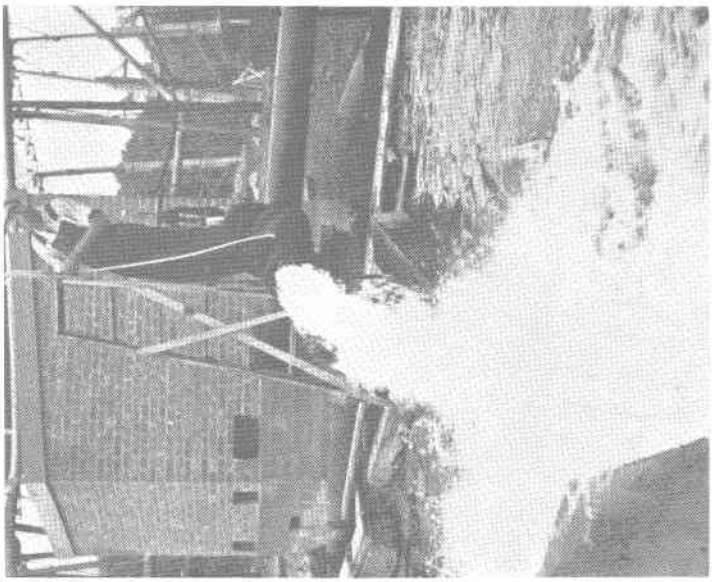
Well with casing perforated at successively lower points in order to maintain a flow as artesian pressure declines; Isle of Wight County.



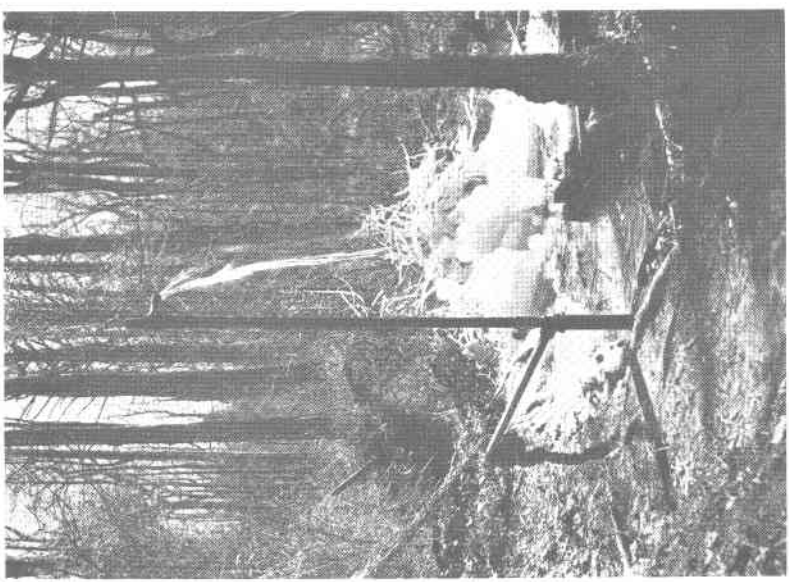
B, Discharge from an industrial well at the Chesapeake-Camp Corp., in Franklin. The man is measuring piezometric pressure.



A, Overflow from artesian well in Isle of Wight County is wasted.



B, Discharge from an industrial well at the Chesapeake-Camp Corp., in Franklin. The man is measuring piezometric pressure.



A, Overflow from artesian well in Isle of Wight County is wasted.

ing the use of large flows for such purposes as freshening fish ponds, urging the substitution of pumps for rams wherever possible, or checking the flow of a well to the amount actually used by the ram. By these means a step toward conservation may be made. The hydraulic ram is the chief offender in the waste and inefficient use of water,[b] and until some measure for the regulation of unchecked flowing wells and use of the hydraulic ram is put into effect, further declines of artesian head and loss of water from underground storage will continue.

DISCHARGE OF PUMPED WELLS

Pump tests which have been made in a number of localities indicate that high yields may be developed from properly constructed wells which penetrate the Cretaceous formations. Where details of pump tests are available the specific capacity of wells may be determined.

Wells which obtain water from only one stratum or, at the most, two strata, generally have a low efficiency and furnish from 2½ to 10 gallons of water per foot of drawdown. Measurements on several 3-inch flowing wells indicate that specific capacities (gallons per foot of drawdown) of 3 to 5 are not uncommon. Larger-diameter industrial and municipal wells have larger specific capacities.

Large-diameter wells which develop water from many strata have much higher specific capacities. The two 18-inch wells at Franklin (160 and 162, Isle of Wight County) yield almost 40 gallons per foot of drawdown, and the Bacons Castle test well (42b, Surry County, Pl. 27) yielded 43 gallons per foot of drawdown (Pl. 29).

At the Chesapeake-Camp mill in Franklin, where the demand for water is great, two large-diameter wells are pumped almost continuously at a rate of about 2,500 gallons a minute each (Pl. 32). Elsewhere demands are much smaller, and most wells are not equipped with pumps capable of furnishing as much water as is available. At the Waverly municipal waterworks, wells 78 and 79 (Table 20) are pumped at a rate of about 145 gallons a minute and the Wakefield wells, 87 and 88, are pumped at 120 gallons a minute. At Franklin two 4-inch wells (157, 158, Table 34) furnish about 250 gallons a minute each. Well 157 is pumped at a rate of 140 gallons a minute, and wells 157 and 158 together are pumped at a maximum rate of 500 gallons a minute. At the Franklin municipal waterworks, well 206 (Table 29) is intermittently pumped at a rate of somewhat less than 1,000 gallons a minute. At Suffolk two wells (109, 110, Table 39) yield respectively about 150

[b] The hydraulic ram may be aptly termed a wolf in sheep's clothing.

and 300 gallons a minute. At Hopewell, wells 23 and 24 (Table 15) yield about 150 gallons a minute each, and the large-diameter wells 20 and 21 yield respectively 640 and 980 gallons a minute. A few other wells in the area are pumped at comparable rates, but specific data on their rates of discharge are not at hand.

The total withdrawal by pumped wells is not great at any one locality except at Hopewell, where, it is estimated, about 2,000,000 gallons a day may be pumped during the warm months and at Franklin, where a total of about 8,000,000 gallons a day is being discharged, largely at the Chesapeake-Camp mills.

Cones of depression surround both Franklin and Hopewell and have been previously discussed. Periodic observations on water levels in wells at Hopewell indicate that safe yield is not being exceeded, but it is not yet possible to state that safe yield is not being exceeded at Franklin. Further details on these localities are set forth in the chapters on Prince George and Isle of Wight counties.

WATER IN UPPER CRETACEOUS DEPOSITS

As far as is known, only a few wells obtain water from Upper Cretaceous deposits. At Franklin the "first artesian sand" is of late Cretaceous age and supplies water to many domestic wells. The sand is fine, and wells penetrating it have not obtained large yields. The piezometric level of artesian water is slightly lower than that in deeper wells which penetrate the Potomac deposits of early Cretaceous age.

Fine sands of late Cretaceous age are present at Lake Prince, Nansemond County. Possibly the first artesian sand at several other localities is also of late Cretaceous age, but detailed data are lacking and the full areal extent of Upper Cretaceous sands is largely conjectural.

WATER IN THE PAMUNKEY GROUP

Glauconite sands free of marl, found in many places in the Pamunkey sediments of Eocene age, are excellent water-bearing formations if permeability alone is considered. It should be possible to obtain small to moderate supplies of water from the glauconite sand in southeastern Virginia. The formation is troublesome, however, in that it caves and tends to clog the well. Cheap wells without strainers ending in the Pamunkey formations generally do not have as great a flow as similarly constructed wells penetrating Potomac strata at slightly greater depths.

A well finished in glauconite sand continues to yield a little glauconite with the water even after years of pumping, and in some places water from the glauconite sand is greenish and has an unpleasant odor. A few wells in Surry County obtain water from Eocene strata.

WATER IN THE CHESAPEAKE GROUP

Ground water is furnished by the Yorktown formation of Miocene age in several places in the area. In the aggregate large quantities are pumped in the vicinity of Norfolk, and a few wells in Princess Anne, Nansemond and Surry counties also obtain water from these strata. A few of the springs which issue from coquina beds of the Yorktown formation furnish water supplies in Surry and Isle of Wight counties.

Water is obtained from wells 30 to 125 feet deep, which penetrate strata made up of shell (coquina) (Pl. 15) or sand, or mixtures of sand and shell (Pl. 40). These strata are exposed along the banks of James River in Isle of Wight and Surry counties and elsewhere, and their occurrence in the vicinity of Yorktown has been recently studied and described in detail by Roberts.[89]

In some places the water is under artesian head in these Miocene strata, and flowing wells of small yield have been obtained at Great Bridge in Norfolk County and at Everetts in Nansemond County. Pumped wells supply larger quantities of water for irrigation, for small industrial purposes or for large farms (Pls. 16 and 17).

In and near Norfolk and Portsmouth as much as 2,000,000 gallons a day is pumped at certain seasons (see Table 43). Each pumping unit generally draws from several wells of small diameter, and the yield of individual wells is not great. Those wells which are pumped by suction-lift yield 2 to 20 gallons a minute, whereas large-diameter wells pumped by air-lift or by force pumps may yield 50 to 100 gallons a minute.

Data obtained recently furnish more details on the yield of Miocene strata in the Norfolk area. In South Norfolk one 8-inch well (53b) yielded 180 gallons a minute with 41 feet of drawdown. From a well at the Liquid Carbonic Company, 60 gallons a minute was obtained with 41 feet of drawdown, and at the Norfolk Navy Yard an 8-inch test well (30) furnished 25 gallons a minute with 2 feet of drawdown.

Although little is known of the variations in water level in the area, reports from well owners or persons in charge of pumping plants indicate that in the Norfolk-Portsmouth area wells

which penetrate Miocene strata are not overpumped. The shell and sand strata lying generally within 75 feet of the surface appear to be very permeable and subject to rapid recharge. South of Portsmouth, however, it is found that when late spring irrigation is carried on, yields of 40,000 to 50,000 gallons a day for each pumping unit may decline to less than 50 per cent of the original yield, undoubtedly due to the decline of water level brought about by local overpumping and light recharge in the summer.

The Portsmouth Ordnance Depot, in northern Nansemond County, obtains its entire supply of water from Miocene strata. Although only about 100,000 gallons of water a day is pumped, the yield of individual wells (65-75, Table 40) at the time of installation is reported to have been from 60 to 140 gallons a minute.

Water from wells 125 feet or less in depth was found to have a temperature of 61° F. to 62° F., being about 6° to 10° cooler than water from the deep Cretaceous strata in the eastern counties. The shallow water is used for cooling purposes by several ice plants and other establishments in Norfolk County, and it is reported that at the plant of Procter and Gamble (33, Table 43) in Portsmouth about 450 gallons a minute is pumped from wells for this purpose. Other establishments pump considerably less water for cooling.

The Miocene strata should not be disregarded as a potential source of water in future developments where ground water may be used to advantage. Although water from these strata is hard, it is generally low in chloride and is a desirable water on that account in an area where both surface waters and deep well waters are liable to be somewhat brackish (Tables 46 and 50). The relatively low yield of many of the older installations does not give a true picture of the potential ground-water supplies to be expected, and in some places it may be possible to obtain hundreds of gallons a minute from one or more fairly shallow wells penetrating Miocene strata. This amount of water, moderately hard but of low chloride content, may be of considerable value as an auxiliary supply, for fire protection, for cooling or for general use. Where surface water is lacking, water from Miocene deposits might be mixed with soft but highly mineralized water from deep wells in order to make up a supply of water of moderate mineral content.

WATER IN THE COLUMBIA GROUP

Shallow dug or driven wells in the terrace deposits of the Columbia group yield ample supplies of water for domestic use throughout the area. Indeed, many small communities draw all or nearly all their supply from them.

Shallow wells are much less expensive to construct than artesian wells and may be located almost anywhere. The water may generally be drawn by a pitcher pump or a bucket, whereas many artesian wells require a deep-well force pump. Shallow wells are more difficult to protect against contamination than artesian wells, and in some places the water obtained from shallow wells is hard or does not have as pleasant a taste as artesian water.

Practically all shallow wells derive water from sand and gravel of the terrace formations which blanket the area. Water fills the open spaces between the sand grains, up to a variable height known as the ground-water level. The surface of the body of ground water is known as the "water-table," and water which fills voids of porous formations to a variable height and is not under hydrostatic pressure, is said to occur under water-table conditions. Where great flat areas exist the ground-water level may lie within a foot or two of the surface during the rainy seasons. Where the terraces are dissected the ground-water level lies at a greater depth below the surface, in some places more than 20 feet.

Terrace sand and gravel are practically everywhere underlain by the thick marl of the Chesapeake group. The marl itself generally yields little or no water to dug wells; it acts as a relatively impervious layer beneath the sand and gravel which transmits water very slowly and prevents the water above from draining downward. Therefore, it may be said that the shallow water bodies are perched.

Data at hand indicate that the terrace formations have an average thickness of 20 to 30 feet. In a few places along the Fall Zone the terraces may be thicker, but in many places the terraces are badly eroded and their deposits are less than 20 feet thick. Figure 11 shows the relationship of the perched ground water to the topography.

On the flat undissected terraces or pocosons[a] the water level is close to the surface and a favorable thickness of water-bearing

[a] The term "pocoson," used on the Suffolk, Smithfield, Surry, and Yorktown topographic sheets, is applied to poorly drained wooded upland areas, according to "Topographic Terms in Virginia," G. D. McJimsey, American Speech, Reprints and Monographs, No. 3, Columbia University Press, pp. 17, 18, 1940. Hence the term is synonymous with high undissected terrace remnants.

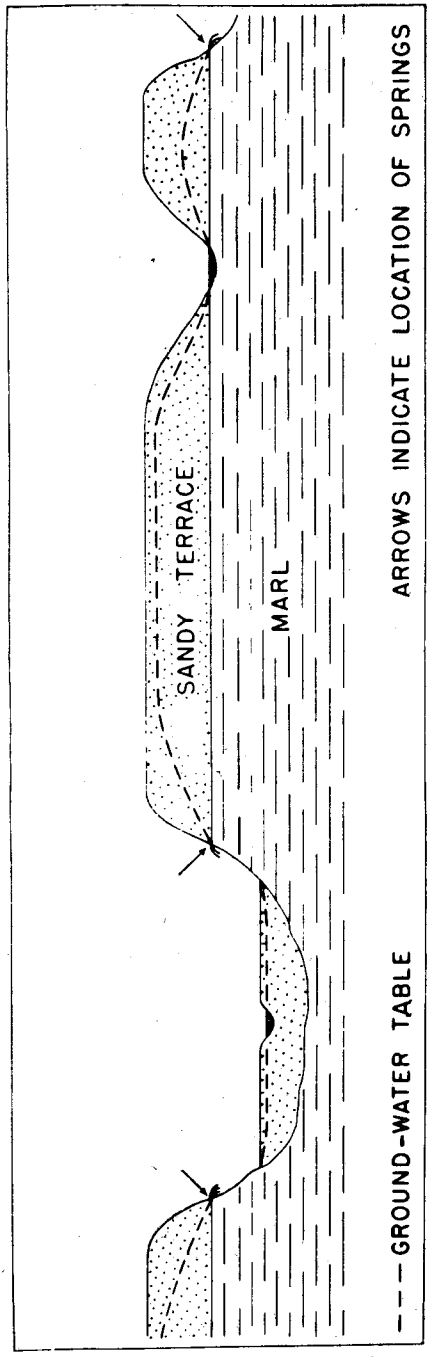


FIGURE 11.—Diagram showing the occurrence of ground water near the surface of the Coastal Plain.

sand and gravel lies between the water table and the marl below. At low places within a dissected terrace the water level is close to the surface but the water-bearing formation is thinner. Near the edge of an undissected terrace or beneath the high ground on a dissected terrace, the water-level lies deeper and the thickness of water-bearing material below water level is variable.

The water contained in these beds is rain water which has seeped down from the surface directly above. It moves outward from the areas where the water level is high and discharges as springs or seeps along river and creek banks. Since the water is local in origin the water level reflects the local rainfall and rises directly after a heavy rain. In periods of dry weather the level gradually falls. As the water level falls, the slope of the water table decreases, the outward movement greatly diminishes, and less water is discharged by springs. Some wells must be deepened to secure water, and a few others, less favorably situated, go dry. In general, however, dug wells in the flat, less dissected areas, do not go entirely dry, even in severe droughts.

The terrace formations have been described as predominantly sandy and gravelly formations. This view is not held by the writer. In nearly every instance where data have been obtained through the inspection of open wells, the reports of drillers and local residents, and exposures in road cuts, it was found that a layer of clay from 2 to 3 feet to 10 to 15 feet thick overlies the sandy deposits. Lensing is not apparent.

Shallow wells do not always yield an ample supply of water. In some places the terrace may be made up almost entirely of clayey sediments, and the possibility of securing more than a small supply of water is not good. Clay yields water from seeps and from tubular channels, such as might have been made by tree roots. A well which encounters several such channels may yield a fairly good supply of water, but a well not encountering such open channels may be practically dry.

Along the larger rivers are areas underlain by clay down to the marl. Elsewhere clay tends to be distributed as discontinuous layers which make water prediction hazardous.

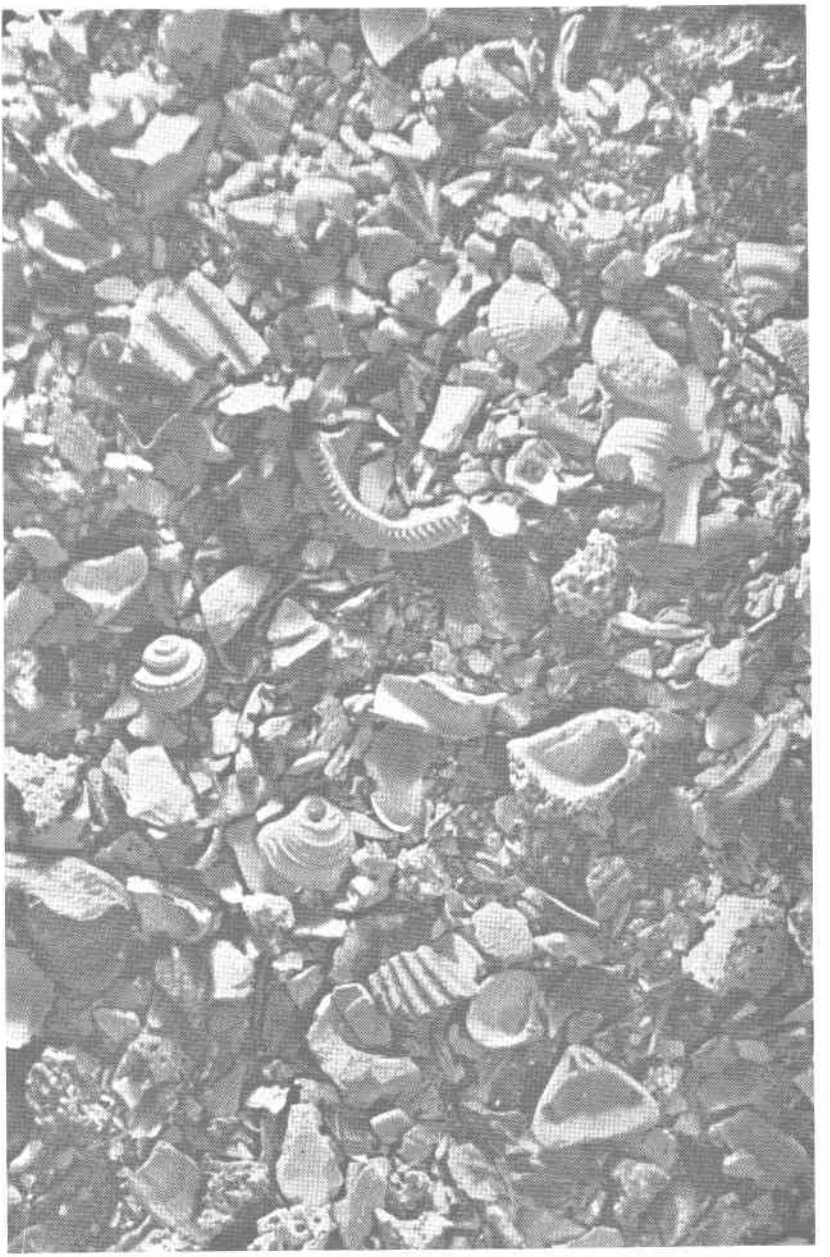
The quality of the shallow water varies from place to place. Where it lies considerably above the marl it is soft and has a pleasant taste. Where the wells reach or enter the marl the water may be hard and in some places contain enough iron to have an objectionable taste.

Accurate information on the amount of water obtainable from wells in sand and gravel is generally lacking. Although shallow ground water is used to good advantage by a number of small industrial plants, the wells supplying these plants are generally poorly constructed, of small diameter, and not equipped with proper strainers. Little is known of the specific yield of the wells, the capacity of the terraces to supply a moderately large quantity of water under continuous pumping conditions, or the variation in yield from place to place.

At the plant of the Diamond Springs Ice Company, in Princess Anne County, 5 miles east of Norfolk, 4 gravel-packed shallow wells (13b, Table 48) have yielded a total of 180 gallons a minute with a drawdown of 9 feet and have continued to yield this amount over a pumping period of 3 months. Similar yields probably can be obtained at many places elsewhere in the Coastal Plain of Virginia where large undissected terraces are present. Shallow well water should, therefore, be considered as a possible auxiliary supply in many places where a large volume of water is needed. It would appear that the full development and most economical utilization of shallow ground water are not being carried out at those establishments in the vicinity of Norfolk at which batteries of fifteen 1½-inch drive point or open-end wells yield a total of less than 50 gallons a minute. On the other hand, if relatively poor water-bearing strata are developed, and the yield of individual wells is limited by the character of the formation, larger supplies can be developed more economically by constructing a large battery of small-diameter wells with inexpensive screens rather than by installing fewer highly developed larger diameter wells.

The low temperature and low mineral content of the water and the economies attendant upon well construction and depth of water, are the factors which are generally recognized as favoring the use of shallow well water.

Shell marl encountered at 90 feet in test hole at Bacons Castle, Surry County.



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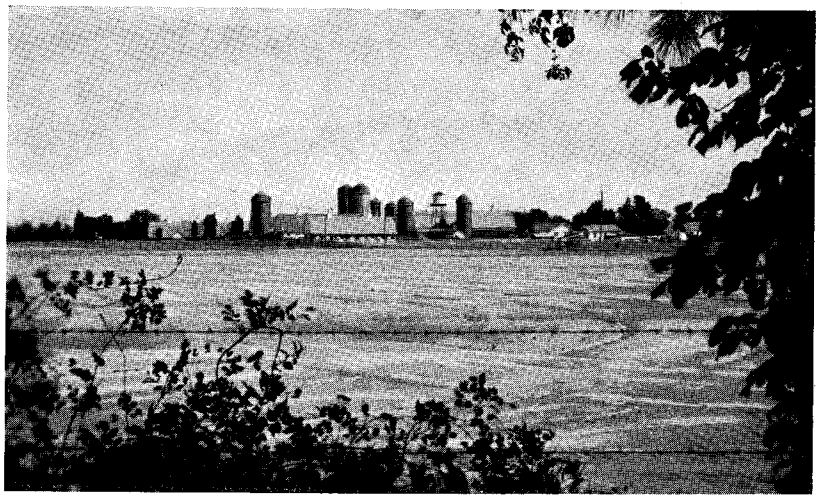
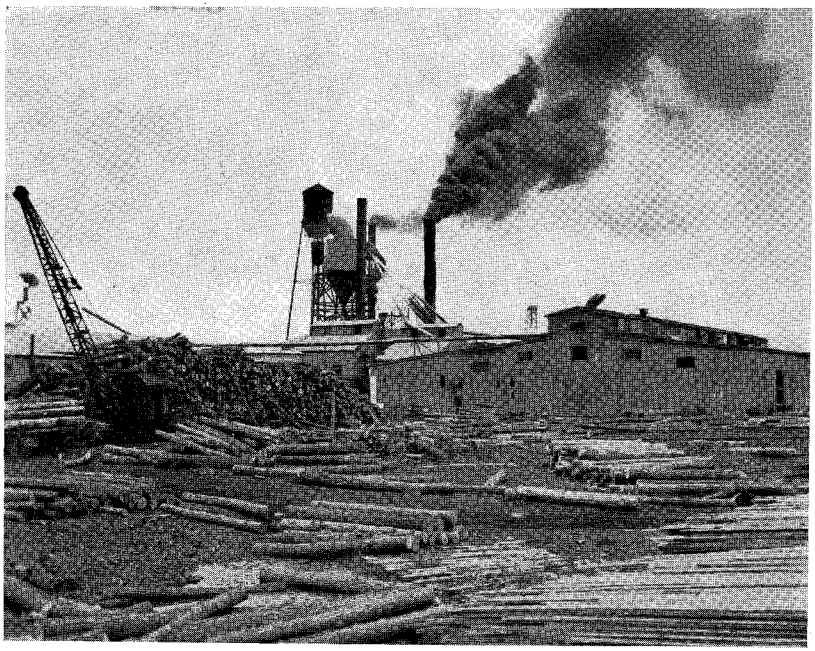


A.



B.

A, Dairy at Bayville Farm, near Ocean Park, Virginia. Many such enterprises depend entirely upon wells for water supply. B, Lumber mill in South Norfolk. Most small industrial plants in this area use ground water for boiler feed.

A.

B.

A, Dairy at Bayville Farm, near Ocean Park, Virginia. Many such enterprises depend entirely upon wells for water supply. B, Lumber mill in South Norfolk. Most small industrial plants in this area use ground water for boiler feed.

QUALITY OF GROUND WATER

During the period of field work, 137 samples of water were collected and were analyzed in the water laboratory of the Geological Survey. The analyses are given in tables following each county report. The tables also include several analyses from an unpublished report prepared in 1921 for the Virginia Geological Survey by H. B. Riffenburg of the Federal Geological Survey, on "Quality of the ground water of the Coastal Plain of Virginia," and a few analyses from other sources. These analyses form the basis for most of the discussion of the chemical character of the ground water given in the following pages. In addition, field tests made by the writer for total hardness and chloride have been used to amplify the "reported quality" of the records of individual wells included in the county reports.

Ground water in the counties covered by this report is derived from four main sources: the granitic bedrock, the Potomac group, the Chesapeake group, and the terrace formations of the Columbia group. A very few wells obtain water from strata of the Pamunkey group and in a few localities water is obtained from Upper Cretaceous deposits.

WATER FROM GRANITIC ROCK

Only a few analyses were made of samples of water from wells drilled into the granitic basement rock. These samples differed greatly in mineral content and in chemical character. Samples 123 (Table 22) and 64d (Table 19) were moderate in mineral content and compared favorably with water derived from the overlying sediments along the Fall Zone. Water from well 67 (Table 19) was moderately mineralized, and Sample 23 (Table 14), taken from the well at Chester High School, contained 857 parts per million of total dissolved solids, with 468 parts per million of sulfate. It is a sodium sulfate water. At the David M. Lea lumber mill, at the du Pont cellophane plant, and at the Greenleaf Dairy (wells 3, 8 and 38, Table 15) commercial analyses indicate that the water has a moderately high mineral content.

The hardness of the water from granitic rocks is usually carbonate or temporary hardness but water from a few wells may have noncarbonate or permanent hardness. The sample of water from Chester High School contained 188 parts per million of hardness, of which 85 parts are noncarbonate hardness. The water at Greenleaf Dairy, Chesterfield County, also contains appre-

ciable noncarbonate hardness, and moderate noncarbonate hardness may be found elsewhere in waters where high sulfate content is reported. Objectionable amounts of iron are reported in the water of some wells.

WATER FROM THE POTOMAC GROUP[a]

Three types of water are found in the Potomac group: soft water of low mineral and low bicarbonate content, found along the Fall Zone; hard calcium bicarbonate water of moderate mineral content, found in the west-central part of the area; and soft sodium bicarbonate water of moderate to high mineral content, found in the central and eastern parts of the area. Water of the third type generally contains one or more parts per million of fluoride and in a few places contains chloride in excess of 50 parts per million, in contrast to water of the other types, which is generally free from fluoride and does not contain more than a few parts per million of chloride. The areas in which the three types of water are found are not sharply defined, but are separated by gradational zones.

SOFT WATER OF LOW MINERAL CONTENT

Along the Fall Zone the waters are generally soft and are low in total dissolved mineral matter. (See Tables 14, 18 and 22.) The hardness of the samples examined ranges from 16 to 78 parts per million. Sulfate and chloride are low, being generally less than 10 parts per million.

In many places the waters contain considerable iron. At Stony Creek and Jarratt nearly all the wells are reported to contain so much iron that considerable difficulty is experienced in using the water for some cooking and most washing purposes. Upon standing, the iron settles out as a sludge or as a coating on the walls of the container. Thus far, no efforts have been made by water users to undertake simple aeration treatment of the water to eliminate this undesirable element.

Elsewhere along the Fall Zone, especially between Richmond and Petersburg, the occurrence of iron in water from the Potomac deposits is sporadic, and the iron is generally not present in objectionable quantities. It is believed that, in waters that contain objectionable amounts of this constituent, the iron is dissolved from the water-bearing formation, inasmuch as continued pumping

[a] May include water from Upper Cretaceous deposits in a few places, as at Franklin.

fails to obtain a water low in iron. The presence of iron oxides and ferruginous sediments in outcrops of the Potomac group has been noted in the literature, and these materials have also been reported in wells by drillers.

HARD WATER OF MODERATE MINERAL CONTENT

Hard waters of moderate mineral content are found in Prince George, eastern Sussex and western Southampton counties. (See Tables 18, 22, and 33.) Such waters generally have 130 to 190 parts per million of total hardness and 150 to 250 parts per million of bicarbonate. The total dissolved solids is generally of about the same order of magnitude as the bicarbonate and is made up predominantly of calcium and bicarbonate; the amount of sodium, potassium, sulfate, chloride and nitrate present is generally low.

It might be expected that the sulfate content would increase with the hardness as these waters migrate down dip and come into contact with various strata of clay and marl. However, this does not occur, the sulfate content remaining uniformly low, generally less than 15 parts per million. This is in contrast to shallow waters of low mineral content, which in many places contains more than twice that amount of sulfate. None of the water analyzed contained more than 0.4 part per million of fluoride.

Iron is not usually present in objectionable amounts. Of the five samples in which iron was determined, only one had more than 0.5 part per million. This sample (53, Table 18), from the well at Prince George Court House, had 2.4 parts per million of iron. The generally low iron content of waters a short distance east of the Fall Zone, along which waters containing iron are commonly found, may be due to the presence of hydrogen sulfide. This gas is present in the water of many artesian wells throughout the Coastal Plain area, and in some places may precipitate the iron from the water, as insoluble ferrous sulfide.

With the exception of the sample from a well at Bermuda Hundred (41, Table 14) which had 18 parts per million of free carbon dioxide, most of the water samples from the Fall Zone that were examined for free carbon dioxide had less than 5 parts per million in solution. The hardness and the bicarbonate content of these waters were about what would be expected if the free carbon dioxide in the waters of the Fall Zone were entirely utilized in dissolving calcium carbonate as the waters move eastward. For example, if the 45 parts per million of free carbon dioxide

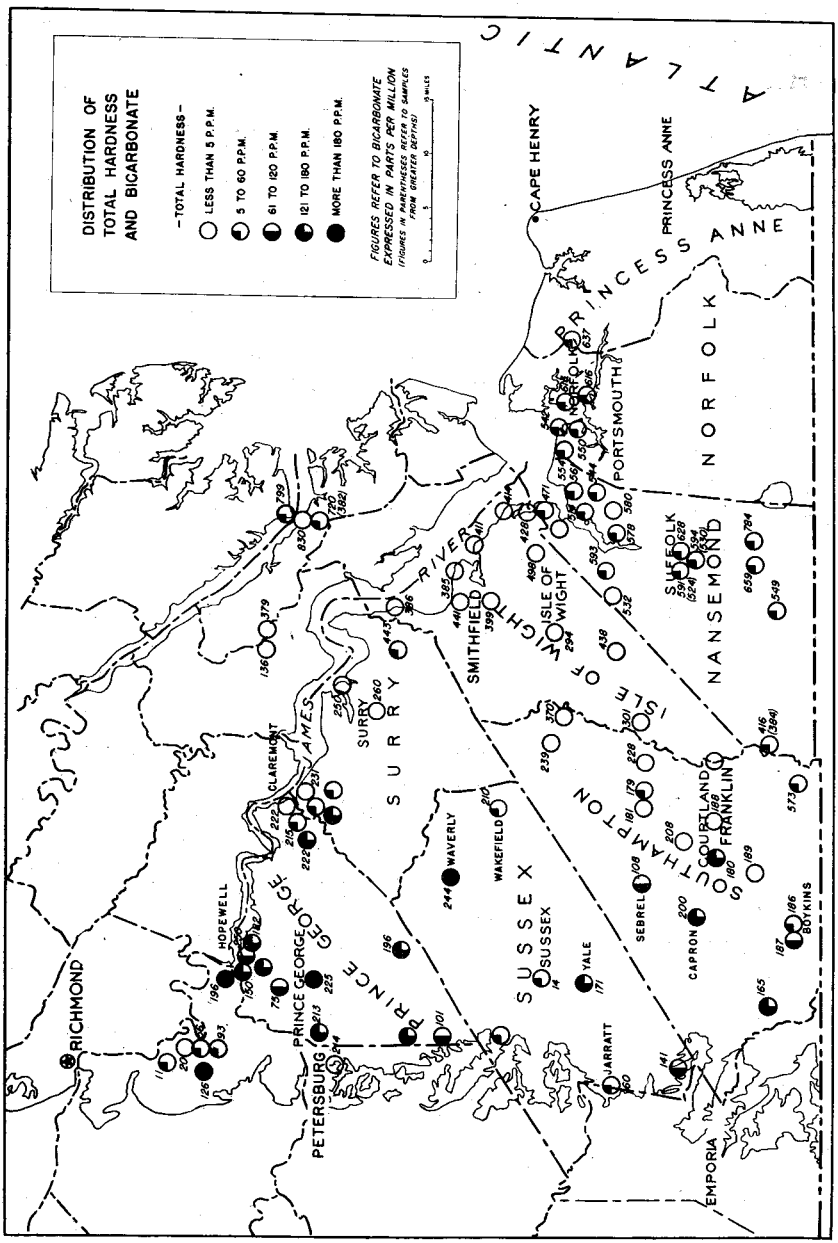


FIGURE 12.—Map of southeastern Virginia showing bicarbonate content and hardness of artesian water.

found in the Jarratt sample (132, Table 22) were to be entirely utilized in the solution of calcium carbonate, and if the hardness thus acquired were to be added to that of the water (32 parts per million), the maximum potential total hardness of the water would be about 139 parts per million—a hardness which is comparable to that of most of the waters in the hard-water zone. The maximum hardness found in this area was 185 parts per million in a sample (53, Table 18) from the well at Prince George Court House, and 186 parts per million in a sample (79, Table 22) from a well at Waverly. Thus it is probable that the increase in the hardness of the water with distance eastward from the Fall Zone may be attributed almost entirely to the action of the free carbon dioxide, carried in solution from the outcrop area, on calcareous material in the sediments. When the free carbon dioxide is used up in this way, there is no further increase in the hardness of the waters.

The western limit of the hard-water zone in some places extends up to the Fall Zone, as at Petersburg. Elsewhere, as in western Sussex County, it lies several miles eastward. The eastern limit may be indicated by a fairly straight north-south line 25 to 30 miles from the Fall Zone. Burrowsville, Waverly, Sebrell, Capron and Boykins lie along the eastern limits. Eastward from this line to the sea only soft sodium bicarbonate waters are found in the Cretaceous sediments.

SOFT WATER OF MODERATE TO HIGH MINERAL CONTENT

The third type of water found in the Cretaceous sediments is characterized by sodium bicarbonate rather than by calcium bicarbonate, the characteristic constituent of water in the hard-water zone. (See Tables 28, 32, 37, 42 and 47.) The content of the other constituents is low except near the coast, where chloride is present in significant amounts (Fig. 15) and a marked increase in sulfate takes place. (See Tables 42 and 47.) The amount of fluoride in the soft waters is much higher than in the hard waters to the west (Fig. 16). A large proportion of the samples analyzed had more than 3 parts per million of fluoride, and some had 6 to 8 parts per million.

The change in the character of the water in the Cretaceous sediments from hard calcium bicarbonate water to soft, sodium bicarbonate water appears to be abrupt in some places (Figs. 12 and 13). The

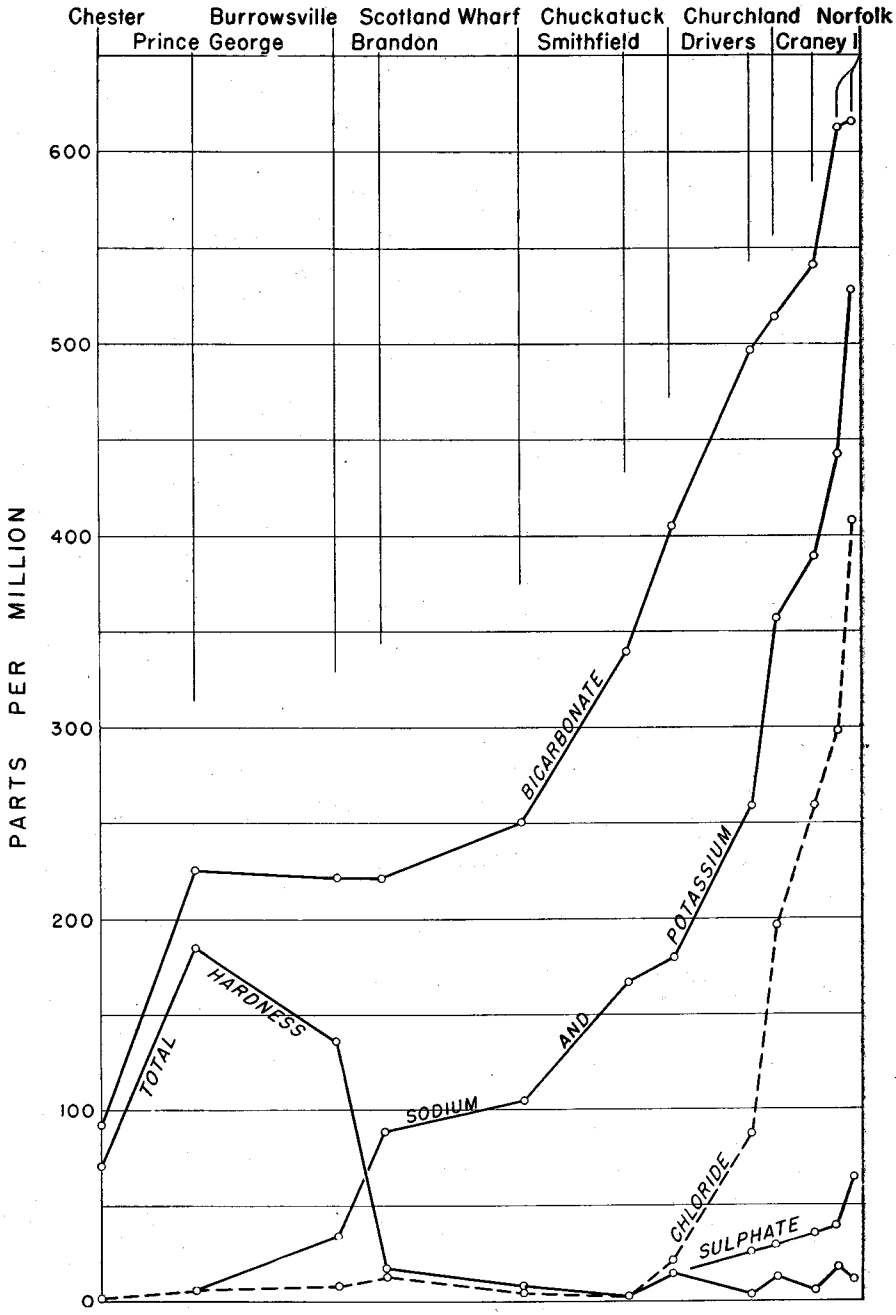


FIGURE 13.—Diagram showing progressive increase in chemical content, in parts per million, of artesian water east of the Fall Zone in southeastern Virginia.

nature of the change that takes place is demonstrated by water of intermediate character. Analyses of waters of this type, together with typical hard and soft waters for comparison, are shown graphically in Figure 14. Diagram A represents the water from the well at Prince George Court House (53, Table 18), a typical hard calcium bicarbonate water. Water from a well at Burrowsville (48, Table 18) is shown in

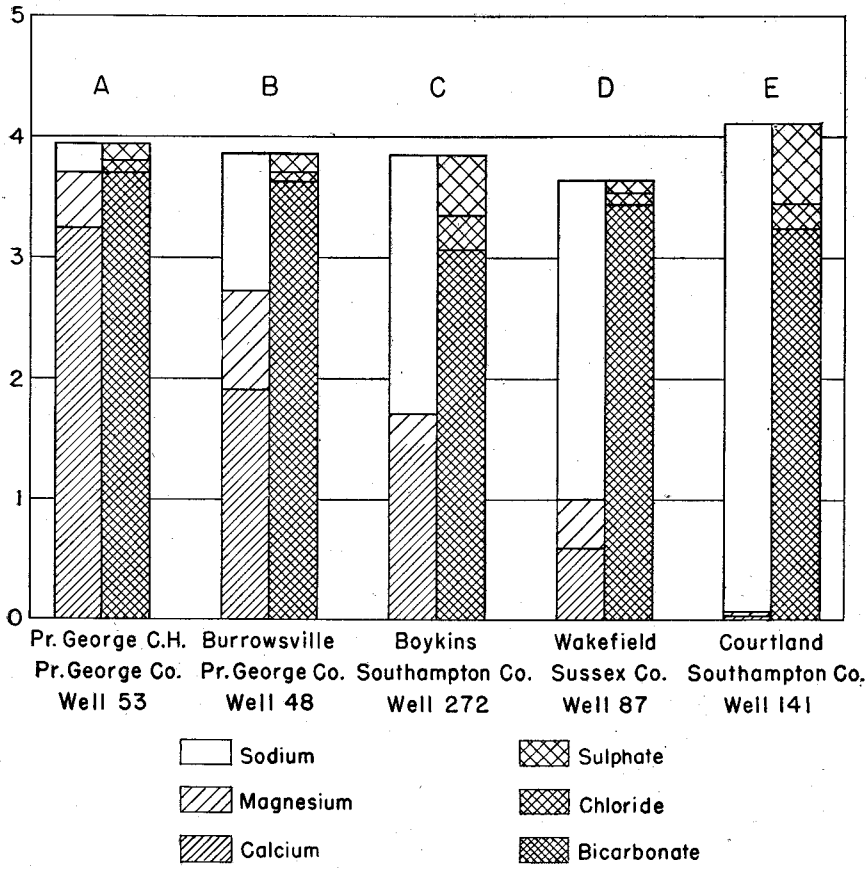


FIGURE 14.—Diagram showing analyses of water of high, intermediate, and low hardness in southeastern Virginia. Figures at left of diagram refer to equivalents per million.

Fig. 14, B. This is predominantly a calcium (and magnesium) bicarbonate water, but contains some sodium bicarbonate. The sample from a well at Boykins (272, Table 33 and Fig. 14, C) has about equal amounts of calcium (and magnesium) bicarbonate and sodium bicarbonate. The sample from a well at Wakefield (87, Table 22 and Fig. 14, D) is predominantly a sodium bicarbonate water but has con-

siderably more calcium (and magnesium) bicarbonate than the typical soft water in the soft-water zone, as represented by a sample from a well at Courtland (141, Table 33 and Fig. 14, E). These analyses show that the change in the character of the water is due to a decrease in calcium (and magnesium) content, accompanied by an equivalent increase in sodium, the bicarbonate and total mineral content remaining essentially unchanged. This alteration in chemical character of the water appears to be the result of base exchange and is discussed in more detail below.

Near the western boundary of the soft-water area the bicarbonate content of the waters is about the same as in the hard water area immediately to the west, but eastward the bicarbonate content (as sodium bicarbonate) increases until, in the vicinity of Norfolk and Suffolk, it is from 550 to 650 parts per million and the sodium content is from 200 to 250 parts per million. One sample of water from a well at Cypress (115, Table 42) had 784 parts per million of bicarbonate. Sanford[98] notes that these waters are practically dilute sodium bicarbonate solutions. The water tastes strongly of its mineral content.

The maximum potential bicarbonate content of waters from the Cretaceous deposits, originating from the free carbon dioxide in solution in it at the outcrop area, is about 200 parts per million. This is essentially the bicarbonate content of the hard calcium bicarbonate waters and of the soft sodium bicarbonate waters directly east of them. Amounts of bicarbonate above this figure, up to almost 800 parts per million in water in eastern Isle of Wight, eastern Nansemond, and Norfolk counties, therefore, do not appear to be caused by the solution of calcium bicarbonate through the action of free carbon dioxide in solution in the outcrop area. Hypotheses as to its source are presented in the section on the origin of the bicarbonates.

Objectionable amounts of chloride[22] are found in water from a few wells in the Norfolk area. Figure 15 shows that chloride in significant quantity first appears in waters along James River in Isle of Wight County, where 55 parts per million was found in the water from a comparatively deep well. In water from several wells in Nansemond County the chloride content approaches 100 parts per million, and in Norfolk County the chloride content of water from wells less than 750 feet deep may exceed 400 parts per million. In western Princess Anne County a sample of water from a well 1,723 feet deep (20, Table 47) contained 1,030 parts per million of chloride. In general the chloride content increases eastward and is greater in the deeper wells in any one locality. The chloride may be due to residual sea water, with which the

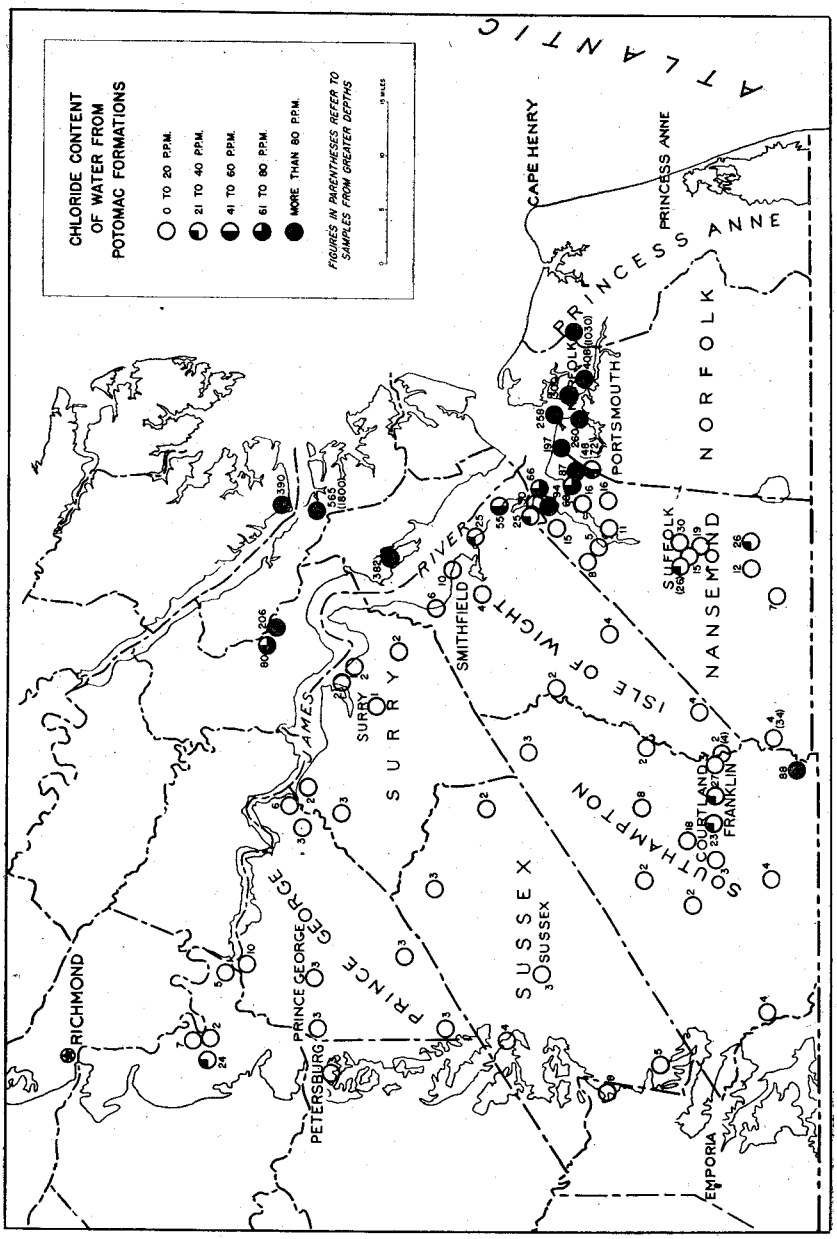


FIGURE 15.—Map of southeastern Virginia showing chloride content of artesian water.

sediments were once saturated. The relation of fresh water to sea water, as it applies to the Coastal Plain of Virginia, is discussed in a later chapter.

WATER SOFTENING BY BASE EXCHANGE

Base exchange, the reversible chemical process by which calcium and magnesium in rock material may be exchanged for sodium in solution, has been long recognized.[129, 139]

Sullivan,[126] in 1907, in addition to reviewing the literature, published the results of his own experiments on base exchange between solutions of salts of metals and finely ground minerals, particularly orthoclase.

Gans[66] may be credited with the idea of utilizing artifically prepared sodium base-exchange silicates for softening water.

Rideal[87] was apparently the first to suggest that water softening by base exchange may take place in nature, and cites as an example the occurrence of the mineral gaylussite, a hydrous carbonate of sodium and calcium, near Great Salt Lake, Utah, over which hard ground water passes and becomes a soft sodium bicarbonate water. The gaylussite is converted to calcium carbonate.

Sanford[97] in 1913 recognized the fact that the ground water of the Virginia Coastal Plain becomes soft down dip due to decrease in calcium content and increase in sodium content but had no explanation for the means by which this took place.

Other early workers in the Coastal Plain[40, 41, 65] do not discuss this feature of the chemical quality of the ground water.

In a discussion of the origin of certain oil field waters, Mills and Wells[79] suggest that the hydrated alkali aluminosilicates, which occur as disseminated constituents in shales and sandstones or in beds such as the bentonite deposits of the western United States, have functioned as base exchange media.

Widner[144] in 1917 and Wherry[143] in 1921 obtained patents on a processed clay which functioned as a water softener.

The discovery of the base exchange property exhibited by glauconite, a mineral which occurs rather abundantly in the Eocene formations in Virginia, initiated a new era in the use of a naturally occurring mineral for water softening. Shreve states:[119]

"Properly processed greensand occupies an unique position in the water-softener field. It has an extremely high rate of exchange, softening water as fast as it can be forced through it, and no synthetic zeolite has yet approached this speed of reaction. Its speed of regeneration

is equally great. It also is not sensitive to waters containing relatively large amounts of free CO_2, so prefiltration through marble beds is not required. Because of its relative non-porous structure it is not injured by iron bearing or moderately turbid waters. It has the same capacity for magnesium as for calcium. It is not injured by overrunning its rated capacity. It is extremely rugged and enduring in use. It is economical on salt consumption. . . . "

Renick[83] in 1924 briefly summarized the literature pertaining to base-exchange silicates and concluded that the hard shallow waters of the Lance and Fort Union formations in Montana had been softened by their passage through base exchange minerals of the leverierite group and perhaps other minerals.

More recently problems of base exchange have been given detailed study by petroleum geologists in connection with the origin of petroleum and oil field waters[10, 70, 127] and the control of swelling clays.[64, 82]

Even more recently, base exchange problems have been considered[63] in connection with coastal plain water-supply problems resulting from industrial expansion along the Atlantic and Gulf seaboards. In discussing the chemistry of ground water of the South Atlantic coastal plain Foster[62] states:

"Many waters of the area are sodium bicarbonate waters, and some contain approximately equal quantities of calcium and sodium.

"The same formation may yield waters of all these different types. In such a formation the calcium bicarbonate waters are usually the shallower waters, and the sodium bicarbonate waters are the deeper waters. The waters undergo an alteration in character with depth. The calcium and magnesium content decreases, the water becomes softer, and at the same time the sodium content increases, the bicarbonate and total mineral content often remaining about the same. . . . These waters appear to be the result of a secondary action between the waters and the rock materials—exchange of calcium and magnesium in solution in the waters for sodium of base-exchange minerals in the rock materials. Descriptions of the lithologic character of the formations of this area in geologic reports frequently note the fact that a certain formation is 'glauconitic.' Glauconite, or greensand, is a green granular silicate of potassium and iron that has pronounced base-exchange properties. . . . Certain hydrous alumino-silicates that are capable of base exchange, derived from the weathering of crystalline rocks, may also make up part of the clastic material of these sediments."

It seems probable that the Eocene glauconite deposits function as a water softener in the sediments of the Coastal Plain of southeastern Virginia. The glauconite sand that overlies the uppermost Cretaceous

water-bearing stratum is widespread. The sand itself is a permeable water-bearing formation (although never developed by the drillers in this area because it caves badly), and therefore it is probable that water that migrates down the dip in the higher Cretaceous deposits tends to move in and out of the overlying glauconite sand from place to place and be subject to such chemical action as the glauconite sand may exert upon it.

In many places, notably at Smithfield, the glauconite beds are separated from the sands of Cretaceous age beneath by a clayey material. In other places, as at Courtland, glauconite sands are absent. In such places the softening agent must be some other material. Water in the deeper sand beds of Cretaceous age has little or no contact with the Eocene glauconite deposits, and there, too, some other material must be active as a medium of base exchange. It seems probable that in the Virginia Coastal Plain clay has been a very important factor in converting hard calcium bicarbonate water to soft sodium bicarbonate water. Water migrating down dip comes into contact with the bounding surfaces of intercalated clay strata. In addition, many excellent water-bearing formations consist of quartz sand with considerable interstitial clay, and such formations are doubtless very active as softeners.

Data at hand indicate that water from the deeper strata is relatively softer than that which is derived from shallower strata in the Cretaceous deposits. East of Hopewell water from well 29, Prince George County, 240 feet deep, contains 147 parts per million total hardness as compared to water from well 28, 351 feet deep, which contains 110 parts per million. At Boykins and at Sedley, Southampton County, the deep water is softer than that occurring near the surface. At each of the 3 localities mentioned, both deep and shallow waters contain essentially the same amount of bicarbonate, so it may be presumed that both waters once contained essentially equal amounts of calcium bicarbonate, but that the deeper water has exchanged more of its calcium for sodium than has the shallow water. This may indicate that the deep water has had more opportunity to be acted upon, either because it has traveled farther, or because the ratio of the total water to the confining or interstitial clayey material which acts as a base-exchange medium is smaller.

The ability of a base-exchange mineral to exchange sodium for calcium is limited. Every commercial water softener working on a base-exchange principle must eventually be regenerated or replaced. Thus, water-softening material that occurs in nature necessarily has a limited period of activity, depending upon the amount and character of the unsoftened water which passes through it, and upon the amount and reactivity of the material.

The zone in which hard water in sands of Cretaceous age is softened extends from Brandon and Burrowsville, near James River, southward through Wakefield and Courtland to Newsoms near the Virginia-North Carolina line. In general the geology is the same immediately to the west and to the east of this zone. Beds of clay and glauconite sand which might act as water softeners occur on both sides of this boundary and extend westward into the hard-water area and, in some instances, all the way to the outcrop area (Fall Zone). Logs of wells within the hard-water area, at Hopewell, Disputanta, Waverly, Yale, Drewryville, Little Texas and Boykins, show that base-exchange material is present, either as clay intercalated in the Cretaceous deposits or as glauconite sand of Eocene age. Thus the conclusion may be drawn that in these areas the base exchange material has already been rendered nonreactive towards calcium bicarbonate water by giving up all or almost all the available sodium to water passing eastward.

The passage of water eastward will continue to convert sodium clay to calcium clay, and the boundary between hard and soft water will migrate eastward so that the hard-water area will increase at the expense of the soft water area. It is believed, however, that this migration of the boundary zone is very slow.

During Pleistocene time the terraces that now cover the surface of the Coastal Plain were formed. Although students of the terrace deposits disagree concerning details of the conditions under which the terraces were formed, all agree that the Coastal Plain area was invaded by marine water to a considerable extent. Clark and Miller state that even the high Sunderland terrace of Pleistocene age, which now lies 100-170 feet above sea level, was formed in large part by material deposited in marine water. Other authors believe that there was a late Pliocene submergence or a succession of Pliocene to Pleistocene submergences. In any event, at some time since the Pliocene the greater part of the sediments of the Coastal Plain probably were saturated with sea water, and there is reason to believe that following submergence the base-exchange materials in the Cretaceous and Eocene deposits were at their stage of greatest potential activity, as they were probably converted to sodium clay and sodium glauconite up to the Fall Zone. The conversion of these reactive sediments to nonreactive calcium clay and sand throughout a belt 10 to 20 miles wide east of the Fall Zone, therefore, may have taken place in a relatively short period of geologic time. Consequently, an appreciable flow of hard water must have passed through these sediments, which has probably been discharged either by submarine drainage along the continental shelf or by upward leakage through the

relatively impermeable Miocene marl cover in places where the artesian head is higher than the shallow ground-water level.

Although base-exchange materials are probably acted upon very slowly, it is possible that they may be rendered inactive more quickly along certain more permeable channelways. Well 257, south of Courtland, Southampton County, yields a relatively hard water and appears to indicate a reentrant of the hard-water area into the soft-water area. It is possible that much of the flow to the Courtland-Franklin discharge area passes this point and this may have created an intrusion of hard water, but it seems more likely that this irregularity of the hard-water boundary zone was created by differences in flow towards the ultimate discharge area to the east, rather than by the relatively small effects of recent developments.

BICARBONATES

It has been shown that ground water near the Fall Zone contains free carbon dioxide, and that as it travels eastward down dip the water increases in calcium bicarbonate content due to the reaction of the free carbon dioxide with calcareous material. About 250 parts per million of bicarbonate may be accounted for thereby. Not far from the Fall Zone the carbon dioxide is entirely converted to bicarbonate, and presumably further solution of calcium carbonate can not take place. The water, however, continues to gain in bicarbonate by taking into solution additional sodium bicarbonate. In Nansemond and Norfolk counties the bicarbonate content of water in most artesian wells ranges from 500 to 600 parts per million, and a well at Cypress yielded water containing 784 parts per million of bicarbonate.

Sanford[98] in 1912 recognized that as the water in the Cretaceous sands travels down dip it increases in total mineralization, notably in sodium bicarbonate. He states that:

"It is certain, however, that the waters in both the Potomac (Lower Cretaceous) and Upper Cretaceous beds show a progressive increase in mineralization toward the southeast. . . . The increase in bicarbonates is the most noteworthy feature. Waters which near the outcrop of the beds may be either soft or hard, take up bicarbonates, and if originally hard, become soft by losing much of the lime they contained . . . as a rule the artesian waters become more mineralized by taking up chlorine, bicarbonate, sulfate, and sodium radicle."

In a discussion of the causes of mineralization in the Norfolk-Newport News area, Sanford[100] says that the brackishness is due to

"the invasion of salt water from up the dip in times when the coast was depressed below its present level. Corresponding beds to the west have been more flushed by downward percolating rain water since the last elevation, hence now contain relatively fresh water."

This statement may be applicable to salinity but is inadequate to explain an increase in sodium bicarbonate, because marine water contains only about 150 parts per million of bicarbonate. The same objection might be made to any hypothesis involving the absorption of bicarbonate from marine water by clays, and later release of dissolved material as fresh water displaced the sea water.[126, 1]

Three sources of the high bicarbonate found in water of the Cretaceous deposits may be considered as follows:

1. Addition by downward percolating water: Analyses of water derived from Miocene formations indicate that their maximum bicarbonate content is nearly everywhere less than 350 parts per million. The addition of such water to water in Cretaceous strata, therefore, can not raise the bicarbonate content of the latter to any figure greater than 350 parts per million.

2. Solution of some bicarbonate mineral: Practically all the bicarbonate minerals found in nature have resulted from evaporation of saline solutions in closed basins. There are several objections to the possibility that such minerals may be the source of the high bicarbonate content of the water. First, no bedded deposits such as gypsum or halite or other minerals characteristic of evaporation of land-locked bodies of water have been found; second, the bicarbonate minerals are very soluble and would probably be quickly and entirely dissolved by the flushing action of ground water; and third, the evaporation of such coastal water as would produce bicarbonate minerals would also produce chlorides and sulfates which would affect the chemical quality of the water.

3. Action of free carbon dioxide liberated by organic matter in Potomac sediments: It has been shown above that the free carbon dioxide found in waters along the Fall Zone is converted to bicarbonate within a relatively short distance by reaction with limy sediments as the water passes down dip. However, it has also been found that small amounts of free carbon dioxide are present in water from the sediments of Cretaceous age a long distance down dip, far beyond where they should be entirely consumed in reaction with calcium carbonate. At Suffolk, Cypress, Drivers, and Norfolk, for instance, the free carbon dioxide content of the water samples examined ranged from 1.4 to 5.0 parts per

million. This carbon dioxide reacts with calcium carbonate to produce calcium bicarbonate, which in turn is converted to sodium bicarbonate by base exchange. The slight hardness found in some high bicarbonate water may indicate that a lag occurs between the conversion of calcium bicarbonate to sodium bicarbonate. Continuous generation of small amounts of carbon dioxide may thus contribute sodium bicarbonate to the water migrating down dip, and raise the concentration of that radicle far beyond the initial concentration of 250 parts per million.

Renick[84] has applied this hypothesis of sulfate reduction by carbonaceous material in explanation of certain high bicarbonate waters low in sulfate.

In a similar fashion[14] the carbon dioxide responsible for the bicarbonate content in excess of 250 parts per million in the Virginia Coastal Plain water may have originated from the action of organic matter contained in deeply buried Cretaceous sediments upon the sulfates in the ground water. It is probable that unless the sulfates were being continually broken up, they would increase to concentrations commensurate with the distance the water had migrated eastward of the Fall Zone. However, abnormally low sulfate content is characteristic where the high-bicarbonate water is not contaminated by marine water. Hydrogen sulfide is reported at many places, and methane was noted in one deep well at Indian Head, Maryland, which is also in the Coastal Plain province.

Rogers[91] and also Plauchud[81] note that in some waters bacterial action may be of very great importance in the reduction of sulfate. This process has been emphasized by Bastin[4]. Thiel's[128] experiments showed that natural unsterilized carbonaceous sediments with their normal bacterial flora are more potent agents in the reduction of meteoric sulfate solutions than the same sediments after biochemical reactions have been suppressed.

Waksman[138] points out that in the presence of cellulose as a source of energy and sulfate as a source of oxygen, methane, acetic and butyric acids are produced from the former and H_2S from the latter, and that carbon dioxide is liberated as this reaction occurs.

In view of the evidence at hand relating to the generation of carbon dioxide resulting from the chemical or biochemical reaction of sulfate with carbonaceous material, it seems possible that this process may account for the progressive increase in bicar-

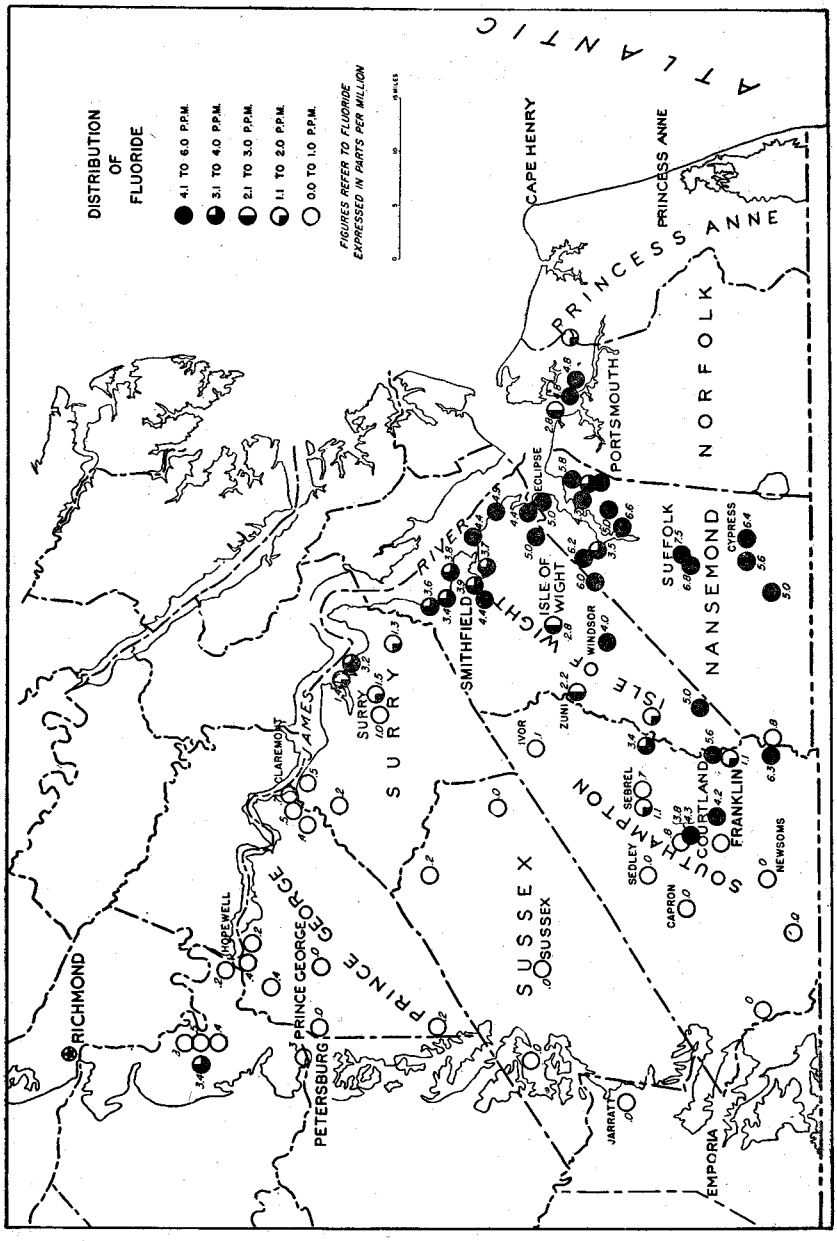


FIGURE 16.—Distribution of fluoride in ground water in southeastern Virginia.

bonate content of artesian waters east of the western boundary of the soft bicarbonate zone.

FLUORIDES

DISTRIBUTION AND SIGNIFICANCE

Figure 16 shows the areal distribution of fluoride in artesian water in southeastern Virginia. It will be noted that more than 1 part per million of fluoride is found only within the soft-water area. Not all of the soft sodium bicarbonate water contains more than 1 part per million of fluoride, however. At Brandon, Claremont, Wakefield, Ivor, Sebrell and Newsoms, all located along the western border of the soft sodium bicarbonate water area, the water contains less than 1 part per million of fluoride. At Scotland, Surry, Zuni, Sedley and Courtland, however, the water contains more than 4 parts per million. Farther east, at Franklin, Windsor, Smithfield, Chuckatuck, Suffolk, Drivers and Norfolk, fluoride in water from the Cretaceous deposits is found almost everywhere in concentrations greater than 4 parts per million. Water at Suffolk appears to have the highest fluoride content, 7.5 parts per million. A sample from the Craney Island well contained only 2.8 parts, however, and several wells along James River north of Smithfield yield water containing between 3 and 4 parts per million of fluoride.

A diagram, Figure 17, has been drawn showing the relationship of bicarbonate to fluoride content. In general the fluoride (in parts per million) increases in proportion to the bicarbonate content. A few exceptions are found, notably at Franklin and Courtland, where the amount of fluoride is considerably higher than normal with respect to the bicarbonate.

At South Quay, Franklin, Sedley, Eclipse, and Norfolk the deep artesian water appears to contain somewhat more fluoride than the shallow artesian water. This difference is not apparent at Courtland.

The presence of fluoride in ground water has caused a great deal of concern in many parts of the United States, and much attention is being devoted to its distribution, origin, and the effects of its consumption on human beings, particularly in relation to teeth.

It was demonstrated in 1931[121] that fluoride in drinking water at St. David, Arizona, was responsible for the prevalence of mot-

tled teeth in that community. H. Trendley Dean[53], of the United States Public Health Service, has described the effects of fluoride in drinking water on the teeth of children as follows:

" . . . from the continuous use of water containing about 1 part per million, it is probable that the very mildest forms of mottled enamel may develop in about 10 per cent of the group. In

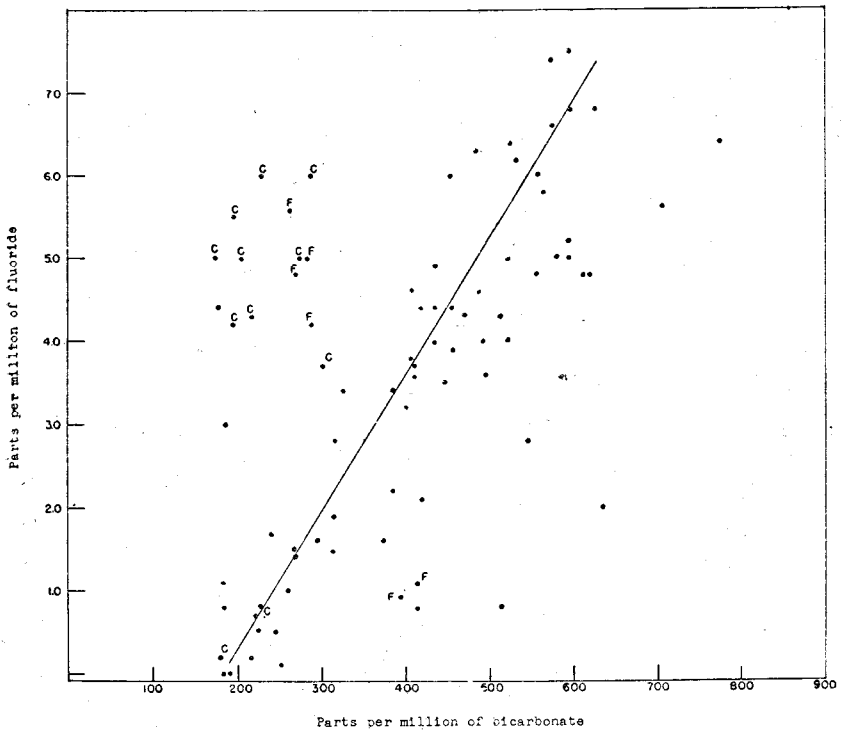


FIGURE 17.—Relation between fluoride and bicarbonate in sodium bicarbonate waters in southeastern Virginia. C, Courtland; F, Franklin.

waters containing 1.7 or 1.8 parts per million, the incidence may be expected to rise 40 or 50 per cent, although the percentage distribution of severity would be largely of the 'very mild' and 'mild' types. At 2.5 parts per million an incidence of about 75 to 80 per cent of all cases falling into the 'moderate' or severer type. A scattering few may show the 'moderately severe' type.

"At 4 parts per million the incidence is, in general, in the neighborhood of 90 per cent, and as a rule, 35 per cent or more of the children are generally classified as 'moderate' or worse. In

concentration of 6 parts per million an incidence of 100 per cent is not unusual. In other words, we are dealing with a low grade chronic fluorine poisoning of children."

Where small opaque, paper-white areas are scattered irregularly or streaked over the tooth surface and brown stain is rarely observed, the effect is classified[55] as very mild. In "moderate" cases, generally all tooth surfaces are white and opaque, brown stain is frequently a disfiguring complication, and minute pitting is often present. According to this classification, cases are classed as "severe" where the teeth are deeply pitted, often to such an extent that the outer surface of the enamel is lost in places, and stains are widespread and range from chocolate-brown to almost black.

The fluoride found in the water samples examined indicates that in a large portion of the southeastern Virginia Coastal Plain the water is unsuitable for drinking purposes for children up to 11 years of age. In many widely scattered localities well owners have reported cases of mottled enamel to the writer.

Samples taken from the Franklin and Smithfield public water supplies contained a high fluoride content. This was also true of the public school supplies at Courtland and Black Creek (east of Sedley) in Southampton County, at Windsor, Isle of Wight, and Carrsville in Isle of Wight County; and at Drivers, Cypress, and probably Whaleyville, in Nansemond County. In some places, however, the effect of the drinking water containing fluoride is minimized by the fact that many children also drink water from other sources which is free from fluoride.

Concerning remedial measures in an area which yields fluoride waters Dean states:

"The logical approach to the solution of this problem is, of course, avoiding the use of water containing fluorides in excess of the permissible limit. In some instances this can be accomplished by simply changing to a readily available source in the same neighborhood that is free of toxic amounts of fluorides . . . . . Where such changes are not entirely feasible, it may be possible in some cases, especially where the water contains less than 2 parts per million, to dilute an otherwise satisfactory water supply with another water that will bring the final fluoride content down within the permissible limits."

Although alternate sources of water supply are present practically everywhere in the affected area, it seems improbable that

present installations supplying water containing fluoride will be replaced by systems furnishing a fluoride-free water because of the expense which would be involved in such changes as well as for other reasons. However, some effort should be made toward this end. The situation would be improved by providing an approved bottled water for drinking purposes for children in the affected schools and in some homes.

More recently Dean[54] has pointed out that although more than 1 part per million of fluoride is detrimental to the teeth of children, less than 1 part is definitely beneficial in helping prevent tooth decay.

"It has been shown epidemiologically that school children using domestic waters containing as little as about one part per million of fluorine experience only half to a third as much dental decay as comparable groups using fluoride-free water, such as the Lake Michigan or the Mississippi River waters. Very recently confirmation of this inverse relationship has come from England, Northern India, and South Africa. * * * * Apparently teeth require traces of fluoride for optimum dental health although excessive amounts may result in the disfiguring condition known as mottled enamel. The difference between 0.0 and 1.0 parts per million of fluoride (F) in the domestic water supply has been shown to be highly significant from the standpoint of the amount of dental decay in a community."

Thus it is apparent that, although some communities suffer from an excess of fluorine in their public supplies, according to a more recent study, other communities may benefit from the presence of this element. The desirability of adding a relatively small amount of ground water containing fluoride to the reservoirs of fluoride-free surface supplies, such as the Norfolk and Portsmouth systems, should be kept in mind pending further investigations. Elsewhere it may be practicable for families who regularly use fluoride-free water to provide properly diluted high-fluoride artesian water for their children.

SOURCE OF FLUORIDES

The source of the fluoride found in ground water in parts of southeastern Virginia is not definitely known. It appears improbable that it is derived from granitic and metamorphic rocks by the solution of relatively rare fluorine-containing minerals, such as

apatite, or from sedimentary rocks containing concentrations of such minerals. If the fluoride had been derived from either of these sources its distribution in water would probably be more irregular and extend generally eastward with diminishing concentrations from the source areas or would follow either lenses or stringers of stream-laid sediments. Further, there are no data at hand thus far which suggest that concentrations of fluorine-bearing minerals are present in the sediments of the Coastal Plain.

Instead, fluoride-bearing water is found throughout a wide area within the high sodium bicarbonate zone. This distribution suggests that the waters derive fluoride from some material commonly present, which is more soluble in a sodium bicarbonate solution than in a calcium bicarbonate solution.

A source of fluoride which is suggested in Clarke's[23] discussion of the phosphates seems worthy of consideration. He points out that the larger calcium phosphate deposits (phosphorite) are probably all of marine origin, and the purest phosphorites approach fluorapatite in composition ($Ca_5(PO_4)_3F$). It has been suggested[13] that phosphatic Eocene and Miocene pebbles function similarly to the phosphatic Hawthorn formation of Florida, which has been indicated to be the source of fluoride found in ground water in that state[5, 125]. Even assuming that sufficient amounts of these deposits are present to furnish the fluoride, however, it is difficult to see how some water in deep strata of the Potomac group of Lower Cretaceous age could have derived its fluoride content from Eocene or Miocene strata. Percolation tests were made by M. D. Foster in the Geological Survey laboratories on samples of Eocene glauconite sand collected by the writer during the drilling of a deep well at Smithfield. This sand yields a few parts per million of fluorides when subjected to the action of soft sodium bicarbonate water, hard calcium bicarbonate water, and distilled water free from carbon dioxide.

This positive evidence is believed applicable only in part to the occurrence of fluoride in this area because in several places the shallower artesian water, derived from a white quartz sand lying immediately beneath the greensand, contains considerably less fluoride than does the deeper water.

E. S. Shepherd[118] published fluorine analyses on a variety of materials, including certain marine muds, as given in Table 11.

TABLE 11.—*Content of fluorine in ocean bottom samples*

Carnegie Station	Type of sediment	Per cent F_2
6	Terrigenous	0.053
43	Globigerina ooze	0.028
44	Globigerina ooze	0.033
51	Globigerina ooze	0.054
60	Globigerina ooze	0.035
62	Globigerina ooze	0.033
67	Globigerina ooze	0.032
113	Terrigenous	0.029
116	Terrigenous	0.020
117	Red clay	0.033
119	Diatomaceous-terrigenous	0.032
127	Blue mud	0.072
131	Red clay	0.071
132	Red clay	0.069
133	Red clay	0.071
136	Red clay	0.086
137	Red clay	0.033
151	Red clay	0.114
156	Red clay	0.050
157	Globigerina ooze	0.010
160	Globigerina ooze	0.038

He also states that "the type of bottom is evidently important. Thus globigerina ooze, being largely calcium bicarbonate, might be expected to hold some excess of fluorine, but obviously calcium fluoride is too soluble in sea water to permit this. On the other hand, the aluminum clays retain larger amounts."

C. S. Ross has called the writer's attention to an unpublished analysis of clay from Hector, Calif., which contains 5.96% fluorine.[a]

Possibly some of the clay beds in the Potomac formations of southeastern Virginia may contain significant amounts of fluorine. Analyses of samples of the clay are lacking, however.

On the basis of the known association of fluorine with volcanic activity,[145] and on the basis of a few analyses[117] for fluoride content which have been made on volcanic ash, it may be suggested that beds of such nature in the Potomac group may furnish fluoride to the ground water. Maher[71] discusses fluoride-bearing water derived from Miocene formations of Louisiana which consist chiefly of sand and clay, with considerable tuffaceous material. No ash beds or clay strata containing volcanic ash have thus far been reported from the Virginia Coastal Plain, although they may be present in the Cretaceous deposits in an altered condition.

[a] Analyzed by R. E. Stevens, U. S. Geological Survey.

The possibility that micas in the water-bearing sand may furnish the fluoride found in the ground water should be emphasized. A great many samples of Cretaceous water-bearing sands contain an appreciable amount of muscovite, and micaceous sand has been reported in many localities by well drillers. Published analyses of 11 samples of muscovite from widely scattered localities[46] indicate that muscovite ordinarily contains fluorine. The fluoride content of the analyses cited ranged from 0.12 per cent to 1.26 per cent. The average of these samples was 0.575 per cent fluorine. Sericite mica is shown to contain considerably more fluorine; 7 samples contained an average of 4.60 per cent. In the absence of information to the contrary, it seems possible that the fluoride content of artesian waters in the Virginia Coastal Plain has been derived, at least in part, from muscovite and sericite micas in the water-bearing sand.

Samples of water from the Petersburg State Colony well and the Chesterfield High School well, both of which penetrate granitic bedrock, contain high fluoride contents, respectively of 7.7 and 3.4 parts per million. This fact further suggests that some mineral disseminated throughout both the water-bearing sand and the granite is the source of the fluoride.

The occurrence of high fluoride in water derived from granitic rocks along the Fall Zone and in the soft-water area to the east, with the absence of fluoride in the intervening hard-water zone, appears to indicate that the solution of fluoride is inhibited in the moderate or high calcium bicarbonate waters. If fluoride were present in greater amount or in more soluble form in the source material, it might also be found in the hard waters since some calcium bicarbonate waters elsewhere in the United States contain a few parts of fluoride.

CHLORIDE

The presence of chloride in some of the deep Coastal Plain waters has long been recognized. Analyses and field tests show that water excessively high in chloride is found in this area only in an artesian well at the Norfolk City Waterworks at Moores Bridge, in western Princess Anne County. This well yields water containing 1,080 parts per million of chloride. (See analyses 20, Table 47.) Water encountered at 738 feet contained 112.33 grains per gallon of sodium chloride, or about 1,160 parts per million of chloride, at the time the well was drilled.[51]

Other wells south of the James are developed in the higher horizons and yield water with only a moderate chloride content. The well at Lamberts Point, Norfolk, 616 feet deep, yielded water containing 351 parts per million of chloride (9, Table 47) in 1891[51]. In 1939 water from the same well contained 300 parts per million of chloride. A 720-foot well at the warehouse of the Old Dominion Peanut Company yields water containing 408 parts per million of chloride (14, Table 47). At Craney Island, however, a 590-foot well yielded water containing 258 parts of chloride (7), and at West Norfolk a 605-foot well yields water containing 260 parts per million of chloride (8).

Lower, but still considerable, quantities of chloride are found in the water of some wells as far west as Isle of Wight County (see Fig. 15), and 196 parts per million is present in the water at Twin Pines, western Norfolk County (4, Table 47). In northeastern Nansemond County isolated wells in an area of very low chloride content yield water containing from 60 to 100 parts per million (29, 30, 63, 65, Table 42). One sample from a well in Isle of Wight County along James River contained 55 parts per million of chloride (111, Table 37).

The occurrence of chloride may be summarized, therefore, as follows: artesian wells more than 700 feet deep in the Norfolk area yield slightly brackish water; wells of lesser depth in Norfolk yield water containing a moderate amount of chloride; and along James River in Nansemond and Isle of Wight counties the chloride content is generally not more than 20 to 30 parts per million, though a few wells may yield water containing as much as 100 parts per million.

RELATION OF FRESH WATER TO SEA WATER

J. S. Brown[6] has stated that the relation of ground water near the coast to sea water is as follows:

"Wherever a coast is formed of pervious rocks containing ground water that receives continual additions from rainfall, this ground water must move downward and laterally toward the shore and mingle ultimately with the salt water of the sea. Such movements have long been a matter of common knowledge. Even on small, porous, sandy islands fresh water can generally be found at an altitude slightly above mean sea level. It might be supposed that in such places the salt water surrounding the island would penetrate the sand to mean sea level and immediately absorb all the fresh water that might percolate downward to its surface. For several physical reasons this does not happen. Such islands are found, in reality, to contain a dome-shaped lens of fresh water

floating upon a concave surface of salt water because it has a considerably smaller density."

This relation of fresh water to salt water was discovered by Badon Ghyben in Holland in 1887, and independently by B. Herzberg of Berlin in 1900, who apparently had no knowledge of the work of Badon

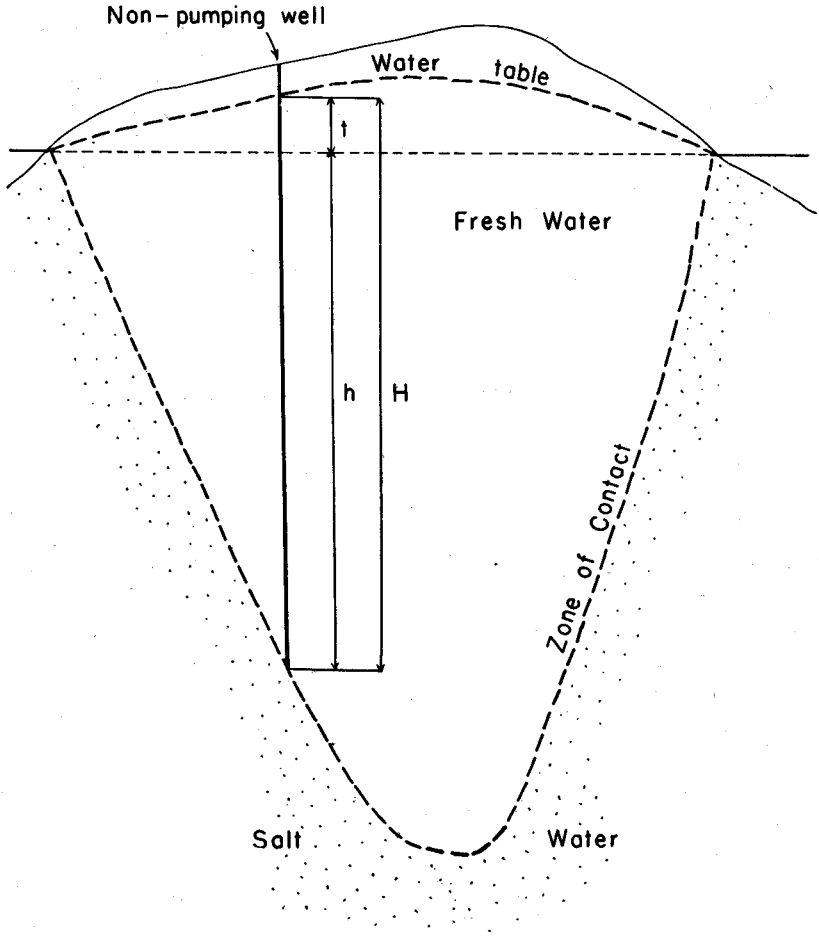


FIGURE 18A.—Diagram showing the relation of fresh water to salt water in a sandy island. H, Total thickness of fresh water; h, depth of fresh water below sea level; t, height of fresh water above mean sea level.

Ghyben. Herzberg found in drilling wells on the island of Norderney, one of the East Frisian islands off the coast of Germany, that the depth to salt water was roughly a function of the height of the water table above mean sea level and of the density of the water of the North Sea.

The following explanation is given by Brown[7] of the relation between salt water and fresh water under a small sand island, and is applicable to Figure 18A.

Let H=total thickness of fresh water.
h=depth of fresh water below sea level.
t=height of fresh water above mean sea level.
Then $H=h+t$

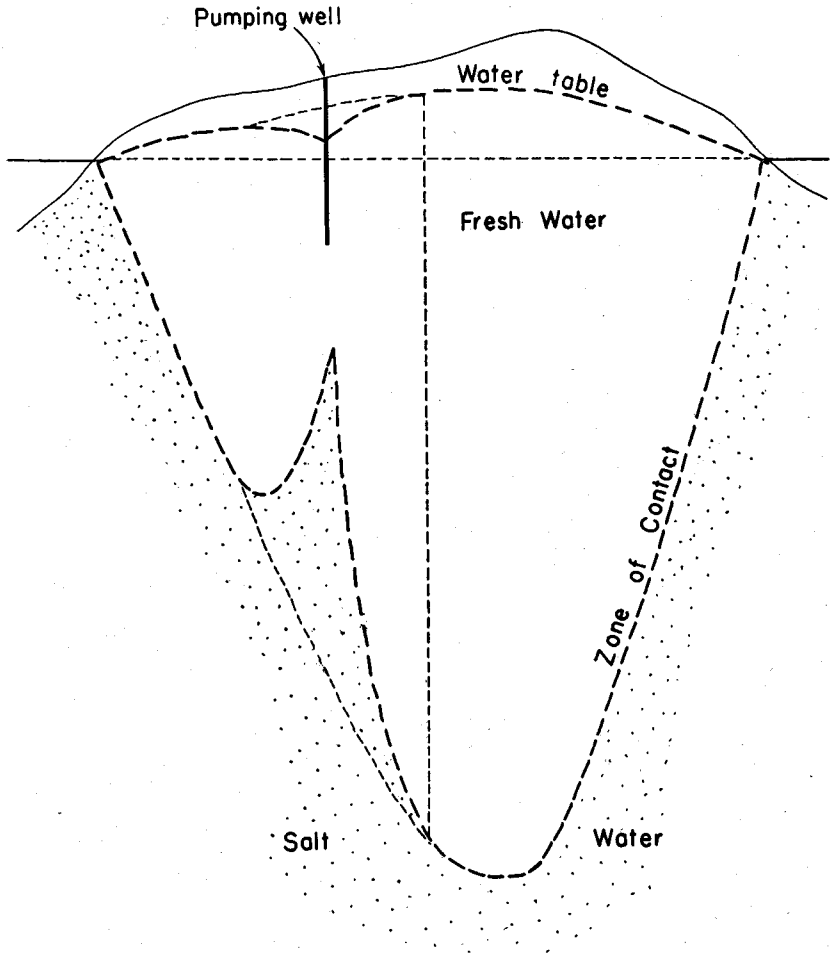


FIGURE 18B.—Diagram showing the relation of fresh water to salt water in a sandy island, under pumping conditions.

But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Wherefore, if g is the

specific gravity of sea water and the specific gravity of fresh ground water is assumed to be *1*,

$$H=h+t=hg, \text{ whence } h=\frac{t}{g-1}$$

In any case $g-1$ will be the difference in specific gravity between fresh water and the salt water.

If it is assumed that the specific gravity of sea water is 1.025, which is about an average figure, then $h=40\pm$. In other words, for every foot that fresh water stands above sea level, it extends 40 feet below sea level.[a]

The corollary of this principle is that if the height of water above sea level is lowered one foot, as by pumping, then the salt water boundary will rise 40 feet. This is shown in Figure 18B.

APPLICATION OF THE THEORY

The original theory of Ghyben and Herzberg has been adapted to apply to artesian waters along the coast of New Jersey[2] by workers investigating the incursion of salt water into wells near Atlantic City. Figure 19A shows the relation between fresh water and salt water under artesian conditions when not disturbed by pumping. The piezometric surface is a pressure-indicating surface, an imaginary plane denoting the elevation to which water would rise if the casings of flowing wells were extended upward. In areas of higher elevation the piezometric surface is the actual static level in a non-flowing well. In Figure 19B the line representing this surface is the hydraulic gradient of the water in the sand. There is no flow in the upper sand, conditions are static, and therefore the piezometric surface is level. The fresh water in deeper sand, however, is under greater head and discharges as a submarine spring. Hence, due to the loss of pressure at the point of discharge, the piezometric surface slopes in that direction. The upper sand crops out at a lower elevation and hence has a smaller column of fresh water to counterbalance the sea water, so the salt-water contact is relatively nearer the surface (farther up dip) than is true of the deeper sand. Barksdale and others[3] state:

"Any general lowering of the head of the fresh water in a sand exposed for a part of its extent to the waters of the ocean will permit

[a] This ratio is so extreme that it is not practicable to show it in the various parts of Figure 18 and for convenience the figure has been drawn with a ratio of 1 to 10 between the head and depth of the fresh water. Figure 19 is drawn with a ratio of 1 to 5.

the salt water to advance farther inland and occupy more of the land. The lowering may be caused by natural conditions, such as a dry year, or a series of dry years, but lowering due to such causes is not likely to have any serious consequences unless it occurs in conjunction with artificial withdrawal of water from the sand . . . either by pumping or by the natural flow from artesian sands."

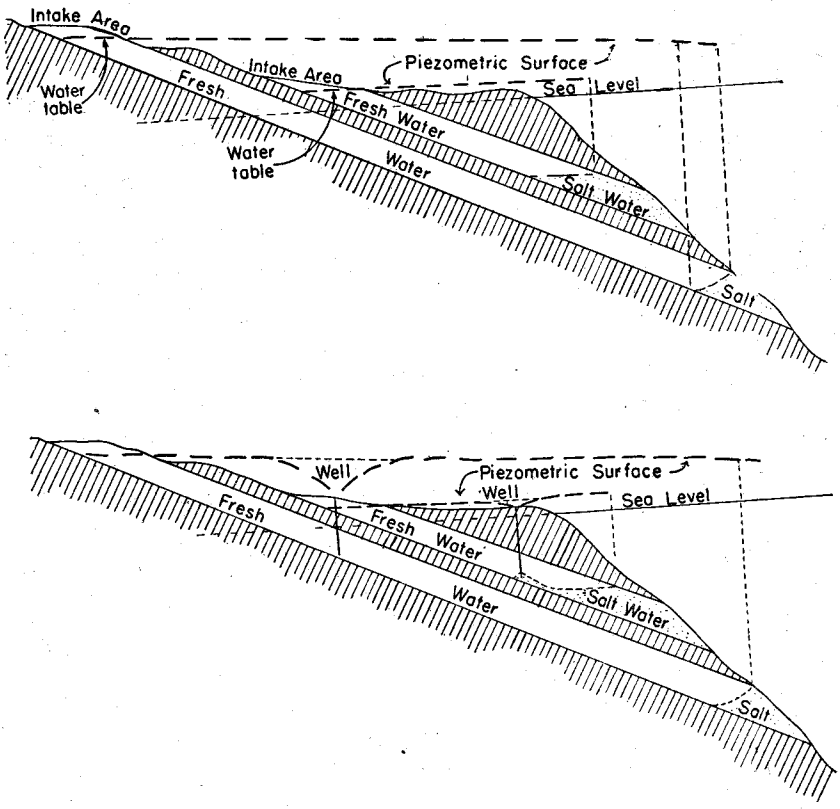


FIGURE 19.—Diagrams showing the relation of fresh water to salt water in the artesian part of the Coastal Plain. (New Jersey Water Policy Commission Special Report No. 6, Figs. 5 and 6.)

Under artesian conditions pumping may have either of two effects. If a cone of depression occurs above or extends beyond the zone of contact, it will disturb the balance between fresh and salt water and permit the salt water to move up through the formation toward a well. In the upper sand, Figure 19B, the cone of depression has extended over the zone of contact, and an intrusion of salt water has taken place and contaminated the well. In the lower sand, however, a cone of

depression has been created but does not extend to the zone of contact of fresh water with salt water, and up-dip migration of salt water has not taken place. Although movement of salt water up dip is blocked by the presence of water under strong head between the well and the lower outcrop of the water-bearing sand, it should be noted that if the cone of depression became sufficiently deep and wide by prolonged heavy pumping, it could extend to the zone of contact and create a salt-water intrusion.

Data given by Darton[51] indicate that the water level at the Lamberts Point well (9, Table 43) was originally about 35 feet above sea level. Water levels in Isle of Wight County were at least that high and probably were higher. Eastward to the edge of the continental shelf the height to which artesian water will rise is not known, but it is believed that over the wide continental area covered by the sea, the piezometric level is at about the same elevation as was determined at Norfolk in 1892.

If we assume that the water level was probably not greater than 40 feet above the sea anywhere in the Norfolk area, then according to the principles of Ghyben and Herzberg the salt-water contact should be encountered at a depth of about 1,600 feet. The Norfolk City Waterworks well (20, Table 43), 1,762 feet deep, encountered a large flow of "very salt water" at 1,480 feet but it is not known whether this approached sea water in composition, or was merely brackish.

Water levels in the vicinity of Norfolk and the area to the west, have changed considerably during the last 30 years. Along James River there has been a considerable withdrawal of water by flowing wells, estimated for Nansemond and Isle of Wight counties as about 5,000,000 gallons a day. The artesian head has decreased, but in 1937-38 was measured as about 30 feet above sea level in Nansemond County (along the river) and 22 to 24 feet in Isle of Wight County. The salt water contact should, therefore, be respectively about 1,200 feet and 960 feet below the surface in those areas.

The writer is inclined to believe that although brackish water undoubtedly is present, sea water does not underlie that portion of the Coastal Plain now above sea level. This belief is based upon the reasoning that across the continental shelf area, extending 60 miles out to sea, the piezometric surface probably is still relatively high and acts as a fresh-water barrier to the incursion of sea water. The Norfolk area is interpreted to occupy the position of the upper (left hand) well in Figure 19B, where the cone of depression does not extend to the zone of contact of fresh water with salt water and the lowering of water

levels has not brought about any upward shift in the contact between salt water and fresh water.

Evidence for this belief is seen in the unchanging quality of water of many wells although considerable losses of head have taken place. No change in the chloride content has been noted since 1923 in the well of the Virginia Smelting and Refining Company at Port Norfolk (8, Table 43), in spite of periods of fairly continuous pumping averaging 30,000 gallons a day.

As mentioned above, water from a flowing well at Lamberts Point was found to contain 351 parts per million of chloride in 1891 (9, Table 47). A sample of water from the same well in 1939 contained 300 parts per million of chloride. The deep well water (20, Table 47) at the Norfolk City pumping station contained 1,100 parts of chloride in 1896; 920 parts of chloride in 1904; and 1,000 parts per million in 1906. A sample collected in 1939 contained 1,080 parts per million of chloride. These differences are not considered significant.

Sanford's[101] conclusions in 1912 were that the salinity of the deeper waters is due to the presence of incompletely flushed strata which at one time contained sea water. Deeper strata and strata down dip in general have been flushed least, hence in some areas salinity increases with depth. Heavy pumping will tend to create a cone of depression and draw in water from down dip and from greater depths, and in some areas there may be danger of a gradual increase in chloride from this cause.

It was found[19] that when artesian wells in the Ft. Eustis area, Warwick County, were overpumped during the drought of 1941-42, as evidenced by the continuous decline of water levels in a near-by observation well, marked temporary increases in the chloride content of well waters occurred. The increases in chloride content are regarded as due to the migration into the well field of more brackish waters from down dip or from depth.

WATER FROM THE CHESAPEAKE GROUP

The water obtained from the deposits of the Chesapeake group of Miocene age is generally designated hard. The total hardness of the samples analyzed ranged from less than 100 to more than 300 parts per million, and was present mostly as carbonate hardness. A sample of water (10a, Table 46) from the 135-foot well of the Ideal Laundry at Norfolk contained 15 parts per million of free carbon dioxide, but a sample of water (40, Table 41) from Miocene strata at Drivers contained no free carbon dioxide. Water from the former well had a total

hardness of 117 parts per million, whereas the water from the latter well had a total hardness of 349 parts per million, the maximum hardness found in any water sample from Chesapeake strata. Other things being equal, it is to be expected that the water containing no free carbon dioxide should have the greater total hardness, as free carbon dioxide is consumed in the solution of limy material.

The chloride content is less than 100 parts per million in most places, and no difficulty with salty or brackish water has been reported. Iron is present in objectionable amounts in some places and exceeds 5 parts per million in 2 samples analyzed (40, Table 41 and 10a, Table 46). In many places, however, iron is not present in the water in sufficient amount to be objectionable. Silica is said to be present in undesirable quantities in many well waters that are used for boiler feed in the vicinity of Norfolk.

Although water from the Miocene deposits is hard and may contain undesirable amounts of silica and iron, it is successfully used for boiler feed by eight firms in South Norfolk and by one firm in Portsmouth. (See Table 43.) The water forms scale if used raw, and in every instance the water is treated before use.

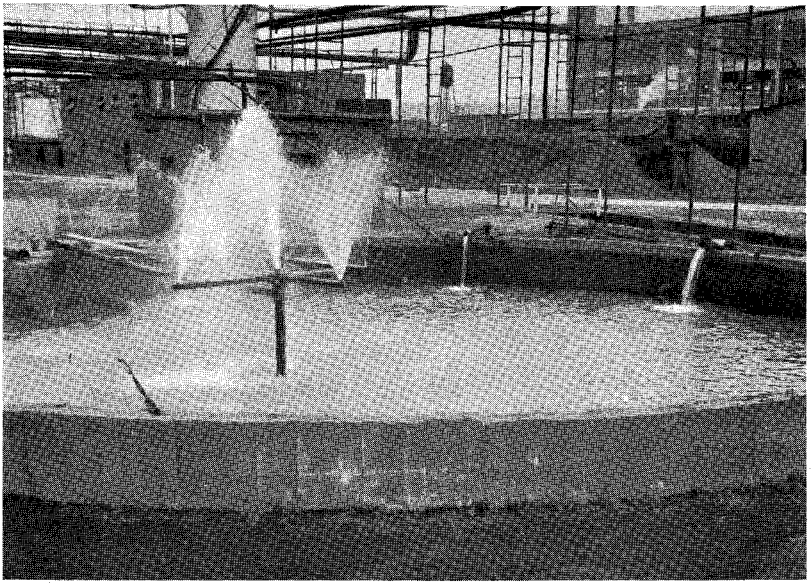
Where used in laundries, the water is treated to remove iron and hardness. The high calcium bicarbonate water is excellent for irrigation.

WATER FROM THE COLUMBIA GROUP

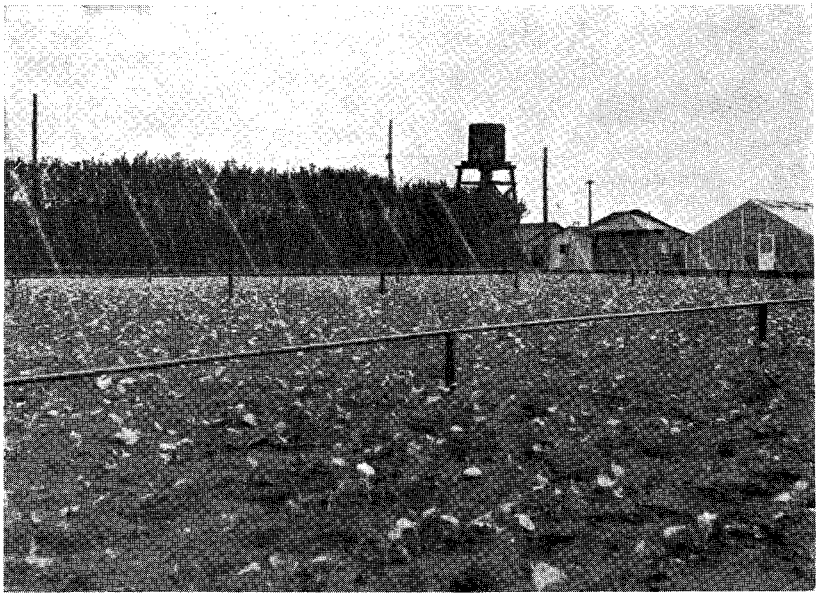
Almost everywhere throughout the area studied, water from terrace sands of the Columbia group of Pleistocene age is obtained by the rural population from wells less than 30 feet deep.

The water obtained from these shallow wells has a low mineral content. This is particularly true in the westerly tier of counties. (Tables 14, 17, 26, 31). The water is generally soft, the total hardness seldom exceeding 50 parts per million. The bicarbonate content may be very low and less than the chloride or sulfate. In Nansemond, Norfolk and Princess Anne counties the low terraces, in part at least, are composed of marly material, and the water derived from them (Tables 41, 45, 50) is generally harder than the water from higher terraces composed largely of sand. Chloride is higher in the water from these easterly counties and may be more than 100 parts per million. Bicarbonate may be moderate (as compared to total hardness) or very low, and may be less than chloride or sulfate.

In all the counties the nitrate content in shallow waters may be high. Nitrate is the final oxidation product of nitrogenous organic mat-

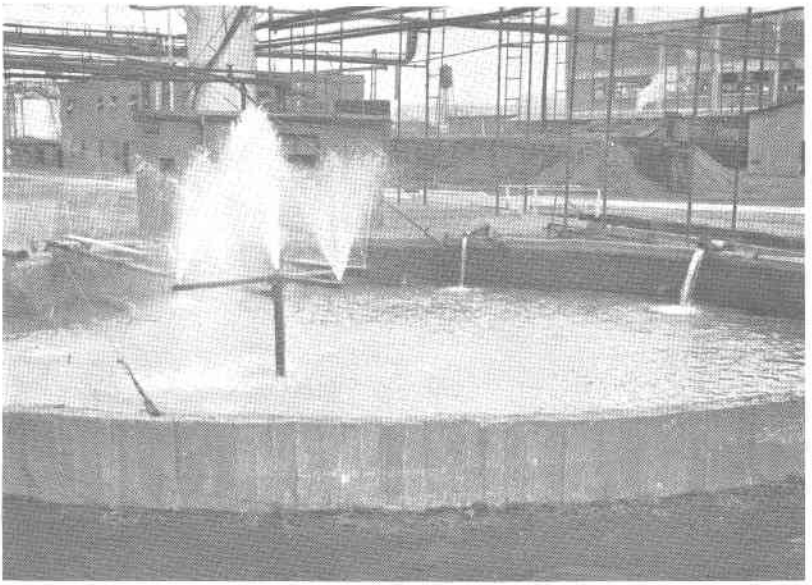


A.

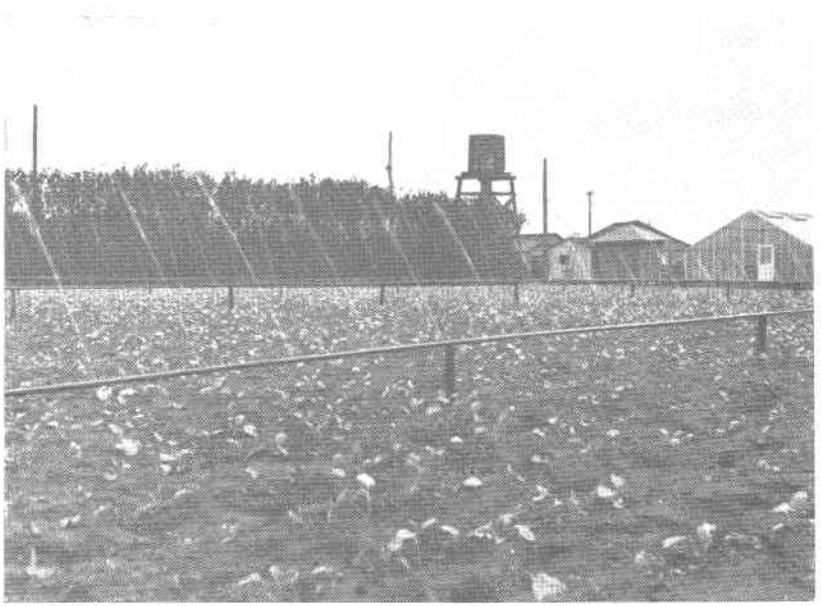


B.

A, Cooling system of a factory which uses ground water, at Portsmouth, Virginia. B, Truck farm using ground water for overhead irrigation, near Portsmouth, Virginia.

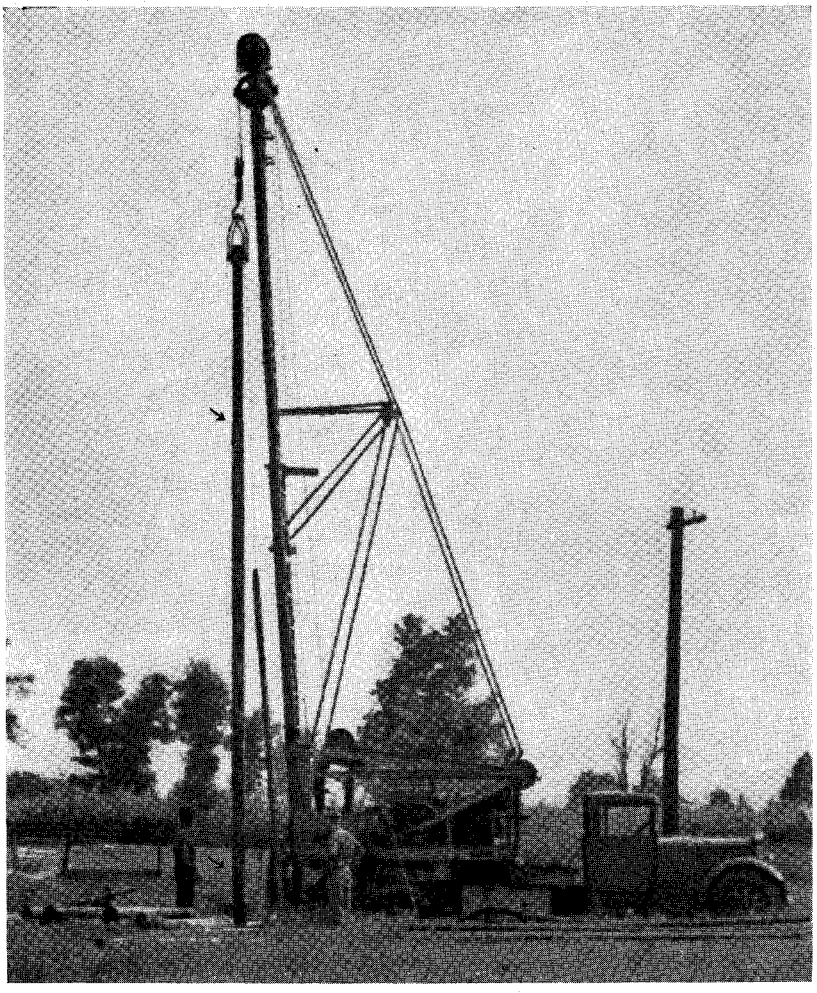


A.

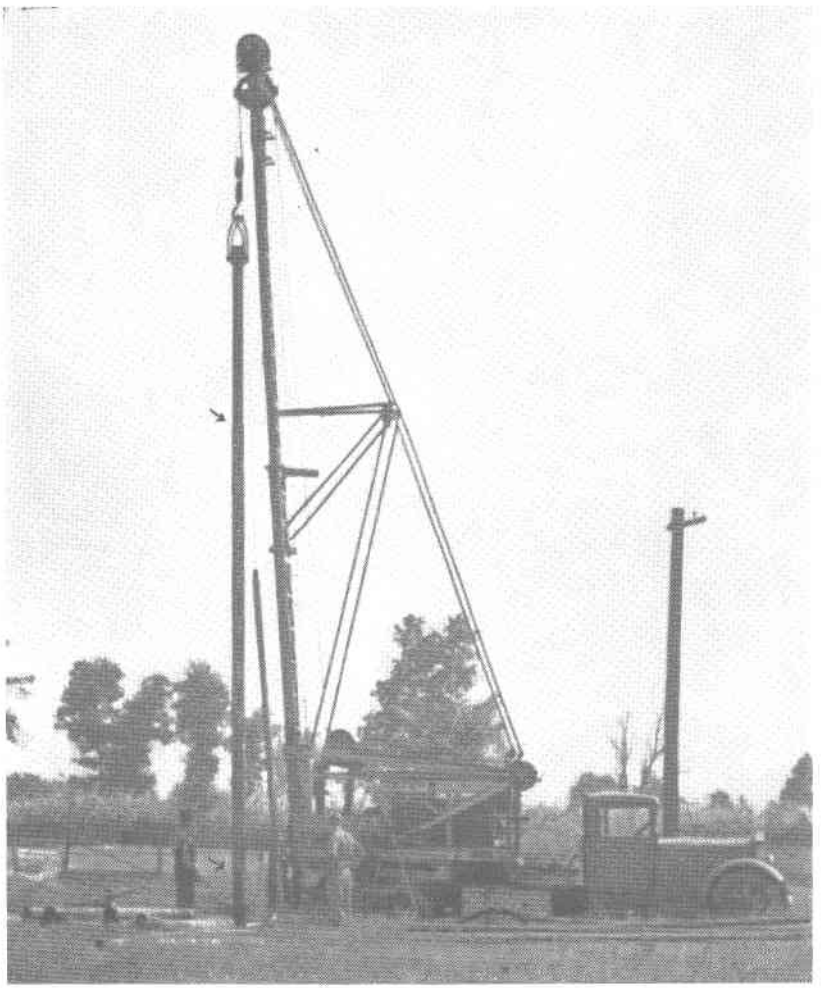


B.

A, Cooling system of a factory which uses ground water, at Portsmouth, Virginia. B, Truck farm using ground water for overhead irrigation, near Portsmouth, Virginia.



Cable-tool rig. Arrows show full length of strainer being lowered in hole.



Cable-tool rig. Arrows show full length of strainer being lowered in hole.

ter, and, when present in shallow waters in abnormal amount, may indicate infiltration of surface organic material, such as barnyard refuse. Some shallow well waters contain a high content of free carbon dioxide and are corrosive in boilers. Simple aeration appears to be effective in treating such waters, and in many places shallow ground water has been used for boiler feed for many years without injurious result.

WATER FROM RECENT DUNE SAND

In several places in Norfolk and Princess Anne counties water is obtained from dune sand bordering the sea. Analyses show that the water from 3 wells (7, 9, 20, Table 50) in dune sands are moderately low in mineral content and are soft. Bicarbonate, chloride, sulfate and nitrate are low. In several places, however, water from dune sand contains objectionable amounts of iron and may also be colored by plant matter.

Near Lynnhaven Inlet it was reported by residents that recent floods of sea water contaminated the fresh-water supply. A sample (7, Table 50) from a "spoiled" well failed to show excessive chlorides or excessive mineral content, however, and it seems probable that iron or organic matter, or both, may give the water a disagreeable taste.

USES OF GROUND WATER

In the area studied, 10 towns or villages obtain municipal supplies from wells. These are Bensley, Jarratt, Franklin, Boykins, Claremont, Rushmere, Smithfield, Battery Park, Waverly and Wakefield. In addition to these, Zuni, Windsor, Holland and Chuckatuck have wells which supply parts of the communities, and at Branchville, Courtland, Capron, Drewryville, Stony Creek and Burrowsville, many individually owned wells supply fully three-fourths of the population with water. Except at Jarratt, where water is obtained from fissures in the granitic bedrock, the above-mentioned wells tap Cretaceous strata.

About 25 public schools in the area derive water from drilled wells, most of them in Cretaceous strata. Most water for industry in the larger towns or cities is used for cooling and for boiler feed. At Franklin large quantities are used in the manufacture of kraft paper. Throughout the rural sections many small sawmills obtain ground water for boiler feed. For this purpose water from the terrace formations is generally preferred, as it is only slightly mineralized, but the more highly mineralized water from the Cretaceous formations is also used successfully. In the area about Suffolk and Norfolk the high sodium bicarbonate water from the Cretaceous deposits is used for boiler feed in a few places, but special treatment in the use of this water is necessary. Hard water from the Miocene strata is also used to some extent for boiler feed in the Norfolk area, but it too requires treatment.

Water for condenser use and other cooling purposes is pumped from wells in all parts of the area. Small to moderate-sized plants at Petersburg, Dutch Gap, Hopewell, Smithfield, Chuckatuck, Waverly, Franklin, Portsmouth and Norfolk use ground water in the manufacture of ice. A much greater amount of water is pumped for industrial cooling at Hopewell, and moderate amounts of water are pumped at numerous industrial plants in Portsmouth and Norfolk for this purpose. (See Pl. 17A). A few dairies (Pl. 16A) also use water for cooling and a few wells supply ground water for air conditioning.

A moderate amount of water from Miocene sediments is pumped for irrigation (Pl. 17B) in Nansemond and Norfolk counties. In Norfolk water from the Miocene beds supplies two laundries, but the water is softened before it is used.

By far the greater number of wells furnish water for domestic consumption only. Most of them are shallow dug or driven wells developed in the terraces, but a few domestic wells are also developed in Miocene formations. These wells are equipped with pitcher pumps or buckets,

and many of them probably use less than 100 gallons a day. Although only a few hundred drilled or jetted wells supplying homes draw water from the Cretaceous deposits, they are of much greater importance than the greater number of shallow domestic wells developed in terrace sands; for many of the drilled wells are flowing wells, and in the aggregate discharge a large amount of water. The amount of water actually used for domestic purposes is small but much water is wasted by unrestricted flow or by the use of hydraulic rams in conjunction with flowing wells.

A few domestic installations include devices for the softening of water or for the removal of iron.

WELL CONSTRUCTION

SHALLOW WELLS

Throughout all the counties covered by the present report there are numerous shallow wells, most of which derive water from the terrace formations. These wells rarely exceed 30 feet in depth, and probably the majority are dug wells. The diameter of dug wells varies from 3 to 6 feet at the surface, and uncased wells generally decrease in diameter with depth.

Most dug wells are equipped with a few feet of curbing of wood, cement, or tile through the surface soil. However, the majority of dug wells lack both cover and casing and hence are liable to contamination. Those wells which are cased generally are constructed by sinking tile pipes of large diameter almost to water level. The joints are not sealed, though clay soil surrounding the pipes, particularly near the surface, may be puddled and be partially effective in preventing surface water from entering the well. A few dug wells are lined to the bottom with brick or wood.

Water is drawn from dug wells by power pumps, by hand pumps or, in most places, by buckets. A few well sweeps are still used.

In general, some effort is made to render dug wells sanitary; but in most instances without success.

Many shallow wells are driven and are generally constructed by hand, with or without the aid of a soil auger. Most of them are equipped with ordinary drive-point strainers. Practically all driven wells are 2 inches or less in diameter. Water from them is drawn by powered or hand-operated suction lift pumps, although a few sawmill wells are pumped by air lift.

DEEP WELLS

Most of the deep wells discussed in this report obtain water from sands at or near the top of the Cretaceous deposits. Near the Fall Zone the Cretaceous sands lie at or near the surface, and wells obtaining water from them may be less than 100 feet deep. Wells more than 100 feet deep in this area generally penetrate granitic bedrock. Eastward, however, Cretaceous sands lie at progressively greater depths, and at Norfolk the sand strata are encountered at about 600 feet below sea level. The increase in depth of wells in an eastward direction is not always apparent, however, due to differences in elevation of the land above sea level, the presence or absence of sand at the very top of the Cretaceous deposits, the development of deeper sand in some wells, and

structural irregularities. Courtland is located about 25 miles east of the Fall Zone, and in that community the first Cretaceous sand is encountered at a depth of 120 feet; but at Spring Grove, Surry County, located an equal distance from the Fall Zone, the Cretaceous sands lie more than 230 feet below the surface.

In Norfolk and Princess Anne counties, and to lesser extent in Nansemond County, there are many jetted or drilled wells from 35 to 200 feet deep which obtain water from Miocene deposits.

JETTED WELLS

In the Norfolk area a number of home-made wells have been "washed-down" (jetted) by simply forcing water under pressure, generally from the City system, down 1- or 2-inch diameter pipe. The water returns alongside the pipe to the surface. Penetration may or may not be aided by a crude bit. As hole is made, the system is disconnected and more pipe added. Where the water-bearing formation is made up largely of shell fragments such a crude well may be very efficient but where deposits are largely sand, the home-made installation is probably quite inefficient and it would be more economical, where more than a minimum amount of water is required, to have a well drilled or jetted by a professional driller. Such wells should be properly equipped with a screen and surged to remove fine-grained material from the water-bearing formation.

The majority of domestic deep wells are jetted wells 2 or 3 inches in diameter. In the jetting process the driller makes hole by the continuous pounding action of a bit through the end of which water is forced from above. The jetters claim that generally the action of the circulating water is more effective than that of the bit. The water is passed down through a string of hollow rods and passes up between the rods and the casing which follows the hole. Mud and cuttings in the return water are allowed to settle and the water is recirculated.

This method of well construction is cheap and quick. Depending on the rig and skill of the operator, wells may be drilled to depths of from 400 to 750 feet. Generally the maximum diameter of casing which can be handled is 6 inches. By this method, a good driller can build wells capable of delivering several hundred gallons a minute if water-bearing conditions are favorable.

Most jetted wells are 2 or 3 inches in diameter, however, and are not fitted with strainers or properly developed. It is claimed that since only very small quantities of water are to be drawn from the well, such

finishing is a needless expense and where wells flow, ample water is obviously available and further work or expense in finishing is unjustifiable.

If properly finished, small domestic jetted wells could be made to yield a great deal more water than most of them are capable of furnishing at present. These additional supplies might be used for fire protection, cooling, and possibly irrigation. Further, no difficulty in sanding would be encountered as flowing wells fail due to decline of head and where pumping equipment is changed to provide larger supplies for dairies, small industries, or other use. By and large, the construction of wells without strainers and proper development should be discouraged as being short-sighted and uneconomical.

Jetting rigs are adapted to the drilling of small test holes cheaply and quickly, and data obtained by jetting rigs would be of advantage in many places. A three- or four-inch test hole would provide an excellent log of formations present, samples of water could be obtained at various depths and a pumping test of some value could be made. Costs would be low because the hole is drilled quickly (from 100 to 200 feet per 8-hour shift), equipment is simple and relatively inexpensive, and casing could be largely recovered. As mentioned above, the depth to which a jetting rig may penetrate is limited by the power of the hoisting equipment and water-circulating pump.

DRILLED WELLS

Most wells intended to supply industries and municipalities are drilled wells, 6 to 10 inches in diameter. These wells are equipped with well screens and have been properly developed practically everywhere.

In drilling by the cable-tool method (Pl. 18), hole is made by the repeated pounding action of a blunt edged bit alternately raised and lowered on the end of a flexible cable. The hole is kept more or less filled with water and the clayey cuttings form a thin mud. At intervals the bit is withdrawn from the hole and the mud and sand is removed by a bailer. In clayey formations a driller may work as much as 40 feet below the casing, but in sandy beds the hole tends to cave and casing follows very closely or may even be driven a foot or two ahead of the hole.

When the water-bearing stratum to be developed is penetrated, an effort is made to make an open hole into it below the casing in order to place a screen (Pl. 19). Where this is not possible it is common practice to drive the casing through the stratum, place the screen, and jack the casing back sufficiently to expose the screen.

The process, as outlined above, is more complicated when reduction from larger diameter to smaller diameter casing is necessary and when two or more screens are to be placed.

When the strainer is sealed in place the well is pumped intermittently for 8 or 10 hours. Special provisions may be made to secure strong surging and backwash. In some instances the well is agitated by air. By these means the fine sand in an area extending outward from the strainer is removed and a natural gravelly envelope is formed around the well screen, thus facilitating the inflow of water to the well. Wells properly screened and developed are almost always far superior to wells which are not screened or which are equipped with make-shift screens of slotted pipe. In a very few places, as where the water-bearing formation is coarse gravel, unscreened wells may be reasonably efficient, but, on the other hand, when unscreened wells, even those ending in gravel, are pumped the danger of partial clogging and diminution of supply is ever present.

Drilling by the cable-tool method is relatively slow, even in unconsolidated sediments, but the costs of drilling are moderate and the completed wells entirely satisfactory in yield and efficiency.

ROTARY WELLS

A few large yield wells in southeastern Virginia were drilled by the rotary drill method (Pl. 20), to supply water for industries at Franklin and Hopewell. Test drilling was done by the rotary method at Bacons Castle and Lake Prince.

The essential difference between a completed rotary drilled well and a completed well drilled by the cable tool method is that the former has an artificial gravel envelope placed around the well screen. Definite advantages accrue from the use of the rotary method; these are mainly the speed and ease with which the deep holes of large diameter may be drilled and the ease with which several widely separated (vertically) water-bearing strata may be developed. However, comparative data on the performance of natural and artificial gravel-packed wells in several places in the Coastal Plain of Virginia indicate that in this area the artificial gravel pack is not more efficient than the natural gravel pack created in properly constructed sand-screen wells drilled by the cable-tool or jetting method. At Camp Peary, York County, it was found that natural gravel-packed wells were about as efficient as artificial gravel-packed wells where either coarse or fine mate-

rial was developed. On the other hand, certain fine Miocene sands in eastern Virginia can not be properly developed by natural gravel-pack methods. It is probable that these and similar sands may be exploited more successfully by proper artificial gravel packing.

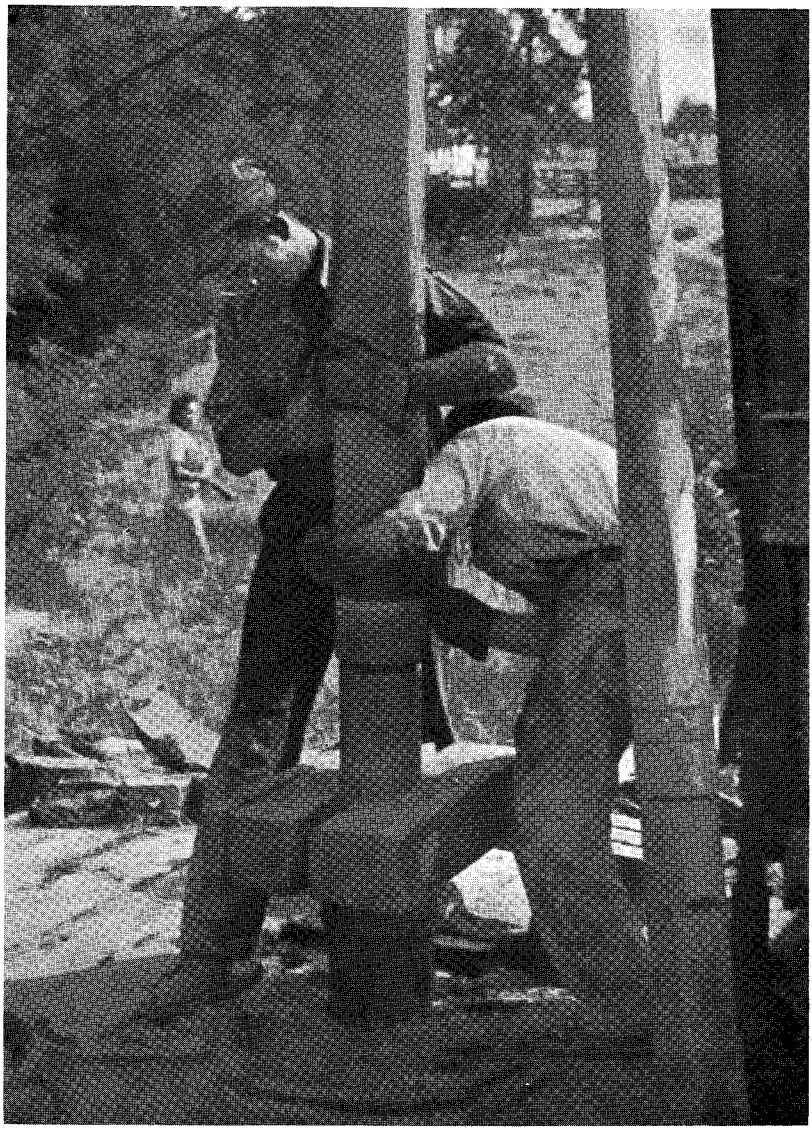
In drilling by the rotary method, hole is made by a bit on the lower end of a rotating string of hollow rods which is lengthened from time to time as progress is made (Pl. 21). A light mud solution (not muddy water, as in the jetting operation) is pumped down through the rods, out through the bit and up again to the surface between the string of rods and the uncased hole. This light mud solution takes drill cuttings in suspension or floats them up to the surface where the cuttings settle out. The light mud solution returns to a pit and is recirculated in the hole. During its upward movement in the hole the mud solution plasters the walls of the hole and prevents caving; hence a hole may be drilled without casing.

When the desired amount of hole has been made the rods are withdrawn and a string of casing with appropriately placed strainers is lowered into the hole. The hole is larger than the casing; the former may be 24 inches in diameter and the casing 18 inches in diameter in its upper portion and 10 inches in its lower portion. The intervening space between the walls of the hole and the casing is generally filled with sized pea gravel. Fine sands require a smaller grained or graded pack;[131] fine sands at Franklin were not held back by the pack generally used successfully elsewhere. In some instances that part of the hole penetrating water-bearing strata is under-reamed before casing is set and gravel is placed.

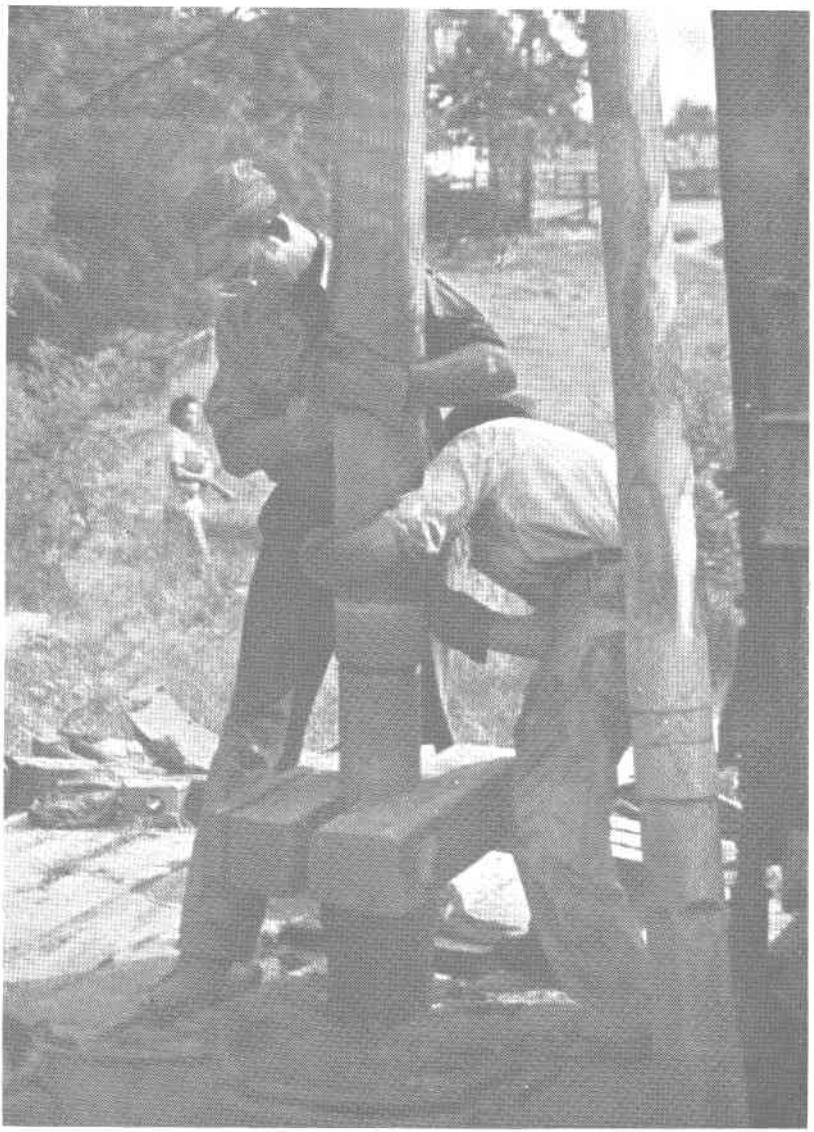
As indicated above, this method of drilling the hole and converting the hole into a well is very efficient and is particularly adapted to the drilling of deep test holes and construction of wells in which many water-bearing sands are to be developed. To date only large rigs and heavy equipment are available to do this work in the area and costs are correspondingly high.

SUMMARY OF WELL CONSTRUCTION

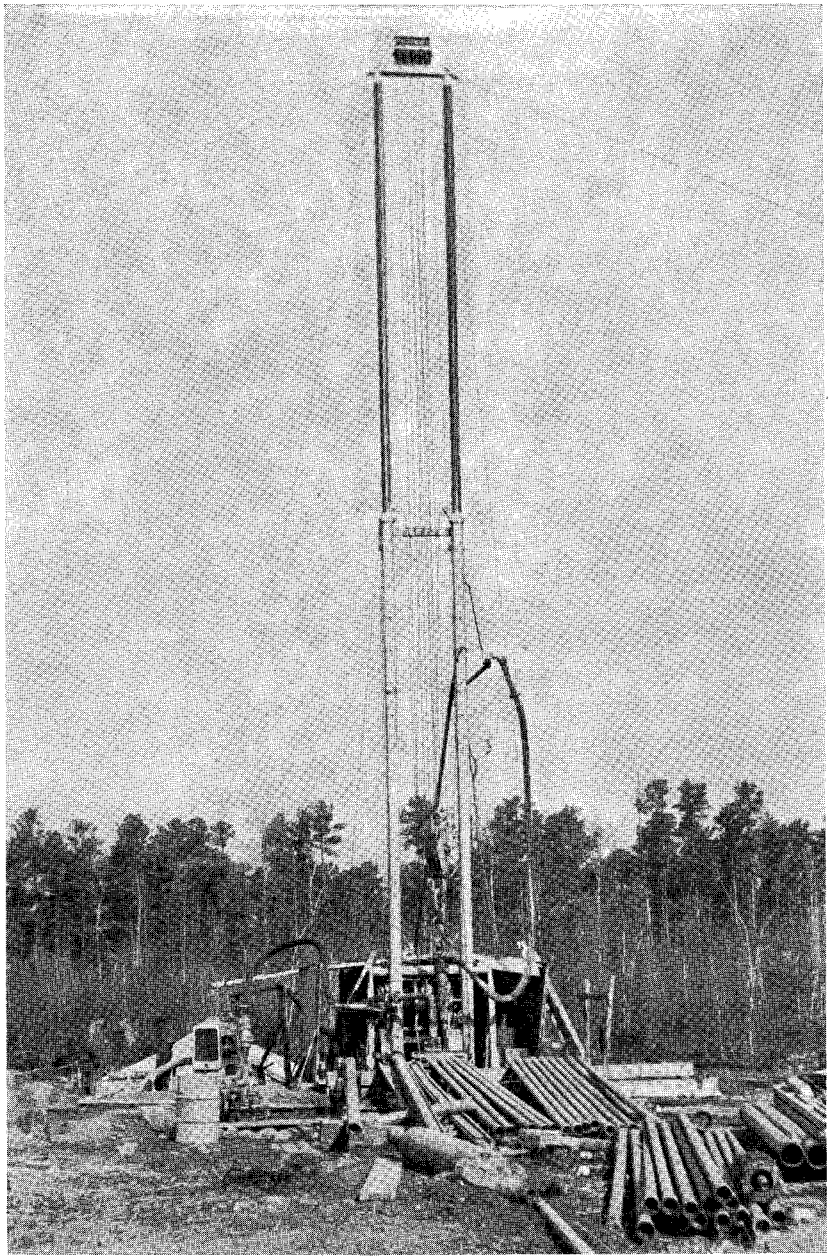
Some wells less than 60 feet deep are made by crude jetting outfits, but most wells in the Coastal Plain deeper than 60 feet are jetted wells constructed by professional drillers. These wells, when properly finished, are both inexpensive and efficient. Muni-



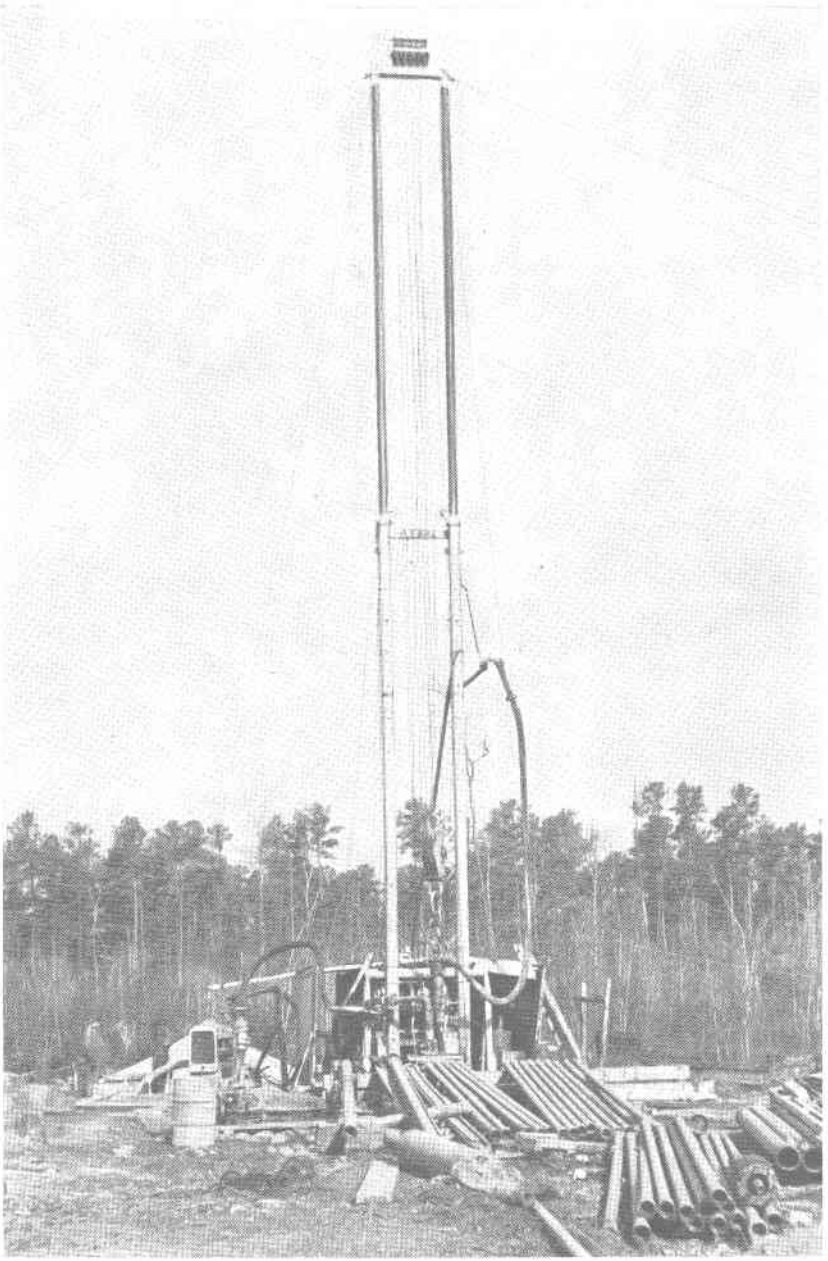
Strainer being screwed onto a length of blank pipe. Drilling bit at right.



Strainer being screwed onto a length of blank pipe. Drilling bit at right.



An A-frame rotary rig used in drilling wells and test holes at Franklin, Bacons Castle, and Lake Prince.



An A-frame rotary rig used in drilling wells and test holes at Franklin, Bacons Castle, and Lake Prince.

cipal and industrial wells are generally drilled wells which are larger in diameter and somewhat deeper, on the average. Nearly all of these are properly screened, and where intended to furnish more than minimum amounts of water they are efficient and moderate in cost. A few large yield wells are drilled by the rotary method, which is particularly suited to the drilling of very deep holes and the development of many water-bearing sands.

Full advantage has not been taken of the jetting process in moderately deep test drilling. Furthermore, it appears that in the Coastal Plain area, a modern, fully equipped light rotary rig, capable of quickly and cheaply drilling 3 and 4 inch test holes to a depth of 1000 feet, is needed. Such a rig could also be used advantageously in rapid construction of relatively deep wells up to 6 inches in diameter, capable of furnishing several hundreds of gallons of water a minute where geological conditions are reasonably favorable.

METHOD OF LIFT

Water is obtained from most nonflowing wells by hand-power or motor-driven suction or deep-well pumps. Many large consumers of water have turbine pump installations, and in a few places air lift is used.

Water from a large number of flowing wells is delivered to higher elevations by hydraulic rams but where larger quantities of water are desired or where a sufficient artesian head is not present, the water may be delivered by power pumps. In the latter type of installation the full flow of the well is wastefully discharged when the pump is not in operation. A number of flowing wells are equipped with neither pump nor hydraulic ram, and water for domestic use is carried in buckets from the point of discharge.

EASTERN CHESTERFIELD COUNTY

LOCATION AND DEVELOPMENT

The portion of Chesterfield County considered in this report lies between U. S. Highway No. 1 and James and Appomattox rivers, and also includes the town of Chester, a short distance west of the highway, and that part of the City of Richmond which lies south of James River.

Although the area is dominantly agricultural, the presence of a number of manufacturing and business establishments gives it a much greater importance than would be attained by farm production alone. Between Richmond and Petersburg are located tobacco factories of the American Suppliers Co. and the U. S. Tobacco Co. and a large plant of E. I. du Pont de Nemours Co., which makes plastic products and cellophane. In addition there are manufacturing concerns of less importance. The Richmond Deep Water Terminal wharves are located a few miles south of the city. A great many small businesses catering to the travelling public have developed along the highway between the two cities. The Richmond Supply Depot (U. S. Army) is located on U. S. Highway No. 1, north of Kingsland Creek.

MUNICIPAL SUPPLIES

That part of the City of Richmond which is south of James River is within the area covered by this report and is served by a surface water supply.[135] The Richmond water supply is taken from James River, about 6 miles upstream. It is brought from the river through a feeder canal into the water treatment plant, which has a capacity of 30 million gallons per day. Water is piped from the plant to the low-service reservoir in Byrd Park, Richmond.

Colonial Heights, north of Appomattox River, receives a surface water supply[133] from the City of Petersburg. Water is taken from Appomattox River about 3 miles upstream from the City of Petersburg and is piped to the city where it is treated. The system had a capacity of about 7 million gallons a day in 1939.

TOPOGRAPHY

The area is one of moderate relief, characterized by steep-sided valleys and flat-topped hills. The latter are the remains of a series of terraces developed at successively lower elevations,

which have been greatly eroded by stream action. Several terraces may be recognized. Southwest of Chester the hills attain an elevation of 200 feet above sea level and represent a formerly extensive terrace of Pleistocene age, the Coharie terrace. Logs of wells indicate that the Pleistocene deposits of pink and red arkosic clay, sand and gravel, underlain by Miocene deposits of blue clay, may attain a thickness of 70 feet in the vicinity of Chester. In other places remnants of the Sunderland terraces are shown by flat-topped hills ranging from 140 to 170 feet above sea level. A terrace at 80 to 100 feet corresponding to the Wicomico terrace also seems to be present. A 20-foot terrace is found in places along the James.

The meandering James and Appomattox rivers have cut their banks and formed steep cliffs at Howlett House, Drewrys Bluff and Point of Rocks. At the first-named locality the flat terrace upland is intersected by an almost vertical cliff 140 feet high. The secondary streams, Swift, Proctor, Kingsland and Falling creeks, cross the eastern portion of the county. Their deeply incised valleys contrast with the more undulating upland topography characteristic of the county as a whole.

GEOLOGY

That part of Chesterfield County that is near U. S. Highway No. 1 between Richmond and Petersburg is underlain by granitic rock overlain by relatively thin sedimentary rocks. Bedrock crops out in some of the streams where they cross the highway, and elsewhere the presence of granitic rock a short distance below the surface is known from logs of wells. The bedrock surface slopes toward the east and lies more than 250 feet below sea level at Bermuda Hundred. The bedrock surface is characterized everywhere by minor irregularities. In the well of J. J. Mitchell (Figure 20 and well 34, Table 12), 4 miles north of Petersburg, bedrock was encountered at 40 feet above sea level. In a well 3¼ miles farther north, at H. L. Moore Tourist Camp (32, Table 12), granitic rock was not encountered at a depth of 85 feet below sea level. At Lake Ely (20), 2¼ miles north-northwest of the last-named locality, a well was drilled 108 feet deep, to about 40 feet below sea level, without encountering hard rock. At Kingsland Creek, however, granite lies at about sea level and where Falling Creek crosses U. S. Highway No. 1 granite crops out in the stream bed at 20 feet or more above sea level. When differences in depth

due to eastward slope are taken into account, it is seen that the bedrock just north of Petersburg lies at altitudes comparable to the altitude of the bedrock near Richmond, and that in the intervening area, depths to bedrock are much greater than might be expected, and a broad trench apparently exists in the bedrock surface. This trench or valley was probably made by a pre-Cretaceous stream, but, instead of being an actual valley trending east-west, it simply may be a reentrant of a buried bedrock scarp trending north-south. Mr. Wm. J. Goyne stated that granite was encountered at 406 feet, 260 feet below sea level, at Howlett House Bluff. The bedrock surface there apparently is at about the same elevation as at Hopewell, Curles Neck Farm 3 miles north of Bermuda Hundred, and at the Camp Lee Station 4 miles northeast of Petersburg, where depth to bedrock was determined by geophysical methods.[57] The first bedrock "terrace," which extends from half way between Petersburg and Hopewell, to Hopewell (Section A-A′, Plate 1), seems to extend northward into Chesterfield County.

Alternating arkosic sand and clay deposits of the Patuxent formation of the Potomac group (Lower Cretaceous), are well exposed along James and Appomattox rivers. The exposures at Howlett House Bluff and at Point of Rocks have been described by Clark and Miller.[29]

The overlying Pamunkey group, of Eocene age, consists chiefly of a marly glauconite sand. This is exposed at Howlett House Bluff, and also along Ashton Creek and vicinity. Both lower and upper members of the Pamunkey group, the Aquia and Nanjemoy formations, are composed essentially of marly greensand, but the base of the Nanjemoy is marked by a pink and white clay. The Nanjemoy formation is exposed along the south bank of James River in the cliffs below the mouth of Bailey Creek, Prince George County, but is not recognized in Chesterfield County.

Diatomaceous clay and blue marl deposits of the Calvert formation, the basal formation of the Chesapeake group of Miocene age, are found at higher elevations in this part of Chesterfield County. They are well exposed at Howlett House Bluff and along Ashton Creek and its tributaries. The formation is well exposed where U. S. Highway No. 1 crosses Kingsland Creek and Procter Creek. Its contact with the Eocene at the former locality is about 80 feet above sea level. At Howlett House Bluff the base of the Calvert is about 50 feet above sea level.

Most of the area is overlain by sandy terraces of Pleistocene age which have already been described.

Regarding the occurrence of the Aquia formation along the Appomattox, southwest of Bermuda Hundred, Clark and Miller state,[32] "at Point of Rocks the Patuxent would be expected to occur at from 25 to 31 feet below tide, as the Aquia deposits at Ashton Creek, two miles directly west, are almost at tide, but instead of this the Patuxent rises about 80 feet above tide. No faulting has apparently occurred."

Since the above statement was made detailed study has shown the existence of several small faults. In the Patuxent section at Drewrys Bluff, 8 miles north-northeast of Ashton Creek, a reverse fault of 2 or 3 feet displacement is present.[12] As shown in Plate 6B, the upthrown side is on the southeast. In addition, local crumpling and faulting of Miocene strata were noted in a tributary to Ashton Creek. Although these examples of deformation in the area are small, they may indicate that more profound earth movements affected the strata of the Coastal Plain.

GROUND WATER

SHALLOW WELLS

A few restaurants and tourist courts along U. S. Highway No. 1 obtain their water supplies from wells dug in the terrace sand. At the Colony Inn, 1 mile north of Dutch Gap, a dug well 26 feet deep (19, Table 12) furnishes water for 10 cottages and the inn. The pump delivers about 8 gallons a minute. The water from a dug well at Grantham's Restaurant (15) contains troublesome quantities of iron. However, 2 dug wells about 40 feet deep at Moore's Brick Cottages (28a, 28b), which supply about 1,000 gallons a day each, yield water that is probably low in iron. A dug well 30 feet deep at the Shadyside Restaurant (30) likewise yields water low in iron.

DEEP WELLS

WATER FROM CRETACEOUS DEPOSITS

Relatively few drilled wells obtain water from Cretaceous strata along U. S. Highway No. 1 between Richmond and Petersburg. One, a well 108 feet deep at Lake Ely (20), furnishes about 65 gallons a minute and is used to augment the natural flow of stream water into the lake.

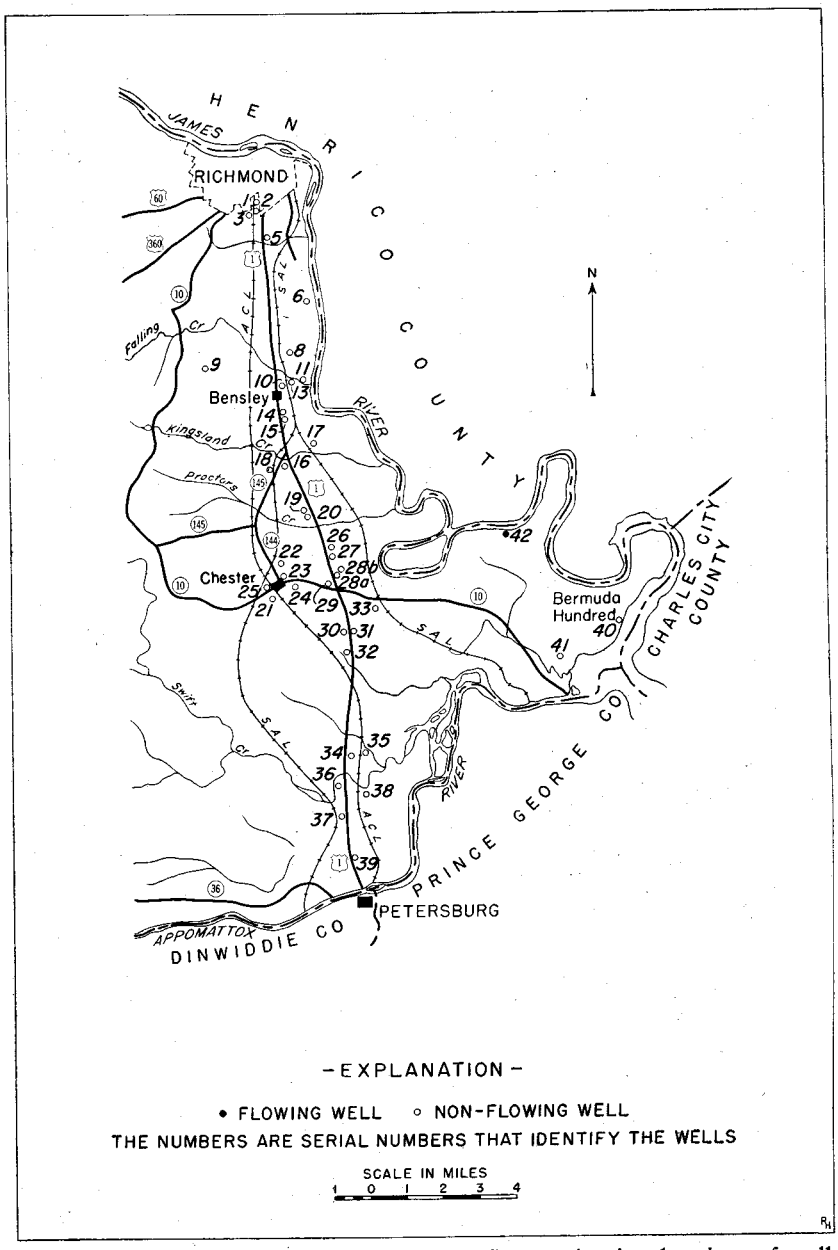


FIGURE 20.—Map of eastern Chesterfield County showing locations of wells listed in Table 12.

Water for cooling and for the manufacture of ice is obtained from a well 95 feet deep at Dutch Gap (26) belonging to the Virginia Ice and Coal Co. The pump delivers about 40 gallons of water a minute. The water is said to contain undesirable amounts of iron, the presence of which detracts from the appearance of the ice. At Dutch Gap Cottages near by, water from a well 107 feet deep (27, Table 14) contains some iron and is soft. The water from a well 184 feet deep at Moore's Brick Cottages (28b) is even softer, and is probably low in iron. The well of the Dutch Gap Motor Co., three-fourths of a mile south of Dutch Gap, 152 feet deep, furnished fairly soft water, as shown by the analysis (29) in Table 14.

The village of Bensley obtains 25 to 30 gallons a minute of soft water from sand at 60 to 63 feet, lying immediately above bedrock (10, Table 13).

The Robertson well (22), half a mile northeast of Chester, obtains water from sand lying between 110 and 138 feet below the surface. Bedrock may be not more than 30 feet below this stratum.

Near the eastern border of the county a flow is obtained from a well 212 feet deep, at Meadowville Farm (42). A good log of this well was not available, and the exact depth of the water-bearing sand is not known. At Bermuda Hundred a well (41) 105 feet deep taps Potomac sands. The analysis (in Table 14) of water from this well shows it to be a hard, calcium bicarbonate water. Sulfate is relatively high, 44 parts per million. Mr. E. A. Lane of Hopewell states that in the area southwest of Bermuda Hundred he has drilled several wells 50 to 100 feet in depth, which obtain water from Cretaceous sands.

In a few places the sand lying a short distance above bedrock is made up in large part of partially decomposed feldspar grains. This arkosic sand is not water-bearing. Such material was encountered in the well of E. I. du Pont de Nemours & Co. (8) at the Old Hickory chemical plant. The sand appears to be similar to that exposed in the banks of James River at Drewrys Bluff.

WATER FROM GRANITIC ROCK

Almost all wells of large yield in this county pump water from the granitic bedrock. This is probably due to the fact that attempts to obtain large supplies have been made only where bedrock is at or close to the surface and favorable thicknesses of sedimentary formations are not present.

The well of largest yield in the county was drilled in 1938 at the warehouse of the U. S. Suppliers Co. (2), near U. S. Highway 1, immediately south of Richmond. This well, 600 feet deep, tested 380 gallons a minute with 94 feet of drawdown in a 24-hour trial. About the same yield was obtained in a trial run of continuous pumping for 30 days. Static water level is normally about 21 feet below the surface. Most of the water is used for cooling purposes. At the David M. Lea mill, one-fourth of a mile to the west, a well 220 feet deep (3) has furnished a maximum of 200 gallons a minute. The well has been pumped continuously each working day, and at the end of the week the yield diminished to about 100 gallons a minute. A commercial analysis showed that the water has a total hardness of 80 parts per million; the sulfate and chloride contents are reported to be respectively 56 and 45 parts per million. The water is used as boiler feed without treatment.

However, at the warehouse of the American Tobacco Co., one-fourth mile north of the warehouse of the U. S. Suppliers Co., a well 700 feet deep (1) yielded only 32 gallons a minute and has been abandoned. At Belle Meade School, less than 1 mile south of the well of the U. S. Suppliers Co., only about 7 gallons a minute was obtained from a well 302 feet deep (5).

At the Richmond Deep Water Terminal, a short distance above the plant of the du Pont Company, a well drilled on the low ground bordering the river failed to obtain more than a very meager supply. A second well, 425 feet in depth (6), located a few hundred feet back from the river, developed 360 gallons a minute with 159 feet of drawdown in a 24-hour pumping test. Mr. William McGill of the Virginia Geological Survey observed that the rock encountered in the first well was schistose, and that the schistosity trended approximately north and south parallel with the river. The second well encountered shattered granitic rock such as is generally found in this part of the Fall Zone.

At the du Pont plant granite was encountered 56 feet below the surface, a few feet below sea level. A well 431 feet deep (8) failed to develop more than 44 gallons a minute with 150 feet of drawdown. The yield was considered to be inadequate, and the well is not used. The temperature of the water is said by the company officials to be 66° F. This water is about 5 degrees warmer than water generally obtained from wells less than 150 feet in depth, and suggests that the water may rise from a considerable depth along fissures in the bedrock. The water is reported by company chemists to have high total mineral content and hardness of 385 parts per million. The hardness is present as non-

carbonate hardness rather than as the carbonate hardness more commonly found in Coastal Plain waters. The chloride content is relatively high, being 188 parts per million.

At the warehouse of the Old Dixie Distilling Co., about 150 gallons a minute is yielded by a well 747 feet deep (11). The official in charge stated that no water was obtained above 500 feet. As the temperature of the water is 61° F., it would seem that water enters the well chiefly from fissures comparatively near the surface.

At Camp Merriwood only a small yield was obtained from a well (13) in the granite. At the Old Hickory plant of the du Pont Company on Kingsland Creek a yield of 60 gallons a minute is reported from a well (17), but only about 20 gallons a minute is pumped. The water is used for cooling in condensers.

In a well at Chester High School granite was encountered at 167 feet, and a yield of 15 gallons a minute was obtained. The water from this well (23), like that of the du Pont Company well (8), has a very high sulfate content, 468 parts per million, and a hardness of 188 parts per million, of which 85 parts is noncarbonate hardness. This water also has an unusually high content of fluoride, 3.4 parts per million. This is one of the few known occurrences of fluoride in ground waters along or near the Fall Zone from Richmond to the North Carolina state line. The effect upon the teeth of children under 10 years of age of fluoride in drinking water has been discussed in the general part of this report dealing with the quality of water.

A few other wells that obtain water from bedrock are found in eastern Chesterfield County, but less detailed information concerning them is available. The water from the well of the Greenleaf Dairy (38, Table 12) has a total hardness of 43 parts per million, of which about one-half is permanent or sulfate hardness, according to a commercial analysis. The water is low in iron. The well supplies about 13 gallons a minute. At the N. B. Wilson planing mill a well 160 feet deep (37) encountered granite at 30 feet. This well fails to supply a 100-HP boiler with sufficient water, and the yield is estimated at not more than 5 gallons a minute. The water foams when used in the boiler.

In summary, supplies up to several hundred gallons a minute are obtained from deep wells in granitic rock. It has been found advantageous in at least one place to drill to a depth of more than 500 feet. Wells penetrating less than 150 feet of granitic rock generally have only a small yield. The occurrence of wells of large yield and small yield within very short distances of one another emphasizes the fact that water

in the granitic rocks occurs only in crevices, and that in general, in an area in which the basement rock is a source of supply, the probability of encountering open fissures which will yield a relatively large supply of water can not be predicted. On the other hand, most wells that have been drilled into bedrock to depths of 100 to 400 feet, have secured supplies of 5 to 50 gallons a minute.

The water obtained from wells which penetrate bedrock differs greatly in mineral content and hardness. Some wells yield soft or moderately hard water of low to moderate total mineral content; others yield very hard water that has a high content of dissolved mineral matter, of which sulfate may be a significant constituent. Some water contains objectionable amounts of iron.

SPRINGS

The town of Chester obtains the greater part of its water supply from a spring located one-fourth of a mile south of the community. The water, which issues from several ill-defined openings in a low swampy area, is pumped from a collecting basin to a 20,000-gallon tank. According to Mr. O. K. Marquis, owner of the system, the spring supplies about 1,000 gallons an hour when pumped continuously, even in periods of drought. The water has a hardness[136] of 49 parts per million, present principally as carbonate hardness. Sulfate and chloride are very low.

Another large spring issues from the base of terrace gravel at the Greenleaf Dairy, 2½ miles north of Petersburg. The water is said to be slightly hard and contains some iron.

WELL RECORDS AND ANALYSES

Records of wells in eastern Chesterfield County, available logs of wells, and analyses of water samples are listed in Tables 12-14, on the following pages. The locations of wells listed are shown in Figure 20.

TABLE 12.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
1	South edge of Richmond city limits.	American Suppliers Co.	Sydnor Pump and Well Co.	1930	102	D
2	South edge of Richmond city limits.	U. S. Tobacco Co.	Virginia Machinery and Well Co.	1938	99	D
3	South edge of Richmond city limits.	David M. Lea	Sydnor Pump and Well Co.	1930	120	D
5	¼ mile north of Broad Rock Creek.	Belle Mead School	Virginia Machinery and Well Co.	1936	85	D
6	On James River, 4 miles south of Richmond.	Richmond Deep Water Terminal.	Virginia Machinery and Well Co.	1939	30±	D
8	1 mile north of Falling Creek	E. I. du Pont de Nemours & Co.	Sydnor Pump and Well Co.	.....	45	D
9	2 miles east of Bensley	E. L. Tessier	Virginia Machinery and Well Co.	1925	200	D
10	¼ mile south of Falling Creek	Village of Bensley	Mitchells Pump and Well Co.	1937	105	D
11	Near mouth of Falling Creek	Old Dixie Distilling Co.	Mitchells Pump and Well Co.	.....	15	D
13	¾ mile south of Falling Creek	Camp Merriewood	Virginia Machinery and Well Co.	1926	80	D
14	1 mile south of Falling Creek	T. L. Grimstead	.....	.....	100	D
15	1 mile south of Falling Creek	Granthams Restaurant	Owner	.....	105	Dug
16	Highway U. S. 2 and Kingsland Creek.	Chimney Corners	E. J. Cousins	.....	70	D
17	North bank of Kingsland Creek.	Old Hickory Chemical Co.	Virginia Machinery and Well Co.	1936	82	D
18	¼ mile south of Kingsland Creek.	Kingsland School	Sydnor Pump and Well Co.	.....	100	D
19	1 mile north of Dutch Gap	Colony Inn	.....	.....	120	Dug
20	¾ mile north of Dutch Gap	Lake Ely	Sydnor Pump and Well Co.	1935	90	D
21a	Chester	O. K. Marquis	.....	.....	145	Dug
21b	Chester	O. K. Marquis	Mitchells Pump and Well Co.	.....	145	D
22	½ mile northeast of Chester	Robertson	Mitchells Pump and Well Co.	1939	155	D
23	Chester	Chester High School	Sydnor Pump and Well Co.	.....	155	D
24	Chester	H. T. Goyne	Mitchells Pump and Well Co.	1935	180	D
25	Chester	T. J. Shepard	Truby	.....	140	D
26	Dutch Gap	Virginia Ice and Coal Co.	Truby	.....	140	D
27	Dutch Gap	Dutch Gap Cottages	Mitchells Pump and Well Co.	.....	140	D
28a	½ mile south of Dutch Gap	Moores' Brick Cottages	.....	.....	130	Dug
28b	½ mile south of Dutch Gap	Moores' Brick Cottages	Mitchells Pump and Well Co.	.....	130	D
29	¾ mile south of Dutch Gap	Dutch Gap Motor Co.	E. J. Cousins	.....	170	D
30	1¾ miles south of Dutch Gap.	Shadyside Restaurant	.....	.....	165	Dug
31	1¾ miles south of Dutch Gap.	Granada Taverns	Mitchells Pump and Well Co.	.....	170	D
32	2¼ miles south of Dutch Gap.	H. L. Moore Tourist Camp.	Mitchells Pump and Well Co.	.....	160	D
33	East of Red Water Lake	McWaters	Mitchells Pump and Well Co.	.....	160?	D
34	4 miles north of Petersburg	J. J. Mitchell	Mitchells Pump and Well Co.	.....	90	D

Chesterfield County, Virginia[a]

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Pumping yield (gallons a minute)	Use of water[c]	Quality[d]	Remarks	No.
.....	10 to 8	−11	1930	32	Ab	.....	Drawdown 89 ft. after pumping 24 hours. Rock at 30 ft.	1
600	10	−21	1938	380	.....	.....	Drawdown 94 ft. after pumping 24 hours. Rock at 36 ft.	2
220	8	−42	1939	100	B	TH, 80 Cl, 45 SO_4, 56	Water not treated.	3
.....	8	− 9	Oct. 1, 1936	7	P	.....	Drawdown 138 ft. after pumping 7 hours. Rock at 9 ft.	5
425	10	−42	1939	360	In.	.....	Drawdown 164 ft. after pumping 24 hours. Rock at 71 ft.	6
431	8	− 9½	.....	44	Ab	TH, 385 SO_4, 385 Cl, 188	Drawdown 150 ft. during pumping test. Rock at 56 ft. Water temp. 66° F.	8
130	8	−10	Aug. 29, 1925	6	D S	.....	Drawdown 70 ft. after pumping 5 hours. Rock at 55 ft.	9
88	6	−40	Apr. 22, 1937	25	M	.....	Rock at 63 ft.	10
747	8	—	.....	150+	C	.....	Rock at 14 ft. Water temp. 61° F.	11
219	8	−35	May 31, 1926	10	D	.....	Drawdown 25 ft. after pumping 15 hours. Rock at 90 ft.	13
200+	.....	—	.....	.....	D	.....	.....	14
18	.....	−13	.....	.....	D	Corrosive, iron	Supplies restaurant and 7 tourist cottages.	15
107	6	+?	.....	44	D	Soft, iron	Flowed 35 gallons a minute in 1930. Installation of pump stopped flow.	16
150	8	—	.....	60	C	.....	Rock at 122 ft.	17
260	8	—	.....	.....	P	Slightly hard and iron	.....	18
26	.....	−22	.....	8	D	Soft, iron	Supplies hotel and 10 tourist cottages.	19
108	10	—	.....	65	.....	.....	Supplies lake. Pumped continuously 4 months each year. Abandoned well 140 ft. deep near by, did not encounter rock.	20
55	.....	−20	.....	.....	M	Iron	.....	21a
177	6	−80	.....	8½	M	Iron	Rock at 135 ft.	21b
138	4	−75	1938	.....	D	.....	Rock not encountered.	22
386	.....	—	.....	15	P	A	Rock at 167 ft.	23
143	6	—	.....	.....	D	Soft	.....	24
360	.....	—	.....	.....	D	Soft	Rock at 100 ft.	25
95	.....	—	.....	.....	C	Slightly hard, iron	Water temperature 62° F.	26
107	6	−30	.....	.....	D	A	Bedrock not encountered.	27
45	.....	−30	.....	.....	D	Slightly hard	.....	28a
184	6	−135	.....	.....	D	A	Supplies 4,000 gallons a day.	28b
152	3	.....	.....	.....	D	A	Bedrock not encountered.	29
30	.....	−25½	.....	5	D	Soft	.....	30
245	6	.....	.....	.....	D	Hard, iron	Bedrock not encountered.	31
165	4	.....	.....	.....	D	Iron	Bedrock not encountered.	32
145	4	−103.9	Oct. 6, 1939	.....	D	.....	Bedrock not encountered.	33
172	6	− 7	.....	65	D	Iron	Rock at 40 ft.	34

TABLE 12.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
35	4 miles north of Petersburg...	Virginia Dept. of Highways.	Mitchells Pump and Well Co.	1939	80	D
36	3 miles north of Petersburg...	Fred Pilcher.....	Mitchells Pump and Well Co.	1937	60	D
37	2½ miles north of Petersburg.	Wilson Planing Mill.....	Mitchells Pump and Well Co.	1928	60	D
38	2½ miles north of Petersburg.	Greenleaf Dairy.....	Mitchells Pump and Well Co.	.....	60	D
39	1¼ miles north of Petersburg.	Delta Oil Co.....	Mitchells Pump and Well Co.	1937	60	D
40	Bermuda Hundred.....	W. T. Johnson.....	.....	.....	5	D
41	Bermuda Hundred.....	A. B. Shands.....	Mitchells Pump and Well Co.	1932	40	D
42	Meadowville.....	Meadowville Farm.....	Mitchells Pump and Well Co.	1937	5	D

[a]Includes only wells within the Coastal Plain portion of the county.
[b]D = drilled. Dug = dug.
[c]Ab = abandoned. B = boiler feed. C = cooling. D = domestic. In = industrial. M = municipal. P = public school. S = stock.
[d]A: Analysis is given in table of analyses. Figures refer to total hardness (TH), chloride (Cl), and sulphate (SO_4) in parts per million as given in commercial analyses.

Chesterfield County, Virginia[a]—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Pumping yield (gallons a minute)	Use of water[c]	Quality[d]	Remarks	No.
126	6	−18	.....	.....	D	.....	Rock at 60 ft.	35
139	6	−17.9	Sept. 22, 1939	4	D	Hard, iron	Rock at 54 ft.	36
160	4	−	.....	5	B	Foams	Rock at 30 ft.	37
160	6	−	.....	13	C	Hard	Rock at 40 ft.	38
73	4	−	.....	15	D	.....	Rock at 61 ft.	39
40	3	− 3.41	Oct. 5, 1939	.....	D	Soft, corrosive	.....	40
105	4	−	.....	10	D S	A	.....	41
212	4	+	.....	± 2	D S	.....	Bedrock not encountered. Yield as flow.	42

TABLE 13.—*Logs of wells in eastern Chesterfield County, Virginia*

Well 9, 2 miles west of Bensley; E. L. Tessier
(Log by Virginia Machinery and Well Co.)
Altitude, 200 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	55	55
Basement rock (pre-Cambrian):		
Fissured granite	54	109
Hard granite	21	130

Well 10, village of Bensley
(Log by Mitchells Pump and Well Co.)
Altitude, 80 feet

	Thickness (feet)	Depth (feet)
Potomac group (Lower Cretaceous):		
Mud and gravel	49½	49½
Sand and gravel	10½	60
Sand, water	3	63
Basement rock (pre-Cambrian):		
Soft rock	18	81
Hard rock	7½	88½

Well 13, Camp Merriwood
(Log by Virginia Machinery and Well Co.)
Altitude, 70 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	18	18
Sand and gravel	11	29
Potomac group (Lower Cretaceous):		
Gray marl	2	31
Clay and boulders	6	37
Clay and sand	5	42
Sand and gravel, water	2	44
Clay and gravel	26	70
Blue marl	20	90
Basement rock (pre-Cambrian):		
Granite	129	219

TABLE 13.—*Logs of wells in eastern Chesterfield County, Virginia—Continued*

Well 23, Chester; Chester High School
(Log by Virginia Machinery and Well Co.)
Altitude, 155 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	45	45
Gravel	12	57
Yellow clay	8	65
Chesapeake group (Miocene):		
Blue sticky clay	30	95
Potomac group (Lower Cretaceous):		
Brown hard clay	8	103
Yellow sand	1	104
Basement rock (pre-Cambrian):		
Light granite and flint	11	115
Sandstone	50	165
Fine gray sand	2	167
Soft white granite	33	200
White granite	123	323
Hard gray granite	4	327

TABLE 14.—*Analyses of ground water from eastern Chesterfield County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 12)

Water-bearing material	Granite	Sand of Potomac group			
	23	27	28b	29	41
	Chester	Dutch Gap	Dutch Gap	Dutch Gap	Bermuda Hundred
Silica (SiO_2)	17	.....	.....	52	.....
Iron (Fe)	.03	.....	.....	.40	.....
Calcium (Ca)	67	.....	.....	17	.....
Magnesium (Mg)	5.0	.....	.....	7.0	.....
Sodium (Na)	197	.....	.....	6.1	.....
Potassium (K)	14	.....	.....	3.7	.....
Bicarbonate (HCO_3)	126	56	20	93	196
Sulphate (SO_4)	468	15	1	8.8	44
Chloride (Cl)	24	2	7.0	2.1	5
Fluoride (F)	3.4	.8	.5	.4	.2
Nitrate (NO_3)	.10	.0	.....	.0	.0
Total dissolved solids	857	.....	.....	138	.....
Total hardness as $CaCO_3$ (calculated)	188	50	18	71	183
Free carbon dioxide (CO_2)	5.0	24	39	8.3	18
Date of collection	Oct. 8, 1939	Oct. 8, 1939	Oct. 8, 1939	Oct. 8, 1939	Oct. 8, 1939

Analyst: Margaret D. Foster.

PRINCE GEORGE COUNTY AND NORTHEASTERN DINWIDDIE COUNTY

LOCATION AND DEVELOPMENT

Prince George County is in the northwestern part of the area treated in the present report and extends eastward from the Fall Zone. It is limited by Appomattox and James rivers on the north and Sussex and Surry counties on the east and south. It has an area of 286 square miles, of which 55½ per cent is classed as farm land. Exclusive of the independent cities of Hopewell and Petersburg, the population in 1940 was listed as 12,226. The population of Hopewell was 8,697.

Most of the land within Prince George County is used for various farm crops. Manufacturing is centered in the independent cities. The total value of manufactured products from Prince George County and Hopewell in 1940 was $31,788,781. Textiles, chemicals, such as anhydrous ammonia, sodium nitrate, chlorine, and ammonium nitrate, and explosives, are produced at Hopewell and make up the greater part of the manufactures.

Petersburg National Military Park, scene of the famous Battle of The Crater in the War between the States, and the site of Camp Lee during the first and second world wars is in Prince George County. A federal reformatory is located on Appomattox River between Petersburg and Hopewell.

The city of Petersburg, the greater portion of which lies in northeastern Dinwiddie County, had a population of 30,631 in 1940. It is a manufacturing city and is perhaps most important for its tobacco products. Brown and Williamson have a large tobacco plant in the city, and a number of small independent establishments are also located there. The American Hardware Company is an important manufacturer of trunks and bags. Several lumber and woodworking mills are active within the city limits. Data on the value of manufactured products in 1940 are not available, but the total value of manufactured products in 1929 was $16,925,302.

The Central State Hospital for colored people is situated a short distance west of the city, and Petersburg State Colony for the colored insane is several miles south of the city.

TOPOGRAPHY

The greater part of Prince George County and northeastern Dinwiddie County consists of low, rolling hills, broken by a few narrow valleys and by flat terraces of moderate extent. The gently seaward-

sloping Sunderland terrace lies at 130 to 170 feet above sea level and makes up the largest part of the county. Lower terraces border James and Appomattox rivers. A 20-foot terrace is present at Brandon, and a more extensive terrace (Wicomico) at 70 to 100 feet above sea level is developed at Burrowsville, and from Hopewell to Petersburg. Flat-topped hills, attaining an elevation of 200 feet above sea level, are present 3 miles south of The Crater and are remnants of a once extensive pre-Sunderland terrace of Pleistocene age, probably the Coharie.

With the exception of a cliff 100 feet high overlooking James River near Jordans Point, the southern banks of James and Appomattox rivers are generally not high in Prince George County, because the lower terraces are extensively developed.

GEOLOGY

The granite which forms the basement or floor beneath the sediments of the Coastal Plain crops out west of the city of Petersburg. Along Appomattox River bedrock lies at or very close to the surface within the city limits. Well 63a, near Petersburg, reached basement rock at 150 feet and well 67, in the town, struck hard rock, presumably granite, at 68 feet. (See logs, Table 16). To the east bedrock lies at greater depths beneath the surface and is not reached by most wells. At Hopewell, however, it was encountered at about 285 feet below sea level. Depth to bedrock has been determined by geophysical methods at Camp Lee, one-third of a mile east of Petersburg, at Youngbloods Store which is half a mile southeast of Petersburg, and at a point one-fifth of a mile southeast of Prince George Court House. At these localities granitic bedrock lies respectively at 230, 260, and 300 feet below sea level. At Newville and Mercy Seat Church in Burrowsville, bedrock was determined to be 300 feet below sea level. The relatively sharp falling off of the bedrock surface east of Petersburg and its flattening still farther to the east, have been discussed previously. The data are plotted in Plate I, section A-A′.

The sediments of the Potomac group, which rest upon the granitic bedrock, are exposed at several places along Appomattox River but do not appear elsewhere at the surface. In most of the county these alternating strata of clay and sand are buried, and their character is known only from the logs of deep wells (Table 16).

These strata are encountered at about 40 feet above sea level at Carson and Petersburg. Eastward they lie deeper and are encountered at 30, 60, 65 and 100 feet below sea level, respectively, at Hopewell, Disputanta, Newville and Burrowsville.

The variability of these sediments may be shown by comparing the logs of wells at the Federal Reformatory and at Hopewell (wells 1, 16, and 20, Table 16). At the former locality the Potomac sediments are predominantly highly colored clays in which sandy material is subordinate. At Hopewell the sediments appear to be lighter in color, cleaner and contain a great deal more sandy material. In a well at

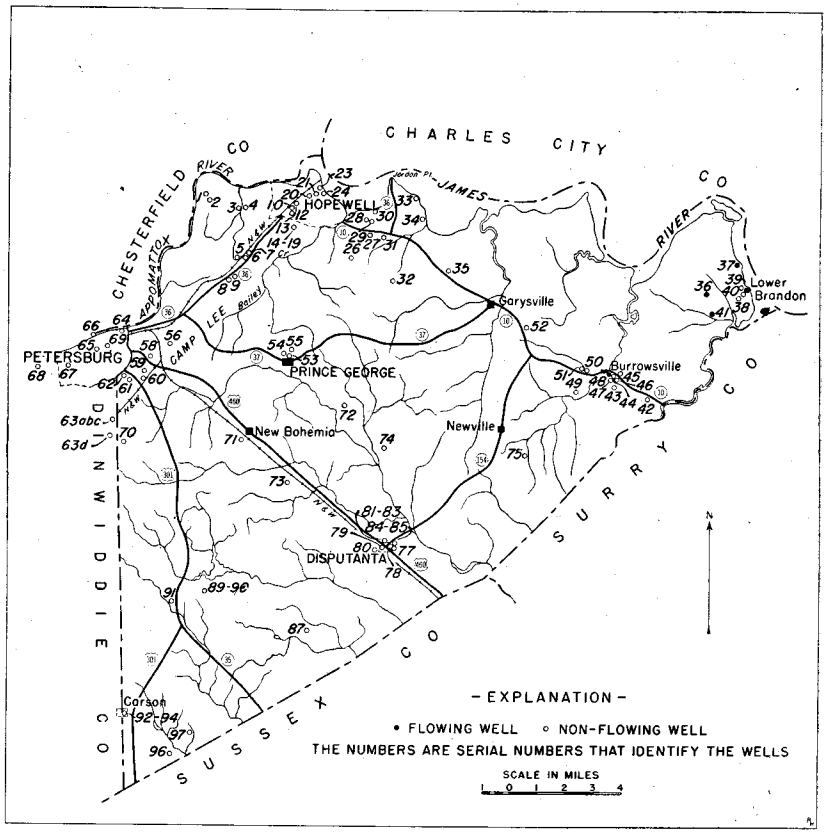


FIGURE 21.—Map of Prince George County and northeastern Dinwiddie County showing location of wells listed in Table 15.

Collier Coal Chute, 2½ miles south of Petersburg (63a, Table 16), the Potomac deposits are made up of indurated sandy strata, probably similar to those exposed at Point of Rocks on Appomattox River. Similar strata were also encountered in the well of the Petersburg State Colony near by. Elsewhere in the county the Potomac deposits have not been penetrated by many wells.

The Aquia and Nanjemoy formations, which are respectively the lower and upper formations of the Pamunkey group of Eocene age, are exposed in the area. The pink clay marking the base of the Nanjemoy crops out along James River, east of Hopewell, below the mouth of Bailey Creek. In Poo Run, Petersburg National Military Park, greensand beds of the Pamunkey group are well exposed, but the pink clay marking the base of the Nanjemoy seems to be absent.

Glauconitic greensand of Eocene age was penetrated in deep wells at Newville, Brandon and Burrowsville; at Burrowsville a maximum thickness of 70 feet was recorded (44, Table 16). Westward along the Fall Zone Eocene deposits may feather out.

In well 79 (Table 16) at Disputanta the base of the Eocene "black sand" is at 70 feet (41 feet above sea level); it seems likely that the underlying blue clay stratum is also of Eocene age. The blue clay is underlain by a red clay stratum which is probably late Cretaceous in age. The Upper Cretaceous (?) red clay is lacking in well 77; it is possible that the dark-green sandy marl penetrated from 125 to 145 feet may be late Cretaceous in age rather than Eocene.

Marly beds of the Calvert formation of Miocene age overlie the Eocene strata and are exposed in many road cuts and stream valleys. Diatomaceous clays crop out at low elevations in the vicinity of Petersburg, and probably in many places along Appomattox River. The greater part of the exposed Miocene deposits, however, has been mapped as clay and sand of the Yorktown formation.[137] According to the logs of wells (28 and 58, Table 16 and Fig. 21) near Hopewell and Petersburg respectively, sand forms a very minor part of the Miocene deposits.

Pleistocene terrace deposits of sand and clay cover the greater part of Prince George County and extend to northeastern Dinwiddie County.

GROUND WATER

Water is obtained from shallow dug or driven wells in the terrace deposits, from deeper drilled wells in the Potomac sediments and from granitic bedrock. A very few drilled wells obtain water from the Chesapeake group of deposits.

SHALLOW WELLS

Dug wells from 15 to 30 feet in depth are in use in all parts of the county and supply the greater part of the rural inhabitants with water. Some of these wells are properly protected, but many others are poorly constructed and are liable to pollution.

Many of the shallow dug or driven wells yield soft water of low mineral content. In a few places the shallow ground water contains objectionable amounts of iron. A high content of free carbon dioxide was found in water from wells 72, 74, 75, and 85 (Table 17) and it may be that this gas causes the solution of iron from pipes through which the water passes. However, many of the wells yield water containing iron even after prolonged pumping which suggests that the iron is derived from the water-bearing formation. Other dug wells in which there is no metal casing or drop pipe and from which water is drawn by bucket, also yield water containing iron.

Although the free carbon dioxide content of water from well 85 is high (43 parts per million), this water is satisfactory for boiler use and has been so utilized for several years without trouble from corrosion. Small sawmills in Prince George County also use water from dug wells with apparent success. The water for the boilers is lifted by steam jets and thereby raised in temperature, and is temporarily stored in open tanks. This treatment may decrease the carbon dioxide content.

DEEP WELLS

WATER FROM CRETACEOUS DEPOSITS

Throughout the county water is obtained from drilled wells, for reasons of economy, sanitation, permanence, quantity, or temperature or a combination of these factors. The larger number of drilled wells are located at village homes, at farms, or at dairies and afford safe, dependable and ample supplies of water. All of these wells obtain water from Cretaceous deposits. Many wells which get water from the uppermost Cretaceous sands are 100 to 150 feet deep, but other wells which are located on higher ground and develop additional or deeper sand strata in the Cretaceous sediments exceed a depth of 300 feet.

Cretaceous deposits yield moderately hard or high calcium bicarbonate water (Table 18) throughout most of the county, except at Brandon, where the water has become almost totally softened by base-exchange. The hardness is not considered to be very objectionable by most users. However, in a few wells the water contains objectionable amounts of iron. This iron can probably be easily removed, in some instances, by simple aeration. For example, it was stated by Mr. Harrison Livesay, owner of well 46 at Burrowsville, that water from this well contains an objection-

able amount of iron. The water is delivered to an overhead tank and after standing about an hour loses most of its unpleasant taste. The accumulated iron oxide is removed from the tank twice a year.

Water from Cretaceous strata rises to about 92 feet above sea level in a well at The Crater (58, Table 15 and Fig. 21), and to about 31 feet above sea level in wells near Burrowsville (44, 46, 49, and Fig. 9). However, the artesian water level surface (piezometric surface) does not slope evenly from the western part of the county to the eastern part. The artesian head has been diminished by industrial pumping at Hopewell and as a consequence of open flowing wells at Brandon and Claremont, as shown in Figure 9. In 1940 artesian water would rise to about 31 feet above sea level at Burrowsville; this is said to be about 6 feet lower than the height to which artesian water would rise before a flowing well was drilled in that community. The maximum depth to water in wells which tap Cretaceous sands is 140 feet, in a well near Hopewell (26, Table 15). In other parts of the county it is considerably less.

WATER FROM GRANITIC ROCK

A few drilled wells in Petersburg obtain water from the granitic bedrock. Two wells of the J. B. Worth Peanut Co. (64a and 64b, Table 15), now obsolete, are reported to have yielded 50 gallons a minute each shortly after they were drilled in 1892. The well of the American Hardware Co. (65) has been pumped at a rate of 60 gallons a minute, although it can furnish a somewhat greater amount. The water is used for cooling boilers. The Zero Ice Co. pumps 30 gallons a minute from a well (66) for cooling. The well (67) of A. G. Smith, florists, at Petersburg, reached granite at 68 feet and was drilled 104 feet deeper in order to obtain a satisfactory supply. An analysis of a sample of water from this well is given in Table 19. It is a moderately hard calcium bicarbonate water. The well at the Central State Hospital (68) just west of Petersburg, was pumped from 1905 to 1915, but since that date has been kept up only as an emergency supply. The well yielded more than 200 gallons a minute, but the water was hard and unsatisfactory for boiler use. A well at the Brown and Williamson tobacco factory (69) within the city encountered bedrock

at a depth of 58 feet, which is about sea level, and was continued to a total depth of 578 feet. Only about 15 gallons a minute could be obained, and the well was abandoned.

INDUSTRIAL PUMPING AT HOPEWELL

A considerable volume of water is pumped at Hopewell. The Solvay Process Co. and the Hummel-Ross Fibre Corp. derive water from sediments of the Potomac group. The water is used for cooling purposes in the production of chemical products. The wells of the Solvay Process Co. (20 and 21, Table 15) were rated as capable of delivering more than 2,000 gallons a minute in 1928, but probably did not produce more than 1,500 gallons a minute in 1940. They are pumped only during the warmer months of the year, at which time the ground water is cooler than water from the public supply. The wells of the Hummel-Ross Fibre Corp. (23 and 24) produced a combined yield of 300 gallons a minute in 1940, which is about three-fourths of the yield of the wells when they were drilled in 1921. These wells have been pumped continuously. A dairy and an ice plant in Hopewell have pumped small amounts of water from drilled wells.

The Tubize-Chatillon Co., manufacturers of rayon cloth, pumped ground water during 1924 to 1931 from wells 14-19 inclusive (Table 15). The yearly consumption during that period was approximately 300,000,000 gallons.

Incomplete data show that two 10-inch wells were drilled for the town of Hopewell in 1915, respectively 110 and 107 feet deep, and five 10-inch wells were drilled for E. I. du Pont de Nemours Co. in 1913, which were respectively 115, 106, 117, 378, and 143 feet deep. Various other wells were drilled which have been abandoned. No information is available on the amount of water pumped previous to 1924.

In summary, it is known that much water was pumped from time to time previous to 1924, and that since that year a considerably greater amount of water has been pumped annually. Rough calculations indicate that in the period 1924-1940 a minimum of 8 billion gallons of water has been pumped at Hopewell. As about 1,500,000 gallons a day was pumped in 1940 and may continue to be pumped, the permanence of the supply and the possibility of further expansion of the deep-well supplies are matters of great importance.

The water levels in the vicinity of Hopewell indicate that the ground-water supply is not being seriously depleted. Water still rises above the water-bearing formations, in wells that penetrate them. That does not mean, however, that no water has been taken from storage. Meinzer[75] has shown that for a period of years the Dakota sandstone has yielded considerably more water to wells than entered the formation. Concurrently, the artesian pressure has dropped considerably. The excess of water yielded to wells, over the amount which entered the formation, was furnished by the formation as a result of the diminution of pore space following the decreases of artesian pressure. Wenzel and Sand[142] have calculated that a generous estimate of the amount of compression which takes place in an elastic artesian aquifer by the lowering of the water level may be arrived at by applying a factor of 0.001. Thus, we may make an estimate of the amount of lowering of water level which would take place if the minimum of 8 billion gallons pumped at Hopewell were derived entirely from storage in the sediments of the surrounding area.

If it is assumed that ground water is flowing toward Hopewell from all directions, from points as distant as 10 miles away, and the total tributary area therefore is assumed to be about 314 square miles, the lowering of water level over this area by 1 foot will release less than 66,000,000 gallons of water.* To release 8 billion gallons of water, a lowering of the water level of about 120 feet over the 314 square miles would need to have taken place. Although data regarding the water levels in Prince George County previous to 1924 are scanty, it is apparent that no such excessive lowering has taken place. In fact, it appears that in 1928 the water levels at Hopewell during the winter non-pumping period, were about as they were in the winter periods of 1938-1940. At the Federal Reformatory very little, if any, lowering of the water level has taken place since 1930.

However, the lowering of water levels which is known to have taken place indicates that a large amount of water has been taken from storage. Sanford[113] reports that about 1910 the artesian water level at Hopewell was more than 15 feet above high tide level and at Coggins Point more than 30 feet above high tide level. A loss of head of about 10 feet has apparently taken place at Coggins Point, and about 30 feet at Hopewell.

*27,878,400,600 sq. ft. x 1 ft. x .001 x 7.48 gals.

Assuming that Hopewell is the center of a cone of depression with a 10-mile radius, in which the greatest decline of water level has been 35 feet, it is roughly estimated that the amount of water removed from storage by such lowering of water levels is less than 800,000,000 gallons. Thus, according to these calculations, the amount of water removed from storage is less than one-tenth of the known total pumpage from 1924 to 1940. It must be borne in mind that the available data are incomplete, but the figures presented may be considered to show the approximate relation of the amount of water removed from storage, to the total amount pumped.

OBSERVATION WELLS IN THE HOPEWELL AREA

Another method of studying the problem of safe yield at Hopewell and obtaining other data of general interest to Coastal Plain hydrology, is by observing the changes in the cone of depression which now exists. Enlargement of this cone, indicated by the lowering of the water level in properly selected observation wells, will mean that more water is being taken from storage and that the water levels at the pumped wells within the cone of depression are declining.

Two observation wells have been selected at Hopewell. One is located on the grounds of the Old Dominion Water Company, half a mile south of the center of heavy pumping at the plants of the Solvay Process Company and the Hummel-Ross Fibre Corp. The other is on the grounds of the Tubize Chatillon Corp., three-fourths of a mile south of the center of heavy pumping. The first well is equipped with an automatic water-stage recorder; the second well is measured weekly by tape, as a check on the first well.

Regular measurements on these wells began in July 1939; the curve from June 1, 1939, to December 31, 1941, is shown in Figure 22. Heavy pumping at Hopewell apparently began early in May in 1939, 1940 and 1941. Water levels fall rapidly in the observation well of the Old Dominion Waterworks Co. during the latter part of May and in June but flatten to slight fluctuation in July. The lowest recorded levels in the periods covered in the hydrograph were respectively 49.44 feet, 49.89 feet, and 48.37 feet below the measuring point at the recorder base.

In the summer of 1942, the water level was generally between 50 and 52 feet below the measuring point. This marked differ-

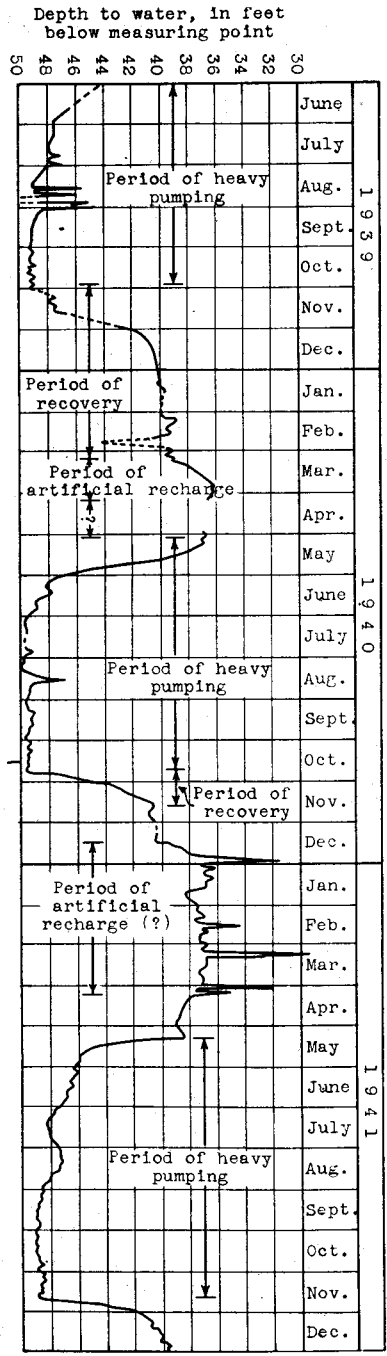


FIGURE 22.—Hydrograph of observation well at Hopewell showing variation in water levels 1940-1942, in periods of pumping, nonpumping, and artificial recharge.

ence in pumping level is ascribed to the lack of natural recharge of the water-bearing formations as a result of the drought conditions which prevailed along the Atlantic seaboard from the spring of 1941 through the summer of 1942.

The lowest levels recorded in the well of the Tubize Chatillon Corp. during the same period were 40.83 feet, 40.76 feet, and 39.41 feet below the measuring point.

The static water level at Hopewell during the winter non-pumping season is not known, because in this area artificial recharge from wells was carried out to a limited extent in the winter of 1939-1940 and for a longer period in the winter of 1940-1941. The highest recorded water levels indicate that millions of gallons of water were added to the underground strata by this means. However, the water levels rose in November and December, 1939, and flattened out by the middle of January, 1940. It is thought that the normal level of the artesian water was recorded in the well of the Old Dominion Waterworks Co. at this time, when the depth to water varied between 39 and 40 feet below the measuring point, or 12½ to 13½ feet above sea level.

Detailed records show that during periods of heavy pumping the water stands from 7 to 8½ feet higher above sea level in the well of the Tubize Chatillon Corp. than in the wells of the Old Dominion Waterworks Co. because a cone of depression is created around the center of heavy pumping. Relative to the deepest part of the cone, the former well is the more distant. During the winter months, when the wells of the Solvay Process Co. are shut down, the difference between the water levels in the two observation wells is less but a difference in level of 3 to 5 feet still exists because pumping is continued at the plant of the Hummel-Ross Fibre Corp. throughout the year.

Weekly observations have also been made on the well at the Federal Reformatory, 3½ miles west of Hopewell (2, Table 15), in an effort to detect any effects of the heavy pumping at Hopewell. It was found, however, that the record at the Reformatory is more nearly comparable with that of a well located on the Fall Zone a few miles north of Petersburg, whose water level fluctuates chiefly in response to the local rainfall.[76] No effects of the withdrawal of large quantities of water at Hopewell could be discerned at the Reformatory.

The records of water-level measurements to January 1, 1940, have been published.[76] Further records and discussions of the significance of future variations in water levels will appear in succeeding reports of the U. S. Geological Survey.

WELL RECORDS AND ANALYSES

Records of wells in Prince George and northeastern Dinwiddie counties, available logs of wells, and analyses of water samples are listed in Tables 15-19, on the following pages. The locations of wells listed are shown in Figure 21.

TABLE 15.—*Records of wells in Prince George*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
1	3½ miles west of Hopewell	U. S. Reformatory	Sydnor Pump and Well Co.	1930	110	D
2	3½ miles west of Hopewell	U. S. Reformatory	Virginia Machinery and Well Co.	1930	100	D
3	2½ miles west of Hopewell	R. L. Sherick	E. J. Cousins	1934	20	D
4	2¼ miles west of Hopewell	J. Broaddus	E. J. Cousins	.....	60	D
5	3¼ miles southwest of Hopewell.	Norfolk and Western Ry. Co.	.....	1916	82	D
6	3¼ miles southwest of Hopewell.	W. H. Mason	Lane Well Co.	1937	84	D
7	3 miles southwest of Hopewell.	G. R. Emerson	Lane Well Co.	.....	90	D
8	4 miles southwest of Hopewell.	D. L. Elder	Mitchells Pump and Well Co.	1938	140	D
9	3½ miles southwest of Hopewell.	E. J. Cousins	E. J. Cousins	.....	79	D
10	Hopewell	Nickell Ice and Coal Co.	.....	.....	50	D
12	Hopewell	Woods Dairy	E. J. Cousins	1928	50	D
13	Hopewell	Old Dominion Water Co.	Sydnor Pump and Well Co.	.....	50	D
14	Hopewell	Tubize Chatillon Corp.	E. J. Cousins	1923	51	D
15	Hopewell	Tubize Chatillon Corp.	Sydnor Pump and Well Co.	1924	51	D
16	Hopewell	Tubize Chatillon Corp.	Sydnor Pump and Well Co.	1924	51	D
17	Hopewell	Tubize Chatillon Corp.	Sydnor Pump and Well Co.	1924	51	D
18	Hopewell	Tubize Chatillon Corp.	Sydnor Pump and Well Co.	1926	51	D
19	Hopewell	Tubize Chatillon Corp.	Sydnor Pump and Well Co.	1926	51	D
20	Hopewell	The Solvay Process Co.	Layne-Atlantic Co.	1928	47	D
21	Hopewell	The Solvay Process Co.	Layne-Atlantic Co.	1927	46	D
23	Hopewell	Hummel-Ross Fibre Corp.	Sydnor Pump and Well Co.	1921	5	D
24	Hopewell	Hummel-Ross Fibre Corp.	Sydnor Pump and Well Co.	1921	5	D
26	2½ miles southeast of Hopewell.	Fountain Dairy	Mitchells Pump and Well Co.	1924	135	D
27	2½ miles south-southwest of Jordan Point.	Norwood Wilson	Mitchells Pump and Well Co.	.....	120±	D
28	1¾ miles southwest of Jordan Point.	Henry Thompson	Mitchells Pump and Well Co.	1939	130	D
29	1¾ miles southwest of Jordan Point.	Norwood Wilson	Mitchells Pump and Well Co.	.....	140	D
30	1½ miles southwest of Jordan Point.	Norwood Wilson	E. J. Cousins	.....	100	D
31	2½ miles south of Jordan Point.	J. Rusnak	Owner	1919	120	Dug
32	3½ miles east-southeast of Hopewell.	E. J. Graves	Owner	.....	125	Dug
33	1½ miles southeast of Jordan Point.	A. H. Trotter	E. J. Cousins	1921	20	D

and Dinwiddie counties, Virginia[a]

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield: Rate (gallons a minute)	Yield: Date of measurement	Use of water[c]	Reported quality[d]	Remarks	No.
.....	10	−38½	June 14, 1939	12	1938	C	.....	Original yield 18 gallons a minute.	1
285	10	−18	June 14, 1939	16	1938	Ab	.....	Original yield 20 gallons a minute. Observation well of U. S. Geological Survey.	2
38	3	—	.....	.....	.....	D	TH, 120 iron	.....	3
145?	3	—	.....	.....	.....	D	TH, 120 iron	.....	4
200	3	—	.....	.....	.....	D	TH, 80 iron	.....	5
67	3	−27	.....	.....	.....	D	TH, 120 no iron	.....	6
84	3	−33	June 14, 1939	.....	.....	D	.....	.....	7
60	6	—	.....	.....	.....	D S	Iron.	.....	8
90	6	−23	June 1, 1939	.....	.....	D	A	.....	9
.....	.....	—	.....	.....	.....	C	.....	.....	10
120	6	—	.....	10+	1939	D C	.....	.....	12
.....	6	−41½	May 29, 1939	.....	.....	Ab	.....	Observation well of U. S. Geological Survey.	13
301	6	−34	May 27, 1939	180 0	1923 1932	Ab	.....	Tubize well #1.	14
265	6	−37	.....	140 127	1924 1932	Ab	.....	Tubize well #2. Observation well of U. S. Geological Survey.	15
304	6	−37	May 27, 1939	140 82	1924 1932	Ab	.....	Tubize well #3.	16
279	6	−40	May 27, 1939	115 102	1924 1932	Ab	.....	Tubize well #4.	17
299	6	−43¼	May 27, 1939	142 70	1926 1932	Ab	.....	Tubize well #5.	18
299	6	—	.....	140 47	1926 1932	Ab	.....	Tubize well #6.	19
336	18	−49	1928	640	1928	C	.....	Rock at 332 ft. Drawdown 122 ft. at yield noted.	20
285	18	−46	Sept. 24, 1927	980	1927	C	.....	Drawdown 126 ft. at yield noted.	21
156	10	0 −15 −25	1921 Feb., 1932 May 27, 1939	160	1939	C	A	Well 24 pumping when water level was measured May 27, 1939.	23
158	10	0 −80±	1921 May 27, 1939	140	1939	C	A	Pumping when water level was measured May 29, 1939.	24
250	4	−140	Aug. 1, 1924	15	.....	D S	TH, 130	.....	26
186	.....	−105	.....	.....	.....	S	.....	In apple orchard.	27
351	4	−120	Spring, 1939	.....	.....	D S	A	.....	28
240	4	−126	.....	.....	.....	D S	A	At old Temple Farm.	29
310	4	—	.....	.....	.....	D S	.....	.....	30
24	.....	—	.....	.....	.....	D S	TH, 50	Water level varies from 6 ft. to 16 ft. below surface.	31
30	.....	—	.....	.....	.....	D S	TH, 25	.....	32
90	3	−16	.....	.....	.....	D	Soft	.....	33

TABLE 15.—*Records of wells in Prince George*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
34	2 miles southeast of Jordan Point.	B. B. MacClure	W. H. Mason	1937	80	D
35	4 miles southeast of Jordan Point.	J. Basl	.....	.....	124	Dug
36	1¼ miles west of Lo rBrandon.	The Virginia Company, Inc.	Jewett	1915	15	J
37	Brandon P. O.	The Virginia Company, Inc.	E. J. Cousins	1930	15	D
38	Lower Brandon	The Virginia Company, Inc.	J. Minton	.....	20	J
39	Lower Brandon	The Virginia Company, Inc.	.....	.....	18½	.....
40	Lower Brandon	The Virginia Company, Inc.	Mitchells Pump and Well Co.	193	20	D
41	1 mile southwest of Lower Brandon.	The Virginia Company, Inc.	.....	.....	10	.....
42	1 mile southeast o f Burrowsville.	M. Wynn	.....	.....	60	Dug
43	½ mile south of Burrowsville	J. W. Ellis	Jewett	.....	71	J
44	Burrowsville	Brandon Church Rectory	Mitchells Pump and Well Co.	1942	75	D
45	Burrowsville	W. B. Goodrich	E. J. Cousins	1933	75	D
46	Burrowsville	H. Livesay	Mitchells Pump and Well Co.	1933	75	D
47	Burrowsville	Burrows	C. W. Daugherty	1914	63	J
48	Burrowsville	L. H. Hayes	Mitchells Pump and Well Co.	1931	10+	D
49	1¼ miles southwest of Burrowsville.	A. Williamson	.....	.....	50	D
50	1 mile west of Burrowsville	S. T. Harrison	.....	.....	68	Dug
51	1¾ miles west of Burrowsville.	A. Williamson	Mitchells Pump and Well Co.	1933	70	D
52	3½ miles northwest of Burrowsville.	M. F. Booth	.....	.....	120	Dug
53	Prince George	County Court House	E. J. Cousins	1928	128	D
54	Prince George	Wiseman	E. J. Cousins	1934	128	D
55	Prince George	Public School	E. J. Cousins	1936	128	D
56	2 miles east of Petersburg	Petersburg National Military Park.	.....	1933	97	D
58	The Crater	Petersburg National Military Park.	Mitchells Pump and Well Co.	1937	127	D
59	Walnut Hill, Petersburg	R. C. Powell	Mitchells Pump and Well Co.	1924	160	D
60	1 mile south of The Crater	Rives School	E. J. Cousins	1936	165	D
61	Walnut Hill, Petersburg	W. Harris	E. J. Cousins	1930	100	D
62	Walnut Hill, Petersburg	H. Seward	Sydnor Pump and Well Co.	1914	130 (?)	D
63a	3 miles south of Petersburg	Atlantic Coast Line R. R.	Virginia Pump and Well Co.	1915	160	D
63b	3 miles south of Petersburg	Atlantic Coast Line R. R.	Virginia Pump and Well Co.	1915	160	D
63c	3 miles south of Petersburg	Atlantic Coast Line R. R.	Virginia Pump and Well Co.	1915	160	Dug
63d	4 miles south of Petersburg	State Colony	Sydnor Pump & Well Co.	1941	150	D
64a	Petersburg	J. B. Worth Peanut Co.	A. P. Jerguson	1892	20	D
64b	Petersburg	J. B. Worth Peanut Co.	A. P. Jerguson	1890	20	D
65	Petersburg	American Hardware Co.	Mitchells Pump and Well Co.	.....	55	D

and Dinwiddie counties, Virginia[a]—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield: Rate (gallons a minute)	Yield: Date of measurement	Use of water[c]	Reported quality[d]	Remarks	No.
160	4	−	.....	.....	.....	D	Moderately soft	.....	34
18	.....	−16	.....	.....	.....	D S	Soft, iron	.....	35
160	2	+ 3½	May 23, 1939	.....	.....	D S	Soft	Flows ¼ gallon a minute.	36
240	3	+	.....	.....	.....	D	.....	Flows 15 gallons a minute.	37
190	3	− 1½	May 26, 1939	.....	.....	S C	A	At dairy.	38
.....	4	− 1¼	May 26, 1939	.....	.....	D	.....	At swimming pool. Flows 30 gallons a minute, in pit 8 ft. below surface.	39
405	4	−	.....	.....	.....	D	A	In front of residence.	40
.....	4	+	.....	.....	.....	.....	A	Supplies fish pond. Flows 30 gallons a minute.	41
36	.....	−29	July 1, 1939	.....	.....	D	TH, 30	.....	42
194	3½	−	.....	.....	.....	D	Hard.	.....	43
204	6	−45	1942	15	1942	D	.....	No strainer. 60 ft of draw-down at yield noted.	44
78	3	−	.....	.....	.....	D	TH, 50	.....	45
202	4	−	.....	.....	.....	D	Iron TH, 110	Most of iron settles out after short storage in tank.	46
185	3	−32	.....	.....	.....	D S	.....	.....	47
120	4	+	.....	.....	.....	D	A	Flows 30 gallons a minute.	48
160	2	−18	.....	.....	.....	D S	TH, 160	.....	49
35	.....	−30½	July 1, 1939	.....	.....	D S	TH, 50	.....	50
178	4	−34	1933	.....	.....	D	TH, 160	.....	51
30	.....	−12½	July 1, 1939	.....	.....	D	.....	.....	52
129	4	.....	.....	.....	.....	D	A	Supplies 6,000 gallons a day.	53
113	4	.....	.....	.....	.....	D	Hard	.....	54
168	4	.....	.....	.....	.....	P	.....	.....	55
96	.....	.....	.....	28	.....	D	.....	.....	56
122	3	−35	June 3, 1937	215	June, 1937	D	A	Drawdown 35 ft. after 24 hours pumping.	58
127	3	.....	.....	.....	.....	D	TH, 140	.....	59
112	.....	.....	.....	.....	.....	P	.....	.....	60
123	4	.....	.....	.....	.....	S	TH, 160	.....	61
355	6	.....	.....	80	.....	Irr.	TH, 100	Granite at 100 ft.	62
368	10	−14½	Apr. 5, 1926	85	.....	B	.....	Drawdown 49½ ft. after pumping 24 hours. Granite at 150 ft.	63a
210	10	.....	.....	.....	.....	B	.....	Granite at 150 ft.	63b
40	.....	.....	.....	.....	.....	B	.....	.....	63c
400±	10	.....	.....	.....	.....	D	A	Water from granite.	63d
193	8	.....	.....	250	.....	Ab	.....	.....	64a
218	.....	.....	.....	.....	.....	Ab	.....	.....	64b
105	6	−	.....	85	.....	B	TH, 160	.....	65

TABLE 15.—*Records of wells in Prince George*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
66	Petersburg	Zero Ice Co.	Mitchells Pump and Well Co.		25	D
67	Petersburg	A. G. Smith	Mitchells Pump and Well Co.	1938	100	D
68	Petersburg	Central State Hospital	Sydnor Pump and Well Co.	1905	110	D
69	Petersburg	Brown & Williamson	Mitchells Pump and Well Co.	1937	70	D
70	3 miles south of Petersburg	Earl Tucker			190	Dug
71	New Bohemia	F. J. Soucek			150	Dug
72	4 miles north-northwest of Disputanta.	Bethlehem Congr. Church				Dug
73	2½ miles southwest of New Bohemia.	A. Sluka			125	Dug
74	3½ miles north of Disputanta.	G. Zuskin			110	Dug
75	1¼ miles southeast of Newville.	S. B. Nickels			105	Dug
77	Disputanta	Colored School	Mitchells Pump and Well Co.	1939	117	D
78	Disputanta	High School	E. J. Cousins	1935?	119	D
79	Disputanta	C. C. Rucks	P. P. Ellis	1940	111½	J
80	Disputanta	Columbian Peanut Co.			120	Dug
81	Disputanta	R. N. Inge	Mitchells Pump and Well Co.	1928	112	D
82	Disputanta	W. C. Webb	E. J. Cousins	1928	109	D
83	Disputanta	J. H. Binford	Mitchells Pump and Well Co.	1930	114	D
84	Disputanta	Southall Stave Mill			112	Dug
85	Disputanta	J. H. Thacker Stave Mill			110	Dug
87	6¾ miles northeast of Carson.	Loving Union Church			105	Dug
89	3½ miles northeast of Carson.	J. H. Birdsong	E. J. Cousins	1920	141	D
90	3½ miles northeast of Carson.	J. H. Birdsong			141	Dug
91	2½ miles north-northeast of Carson.	Owl Tavern	Mitchells Pump and Well Co.		130	D
92	Carson	High School			160	D
93	Carson	Wilkerson Bros.	E. J. Cousins		158	D
94	Carson	Baugh Bros.	G. Wilkins	1906	158	J
96	3½ miles southeast of Carson.	D. R. King			130	Dug
97	3 miles east-southeast of Carson.	R. Saunders			105	Dug

[a]Wells 63 to 69 are in Dinwiddie County.
[b]D = drilled. Dug = dug. J = jetted.
[c]Ab = abandoned. B = boiler feed. C = cooling. D = domestic. Irr = irrigation. P = public school. S = stock.
[d]A: analysis is given in table of analyses. Figures refer to total hardness (TH), and chloride (Cl) in parts per million as determined by field test.

and Dinwiddie counties, Virginia[a]—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield: Rate (gallons a minute)	Yield: Date of measurement	Use of water[c]	Reported quality[d]	Remarks	No.
128+	.....	− 3	.....	70	.....	C	.....	Drawdown 40 ft. after pumping 14 hours. Rock at 9 ft.	66
172	.....	−41½	April, 1939	60	.....	D Irr.	A	Drawdown 46 ft. after pumping 8 hours. Rock at 68 ft.	67
.....	.....	.....	.....	200+	.....	D	Hard	Granite at 8 ft.	68
578	10 to 8	−30	Apr. 24, 1937	15	.....	Ab	.....	Hard rock encountered at 80 ft. Small yield.	69
24	.....	− 4	July 10, 1939	.....	.....	D	TH, 35 Cl, 20	.....	70
26	6	.....	.....	.....	.....	D	.....	During drought of 1930 water level was 20 ft. below surface.	71
35	.....	.....	.....	.....	.....	D	A	.....	72
32	.....	−16½	May 24, 1939	.....	.....	D S	.....	.....	73
25	.....	−15½	July 11, 1939	.....	.....	D S	A	.....	74
38	.....	−35.0	July 11, 1939	.....	.....	D S	A	.....	75
219	4	−39¼	May 22, 1939	10	April, 1939	P	.....	Drawdown 32 ft. after pumping 8 hours.	77
200?	.....	.....	.....	.....	.....	P	.....	.....	78
140	2	−37	1940	.....	.....	D	A	.....	79
18	.....	− 7	May 22, 1939	.....	.....	B	Soft	Yields 2 gallons a minute when pumped for several hours.	80
125	6	.....	.....	.....	.....	D S	Hard	.....	81
235	4	.....	.....	.....	.....	D	Hard	.....	82
132	4	−41	May 22, 1939	.....	.....	S	Hard	.....	83
15	.....	− 9¾	May 22, 1939	.....	.....	B	.....	.....	84
26	.....	− 6	May 22, 1939	5	.....	B	A	Water does not foam nor corrode boilers and deposits very little scale.	85
17	.....	−12¼	May 24, 1939	.....	.....	D	TH, 20 Cl, 22	.....	87
125	6	.....	.....	.....	.....	S	Hard	.....	89
28	.....	−22	May 24, 1939	.....	.....	D	Soft	.....	90
127	4	.....	.....	.....	.....	D	TH, 120	Bedrock not encountered.	91
.....	.....	.....	.....	.....	.....	P	.....	.....	92
118	4	−50	1939	.....	.....	D	A	Bedrock not encountered.	93
118	4	.....	.....	.....	.....	D	Iron	.....	94
24	.....	− 8¾	May 24, 1939	.....	.....	D S	Soft	.....	96
16	.....	−12	.....	.....	.....	D S	TH, 35 Cl, 20	.....	97

TABLE 16.—*Logs of wells in Prince George County, Virginia*

Well 1, 5½ miles northeast of Petersburg; Federal Reformatory
(Log by Sydnor Pump and Well Co.)
Altitude, about 110 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	40	40
Potomac group (lower Cretaceous):		
Clayey sand	20	60
Sandy clay	31	91
Yellow sand	14	105
Dark sand	25	130
Coarse sand	10	140
Black clay	35	175
Coarse sand and gravel	3	178
Brown sandy clay	15	193
Clayey sand	9	202
Brown sand and gravel	15	217
Brown slimy mud	61	278
Clean quartz sand	9	287
Red quartz sand	8	295
Brown sandy clay	53	348

Well 16, Hopewell; Tubize Chatillon Corporation
(Log supplied by Tubize Chatillon Corp.)
Altitude, 51 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow sand	40	40
Pamunkey group (Eocene):		
Green glauconitic sand	15	55
Potomac group (Lower Cretaceous):		
Alternating white water-bearing sand and light-colored clay	241	296
Gray clayey sand	12	308
Fine arkosic sand	6	314

TABLE 16.—*Logs of wells in Prince George County, Virginia—Continued*

Well 21, Hopewell; Solvay Process Company
(Log by Layne-Atlantic Co.)
Altitude, 46½ feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	18	18
Coarse sand	21	39
Pamunkey group (Eocene):		
Black sand	8	47
Hard black sand	5	52
Hard pan	2	54
Black sandy clay	28	82
Potomac group (Lower Cretaceous):		
Sand, water	7	89
Boulders, water	3	92
Coarse sand, water	23	115
Fine gravel and boulders, water	17	132
Sand and gravel, water	20	152
Hard coarse sand and gravel, water	25	177
Clay and gravel	4	181
Clay	14	195
Hard sand and gravel, water	23	218
Clay and shale	4	222
Loose sand and gravel, water	17	239
Hard sand and gravel, water	46	285

Well 28, 2½ miles southeast of Hopewell; Harry Thompson
(Log by Mitchells Pump and Well Co.)
Altitude, 130 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	3	3
Clay	3	6
Sandy clay	18	24
Chesapeake group (Miocene):		
Gravel and mud	24	48
Blue clay	27	75
Marl	15	90
Blue marl	20	110
Light-colored marl	8	118
Blue marl	15	133
Pamunkey group (Eocene):		
Marl and mud	35	168
Potomac group (Lower Cretaceous):		
Gravel and mud	3	171
Sandstone	9	180
Light-colored mud	20	200
Sand and mud	100	300
Gravel and sand	3	303
Sand and mud	17	320
Black marl and gravel	16	336
Sand	6	342
Sand and marl	9	351

TABLE 16.—*Logs of wells in Prince George County, Virginia—Continued*

Well 44, Burrowsville; Brandon Church Rectory
(Log by Mitchells Pump and Well Co.)
Altitude, 75 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
White clay	20	20
Chesapeake group (Miocene):		
Yellow clay and sand	40	60
Blue clay	40	100
Pamunkey group (Eocene):		
Black mud	70	170
Potomac group (Lower Cretaceous):		
White clay[a]	10	180
White sand and minor black sand[a]	10	190
Gray sand, water	14	204

[a]Geologic age questionable.

Well 55, Prince George; High School
(Log by Earl McKesson, from memory)
Altitude, 128 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	25	25
Chesapeake group (Miocene):		
Gray clay	..	..
Pamunkey group (Eocene):		
Black marl	...	160
Potomac group (Lower Cretaceous):		
White sand, water	8	168

Well 58, Petersburg National Park at The Crater
(Log by Mitchells Pump and Well Co.)
Altitude, 127 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	25	25
Chesapeake group (Miocene):		
Blue clay	10	35
Marl, shells	5	40
Marl, shells, and blue clay	30	70
Blue mud	25	95
Pamunkey group (Eocene):		
Fine black sand and blue mud	10	105
Coarse sand and blue mud	3	108
Potomac group (Lower Cretaceous):		
White sand, water	4	112
Gravelly sand, water	10	122

TABLE 16.—*Logs of wells in Prince George County, Virginia—Continued*

Well 60, 1 mile south of The Crater; Rives School
(Log by Earl McKesson, from memory)
Altitude, 165 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene)		
Sand	6	6
Chesapeake group (Miocene):		
Gray clay	100	106
Potomac group (Lower Cretaceous):		
Sand, water	6	112

Well 63a, 2½ miles south of Petersburg; Atlantic Coast Line Railroad, Colliers Coal Chute
(Log by Virginia Machinery and Well Co.)
Altitude, 160 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	20	20
Alternating fine sand and white clay, each stratum only a few inches thick; some strata contain coarser sand and gravel; yields only a little water	19	39
Coarse-grained yellow sand, water	1	40
Chesapeake group (Miocene):		
Marl	60	100
Potomac (?) group (Lower Cretaceous):		
Sandstone	50	150
Basement rock (pre-Cambrian):		
Soft fissured granite[a]	70	220
Hard solid granite and hard fissured granite[b]	92	312
Hard granite[c]	56	368

[a]Yield of 8 gallons a minute from crevice at 191 feet.
[b]Yield of 40 gallons a minute when well was 309 feet deep.
[c]Yield 85 gallons a minute with 49½ feet of drawdown. Well is cased to 121 feet below surface.

TABLE 16.—*Logs of wells in Prince George County, Virginia—Continued*

Well 63d, 3 miles south of Petersburg; Petersburg State Colony
(Log by Sydnor Pump and Well Co.)
Altitude, 158 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow sandy clay soil	3	3
Reddish clay	12	15
Brown sandy clay	15	30
Gray-brown sandy clay	5	35
Chesapeake group (Miocene):		
Gray-blue clay	3	38
Blue marl	2	40
Blue marl with shells	7	47
Grayish sand	5	52
Shells	2	54
Blue marl with few shells	12	66
Gray marl with few shells	3	69
Shells	3	72
Blue marl	42	144
Potomac group (Lower Cretaceous):		
Coarse gravel	2	116
Rock	1	117
Rotten rock and mud	8	125
Sandy clay	5	130
Coarse gravel	7	137
Loose sand	3	140
Sandy clay	2	142
Loose sand	18	160
Hard sand	8	168
Blue mud	7	175
Hard sand	2	177
Basement rock (pre-Cambrian):		
Rotten granite	1	178
Gray and brown granite	522	700

Well 67, Petersburg; A. G. Smith
(Log by A. G. Smith)
Altitude, 100 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Blue mud	40	40
Shell marl	3	43
Blue mud	25	68
Basement rock (pre-Cambrian):		
Hard rock	104	172

TABLE 16. *Logs of wells in Prince George County, Virginia—Continued*

Well 77, Disputanta; School for Colored
(Log by D. J. Cederstrom[a])
Altitude, 115 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	5	5
Red clay	20	25
Chesapeake group (Miocene):		
Sandy blue marl	50	75
Blue marl	10	85
Pamunkey group (Eocene):		
Dark-green glauconite marl; glauconite is powdery	40	125
Dark-green marl containing minor quartz sand and a trace of glauconite; glauconite grains are medium to fine in size	20	145
Potomac group (Lower Cretaceous):		
Light-gray clayey medium-grained sand	20	165
Light-gray sandy clay	30	195
Medium-grained white quartz sand, water	10	205
Medium- to coarse-grained white quartz sand, water	10	215
Coarse-grained white sand, water	4	219

[a]From samples furnished by Mitchells Pump and Well Co.

Well 79, Disputanta; C. C. Rucks
(Logs by P. P. Ellis)
Altitude, 111 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	18	18
Fine sand	12	30
Chesapeake group (Miocene):		
Coarse-grained red sand	20	50
Blue mud and marl	15	65
Pamunkey group (Eocene):		
Black sand	5	70
Blue clay	35	105
Undifferentiated (Upper Cretaceous (?)):		
Red clay	15	120
Potomac group (Lower Cretaceous):		
Sand, water	17	137

TABLE 16. *Logs of wells in Prince George County, Virginia—Continued*

Well 93, Carson; Wilkerson Brothers
(Log by L. Wilkerson, from memory)
Altitude, 93 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand and gravel	30	30
Chesapeake group (Miocene):		
Marl, shelly in places	82	112
Potomac group (Lower Cretaceous):		
White sand, water	6	118

TABLE 17.—*Analyses of waters from Miocene[a] and Quaternary deposits in Prince George County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding numbers in Table 15)

	72	74	75	79	85
	Disputanta	Disputanta	Newville	Disputanta	Disputanta
Iron (Fe)	1.5	.....	1.3	.....	.....
Bicarbonate (HCO_3)	8.0	6.0	146	196	11
Sulfate (SO_4)	3	1	25	7	1
Chloride (Cl)	8.0	21	4	3	9.0
Fluoride (F)	.2	.4	.1	0	.2
Nitrate (NO_3)	1.0	.77	1.0	.0	6.0
Total hardness as $CaCO_3$	15	15	132	171	14
Free carbon dioxide (CO_2)	44	49	16	.....	43
Date of collection (1939)	July 10	July 10	July 11	July 10	July 10

[a]Wells 75 and 79 penetrate Miocene marl below 30 feet.

Analyst: Margaret D. Foster.

TABLE 18.—*Analyses of waters from Cretaceous deposits in Prince George County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 15)

	9	23-24	28	29	38	40	41	48	53	58	93
	Hopewell	Hopewell	Hopewell	Hopewell	Brandon	Brandon	Brandon	Burrowsville	Prince George	Crater Park	Carson
Silica (SiO_2)	.....	37	.....	.....	.....	38	.....	31	26	.....	.....
Iron (Fe)	5.1	.09	2.0	.....	.....	.03	.....	.25	2.4	.....	.....
Calcium (Ca)	.....	44	.....	.....	.....	1.9	.....	38	69	.....	.....
Magnesium (Mg)	.....	5.1	.....	.....	.....	.5	.....	10	3.1	.....	.....
Sodium (Na)	.....	17	.....	.....	.....	83	.....	15	3.7	.....	.....
Potassium (K)	.....	4.5	.....	.....	.....	4.6	.....	19	2.0	.....	.....
Bicarbonate (HCO_3)	75	180	200	182	222	221	215	222	225	213	101
Sulfate (SO_4)	10	8.4	12	13	5	5.2	3	3.3	6.0	7	5
Chloride (Cl)	3	9.5	8.0	4	2	5.8	3	3.0	2.2	3	3
Fluoride (F)	.4	.4	.2	.2	.5	.7	.2	.4	.0	.0	.2
Nitrate (NO_3)	.0	.10	.0	.0	.0	.15	.....	1.1	.0	.0	.0
Total dissolved solids at 180°C	.....	213	.....	.....	.....	240	.....	219	225	.....	.....
Total hardness as $CaCO_3$	62	131	110	147	6	6.8	14	136	185	148	78
Free carbon dioxide (CO_2)	23	.....	.7	.4	.....	7.6	6.9	2.2	.0	.4	.....
Date of collection	July 13, 1939	June 29, 1939	July 2, 1939	July 13, 1939	June 16, 1939	Oct. 3, 1939	Oct. 3, 1939	Oct. 3, 1939	July 14, 1939	July 13, 1939	June 10, 1939

Analysts: 93, Margaret D. Foster and J. D. Hem; others by Margaret D. Foster.

TABLE 19.—*Analyses of waters from granitic rock in Dinwiddie County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding numbers in Table 15)

	63d	63d	67
	Petersburg	Petersburg	Petersburg
Silica (SiO_2)	.....	.....	41
Iron (Fe)	.....	.....	.65
Calcium (Ca)	.....	.....	40
Magnesium (Mg)	.....	.....	7.3
Sodium (Na)	.....	.....	25
Potassium (K)	.....	.....	6.1
Bicarbonate (HCO_3)	295	309	214
Sulfate (SO_4)	13	15	7.6
Chloride (Cl)	17	26	2.6
Fluoride (F)	5.8	.....	.3
Nitrate (NO_3)	.....	.....	.33
Total dissolved solids at 180°C	.....	.....	232
Total hardness as $CaCO_3$	24	38	130
Free carbon dioxide (CO_2)	.....	.....	2.5
Date of collection	Jan. 7, 1941	Mar. 5, 1941	July 13, 1939

Analysts: 63d, Margaret D. Foster and L. W. Miller; 67, Margaret D. Foster.

SUSSEX COUNTY

LOCATION AND DEVELOPMENT

Sussex County is in the west-central portion of the area treated by the present report, and extends eastward from the Fall Zone. Southampton and Prince George counties lie to the south and north respectively, and Dinwiddie County is to the west. Sussex County has an area of 496 square miles. The population was 12,485 according to the Census of 1940. The chief industry is farming, 52 per cent of the land being classed as farm land, but lumbering is also of importance. The county is also a producer of hams from peanut-fed hogs.

In 1938-39 a large mill was erected by the Johns-Manville Co. at Jarratt in Greensville County just west of the Sussex County line. In 1940 the economic effects of this mill were being felt in Sussex County, and the company policy of employing local workers may have its greatest effect on the residents of Sussex County rather than those of Greensville County.

TOPOGRAPHY

The county is covered by dissected terrace deposits, whose highest parts (Sunderland terrace) descend from 150 feet above sea level at Jarratt to about 110 feet above sea level at Wakefield. Most of the county is made up of low, irregular hills, but some level land is found bordering Nottoway River and at higher elevations to the east. In the extreme western part of the county remnants of flat-lying terrace deposits (Coharie and Brandywine) are present at 200 to 250 feet above sea level.

Flood-plain terraces have been developed along Nottoway River, which follows a meandering course through the county. North of Jarratt the land bordering the stream is about 90 feet above sea level, but where the stream leaves Sussex County the floodplain is about 50 feet above sea level.

GEOLOGY

The pre-Cambrian granitic bedrock is exposed in the bed of Stony Creek near Sappony Church. It has not been noted elsewhere in the county by the writer, but as the erosion surface upon which Cretaceous sediments were deposited is as high as 140 feet above sea level in the western part of the county, granite probably crops out in some places along Nottoway River in that area. Elsewhere granite rock is known only from the logs of wells. It has been encountered in wells 365 and

7 to 9, near Stony Creek; 49, in Stony Creek; 118, east of Jarratt; 123, at Grizzards School; and in 129 and 134 to 137, at Jarratt.

Strata of the Potomac group lie upon the granitic bedrock and are reached by wells in many parts of the county. According to the Geologic Map of Virginia, published in 1928, Potomac strata crop out in the vicinity of Stony Creek.

In the westernmost part of the county, the surface of which is at an altitude of 180 feet, a few drilled wells derive water from sand and gravel. Well records indicate, however, that in places on still higher ground the unconsolidated material overlying bedrock may be more than 100 feet thick. An outcrop of deep red-brown, very ferruginous, nodular sandstone, with which is associated white clay and clean arkosic sand, occurs near Concord Church at an elevation of 230 feet above sea level. These materials may belong to the Potomac group. If so, these strata are present at an unusually high elevation, although near the town of Lorton, north of the area covered by the present report, Potomac strata crop out at about 200 feet above sea level.

At Little Mill School and Grizzard School in the southwestern part of Sussex County, logs of wells (9 and 123, Table 21) indicate that the Potomac strata are absent and marls of the Chesapeake group rest directly on the granitic bedrock, but elsewhere the Potomac strata are present and appear to be the usual series of alternating sand and clay beds found in other counties. At Jarratt, the deposits are very irregular in character. Sandy deposits in well 134 at the Johns-Manville mill, three-quarters of a mile west of the town, give way to clay beds in the well at Jefferson School (125). Three-fourths of a mile east of the latter locality a cobble bed is reported to rest on the granitic bedrock.

Glauconite beds ("black sand") of the Pamunkey group (Eocene) are present in the central and eastern parts of the county, and at Wakefield attain a thickness of 56 feet (87, Table 21). They are not reported in logs of wells in the southwestern part of the county nor at Jarratt, Sussex, or Stony Creek, and, therefore, in these places the Eocene strata appear to have been largely eroded before the deposition of Miocene sediments. Clark and Miller note[34] that the southernmost exposure of Eocene strata in Virginia is near Bolling's Bridge on Nottoway River.

Pink or red clay is present at the base of the glauconite beds at Wakefield. This clay below the base of the Pamunkey group has a wide

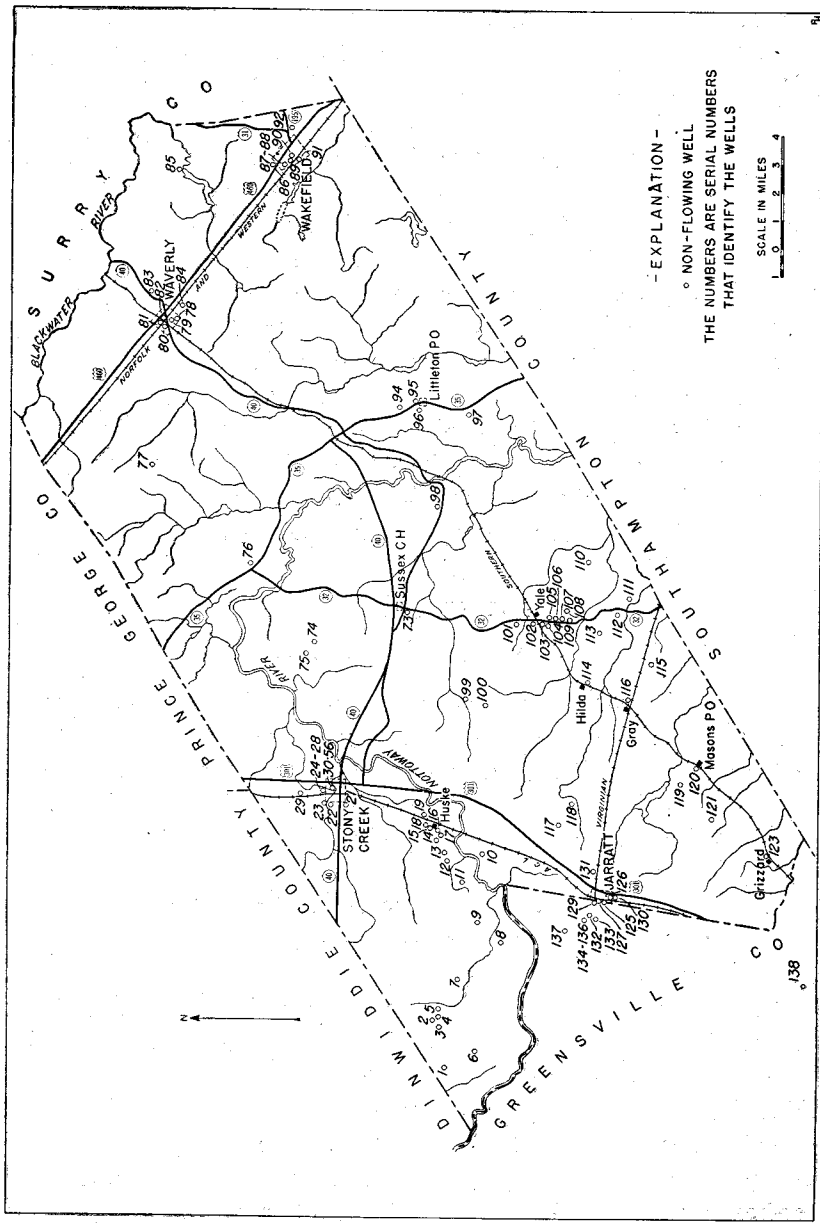


FIGURE 23.—Map of Sussex County and northeastern Greensville County, showing location of wells listed in Table 20.

but patchy distribution, and is well developed in Southampton, Isle of Wight and Nansemond counties.

At Wakefield the clay is not more than 10 feet thick but at Chuckatuck, Nansemond County, it attains a thickness of about 100 feet. It is considered to be of late Cretaceous age.

The clayey and marly strata of the Chesapeake group of Miocene age appear to be present beneath the terrace deposits of clay and sand except in the westernmost part of Sussex County. In most places the Chesapeake strata rest on the strata of the Pamunkey group, but inasmuch as the Chesapeake is an overlapping group, especially its uppermost formation, the Yorktown, in some places it rests either directly on the Cretaceous sediments or on the granitic bedrock.

Logs of wells show that the terraces are composed of clay or sand, or both, and in some places exceed 50 feet in thickness. The terrace sediments generally rest on strata of the Chesapeake group, but west of Stony Creek they rest directly upon the granitic bedrock or upon sediments of the Potomac group of early Cretaceous age.

GROUND WATER

SHALLOW WELLS

Most of the inhabitants of Sussex County obtain water from shallow dug wells or driven wells sunk in the terrace deposits. These wells generally yield an adequate supply of water for domestic purposes. Field tests of water from shallow wells near Wakefield and Waverly indicate that the total hardness of the water is generally less than 60 parts per million. (See Table 20.)

Many of the shallow wells are properly constructed and protected from contamination, but others are poorly furnished with curb or casing.

The terrace formations are not drawn upon to furnish much water. At Wakefield three 2-inch drive-point wells about 25 feet deep (86, Table 20) furnish a total of about 10 gallons a minute throughout each working day. The water is used for boiler feed, is not corrosive, and forms only a small amount of scale. Wells of larger diameter and more favorably situated within large level terraces having greater areas of water-bearing sand to draw from, might obtain a great deal more water from shallow depths than is indicated by the yield of the Waverly wells.

At Stony Creek many drilled wells less than 50 feet deep obtain water from the sandy terrace bordering the Nottoway River, or from deeper sands which probably belong to the Potomac group. Most of the wells yield water containing such high amounts of iron that it is unpleasant in taste and difficult to use for cooking or laundry purposes. A few shallow wells in the terrace deposits yield water in which the iron is not present in sufficient amounts to be objectionable. The deeper water that has a high iron content, may be derived from the basal portion of the terrace deposits as well as from sand of the Potomac group.

DEEP WELLS

Deep wells obtain water from the granitic bedrock and from the Potomac strata. So far as the writer is aware no wells in the county obtain water from the Chesapeake group.

WATER FROM CRETACEOUS DEPOSITS

A moderate number of drilled wells throughout the county get excellent supplies of water from the Potomac group of early Cretaceous age. The public supplies of Waverly and Wakefield are obtained from these strata or similar strata of possible late Cretaceous age. At the former locality 2 wells (78, 79), each 10 inches in diameter, yield the maximum requirement of 25,000 gallons a day without great drawdown. The installation includes a 100,000 gallon elevated tank. At Wakefield 100,000 gallons a day has been supplied for short periods from one 8-inch and one 10-inch well (wells 87, 88). The installation includes a 100,000 gallon elevated tank. An ice plant at Waverly pumps 20 gallons a minute (well 82) continuously for 6 months of the year and about one-fourth that amount for the remainder of the year. About 5¼ miles west of Waverly a 4-inch well (77) of the Sussex Game Refuge supplied about 20,000 gallons a day during 1935-1938 to a camp of the Civilian Conservation Corps.

It seems likely that much larger supplies of water could be obtained in the central and eastern parts of the county if needed.

Less success is to be expected in the development of water from Potomac strata along the Fall Zone. Near the plant of the Johns-Manville Co. at Jarratt only about 35 gallons a minute was obtained from each of 4 wells drilled to fine sand immediately above bedrock (wells 130, 135-137, Table 20). However, about one-quarter of a mile

east of High Hill Church, near Jarratt railway station, a cobble bed was encountered in well 131, just above bedrock, and pumping tests indicate that a yield of 300 gallons a minute might be expected. In general, however, it appears that the Potomac deposits in this vicinity, as in other parts of the Fall Zone, are too thin or include too little sand to be a source of large supplies of water. A few wells of large yield may be obtained from place to place along the Fall Zone; but the storage capacity of the sediments may be small, and the possibility of creating a large deep cone of depression which would cause water to flow into the pumped strata from several miles around is not apparent; and it is believed that a water supply comparable to that obtained at Hopewell can not be secured from beds of the Potomac group.

At Grizzards School and Bethlehem School in the southwest part of the county, Potomac strata are lacking, and marl of the Chesapeake group rests directly on bedrock. At Mitchells Sawmill, 4 miles east-northeast of Jarratt, the Potomac deposits are thin and water-bearing strata are apparently absent (well 118, Table 21; and Fig. 23). These examples show that Potomac strata in the Fall Zone are not dependable sources of water supply. Efforts to develop large supplies in this zone should therefore be preceded by test drilling.

Some records of water levels are available which allow a rough estimate to be made of the loss of artesian head over a period of years. It was reported that the water level in the well of the Norfolk and Western Railway (80, Table 20) at Waverly was 40 feet below the surface in 1910. In 1938 the water level was about 70 feet below the surface. The water level in the municipal wells (78, 79) at Waverly, at approximately the same elevation, is reported to have been 60 feet below the surface in 1932.

At the well of the Norfolk and Western Railway (91) in Wakefield, the water level was reported to be 57 feet above sea level (50 feet below the surface) in 1910. The highest water level recorded in the well of J. S. White at Wakefield (90) in 1940 was 64.55 feet below the surface or 37.20 feet above sea level. A decline of 20 feet in the water level therefore seems to have taken place.

A comparable decline of water levels has taken place throughout eastern Sussex County. This decline is not attributed to local pumping, but to the withdrawal of water from wells outside the county. Inspection of the water level contour map, Figure 9, indicates that the water in the Potomac strata is moving from the area around Waverly and

Wakefield, northeastward toward the flowing-well area bordering James River. It is therefore believed that the marked lowering of water levels in eastern Sussex County has been caused by the flow of water to the area of artesian discharge.

It is not known whether the lowering of water levels has ceased or even whether the rate of lowering has diminished. It is thought, however, that the rate of decline has not ceased, but may now be relatively slow. Declines will continue as long as loss of head continues along James River, and probably for some time after, during the period when water is drawn from storage and the cone of depression expands to establish a balance between recharge and discharge.

Although the water-level contour map (Fig. 9) indicates that water from southern Sussex County is moving toward the Franklin-Courtland cone of depression, and probably also towards Branchville and Boykins, the effect of withdrawal in those areas upon the water levels in southern Sussex County is not known.

Water levels are higher above sea level at Jarratt than anywhere else in the counties south of James River, due in large measure to the fact that the water-bearing strata rise westward and lie at greater elevations near Jarratt than they do along the Fall Zone to the north and south. However, from 150 feet above sea level at Jarratt, the water level declines sharply eastward to 70 feet above sea level at Yale. East of Yale the level declines gradually and at Waverly and Wakefield water stood respectively 51 and 40 feet above sea level, in 1940.

The marked change in slope of the water levels is in large part a reflection of the thickening of the Potomac group of sediments. With an increase of cross-sectional area through which water may pass, the hydraulic gradient decreases, in accordance with Darcy's Law.[a]

QUALITY OF ARTESIAN WATER

Three types of water are derived from Potomac strata in Sussex County. At Stony Creek, Sussex Court House and Jarratt, soft water of low or moderate total mineral content is obtained (analyses 21, 73, and 132, Table 22). The water may contain objectionable amounts of iron, however, and in Stony Creek considerable difficulty is experienced with the iron in water from wells more than 30 feet deep. It is probable

[a] Q equals PIA, in which Q is the quantity of water transmitted, P is the permeability, I the hydraulic gradient, and A the cross-sectional area through which water moves. Q and P are assumed to be constant.

that much or most of the iron could be removed by simple aeration. Any arrangement by which the pumped water can be thoroughly mixed with air and allowed to stand for an hour or two will probably be effective. The iron oxide which forms will settle to the bottom of the container and the iron-free water can then be drawn off. One resident of Stony Creek allows water that is to be used for laundering to stand several hours in an open tub. By this simple action iron oxide is formed and settles, and the greater part of the clear water is decanted and used.

East of the soft-water area harder water of moderate mineral content is obtained, as in well 79 at Waverly and well 106 near Yale. (See analyses, Table 22.) The total hardness of the water samples from Waverly was 186 parts per million, as carbonate hardness. This hardness is enough to cause difficulty in the use of the water for many purposes.

In the easternmost part of the county water from the Potomac strata is soft, with a moderate mineral content made up predominantly of sodium bicarbonate. The total hardness of a sample of well water from Wakefield (analysis 87) was only 50 parts per million.

All three types of Coastal Plain water are present in Sussex County. Along the Fall Zone the water is soft, and has a low mineral content. As it travels eastward it takes limy material into solution, and the water becomes hard. Still farther east the hard water comes in contact with natural softening material, in part at least the glauconite sand ("black sand"), and exchanges its calcium for sodium and becomes a soft water, but without losing any of its total mineral content.

WATER FROM GRANITIC BEDROCK

The granitic bedrock is, in general, a poor water-bearing material. Water is derived from fissures in the rock, and where the bedrock is massive and unbroken the yield may be very meager. Well 118, in the southwestern part of the county, yielded less than 1 gallon a minute. However, where a large fissure or zone of fissures is encountered, the yield may be excellent. Such a well (134, Table 21 and Fig. 23) was drilled on the property of Johns-Manville Co. at Jarratt, and in an 8-hour pump test a yield of 300 gallons a minute with drawdown of about 60 feet was obtained. This well in 1940 supplied the town of Jarratt with water.

A few other wells in western Sussex County reach bedrock but probably derive their water from overlying sediments.

WELL RECORDS AND ANALYSES

Records of wells in Sussex County, available logs of wells, and analyses of water samples are listed in Tables 20-22, on the following pages. The locations of the wells listed are shown in Figure 23:

TABLE 20.—*Records of wells in Sussex County*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
1	11 miles west-southwest of Stony Creek.	Wesley Barnes	Mitchells Pump and Well Co.	.....	241	D
2	9 miles west-southwest of Stony Creek.	H. F. Croshaw	Mitchells Pump and Well Co.	1917	183	D
3	9 miles west-southwest of Stony Creek.	M. M. Mays	Mitchells Pump and Well Co.	1918	190	D
4	9 miles west-southwest of Stony Creek.	Piney Forest School	Mitchells Pump and Well Co.	1925	181	D
5	9 miles west-southwest of Stony Creek.	E. H. Croshaw	Mitchells Pump and Well Co.	1915	181	D
6	10¾ miles southwest of Stony Creek.	Concord School	Mitchells Pump and Well Co.	1937	256	D
7	8 miles west-southwest of Stony Creek.	Carrie Neaves	Mitchells Pump and Well Co.	1922	175	D
8	8 miles southwest of Stony Creek.	W. J. Mays	Mitchells Pump and Well Co.	1924	112	D
9	7½ miles southwest of Stony Creek.	Little Mill School	Mitchells Pump and Well Co.	1937	122	D
10	5½ miles south-southwest of Stony Creek.	A. H. Crowder	Mitchells Pump and Well Co.	1922	90	D
11	5¾ miles southwest of Stony Creek.	R. E. Kennedy	Mitchells Pump and Well Co.	1925	112	D
12	1½ miles southwest of Huske.	J. C. Poole	Mitchells Pump and Well Co.	1925	112	D
13	1½ miles southwest of Huske.	J. H. Lewis	Mitchells Pump and Well Co.	.....	87	D
14	½ mile west of Huske	J. G. Mays	Mitchells Pump and Well Co.	1918	86	D
15	Huske, at store	J. G. Mays	Mitchells Pump and Well Co.	1918	85	D
16	Huske, at gin	J. G. Mays	Mitchells Pump and Well Co.	1924	85	D
17	Huske, at residence	J. G. Mays	Mitchells Pump and Well Co.	1918	85	D
18	Huske	E. M. Blood	Mitchells Pump and Well Co.	1918	83	D
19	Huske	E. W. Hardaway	Mitchells Pump and Well Co.	1921	86	D
21	Stony Creek	Colored School	Mitchells Pump and Well Co.	1937	77	D
22	Stony Creek	Mack Jones	.....	.....	75	Dv
23	Stony Creek	F. Remeranko	Mitchells Pump and Well Co.	1927	74	D
24	½ mile north of Stony Creek	D. P. Mays	Mitchells Pump and Well Co.	1930	71	D
25	½ mile north of Stony Creek	Cecil Williams	Mitchells Pump and Well Co.	.....	72	D
26	½ mile north of Stony Creek	C. J. Clemens	Mitchells Pump and Well Co.	.....	73	D
27	½ mile north of Stony Creek	H. B. Prince	Mitchells Pump and Well Co.	1917	73	D
28	½ mile north of Stony Creek	W. D. Prince	Mitchells Pump and Well Co.	.....	74	D
29	1¾ miles north of Stony Creek.	D. P. Mays	Mitchells Pump and Well Co.	1910	100	D
30	West of railroad, Stony Creek.	S. E. Teretta	Mitchells Pump and Well Co.	1930	76	D
31	Stony Creek	I. A. Prince	G. Wilkins	1899	76	D
32	Stony Creek	T. W. Baicy	Mitchells Pump and Well Co.	1928	76	D
33	Stony Creek	Jonas Tyus	Mitchells Pump and Well Co.	1931	76	D
34	Stony Creek	J. K. Crowder	Mitchells Pump and Well Co.	1936	75	D
35	Stony Creek	B. F. Jarratt	Mitchells Pump and Well Co.	1915	75	D

and northeastern Greensville County, Virginia[a]

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Use of water[c]	Reported quality	Remarks	No.
112	4	−18½	July 26, 1938	D S	Iron	Bedrock not encountered.	1
50	4	—	.....	D S	Iron	.....	2
56	4	−13	July 26, 1938	D S	.....	Rock at 50 ft.	3
58	4	− 6½	July 26, 1938	.....	Iron	Rock at 50 ft.	4
54	4	—	.....	D S	Iron	Rock at 50 ft.	5
45	4	− 4	July 26, 1938	P	.....	.....	6
34	4	—	.....	D S	Iron	Rock at 34 ft.	7
29	4	−10	.....	D S	Iron	Rock at 29 ft.	8
114	4	−10	July 26, 1938	P	.....	Granite at 30 ft.	9
45	4	—	.....	D S	Iron	Rock not encountered.	10
75	4	−18	July 26, 1938	D	.....	Small yield.	11
35	4	—	.....	S	Much iron	.....	12
30	4	—	.....	Ab	Much iron	.....	13
35	4	− 5	July 26, 1938	S	.....	.....	14
30+	4	—	.....	D	Iron	.....	15
25+	4	—	.....	B	.....	.....	16
60	4	—	.....	D	Iron	.....	17
90?	4	—	.....	D	Iron	.....	18
36	4	—	.....	D	Iron	.....	19
36	4	[d]− 3	1937	P	A	Temp. 62½° F.	21
24?	.....	—	.....	D	.....	.....	22
32	4	—	.....	D	Iron	.....	23
35	4	—	.....	D	Iron	.....	24
30	4	—	.....	D	Much iron	.....	25
75	4	—	.....	D	Much iron	.....	26
85	4	—	.....	D	Much iron	.....	27
50	4	—	.....	D	.....	.....	28
75	4	—	.....	D S	Iron	.....	29
50	4	− 4	July 26, 1938	D	Iron	.....	30
43	4	—	.....	D	Iron	.....	31
65	4	—	.....	D	Iron	.....	32
45	4	—	.....	D	Iron	.....	33
50	4	—	.....	D	Much iron	.....	34
28	4	—	.....	D	Iron	.....	35

TABLE 20.—*Records of wells in Sussex County*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
36	Stony Creek	J. E. Hartes	J. E. Hartes	1921	75	Dv
37	Stony Creek	J. K. Crowder	Mitchells Pump and Well Co.	1929	75	D
38	Stony Creek	Stony Creek High School	Mitchells Pump and Well Co.	1921	75	D
39	U. S. Highway 301, Stony Creek	J. E. Hartes	Mitchells Pump and Well Co.	1931	74	D
40	U. S. Highway 301, Stony Creek.	J. K. Crowder	Mitchells Pump and Well Co.	1936	74	D
41	U. S. Highway 301, Stony Creek.	G. E. Crowder	Mitchells Pump and Well Co.	1931	40	D
42	Stony Creek	H. E. Poarch	Mitchells Pump and Well Co.	1933	42	D
43	Stony Creek	W. O. Field	Mitchells Pump and Well Co.	.....	42	D
44	Stony Creek	J. L. Prince	Mitchells Pump and Well Co.	1933	42	D
45	Stony Creek	I. A. Prince	Mitchells Pump and Well Co.	1933	42	D
46	Stony Creek	E. H. Croshaw	Mitchells Pump and Well Co.	1937	42	D
47	Stony Creek	M. Hardaway	Mitchells Pump and Well Co.	1917	42	D
48	Stony Creek	J. L. Freeman	G. Wilkins	1907	42	D
49	Stony Creek	J. L. Freeman	Mitchells Pump and Well Co.	1924	42	D
50	Stony Creek	John Cole	Fisher	1923	75	D
51	Stony Creek	S. E. Teretta	S. E. Teretta	1933	75	Dug
52	Stony Creek	G. L. Parson	Mitchells Pump and Well Co.	1935	75	Dv
53	Stony Creek	Methodist Parsonage	G. Wilkins	1907	75	D
54	Stony Creek	Milton Tyus	G. Wilkins	1907	75	D
55	Stony Creek	Atlantic Coast Line Railroad.	.....	1932	77	D
56	Stony Creek	Bank of Southside Virginia	Mitchells Pump and Well Co.	1929	77	D
73	Sussex C. H.	High School	Mitchells Pump and Well Co.	.....	105	D
74	3 miles north-northwest of Sussex C. H.	Bethel Church	Mitchells Pump and Well Co.	1910	106	D
75	3½ miles north-northwest of Sussex C. H.	J. R. Hunnicutt	Mitchells Pump and Well Co.	1919	100	D
76	5¼ miles north of Sussex C. H.	F. L. Gale	Mitchells Pump and Well Co.	1934	68	D
77	5¼ miles west of Waverly	Sussex Game Refuge	Cousins	1930	122	D
78	Waverly	Town of Waverly	Sydnor Pump and Well Co.	1932	112	D
79	Waverly	Town of Waverly	Sydnor Pump and Well Co.	1932	112	D
80	Waverly	Norfolk and Western Railway Co.	J. A. Coffman	1910	118	D
81	Waverly	A. Mayfields	A. Mayfields	.....	117	D
82	Waverly	Waverly Ice Co	.....	1920	112	D
83	Waverly	H. R. Horne	Owner	.....	112	Dv
84	Waverly	A. C. Drewry	.....	.....	106	Dug
85	3¾ miles north of Wakefield	R. T. Wheeler	Mitchells Pump and Well Co.	1937	74	D
86	Wakefield	Richardson & Bishop Sawmill.	Owner	.....	90	Dv
87	Wakefield	Town of Wakefield	Virginia Machinery and Well Co.	1925	100	D
88	Wakefield	Town of Wakefield	Virginia Machinery and Well Co.	1925	100	D

and northeastern Greensville County, Virginia[a]*—Continued*

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Use of water[c]	Reported quality	Remarks	No.
21	1¼	−	.....	D	Iron	.....	36
50	4	−	.....	D	Iron	.....	37
65	4	−	.....	P	.....	.....	38
42	4	−	.....	D	Iron	.....	39
52	4	−	.....	D	Iron	.....	40
42	4	−	.....	D	Iron	.....	41
31	4	−	.....	D	.....	Supplies 7 families.	42
47	4	−	.....	D	Iron	.....	43
50	4	−	.....	D	Iron	.....	44
37	4	−	.....	D	.....	.....	45
22	4	[d]−17	Oct. 8, 1937	D	.....	.....	46
78	4	−	.....	D	Iron	.....	47
65	.....	−	.....	D	Iron	.....	48
114	4	−	.....	Ab	Hard	Granite at 111 ft. Well abandoned because of small yield.	49
49	4	−	.....	Ab	Much iron	.....	50
25	.....	−	.....	D	Iron	.....	51
35	4	−	.....	D	Iron	.....	52
40	.....	−	.....	D	Much iron	.....	53
45	1¼	−	.....	D	Iron	.....	54
46	4	−	.....	D	Iron	.....	55
57	4	−	.....	D	Iron	.....	56
93	4	−	.....	P	A	.....	73
100	.....	−	.....	Ab	.....	.....	74
52½	4	−	.....	Ab	Iron	.....	75
57	4	−13	July 26, 1939	D A	Iron	Small yield.	76
172	4	−	.....	D	Very hard	.....	77
260	10	−60	1932	M	.....	Yields 300 gallons a minute.	78
240	10	−60	1932	M	A	Yields 300 gallons a minute.	79
283	6	−70	July 28, 1938	D	Hard	Water level 40 ft. below surface in 1910.	80
.....	.....	−	.....	D	.....	.....	81
224	6	−	.....	C	Hard	Pumps 50 gallons a minute continuously 7 months of the year and 20 gallons a minute the remainder of the year.	82
16	2	−12	July, 1939	D	Slightly hard	Water in terrace sand at 15 to 16 ft. and 26 to 30 ft.	83
20	.....	−	.....	D S	Slightly hard	Supplies 1,000 gallons a day.	84
200+	4	−36	July 28, 1936	D	Iron	.....	85
25	2	− 7	.....	B	.....	Yield 10 gallons a minute; 2 other wells supply less. Water not corrosive and forms only slight scale.	86
230	10	−57	Oct. 29, 1927	M	A	Drawdown 20 ft. after pumping 85 gallons a minute for 30 hours.	87
235	8	−60	Oct. 29, 1927	M	Soft	Drawdown 20 ft. after pumping 90 gallons a minute for 20 hours.	88

TABLE 20.—*Records of wells in Sussex County*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
89	Wakefield	Bain Peanut Co.	J. R. McLane	1915	100	J
90	Wakefield	J. S. White	J. S. White	1910	100	D
91	Wakefield	Norfolk and Western Railway Co.	J. A. Coffman	1910	107	Dv
92	1 mile east of Wakefield	W. A. Bailey			110	Dug
94	1 mile north of Littleton	W. T. Parker	R. E. Williams	1918	101	J
95	Littleton	R. E. Williams	R. E. Williams	1917	118	J
96	Littleton	R. H. Stephenson	R. H. Stephenson	1919	118	J
97	2 miles south of Littleton	R. E. Williams	R. E. Williams	1923	120	J
98	4 miles east-southeast of Sussex C. H.	F. T. Ellis	Mitchells Pump and Well Co.	1925	89	D
99	4 miles northwest of Yale	A. W. Parker	A. W. Parker	1929	120	J
100	3½ miles northwest of Yale	A. W. Parker	Mitchells Pump and Well Co.	1928	110	D
101	1 mile north of Yale	J. M. Zimmerman	Mitchells Pump and Well Co.	1932	121	D
102	Yale	M. D. Magee, Sr.	Mitchells Pump and Well Co.	1927	111	D
103	Yale	J. H. Dunn	Mitchells Pump and Well Co.	1927	111	D
104	Yale	W. A. Owen	Mitchells Pump and Well Co.	1917	120	D
105	½ mile south of Yale	Wynn Crawford	Mitchells Pump and Well Co.	1915	110	D
106	¾ mile south of Yale	M. D. McGee, Jr.	Mitchells Pump and Well Co.	1937	110	D
107	¾ mile south of Yale	S. Kitchen	Mitchells Pump and Well Co.	1916	100	D
108	1¼ miles southeast of Yale	J. B. Dunne Estate	Mitchells Pump and Well Co.	1918	123	D
109	1¼ miles south of Yale	H. J. Zimmerman	Mitchells Pump and Well Co.	1929	82	D
110	2½ miles southeast of Yale	J. M. Dunn	Mitchells Pump and Well Co.	1926	95	D
111	3½ miles south of Yale	L. J. Bain	Mitchells Pump and Well Co.		70	D
112	3 miles south of Yale	J. L. Gilliam	Mitchells Pump and Well Co.	1919	100	D
113	2¼ miles south of Yale	B. T. Horne	Mitchells Pump and Well Co.	1924	110	D
114	Hilda	J. Seaborn	Mitchells Pump and Well Co.	1925	120	D
115	1¾ miles east-southeast of Gray.	River School	Mitchells Pump and Well Co.	1937	122	D
116	Gray	Virginian Railway Co.		1932	129	D
117	3½ miles northeast of Jarratt	Colored School	Mitchells Pump and Well Co.	1937	155	D
118	3¾ miles east-northeast of Jarratt.	P. Mitchell	Mitchells Pump and Well Co.	1937	105	D
119	1 mile northwest of Masons P. O.	W. B. Webb	Mitchells Pump and Well Co.	1930	126	D
120	Masons P. O.	C. Mason	J. R. McLane	1915	122	J
121	2 miles west of Masons P. O.	Bethlehem School	Mitchells Pump and Well Co.	1937	139	D
123	Grizzard	Grizzard School	Mitchells Pump and Well Co.	1937	152	D
125	Jarratt	Jefferson School	Mitchells Pump and Well Co.	1937	155	D
126	Jarratt	R. E. Jarratt	Mitchells Pump and Well Co.	1922	155	D
127	Jarratt	J. H. Batte	Mitchells Pump and Well Co.	1915	155	D
129	Jarratt	Julia A. Jarratt	Mitchells Pump and Well Co.	1923	155	D
130	Near Jefferson School, Jarratt.	Johns-Manville Co.	Layne-Atlantic Co.	1938	155	D
131	¼ mile east-southeast of High Hill Church.	Johns-Manville Co.	Layne-Atlantic Co.	1938	162	D

and northeastern Greensville County, Virginia[a]*—Continued*

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Use of water[c]	Reported quality	Remarks	No.
223	4	—	.....	Ab	Soft	.....	89
225	3	−63⅔	July 28, 1938	Ab	Soft	Observation well of U. S. Geological Survey. Formerly supplied town with water.	90
265	6	−50	1910	D	.....	.....	91
35	.....	−11	July 5, 1939	D S	Soft	Supplies 1,000 gallons a day.	92
65	2	—	.....	D S	Hard	.....	94
65	2	—	.....	D S	.....	.....	95
62	2	—	.....	D S	Hard	.....	96
65	2	—	.....	D S	Hard	.....	97
104	4	−36	July 27, 1938	D S	.....	.....	98
94	4	—	.....	Ab	.....	Was used for boiler feed.	99
140	4	—	.....	Ab	.....	Was used for boiler feed.	100
141	4	—	.....	D S	Moderately hard	.....	101
120	4	—	.....	D S	Hard	.....	102
114	4	—	.....	D S	Hard	.....	103
187	4	−51	July 27, 1938	D S	Very hard	.....	104
128	4	—	.....	D S	Hard	.....	105
100	4	—	.....	D	A	.....	106
150	4	—	.....	D S	Hard	.....	107
119	4	—	.....	S	Hard	.....	108
94	4	—	.....	D S	Hard	.....	109
105	4	−32	July 24, 1938	D S	Hard	.....	110
.....	.....	—	.....	D S	Iron	.....	111
145	4	—	.....	D S	Iron	.....	112
116	4	—	.....	D S	Iron	.....	113
250	4	−46½	July 27, 1938	D	Hard	.....	114
145	4	−55	July 24, 1938	P	.....	.....	115
97	4	−48	July 24, 1938	D	A	.....	116
54	4	—	.....	P	.....	.....	117
97	6	−8½	July 26, 1938	B	Hard	Granite at 87 ft. Yield less than 10 gallons a minute.	118
217	4	−39½	July 27, 1938	D	.....	.....	119
110	4	—	.....	D	Iron	.....	120
105	4	−32½	July 26, 1938	P	Iron	.....	121
113	4	−20	July 22, 1938	P	A	Granite at 79 ft.	123
103	4	—	.....	P	.....	.....	125
107	4	—	.....	D	.....	.....	126
140	4	—	.....	D	Hard	.....	127
180	4	—	.....	D	.....	.....	129
143	8	—	.....	Tw	.....	Granite at 143 ft.	130
138	8	—	.....	Tw	.....	.....	131

TABLE 20.—*Records of wells in Sussex County*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[b]
132	¾ mile west of Jarratt	Grays Mill	Mitchells Pump and Well Co.	1937	155	D
133	¾ mile west of Jarratt	Virginian Railway Co.			155	D
134	¾ mile west of Jarratt	Johns-Manville Co.	Mitchells Pump and Well Co.	1938	155	D
135	¾ mile west of Jarratt	Johns-Manville Co.	Layne-Atlantic Co.	1938	155	D
136	¾ mile west of Jarratt	Johns-Manville Co.	Layne-Atlantic Co.	1938	155	D
137	1½ miles northwest of Jarratt	Johns-Manville Co.	Layne-Atlantic Co.	1938	135	D
138	1½ miles north of Emporia	Daughtery and Davis Mill	Owner			Dv

[a]Wells 132 to 138 are in Greensville County.
[b]D = drilled. Dv = driven. Dug = dug. J = jetted.
[c]Ab = abandoned. B = boiler feed. C = cooling. D = domestic. M = municipal. P = public school. S = stock. Tw = test well.

and northeastern Greensville County, Virginia[a]—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Use of water[c]	Reported quality	Remarks	No.
98	4	−.6	July 26, 1939	B	A	.....	132
106	4	—	.....	D	.....	.....	133
180	8 to 6	—	.....	M	.....	Bedrock at 139 ft. Yields 300 gallons a minute with drawdown 64 ft. after pumping 8 hours. Supplies town.	134
112	8	—	.....	Tw	.....	Bedrock at 112 ft.	135
80	8	—	.....	Tw	.....	Bedrock at 80 ft.	136
56	8	—	.....	Tw	.....	Bedrock at 56 ft.	137
17	1¼	—	.....	B	Soft	Pumps 3 gallons a minute.	138

TABLE 21.—*Logs of wells in Sussex County, Virginia*

Well 9, 7.6 miles southwest of Stony Creek; Little Mill School
(Log by Mitchells Pump and Well Co.)
Altitude, 122 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	10	10
Sand and clay	10	20
Chesapeake group (Miocene):		
Blue marl	10	30
Basement rock (pre-Cambrian):		
Hard rock	84	114

Well 78, Town of Waverly
(Log by Sydnor Pump and Well Co.)
Altitude, 112 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Gray clay	75	75
Compact blue clay	100	175
Pamunkey group (Eocene):		
Very fine black sand	15	190
Potomac group (Lower Cretaceous):		
Coarse sand and gravel, water[a]	40	230
Blue clay	10	240

[a]Screen set at 200 to 230 feet.

Well 80, Waverly; Norfolk & Western Railway Co.
(Log furnished by Norfolk & Western Railway Co.)
Altitude, 118 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Earth	15	15
Sand	25	40
Chesapeake group (Miocene):		
Marl	70	110
Blue mud	60	170
Pamunkey group (Eocene):		
Black sand	50	220
Potomac group (Lower Cretaceous):		
White sand, water	63	283

TABLE 21.—*Logs of wells in Sussex County, Virginia—Continued*

Well 83, Waverly; H. R. Horne
(Log by owner)
Altitude, 110 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	3	3
Clay	12	15
Coarse sand, water	1	16
Blue clay	10	26
Very fine sand, water	..	..

Well 87, Town of Wakefield
(Log by Virginia Machinery and Well Co.)
Altitude, 100 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Light-yellow clay	30	30
Chesapeake group (Miocene):		
Light-blue marl	35	65
Black mud with some sand	35	100
Dark-blue sticky gumbo	60	160
Pamunkey group (Eocene):		
Black sand	56	216
Undifferentiated (Upper Cretaceous ?):		
Light-pink gumbo	4	220
White sand, water	8	228
Light gumbo	2	230

Well 91, Wakefield; Norfolk & Western Railway Co.
(Log furnished by Norfolk & Western Railway Co.)
Altitude, 107 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	20	20
Sand	15	35
Chesapeake group (Miocene):		
Marl	70	105
Blue mud	65	170
Pamunkey group (Eocene):		
Black sand	55	225
Undifferentiated (Upper Cretaceous ?):		
Red mud	10	235
Sand and shells	10	245
Blue mud	15	260
Potomac group (Lower Cretaceous):		
White sand, water	5	265

TABLE 21.—*Logs of wells in Sussex County, Virginia—Continued*

Well 96, Littleton; R. H. Stephenson
(Log by owner, from memory)
Altitude, 118 feet

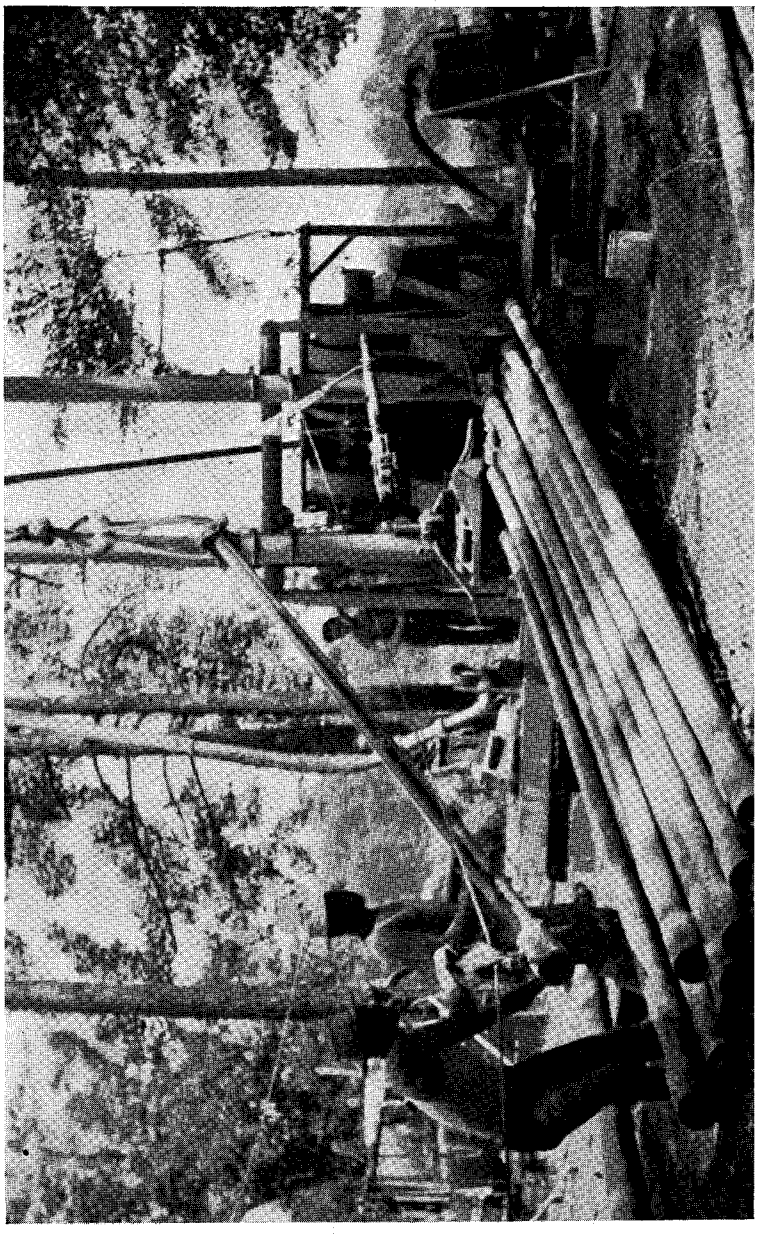
	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	20	20
Chesapeake group (Miocene):		
Marl	40	60
Rock	1	61
Potomac group (Lower Cretaceous):		
White sand, water	1	62

Well 106, Yale; M. D. McGee, Jr.
(Log by Mitchells Pump and Well Co.)
Altitude, 110 feet

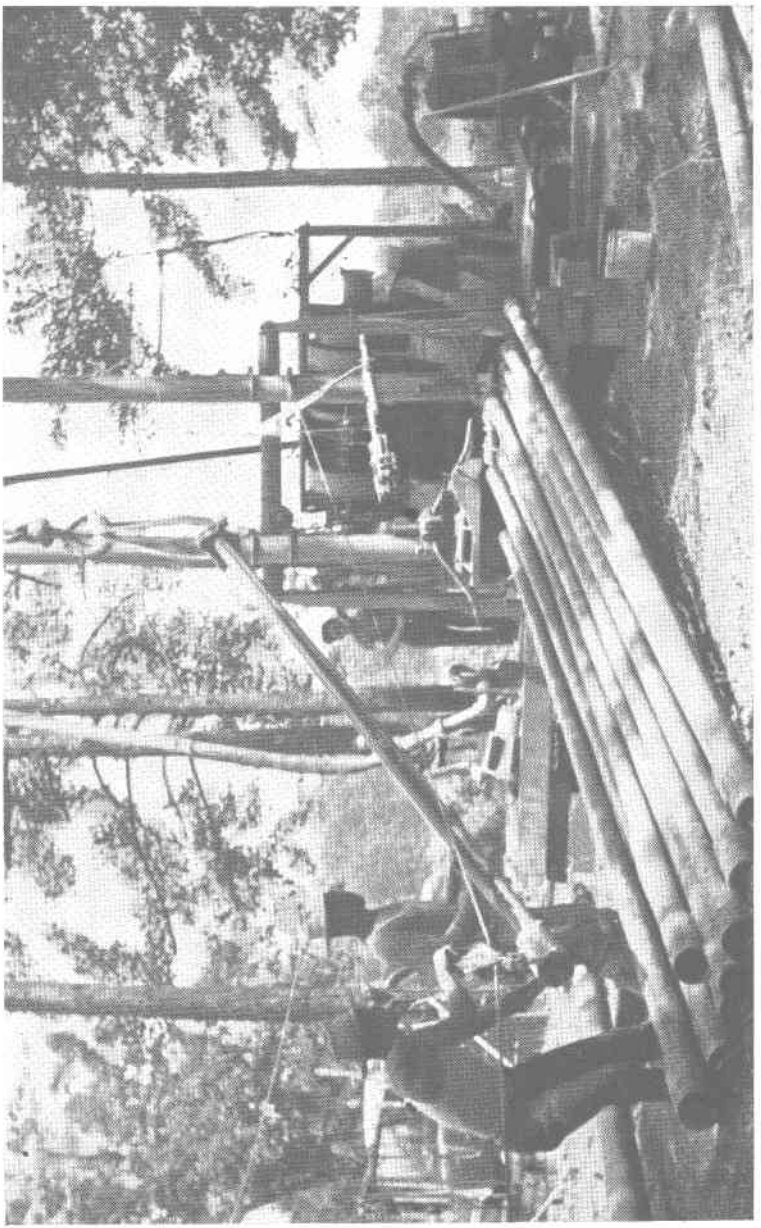
	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow mud	20	20
Chesapeake group (Miocene):		
Blue mud	40	60
Pamunkey group (Eocene):		
Black sand	28	88
Potomac group (Lower Cretaceous):		
White sand, water	12	100

Well 115, 18 miles east-southeast of Gray; River School
(Log by Mitchells Pump and Well Co.)
Altitude, 122 feet

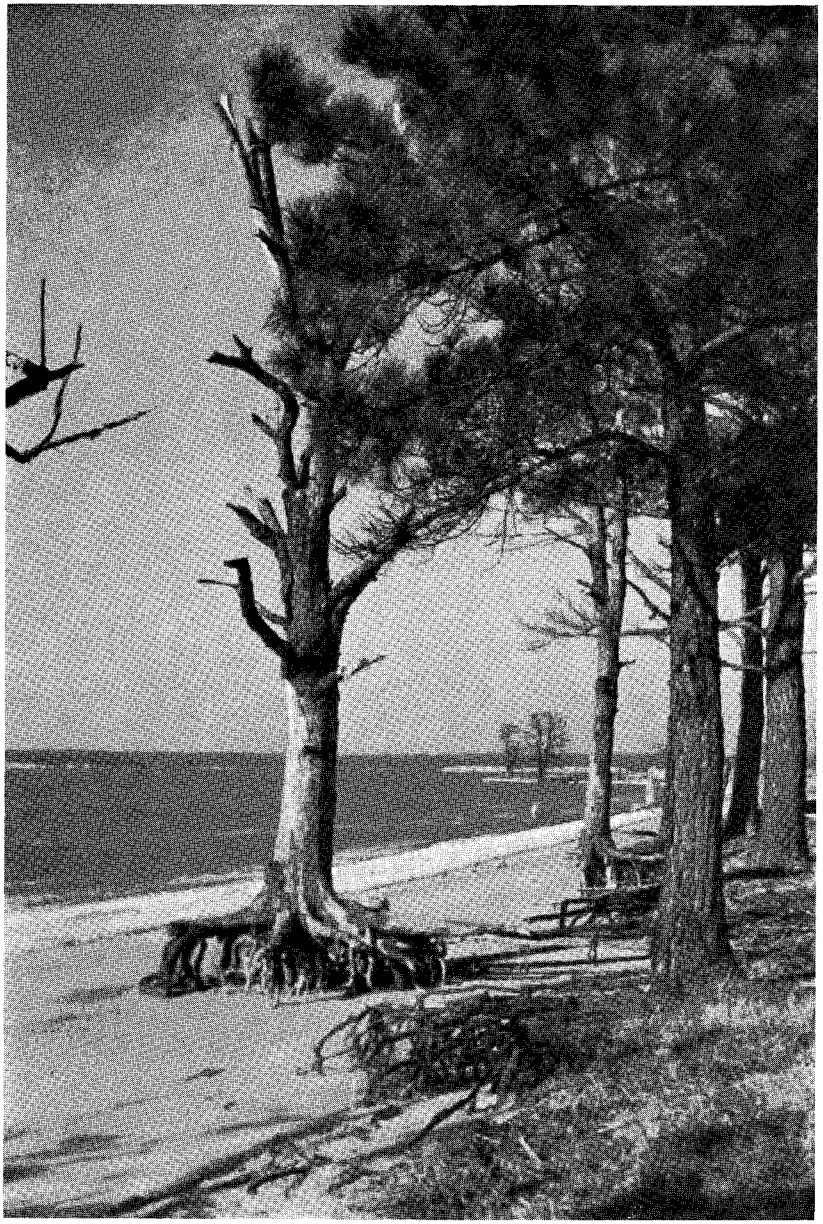
	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Gray mud	25	25
Chesapeake group (Miocene):		
Blue mud	50	75
Marl	55	130
Potomac group (Lower Cretaceous):		
Sand and gravel, water	15	145



Changing rods on rotary rig at Lake Prince. Rods still in hole project through rotary, at center. Keyed rod ("kelly"), to which mud line is attached, is resting in a "rat-hole" at left of man operating hoist. Mud pump at right.



Changing rods on rotary rig at Lake Prince. Rods still in hole project through rotary, at center. Keyed rod ("kelly"), to which mud line is attached, is resting in a "rat-hole" at left of man operating hoist. Mud pump at right.



Erosion along James River at Hog Island, Surry County.

Erosion along James River at Hog Island, Surry County.

TABLE 21.—*Logs of wells in Sussex County, Virginia—Continued*

Well 118, 3.8 miles east-northeast of Jarratt; Mitchells Sawmill
(Log by Mitchells Pump and Well Co.)
Altitude, 105 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	20	20
Chesapeake group (Miocene):		
Blue mud	30	50
Potomac group (Lower Cretaceous):		
Sand and gravel	5	55
Blue mud	32	87
Basement rock (pre-Cambrian):		
Granite	10	97

Well 121, 2 miles east of Masons P. O.; Bethlehem School
(Log by Mitchells Pump and Well Co.)
Altitude, 139 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Mud and gravel	40	40
Chesapeake group (Miocene):		
Blue mud	60	100
Potomac group (Lower Cretaceous):		
Sand and gravel, water	5	105

Well 123, Grizzard; Grizzard School
(Log by Mitchells Pump and Well Co.)
Altitude, 152 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow mud	45	45
Chesapeake group (Miocene):		
Blue mud	34	79
Basement rock (pre-Cambrian):		
Granite	34	113

TABLE 21.—*Logs of wells in Sussex County, Virginia—Continued*

Well 125, Jarratt; Jefferson School
(Log by Mitchells Pump and Well Co.)
Altitude, 155 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	40	40
Chesapeake group (Miocene):		
Blue mud	35	75
Potomac group (Lower Cretaceous):		
Gravel	10	85
Blue clay	18	103

Well 134, Jarratt; Johns-Manville Co.
(Log by Mitchells Pump and Well Co.)
Altitude, 155 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clayey sand	10	10
Yellow sand	15	25
Clean sand	9	34
Chesapeake group (Miocene):		
Gray sandy marl	16	50
Gray marl	25	75
Shell marl	16	91
Potomac group (Lower Cretaceous):		
Yellow pebbly clay	9	100
Coarse sand, water	1½	101½
Soft sandstone	18½	120
Blue sandstone	19	139
Basement rock (pre-Cambrian):		
Granite	41	180

TABLE 22.—*Analyses of waters from Cretaceous deposits in Sussex County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 20)

	21	73	79	87	106	116	123[a]	132
	Stony Creek	Sussex	Waverly	Wakefield	Yale	Gray	Grizzard	Jarratt
Silica (SiO_2)	39	7.6	37	18	.....	.....	.....	30
Iron (Fe)	4.3	1.7	.03	.08	.....	.....	6.46	8.9
Calcium (Ca)	3.2	1.6	58	12	.....	.....	.....	8.4
Magnesium (Mg)	2.0	1.4	10	4.8	.....	.....	.....	2.7
Sodium (Na)	8.7	3.0	14	61	.....	.....	.....	9.8
Potassium (K)	.3							14
Bicarbonate (HCO_3)	12	14	244	210	171	244	141	60
Sulphate (SO_4)	4.9	1.5	6.0	3.0	10	1	1	9.6
Chloride (Cl)	14	2.9	2.9	2.2	2.0	3	5.0	8.1
Fluoride (F)	.0	.0	.2	.0	.0	.0	.....	.0
Nitrate (NO_3)	.05	.0	2.0	1.9	.05	.0	.05	.98
Total dissolved solids at 180°C	85	29	245	209	.....	.....	.....	120
Total hardness as $CaCO_3$	16	9.7	186	50	122	162	108	32
Free carbon dioxide (CO_2)	.....	.....	.....	.....	.....	.7	.....	45
Date of collection	Nov. 27, 1937	Nov. 27, 1937	Nov. 26, 1937	Nov. 26, 1937	Apr. 19, 1938	Nov. 10, 1938	Apr. 19, 1938	Apr. 19, 1938

[a]Well 123 obtains water from bedrock.

Analysts: 21, 73, 79, 87, 116, Margaret D. Foster; 106, 123 and 132, W. M. Noble.

SURRY COUNTY

LOCATION AND DEVELOPMENT

Surry County lies along the south bank of James River, opposite Jamestown. The county was partly settled soon after the Jamestown colonists had become established; and the home of Thomas Rolfe, son of John Rolfe and Pocahontas, now a museum, and Bacons Castle attest to its early history. Lumbering was at one time a great industry and centered about the large sawmills of the Surry Lumber Co. at Dendron. The narrow gauge Sussex, Surry, and Southampton Railway was built prior to the War between the States and connected Emporia with Claremont via Waverly and Dendron. This railway and the mills at Dendron are now gone, and Dendron has again become a farming community, much smaller than the extensive town shown on the topographic map of the Surry quadrangle published by the U. S. Geological Survey in 1917. A few small sawmills are still scattered about the country, however.

The county has an area of 278 square miles of which 52 per cent is classed as farm lands. The population was 6,193 in 1940. In addition to the raising of crops, ham is produced from peanut-fed hogs as is done in other counties of southern Virginia. The precedent for Surry County was set by the Jamestown colonists, who in 1609 began to use Hog Island as a convenient feeding ground for their swine.

TOPOGRAPHY

The Sunderland terrace, at an elevation of about 120 feet above sea level, and the Wicomico terrace, at about 95 feet above sea level, make up nearly all the surface of Surry County. The surface of the Sunderland terrace in the west is somewhat more dissected than the surface of the Wicomico terrace in the east where extensive flat plains still remain comparatively unaffected by erosion. Wentworth[141] considers that the Surry scarp limits the eastern edge of the Sunderland terrace in Surry County, but this scarp is not a prominent topographic feature.

Except at Hog Island, where the Pamlico terrace forms low bluffs (Pl. 22), the terraces approach the bank of James River and form abrupt cliffs 60 to 90 feet in height. Rugged areas of limited extent are also formed by short tributaries of James River.

GEOLOGY

The granitic basement lies below the limit of the deepest wells in Surry County. However, its position is not entirely conjectural, because geophysical workers have determined the depth to bedrock at 2 stations in the county, in a traverse extending from Petersburg into the Atlantic Ocean beyond Cape Henry. (Section A-A′, Plate 1.)

At Mercy Seat Church, 2½ miles west-northwest of Surry, granitic bedrock was found to be 830 feet below sea level or 930 feet below the surface. At Brandon station, at Burrowsville in Prince George County, bedrock is 300 feet below sea level. The eastward slope of the bedrock surface in western Surry County is therefore 47 feet to the mile. At the second station, near California Crossroads, 3¼ miles southeast of Surry, bedrock was found to be 1,030 feet below sea level or 1,165 feet below the surface. The slope of the basement rock surface in central Surry County is therefore 55 feet to the mile in an eastward direction, slightly greater than that in the western part of the county.

In eastern Surry County the bedrock slope to the east flattens to 24½ feet to the mile, as shown by geophysical observations at Mulberry Island. The significance of the bedrock slope and its possible effect upon the overlying sediments have been considered in the chapter on geology.

The sediments of the Potomac group are reached by wells along James River, from Claremont to Hog Island. The top of the Potomac group lies about 150 feet below sea level at Claremont, where these deposits are about 200 feet thick. At Hog Island the deposits are reached at about 310 feet below sea level and the total thickness is about 900 feet. However, since only a very limited portion of the sediments is penetrated by wells, about all that can be said of these strata immediately adjacent to James River is that the upper 125 feet consists of alternating quartz sand and clay strata. (See log of well 4, Table 25.) A sand layer forms the uppermost part of the deposits. This sand is of variable thickness but appears to thicken eastward and is coarsest in the lower portion.

Other sand beds lie deeper. At Swann Point 4 sand strata, separated by clay beds, have been encountered within 125 feet of the top of the group. In a well at Claremont (6, Table 24), the driller, C. W. Daugherty, reported that a lignitic bed 3 feet thick separates the first from the second sand stratum. Other sands at still greater depths are described in this chapter under the heading "The Bacons Castle Test Drilling Project."

In well 40 (Table 25) at Bacons Castle, 20 feet of red clay was reported below the Eocene deposits of glauconite. This is the only report of its occurrence in Surry County. The red clay is found in many places elsewhere, but particularly in Isle of Wight, Nansemond and Southampton counties, and appears to be patchy in areal extent. It may be present in the southern part of Sussex County, where detailed information regarding deep strata is lacking. It is suggested that this stratum is of late Cretaceous age.

In a few wells in the vicinity of Claremont (4 and 15), about 8 feet of chocolate-brown clay lies below the Eocene beds of glauconite and above a consolidated conglomeratic stratum. The brown clay is considered to be a lateral variation of the red clay which is present below the glauconite beds, and the underlying conglomerate bed may also be of late Cretaceous age. About 35 feet of brown clay at the same horizon as that near Claremont is reported in a well at Carrolton, Isle of Wight County.

Glauconite beds ("black sand") of Eocene age have been penetrated in wells along James River; they are reported to be 85 feet thick at Swann Point and 90 feet thick at Cabin Point. Detailed logging of the Bacons Castle test wells (42a and 42b) showed that the glauconitic Eocene strata there were respectively 19 and 46 feet thick (Pls. 23 and 26); gray clay strata containing only a trace of glauconite, which occur immediately below, are tentatively assigned to the Upper Cretaceous rather than Eocene deposits because of similarities to the geologic section in Nansemond County where Upper Cretaceous sediments are known to be present. At Cabin Point and Swann Point the glauconitic beds are underlain by a rock stratum, 3 to 12 feet thick. This consolidated bed may be of late Cretaceous age, or it may correspond to the thin basal Eocene conglomerate found along the Fall Zone. It appears to be absent in most of the wells in surrounding counties but has been reported to be present at Jamestown, north of James River.

Miocene deposits of clay, marl and sand overlie the Eocene sediments and crop out at the surface in many places. Prominent exposures of fossiliferous marl of the Yorktown formation are to be seen along the banks of James River and the stream shores are littered with shell fragments of various kinds which have weathered from the soft sediments (Fig. 5). The base of the Miocene deposits lies about 130 feet below sea level at Claremont and 280 feet below sea level at Hog Island.

As shown in Plates 23 and 25, at Bacons Castle the upper part of the Miocene deposits consists of marly beds replete with fossil shells. Below these deposits, unfossiliferous tough gray clays were penetrated

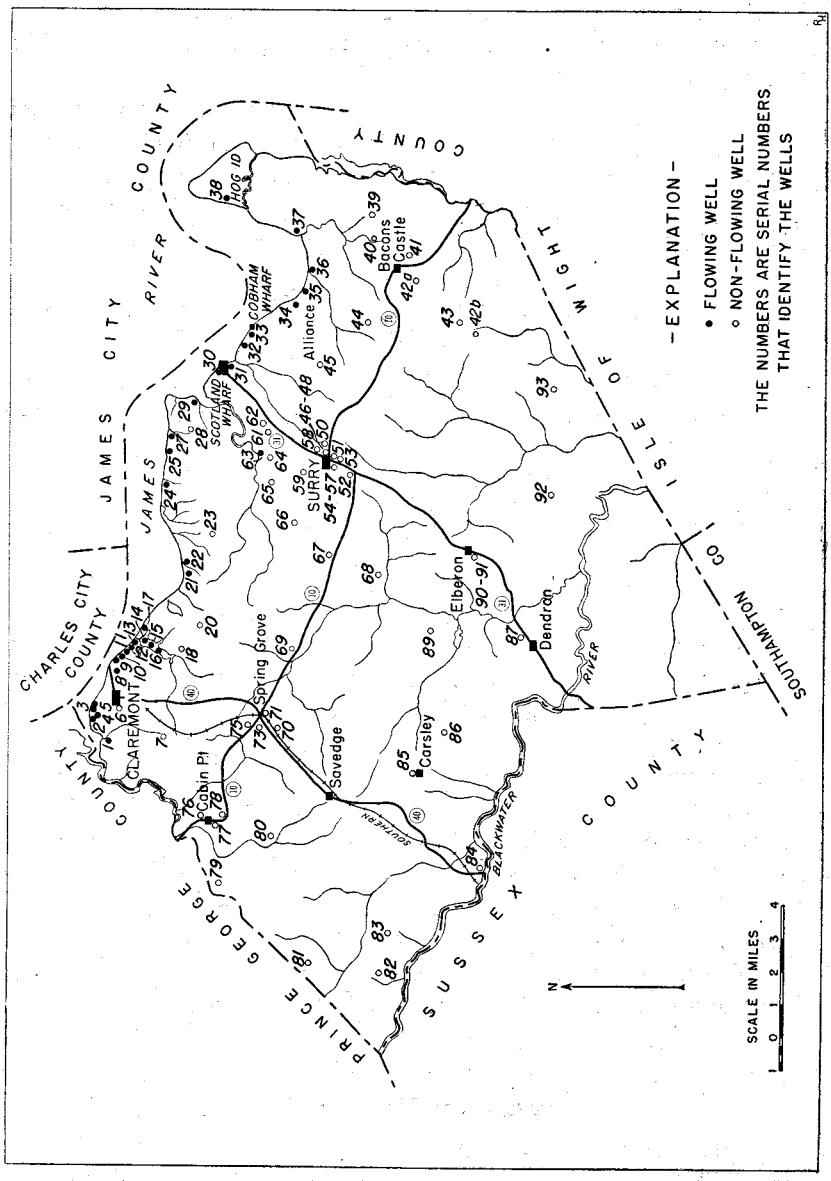


FIGURE 24.—Map of Surry County showing location of wells listed in Table 24.

and the lowest portion of the Miocene strata consists of sandy marls. At Claremont 30 feet of gray sand is reported at the base of the Miocene strata. The lithologic units recognized at Bacons Castle may correspond approximately with the Yorktown, St. Marys and Calvert formations.

Terrace formations of Pleistocene age, not more than 40 feet thick, make up most of the surface area in the county. A clay stratum of variable thickness generally lies at or near the surface and overlies a bed of sandy and gravelly material. In one place near Bacons Castle the terrace was reported to be made up entirely of clay.

GROUND WATER

SHALLOW WELLS

Water is obtained from shallow wells driven or dug in the terrace deposits in many parts of the county. Many dug wells are cased with tile pipe from the surface down to sand strata, generally below water level, but others are entirely uncased and have no platform or cover. Water is drawn from many dug wells by bucket.

Shallow wells supply most of the rural population with water. Since at most only a few hundred gallons a day is drawn from each well it is difficult to estimate the capacity of such wells. It is reported that at Spring Grove a 2-inch driven well (75, Table 24) supplies 15 gallons a minute to a sawmill. The small consumption of the ordinary sawmill boiler, however, suggests that the well was pumped at that rate for only short periods of time; the continuous yield is probably less than 10 gallons a minute.

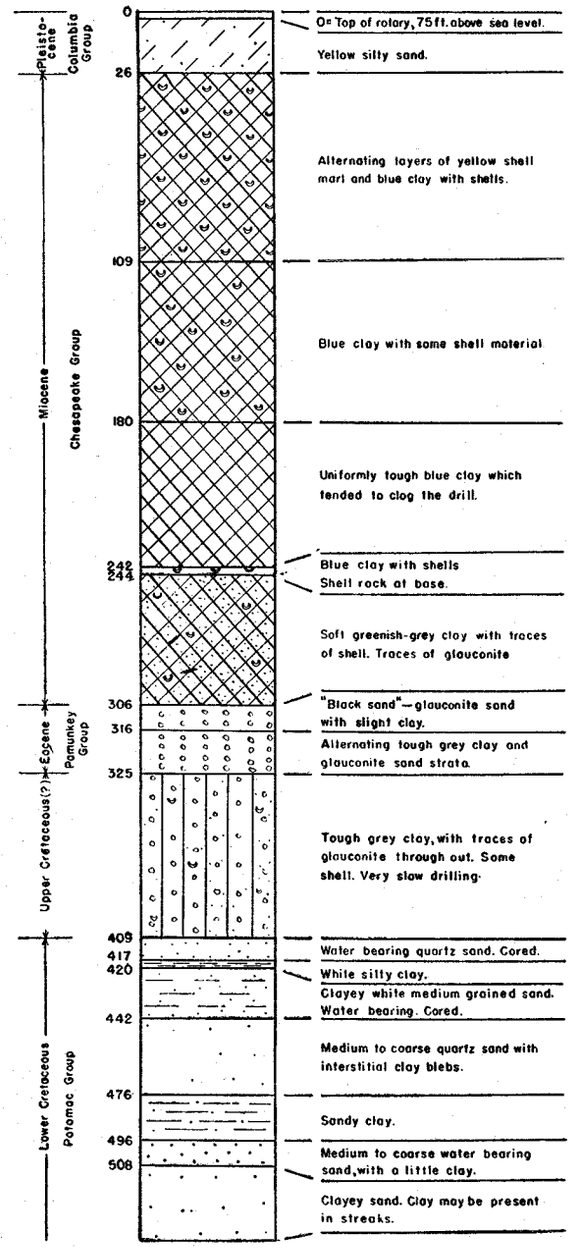
On the flat 'pocosons,' or high undissected terraces, the water level in shallow wells may lie within a few feet of the surface in wet seasons. Where the terraces are dissected, or where a well is located close to the edge of a terrace, the water level may be 20 feet or more below the surface.

The water obtained from shallow wells is generally soft, but in a few places it is reported to contain objectionable amounts of iron.

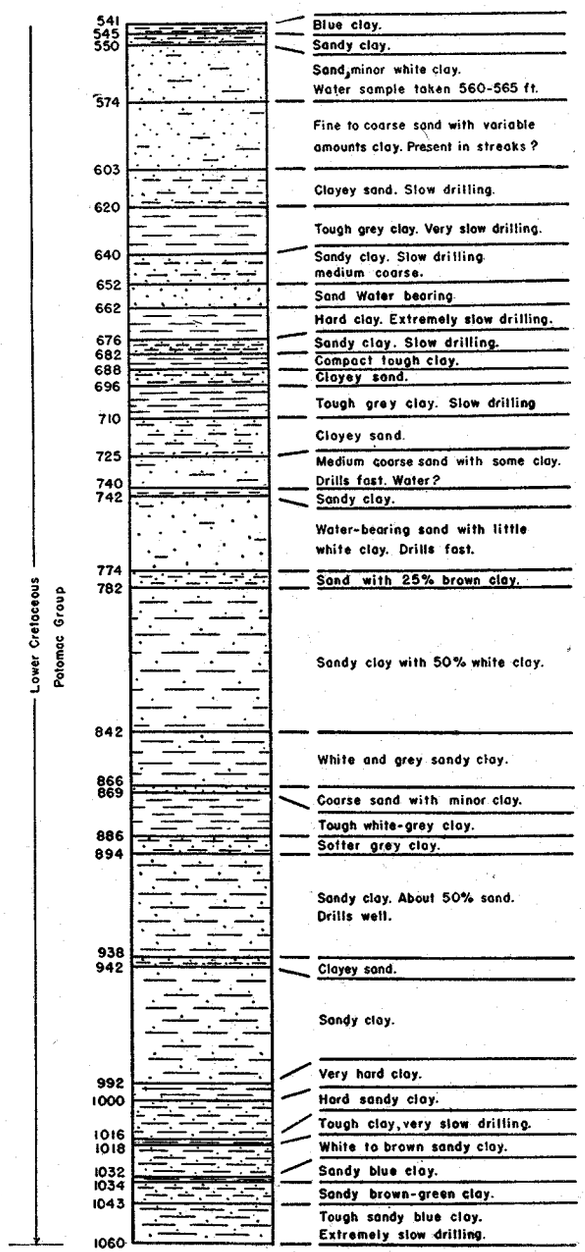
DEEP WELLS

WATER FROM MIOCENE DEPOSITS

Several drilled wells 100 feet or less in depth obtain water from strata of the Chesapeake group at Surry. In part at least, the water is derived from shell, or sand and shell, beds. Ample supplies for domestic purposes are obtained in several places, but the water is generally hard and in some wells it contains undesirable amounts of



Graphic log of test hole at Bacons Castle.
(Continued on next page.)



iron. The occurrence of permeable beds is irregular, however, and good yields can not be obtained everywhere.

In the ravines which extend into the higher upland from the James River, springs issue from the Miocene shell beds. Channelways appear to have been developed, along which much of the clayey matrix of the original formation has been removed by the action of the percolating water. Near Eastover, between Claremont and Scotland Wharf, 2 such springs are being used and are equipped with hydraulic rams. It is estimated that each of these springs discharges 50 gallons a minute. The water of one of the springs has a total hardness of about 100 parts per million, according to field test. There are many other similar springs in the county, but they are not used to any great extent.

WATER FROM EOCENE DEPOSITS

A few wells in Surry County obtain water from Eocene glauconite beds. The log of well 51 (Table 25) at Surry indicates that wells 47 and 56 at Surry obtain water from a quartz and glauconite sand occurring near the base of the Pamunkey deposits and well 54 obtains water from glauconite beds at the top of the Eocene formations. Well 41 at Bacons Castle, 360 feet deep, presumably ends in gray clay (Pl. 23) but may obtain water from glauconite beds at a slightly lesser depth. Well 38a at Hog Island ends in black sand of the Pamunkey group.

Water from wells 38a and 41 (Table 27) contains a relatively high bicarbonate content, respectively 542 and 487 parts per million, as compared with water from Cretaceous deposits which contains only from 200 to 350 parts.

Water from well 38a contained more dissolved mineral matter than any of the other deep wells in the county, possibly because of its location relatively near the area of highly mineralized ground waters in the lower York-James Peninsula[18]. Chloride is notably high for Surry County, 69 parts per million. However, at the same place a well (38b) reaching Cretaceous sands yields water which contains 15 parts per million of chloride. Presumably here along the margin of the high chloride area to the north and east the more permeable quartz sands have been flushed of nearly all their chloride content, whereas the less permeable glauconite sands still contain a moderate amount of chloride mineralization. A similar relationship has been noted at Jamestown where 2 wells less than 300 feet deep are reported[114] to have yielded water containing 57 and 135 parts per million of chloride, and wells deeper than 300 feet in the same area contain less than 15 parts of chloride. Chloride is low in other waters from Eocene deposits in Surry County.

Fluoride is high, 4.6 parts per million in water from well 41 at Bacons Castle and 4.0 parts in well 38b at Hog Island, but is less than 1 part in water from well 56 at Surry.

WATER FROM CRETACEOUS DEPOSITS

A number of deep wells along James River and a few on the high terraces obtain water from sand of the Potomac group. At Claremont (Fig. 24) the first sand is encountered about 160 feet below sea level, but at Hog Island this sand lies about 310 feet below sea level. At Surry, on the high terrace, the first sand of the Potomac group is encountered about 275 feet below sea level or 400 feet below the surface. As Potomac deposits consist of alternating quartz sand and clay, several wells in the county obtain water from other than the first sand; in well 4 (Table 25) the fourth sand is developed.

In 1888 an effort was made to obtain water by drilling a well at Dendron where a large supply was needed to feed the boilers of the Surry Lumber Co., which was operating extensively in southeastern Virginia at that time. The well reached a total depth of 380 feet and probably encountered Potomac strata at about 300 feet. Although several pumping tests were made, an adequate supply was not obtained. With the use of modern screens and the development of better methods of drilling, a successful well probably could be drilled. However, the variability of the sediments of the Coastal Plain is recognized, and the upper sand beds may be thinner and less permeable at Dendron than they are along James River to the north, and at Waverly, Wakefield and Ivor to the south. Mr. D. C. Magette, of Courtland, states that about 12 feet of medium sand was penetrated in the well of J. Collier at Dendron (altitude, about 100 feet) at from 303 to 315 feet.

Nearly all the wells along James River are located only a few feet above sea level and are flowing wells. The greater number of wells have their casing extended 8 to 12 feet above the surface. Near the top of the extended casing a pipe leads off to a hydraulic ram. The combined discharge of the ram and the water which flows out from the extended casing of some wells averages about 20 gallons a minute. This estimate does not include the large wells at Sunken Meadow (14-16) nor the Claremont waterworks well (8). The small wells would yield greater amounts of water if their casings were not extended so high above the ground. At Sunken Meadow pond 2 wells flow at the surface of the pond, about 5 feet above sea level. They have unrestricted flows and are reported to discharge respectively 80 and 125 gallons a minute. A third well discharges 60 gallons a minute. The Clare-

mont waterworks well flows about 65 gallons a minute from its outlet 16 feet above sea level.

The maximum amount of water which might be obtained if the small flowing wells were pumped is not known. It is estimated that the 2-inch and 3-inch flowing wells discharge 3 to 6 gallons a minute for each foot of "drawdown" (difference in elevation between the outlet of the well and the height to which water would rise, as in an extended casing).

The excellent yields of the many small-diameter, unscreened poorly developed domestic wells along James River seem to indicate that properly constructed wells of large diameter, drawing upon many sands, might yield very large quantities of water. Accordingly, the northeastern part of Surry County was recommended as an area favorable for exploration when large supplies of ground water were sought as a supplementary supply for the City of Newport News. The results of test drilling at Bacons Castle and 3 miles south of Bacons Castle are discussed below.

It seems likely that high yields might be obtained also from wells in Surry County bordering James River. However, with the problem of chloride contamination in mind, it would probably be better that very large installations be located nearer Claremont than Hog Island. Conditions are somewhat more conjectural inland, but it is likely that equally good yields might also be obtained there from properly constructed deep wells.

The static level of artesian water in 1940 along James River in Surry County was 16 to 19 feet above sea level. It was about 21 feet above sea level near Spring Grove (70, Table 24). Water level in the Bacons Castle test wells was respectively 18.4 and 20.5 feet above sea level, indicating a slope of the piezometric surface toward James River. According to local reports the water level was at least 31 feet above sea level at Claremont previous to 1920. The loss of 12 to 15 feet of head may be attributed directly to the numerous unrestricted flowing wells. It seems probable that further loss of head will take place, but the head may not fall below 10 feet above sea level unless wells are allowed to flow at lower outlets than they did in 1940. An additional loss will seriously affect the operation of many rams which supply homes with water.

QUALITY OF WATER FROM CRETACEOUS DEPOSITS

About 2 miles south of Cabin Point water with a total hardness of 130 parts per million, as carbonate hardness, is obtained from Cretace-

ous strata (80, Table 28). Elsewhere in the county the water from deep wells is very soft. In several samples that were examined the hardness was less than 5 parts per million. The process by which hard water in the western part of the county becomes less hard as it moves eastward has been described under "Water Softening by Base Exchange."

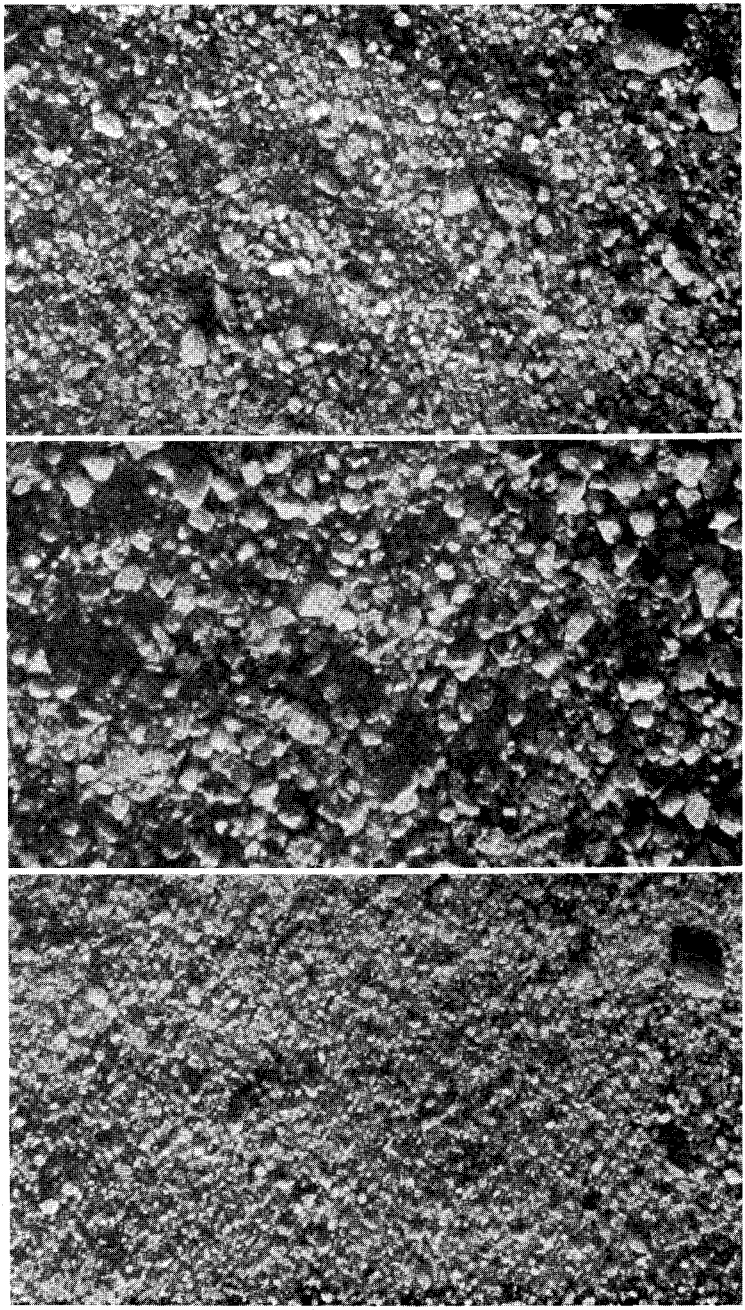
The mineral content of the soft water is made up almost entirely of sodium bicarbonate. Only a very few parts per million of other constituents are present. This water is excellent for all domestic purposes but, if used without treatment in boilers, might cause trouble due to foaming.

Fluoride is present in appreciable amounts in some well waters in the eastern part of the county (Fig. 16). A sample of water from Cobham Wharf (33) contained 3.2 parts per million of fluoride. In well 42b, 3 miles south of Bacons Castle, a sample from a stratum 693 to 711 feet below the surface contained 3.2 parts of fluoride, whereas a sample taken when the test well was completed and water from 462 to 711 feet was being discharged, contained only 1.8 parts per million of fluoride. However, samples from other localities in Surry County had less than 2 parts per million of fluoride, and some had less than 1 part per million. The deleterious effect of more than 1 part per million and beneficial effect of less than 1 part per million of fluoride upon the teeth of children up to 10 years of age are discussed in detail in the chapter on "Fluorides."

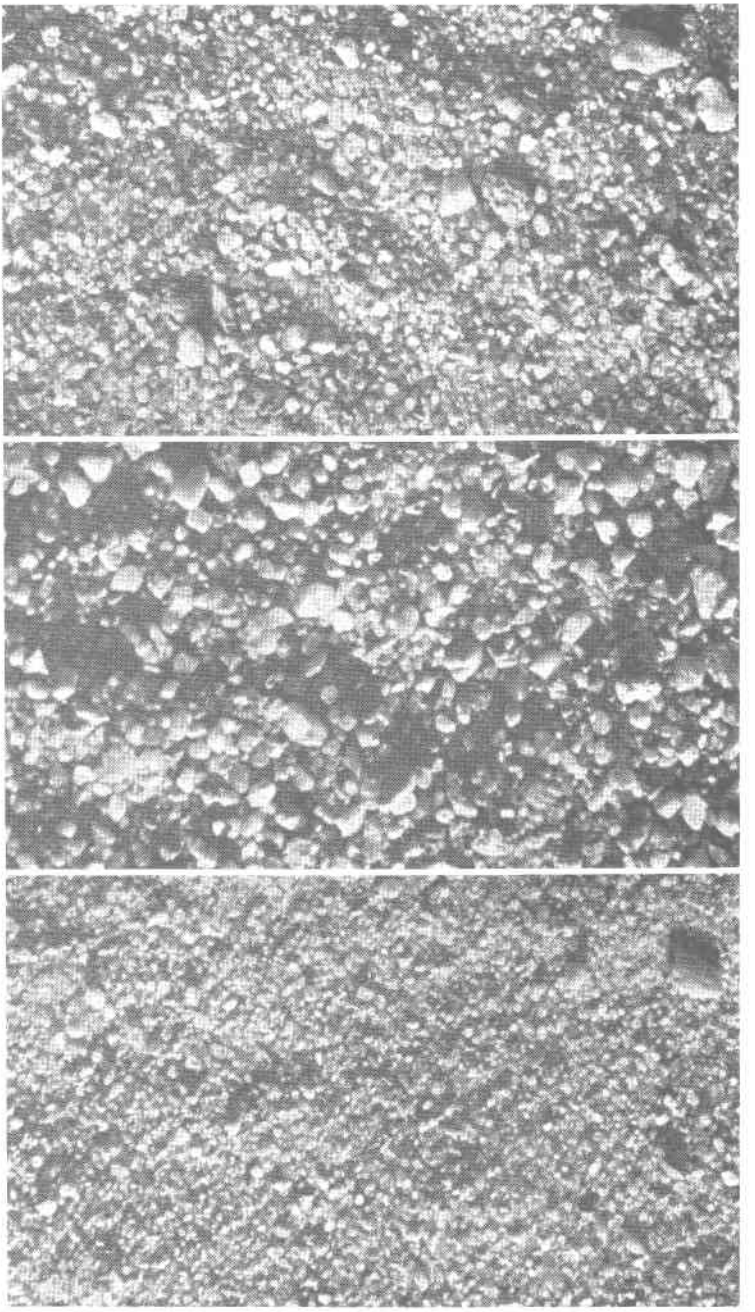
BACONS CASTLE TEST DRILLING PROJECT

GENERAL STATEMENT

In January, 1942, a test drilling project was initiated by the Newport News Water Commission in northeastern Surry County, Virginia, for the purpose of determining whether it would be possible to obtain 15,000,000 gallons of water per day from wells in that area to supplement the Newport News water supply. Contingent upon the availability of such a supply, it was planned to bring the water from the Surry County well field across James River, by means of a pipe line laid on the river bottom, and into the Lee Hall reservoir. By this means, the supply of surface water, normally about 10,000,000 gallons a day, would be augmented and the shortage of water, due to the severe drought of 1941-42 and the increased demands for water for defense and domestic use in the Newport News area, would be alleviated. The partially depleted surface-water reservoirs would furnish ample storage for the additional water, and it might have been practicable to by-pass the filter



Water-bearing sands penetrated in test hole at Bacons Castle Top, at 476 feet; middle, at 597 feet; bottom, at 655 feet. (Natural size.)



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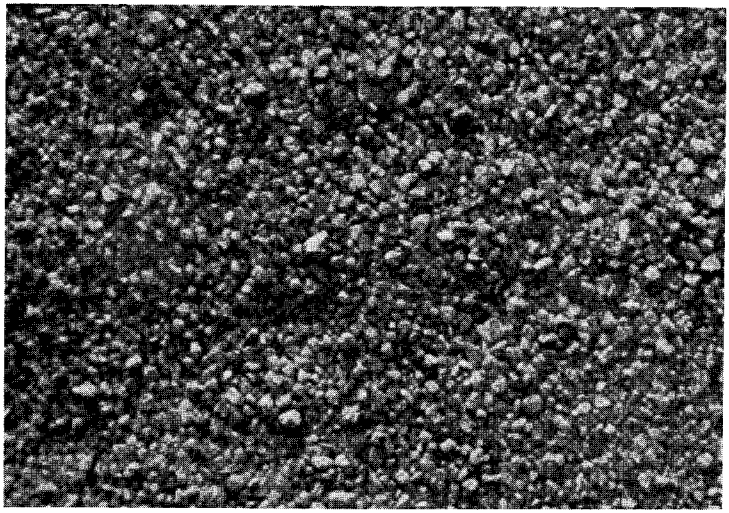

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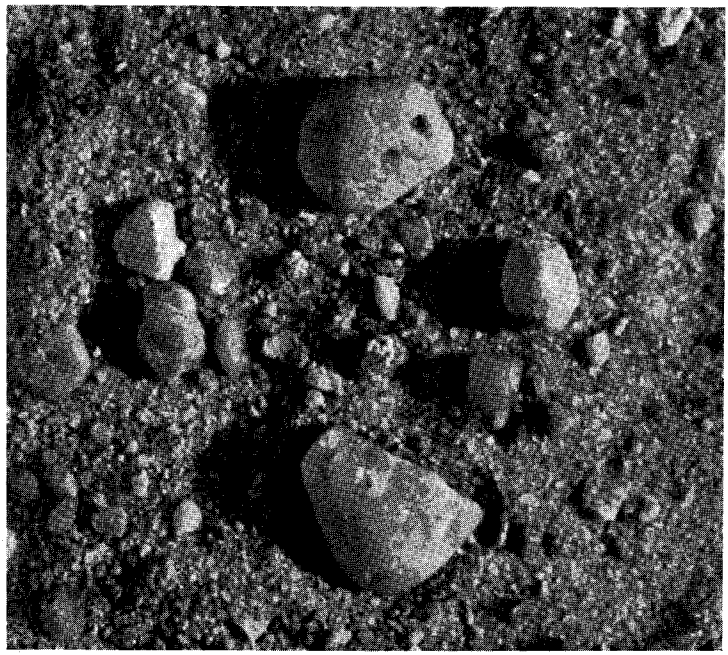
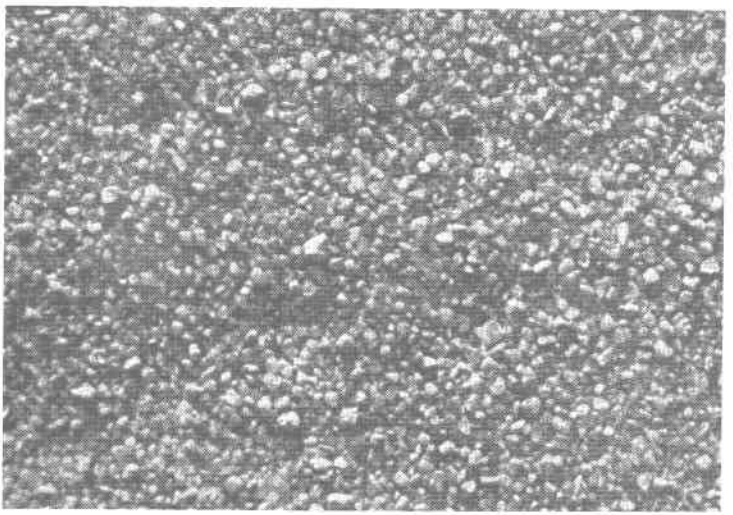
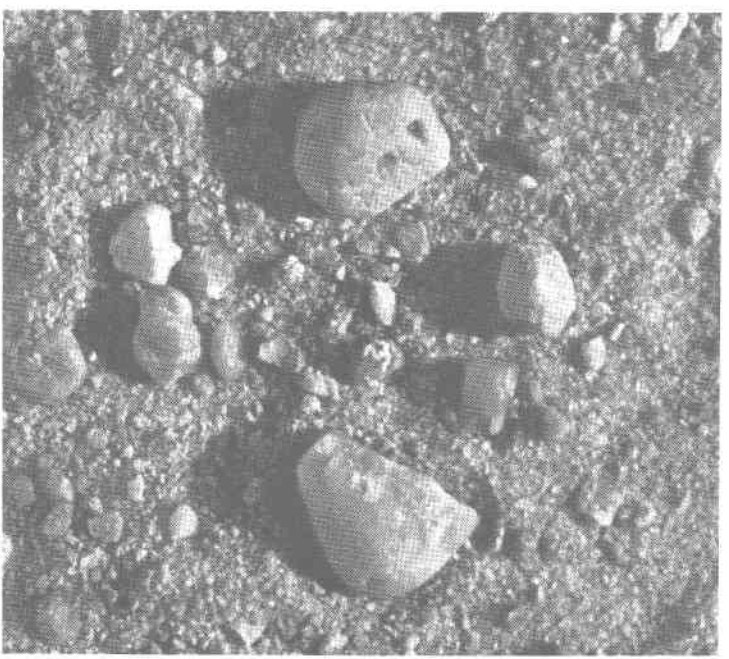


B.

A, Sample of water-bearing sand at a depth of 555 feet from second test well, south of Bacons Castle. Natural size. Most of the sands penetrated were of about this grain size. B, Core samples from a depth of 557 feet in test hole at Bacons Castle. Pebbles of this size were not brought up by the routine drilling processes. X¾.



A.



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A, Sample of water-bearing sand at a depth of 555 feet from second test well, south of Bacons Castle. Natural size. Most of the sands penetrated were of about this grain size. B, Core samples from a depth of 557 feet in test hole at Bacons Castle. Pebbles of this size were not brought up by the routine drilling processes. X¾.

and supply the ground water directly into the pipe line to Newport News.

Geological supervision of the test drilling was furnished by the Federal Geological Survey as part of the cooperation with the State Geological Survey and the Newport News Water Commission, Eugene F. Dugger, General Manager. The writer was in charge of the field work and was assisted in the field by William R. Jones. R. G. Kazmann made computations of various hydrologic quantities, using the data obtained by means of the pumping test. Mr. O. E. Meinzer and Mr. A. G. Fiedler exercised general supervision of the project and furnished advice and direction.

The engineering phases of the project were in charge of Messrs. Newsoms and Aldrich, Consulting Engineers, New York City, for the Newport News Water Commission, who in turn contracted with the Layne-Atlantic Company of Norfolk, Virginia, to drill test holes and test wells.

SELECTION OF DRILLING SITES

In the York-James Peninsula a zone of high chloride ground waters extends inland to a point near Toano, James City County[18]. Artesian waters east of this point usually contain from 40 to more than 1,000 parts per million of chloride. Hence, the first consideration in selecting a site for the development of large amounts of water was the choice of a location where the chloride content of artesian waters was not only very low but at some appreciable distance from the western boundary of the high chloride area. This choice would tend to eliminate the danger of chloride contamination under conditions of heavy draught.

The area of low-chloride waters nearest the Newport News water system lies in Isle of Wight and Surry counties, bordering James River. Of the two localities, the development of large-yield wells in Surry County was considered the more desirable because (1) a shorter crossing of the James River could be effected, (2) a shorter pipe line would bring water to the Lee Hall reservoir where it could be stored, (3) there was less danger of chloride intrusion, (4) the quality of water was known to be better, in particular, less sodium bicarbonate and less fluoride (Fig. 16) being present and (5) there would be less danger of interference with domestic and small municipal supplies at Smithfield, Battery Park and Rescue if the Surry County area were chosen for development.

As far as was known, favorable thicknesses of good water-bearing sands were believed to be present in both areas. The total thickness of

Coastal Plain sediments is greater in Isle of Wight County than in Surry County and presumably more sands should be present there. However, it was thought that the additional thickness would be below a depth of 1,000 feet, the maximum contemplated depth of wells to be constructed, and hence this would not be a factor in the selection of the test drilling sites.

In both counties the water-yielding character of the sands near the top of the Cretaceous formations was known to be generally good. The large number of domestic and a few small municipal installations along James River (Tables 24 and 34) indicated that several millions of gallons a day should be available from properly located and constructed wells. It was believed that a minimum of 5 million gallons a day could be obtained and that 10 million gallons a day seemed possible. There were not sufficient data at hand to indicate whether 15 million gallons could be obtained.

TEST PROGRAM

It was decided to drill three test holes and one observation well in northern Surry County to a depth of 1,000 feet, if necessary, to determine (1) the average thicknesses of water-bearing sands present, (2) the depths at which water-bearing sands occur, (3) the amount of water available (a) by determinations of permeability from sand cores and by pump tests, (b) by pumping one test well for a period of time and observing changes in pumping level and static level and (c) by observing the effect of heavy pumping on the water level in a near-by observation well, (4) the exact quality of ground water available to deep wells, with particular reference to chloride content and (5) the cost of developing 15 million gallons a day, if that amount of ground water was proved to be available.

Data on the flow of the Chickahominy River, obtained after the test drilling project was under way, indicated that a large quantity of surface water should be available on the York-James Peninsula and, simultaneously, objection was raised to the fluoride content of the Surry County ground waters. Hence, the program for the exploration of the ground waters in Surry County was brought to an end, at the order of the City of Newport News, when the second test hole was drilled and converted into a producing well.

However, in order to obtain quantitative data available at a moderate additional cost, the Layne-Atlantic Company drilled an observation well 200 feet south of the producing well (42b), installed a pump on the producing well, and operated the pump in a 3-day pump test according

to the advice given by the Geological Survey, insofar as possible. Particular thanks are due the Layne-Atlantic Company in making possible the acquisition of these data that are more or less applicable to large parts of the Virginia Coastal Plain.

Drilling was done by the rotary hydraulic method. (See chapter on "Well Construction.") Two test holes, 18 inches in diameter, were sunk with the aid of a semiportable A-frame rig (Pl. 20). A core-barrel was used in taking undisturbed samples of sediments and an expanding rubber packer was used to seal off water from higher strata in taking water samples by pumping through the drill rods.

During actual drilling operations, conducted on a 24-hour a day basis, Mr. W. R. Jones or the writer was present to obtain a record of the formations penetrated by the drill. This procedure resulted in a detailed and highly accurate log of formations throughout the entire section penetrated.

Test hole no. 1 (42a) was located at Bacons Castle, hole no. 2 (42b) was located 3.2 miles south-southwest of Bacons Castle, and test hole no. 3 was to be drilled 3 miles south of hole no. 2, near the Surry-Isle of Wight County line. An observation well was constructed near no. 2 well.

TEST HOLE NO. 1

Test hole no. 1 (42a, Fig. 24), at Bacons Castle, was drilled to a depth of 1,060 feet. A graphic log of the formations encountered in this hole is given in Plate 23, and may be summarized as follows: 26 feet of yellow silty sand belonging to the Columbia group of Pleistocene age, and 280 feet of blue or gray clay and shell marl (Pl. 15) belonging to the Chesapeake group of Miocene age. The Pamunkey formations of Eocene age consisted of 19 feet of glauconitic sand. This was underlain by 72 feet of gray clay, which is tentatively assigned to the Upper Cretaceous. Strata of early Cretaceous age (the Potomac group) consist of alternating nondescript sandy and clayey beds. Clays were generally bluish or gray while sands or sandy clays were lighter in color. Individual strata were generally less than 35 feet thick. In all, 653 feet of Cretaceous deposits was explored.

In the test hole, 95 feet of fairly clean quartz sand, moderately fine to coarse in texture (Pls. 24 and 25B), was found to be present above a depth of 766 feet. Two strata, each 24 feet in thickness, and four strata, respectively 10, 10, 12 and 15 feet thick, were logged. In addition, 85 feet of sandy material containing more or less clay was present. This material is probably water bearing too, since much of the included

clay is present in streaks, but it is probably not as good a water-bearing formation as the clean sand. Summarizing, then, about 180 feet of water-bearing material was encountered between 409 and 766 feet below the surface and more than half of this material appeared to have a relatively high permeability.

It is of interest to note that, below a depth of 770 feet, clayey material predominated and much of it was distinctly harder and more difficult to drill than the higher formations. At times almost no progress was made from one hour to the next.

A sample of water was taken from the stratum extending from 550 to 574 feet below the surface. The cylinder of a small plunger pump was set inside the drill rods, which extended to the water-bearing stratum. Above the sand stratum being tested a rubber packer effectively sealed off waters from higher strata.

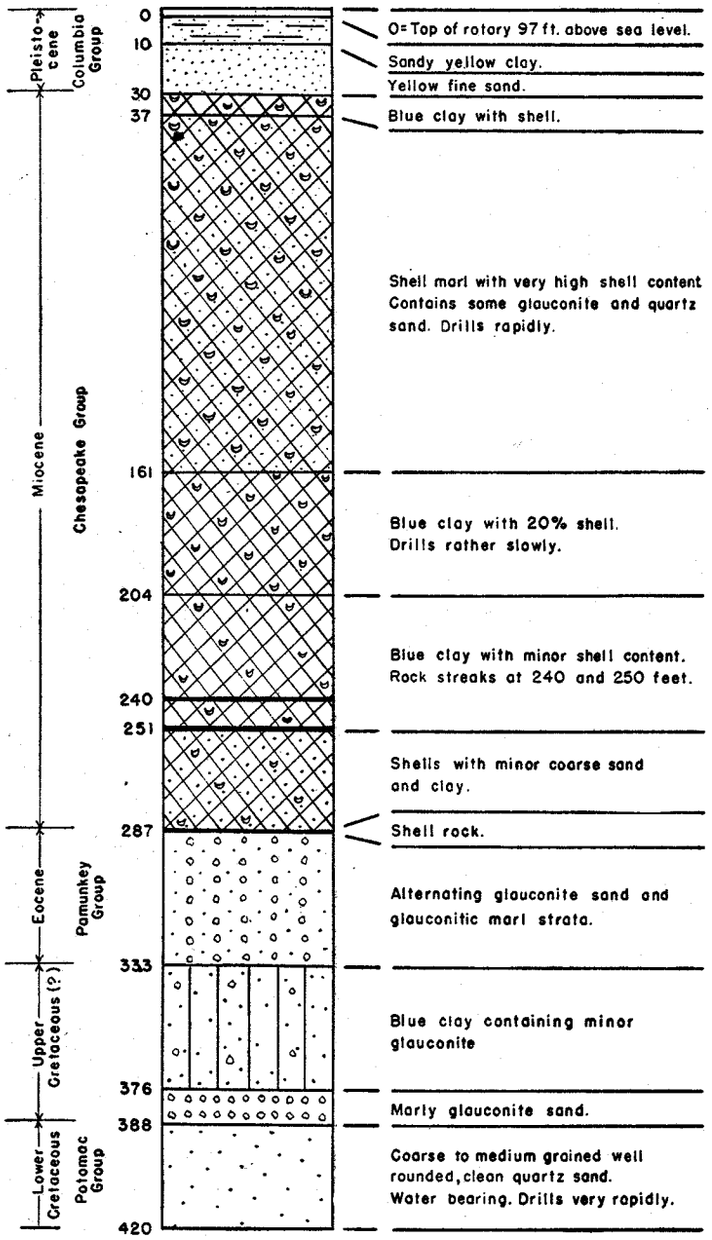
The quality of this water will be discussed below. Depth to water was measured inside the drill rods, after pumping about 3 gallons a minute for 8 hours, and was found to be 51.8 feet below the surface, or 18.4 feet above sea level.

TEST HOLE NO. 2

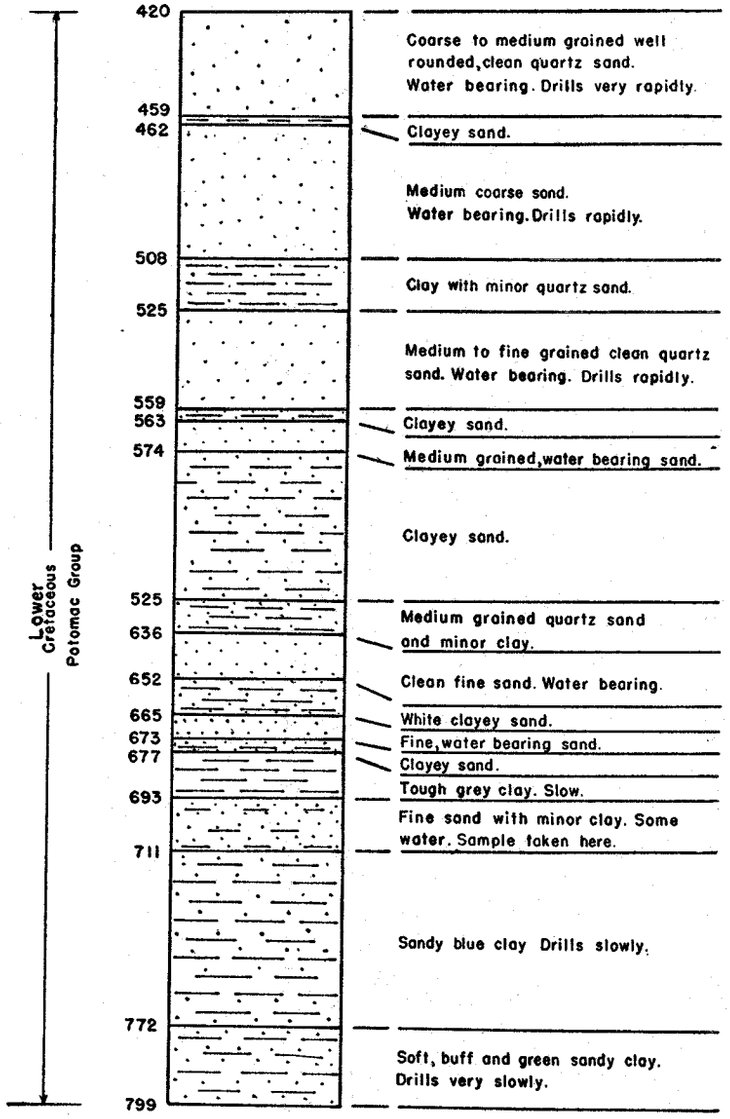
Test hole no. 2 (42b, Fig. 24) was not drilled to as great a depth as no. 1 because very favorable thicknesses of water-bearing sands were encountered at lesser depths, and because material penetrated between 700 and 800 feet below the surface was similar to that which was found at comparable depths in no. 1. Below 700 feet clean sandy strata were lacking and the clayey strata which were present became increasingly harder to drill.

Clay and sand of the Columbia group of Pleistocene age extend to a depth of 30 feet below the surface. (See Pl. 26.) Sediments of the Chesapeake formation of Miocene age consist of 257 feet of blue clay and shell marl. In this test hole the Pamunkey group of sediments of Eocene age consists of 46 feet of alternating glauconite sand and marl. These sediments are underlain by 43 feet of blue clay and 12 feet of glauconitic marly sand; both these strata are tentatively considered to be of late Cretaceous age.

At 388 feet below the surface the top of the Potomac group of early Cretaceous age was encountered. At the top of this group 120 feet of clean medium to medium-coarse water-bearing quartz sand was penetrated. (This thickness included 3 feet of clayey sand.) Seventeen feet below this sand stratum another clean sand stratum, 34 feet thick, was encountered and 4 feet below the base of this second stratum,



Graphic log of test hole south of Bacons Castle.
(Continued on next page.)



an 11-foot thickness of water-bearing sand was found. Four water-bearing strata, totaling 48 feet in thickness, are present at still greater depths, between 652 and 711 feet below the surface. The sands penetrated ranged in texture from moderately fine to moderately coarse (Pl. 25A).

A water sample was taken from the stratum from 693 to 711 feet below the surface (Table 28). Water samples were also taken when the test hole was converted into a well and heavily pumped. The results of analysis of these samples are discussed under "Quality of Water."

COMPARISON OF FORMATIONS IN TEST HOLES

One outstanding difference in the geology of the two sites chosen for drilling is that at the southerly location the same formations occur about 43 feet higher above sea level than at the northerly location. This difference may be ascribed to a relatively high northeastward dip of the formations in this area.

Although differing in detail the Chesapeake and Pamunkey groups are seen to be of the same general character in both places.

Outstanding differences occur in the formations of the Potomac group encountered above a depth of 750 feet. The section penetrated in test hole no. 1 may be characterized as consisting of clayey sand with subordinate clean quartz sand and with minor clayey strata. Test hole no. 2 penetrated a section consisting of clean quartz sand and subordinate intercalated clay strata. Gravelly material was present at several horizons in the first hole, but little or no gravel was present in the second hole, although there the aggregate thickness of sands was greater.

The logs of the two wells show that correlation of individual Potomac formations from the one test hole to the other can not be made with certainty. It is apparent that the respective upper 197 and 186 feet of Potomac strata in the two wells are predominantly sandy, and another sandy zone, respectively 58 and 49 feet thick, lies a short distance below the upper zone in both places. Correlation of individual strata in these zones is not very certain, and correlation of deeper sandy (or clayey) strata appears to be even less certain.

THE TEST WELL

Test hole no. 2 was converted into a gravel-packed well, and a pump, driven by a Diesel engine, was installed (Pl. 28B). In a test during which the well was pumped almost continuously for 70 hours, the fol-

lowing observations were made: (1) the amount of water pumped (Pl. 28A); (2) the level of the water in the pumped well (Pl. 27); (3) the level of the water in a 3-inch supply well, 17.4 feet south of the pumped well; and (4) the level of the water in the observation well, 206 feet south of the pumped well. At the conclusion of the pumping period, the recovery of water levels in the three wells was measured for another 50 hours.

These data are given graphically in Plate 29. Table 23 gives data in figures for several points on the graph. The results of the pump test may be summarized in general terms as follows: the well was pumped for 22½ hours at a rate of 520 gallons a minute with a maximum drawdown of 9½ feet. The decline of water levels in the near-by supply well and the more distant observation well was 3¾ and 2½ feet, respectively, at the end of this period. The pump was then operated at a rate of 660 gallons a minute for 23½ hours, with a maximum drawdown of 13¼ feet. The total decline of water levels in the two adjacent wells during this pumping period was 5¼ and 3¼ feet respectively. For the next 23½ hours the well was discharged at an average rate of 940 gallons a minute. The drawdown in the pumped well was 20¼ feet. The decline of water levels in the supply well and observation well was 7½ and 4¾ feet respectively.

One hour after pumping ceased the water level in the pumped well had recovered about 91 per cent and in the next 3 hours it recovered an additional 6 per cent.

Brief inspection of the results of the pump test indicates that the area is a favorable one for large ground-water developments. A relatively shallow cone of depression formed around the well during the time that the discharge was generally more than 1,350,000 gallons per day. The lowering of water levels in the observation well, 206 feet distant from the pumped well, was less than 5 feet at all times. However, if many wells were constructed, it is apparent that much of the recharge available to a single well would be intercepted, and cones of depression around each of many wells would be wider in extent and deeper. Therefore, if a group of wells were contemplated, a distance between them of about ½ mile would be recommended. The optimum spacing of wells, whereby some efficiency might be sacrificed to shorten pipe line, could be more accurately determined by observations made in one or two observation wells located at greater distances from a well discharging more or less continuously for several weeks.

The character of the water-bearing formations may vary in short distances, as noted above. Hence, it should not be assumed that every

well constructed in this area will be as efficient as the well tested. On the other hand, a highly efficient well, such as the one tested, could be counted upon to yield more than 1 million gallons a day.

Computations made by R. G. Kazmann from the single pumping test conducted during the Surry County investigation indicate a transmissibility of about 150,000 and a coefficient of storage of about .001.

The transmissibility is the figure which measures the rate at which the aquifer will permit water to travel through it under a given dif-

TABLE 23.—*Summary of Surry County pump test*

Time		Yield (gallons per minute)	Drawdown in pumped well (feet)	Drawdown in supply well (feet)	Drawdown in observation well (feet)
March 10	10:18 A. M.	.....	.....pumpin	g began.....	
March 10	10:30 A. M.	510	8.14	2.58	0.59
March 10	3:30 P. M.	520	9.11	3.40	1.92
March 10	8:45 P. M.	510	9.16	3.58	2.13
March 11	9:00 A. M.	520	9.48	3.85	2.34
March 11	12:00 N.	665	12.78	4.92	2.94
March 11	4:00 P. M.	670	12.95	5.03	3.07
March 11	8:00 P. M.	655	12.91	5.09	3.10
March 12	7:30 A. M.	660	13.14	5.14	3.18
March 12	11:30 A. M.	945	18.90	6.66	3.91
March 12	3:35 P. M.	965	20.20	7.17	4.38
March 12	8:00 P. M.	935	20.18	7.26	4.50
March 12	11:00 P. M.	940	20.14	7.20	4.53
March 13	8:50 A. M.	960	20.31	7.60	4.78
March 13	9:00 A. M.	.....	.....pump	shut off.....	
March 13	9:30 A. M.	0	2.36	2.49	2.46
March 13	10:00 A. M.	0	1.98	2.10	2.09
March 13	11:00 A. M.	0	1.58	1.77	1.70
March 13	1:00 P. M.	0	1.23	1.41	1.44
March 13	5:00 P. M.	0	.99	1.07	1.02
March 13	9:00 P. M.	0	.90	.93	.84
March 14	10:00 A. M.	0	.52	.62	.56
March 14	12:00 N.	0	.54	.59	.53
March 14	3:00 P. M.	0	.50	.56	.47

ference in head. For example, the figure given above indicates that about 150,000 gallons of water will pass through each lineal mile of cross section of the aquifer (the cross section being taken at right angles to the direction of flow) during each day under a hydraulic gradient of 1 foot to the mile. If the hydraulic gradient is other than 1 foot to the mile, this quantity must be multiplied proportionately.

The coefficient of storage indicates the quantity of water (in cubic feet) that the aquifer will release from each vertical column with a base 1 foot square as the water level falls 1 foot.

If 15 wells were put down in a straight line at half-mile intervals in an aquifer with the hydrologic characteristics obtained from the pumping test, and each were pumped continuously at the rate of one million gallons a day, the drawdown, just outside of the wells, would be about 50 feet at the end of 1 year and about 65 at the end of 5 years. This computation is based on withdrawal from storage. Equilibrium would be established when the cone of depression had been enlarged sufficiently to intercept a natural underflow of about 15 million gallons a day.

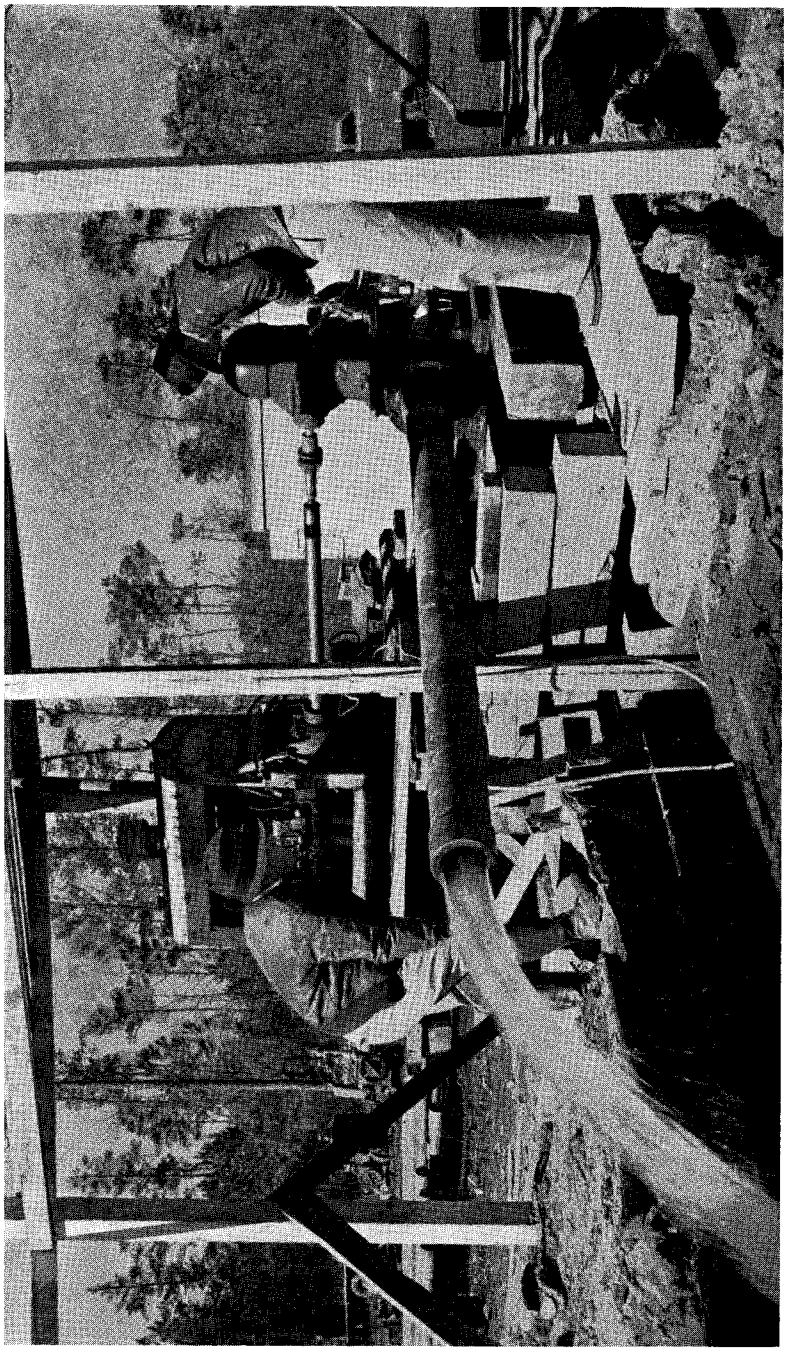
QUALITY OF WATER

A sample of water was taken from the stratum that is 550 to 574 feet below the surface in test hole no. 1 and from the stratum 693 to 711 feet below the surface in test hole no. 2. Further samples were taken from test hole no. 2 (42b) after it had been converted into a test well and pumped heavily. The results of analysis of these samples are given in Table 28.

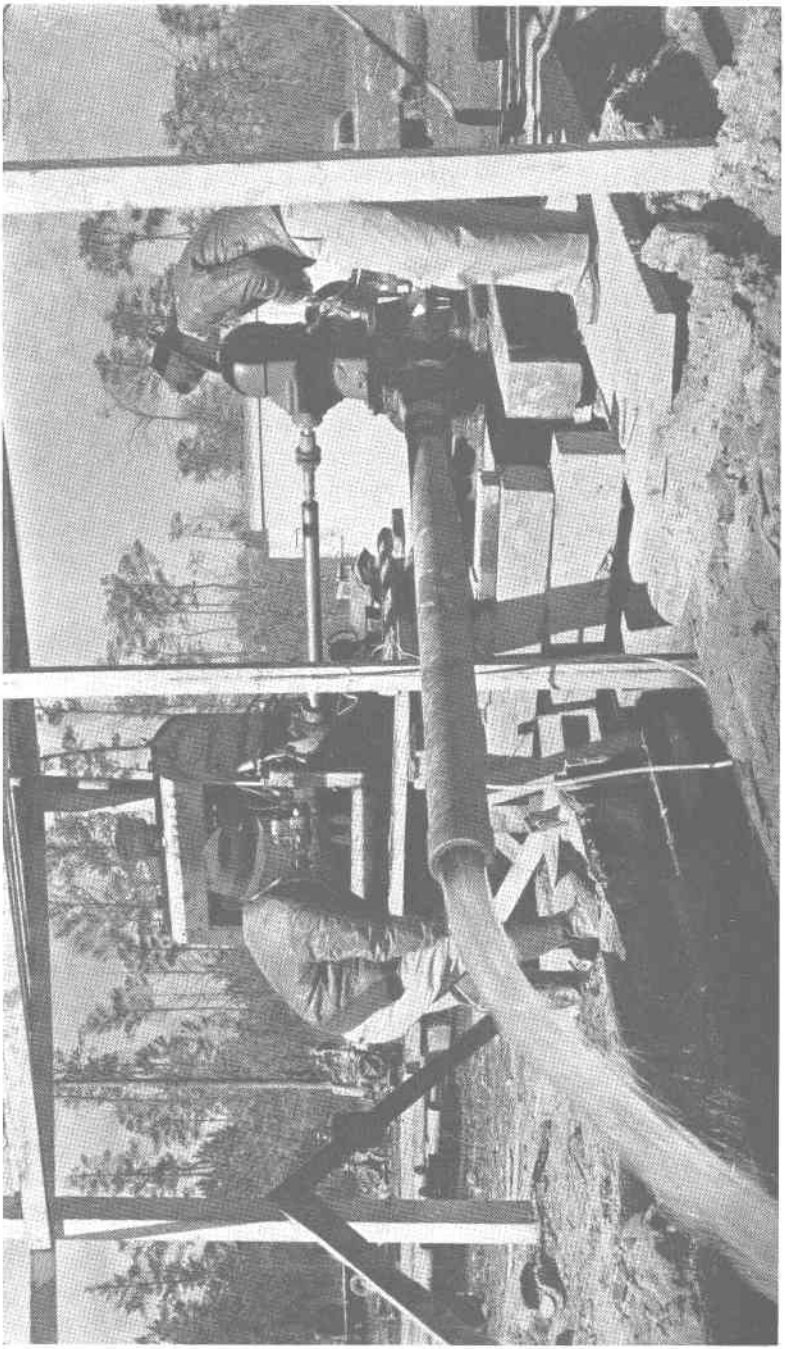
Chloride: In all the samples taken the chloride content was found to be low, less than 7 parts per million. With consideration of the relative nearness of northeastern Surry County to the high-chloride zone north of James River, the low chloride content of the waters tested was most gratifying. In addition to the fact that water of only moderate chloride content is undesirable from many standpoints, the presence of more than 25 to 30 parts per million of chloride would suggest that still higher chloride waters might be present within short distances and contamination of the well under conditions of heavy pumping would be an uncomfortable possibility. It is of interest to note, therefore, that the chloride content of the water from the pumped well decreased from 7 to 3.2 parts per million during the last 27 hours of pumping (at end of the 51-hour pumping period).

Hardness: The waters tested were almost entirely soft in that the hardness of all samples taken ranged from 4.5 to 15 parts per million. On that score the water should be admirably suited to domestic and industrial uses. The slight hardness of the water from the pumped well was less at the end of the pumping period than it was 27 hours earlier.

Bicarbonate: The bicarbonate content of the waters tested was moderately low in comparison to Coastal Plain waters available and

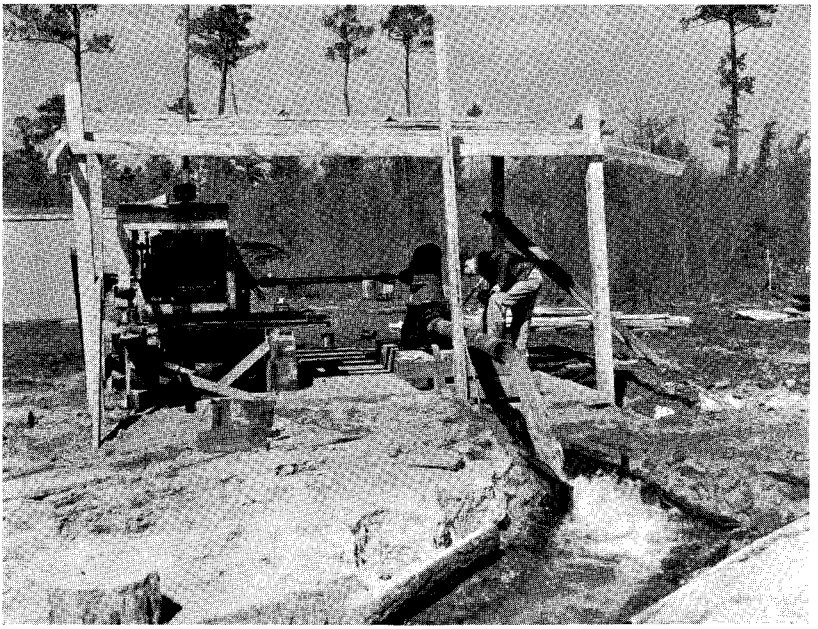


Discharge from test well south of Bacons Castle. The man on left is reading piezometric pressure. The man on right is measuring depth of water in pumping well. Photograph by Paul Schweitzer.



Discharge from test well south of Bacons Castle. The man on left is reading piezometric pressure. The man on right is measuring depth of water in pumping well. Photograph by Paul Schweitzer.

A.



B.

A, Measuring discharge, by current meter, from test well south of Bacons Castle. B, Test well south of Bacons Castle, in operation. Note attachment of piezometric pressure tube into the side of the discharge pipe. Photograph by Paul Schweitzer.

A.

B.

A, Measuring discharge, by current meter, from test well south of Bacons Castle. B, Test well south of Bacons Castle, in operation. Note attachment of piezometric pressure tube into the side of the discharge pipe. Photograph by Paul Schweitzer.

used in many places, and is present largely as sodium bicarbonate. For some industrial purposes, such as high pressure boiler feed, water with a bicarbonate content of more than 250 parts per million would probably need treatment. Treatment needed would be simple and inexpensive, however. Waters of similar sodium bicarbonate content are highly favored for domestic consumption throughout the Virginia Coastal Plain.

Sulfate and Nitrate: The sulfate radicle is very low in these waters and may be disregarded. The nitrate content is zero and may be regarded as being indicative of (although not proof of) the absence of pollution.

Iron: Iron, a very troublesome constituent in some places in the Coastal Plain, is very low in the waters tested. The slight amount present should make treatment unnecessary so far as all ordinary uses are concerned.

Silica: Silica is rather high in all samples analyzed and the waters might be classed as more or less undesirable for boiler feed on this account if used raw.

Fluoride: The deepest stratum in test hole no. 2 yielded water containing 3.2 parts per million of fluoride. However, upon heavy pumping this well yielded water containing only 1.6 parts per million of fluoride, indicating that water of still lower fluoride content might possibly be obtained by shutting off the water from the deepest stratum. The presence of more than 1 part per million of fluoride is likely to be somewhat deleterious to the teeth of some of the children who drink such waters regularly.[53] Dilution with water that is free of fluoride would proportionately reduce the fluoride content of the mixture.

Recently, it has been shown that the presence of less than 1 part per million of fluoride in drinking water[54] is an important factor in inhibiting tooth decay. Had the Surry County well field materialized and had the water been used as planned, that is, diluted with Lee Hall reservoir surface water, the resultant blend would have been low in bicarbonate, possibly eliminating entirely the need for treatment on that account, and would have contained a low but desirable amount of fluoride.

WELL RECORDS AND ANALYSES

Records of wells in Surry County, available logs of wells, and analyses of water samples are listed in Tables 24-28, on the following pages. The locations of wells listed are shown in Figure 24.

TABLE 24.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
1	1¼ miles northwest of Claremont.	.....	C. W. Daugherty.....	1919	3	J
2	1 mile north-northwest of Claremont.	.....	J. R. McLane.....	1917	3	J
3	Burdicks Wharf, Claremont...	Smallwood School.....	Jewett.....	1925	10	J
4	Above Burdicks Wharf, Claremont.	O. E. Belding.....	C. W. Daugherty.....	1917	17	J
5	Telluride School, Claremont..	Burdick.....	Jewett.....	.....	6	J
6	Claremont.....	Monad.....	C. W. Daugherty.....	1917	90	J
7	2 miles southwest of Claremont.	Cool Spring Farm.....	Jewett.....	1918	110?	J
8	Claremont.....	Town waterworks.....	Jewett.....	1916	6	J
9	Claremont Wharf.....	W. O. Rogers.....	Jewett.....	.....	5	J
10	¼ mile southeast of Claremont Wharf.	C. Allen.....	F. Wells.....	.....	5	J
11	¾ mile southeast of Claremont Wharf.	Rook.....	J. Mitchell.....	.....	14?	D
12	1 mile southeast of Claremont Wharf.	Worth.....	Jewett.....	.....	4	J
13	1¼ miles southeast of Claremont Wharf.	Worth.....	F. Wells.....	.....	4	J
14	Sunken Meadow Creek.....	Sunken Meadow Beach....	C. W. Daugherty.....	.....	5	J
15	Sunken Meadow Creek.....	Sunken Meadow Beach.....	C. W. Daugherty.....	.....	5	J
16	Sunken Meadow Creek.....	Sunken Meadow Beach....	C. W. Daugherty.....	.....	5	J
17	¾ mile southeast of Sunken Meadow.	F. Wells.....	.....	.....	.....	J
18	1½ miles south of Sunken Meadow.	R. Elliot.....	.....	.....	86	Dug
20	2 miles south of Sunken Meadow.	C. E. Barnes.....	Owner.....	.....	94	Dug
21	2½ miles southeast of Sunken Meadow.	A. Ochsner.....	C. W. Daugherty.....	1917	4	J
22	2½ miles southeast of Sunken Meadow.	A. Ochsner.....	C. W. Daugherty.....	1918	4	J
23	Eastover.....	J. L. Calhoun.....	.....	.....	100	Dug
24	2¼ miles northeast of Eastover.	Four Mile Tree Estate.....	C. W. Daugherty.....	1917	5	J
25	2 miles west of Swann Point...	R. E. Eppes.....	J. Minton.....	1930	5	J
27	1 mile west of Swann Point...	J. T. Battle.....	J. Minton.....	1938	.....	J
28	Swann Point.....	G. Gray.....	Gwaltney.....	.....	80	J
29	Swann Point.....	G. Gray.....	C. W. Daugherty.....	1920	4	J
30	Scotland Wharf.....	A. F. Jester.....	J. Minton.....	1925	7	J
31	¼ mile south of Scotland Wharf.	Camp Waters.....	.....	.....	10	J
32	½ mile northeast of Cobham Wharf.	Morrison.....	.....	.....	6	J
33	Cobham Wharf.....	R. W. Berryman.....	R. W. Sillings.....	1913	17	J
34	1 mile southeast of Cobham Wharf.	B. C. Berryman.....	J. Minton.....	1935	8	J
35	2 miles southeast of Cobham Wharf.	W. H. Berryman.....	J. Minton.....	1910	9	J
36	At mouth of College Run.....	Chippokes.....	J. Minton.....	1913	10	J
37	1 mile east of mouth of College Run.	P. H. Drewry.....	J. Minton.....	.....	5	J
38	Hog Island.....	Hog Island Game Preserve..	J. Minton.....	1933	6	J

Surry County, Virginia

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
210	2	+	.....	20	D	.....	Water from second Cretaceous sand, at 210 to 230 ft.	1
220	3	+13	June 20, 1939	0 to 15	D	.....	Does not flow at low tide. At high tide flows 15 gallons a minute, out of casing extended 13 ft. above surface.	2
.....	3	+	.....	15	Ab	.....	Flowed 31 ft. above sea level in 1925.	3
287	2	+	.....	4	D S	.....	Flowed 45 gallons a minute in 1917.	4
228	2	+	.....	5	Ab	.....	Flows from casing extended 10 ft. above surface.	5
264	2	−	.....	.....	D	.....	Water level 67 ft. below surface in 1917.	6
276	2	−	.....	.....	D S	TH, 15	.....	7
264	6 to 4	+	.....	65	P	A	Water head 16 ft. above sea level. Flowed 130 gallons a minute in 1916 from third Cretaceous sand at 252 to 264 ft. Temp. 61° F.	8
228	.....	+	.....	55	D	.....	.....	9
240	2	+14	June 20, 1939	8	D	.....	Flows from casing extended 12 ft. above surface.	10
.....	.....	+	.....	7	D	.....	.....	11
278	.....	+	.....	15	D	.....	.....	12
241	.....	+	.....	15	D	.....	.....	13
268	3	+	.....	60	D	.....	Water from second Cretaceous sand below 268 ft. Supplies resort.	14
243	3	+	.....	80	.....	.....	Water from first sand.	15
258	3	+	.....	125	.....	.....	Supplies fish pond.	16
.....	.....	+	.....	.....	D	.....	.....	17
49	.....	−30½	June 21, 1939	.....	D	Soft	.....	18
30	.....	−25	.....	.....	D S	Soft	.....	20
247	2	+	.....	15	D	.....	.....	21
204	3	+	.....	20	D	.....	.....	22
55	.....	−40	.....	.....	D S	Hard	.....	23
271	.....	+	.....	15	D S	.....	.....	24
190	2	+	.....	10	D S	.....	.....	25
270	3	+	.....	25	D	.....	.....	27
.....	2	−	.....	.....	S	.....	.....	28
333	3	+	.....	25	D	.....	Water from second Cretaceous sand below 333 ft. Flow is from casing extended 12 ft. above surface. Water more than 31 ft. above surface in 1920.	29
300	2	+	.....	40	D	A	.....	30
.....	3	+	.....	20	D	.....	.....	31
.....	3	+	.....	25	D S	.....	.....	32
288	2	+	.....	15	D	A	Water from first Cretaceous sand, below 286 ft.	33
280	2	+	.....	50	D S	.....	.....	34
320	2	+	.....	20	D S	.....	.....	35
330	2	+	.....	.....	D S	.....	.....	36
340	3	+	.....	35	D	.....	.....	37
340	.....	+	.....	35	D S	A	Flow shut off when water is not being used.	38

TABLE 24.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
39	2 miles east-northeast of Bacons Castle.	N. M. Hunter			57	Dug
40	Bacons Castle	Bacons Castle Estate	R. W. Sillings	1917	19	J
41	Bacons Castle	B. C. Baptist Church	E. J. Cousins	1925	83	J
42a	Bacons Castle	City of Newport News	Layne-Atlantic Co	1942	70	D
42b	3.2 miles south of Bacons Castle.	City of Newport News	Layne-Atlantic Co	1942	94	D
43	2½ miles southwest of Bacons Castle.	A. V. Council			95	Dug
44a	2 miles east-southeast of Alliance.	W. C. Mitchell	R. W. Sillings	1918	21?	J
44b	2 miles east-southeast of Alliance.	W. C. Mitchell	Owner		72	Dug
45	Alliance	J. H. Savedge	J. Minton	1927	78	J
46	Surry C. H	Paul Cox	Mitchells Pump and Well Co.	1939	125	D
47	Surry C. H	Paul Cox	Mitchells Pump and Well Co.	1924	125	D
48	Surry C. H	Roy Edwards		1930	125	D
50	Surry C. H	C. T. Hamlin	Mitchells Pump and Well Co.	1928	120	D
51	Surry C. H	Paul Cox	Mitchells Pump and Well Co.	1943	125	D
52	Surry C. H	M. L. Crest			120	Dug
53	Surry C. H	High School	J. R. McLane	1935	125	J
54	Surry C. H	H. Holleman	E. J. Cousins	1930	120	D
55	Surry C. H	Roger Cox			125	D
56	Surry C. H	C. H. Gwaltney	Mitchells Pump and Well Co.	1931	122	D
57	Surry C. H	Berryman Tea Room	E. J. Cousins	1928	120	D
58	Surry C. H	Wallace Edwards	E. J. Cousins	1925	120	D
59	1 mile north-northwest of Surry C. H.	Baptist Church			105	Dug
61	2 miles north-northeast of Surry C. H.	T. J. Jones	Mitchells Pump and Well Co.		90	D
62	2¼ miles north-northeast of Surry C. H.	John Rolfe Place			96	Dug
63	2 miles north of Surry C H	E. A. Humphreys	R. W. Sillings		10?	J
64	1½ miles north of Surry C. H	T. J. Jones	Owner		120	Dug
65	2 miles north-northwest of Surry C. H.	Eva Tynes			110	Dug
66	2½ miles west-northwest of Surry C. H.	Goodman Brown			110	Dug
67	3 miles west of Surry C. H	C. E. Warren			105	Dug
68	3 miles west-southwest of Surry C. H.	T. S. Collier		1915	100	Dug
69	2 miles east-southeast of Spring Grove.	L. R. Wrenn			101	Dug
70	½ mile southwest of Spring Grove.	A. Ochsner			110	D
71	Spring Grove	O. Haffs			100	Dug
73	Spring Grove	J. H. Rogers	Mitchells Pump and Well Co.	1933	100	D
75	Spring Grove	J. F. Huber			105	Dv
76	½ mile north of Cabin Point	O. A. Grasswitt	Jewett	1912	60	J
77	Cabin Point	E. L. Pennington	C. W. Daugherty	1918	68	J
78	Cabin Point	R. Riebsamen			90	Dv
79	2 miles west of Cabin Point	J. H. Clements			100	Dug
80	2 miles south of Cabin Point	H. B. Holdsworth	C. W. Daugherty	1918	92	J
81	Union	S. G. Barham			120	Dug
82	2 miles south of Union	H. G. Bailey			120	Dug

Surry County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
32	.....	−	.....	.....	D S	Hard, iron	Water from sandy clay.	39
367	2	+2¼	July 6, 1939	.....	Ab	.....	Water level 13 feet below top of casing July 6, 1939; 12 ft. above top of casing in 1918.	40
360	2	−	.....	.....	D	.....	.....	41
1,060	8	−51¾	Jan. 22, 1942	.....	T	A	Was not cased.	42a
799	18-10	−74⅔	Mar. 10, 1942	.....	T	A	Yields 940 gallons a minute with 20¼ feet drawdown.	42b
15	.....	−12	July 7, 1939	.....	D S	Soft	.....	43
348	.....	−	.....	.....	Ab	.....	Stopped flowing in 1925.	44a
40	.....	−	.....	.....	D S	Soft, iron	Water from sandy clay.	44b
378	2	−	.....	.....	D	.....	.....	45
60	6	−40	.....	.....	D	TH, 50	Pumps 8 gallons a minute.	46
398	3	−	.....	.....	D	.....	.....	47
102	3	−30?	.....	.....	D	Moderately hard	.....	48
77	3	−38	.....	.....	D	TH, 140	Water from Miocene shell bed.	50
454	6	−112	Nov. 4, 1943	.....	D	.....	Water level measured before well was fully developed; may be slightly higher.	51
23	.....	−9¾	June 30, 1939	.....	D S	Soft	Water from terrace sand.	52
465	4	−	.....	.....	P	A	.....	53
360	.....	−	.....	.....	D	.....	Supplies 3 homes.	54
56	4	−	.....	.....	D	Soft, iron	.....	55
375	.....	−	.....	.....	D	A	.....	56
210?	3	−	.....	.....	D	Hard, iron	.....	57
100	.....	−50	.....	.....	D	Hard	.....	58
30	.....	−28½	June 30, 1939	.....	D	TH, 60	.....	59
425	3	−	.....	.....	D S	.....	.....	61
40	.....	−36¼	June 29, 1939	.....	D	TH, 100	.....	62
.....	2	+	.....	10	D	.....	.....	63
23	.....	−19	.....	.....	D S	Hard	.....	64
23	.....	−20½	June 30, 1939	.....	D S	Hard	.....	65
54	.....	−52½	June 30, 1939	.....	D S	TH, 30	.....	66
24	.....	−20½	June 30, 1939	.....	D S	Soft	Water from terrace sand.	67
24	.....	−21	.....	.....	D S	Soft	.....	68
22	.....	−11¾	June 22, 1939	.....	D S	Soft	.....	69
237	.....	−88¾	June 22, 1939	.....	D S	TH, 60	Water level measured from top of casing which is ½ ft. above surface.	70
35	.....	−30	.....	.....	S	A	.....	71
60?	.....	−	.....	.....	D	Very hard	.....	73
21	2	−8	.....	.....	B	Soft	Pumps 4 gallons a minute. Water does not foam, corrode, or form scale in boilers.	75
206	3	−	.....	.....	D S	.....	From first Cretaceous sand. Water level 26 ft. below surface in 1926.	76
231	3	−	.....	.....	D	TH, 40	.....	77
32	2	−	.....	.....	D S	Soft	.....	78
26	.....	−22	July 5, 1939	.....	D S	Soft	.....	79
219	.....	−	.....	.....	D S	A	Water from first Cretaceous sand, at 219 to 241 ft.	80
24	.....	−16	.....	.....	D S	TH, 50	.....	81
23	.....	−15	July 5, 1939	.....	D S	Soft	.....	82

TABLE 24.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
83	2¾ miles south-southeast of Union.	Strother Stave Mill			122	Dug
84	3 miles northeast of Waverly	A. Thomas			62	Dug
85	Carsley	J. W. Rogers			121	Dug
86	4 miles northwest of Dendron	R. Holmes			110	Dug
87	Dendron	W. E. Rogers			100	Dug
89	3 miles north of Dendron	P. Stewart			89	Dug
90	Elberon	O. T. Cox	Mitchells Pump and Well Co.		116	D
91	Elberon	O. T. Cox			116	Dug
92	3 miles southeast of Elberon	R. W. James			92	Dug
93	6 miles east-southeast of Elberon.	E. H. Almond			91	Dug

[a]D = drilled. Dv = driven. Dug = dug. J = jetted.
[b]Estimated unless otherwise indicated.
[c]Ab = abandoned. B = boiler feed. D = domestic. M = municipal supply. P = public school. S = stock. T = test.
[d]A: Analysis given in table of analyses. Figures refer to total hardness (TH), in parts per million, as determined by field test.

Surry County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
25	.....	−22	.....	.....	B	.....	Pumps 3 gallons a minute.	83
10	.....	−2	.....	.....	D	Soft	On sandy terrace of Blackwater River.	84
21	.....	—	.....	.....	D S	Soft	Pumps 15 gallons a minute for short periods.	85
18	.....	−12	June 30, 1939	.....	D S	Soft	.....	86
15	.....	−12½	Aug. 21, 1938	.....	D	Soft, iron	.....	87
30	.....	−27½	June 30, 1939	.....	D S	Hard	Marl in bottom of well.	89
400	.....	—	.....	.....	D	Soft	.....	90
15	.....	− 5	July 5, 1939	.....	S	Soft	.....	91
16	.....	−12	July 7, 1939	.....	D S	A	.....	92
14	.....	− 5	July 7, 1939	.....	D	Soft	.....	93

TABLE 25.—*Logs of wells in Surry County, Virginia*

Well 4, 1 mile west of Claremont; O. E. Belding
(Log by C. W. Daugherty)
Altitude, 17 feet

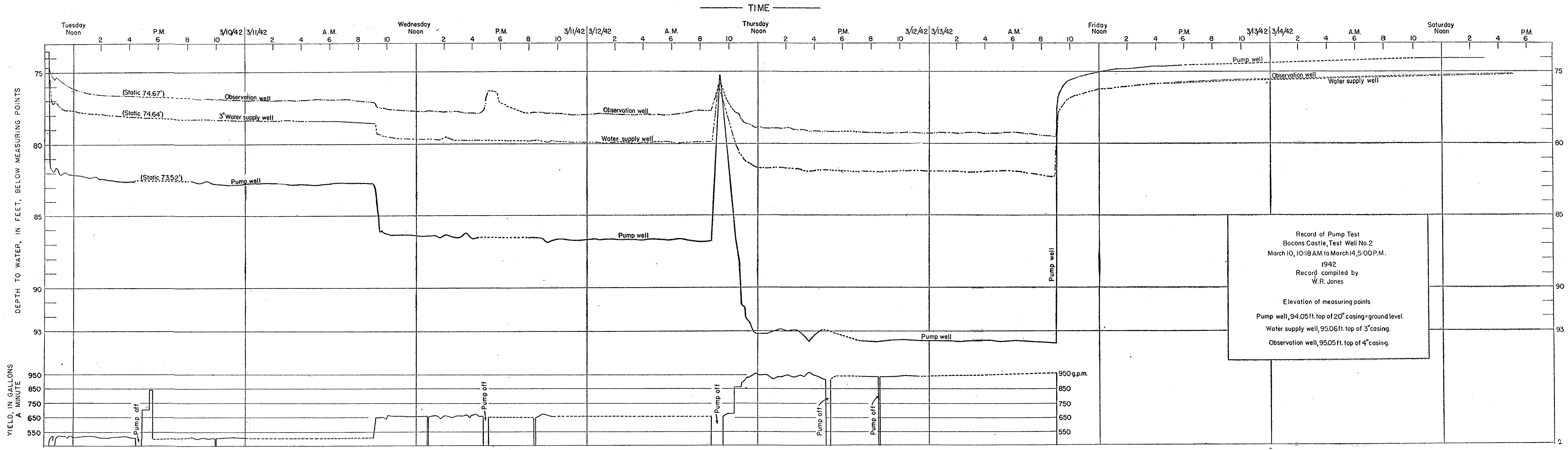
	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Clay	30	30
Gray marl and shells	50	80
Marl	20	100
Gray loose sand	12	112
Pamunkey group (Eocene):		
Black sand	35	147
Undifferentiated (Upper Cretaceous ?):		
Chocolate clay	8	155
Hard rock (conglomerate)	12	167
Potomac group (Lower Cretaceous):		
Water-bearing sand alternating with clay strata in a 1:2 ratio; fourth sand encountered at 287 feet	120	287

Well 33, Cobham Wharf; R. W. Berryman
(Log by R. W. Sillings)
Altitude, 17 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Hard blue marl	60	60
Blue clay	200	260
Pamunkey group (Eocene):		
Black sand (glauconite)	20	280
Potomac group (Lower Cretaceous):		
Fine white sand becoming coarser, water	8	288

Well 40, Bacons Castle; W. P. Warren, Bacons Castle Estate
(Log by R. W. Sillings)
Altitude, 19+ feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Blue marl	60	60
Blue mud	180	240
Hard brown clay	3	243
Blue mud	42	285
Pamunkey group (Eocene):		
Black sand (glauconite)	30	315
Undifferentiated (Upper Cretaceous ?):		
Red clay	20	335
Potomac group (Lower Cretaceous):		
Fine white sand	30	365
Coarse sand, water	2	367



HYDROGRAPH SHOWING RELATIONSHIP OF WATER LEVELS IN OBSERVATION WELLS TO DISCHARGE OF TEST WELL SOUTH OF BACONS CASTLE.

TABLE 25.—*Logs of wells in Surry County, Virginia—Continued*

Well 44a, 2 miles northwest of Bacons Castle; W. C. Mitchell
(Log by R. W. Sillings)
Altitude, 21 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Blue marl	70	70
Blue clay	200	270
Pamunkey group (Eocene):		
Black sand (glauconite)	30	300
Potomac group (Lower Cretaceous):		
Coarse sand and gravel, water	47	347

Well 46, Surry; Cox Drug Store
(Log by Mitchells Pump and Well Co.)
Altitude, 125 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sandy soil	10	10
Clay	30	40
Sand	7	47
Chesapeake group (Miocene):		
Blue clay	10	57
Sand, water	10	67

Well 51, Surry; P. C. Cox
(Log by Mitchells Pump and Well Co.)
Altitude, 125 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	30	30
Chesapeake group (Miocene):		
Yellow clay and sand, little water	28	58
Blue marl and shells	117	175
Blue marl and some shells	165	340
Pamunkey group (Eocene):		
Black sand	20	360
Blue clay	30	380
White and black sand	8	398
Blue clay	5	403
Potomac group (Lower Cretaceous):		
White sand, water	51	454

TABLE 25.—*Logs of wells in Surry County, Virginia—Continued*

Well 67, 3 miles west of Surry; C. E. Warren
(Log by owner)
Altitude, 105 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	3	3
Red clay	12	15
Sand, water	9	24

Well 80, Cabin Point; H. B. Holdsworth
(Log by owner, from memory)
Altitude, 92 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	40	40
Chesapeake group (Miocene):		
Marl	86	126
Pamunkey group (Eocene):		
Black sand (glauconite)	90	216
Rock	3	219
Potomac group (Lower Cretaceous):		
Sand, water	22	241

TABLE 26.—*Analyses of water from Miocene and Quaternary deposits in Surry County, Virginia*

(Parts per million. Numbers at heads of columns refer to well numbers in Table 24)

	Miocene	Quaternary	
	[a]S	[b]71	[b]92
Iron (Fe)	2.88	.....	.....
Calcium (Ca)	115	.....	.....
Magnesium (Mg)	3.22	.....	.....
Sodium (Na)	11.2	.....	.....
Potassium (K)	2.12	.....	.....
Bicarbonate (HCO_3)	395	12	13
Sulfate (SO_4)	3.8	1	13
Chloride (Cl)	3.5	1	15
Fluoride (F)	.....	.2	.0
Nitrate (NO_3)	.....	1.7	1.7
Total dissolved solids	573	.....	.....
Total hardness as $CaCO_3$	255	10	20
Date of collection	1907	June 22, 1939	July 7, 1939

[a]Spring located ¼ mile east of Claremont. High calcium bicarbonate indicates Miocene strata. Analysis from: Sanford, Samuel, Bull. 5, Virginia Geol. Survey, p. 277, 1913.
[b]Analysis of 71 by Margaret D. Foster and J. D. Hem; 92 by Margaret D. Foster.

TABLE 27.—*Analyses of waters from Eocene deposits in Surry County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 24)

	38a	41	56
	Hog Island	Bacons Castle	Surry Court House
Iron (Fe)	.12	.....	.....
Calcium (Ca)	4.8	.....	.....
Magnesium (Mg)	2.8	.....	.....
Sodium (Na)	239	.....	.....
Potassium (K)	10	.....	.....
Bicarbonate (HCO_3)	542	450	260
Sulfate (SO_4)	18	1	4
Chloride (Cl)	69	4	2
Fluoride (F)	.....	4.6	1.0
Nitrate (NO_3)	.39	.....	.88
Total dissolved solids at 180°C	754	.....	.....
Total hardness as $CaCO_3$	24	16	6
Free carbon dioxide (CO_2)	.....	1.4	.....
Date of collection	Oct. 19, 1918	Oct. 3, 1939	June 22, 1939

Analyst: Margaret D. Foster.

TABLE 28.—*Analyses of waters from Cretaceous deposits in Surry County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 24)

	8	30	33	38b	42a[a]	42b[b]	42b[c]	42b[d]	53	80
	Claremont	Scotland Wharf	Cobham Wharf	Hog Island	Bacons Castle	3.2 miles south of Bacons Castle			Surry Court House	Cabin Point
Silica (SiO_2)	.....	.....	.....	.....	42	35	.....	30	.....	.....
Iron (Fe)	.....	.....	.....	.....	.63	.02	.....	.02	.....	.....
Calcium (Ca)	.....	.....	.....	.....	1.2	3.2	.....	1.3	.....	.....
Magnesium (Mg)	.....	.....	.....	.....	.5	.8	.....	.3	.....	.....
Sodium (Na)	.....	.....	.....	.....	91	78	.....	112	.....	.....
Potassium (K)	.....	.....	.....	.....	2.8	2.0	.....	4.5	.....	.....
Bicarbonate (HCO_3)	247	266	282	336	234	196	301	295	266	199
Sulfate (SO_4)	1	3	5	5	7.0	9.8	4	4.2	4	3
Chloride (Cl)	2	2	2	15	3.0	4.4	7	3.2	1	3
Fluoride (F)	.5	1.4	3.2	.....	2.3	3.2	1.8	1.6	1.5	.2
Nitrate (NO_3)	.25	.25	.....	0	.0	.0	.....	.0	.38	1.1
Total dissolved solids at 180°C	.....	.....	.....	.....	268	236	.....	300	.....	.....
Total hardness as $CaCO_3$	4.5	3	<5	4.5	5.0	11	15	4.5	4.5	130
Free carbon dioxide (CO_2)	.....	.....	4.0	.....	.....	.....	.....	.....	.....	.....
Date of collection	June 17, 1939	June 29, 1939	Oct. 4, 1939	Dec. 28, 1943	Jan. 24, 1942	Feb. 12, 1942	Mar. 11, 1942	Mar. 12, 1942	June 22, 1939	June 19, 1939

[a]Water from a depth of 550 to 574 feet.
[b]Water from a depth of 693 to 711 feet.
[c]Water from a depth of 383 to 711 feet after pumping 24 hours.
[d]Water from a depth of 383 to 711 feet after pumping 51 hours.

Analyst: Margaret D. Foster, except 38b by E. W. Lohr.

SOUTHAMPTON COUNTY

LOCATION AND DEVELOPMENT

Southampton is the largest of the counties considered in this report and has an area of 607 square miles. The population was 26,442, according to the Census of 1940. Franklin is the largest town, with a population of 3,466. It is limited on the south by the Virginia-North Carolina State line, and on the east and west respectively by Blackwater and Meherrin rivers. On the north it adjoins Sussex County.

The county is largely devoted to agricultural and dairying pursuits, and 69 per cent of the land is classed as farm land, a higher proportion than in any of the other counties considered. Ham from peanut-fed hogs is processed, and many small sawmills are located in the county. The value of agricultural and dairy products is about twice that of manufactured products. The products of the lumber and kraft paper mills at Franklin are not considered since these mills are situated across Blackwater River in Isle of Wight County.

TOPOGRAPHY

Rolling country of moderate relief is characteristic of the greater part of Southampton County. The dissected Wicomico terrace, whose gently seaward-sloping surface lies 95 to 90 feet above sea level, occupies most of the area. Although a few flat, undissected terrace remnants are present in the eastern and northern sections of the county, the greater part of the county is hilly. In the extreme western part, remnants of the even more completely dissected Sunderland terrace attain elevations of about 130 feet above sea level.

Low terraces along the Meherrin, Nottoway and Blackwater rivers appear to have been formed when those streams were estuaries in Penholoway, Talbot and Pamlico times. They are partially covered by Recent stream deposits. Low elongate mounds lying parallel to the river are found on these terraces and have been interpreted by Monroe[80] to be sand bars formed at an earlier stage of erosional history. They are present south of Franklin, near Courtland and south of Boykins. Older river-cut cliffs, made before the rivers had cut to their present depth, exist in many places. Elsewhere, cliffs are now being cut or steepened. Swamps border parts of the courses of the larger rivers and some of the smaller tributaries, and indicate loss of erosional power and filling of the stream channels.

GEOLOGY

Bedrock was reached at a depth of 396 feet (about 300 feet below sea level) at the Old Wade or Richardson farm at Joyner in western Southampton County in a wildcat well drilled for oil in 1912 by the Sydnor Pump and Well Co. Mr. P. P. Ellis reports that at Branchville red gravel was penetrated at 410 feet (370 feet below sea level). The red, presumably iron-stained, gravel may be indicative of nearness to bedrock at this place.

Bedrock may have been reached at about 545 feet below sea level in the well of the Virginian Railway Co. at Sedley (25, Table 30, Fig. 25). A railroad employee, who was present when the well was drilled, stated to the writer that very hard rock was reached at the bottom of the well and only about a foot a day was made by the drill during the last two days of drilling.

In western and southwestern Sussex County bedrock lies near sea level; the data on depth to bedrock in Sussex and Southampton counties suggest that the configuration of the bedrock here may be similar to that shown near Petersburg in section A-A′, Plate 1.

In the easternmost part of the county, at Franklin, bedrock lies more than 800 feet below sea level.

Strata of the Potomac group do not crop out in this county, but the upper portion of these deposits are fairly well known from the logs of many wells, and the logs of deep wells which were recently drilled at Franklin, Isle of Wight County, furnish important data on deeper strata which are applicable to eastern Southampton County.

The upper formations of the Potomac group are reached by wells in many places throughout the county, and here, as in other counties, these deposits consist of alternating sand and clay beds. At Branchville (337, Table 30 and Fig. 25) the first 190 feet of material is sandy, except for a 60-foot stratum of "gumbo". At Newsoms (263) 151 feet of clay of the Potomac group is underlain by 28 feet of fine white sand. Below a stratum of dark-gray or chocolate-brown clay of probable late Cretaceous age, the Potomac deposits at Franklin are made up of alternating sands and clays of various thicknesses. Between 250 and 601 feet below the surface, 8 sand strata were penetrated, respectively, 13, 20, 35, 8, 50, 5, 18 and 45 feet thick, separated by clayey strata (207, Table 30). The reader is referred to the chapter on Isle of Wight County for further details (150, 161, 162, Table 35 and 160, Pl. 33). A few miles south of Franklin the Potomac deposits are apparently less sandy and 170 feet of clay is included in 193 feet of Potomac strata (238). Three miles northwest of Franklin (196, Table

30) 182 feet of Potomac strata are made up of approximately one-fourth clean sand, one-fourth clay and one-half clayey sand.

At Courtland (141) the uppermost 110 feet of Potomac strata is predominantly sandy; and 300 feet of Potomac strata in well 187, about 2 miles southeast of Courtland, was reported by J. R. McLane, driller, to also be predominantly sandy. At Sebrell (29), in the central part of the county, clays form a much larger proportion of the Potomac beds.

A log of the Virginian Railway Co. well (25, Table 30), near Sedley, 633 feet deep, affords data on 275 feet of Potomac strata. Sands form only a subordinate part of the Lower Cretaceous sediments penetrated in this well, in distinct contrast to conditions found at Franklin, Courtland and Boykins.

As discussed above in detail in the section "Geologic materials and their water-bearing character," it is thought that certain strata of distinct lithologic characteristics which occur immediately below glauconitic beds of Eocene age may possibly be assigned to the Upper Cretaceous, and accordingly these strata have been tentatively designated as such in the logs of wells, Table 30, and in the geologic cross section, Plate 1.

Red clay underlies glauconite beds of Eocene age in southwestern and part of central Southampton County. In some places the red clay is as much as 100 feet thick, as shown in section D-D′ and E-E′, Plate 1. It is thought that it is late Cretaceous in age. The red clay stratum is found at Branchville, Boykins and Capron, and may extend continuously from Capron almost to Courtland, though it is not found in wells in Courtland. In a well on the old Edwards Farm (186), about 4 miles south-southeast of Courtland, the red clay is reported to be 130 feet thick and appears to occupy a restricted channel. Red clay was not found in wells drilled in Sebrell, Sedley and Ivor, nor in the area between Newsoms and Franklin, but was found to be 75 feet thick in a well (196) 3 miles northwest of Franklin.

A thick "chocolate-brown clay," found below Eocene glauconite sands at Ivor in the northern part of the county, may be correlated with the thick variegated clay at Sedley, the "chocolate-brown clay" at Franklin, and with the red clay stratum discussed in the preceding paragraph (Fig. 5), all of which seem to occur at the same stratigraphic level. At Franklin (160, Isle of Wight County) a species of *Exogyra,* of late Cretaceous age, was found in a sample taken when the drill was a few feet below the chocolate-brown clay. (Neither macrofossils nor microfossils of late Cretaceous age were found in samples collected by the writer during the drilling of well 207b in the fall of 1944.)

At Sedley deposits of probable late Cretaceous age consist of bright-yellow and red clayey strata which alternate with gray sandy beds, blue clays containing shells, "shell rock" and "lime rock" (25, Table 30). This group of deposits appears to be totally different in lithology from either Potomac (Lower Cretaceous) or Pamunkey (Eocene) deposits in the surrounding area. A fossiliferous marl stratum occurring above the brightly colored clays is also assigned to the Upper Cretaceous (?).

The glauconite beds ("black sand") of the Pamunkey group are 54 feet thick at the Franklin municipal waterworks (207, Table 30 and Fig. 5) and contain 3 indurated glauconitic limestone strata, respectively 2, 2 and ½ foot thick. A few miles south of Franklin (238) beds of Eocene age are only 25 feet thick and contain intercalated "blue clays," probably glauconitic marls, as well as consolidated beds. At Newsoms (263), west of Franklin, Eocene deposits may be absent, but a thin glauconite bed is present in the Boykins-Branchville area. Glauconite beds are not found at Courtland (141). J. R. McLane, driller, stated that at Sebrell glauconite beds are present but are only a few feet thick. At Ivor (2) the glauconite beds are 30 feet thick. At Sedley (25) the Pamunkey group may be absent.

The Eocene in the Burdette well (11a) in east-central Southampton County consists of green and black glauconite beds and glauconitic marls.

In the western part of the county 75 feet of black sand is reported at Capron (49). Thirty feet of blue clay which underlies it may be either of Eocene or late Cretaceous age. East of Capron at the Southampton State Farm (47c), glauconitic strata are absent, and the data at hand are insufficient to assign most of the beds penetrated in wells to any group with a reasonable degree of certainty.

The Chesapeake group of sediments is exposed in many places along the Meherrin, Nottoway and Blackwater rivers, and has been described[38] as consisting of sand, sandy marl, marl, and sandy clay, generally fossiliferous, and blue in color. At Franklin the lower portions of the Miocene deposits are fairly tough blue clays containing a very little shell (marl), but higher in the section sandy marls seem to be more characteristic. Foraminifera characteristic of the basal Calvert formation have not been found by the writer, and presumably only the Yorktown and St. Marys formations are present. Thin "rock" beds are reported at Ivor and Drewryville. These are, most likely, more or less indurated shell deposits.

Sand and clay beds of Pleistocene age, which were deposited as terraces, cover the older formations.

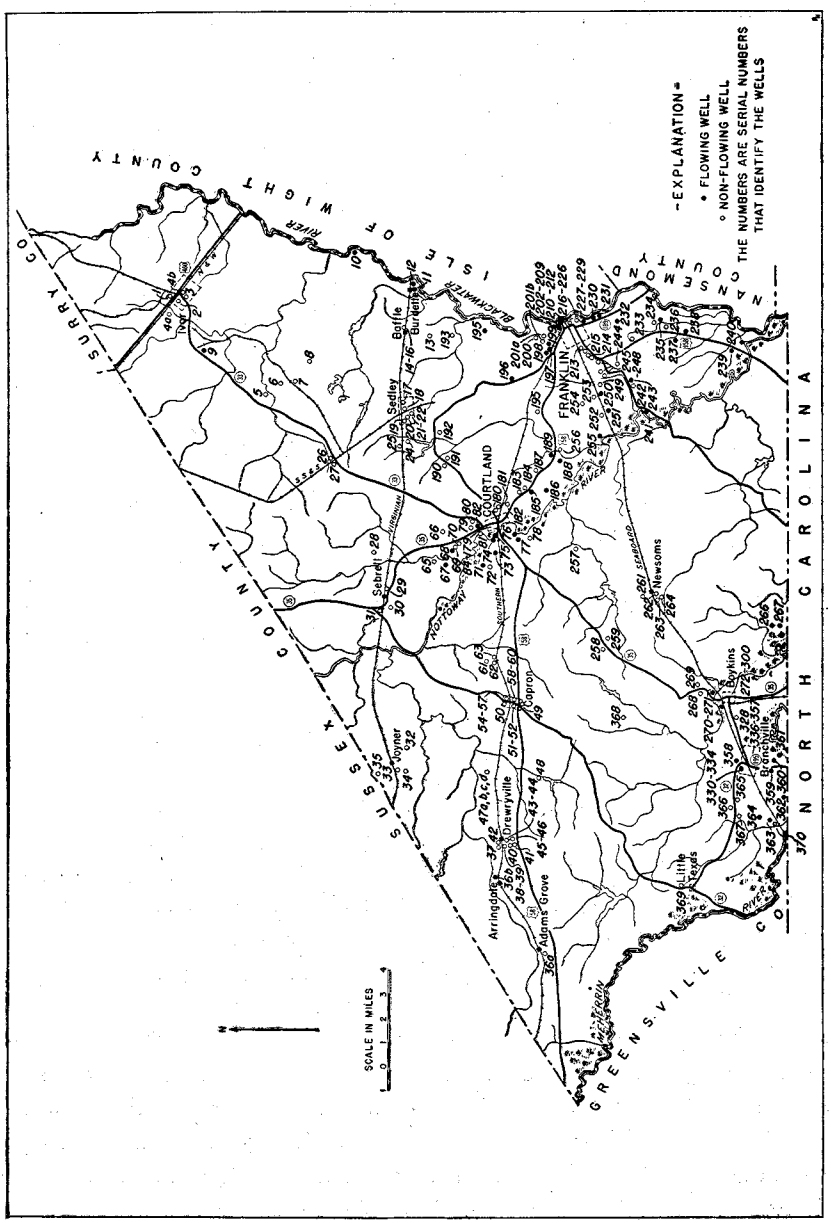


FIGURE 25.—Map of Southampton County showing location of wells listed in Table 29.

The sediments do not everywhere have uniform gentle seaward dip. At Franklin the strata bend sharply downward to the east in a monoclinal fold. A slight dome is present at Boykins and a downwarp exists west of Branchville. These and other structures are shown in cross-section in Plate 1. A contour map drawn on the base of the Chesapeake group (Miocene), Figure 6, also shows the character of the deformation.

GROUND WATER

SHALLOW WELLS

Shallow dug or driven wells supply water to a large number of homes throughout the county. They are sunk entirely in the terrace deposits and range from 10 to 30 feet in depth.

The wells in the older and higher terraces generally encounter water-bearing sand beneath a stratum of clay 5 to 15 feet thick. There are no available data to indicate the maximum yield of such wells. The water is generally soft, but in a few places some wells yield water that is high in iron, or is moderately hard, as at Ivor.

The low terraces bordering the large rivers appear to be of somewhat different materials from the terraces forming the higher lands. As shown on the soil survey map of the county,[56] various soil types tend to be elongated nearly parallel with the river. A brief study was made in correlating the soil types with the underlying strata, and it was found that sandy or clayey beds could be predicted accurately from the data of the soil map. The part of the wide terrace which borders Nottoway River from Courtland to Franklin, and is covered by the soil known as the "Norfolk fine sand," is predominantly sandy and contains very good water-bearing beds. At a variable distance from the river the sandy sediments give way to thick, massive clayey beds, from which only very limited supplies of water can be obtained.

In the vicinity of Franklin and Courtland low, rounded elongate hills which make up parts of the area lying near the river are composed almost entirely of sand. These have been interpreted by some geologists[80] to be typical sand bars characteristically associated with river deposition. Wells sunk in these low sandy river terraces generally yield ample supplies. Several wells at Franklin yield 4 to 6 gallons a minute. At Courtland both the Columbia Peanut Co. and the A. B. Hartz Stave Mill obtain about 2,000 gallons a day from driven wells of small diameter. A stave mill at Branchville obtains about 3,000 gallons

a day from a 1½-inch driven well, 16 feet deep, sunk in the sandy terrace bordering Meherrin River.

The clayey strata within the low terraces which border the rivers generally form poor water-bearing beds. Fissures and channels in the clay, such as might have been made by tree roots, are the sources of water. In some places a supply which is adequate for a large farm is obtained; but some wells dug in the clayey beds have very small yields.

Water obtained from shallow wells is generally soft (Table 31), has a pleasant taste and is considered to be excellent for boiler feed. At Ivor, water from some shallow wells contains objectionable amounts of iron. A few deeper wells encounter Miocene marl deposits, and in these wells the water may be moderately hard. In a few places marl is found at the surface. Water obtained from wells in such places is said to be unpleasant in taste and odor.

DEEP WELLS

WATER FROM CRETACEOUS DEPOSITS

FLOWING WELLS

Water is obtained from wells drilled in Cretaceous strata throughout the county. In 1913 Sanford[110] stated that Southampton County probably contained a greater number of drilled wells than any other county in southeastern Virginia except King William County. This statement was probably still valid in 1940, for there were more than 330 drilled or jetted wells in Southampton County, the greater number of which were in use (Table 29 and Fig. 25).

Most of the wells are 2 inches in diameter and were constructed for domestic supply only. A few 3-inch wells yield water for dairies and schools; and wells 6 to 10 inches in diameter have been drilled for municipal supply, locomotive feed and lumber mills.

Practically all the older small-diameter wells lack strainers, and many were improperly cased. Strainers have generally not been installed on the newer wells that yield strong flows, but many of those recently drilled wells which must be pumped are equipped with screens of good quality. At Branchville, however, local drillers state that the sandy water-bearing strata that are drawn upon are sufficiently coarse to make the use of screens unnecessary. At Courtland many wells are cased only to the black clay which overlies the water-bearing stratum, and elsewhere in the county the casing generally extended into the water-bearing sand.

In Branchville and Boykins the first artesian sand is encountered about 90 feet below sea level (see log of well 337, Table 30). The uppermost sand is said to be 100 feet thick at Branchville. An even greater thickness of sand, with subordinate clay lenses, is reported to be present at Boykins. Less is known of the geologic conditions in western Southampton County, but it is believed that wells less than 100 feet deep at Arringdale and Adams Grove may obtain water from Miocene deposits. At Drewryville, well 42 ends in a cavernous limestone of Miocene (?) age, but most wells here are deeper and probably penetrate Cretaceous beds. At Capron wells about 200 feet deep encounter sand of the Lower Cretaceous Potomac group (see Table 30).

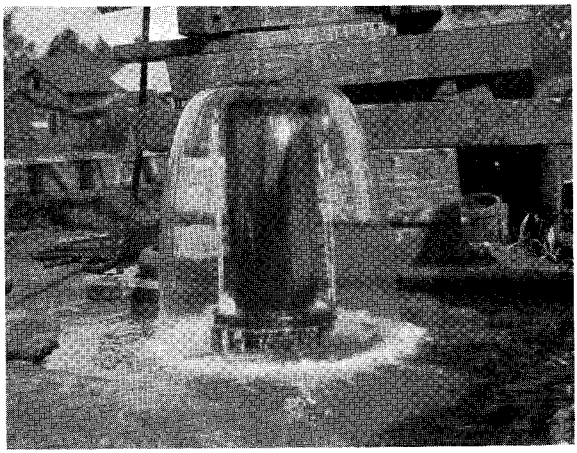
A great many wells at Courtland, 120 to 160 feet deep, are developed in a sand 40 feet thick which lies at the top of the Potomac group. At Franklin the "first" sand, which is 10 feet thick, is of late Cretaceous (?) age. It yields water to many domestic wells. At Newsoms and Ivor, the first artesian sand is also of late Cretaceous (?) age. In these places the first stratum is not as permeable as somewhat deeper sands of the Potomac group. Wells 10 and 11 at Unity and Burdette obtain water from basal Miocene sands. A deeper more permeable sand of the Potomac group is drawn upon in well 11a at Burdette. (See log, Table 30.)

In some places the uppermost artesian sand pinches out laterally and in those places wells must tap deeper beds in order to obtain water. In wells 238, 196 and 186, near Franklin and Courtland, red clay of late Cretaceous (?) age is encountered where the first water-bearing sand might be expected.

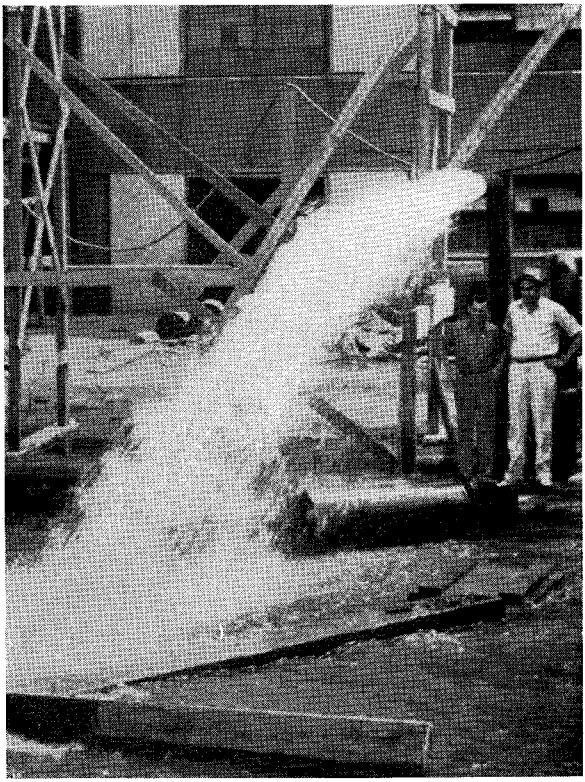
Deeper sands yield water supplies at Branchville, Boykins, Franklin, Courtland, Sebrell, Sedley and Ivor. At Franklin, Isle of Wight County, recent drilling showed the presence of 237 feet of water-bearing sand in 375 feet of section (from 225 to 600 feet). (See log of well 207, Table 30 and Fig. 5). At Courtland 3 water-bearing sands are developed. Deep sands are developed in the well of the Virginian Railway Co. at Sebrell, but here ground-water conditions are much less favorable than elsewhere in the county.

At Sedley sandy strata lie deep and are not very thick but appear to be very coarse and permeable.

The probable geologic origin of sand and clay deposits of the Potomac group has been discussed in a previous chapter. It was

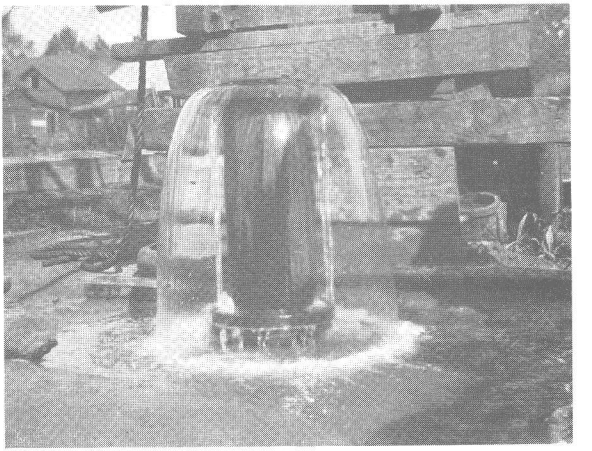


A.

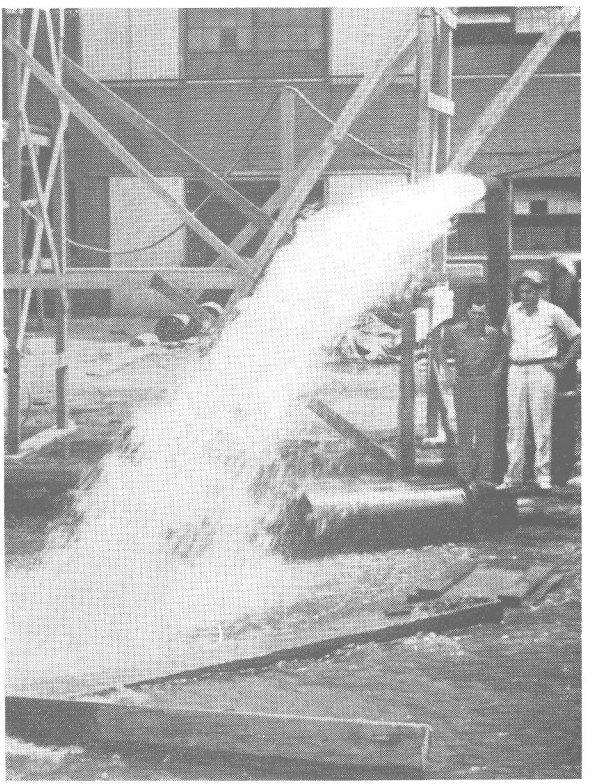


B.

A, Municipal well at Franklin, showing initial flow, 1925. Photograph by J. R. McLane. B, Deep well which furnishes industrial water supply at Franklin.

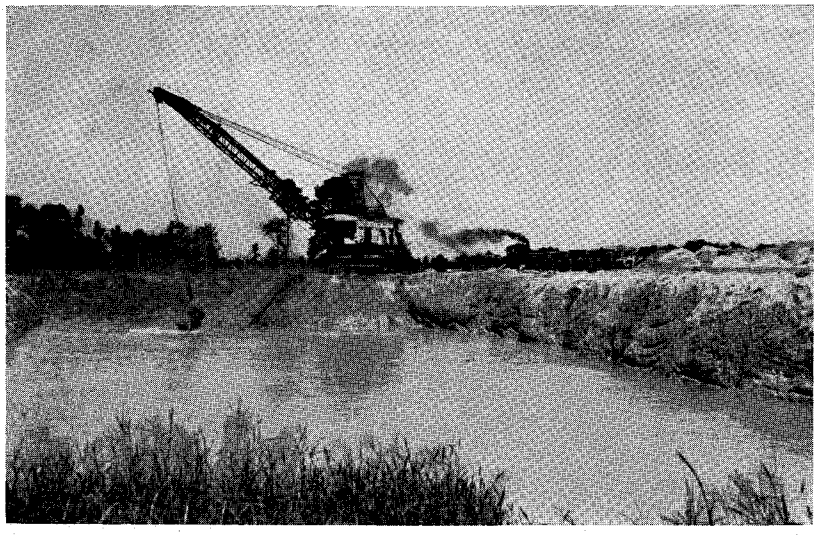


A.



B.

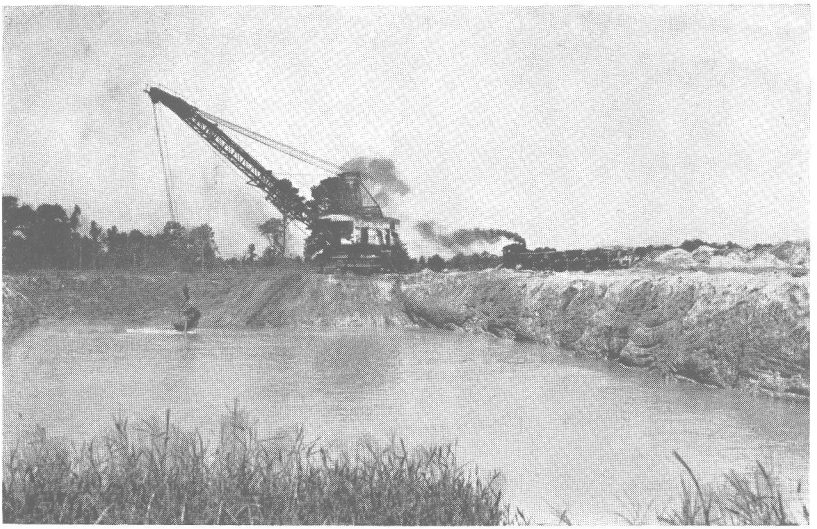
A, Municipal well at Franklin, showing initial flow, 1925. Photograph by J. R. McLane. B, Deep well which furnishes industrial water supply at Franklin.



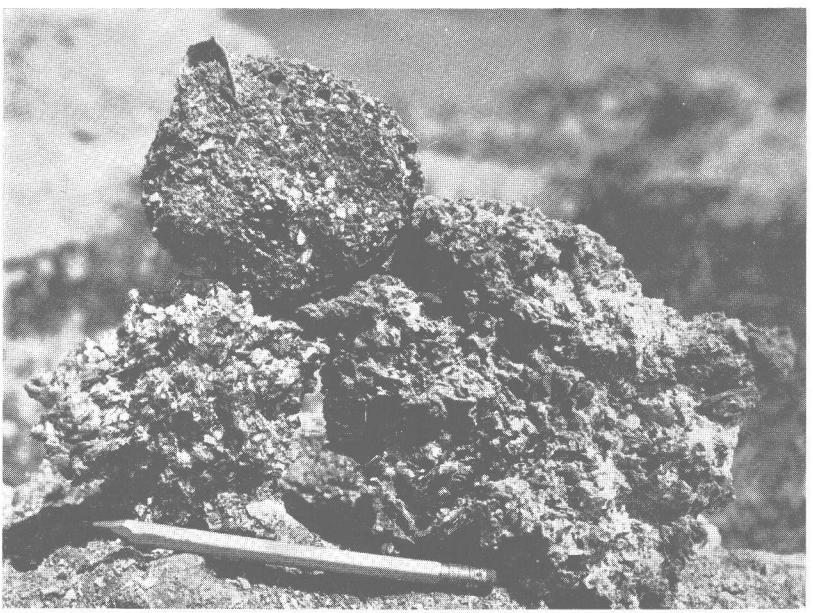
A.

B.

A, Marl quarry near Chuckatuck, Virginia. B, Marl from the Chuckatuck quarry. Lower specimens are cemented coquina; upper specimen is coquina with clay filling the interstices.



A.



B.

A, Marl quarry near Chuckatuck, Virginia. B, Marl from the Chuckatuck quarry. Lower specimens are cemented coquina; upper specimen is coquina with clay filling the interstices.

pointed out that if, in response to loading by stream deposits, local downwarping of the earth's crust occurred, then Cretaceous stream channels (marked by thick sand strata, as at Courtland and elsewhere) may tend to be persistent, and a thickness of 100 to 200 feet of sandy material may be indicative of further thick sand beds at greater depths. Insofar as data are available it is seen that where water-bearing sands are present at the top of the Potomac strata, further sands may be expected at greater depths. Thus Courtland, Boykins and Branchville and possibly Capron appear to be favorable areas for exploration if very large quantities of water are needed. Sebrell and Sedley seem unfavorable for large developments, and there are not sufficient data at hand to state that other localities appear or do not appear favorable.

Flowing wells are obtained in Branchville, Boykins, Courtland and Franklin. In 1940 there were also 2 flowing wells at Burdette, near Blackwater River, and 1 flowing well at Arringdale in the western part of the county.

The average individual yield of 18 flowing wells at Branchville was 3 gallons a minute in 1938. This estimate includes the discharge of 1 well located on low ground, which had discharge of about 25 gallons a minute. Only a few wells flow at Boykins, and these yield only small quantities of water.

The average individual yield of 64 wells in Courtland and vicinity was about 4 gallons a minute in 1938. In this estimate 2 wells are included which have flows of 30 and 35 gallons a minute. They are the only wells which have an individual discharge of more than 10 gallons a minute. The average individual yield of 19 domestic and farm wells in the vicinity of Franklin was about 8 gallons a minute in 1938.

The average yield in 1938 of flowing wells in the localities mentioned is no indication of the water-bearing quality of the strata in these localities; but the yield does indicate the loss of artesian head throughout the area. At Boykins most wells are about 40 feet above sea level; at Courtland about 30 feet; and at Franklin less than 20 feet above sea level. The average yield in these 3 localities is much the same, because in each area so many wells have been sunk and allowed to flow freely for a long time that the height to which water will rise is only a short distance above the outlets of most wells, and the flow is correspondingly small.

Of the 3 municipal wells at Franklin, well 206 draws water from the first, second and third Potomac sand strata; wells 205 and 207 draw from only the third Potomac sand. The flow of well 206, which is 10 to 8 inches in diameter, is reported to have been 200 gallons a minute in 1931. The flows of wells 205 and 207 (Pl. 30,A), respectively 4 inches and 8 inches in diameter, were 40 and 90 gallons a minute in 1930 and 1926, respectively.

In most places loss of artesian head has been noted, and many wells on high ground have ceased flowing. In some localities the loss of head is attributed to certain wells of large diameter on low ground near by. In several instances the interference of a particular well may be easily demonstrated. The mutual interference of many small wells is not so generally recognized, although the total effect of their flows may be as important as that of one well of large flow.

Unchecked flowing wells probably will not lower the artesian head very much in the vicinity of Branchville, Boykins, or Courtland because most of the wells in these localities are on the lowest ground, and the head is only slightly higher than the outlets of the wells. Some lowering will undoubtedly take place, however. But in and near Franklin many wells have been drilled since 1935 on low ground where the artesian water will rise several feet above the outlet and industrial pumping has greatly increased. The increased draught on the artesian water supply will cause the head to decline appreciably, as discussed below.

Steps which might be taken to prevent further loss of head have been discussed in the chapter on ground water in the Potomac group. These measures might be effective if applied at Branchville and Courtland, particularly.

PUMPED WELLS

The maximum pumping yield of wells in Southampton County is not well known. The well of the Virginian Railway Co. at Sebrell is reported to yield 180 gallons a minute, but no details of the pumping test are known. The well has not been used since about 1930. At Sedley the well of the Virginian Railway Co. is reported to yield 150 gallons a minute with drawdown of 20 feet. The pumping test was not carried on long enough, however, to furnish an adequate test. In 1940 about 100,000 gallons a day was pumped for locomotive boiler feed.

According to Mr. J. Mehaffey, Town Manager of Franklin in 1940, the largest of the municipal wells (206) yielded about 1,000 gallons a minute for several three- to four-hour pumping periods. The city uses about 300,000 gallons a day. The greater part of this supply was originally delivered to a sump by natural flow from wells 205, 206, and 207a, which have been described. However, in 1940 it was necessary to pump from one-fourth to one-half of the total required amount of water. A deeper stand-by well (207b, Table 29) was constructed in 1944.

The Lyons Theater Co. pumps about 18,000 gallons a day (210, Table 29) at least 3 months in each year for air-conditioning.

The original artesian head has been lowered by the extensive development of water supplies in and near Franklin and Courtland. (See Fig. 9.) Including about one-third of a million gallons a day discharged by flowing wells, it was estimated that in 1940 the total amount of water yielded by wells in the Franklin area ranged from 1,000,000 gallons a day in the winter to a maximum of 1,500,000 gallons in winter. To this should be added 250,000 gallons a day discharged by flowing wells in the Courtland area. In 1942 the total discharge increased to about 8,000,000 gallons a day after high-yield wells at the Chesapeake-Camp Corporation were put into service. It is believed, however, that the relatively low artesian pressure in large part was created by the discharge of flowing wells, before the comparatively recent establishment of municipal and industrial ground-water supplies. Pumping development, which has increased the total withdrawal of ground water, will deepen and expand the cone of depression.

That the cone of depression around Franklin and Courtland is slowly increasing in size at present is shown by the records of several observation wells established in the area in 1940 and 1941. The data obtained have a general application and will be of value to all present and prospective large consumers of water in the Coastal Plain in southeastern Virginia as well as to the people in and near Franklin. These data are discussed in detail in the chapter on "Isle of Wight County."

QUALITY OF ARTESIAN WATER

The water obtained from Cretaceous strata in Southampton County varies from a moderately hard calcium bicarbonate water to a very soft sodium bicarbonate water (Fig. 12 and Table 33).

A sample of water from a well near Capron (56) had 146 parts per million of total hardness, as calcium carbonate; another from a well at Little Texas (369) had a hardness of 136 parts per million. At Boykins water from a well 100 feet deep (275) had 84 parts per million of hardness, whereas the municipal supply, obtained from a well 225 feet deep (272), had only 39 parts per million of total hardness. The bicarbonate content of water from each of these wells was respectively 187 and 186 parts per million. These analyses indicate that waters in the shallow and the deep strata in the western part of the county are similar in mineral content, but that the deeper water has been softened more than the shallower water.

At Sebrell water having hardness of 70 parts per million is yielded by a well 132 feet deep (31, Table 33).

Near Sedley (wells 21, 25), Courtland (wells 68, 139, 141, 151, 162, 167 and 187) and Newsoms (well 262), and in the areas east of these communities, the Cretaceous strata yield very soft sodium bicarbonate water. However, the well of R. B. Storey, 3½ miles southwest of Courtland (257), yields water with a hardness of 134 parts per million.

At Franklin the first artesian sand yields water containing more than 350 parts per million of bicarbonate, mostly as sodium bicarbonate.

A composite sample from the deeper sands (wells 205-207, Table 33) contained 262 parts per million of bicarbonate. Other constituents are present in small quantities. The silica content of the water sample from the first sand was 11 parts per million, whereas in the sample from the fourth sand the silica content was 19 parts per million.

At Courtland there is very little difference in the mineral content of waters from wells 135 to 230 feet in depth. The bicarbonate content of samples examined ranged from 177 to 229 parts per million (68, 139, 141, 151, 162, and 176). The 3 sand strata that furnish water are considered to mark a Lower Cretaceous stream channel. They are separated by thin clay layers which are probably discontinuous, and therefore no great differences in water from various horizons in the sandy section are to be expected. The well of the T. L. Baine estate, 2 miles southeast of Courtland (187, Tables 29 and 33), is possibly in the same channelway. It obtains water from a depth of 438 feet. The bicarbonate content of the sample taken from this well was 188 parts

per million, and the water was in other respects similar to water from lesser depths at Courtland. It is also interesting that there is practically no difference in the bicarbonate content of water from the Public School well (21) at Sedley, 270 feet deep, and the well (25) at Morgan's Siding, 1½ miles west of Sedley, which draws water from beds 429 to 463 feet and 560 to 565 below the surface. Both wells yield water containing about 180 parts per million of bicarbonate. In content of other constituents the waters are very similar. The waters are very soft.

Fluoride has been found in water from many artesian wells in Southampton County (Fig. 16). At Courtland the fluoride content ranges from 4.3 to 6.0 parts per million; in the 5 samples analyzed no significant differences in fluoride content in water from different depths was noted. The deep well of the T. L. Baine estate (187), 2 miles southeast of Courtland, yields water containing 4.2 parts per million of fluoride. This water is therefore comparable to Courtland water from lesser depths, in its fluoride content as well as its bicarbonate content. A short distance northwest and west of Courtland the fluoride content of artesian water is very low. At the C. W. & W. S. Williams farm, 2 miles north-northwest of Courtland, the fluoride content of the water from a well 180 feet deep (well 68) was 0.8 parts per million and at the Davis farm, 1½ miles west-northwest of Courtland, a well 190 feet deep yields water likewise containing 0.8 parts per million fluoride. The reason for the marked differences in fluoride content in these localities only a short distance from Courtland is not known.

In the vicinity of Franklin artesian water from the first sand contains 1 to 2 parts per million of fluoride. Deeper strata, however, yield water containing about 5 parts per million. At Sedley, water pumped from the deep well at Morgan's Siding (25) contains a little more fluoride than that from the artesian well of lesser depth at the Sedley Public School (21), the amount being respectively 1.1 and 0.7 parts per million.

No fluoride was found in samples taken from artesian wells at Branchville (369), Boykins (272 and 275), Newsoms (262 and 263), Capron (56) and Sebrell (31). Only 0.1 part per million was found in a sample taken from the Ivor High School well (2). A sample from well 16, at Baffle, contained 1.7 parts per million of fluoride, however.

The presence of objectionable amounts of fluoride in artesian water in several communities is a serious problem. The effects of fluoride in drinking water are recognized[53] and commented upon by a great many

individuals in and about Franklin and Courtland, where water with a high fluoride content is used almost exclusively by most people. A few individuals provide fluoride-free drinking water for their children.

More recently it has been shown[54] that the presence of a little fluoride (less than 0.1 part per million) is probably beneficial in inhibiting tooth decay.

Wells 10 and 11 at Unity and Burdette probably obtain water from basal Miocene sands (Table 32). They are of about the composition that would be expected when analyses from near-by wells at Baffle (16) and Ivor (2, Table 33) in Southampton County, and Zuni (142) and Walters (147 and 148, Table 37) in Isle of Wight County, are considered. However, it may be noted that the waters contain respectively 3.2 and 3.4 parts per million of fluoride, rather more than the amount found in the deeper near-by wells which penetrate Cretaceous deposits.

WELL RECORDS AND ANALYSES

Records of wells in Southampton County, available logs of wells, and analyses of water samples are listed in Tables 29-33, on the following pages. The locations of the wells listed are shown in Figure 25.

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
1	Ivor	Ivor Meat Packing Co	Mitchells Pump and Well Co.	1939	85	Dv
2	Ivor	High School	J. R. McLane	1927	88	J
3	Ivor	J. Mahoney	W. H. Holt		92	
4a	Ivor	R. C. Ritter	Owner		75	Dug
4b	Ivor	J. H. Luter	Owner		91	Dug
5	Berlin	C. R. Stephenson	J. R. McLane	1931	72	J
6	1¼ miles southeast of Berlin	L. H. Babb	J. R. McLane	1926	79	J
7	1¾ miles southeast of Berlin	W. L. Joyner	Owner	1926	90	Dug
8	Corinth	H. D. Raiford	W. Barlow	1910	87	J
9	1½ miles northeast of Berlin	L. H. Brantley	J. J. Mitchell		82	Dv
10	1½ miles east-southeast of Unity.	Camp. Mfg. Co	A. Johannson	1908	22	J
11a	Burdette	FWA	Mitchells Pump and Well Co.	1942	12	D
11b	Burdette	J. B. Joyner	W. Barlow	1905	20	J
12	Burdette	W. A. Talley	W. Barlow	1905	26	J
13	1½ miles south of Baffle	J. J. Bradshaw	J. B. Joyner	1897	48	Dug
14	Baffle	J. L. Doughtie	J. R. McLane	1937	60	J
15	Baffle	Black Creek Baptist Church.	J. R. McLane	1922	62	J
16	Baffle	Black Creek School	J. R. McLane	1936	61	J
17	Sedley	C. L. Wellans	J. R. McLane	1934	90	J
18	Sedley	C. B. Owens	J. R. McLane	1935	90	J
19	Sedley	P. P. Causey	Sydnor Pump and Well Co.	1920	100	J
20	Sedley	T. Blythe	J. R. McLane	1922	98	J
21	Sedley	Public School	J. R. McLane	1920	93	J
22	Sedley	Colored School	Sydnor Pump and Well Co.	1920	92	Dv
24	North end of Darden Mill Pond.	A. B. Hartz Sawmill	Owner		80	Dv
25	1½ miles west of Sedley	Virginian Railway Co	A. Johannson	1926	84	Dv
26	Vicksville	W. H. Lewis	Owner		94	Dug
27	Vicksville	W. H. Lewis	J. R. McLane	1918	94	J
28	1 mile east-northeast of Sebrell.	C. C. Vaughn	J. R. McLane		93	J
29	Sebrell	Virginian Railway Co	Sydnor Pump and Well Co.	1907	62	Dv
30	Sebrell	J. T. Rowe	F. A. Hargrave	1910	60	J
31	Sebrell	S. V. Camp	S. V. Camp	1915	62	Dv
32	1 mile east-southeast of Joyner.	C. B. Parker	J. R. McLane	1927	100	J
33	Joyner	M. Everett	J. R. McLane	1917	108	J
34	Joyner	P. B. Edwards, Jr	J. J. Mitchell	1922	105	Dv
35	¾ mile northwest of Joyner	Sawmill	J. R. McLane		55	J
36a	Adams Grove	Cotton Gin	J. R. McLane	1924	84	J
36b	Arringdale	Camp Mfg. Co	J. Moore	1891	62	J
37	North of railroad, Drewryville.	V. R. Leigh	J. R. McLane	1919	95	J
38	Drewryville	T. P. Wynn Estate	J. R. McLane		100	J
39	Drewryville	J. A. Grizzard	J. R. McLane	1920	100	J
40	Drewryville	V. R. Leigh	J. R. McLane	1915	115	J
41	Drewryville	S. P. Johnston	J. R. McLane	1914	116	J
42	North of railroad, Drewryville.	R. A. Pope	J. R. McLane	1915	100	J
43	Drewryville	B. S. Turner	J. R. McLane	1917	106	J
44	Drewryville	C. E. Cobb	J. R. McLane	1925	108	J
45	Drewryville	R. L. Grizzard	P. P. Ellis	1931	120	J
46	Drewryville	Public School	J. R. McLane	1913	120	J
47a	2 miles east-northeast of Drewryville.	Southampton State Farm	J. R. McLane	1937	100	J
47b	2 miles east-northeast of Drewryville.	Southampton State Farm	Mitchells Pump and Well Co.	1940	100	D
47c	2 miles east-northeast of Drewryville.	Southampton State Farm	Mitchells Pump and Well Co.	1940	100	D
47d	2 miles east-northeast of Drewryville.	Southampton State Farm	Mitchells Pump and Well Co.	1940	80	D

Southampton County, Virginia

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
278	4	−54¼	July 7, 1939	.....	C	.....	.....	1
278	3	—	.....	.....	P	A	.....	2
276	.....	—	.....	.....	D	.....	.....	3
20	.....	−10	July 7, 1939	.....	D S	Soft	.....	4a
15	.....	− 3	July 7, 1939	.....	D	Hard, iron	.....	4b
185	3	—	.....	.....	D S	.....	.....	5
205	3	−42	April, 1938	.....	D S	A	.....	6
14	.....	− 2½	Sept. 9, 1937	.....	B	.....	.....	7
325	2	—	.....	.....	D	.....	.....	8
267	3	+	.....	½	D S	.....	.....	9
150	2	+	.....	1	D S	A	Water from Miocene deposits.	10
231	4	+10+	Sept. 28, 1942	[e]17	D	.....	See log, Table 30. Flows 4 gallons a minute at 10 ft.	11a
130	2	+ 4	July 28, 1938	1½	D S	A	Temp. 61° F. Water from Miocene deposits.	11b
130	2	+	.....	.....	D S	.....	Water from Miocene deposits.	12
40	.....	− 7	Sept, 1938	.....	D	.....	.....	13
289	2	—	.....	.....	D	.....	.....	14
287	2	—	.....	.....	P	.....	.....	15
270	3	−25½	July 28, 1938	.....	P	A	.....	16
256	2	—	.....	.....	D	.....	.....	17
248	4−2	—	.....	.....	D	.....	.....	18
265	3	—	.....	.....	D	.....	.....	19
240	2	—	.....	.....	D	.....	.....	20
270	3	−60	July 28, 1938	.....	D	A	Temp. 61° F.	21
274	.....	—	.....	.....	P	.....	.....	22
16	1¼	—	.....	.....	B	.....	Drawdown 20 ft. after pumping 175 gallons a minute in 1926. Pumps more than 100,000 gallons a day. Temp. 65° F.	24
633	10−6	[e]−53	Aug., 1926	.....	B	A	.....	25
20	.....	[e]−10½	June, 1939	.....	D	Soft	.....	26
250	3	−58.0	Sept. 8, 1937	.....	Ab	.....	Old Surry Lumber Co. well.	27
168	2	—	.....	.....	S	.....	Water level declined 6 ft., 1910 to 1938[e].	28
344	10	−21.0	July 21, 1938	.....	D	.....	Pumped 180 gallons a minute in 1907. Water level was 15 ft. below surface in 1907.	29
148	1½	—	.....	.....	D	.....	.....	30
132	2	—	.....	.....	D S	A	.....	31
125	4	—	.....	.....	D S	Hard	.....	32
165	4−2	—	.....	.....	D S	Hard	.....	33
114	4	—	.....	.....	D S	.....	.....	34
98	3	− 9.6	Sept. 15, 1937	.....	B	.....	Casing was pulled in 1937.	35
90	3	−12.0	July 27, 1938	.....	B	.....	.....	36a
75	1½	+	.....	2	S	Hard	.....	36b
165	2	—	.....	.....	D	.....	.....	37
180	2	[e]−41	May, 1938	.....	D	.....	.....	38
160	2	—	.....	.....	D	Hard	.....	39
160	2	—	.....	.....	D	Hard	.....	40
190	2	—	.....	.....	D	Hard	.....	41
120	2	—	.....	.....	D	.....	.....	42
165	2	—	.....	.....	D	.....	.....	43
.....	.....	—	.....	.....	D	.....	.....	44
237	3	—	.....	.....	D	.....	Supplies 5 homes.	45
178	2	—	.....	.....	P	A	.....	46
140	3	—	.....	.....	D	.....	Supplies 100 people.	47a
157½	4½	[e]−59	1940	.....	D	.....	Drawdown 5 feet after pumping 20 gallons a minute for 10 hours.	47b
225	10	[e]−60	1940	.....	D	.....	Drawdown 30 feet after pumping 150 gallons a minute for 49 hours.	47c
93	4½	—	.....	.....	B	.....	Located at gin. Drawdown 65 ft. after pumping 20 gallons a minute for 4 hours.	47d

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
48	2 miles east-southeast of Drewryville.	Sawmill	P. P. Ellis	1937	80	J
49	Highway U. S. 58, Capron	Filling Station	P. P. Ellis	1940	120	J
50	North of railroad, Capron	D. D. Barham	J. R. McLane	1919	115	J
51	Capron	E. E. Rawlings	J. R. McLane	1920	117	J
52	Capron	L. J. Baine	J. R. McLane	1915	115	J
54	North of railroad, Capron	E. Felts	J. R. McLane	1919	118	J
55	North of railroad, Capron	J. E. Fox	J. R. McLane	.....	115	J
56	North of railroad, Capron	Public School	J. R. McLane	1925	117	J
57	North of railroad, Capron	J. T. Barham	J. R. McLane	1929	119	J
58	South of railroad, Capron	Bank of Capron	P. P. Ellis	1922	117	J
59	South of railroad, Capron	G. A. Lankford	.....	1900	115	.....
60	South of railroad, Capron	L. W. McGrath	J. R. McLane	1917	118	J
61	Pope	A. P. Marks	J. Moore	1915	86	J
62	Pope	Robert Marks	.....	.....	70	.....
63	Pope	William Marks	J. Moore	.....	70	J
65	3¼ miles northwest of Courtland.	C. H. Rowe and R. N. Wells.	W. Barlow	1910	36	J
66	2¼ miles north of Courtland	G. L. Bryant	J. R. McLane	1916	40	J
67	3 miles northwest of Courtland.	F. Whitehead	J. R. McLane	1912	30	J
68	2 miles northwest of Courtland.	C. W. and W. S. Williams	J. R. McLane	1925	10	J
69	River Road, northwest of Courtland.	C. W. and W. S. Williams	J. R. McLane	1922	39	J
70	River Road, northwest of Courtland.	C. W. and W. S. Williams	J. R. McLane	1914	40	J
71	Indian Road, Courtland	Emmett Davis	J. R. McLane	1932	20	J
72	Indian Road, Courtland	E. A. Davis	J. Moore	.....	.....	J
73	Indian Road, Courtland	Ida Williams	.....	.....	24	.....
74	West bank of Nottoway River	B. K. Bascho	.....	.....	.....	.....
75	U. S. Highway 58 west of Courtland.	B. K. Bascho	J. R. McLane	1924	10	J
76	1 mile southwest of Courtland.	B. K. Bascho	J. R. McLane	.....	10	J
77	1 mile southwest of Courtland	B. K. Bascho	J. R. McLane	.....	10	J
78	1½ miles southwest of Courtland.	C. W. Dickens	J. Moore	1911	32	J
79	U. S. Highway 33, north of Courtland.	H. D. Babb	J. Moore	1897	35	J
80	U. S. Highway 33 north of Courtland.	E. F. Babb	R. G. Edwards	1923	34	J
81	North end of Courtland	Poor Farm	J. R. McLane	1913	38	J
82	U. S. Highway 33, north of Courtland.	W. S. Williams	J. R. McLane	1933	31	J
84	Courtland	J. D. Kitchen	J. R. McLane	1910	27	J
85	Courtland	E. F. Reese	J. J. Mitchell	1920	15	J
86	Courtland	E. F. Reese	J. Moore	1918	27	J
87	Courtland	F. N. Barker	.....	1905	28	J
88	Courtland	Southampton Court House	J. R. McLane	.....	27	J
89	Courtland	Southampton Court House	A. White	1890	29	J
90	Courtland	J. W. Pulley	P. P. Ellis	1937	27	J
91	Courtland	J. W. Pulley	.....	1890	28	.....
92	Courtland	R. G. Edwards	.....	1900	27	.....
93	Courtland	R. G. Edwards	.....	1891	28	.....
94	Courtland	C. L. Bailey	.....	.....	28	.....
95	Courtland	D. C. Magette	J. Moore	1893	26	J
96	Courtland	R. T. Whitfield	J. Moore and J. R. McLane	1902	27	J
97	Courtland	L. A. Clements	J. R. McLane	1928	27	J
98	Courtland	Town of Courtland	J. Moore	1907	27	J
99	Courtland	Leroy Magette	J. R. McLane	1911	26	J
100	Courtland	E. F. Reese	J. R. McLane	1936	28	J
101	Courtland	S. W. Rawls	S. Cutchins	1892	28	J
102	Courtland	S. W. Rawls	J. R. McLane	.....	28	J
104	Courtland	E. F. Reese	J. Moore	1912	27	J
105	Courtland	T. H. Birdsong	J. Moore	1905	28	J
106	Courtland	A. B. Cobb	J. R. McLane	1911	28	J

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
110	3	−	.....	.....	B	.....	.....	48
200	3	−	.....	.....	D	.....	.....	49
265	2	−	.....	.....	D	Hard	.....	50
260	2	−	.....	.....	D	Hard	.....	51
260	2	−	.....	.....	D	.....	.....	52
250	2	−75	July 21, 1938	.....	D	.....	.....	54
.....	.....	−	.....	.....	D	Hard	.....	55
265	3	−	.....	.....	P	A	.....	56
.....	.....	−	.....	.....	D	.....	.....	57
220	3	−	.....	.....	D	.....	.....	58
260	.....	−	.....	.....	D	.....	Supplies 5 homes.	59
260	2	−	.....	.....	D S	Hard	.....	60
.....	.....	−	.....	.....	D S	.....	.....	61
.....	.....	−	.....	.....	D S	A	.....	62
190	2	[e]−55	March, 1938	.....	D S	.....	.....	63
149	1½	[e]− 3	Aug., 1936	.....	D S	Soft	Flowed until 1914.[e]	65
180	2	−	.....	.....	D S	Soft	.....	66
200+	2	+	.....	.....	D S	.....	Flows in winter.[e]	67
180	2−1	+	.....	9	S	A	Temp. 60° F.	68
290	3	− 5	Aug. 27, 1937	.....	S	.....	.....	69
180	2	−	.....	.....	D	.....	Flowed until 1922.[e]	70
190	2	+	.....	6	D S	A	.....	71
.....	2	−	.....	.....	D S	.....	.....	72
160	2	+	.....	2¼	D S	.....	Cased 80 ft.	73
160	2	+	.....	½	.....	.....	.....	74
160	2	+	.....	10	D	.....	Cased 100 ft.	75
150	2	+	.....	[f]10	D	.....	Cased 80 ft.	76
150	2	+	.....	3½	D	.....	Cased 80 ft.	77
190	1½	[e]− 1½	1934	.....	D S	Soft	Formerly flowed. Stopped by interference of near-by wells.	78
125	2	−	.....	.....	D S	.....	Flowed until 1918.	79
190	3	−	.....	.....	D S	.....	Flowed until 1925.	80
180	2	−	.....	.....	D	.....	Cased 80 ft.	81
180	2	+	.....	1	D S	.....	.....	82
160	2	+	.....	¾	D	.....	Cased 100 ft.	84
220	3	+	.....	30	D	.....	Flowed 60 gallons a minute in 1920.[e]	85
228	2	+	.....	9	D	.....	.....	86
.....	.....	+	.....	2½	D	.....	.....	87
180	2	+ 5	July 30, 1938	1½	D	.....	Cased 100 ft.	88
125	2	+	.....	.....	D	.....	.....	89
130	2	+	.....	2	D	Soft	Temp. 64° F.	90
130	2	+	.....	¼	D	.....	Flow is intermittent.[e]	91
180	2	+	.....	6	D	.....	.....	92
.....	2	+	.....	2½	D	.....	.....	93
.....	.....	+	.....	2½	D	.....	.....	94
120	2	+ 3½	April 4, 1940	2	D	.....	.....	95
182	2−1	+	.....	2½	D	.....	Temp. 62° F.	96
187	2	+ 4½	July 30, 1938	7½	D	.....	Cased 100 ft. Temp. 62½° F.	97
160	2	+	.....	.....	D	.....	Cased 40 ft. Supplies 3 stores.	98
150	2	+	.....	1½	D	.....	Cased 55 ft.	99
180	2	+	.....	1	D	.....	Cased 100 ft.	100
120	2	+	.....	1	D	.....	Cased 50 ft.	101
185	2	+	.....	5	D	.....	Cased 100 ft.	102
180	2	+	.....	10	D	.....	Cased 100 ft.	104
140	2	+	.....	1	D	.....	Bain & Co. well of Bull. 5, Virginia Geological Survey, p. 326.	105
180	2	+	.....	1½	D	.....	Cased 80 ft.	106

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
108	Courtland	E. Whitfield	J. R. McLane	1910	20	J
109	Courtland	Southern Railway Co	J. R. McLane	1914	28	J
110	Courtland	Cora Taylor	J. R. McLane	1915	26	J
111	Courtland	Cora Taylor	J. Moore	1905	30	J
112	Courtland	W. T. McLemore	J. R. McLane	1910	26	J
113	Courtland	W. T. McLemore	R. G. Edwards		30	J
114	Courtland	H. C. Edwards	S. T. Whitfield	1907	26	J
115	Courtland	H. C. Edwards	W. E. Edwards	1920	29	J
116	Courtland	W. E. Edwards	J. Moore	1895	28	J
117	Courtland	H. B. McLemore	J. R. McLane		26	J
118	Courtland	C. W. and W. S. Williams	P. P. Ellis	1937	30	J
119	Courtland	Louis Worrell			33	J
120	Courtland	W. S. Williams	J. Moore	1895	34?	J
121	Courtland	W. S. Williams	J. Moore	1900	33	J
122	Courtland	Inez Watson	J. Moore		30	J
123	Courtland	H. A. Gillette	J. R. McLane	1925	27	J
124	Courtland	Laura Williams	J. R. McLane	1921	28	J
125	Courtland	Methodist Parsonage	J. Moore	1912	31	J
126	Courtland	L. Storey	J. Moore	1897	31	J
127	Courtland	Baptist Parsonage	J. Moore	1900	30	J
128	Courtland	E. Whitfield	J. Moore	1901	29	J
129	Courtland	Ida Williams			29	
130	Courtland	W. H. Joyner			29	
131	Courtland	Sebrell Peanut Co		1932	27	Dv
132	Courtland	E. F. Reese Store	J. Moore	1890	27	J
133	Courtland	W. J. Sebrell	J. Moore		27	J
136	Courtland	W. T. McLemore Drug Store.	J. Moore	1894	27	J
137	Courtland	C. W. Williams	J. R. McLane	1922	27	J
138	Courtland	Mattie Tyler Estate	J. R. McLane	1912	27	J
139	Courtland	E. Whitfield			27	
140	Courtland	W. Shands	J. Moore	1900	27	J
141	Courtland	High School	J. R. McLane		28	J
143	Courtland	Southampton Hotel	J. R. McLane	1912	28	J
144	Courtland	P. E. Knight	J. Moore	1910	29	J
145	Courtland	L. M. Marks	J. R. McLane	1931	29	J
146	Courtland	F. Grizzard	J. Moore		29	J
147	Courtland	E. Westbrook	P. P. Ellis	1933	28	J
148	Courtland	Gillette Bryant	J. Moore		28	J
149	Courtland	W. B. Ellis	P. P. Ellis	1932	27	J
150	Courtland	G. H. Quillan		1900?	27	J
151	Courtland	W. T. Manry	P. P. Ellis	1933	27	J
152	Courtland	S. C. Richardson	J. R. McLane	1913	29	J
153	Courtland	O. M. Joyner	J. R. McLane	1922	29	J
154	Courtland	H. H. Macklin	J. R. McLane	1925	29	J
155	Courtland	B. B. Rogers	J. R. McLane	1926	26	J
156	Courtland	L. R. Pittman	P. P. Ellis	1934	27	J
157	Courtland	J. H. Joyner		1912	29	J
158	Courtland	E. Wynns	J. Moore	1907	28	J
159	Courtland	E. Whitfield	J. Moore		29	J
160	Courtland	Bertie Magette	J. Moore	1902	29	J
161	Courtland	Ida Williams			29	
162	Courtland	W. J. Sebrell	J. R. McLane	1912	28	J
163	Courtland	I. P. Gilbert	P. P. Ellis	1937	28	J
164	Courtland	M. Sebrell	J. R. McLane	1921	29	J
165	Courtland	M. Sebrell	J. Moore	1892	29	J
166	Courtland	W. T. Pittman	J. R. McLane	1918	30	J
167	Courtland	W. J. Sebrell	J. Moore	1907	29	J
168	Courtland	W. J. Sebrell	J. R. McLane	1913	25	J
169	Courtland	W. N. Thornton	J. R McLane	1908	29	J
171	Courtland	G. L. Cook	J. R. McLane		28	J
172	Courtland	Mattie Tyler Estate	J. R. McLane	1920	28	J
173	Courtland	C. W. Davis	J. Moore	1890	26	J
174	Courtland	M. A. Whitfield	J. R. McLane	1910	28	J
175	Courtland	M. Sipiczky	M. Sipiczky	1932	27	Dv
176	Courtland	G. H. Yates	J. Moore	1909	29	J
177	Courtland	F. L. Davis	J. Moore		29	J

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
165	2	+	.....	5	D	.....	Cased 60 ft. Supplies 7 families.	108
180	2	+	.....	¼	D	.....	Cased 80 ft.	109
185	2	+	.....	3	S	.....	.....	110
125	2	+	.....	.....	D	.....	.....	111
.....	2	+	.....	1	D	.....	.....	112
175	1¼	+	.....	.....	D	.....	.....	113
120	2½	+	.....	2	D	.....	.....	114
170	1¼	+	.....	.....	.....	.....	Flow is intermittent.	115
170	1¼	−	.....	.....	D	.....	.....	116
190	2	+	.....	5	D	.....	Cased 160 ft.	117
180	2	−	.....	.....	D	.....	.....	118
.....	2	−	.....	.....	D	.....	.....	119
150	2	−	.....	.....	S	.....	Flowed until 1900.[e]	120
195	2	[e]− 2	June, 1935	.....	D S	.....	Flowed until 1916.[e]	121
.....	2	+	.....	½	D	.....	.....	122
190	2	+	.....	2½	D	.....	.....	123
180	2	+	.....	1½	D	.....	.....	124
160	2	−	.....	.....	D	.....	Cased 100 ft.	125
150	2	−	.....	.....	Ab	.....	Flowed until 1917.[e]	126
.....	2	−	.....	.....	D	.....	.....	127
.....	2	−	.....	.....	D	.....	Flowed until 1920.[e]	128
.....	.....	−	.....	.....	Ab	.....	.....	129
.....	.....	−	.....	.....	Ab	.....	.....	130
10	1¼	−	.....	.....	B	.....	Pumps 2,000 gallons a day.[e]	131
150	2	?	.....	.....	D	.....	Cased 40 ft.	132
120	2	+	.....	1	D	.....	Cased 40 ft.	133
160	2	+	.....	.....	D	.....	William and Ketchman well of Bull. 5, Virginia Geol. Survey, p. 326.	136
180	2	+	.....	2½	.....	.....	.....	137
180	2	+	.....	.....	D	.....	Well was plugged in 1929. Cased 80 ft.	138
180	2	+	.....	½	D	A	.....	139
170	2	+	.....	1	D	.....	.....	140
230	3	+	.....	1	P	A	Temp. 62¼° F.	141
180	2	+	.....	5	D	.....	Cased 100 ft.	143
181	2	−	.....	.....	D	.....	Ceased flowing in 1933.[e]	144
180	2	−	.....	.....	D	.....	Cased 80 ft. Flow is intermittent.[e]	145
.....	2	+	.....	1	D	.....	.....	146
130	2	+	.....	1½	D	.....	.....	147
.....	2	+	.....	½	D	.....	.....	148
125	2	+	.....	1½	D	.....	.....	149
.....	2	+	.....	½	D	.....	.....	150
120	2	+	.....	3½	D	A	Temp. 62¼° F.	151
182	2	+	.....	1½	D	.....	.....	152
160	2	−	.....	.....	D	.....	Flowed until 1935.[e]	153
180	2	+	.....	½	D	.....	Cased 80 ft.	154
200	2	+	.....	6	D	.....	.....	155
170	2	+	.....	1½	D	.....	.....	156
130	2	−	.....	.....	D	.....	.....	157
125?	2	+	.....	¾	D	.....	.....	158
125	2	−	.....	.....	D	.....	Flowed until 1936.[e]	159
.....	2	−	.....	.....	D	.....	Flowed until 1934.[e]	160
180	2	−	.....	.....	D	.....	Flowed until 1920.[e] Cased 80 ft.	161
180	2	−	.....	.....	D	A	Cased 80 ft.	162
150	2	+	.....	1	D	.....	.....	163
200	2	+	.....	.....	D	.....	.....	164
120	2	−	.....	.....	Ab	.....	Flowed until 1920.[e]	165
185	2	+	.....	.....	D	.....	Cased 100 ft.	166
120	2	−	.....	.....	Ab	.....	Flowed until 1936.[e] Cased 60 ft.	167
186	2½	+	.....	9	D	.....	.....	168
160	2	+	.....	1¼	D	.....	Cased 80 ft.	169
.....	.....	−	.....	.....	D	.....	Flowed until 1937.	171
180	2	+	.....	5	D	.....	Cased 80 ft.	172
126	2	+	.....	½	D	.....	.....	173
140	2	+	.....	¾	D	.....	Cased 75 ft.	174
10	1¼	−	.....	.....	D	A	Temp. 68° F.	175
207	2	−	.....	.....	D	A	W. A. Howell well of Bull. 5, Virginia Geol. Survey, p. 326.	176
.....	2	−	.....	.....	D	.....	Was flowing in 1936, when pump was installed.[e]	177

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
178	Courtland	T. W. Reese	J. R. McLane		30	J
179	Courtland	F. L. Davis	J. R. McLane		26	J
180	¼ mile east of Courtland	A. B. Hartz and Co		1931	9	Dv
181	½ mile southeast of Courtland.	L. M. Manry	L. M. Manry	1934	32	Dv
182	¾ mile southeast of Courtland.	Rogers Saw Mill	J. R. McLane	1933	27	J
183	1 mile southeast of Courtland.	Fireside Inn	H. Carlton	1936	29	Dv
184	1¼ miles south-southeast of Courtland.	M. J. Overby	J. R. McLane	1934	30	J
185	2 miles south-southeast of Courtland.	R. L. Hancock	P. P. Ellis	1937	19	J
186	2 miles south of Courtland	Camp Mfg. Co	R. G. Edwards		21	J
187	2 miles southeast of Courtland	T. L. Baine Estate	J. R. McLane	1918	29	J
188	3½ miles southeast of Courtland.	Galie Ricks	J. Moore	1915	21	J
189	3½ miles southeast of Courtland.	Colgate W. Darden	J. R. McLane	1912	19	J
190	3 miles northeast of Courtland	E. Manry	J. Moore	1905	82	J
191	3 miles northeast of Courtland	Manry Sawmill	E. Manry	1937	70	Dug
192	4½ miles northeast of Courtland.	Colgate W. Darden, Jr	J. R. McLane		76	J
193	2 miles south of Baffle	J. L. Doughtie	J. R. McLane	1925	33	J
194	3¼ miles south of Baffle	J. L. Doughtie	J. R. McLane	1937	30	J
195	3½ miles west-northwest of Franklin.	Colgate W. Darden	J. R. McLane	1912	72	J
196	3 miles northwest of Franklin at Joyners Church.	Housing Project	Mitchells Pump and Well Co.		88	D
197	½ mile northwest of Franklin.	Lytton Mfg. Co	G. Wilkins	1910	22	J
198	½ mile northwest of Franklin.	E. A. Bradshaw	J. R. McLane	1915	32	J
199	½ mile northwest of Franklin.	E. A. Bradshaw	J. R. McLane	1918	20	J
200	1 mile north of Franklin	Dr. Ray			22	Dv
201a	¾ mile north of Franklin	H. Lowe	J. R. McLane	1920	22	J
201b	1 mile north-northeast of Franklin.	Camp Mfg. Co	J. R. McLane		31	J
202	Near Blackwater River Bridge, Franklin.	J. R. Boyette	J. R. McLane	1929	14	J
203	Fourth Ave., Franklin	R. C. Motor Co	J. R. McLane	1922	12	J
205	Fifth Ave. and Middle St., Franklin.	Town of Franklin	J. R. McLane	1930	21	J
206	Fourth Ave. and Mechanic St., Franklin.	Town of Franklin	Sydnor Pump and Well Co.	1931	21	Dv
207a	Fifth Ave. and Mechanic St., Franklin.	Town of Franklin	J. R. McLane	1925	21	Dv
207b	Fifth Ave. and Mechanic St., Franklin.	Town of Franklin	Layne-Atlantic Co	1944	21	D
208	Second Ave. and Main St., Franklin.	Town of Franklin	J. R. McLane		18	J
209	High and Barrett Sts., Franklin.	H. J. Lyons	J. R. McLane	1917	20	J
210	Main and Bogart Sts., Franklin.	Lyons Theatre	J. R. McLane	1938	11	J
211	Near Beale Court, Franklin	Chesly Beale	J. R. McLane		10	
212	Beale Court, Franklin	Chesly Beale	J. R. McLane	1927	11	J
213	½ mile southwest of Franklin.	T. K. Hahn	T. K. Hahn	1937	27	Dug
214	1¼ miles southwest of Franklin.	P. R. Camp	G. Wilkins	1910	28	J
215	¾ mile southwest of Franklin.	McClenny Dairy	L. C. McClenny	1936	30	Dug
216	Chestnut and South Sts., Franklin.	W. H. Jones	J. R. McLane	1921	22	J
217	Chestnut St., near South St., Franklin.	L. A. Whittely	J. R. McLane	1920	22	J
218	Chestnut and Birch Sts., Franklin.	T. C. Whittely	J. R. McLane	1921	22	J

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
.....	2	−	.....	.....	D	.....	.....	178
180	2	+	.....	4	S	.....	Cased 80 ft.	179
11	1¼	−	.....	.....	B	.....	Pumps 2,000 gallons a day.	180
15	1½	[e]− 2	Nov., 1933	.....	D S	.....	Pumps 1,000 gallons a day.	181
125	3	−	.....	.....	B	.....	Not jetted down to coarse sand. Pumps 10,000 gallons a day.	182
14	1¼	−	.....	.....	D	.....	.....	183
216	2	[e]−	1938	.....	D S	.....	.....	184
190	2	+	.....	17	D	.....	.....	185
215	2−1	+7½	July 11, 1941	3	D	.....	.....	186
438	2	−	.....	.....	D S	A	Temp. 61½° F.	187
300	1	+ 9	Aug. 18, 1937	5½	D	Soft	.....	188
300	3	+12½	July 20, 1938	35	D	.....	Flow checked to 2 gallons a minute.	189
180	2	−	.....	.....	Ab	.....	.....	190
16	.....	−	.....	.....	B	.....	Pumps 1,000 gallons a day.[e]	191
285	2	−	.....	.....	D	.....	.....	192
285	2	−	.....	.....	D S	.....	.....	193
307	1¾	+	.....	7	S	.....	.....	194
350	3	−	.....	.....	D	.....	.....	195
500	6	−	.....	.....	D	.....	See log., Table 30.	196
275	3	+	.....	1	D	.....	.....	197
340	3	+	.....	.....	S	A	.....	198
224	3	+	.....	8	D S	.....	Flowed 45 gallons a minute in 1918.[e]	199
20 shallow	1¼	−	.....	.....	D S	A	.....	200
275	2−1¼	− 2	.....	.....	D	.....	Water head was 20 ft. above surface in 1920.[e]	201a
275±	3	−16.15	Apr. 6, 1940	.....	.....	.....	.....	201b
250	2	+ 9½	July 20, 1938	10	D	.....	Temp. 62° F.	202
353	2	[e]+12	1937	4	D	A	Water head was 30 ft. above surface in 1922.[e] Temp. 62½° F.	203
354	4	+	.....	[e]40	Ab	.....	Water level 15 ft. below surface in July, 1942.	205
362	10−8	+	.....	[e]200	M	A	Pumps 1,000 gallons a minute, see log, Table 30.	206
339	8	+	.....	[e]90	M	.....	See log, Table 30	207a
604	.....	.....	.....	.....	P	.....	Used as stand-by supply.	207b
250	2−1¼	+	.....	2¼	D	.....	.....	208
275	2	+	.....	5	D	.....	Flow varies from slight to 5 gallons a minute.[e]	209
150	2	.....	.....	.....	C	.....	In summer pumps 18,000 gallons a day for air conditioning.	210
.....	.....	.....	.....	.....	D	.....	.....	211
340	3	.....	.....	.....	D	.....	.....	212
8	.....	−1.16	Dec. 2, 1937	.....	B	.....	Three dug wells supply 2,000 gallons a day.[e]	213
150	.....	−	.....	.....	D S	.....	.....	214
18	.....	−	.....	.....	C S	.....	Pumps 1,500 gallons a day.	215
150	2	[b]− 2	Aug., 1937	.....	D	.....	.....	216
175	2	[e]− 2	Aug., 1937	.....	D	.....	.....	217
163	2	[e]− 3½	Aug., 1937	.....	D	.....	.....	218

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
219	Chestnut and Magnolia Sts., Franklin.	J. A. Gaye	J. A. Gaye	1914	22	J
220	Chestnut and Magnolia Sts., Franklin.	W. M. Bradshaw	J. A. Gaye	1924	22	J
221	Walnut and Birch Sts., Franklin.	W. M. Schaffer	J. R. McLane	1925	22	J
222	Walnut and Birch Sts., Franklin.	R. L. Wellans	J. R. McLane	1927	22	J
223	Walnut St, near Birch St., Franklin.	J. A. Gaye	J. R. McLane	1934	22	J
224	Walnut and Magnolia Sts., Franklin.	J. R. Boyette	J. R. McLane	.....	22	J
225	Walnut and Magnolia Sts., Franklin.	W. H. Jones	J. R. McLane	1922	22	J
226	Walnut St., near Magnolia St., Franklin.	J. Carter	J. R. McLane	1920	22	J
227	South end of High St., Franklin.	J. R. McLane	J. R. McLane	1918	22	J
228	South end of Main St., Franklin.	T. C. Whittely	J. R. McLane	1928	8	J
229	South end of Chestnut St., Franklin.	State Highway Dept	J. R. McLane	1936	12	J
230	1¾ miles south-southeast of Franklin.	R. A. Pretlow	J. R. McLane	1922	20	J
231	1¾ miles south-southeast of Franklin.	R. A. Pretlow	J. R. McLane	1928	12	J
232	2 miles south of Franklin	W. M. Bradshaw	J. R. McLane	1937	30?	J
233	3 miles south-southwest of Franklin.	John Camp	J. R. McLane	1924	26	J
234	3½ miles south of Franklin	J. McClenny	J. R. McLane	1927	21	J
235	4 miles south of Franklin	C. C. Vaughn	J. R. McLane	1928	20	J
236	3¾ miles south of Franklin	R. F. Fahy	J. R. McLane	1932	22	J
237	4½ miles southwest of Franklin.	J. E. Howell	J. R. McLane	1922	25	J
238	5 miles south-southwest of Franklin.	Hunter Darden	J. R. McLane	1928	22	J
239	7 miles south-southwest of Franklin.	S. W. Rawls	J. R. McLane	.....	20	J
240	7½ miles south-southwest of Franklin.	Nottowaters Club	J. R. McLane	1931	12	J
241	4½ miles southwest of Franklin.	J. D. Burgess	P. P. Ellis	1937	18	J
242	3½ miles southwest of Franklin.	Otto Harcum	Otto Harcum	1927	23	Dv
243	3½ miles southwest of Franklin.	W. T. Harcum	J. R. McLane	1922	24	J
244	2¾ miles southwest of Franklin.	T. M. Cobb	J. R. McLane	1917	29	J
245	1 mile southwest of Franklin	W. H. Beale	J. R. McLane	1937	31	J
246	1½ miles southwest of Franklin.	Four Brothers Cafe	.....	.....	31	Dv
247	2 miles southwest of Franklin.	W. F. Howell	J. R. McLane	1930	31	J
248	2½ miles southwest of Franklin.	W. D. Darden	W. D. Darden	.....	25	Dv
249	2½ miles southwest of Franklin.	W. L. Beale	W. L. Beale	1920	30	Dv
250	3 miles west-southwest of Franklin.	W. L. Taylor	J. R. McLane	1914	29	J
251	4 miles west-southwest of Franklin.	Tyler Edwards	J. R. McLane	1916	26	J
252	4 miles west-southwest of Franklin.	B. N. Edwards	J. R. McLane	1918	31	J
253	3 miles west of Franklin	Webb School	J. R. McLane	1912	29	J
254	3 miles west-southwest of Franklin.	G. W. Watkins	P. P. Ellis	1937	30	J
255	5 miles west-southwest of Franklin.	Delaware Park	.....	.....	8	.....

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
158	2	[e]− 4	Aug., 1937	.....	D	.....	.....	219
148	2	−	.....	.....	D	.....	.....	220
150	2	[e]− 3	Aug., 1937	.....	D	.....	.....	221
140	2	−	.....	.....	D	.....	.....	222
143	2	−	.....	.....	D	.....	.....	223
158	2	−	.....	.....	D	.....	.....	224
147	2	−	.....	.....	D	.....	.....	225
147	2	−	.....	.....	D	.....	.....	226
360	3	[e]+ 2	Aug., 1939	3	D	.....	Flowed 25 gallons a minute in 1918.	227
135	2	+ 9½	July 20, 1938	9½	D	.....	Temp. 62° F.	228
140	2	+13	July 20, 1938	20	D	A	Temp. 61° F.	229
275	3	+	.....	.....	D S	.....	.....	230
140	3	+	.....	25	S	.....	Flowed 60 gallons a minute in 1928.[e]	231
330	3	+	.....	30	S	.....	.....	232
437	2	?	.....	.....	D S	.....	.....	233
160	2	.....	.....	.....	D S	.....	.....	234
160	3	+	.....	9	D S	.....	.....	235
180	2	.....	.....	.....	D S	.....	.....	236
316	2	+	.....	½	D	.....	Flow is greater in winter.[e]	237
333	2	+ 6¾	July 11, 1941	15½	D S	.....	See log, Table 30.	238
158	2	+ 3	July 20, 1938	2	D	A	.....	239
176	2	+17¾	July 11, 1941	13	D	.....	.....	240
130	2	+ 3	July 20, 1938	10½	D	A	.....	241
14	1½	−	.....	.....	D	A	.....	242
275	2	+	.....	3	D S	.....	.....	243
350	2	[e]− 1	Aug., 1937	.....	D S	.....	.....	244
140	2	[e]− 3	Aug., 1937	.....	D	.....	.....	245
18	1½	−	.....	.....	D	.....	Supplies restaurant and tourist camp.	246
480	2	−	.....	.....	D S	.....	.....	247
13	1¼	−	.....	.....	B	.....	Pumps 3,000 gallons a day in winter, less in summer.	248
12	1¼	−	.....	.....	D S	.....	.....	249
258	2	+	.....	2	S	.....	.....	250
275	2	+	.....	4¼	D S	.....	Flowed 10 gallons a minute in 1916.[e]	251
280	2	[e]−	July, 1937	.....	D S	.....	Flowed until 1936.[e]	252
375	2	− 5	July 9, 1941	.....	D	.....	Used as Geological Survey observation well. Flowed until 1935.	253
153	2	−	.....	.....	D S	.....	.....	254
.....	.....	+	.....	50	.....	A	.....	255

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
256	5 miles west of Franklin	Fisher Sawmill	L. J. Fisher	1935	12	Dug
257	3½ miles south-southwest of Courtland.	R. B. Storey	J. R. McLane	1916	70	J
258	3 miles northwest of Newsoms.	B. D. Prince	P. P. Ellis	1930	92	J
259	3 miles northwest of Newsoms.	J. H. Johnson	P. P. Ellis	1929	97	J
261	¼ mile north of Newsoms	Colored School	J. R. McLane		96	J
262	Newsoms	Methodist Parsonage	J. R. McLane		90	J
263	Newsoms	Newsoms High School	J. R. McLane		90	J
264	Newsoms	H. E. Bailey		1927	92	Dug
266	3½ miles southeast of Boykins.	H. T. Porter	R. G. Ellis	1907?	30	J
267	4 miles southeast of Boykins	H. T. Porter	R. G. Ellis	1907	25	J
268	1 mile north-northeast of Boykins.	F. N. Powell, Sr.	J. R. McLane	1930	93	J
269	1 mile north-northeast of Boykins.	F. N. Powell, Sr.	P. P. Ellis		94	J
270	½ mile north-northeast of Boykins.	E. R. Bryant	P. P. Ellis		33	J
271	½ mile north-northeast of Boykins.	E. R. Bryant	P. P. Ellis		33	J
272	Boykins	Town of Boykins	Sydnor Pump and Well Co.		40	D
273	Boykins	Columbia Peanut Co.	P. P. Ellis		40	J
274	Boykins	A. S. Francis	P. P. Ellis	1920	41	J
275	Boykins	Baptist Church	P. P. Ellis		40	J
276	Boykins	S. H. Dodd	P. P. Ellis		41	J
277	Boykins	Rock Motor Co.	P. P. Ellis		42	J
278	Boykins	John Phelps	R. G. and P. P. Ellis	1912	40	J
279	Boykins	Town of Boykins	R. G. and P. P. Ellis		38	J
280	Boykins	R. S. Bryant	R. G. and P. P. Ellis		41	J
281	Boykins	A. D. Knight			42	J
282	Boykins	S. J. Branch	J. Moore	1906	39	J
283	Boykins	S. J. Myrick	P. P. Ellis	1908	41	J
284	Boykins	W. H. Britt	P. P. Ellis	1910	42	J
285	Boykins	J. Y. Mason	R. G. Ellis	1915	41	J
286	Boykins	A. L. Knight	P. P. Ellis		42	J
287	Boykins	J. M. Bland	P. P. Ellis	1918	40	J
288	Boykins	J. L. and J. D. Sykes	R. G. Ellis	1910	42	J
289	Boykins	J. M. Bland	J. Moore	1907	40	J
290	Boykins	J. M. Bland	P. P. Ellis	1914	36	J
291	Boykins	W. W. White, Jr.	P. P. Ellis	1932	39	J
292	Boykins	W. W. White	J. T. Moore		40	J
293	Boykins	Meherrin Valley Bank			40	J
294	Boykins	J. R. Person	P. P. Ellis	1916	37	J
295	Boykins	H. E. Barnes	P. P. Ellis	1916	38	J
296	Boykins	R. E. Barrett	P. P. Ellis	1917	32	J
297	Boykins	R. M. Edwards	P. P. Ellis	1908	41	J
298	Boykins	J. T. Davis	P. P. Ellis	1924	42	J
299	Boykins	S. J. Wilson	P. P. Ellis	1905	42	J
300	Boykins	C. L. Johnson	J. Moore		42	J
328	1 mile west of Boykins	Hartz and Rogers Sawmill	E. F. Noon	1934	41	Dv
330	¼ mile north of Branchville	Cicero Vick	P. P. Ellis		41	J
331	¼ mile north of Branchville	E. R. Vick, Jr.	P. P. Ellis		41	J
332	¼ mile north of Branchville	Home Loan Corp.	P. P. Ellis		40	J
333	¼ mile north of Branchville	L. Harris	P. P. Ellis		40	J
334	¼ mile north of Branchville	W. S. DeLoatche	P. P. Ellis		35	J
336	Branchville	P. G. Ellis	R. G. Ellis		40	J
337	Branchville	P. P. Ellis	P. P. Ellis	1896	40	J
338	Branchville	W. R. Sykes	P. P. Ellis	1912	40	J
339	Branchville	L. O. Tyler	P. P. Ellis		41	J
340	Branchville	J. W. H. Darden	P. P. Ellis	1925	43	J
341	Branchville	B. H. Beale	P. P. Ellis	1919	44	J
342	Branchville	W. R. Sykes	P. P. Ellis	1927	40	J
343	Branchville	Town of Branchville	P. P. Ellis	1925	45	J

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
11½	.....	−	.....	.....	B	.....	Yields 2 gallons a minute from sandy lens in blue marl.[e]	256
279	2	−	.....	.....	D S	A	Temp. 60° F.	257
290	2	−	.....	.....	D S	.....	.....	258
240	2	−57	July 25, 1938	.....	D S	.....	.....	259
320	3	−57	July 25, 1938	.....	.....	.....	.....	261
316	3	[d]−60	.....	.....	D	A	.....	262
316	3	−	.....	.....	P	A	.....	263
18	.....	−16	Sept. 16, 1937	.....	D	A	.....	264
.....	.....	+	.....	2	S	.....	.....	266
106	2	+	.....	5¼	D S	.....	Temp. 59½° F.	267
325	3	−	.....	.....	D S	.....	.....	268
100	2	−	.....	.....	Ab	.....	Data from Bull. 5, Virginia Geol. Survey, p. 326.	269
120	2	+	.....	7	D S	.....	Affected by pumping at Boykins.[e]	270
120	2	+	.....	5	D S	.....	.....	271
238	10	−	.....	.....	.....	A	Turbine pump delivers 350 gallons a minute to 75,000 gallon tank.	272
135	2	+	.....	4	D	.....	.....	273
130	2	+	.....	.....	Ab	.....	Flow is intermittent.	274
135	2	+ 4½	July 21, 1938	2	D	A	Temp. 60¾° F.	275
130	2	+	.....	.....	D	.....	.....	276
130	2	−	.....	.....	.....	.....	.....	277
115	2	+	.....	2	D	.....	Temp. 60½° F.	278
120	2	+ 2	July 21, 1938	1¼	D	.....	Temp. 61° F.	279
135	2	−	.....	.....	D	.....	Flowed until 1927.[e]	280
110	2	−	.....	.....	Ab	.....	R. M. Knight well of Bull. 5, Virginia Geol. Survey, p. 326.	281
120	2	−	.....	.....	D	.....	.....	282
125	2	−	.....	.....	D	.....	.....	283
120	2	+	.....	.....	D	.....	Flow is intermittent.	284
110	2	+	.....	½	S	.....	.....	285
120	2	[e]−	.....	.....	D	.....	.....	286
120	2	+	.....	1½	D	.....	Temp. 61¼° F.	287
130	2	−	.....	.....	S	.....	.....	288
.....	2	−	.....	.....	Ab	.....	Flowed until 1914.	289
120	2	+	.....	4⅓	S	.....	Temp. 60½° F.	290
138	2	+	.....	½	S	.....	.....	291
130	2	−	.....	.....	D	.....	.....	292
105	2	−	.....	.....	Ab	.....	W. J. Drury well of Bull. 5, Virginia Geol. Survey, p. 326.	293
180	2	+	.....	¾	D	.....	Temp. 60¾° F.	294
139	2	+	.....	2	D	.....	Temp. 61° F.	295
135	2	+	.....	1	D	.....	Temp. 60½° F.	296
135	2	−	.....	.....	D	.....	.....	297
135	2	+	.....	.....	D	.....	Pump installed in 1935.	298
145	2	−	.....	.....	D	.....	.....	299
105	2	[f]−½	.....	.....	D	.....	.....	300
16	1½	−	.....	.....	B	.....	Pumps 4,000 gallons a day.	328
235	2	+	.....	1	D	.....	.....	330
270	2	+	.....	1½	D	.....	.....	331
180	2	+	.....	1	D	.....	.....	332
160	2	+	.....	.....	D	.....	.....	333
160	2	+	.....	½	D	.....	.....	334
250	2	+	.....	.....	D	.....	.....	336
155	2	+	.....	½	D	.....	Flowed 17 gallons a minute in 1896.[e]	337
120	2	+1	July 21, 1938	½	D S	.....	Temp. 60½° F.	338
160	2	+	.....	½	D	.....	.....	339
.....	2	+	.....	¼	D	.....	.....	340
180	2	−	.....	.....	D	.....	Flowed until 1931.[e]	341
220	2	+	.....	4½	D	.....	.....	342
210	2	−	.....	.....	D	.....	Flowed until 1932.[e]	343

TABLE 29.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
344	Branchville	J. E. Harrison	P. P. Ellis	1907	45	J
345	Branchville	H. Stephenson	G. Wilkins	.....	45	J
346	Branchville	E. T. Story	P. P. Ellis	.....	44	J
347	Branchville	W. R. Sykes	.....	.....	44	J
348	Branchville	H. H. Webb	P. P. Ellis	1914	44	J
349	Branchville	T. A. Booth	G. Wilkins	.....	45	J
350	Branchville	Callie Harrell	P. P. Ellis	.....	45	J
351	Branchville	J. J. Grizzard, Jr.	G. Wilkins	.....	45	J
352	Branchville	A. P. DeLoatche	P. P. Ellis	.....	45	J
353	Branchville	W. T. Grizzard	R. G. Ellis	1910	45	J
354	¼ mile west of Branchville	L. A. Wood	P. P. Ellis	1909	45	J
355	¼ mile west of Branchville	J. J. Johnson	R. G. and P. P. Ellis	1905	45	J
356	¼ mile south of Branchville	S. T. Booth	P. P. Ellis	1930	42	J
357	¼ mile south of Branchville	H. G. Harrell	P. P. Ellis	.....	41	J
358	½ mile north-northeast of Branchville.	Galilee Baptist Church	P. P. Ellis	1920	37	J
359	1 mile south-southwest of Branchville.	J. W. Smith	J. R. McLane	.....	34	J
360	1 mile south of Branchville	W. A. Joyner	P. P. Ellis	1925	38	J
361	1½ miles south of Branchville	J. Newsoms	P. P. Ellis	1937	35	J
362	2½ miles south-southwest of Branchville.	W. H. Stephenson	P. P. Ellis	.....	41	J
363	2¼ miles southwest of Branchville.	N. L. Rogers	P. P. Ellis	1926	40	J
364	2¼ miles west-southwest of Branchville.	W. Jackson	P. P. Ellis	1925	40	J
365	1½ miles west of Branchville	B. H. Beale	P. P. Ellis	.....	63	J
366	2 miles west of Branchville	W. Jackson	P. P. Ellis	1927	63	J
367	2 miles west of Branchville	Odd Fellows Society Hall	P. P. Ellis	1935	63	J
368	5 miles north-northwest of Branchville.	Zoar Colored School	P. P. Ellis	.....	83	J
369	6 miles west-northwest of Branchville.	Little Texas School	P. P. Ellis	1929	85	J
370	3 miles southwest of Branchville.	Farmers Mfg. Co.	P. P. Ellis	1908	38	J

[a]D = drilled. Dv = driven. Dug = dug. J = jetted.
[b]As of August and September, 1937, unless otherwise noted.
[c]Ab = abandoned. B = boiler feed. C = cooling. D = domestic. M = municipal. P = public school. S = stock.
[d]A: Analysis in Tables 31–33.
[e]Reported by owner or driller.
[f]Estimated.

Southampton County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
190	2	−	.....	.....	D	.....	Flowed until 1931.[e]	344
207	2	−	.....	.....	D	.....	T. J. Harrel well of Bull. 5, Virginia Geol. Survey, p. 326. Flowed until 1930.	345
180	2	−	.....	.....	D	.....	.....	346
155	2	−	.....	.....	D	.....	.....	347
190	2	−	.....	.....	D	.....	.....	348
.....	2	−	.....	.....	D	.....	.....	349
190	2	−	.....	.....	D	.....	.....	350
150	2	−	.....	.....	D	.....	Grizzard Bros. & Co. well of Bull. 5, Virginia Geol. Survey, p. 326.	351
135	2	−	.....	.....	D	.....	.....	352
.....	2	−	.....	.....	.....	.....	Flowed until 1927.[e]	353
120	2	−	.....	.....	D	.....	.....	354
.....	.....	−	.....	.....	D	.....	.....	355
180	2	+	.....	½	D	.....	.....	356
180	2	+	.....	1½	D	.....	Temp. 60½° F.	357
140	2	+9½	July, 1938	10	D	.....	Fills baptismal tank. Water head was 17 ft. above surface in 1920.[e]	358
.....	4	+9	July, 1938	25	S	.....	Supplies fish pond. Temp. 61¾° F.	359
140	2	+	.....	2½	D S	.....	Temp. 61° F.	360
212	2	+	.....	1	D S	.....	Temp. 61½° F.	361
220	2	+3	July, 1938	1½	D S	.....	Temp. 61½° F.	362
192	2	+	.....	1½	D S	.....	.....	363
192	2	+	.....	1	D S	.....	Temp. 62° F.	364
130	1	−	.....	.....	D S	.....	.....	365
170	2	−	.....	.....	D S	.....	.....	366
150	2	[e]−17	1935	.....	D	.....	.....	367
150	2	−31	July, 1938	.....	P	.....	.....	368
190	3	−37	July, 1938	.....	P	A	.....	369
125	3	+ 4	July, 1938	10	D	.....	.....	370

TABLE 30.—*Logs of wells in Southampton County, Virginia*

Well 2, Ivor; Ivor High School
(Log by J. R. McLane)
Altitude, 88 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil and clay	10	10
Sand and clay	10	20
Chesapeake group (Miocene):		
Sand and blue mud or marl	30	50
Marl rock	8	58
Fine sand and shell	50	108
Blue clay	60	168
Pamunkey group (Eocene):		
Black sand	30	198
Marl rock	2	200
Undifferentiated (Upper Cretaceous ?):		
Sand	10	210
Chocolate-colored clay	50	260
Potomac group (Lower Cretaceous):		
Sand, water	18	278

Well 11a, Burdette; FWA
(Log by Newsoms & Aldrich, Engineers)
Altitude, 12 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	30	30
Chesapeake group (Miocene):		
Dark fine sand	10	40
Clayey sand	10	50
Sand with some shells	10	60
Sand shell marl	34	94
Sandy marl	14	108
Dark sandy marl, water	4	112
Dark sand, water	6	118
Pamunkey group (Eocene):		
Green glauconite sand, powdery when dry	22	140
Black glauconitic marl; mud content high; forms mud balls	35	175
Dark sand	7	182
Black glauconite sand	6	188
Fine dark glauconite sand	14	202
Undifferentiated (Upper Cretaceous ?):		
Coarse white sand, water	29	231

TABLE 30.—*Logs of wells in Southampton County, Virginia—Continued*

Well 25, Sedley; Morgan's Siding
(Log by courtesy Virginian Railway Co.)
Altitude, 84.5 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	4	4
Red clay	8	12
Yellow sand	8	20
Light-gray coarse sand and gravel	14	34
Chesapeake group (Miocene):		
Blue muddy clay	5	39
Light-gray coarse sand	4	43
Blue sandy mud	12	55
Blue solid mud	9	64
Gray sand and shells	18	82
Blue solid mud	92	174
Undifferentiated (Upper Cretaceous ?):		
Blue mud with large shells and hard layers of lime rock	34	208
Yellow and purple hard clay making pink washings	39	247
Red sandy clay	5	252
Blue clay	16	268
Gray sandy clay with fine gray and yellow sand	6	274
Yellow clay; soft	6	280
Hard blue clay with large shells	3	283
Soft red clay	5	288
Hard red clay with soft spots	9	297
Clay with layers of shells and some gravel	41	338
Hard shell rock	1	339
Soft gray sandy lime rock	9	348
Hard gray lime rock	1	349
Sandstone, not so hard	7	356
Hard sandstone	2	358
Potomac (?) group (Lower Cretaceous):		
Dark-green and brown clay (gumbo)	6	364
Light-green sandy clay	11	375
Dark-green and brown clay (gumbo)	7	382
Light-green sandy clay	9	391
Hard brown clay (gumbo)	4	395
Light-green sandy clay	3	398
Dark-green and brown clay (gumbo)	11	409
Hard blue sandy clay	3	412
Hard blue clay	5	417
Hard blue sandy clay	8	425
Hard blue clay	4	429
Hard gray sand	5	434
Brown sandstone	2	436
Hard fine gray sand	8	444
Sandstone	2	446
Gray sandy clay	3	449
Hard gray clay	1	450
Hard porous sandstone	6	456
Soft gray sand	7	463
Hard sandy clay	6	469
Hard slate-gray clay	19	488
Hard green sandy clay	8	496
Light-green sandy clay	9	505

TABLE 30.—*Logs of wells in Southampton County, Virginia—Continued*

Well 25, Sedley; Morgan's Siding—Continued

	Thickness (feet)	Depth (feet)
Potomac (?) group (Lower Cretaceous)—Continued		
Green solid marl	49	554
Light-green sandy clay and gravel	7	561
Dark-brown clay (peat)	10	571
White sandy clay	15	586
Green sandy clay	3	589
Basement rock (?) (pre-Cambrian ?):		
Soapstone	7	596
Green sandy soapstone and soft brown clay	37	633

NOTE: Ten-inch casing extends from surface to 346 feet; 8-inch casing from 337 to 400 feet; and 6-inch casing from 380 to 521 feet. Screens are set at 75 to 80 feet, 429 to 462 feet, and 559 to 564 feet.

Well 29, Sebrell; Virginian Railway Co.
(Log by Sydnor Pump and Well Co.)
Altitude, 58.4 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	10	10
Clay and sand	20	30
Chesapeake group (Miocene):		
Light-blue clay	21	51
Blue mud and sand	10	61
Blue mud	56	117
Undifferentiated deposits[a]		
Sand and gravel	10	127
Blue clay	27	154
Sand and clay	13	167
Blue clay	8	175
Fine yellow sand	11	186
Blue clay and sand	5	191
Coarse sand and gravel, water	11	202
Hard blue clay	4	206
Dark mucky clay	18	224
Blue clay	12	236
Soft mucky blue clay	53	289
Blue clay	53	342
White sand and gravel about size of hen's egg, water	10	352

[a]May include deposits of Eocene, late Cretaceous and early Cretaceous age.

TABLE 30.—*Logs of wells in Southampton County, Virginia—Continued*

Well 42, Drewryville; R. A. Pope
(Log by J. R. McLane)
Altitude, 100 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Clay	30	30
Chesapeake group (Miocene):		
Blue clay	60	90
White clay	24	114
Extremely hard rock, cavern beneath yields water	6	120

Well 47c, Capron; Southampton State Farm
(Log by D. J. Cederstrom[a])
Altitude, 100 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red clay	36	36
Chesapeake group (Miocene):		
Blue marl with few shells	64	100
Gray marly sand	5	105
Gray shell marl; sharks teeth; trace of black sand	5	110
Undifferentiated (Upper Cretaceous ?):		
Medium sand; micaceous	8	118
Marly quartz sand	52	170
Green sandy marl	25	195
Medium sand	5	200
Yellow green sandy marl	10	210
Potomac group (Lower Cretaceous):		
Medium quartz sand, water	15	225

[a]From samples supplied by Mitchells Pump and Well Co.

Well 49, Capron; Filling Station, U. S. Highway 58
(Log by P. P. Ellis)
Altitude, 120 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow loam	9	9
Sandy clay	16	25
Chesapeake group (Miocene):		
Blue mud and marl	40	65
Pamunkey group (Eocene):		
Black sand containing nodules 1 inch or more in diameter	75	140
Undifferentiated (Upper Cretaceous ?):		
Blue clay	30	170
Red clay	15	185
Potomac group (Lower Cretaceous):		
Sand, water	15	200

TABLE 30.—*Logs of wells in Southampton County, Virginia—Continued*

Well 141, Courtland; Courtland High School
(Log by J. R. McLane)
Altitude, 28 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil and sand	20	20
Chesapeake group (Miocene):		
Blue mud	30	50
Sand	50	100
Pamunkey group (Eocene):		
Hard black earth, slightly glauconitic	20	120
Potomac group (Lower Cretaceous):		
White sand, water	40	160
Yellowish clay	10	170
Sand, water	20	190
Fine micaceous dark sand and black mud	15	205
White sand, water	25	230

Well 196, Joyners Church; Housing Project
(Log by Mitchells Pump and Well Co.)
Altitude, 88 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	20	20
Red clay	10	30
Chesapeake group (Miocene):		
Blue clay	73	103
Sand	12	115
Clay, blue	35	150
Pamunkey group (Eocene):		
Rock	4	154
Greensand	6	160
Rock	3	163
Clayey sand	17	180
Blue clay	40	220
Black sand	10	230
Undifferentiated (Upper Cretaceous ?):		
Blue clay	10	240
Red clay	75	315
Potomac group (Lower Cretaceous):		
Yellow clayey sand	3	318
White sand, water	22	340
White sand, minor clay	60	400
White sand, water	15	415
White sandy clay	5	420
Hard dark-blue clay	5	425
Clayey sand	30	455
Hard blue clay	5	460
White clay	10	470
Slightly clayey white sand, water (?)	10	480
Sandy clay	5	485
Hard blue clay	7	492
White sand, water	4	496
Hard blue clay	4	500

TABLE 30.—*Logs of wells in Southampton County, Virginia—Continued*

Well 207a, Franklin; Municipal Water Works
(Log by J. R. McLane)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	5	5
Sand	15	20
Chesapeake group (Miocene):		
Blue clay, marl and shells	55	75
Pamunkey group (Eocene):		
Black sand	15	90
Rock	2	92
Black sand	5	97
Very hard rock	2	99
Black sand	29½	128½
Very hard rock	½	129
Undifferentiated (Upper Cretaceous ?):		
Gray water-bearing sand	10	139
Chocolate-colored clay	85	224
Potomac group (Lower Cretaceous):		
Sand[a], water	20	244
Yellow pipe clay	12	256
Sand, water	20	276
Clay	22	298
Sand[b], water	42	340

[a]According to log by Sydnor Pump and Well Co., water-bearing sands were encountered in well 206 between 222 and 255, 274 and 306, and 307 and 359 feet below the surface.
[b]Well screen placed at from 320 to 338 feet below the surface.

Well 207b, Franklin; Municipal Water Works
((Log[a] by D. J. Cederstrom, paleontological determinations by H. G. Richards and J. A. Cushman)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Fine yellow sand	18	18
Chesapeake group (Miocene):		
Sandy gray marl, becoming shelly at 45 feet, dark olive-green at base	57	75
Aquia formation, Pamunkey group (Eocene):		
Marly black glauconite sand with subordinate shell; *Gryphaeostrea vomer*	22	97
Rock	½	97½
Glauconite sand	3½	101
Rock	1	102
Marly glauconite sand, some shell; *Gryphaeostrea vomer*, and *Eouvigerina excavata*, *Dentalina colei*, *Globorotalia wilcoxensis*, and numerous Naheola and Wilcox species of foraminifera	15	117
Fine marly glauconite; same fossils as above with *Spiroplectamnina wilcoxensis*	11	128
Marly glauconite sand; same fossils as above with *Robulus midwayensis* and *Lamarckina limbata*	10	138
Small gravel and glauconite sand; very few foraminifera	16	154
Undifferentiated (Upper Cretaceous) (?):		
Fine glauconitic quartz sand, no shells	10	164
Dark gray micaceous clay, showing faint mottling in places; unfossiliferous	63	227
Dark-gray micaceous clay, becoming increasingly sandy with depth; unfossiliferous	23	250
Potomac group (Lower Cretaceous):		
Gray sand, medium texture but coarse at base, water	13	263
Light olive-green clay with brown and light-gray mottling	19	282
Gray sand, fine to medium texture, water	20	302
Mottled olive-green clay	18	320
Light-gray sand, medium texture, water	35	355
Dark clayey sand	15	365
Fine gray sand, water ?	8	373
Sand, varying in texture from coarse to small gravelly, alternating with thin clay streaks, water	50	423
Light-green hard clay	10	433
Sandy clay	14	477
White and blue mottled clay	73	520
Moderately coarse sand, water	5	525
Sandy blue clay	9	534
Blue clay	4	538
Fine sand, water	18	556
Moderately coarse sand, water	45	601
Black clay	3	604

[a]Well drilled by rotary method by Layne-Atlantic Co.

Well 238, Franklin; Hunter Darden
(Log by J. R. McLane)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Undescribed deposits	65	65
Pamunkey group (Eocene):		
Black sand	25	90
Clay	50	140
Undifferentiated (Upper Cretaceous ?):		
Sand, water	10	150
Black clay	80	230
Potomac group (Lower Cretaceous):		
Red and white clay	90	320
Sand, water	13	333

Well 263, Newsoms; Newsoms High School
(Log by J. R. McLane)
Altitude, 90 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand and clay	20	20
Chesapeake group (Miocene):		
Blue clay	35	55
Muddy sand	40	95
Undifferentiated (Upper Cretaceous ?):		
White sand, water	15	110
Chocolate clay	25	135
Hard marl rock	2	137
Potomac group (?) (Lower Cretaceous):		
Greenish and yellow clay	151	288
Fine white micaceous sand, water	28	316

Well 337, Branchville; P. P. Ellis
(Log by P. P. Ellis)
Altitude, 40 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Solid yellow clay	17	17
White sand, water	12	29
Chesapeake group (Miocene):		
Blue marl	31	60
Pamunkey group (Eocene):		
Black sand	20	80
Undifferentiated (Upper Cretaceous ?):		
Red clay	50	130
Potomac group (Lower Cretaceous):		
White sand, water	110	240
Gumbo	60	300
Yellow sand, water	20	320

TABLE 31.—*Analyses of waters from Quaternary deposits in Southampton County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 29)

	175	200	242	264
	Courtland	Franklin	Franklin	Newsoms
Iron (Fe)	.75	8.3	.4	.08
Bicarbonate (HCO_3)	10	.0[a]	11	3.0
Sulfate (SO_4)	17	23	22	6
Chloride (Cl)	6.0	18	6.0	6.0
Fluoride (F)	.0	.10	.0	.3
Nitrate (NO_3)	30	75	9.7	5.7
Total hardness as $CaCO_3$	48	76	40	9.0
Date of collection	Sept. 30, 1937	Dec. 13, 1937	Dec. 13, 1937	Sept. 16, 1937

[a]Acid. pH = 4.5.

Analysts: 175 and 264, Margaret D. Foster; 200 and 242, W. M. Noble.

TABLE 32.—*Analyses of waters from Miocene deposits in Southampton County, Virginia*

(Parts per million. Numbers in name column refer to corresponding well numbers in Table 29)

	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$	Date of collection
Unity (10)	400	3	2.0	3.2	.98	3.0	Apr. 18, 1938
Burdette (11)	324	5	2.0	3.4	.49	<5	Apr. 18, 1938

Analyst: W. M. Noble.

TABLE 33.—*Analyses of waters from Cretaceous*

(Parts per million. Numbers in first column refer

	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Ivor (2)	.....	.....	.....	.....	.....	.....	251
Ivor (6)	.....	.....	.....	.....	.....	.....	238
Baffle (16)	.....	.....	.....	.....	.....	.....	240
Sedley (21)	.....	.....	.....	.....	.....	.....	179
Sedley (25)	.....	.....	.....	.....	.....	.....	181
Sebrell (31)	.....	.....	.....	.....	.....	.....	108
Drewryville (46)	.....	.....	.....	.....	.....	.....	158
Capron (56)	.....	.....	.....	.....	.....	.....	200
Pope (62)	.....	.....	.....	.....	.....	.....	144
Courtland (68)	.....	.....	.....	.....	.....	.....	228
Courtland (71)	.....	.....	.....	.....	.....	.....	184
Courtland (139)	27.4	0.10	0.6	0.7	86		177
Courtland (141)	32	.0	.5	.3	90	6.4	196
Courtland (151)	26	.03	.7	.6	90	6.6	202
Courtland (162)	.....	.....	.....	.....	.....	.....	214
Courtland (176)	20	.08	1.2	.08	112		229
Courtland (187)	.....	.....	.....	.....	.....	.....	196
Franklin (198)	.....	.....	.....	.....	.....	.....	282
Franklin (203)	19	.0	.7	.4	110	8.8	280
Franklin (205-207)	30.5	.13	4.9	.7	120		262
Franklin (229)	11	.01	1.5	1.3	150	11	420
Franklin (239)	.....	.....	.....	.....	.....	.....	393
Sycamore Church (241)	.....	.....	.....	.....	.....	.....	337
Delaware Park (255)	.....	.....	.....	.....	.....	.....	373
Courtland (257)	.....	.....	.....	.....	.....	.....	180
Newsoms (262)	.....	.....	.....	.....	.....	.....	190
Newsoms (263)	.....	.....	.....	.....	.....	.....	189
Boykins (272)	.....	.....	.....	.....	.....	.....	186
Boykins (275)	.....	.60	.....	.....	.....	.....	187
Little Texas (369)	.....	1.3	.....	.....	.....	.....	187

[a]In sample collected July 2, 1944.

Analysts: 2, 6, 21, 31, 46, 56, 62, 68, 71, 162, 187, 198, 239, 241, 255, 257, 263, 272, 275, Margaret D. Foster; 16, 25, 141, 151, 203, 229, 262 and 369, W. M. Noble; 139, 176 and 205-207, E. Elvove.

deposits in Southampton County, Virginia

to corresponding well numbers in Table 29)

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids (180°C)	Total hardness as $CaCO_3$	Free carbon dioxide (CO_2)	Date of collection
3	3.0	0.1	0.20	.....	<5	.....	Sept. 15, 1937
1	1.0	0.5	.0	.....	6	.....	Nov. 10, 1938
5	1.0	1.7	.23	.....	<5	.....	Apr. 18, 1938
1	2.0	.7	.75	.....	16	9.4	Sept. 14, 1937
8.0	8.0	1.1	.14	.....	<5	.....	Nov. 27, 1937
3	2.0	.0	.15	.....	70	12	Sept. 15, 1937
7	2.0	.0	.0	.....	129	.....	.....
18	2.0	.0	.41	.....	146	.....	Sept. 14, 1937
6	2.0	.0	.0	.....	120	.....	Nov. 10, 1938
5	3.0	.8	.0	.....	<5	.....	Oct. 1, 1937
4	9	.8	.0	.....	<5	.....	Nov. 10, 1938
14	16	5.0	.3	246	4.1	.....	Oct. 6, 1933
12	16	5.5	.20	269	2.5	.....	Apr. 20, 1938
12	16	5.0	.05	270	4.2	.....	Apr. 20, 1938
12	20	4.3	.20	.....	<5	.....	Sept. 30, 1937
13.4	24	6.0	.5	304	2.9	.....	Oct. 6, 1933
15	23	4.2	.0	.....	<5	.....	Sept. 25, 1937
8	3.0	5.0	.6	.....	<5	.....	Sept. 15, 1937
6.6	4.2	4.8	.27	300	2.8	.....	Apr. 18, 1938
8.4	6.0	5.6	.4	.....	13.2	4.0[a]	.....
2.6	3.0	2.1	.0	395	9.1	.....	Apr. 18, 1938
20	88	.9	.0	.....	16	.....	Oct. 1, 1937
13	58	1.1	.0	.....	6	.....	Nov. 10, 1938
13	27	1.6	.05	.....	10	.....	Apr. 19, 1938
4	3.0	.2	.08	.....	134	.....	Sept. 30, 1937
7.0	4.0	.0	.36	.....	<5	.....	Nov. 26, 1937
12	4.0	.0	.20	.....	<5	.....	Sept. 16, 1937
13	3.0	.0	1.5	.....	39	14	Sept. 29, 1937
14	4.0	.0	.94	.....	84	.....	Sept. 22, 1937
12	4.0	.0	.13	.....	136	.....	Oct. 16, 1937

ISLE OF WIGHT COUNTY

LOCATION AND DEVELOPMENT

Isle of Wight County lies along the south bank of James River. Surry County adjoins it on the northwest and Nansemond County on the east. It is separated from Southampton County on the southwest by Blackwater River.

The county has an area of 321 square miles, about 62 per cent of which is classed as farm land. In addition to vegetable crops, many hams from peanut-fed hogs are processed at Smithfield. A few stave and planing mills are scattered throughout the county. According to the Census of 1940, Smithfield was the largest town, with a population of 1,178; the total population of the county being 13,381.

The sawmills of the Camp Lumber Co. are located on Blackwater River opposite the city of Franklin, in the southern part of the county; and in 1939 the Chesapeake-Camp Corp. kraft paper mill was built near Franklin. These large factories make their influence felt more in Southampton County than in Isle of Wight County although they draw labor and raw materials from both counties.

TOPOGRAPHY

The surface is made up chiefly of the very gently southeastward-sloping Wicomico terrace, into which creeks have cut broad shallow channels. James and Blackwater rivers and their many tributaries have created rolling to rugged topography, which is in pleasing contrast to the monotonous higher level tracts. The steepest cliffs are present along James River, but abrupt banks formed by meandering streams are found to lesser extent elsewhere. Large remnants of the Wicomico terrace make the "high plains" of the county at elevations of 76 to 88 feet above sea level. These are known as pocosons. String-of-Logs Pocoson, near Isle of Wight, is part of a long narrow terrace (Wicomico) which extends from near the northern border of the county, southward into Southampton County. A lower terrace (Talbot), which lies 28 to 42 feet above sea level, has a limited development along James River. The Pamlico terrace, whose altitude ranges around 25 feet above sea level, occupies the eastern corner of the county. It is separated from higher terraces by the northward continuation of the Suffolk scarp.

GEOLOGY

Depth to the granitic bedrock has not been determined in Isle of Wight County. However, at Mulberry Island, across James River from Smithfield, the bedrock surface was determined by geophysical methods to be 1,300 feet below sea level.

Logs of wells throughout the largest part of the county furnish only limited information on the uppermost deposits of the Potomac group of early Cretaceous age. However, recent drilling at Franklin (160-162, Table 30 and Pl. 33) has brought to light much detailed data on the deeper lying beds. Wells did not reach bedrock but it is thought that bedrock may have been within 100 feet of the bottom of the 800-foot test hole. Hence, information on nearly the complete thickness of strata of the Potomac group is at hand in that place. These data are discussed below in this chapter. The results of deep drilling at Bacons Castle, discussed in the chapter on Surry County, furnish information on these strata down to a depth of 1,000 feet below sea level and are applicable in some degree to northwestern Isle of Wight County, and the data gained in drilling to about 900 feet below sea level at Lake Prince, Nansemond County, are likewise applicable in part to east-central Isle of Wight County.

In a well at Windsor (144b, Table 35) Mr. Jesse Minton stated that below a glauconite sand (considered by the writer to be quite certainly of Eocene age) the strata penetrated were as follows:

	Thickness (feet)	Depth (feet)
Red clay	25	350
Blue clay	35	385
White quartz sand, water	5	390
Glauconite sand, mud	37	427
Fine green sand	3	430
White arkosic quartz sand	13	443
Glauconite and quartz sand	15	458
White arkosic sand	10	468

Because glauconite sand occurs below the red clay, it is quite certain that the red clay can not belong to either the Patuxent or Patapsco formation of the Potomac group. Hence the red clay is

either late Cretaceous or Eocene in age. A red clay member has not been found in the Eocene formations along the Fall Zone. Glauconite sand, a characteristic and almost invariable component of the Pamunkey group, is known to occur below the red clay in only one of the many places where the red clay is known, hence the red clay and glauconite sand which does occur below it (325 to 458 feet) at Windsor are believed to be most probably of late Cretaceous age.

In addition to its occurrence at Windsor the red clay, which underlies Eocene deposits of glauconite sand, has been reported in several other places in the county. It is about 35 feet thick in a well near Benns Church (124, Table 34) in the northeast part of the County. In a well at Battery Park (54, Table 35) 25 feet of clay is reported. The red clay is patchy in distribution but has been found in at least one locality in each of the counties west of Norfolk County and south of the Appomattox River.

A 72-foot stratum of variegated clay at Walters (146) may be correlated with the red clay present at Windsor. At Carrolton (108) 47 feet of brown clay occurs above Upper Cretaceous (?) red clay; it may be a variant of the red clay which it overlies. The chocolate-brown clay logged in wells at Franklin is considered to be a correlative of the red clay. An Upper Cretaceous index fossil, a species of *Exogyra,* was collected from well 160 when the drill had reached a point a few feet below this chocolate-brown stratum.

In a well at Walters (146) gray marl containing marine shells was encountered at 220 to 258 feet. It lies beneath black glauconitic clay or marl of Eocene age and above a variegated clay stratum of probable late Cretaceous age. The shell marl is therefore tentatively considered to be of late Cretaceous age. It seems possible that blue clay found below the glauconite sand at Smithfield may also be of late Cretaceous age, but, on the other hand, blue clay may be present at the top of the Potomac group, or may belong to the Eocene deposits.

Glauconite beds ("black sand") of Eocene age are present throughout the county and are 50 feet thick in some places, although generally they are less than 30 feet thick. At Franklin 45 feet of glauconitic material includes 3 strata of limy rock totaling 32 feet in thickness. (See log of well 156, Table 35.) A rock stratum, 3 feet in thickness, was reported by Sanford[102] at the base of the glauconite beds at Morgarts Beach.

The Miocene formations are well exposed in the cliffs along James River, and to lesser extent along Blackwater River.

A feature of the exposure along James River is the line of outcrop of indurated shell beds, high on the cliffs near the base of the overlying Pleistocene terrace deposits. These indurated beds were originally coquina but have been so firmly cemented by calcareous material deposited by percolating ground water that the rock is used for stone fence construction.

GROUND WATER

SHALLOW WELLS AND SPRINGS

Water is obtained from wells 10 to 25 feet deep sunk in the terrace formations throughout the county. On wide undissected terraces or pocosons wells may be only about 10 feet deep, as the water level is close to the surface (Fig. 11). In rainy seasons the water in some of these wells is less than 18 inches below the surface. Wells located near the edges of the pocosons, or in dissected terraces of small area, generally are deeper, and the water level may be more than 20 feet below the surface. According to local residents, water levels may be 4 to 7 feet lower in the dry seasons than in the wet seasons; only a very few wells are reported to have gone dry during the drought of 1930-1932.

Many of the wells are properly constructed with respect to sanitary conditions. The greatest number of them, however, lack proper casing or cover, or both. Water is drawn from many shallow wells by bucket; and in addition some wells are poorly located with respect to sources of pollution.

The water obtained from shallow wells in the terrace formations is generally soft and low in total mineral content (Table 36), but it may have an appreciable nitrate content.

No shallow wells are sunk in the Miocene deposits, as far as it is known. However, a few springs that issue from coquina beds in the ravines along James River are utilized as sources of domestic supply. The water is usually lifted by hydraulic rams about 50 feet to the high terrace on which are the residences to be supplied. All the spring water that issues from calcareous beds is reported to be hard.

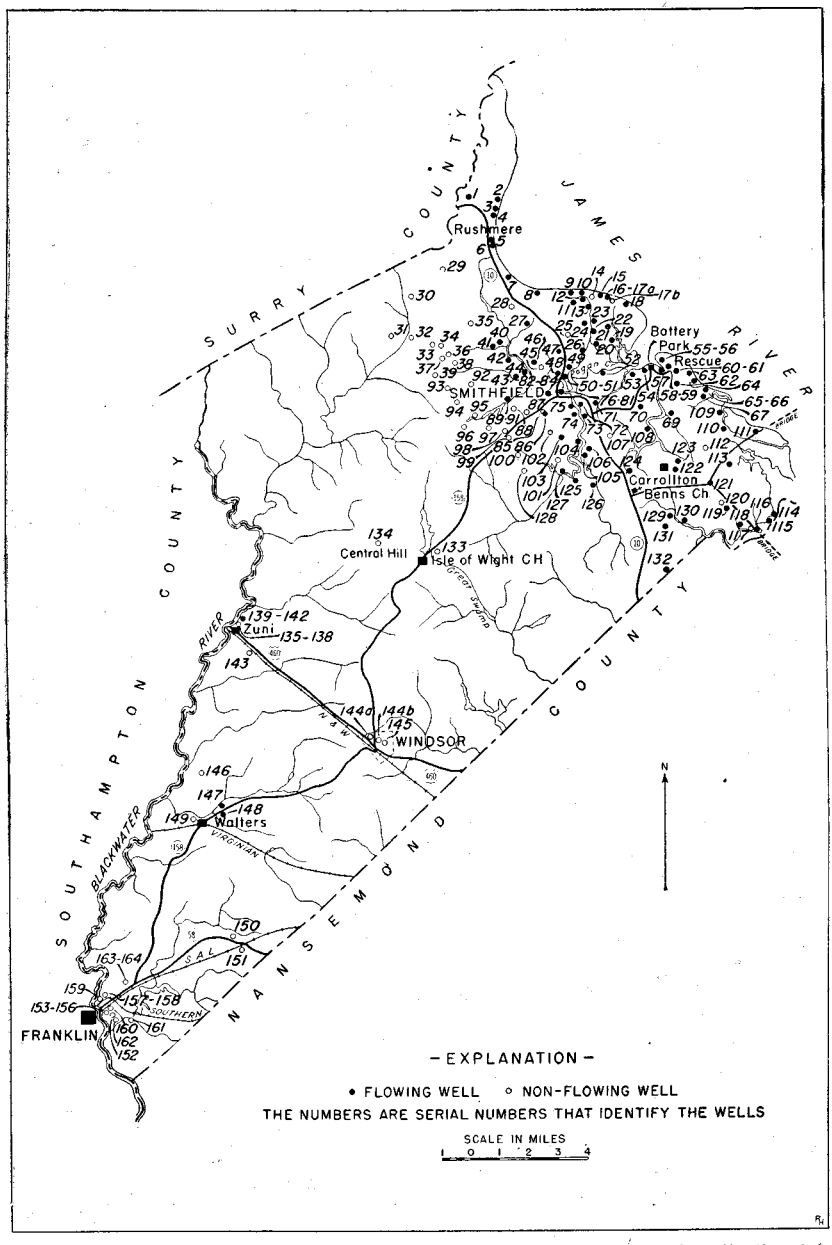


FIGURE 26.—Map of Isle of Wight County showing location of wells listed in Table 34.

DEEP WELLS

WATER FROM CRETACEOUS DEPOSITS

Small-diameter deep wells furnish an ample and constant supply of uncontaminated water to homes, farms and small industries throughout the county. Most of these wells are located on low ground along James River and its tributaries and along Blackwater River, and are or were, when drilled, flowing wells. Several large-diameter industrial wells have been drilled at Franklin.

At Smithfield water-bearing sand is encountered 320 feet below sea level. (See log of well 81, Table 35). The sand stratum dips generally seaward but, due to a fold trending east and west through Smithfield (Fig. 6), wells in the Shoals Bay area to the northwest encounter the water-bearing sand at somewhat greater depths. At Battery Park the water-bearing sand is encountered at about 335 feet below sea level.

In a well at Windsor (144b, Table 35) water-bearing sand occurs at 385 to 390 feet, 430 to 443, and 458 to 469 feet below the surface.

At Zuni water-bearing sand lies less than 200 feet below sea level. In the well at the sawmill of the Camp Lumber Co. at Franklin (156, Table 35) the first water-bearing sand is 35 feet thick and lies about 153 feet below sea level. Due to a monoclinal fold (see section D-D′, Plate I) this sand lies about 35 feet lower than the level at which it is found in the wells which supply the city of Franklin. A few miles to the east this sand thins to only 2 feet in thickness, at Carrsville (well 151, Table 34). At Walters the sand might be expected at 258 feet below sea level but none is present (see log of well 146, Table 35); however, a stratum which may correspond to the second sand at Franklin is encountered at 330 feet.

Other water-bearing sands lie deeper and are drawn upon at Franklin and at Smithfield. The second water-bearing sand is separated from the one above it by clay of variable thickness, but in a few places near Smithfield the first sand seems to merge with the second sand, as no parting is evident.

The red clay of upper Cretaceous age which underlies the Eocene deposit of glauconite sand ("black sand") has already been mentioned. In some places it seems to be present either where water-bearing sand has been locally eroded or was not deposited.

Most of the deep wells are on low ground along James and Blackwater rivers and yield artesian flows. Flowing wells near James River in 1938 had an average yield of about 16 gallons a minute. The well of largest yield discharged 42½ gallons a minute. In general all these wells have decreased in yield since they were constructed. The amount of water they might yield by pumping is not known. The oldest wells, on the high bluffs and close to the residences which they supplied with water, were drilled to the first water-bearing sand of the Potomac (?) group. As these wells became weak or ceased to flow they were abandoned, and newer wells were put down in near-by ravines at elevations from 10 to 25 feet above sea level. Many of these wells have nearly ceased to flow. The most recent wells have been sunk at the lowest possible elevations, in some places only 5 or 6 feet above sea level; and many are drilled to the deeper water-bearing strata in order to obtain greater artesian pressures.

Most of the flowing wells deliver water to hydraulic rams, which in turn force a small part of the total flow to the higher elevations on which the homes are situated. In some places, however, rams are unable to lift the water the required height, and pumps have been installed in order to insure a plentiful supply.

It is estimated that in 1938 nearly 2,000,000 gallons a day was being wasted by flowing wells in that part of Isle of Wight County which borders James River.

Flowing or pumped wells for domestic supplies are used at Zuni and Walters, but the yields are small. Larger amounts of ground water are used at Franklin. The Hygeia Ice Co. obtains 500 gallons a minute from two 4-inch wells (157, 158, Table 34), respectively 300 and 135 feet deep. This amount is pumped only about 6 months of the year, and during the remainder of the year about 250 gallons a minute is pumped. A well at the Camp Manufacturing Co. (156), drilled in 1937, is reported to have had an initial flow of 75 gallons a minute. Water from this well is pumped through the mill and also supplies several tenant houses. The pump runs continuously and furnishes about 90 gallons a minute. At the factory of Chesapeake Camp Corp. 2 wells, 307 and 368 feet in depth (152, 153), furnished water for air conditioning and other purposes up to 1942. The deeper well furnished 140 gallons a minute and was pumped continuously for about 7 months

each year. The shallower well yielded 50 gallons a minute and was pumped continuously all year. The large-diameter deep wells (160, 162) now furnish the mill with water for these purposes and provide additional millions of gallons a day for industrial use. These wells are discussed in a special section which follows.

It was estimated in 1940 that a maximum of 1,500,000 gallons a day was pumped at Franklin during the summer months, about 80 per cent of which was from wells in Isle of Wight County. During the winter, due to the decreased demand by air conditioning plants and by the ice plant, the total amount of water pumped at Franklin may have fallen to less than 1,000,000 gallons a day of which about 65 per cent came from wells in Isle of Wight County.

ARTESIAN HEAD

The height to which artesian water will rise in wells along James River varies from 12 to 22 feet above sea level. (See Fig. 9.) Water in the deeper wells rises higher than in wells drilled only to the upper sands.

At Zuni artesian water will rise to about 30 feet above sea level; at Franklin (in 1940) to about 24 feet above sea level; and at Walters to about 39 feet above sea level. Some loss of head has undoubtedly taken place at Zuni in response to a number of unchecked flowing wells. A smaller loss of head may have occurred at Walters. On the other hand, at Waverly and Wakefield in Sussex County, water levels have declined markedly over a period of years, even though at considerable distance from regions of heavy withdrawal. Hence the figure of 39 feet above sea level at Walters may not even closely approach the original water level at this place.

At Smithfield, Zuni and Franklin there has been appreciable loss of artesian head since about 1910. In that year Sanford[112] noted that in the well of J. A. Morgart, at Morgarts Beach, the static head of the artesian water was 36 feet above sea level. The well was 383 feet deep and reached the first water-bearing sand commonly drawn upon in that area. The well of Roy Conklin (17a, Table 34), in the same locality and of approximately the same depth, had a static head of 34 feet above sea level in 1908. In 1938 the head was only 15 feet above sea level. A loss of head of 19 feet in 30 years, therefore, seems to have taken place in this well. Diminution or cessation of yield has been reported by

local residents throughout the James River area in this county, and it is evident that a marked loss of artesian head has taken place generally.

The loss of head at Franklin is not known. However, reasoning from the present water level at Walters, we may be quite certain that the water rose at least 40 feet above sea level at Franklin and that the level in 1940 represents a loss of at least 16 feet. The water levels have been depressed here by the loss of water from flowing wells and by industrial pumping. Further growth of Franklin has meant increased use of ground water for industrial purposes and, to a much lesser extent, for public supply, with the result that water levels have been depressed still further.

Further losses of head along James River may be of significance chiefly because nearly all water supplies may have to be pumped instead of being lifted by hydraulic rams. Great loss of head, however, such as might be caused by heavy pumping, would result in danger of brackish-water intrusion[20], as discussed under the heading "Chloride." The danger would be greater in the area near Battery Park than in the area above Smithfield, but in either place very large installations should not be contemplated, and industries and others seeking very large supplies of ground water should be encouraged to go inland in Isle of Wight County or upstream to Surry County.

TEMPERATURE AND USE OF WATER

The temperature of the water from strata of the Potomac group in the county varies from place to place and appears to be influenced by the depth of the particular well and by the amount of the artesian flow. In general, it is apparent that the deeper the well, the warmer the water. Along James River, water from wells about 350 feet deep varies in temperature from 64½° to 67° F. Wells about 470 feet yield water varying in temperatures from 67° to 72°. At Zuni well water temperatures are 61° to 62°; and at Franklin, water from a 250-foot well has a temperature of 62°.

In many places, particularly on low ground along and near James River where good flows may be obtained, water from the Potomac strata is used for domestic purposes. The municipal supply for the city of Smithfield is obtained from 3 flowing wells near Mount Holly Pond (89-91, Table 34), drilled into sand of the

Potomac (?) group. In 1940 the water from these wells flowed into a sump and was lifted by a water-powered pump to an elevated 65,000 gallons tank. The flow of water from Mount Holly dam was used to operate the pumps, but in 1942 electric pumps were installed for this purpose.

Small waterworks systems at Zuni (well 138) and Battery Park (well 54) supply parts of those villages with artesian water. At Franklin artesian water is piped through the mills of the Camp Lumber Co., and at the Chesapeake-Camp Corp. large quantities are used for industrial purposes as well as for air conditioning and general use. As noted above, the Hygeia Ice Co. pumps a maximum of 720,000 gallons a day for cooling purposes.

QUALITY OF ARTESIAN WATER

The water obtained from deep wells in Isle of Wight County is a very soft sodium bicarbonate water. In the samples analyzed, bicarbonate ranged from 274 parts to 520 parts per million. Most of the samples had less than 5 parts per million of hardness.

Chloride is generally very low, but each of 2 samples analyzed (59, 115, Table 37) contained 25 parts per million of chloride, and one sample (111) had 55 parts per million of chloride. These 3 samples were from wells deeper than the average, in the northeast part of the county bordering James River (Fig. 26). Chloride from well 152 at Franklin, 304 feet deep, contained 4 parts per million, and a composite sample from a well (160) at the same place, 600 feet deep, contained 10 parts per million.

More than half of the waters analyzed had more than 3.5 parts per million of fluoride, and all but one had more than 1 part per million. As shown in Table 37, a sample from the 304-foot well (152) of the Chesapeake-Camp Corp. at Franklin contained 4.2 parts per million of fluoride; water from the well 600 feet deep contained 6.6 parts. Water from the well at Carrsville High School (150) contained 5.0 parts per million. At Isle of Wight High School (133), at Windsor (145), Zuni (142) and in many wells bordering James River (3, 8, 17, 40, 59, 71, 111, 115, 132), the fluoride content of the water ranged from 2 to 5 parts per million. The Smithfield municipal supply (89) contained 4.4 parts per million, but samples from 2 wells at Walters (147, 148), however, contained respectively only .8 and 1.5 parts per million of fluoride.

The presence of more than 1 part per million of fluoride in

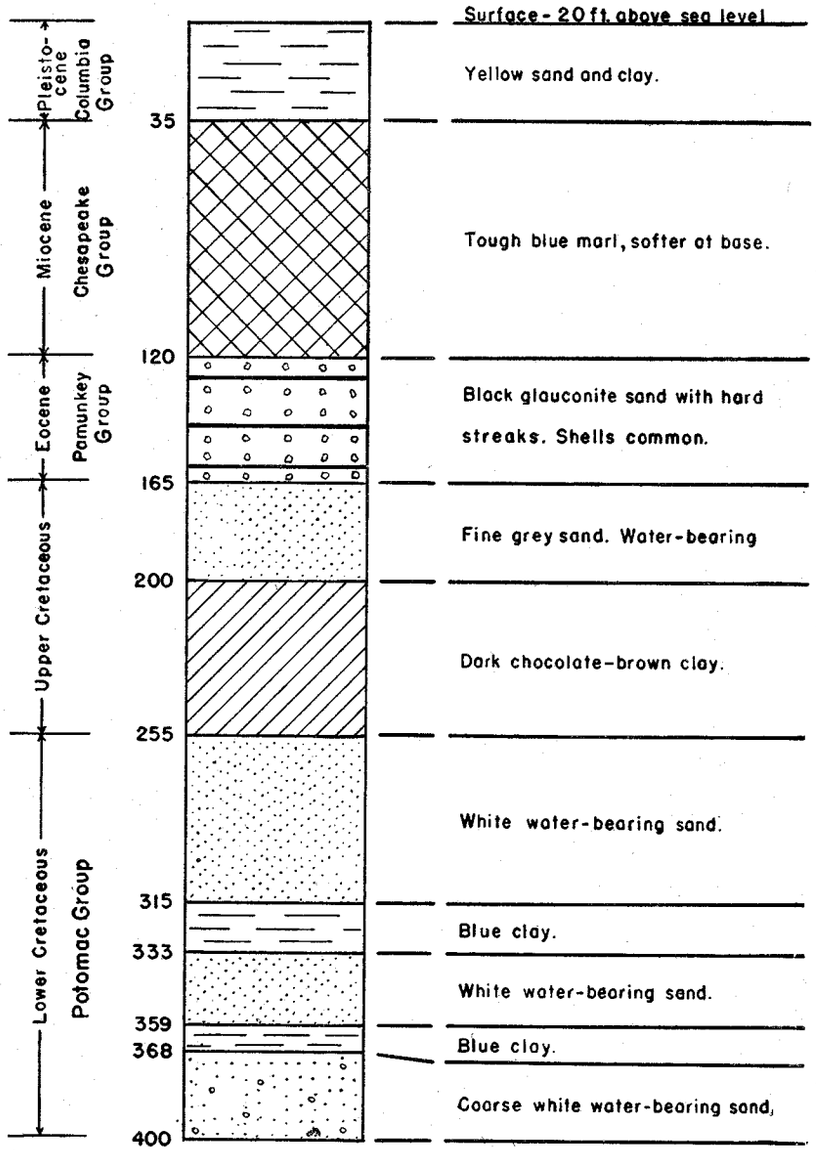
the water from many wells in the county (Fig. 16) constitutes a serious problem because of the mottling action of fluoride in drinking waters upon the teeth of children up to ten years of age.[53]

The effect of fluoride in drinking waters is recognized by many individuals in and near Smithfield and Battery Park, where water of high fluoride content is used, and some families provide fluoride-free drinking water for their children. As more than 1 part per million of fluoride in water is harmful only to the teeth of children, it would seem desirable that all children of the Smithfield and Battery Park areas be provided with drinking water from sources other than local artesian wells, rather than that existing municipal and school water-supply systems be changed. A safe drinking-water supply might be easily and cheaply provided by bottled water, taken from properly safeguarded and inspected shallow wells, or from artesian wells whose water contains no fluoride, like the one at Surry. Although the artesian wells supplying schools at Windsor yield water containing fluoride in undesirable quantities, most children at those schools have fluoride-free waters to drink in the home, and the effect of drinking artesian well water only in school is probably not serious.

The probable beneficial effect of drinking water containing up to 1.0 part per million of fluoride in inhibiting tooth decay is now recognized.[54] Families with children, having a fluoride-free source of drinking water—might find it desirable to use some high-fluoride artesian water as table water regularly.

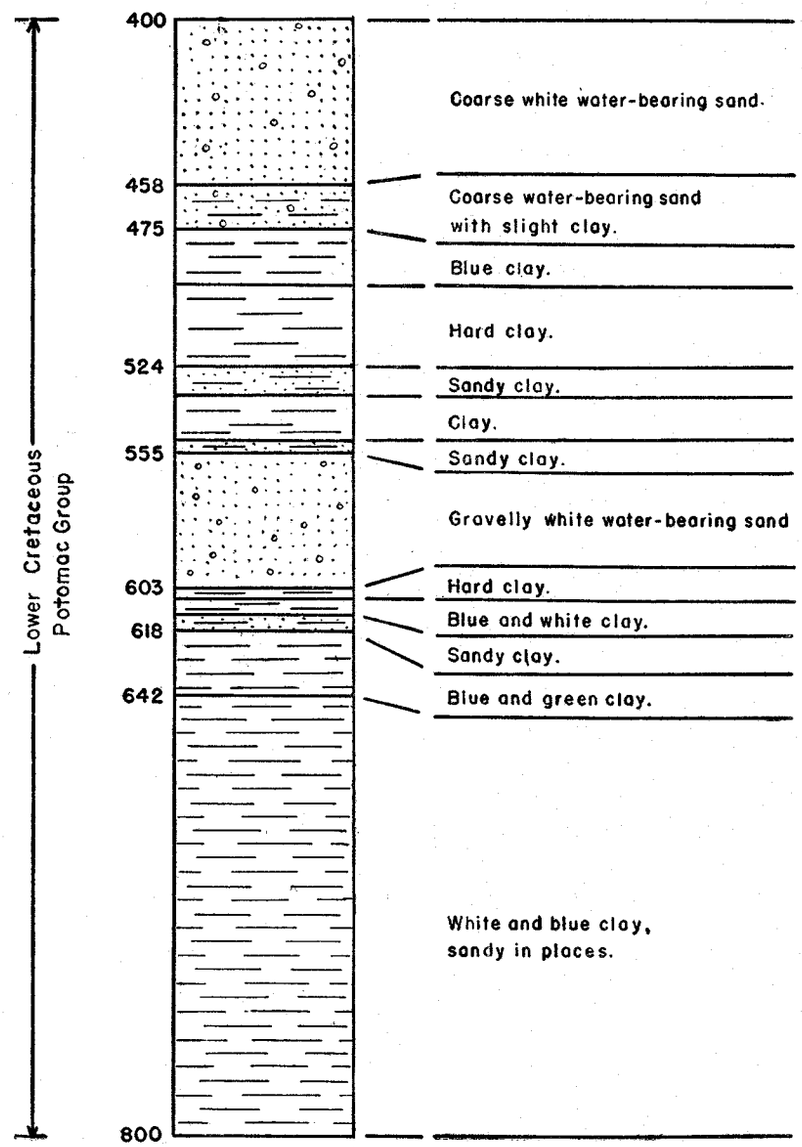
LARGE-YIELD WELLS AT FRANKLIN

The Chesapeake-Camp Corporation mill at Franklin was built in 1937-38. It produces kraft paper from wood pulp. Large quantities of water were needed in the manufacture of paper, and for a time the water used was pumped from the near-by Blackwater River. However, during the drought which began in the spring of 1941, difficulties were encountered in the use of this supply. During low-water stages flow in Blackwater River was very small and not sufficient to carry downstream the waste liquids from the mill and, in fact, incoming tides would occasionally carry waste waters upstream. For a time it was necessary to bring water to the mill from Nottoway River (where it joined the Blackwater below Franklin) by barge.



Graphic generalized geologic section at Franklin, Va.; from data by J. R. McLane and Layne-Atlantic Company.

(Continued on next page.)



It was decided to drill large-diameter wells in the hope of alleviating this situation, and in November 1941 a test well was drilled by the hydraulic rotary method (Pl. 20) to a depth of 800 feet. In addition to previously known water-bearing strata occurring above a depth of 367 feet (207, Table 30), thick sand strata between 367 and 603 feet were penetrated.[15] A 107-foot thickness of permeable sand was found at from 368 to 475 feet and a 48-foot thickness at from 555 to 603 feet (Pl. 32). Sandy strata were absent from 603 to 800 feet.

The test hole was converted into a well. Eighteen-inch casing was set from the surface to 236 feet and a string of 10-inch casing and shutter screen was set from 236 to 605 feet. Two 10-foot lengths and one 20-foot length of screen were placed at from 345 to 355 feet, from 435 to 455 feet and from 570 to 590 feet. The well was gravel packed and a turbine pump installed.

When completed the well flowed 200 gallons a minute. When the pump was put into operation the well yielded 3,200 gallons a minute, but in a few days the yield decreased to 2,500 gallons a minute (Pls. 14B and 30B). The discharge was measured volumetrically by company engineers. At that time the pumping level was 62 feet below the gauge in the pumping house. Since the original artesian head was probably not more than 2½ or 3 feet above the measuring point, the total drawdown was about 65 feet.

A second large diameter well was constructed 2,200 feet south of the first well in December, 1941. A 35-foot thickness of sand at from 281 to 316 feet (162, Table 35) was not developed in the finished well. Deeper sands, a 93-foot thickness at from 330 to 423 feet, a 67-foot thickness of clayey sand at from 423 to 490 feet, an 11-foot stratum at from 531 to 542 feet and a 49-foot thickness at from 558 to 607 feet, were developed. Eighteen-inch casing was set from the surface to 233 feet, and 10-inch casing and screen were placed from 233 to the bottom of the hole. One 10-foot length and two 20-foot lengths of screen were used and were placed at from 340 to 350 feet, from 395 to 415 feet, and at from 580 to 600 feet below the surface. The well was gravel packed and a turbine pump installed. It proved to yield about as much water as the first well.

Both wells have been operated almost continuously since they were completed (Pl. 31). On July 2, 1942, it was found that, when well 160 was in operation, the pumping level in well 162 was 82½ feet below the measuring point. After shut-down of well 162, and

24 hours recovery, depth to water was 11 feet. The drawdown when this well is in operation is therefore 70½ feet.

The pumping level on July 5, 1942, in well 160, with well 162 in operation, was 84¼ feet, or 22¼ feet more than when the well was first put into use and operated as sole supply. With well 162 shut off, the pumping level in well 160 was 82 feet, on July 5, 1941. Data on static level in well 160 are not available.

On March 8, 1944, pumping levels in both wells were essentially the same as those measured on July 5, 1942. Measurements of discharge are generally lacking; the original measurements made by the company are the only data available. To date no diminution in yield has been noted.

At the writer's suggestion an observation well[77] was constructed by the company. The observation well is 1,700 feet southeast of well 162 and 3,900 feet south-southeast of well 160. Sands were penetrated at from 285 to 440 feet, and from 575 to 605 feet (161, Table 35). Six-inch pipe was set from the surface to 129 feet, and 4-inch pipe from 129 feet to the bottom of the hole. The 4-inch pipe was slotted at from 330 to 335 feet, from 400 to 405 feet, and from 595 to 600 feet.

The well was completed with the casing extending 10 feet above the surface in order that the flow might be checked and to make possible the use of a water-level recorder activated by a float. When completed, the water stood inside the extended casing 6½ feet above the surface. By means of a siphon arrangement the well was permitted to flow for 3 days in order to clear out fine sand which might otherwise have lodged inside the casing. The rate of flow was about 10 gallons a minute.

A platform and shelter were built, and a recorder was installed over the extended casing (Pl. 9) and put into operation November 27, 1941. It has proved to be an excellent observation well and immediately sensitive to all changes in operation of wells 160 and 162 (Pl. 31).

OBSERVATION WELLS IN THE FRANKLIN AREA

The record of the Chesapeake-Camp Corp. observation well, in conjunction with other observation wells at Sebrell, Courtland, and Franklin, Southampton County, and at South Quay in Nansemond County, furnishes a picture of what is happening to the artesian head in the area as a result of pumping 7 million gallons of water a day at Franklin.

Generally speaking, the effect of heavy pumping was less than might have been expected. The record appears to be favorable insofar as continued use of large supplies of ground water are concerned. Gradually declining water levels indicate that equilibrium between discharge and recharge has not yet been reached and the pumping level is gradually increasing. A cone of depression forming about pumped wells widens as it deepens, and eventually it widens and deepens sufficiently to cause the inflow of an amount of water equal to the amount discharged. If this increase is limited by geological factors, such as lensing out or other discontinuity of water-bearing sediments, the amount of inflow will be limited and total pumpage will eventually decrease to some amount less than the amount which is being yielded at present. There are not sufficient data available to state with certainty that the cone of depression around Franklin will be limited by geological factors, and it is believed that such limitation will not occur. However, it should be pointed out that as water levels decline, water from storage is being used in part and, when equilibrium is established and water levels no longer decline, the amount of withdrawal will be somewhat less than that characteristic of the early stages of operation.

It appears that, although safe yield probably is not being exceeded at present, installation of additional large-yield wells near Franklin would alter conditions greatly. Not only would it be expected that a sharp decline of water levels would occur immediately, as great or greater than that which occurred in May, 1942 (Pl. 31), but after the initial sharp decline the water-level curves in observation wells would undoubtedly be much steeper than the curves in the period June, 1942, to July, 1943, in the Franklin area. In summary, water-level curves at present seem to indicate that the limit of safe yield is being approached, if not exceeded, and that additional discharge would exceed safe yield.

WATER-LEVEL FLUCTUATIONS

Franklin, Isle of Wight County.—The continuous record of the water level in well 161, Isle of Wight County, has furnished data on water levels at Franklin since the large-yield wells were put into operation, late in 1941.[77] From November 28, 1941, to January 12, 1942, the water level declined 2.81 feet. In this period well 160 was put into continuous operation, and well 162 was

completed and began to flow at a rate of about 200 gallons a minute. Since well 160 had been in intermittent service previous to the first observation well measurement, the water level in the area had probably declined at least two feet before the first measurement.

On January 12, 1942, kerosene was added to the well to prevent freezing of water in the extended casing and the water level rose 1.61 feet. The kerosene was removed on July 8, 1943, and the water level declined 1.8 feet. Therefore, in the intervening period the water level, as shown on Plate 33, is, on the average, 1.7 feet higher than true static level.

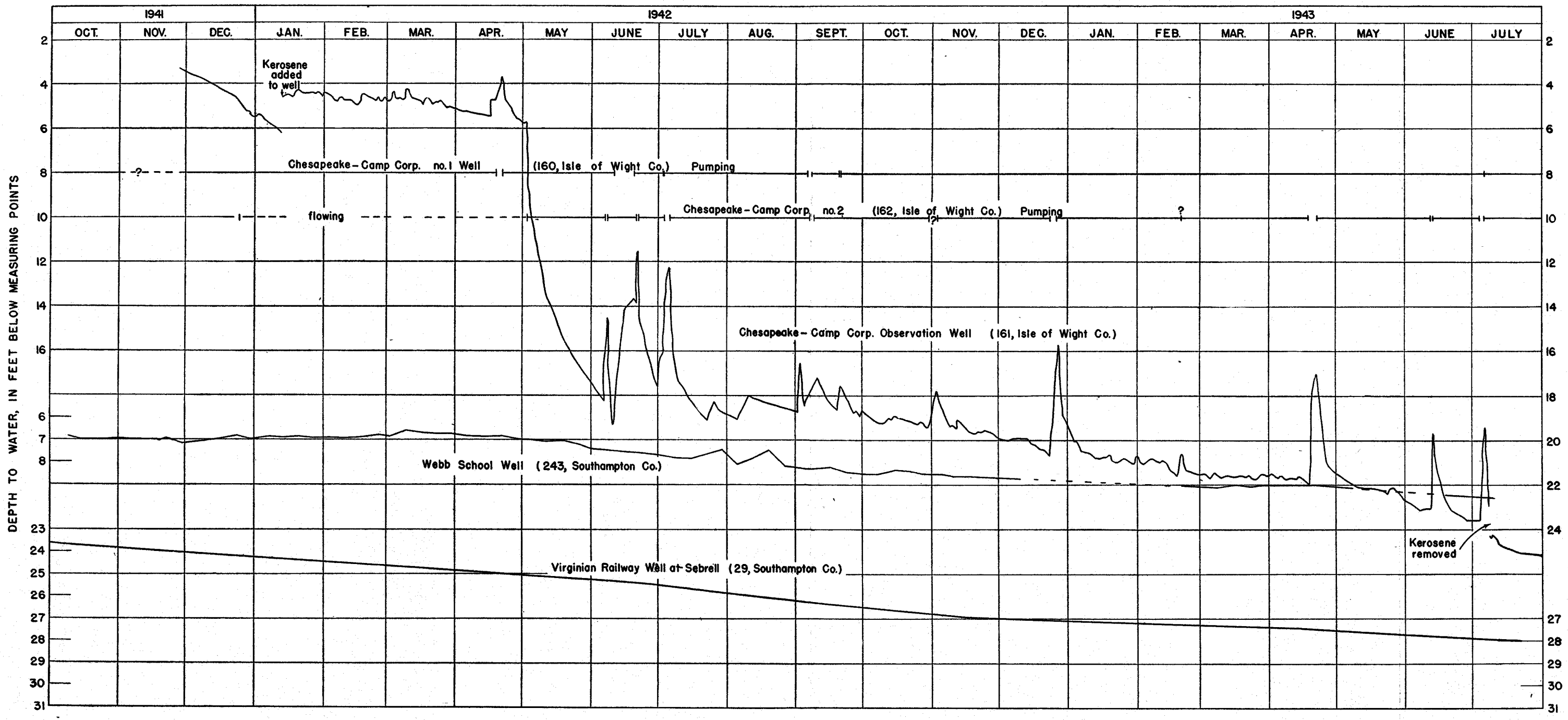
After the estimated decline of about 5 feet to January 12, 1942, the level declined 1.07 feet by May 2. When well 162 was put into operation, and the total amount of water pumped at the mill increased to about 7 million gallons a day, the water level fell sharply and in the following 37 days (by June 6) had declined 12.59 feet, or a total of about 18½ feet since November 1, 1941.

Although subject to marked variations during temporary shutdown of wells 160 or 162, the water-level curve from June 6, 1942, to July 4, 1943, trends uniformly and gradually downward. In that period it declined 4.4 feet. The total decline shown in Pl. 33 is, therefore, approximately 23 feet.

Franklin, Southampton County.—Measurements were begun on well 243, Southampton County, on August 13, 1941[77]. This well is located at Webb School, 4 miles west-southwest of Franklin. The well is 375 feet deep and taps the highest stratum developed by the large-yield wells at Franklin. From August 13, 1941, to May 1942, the water level was generally 6½ to 7 feet below the measuring point. However, as the cone of depression forming around the heavily pumped wells at Franklin advanced, the water-level in this well began to decline steadily, and by November 4, 1943, it was 10.2 feet below the measuring point (Pl. 31).

The maximum decline in the Webb School well since pumping began at Franklin to July 9, 1943, was about 3.5 feet.

South Quay, Nansemond County.—An observation well at South Quay (97b, Nansemond County),[77] 4¼ miles south-southeast of Franklin, shows no appreciable effect of heavy pumping at Franklin. From September 28, 1941, to July 9, 1943, depth to water varied only within a range of ½ foot.



HYDROGRAPH SHOWING VARIATIONS IN WATER LEVELS IN OBSERVATION WELLS AT FRANKLIN AND SEBRELL FROM NOVEMBER 1941 TO JULY 1943.

Courtland, Southampton County.—At Courtland, Southampton County, measurements have been made on well 89, at the Southampton County Court House,[78] which is 8½ miles northwest of Franklin. This well ends in the first artesian stratum at a depth of 125 feet. No appreciable decline of water levels was noted in the spring of 1942, but by the end of the year a decline of about 1 foot had occurred, and by November 1, 1944, the total apparent decline was about 5 feet.

It was not apparent at first that heavy pumping from strata below 333 feet (well 160, Isle of Wight County) affected artesian pressure in strata occurring at lesser depths, but the record of the Courtland observation wells appears to indicate that this may be so. It may be noted that the water level in the observation well at Wakefield (90, Sussex County), as discussed under "Artesian water levels" in the chapter "Water in the Potomac Group," declined about as much as the Courtland well in the same period of time. Thus a problem is presented: is the decline of artesian head at Courtland and Wakefield due to lack of recharge of Coastal Plain sediments as a result of the recent drought, or does the cone of depression centering around Franklin extend to Wakefield, 20 miles north of Franklin? Additional records will be necessary before this question can be answered.

Sebrell, Southampton County.—Although it is not certain that the cone of depression centering at Franklin extends as far as Wakefield, records[78] show that it does extend as far as Sebrell, 13 miles north-northwest of Franklin. The water level in the Virginian Railway Company well (29, Table 29) was 15 feet below the surface in 1907, according to Sanford.[111] The writer measured the depth to water on July 28, 1938, and found that the water level had declined 6.25 feet since that date (Fig. 27). This decline of .20 foot per year is attributed largely to the formation of a cone of depression resulting from the combined discharge of many flowing wells at Franklin and Courtland. The influence of the municipal wells in deepening and widening the Franklin cone was undoubtedly marked since the three (205, 206, 207, Table 29) discharge, on an average, more than 200 gallons of water a minute continuously and the rate of decline was probably quickened after those wells were installed. Installation of relatively small-yield wells, which were used more or less continuously, and installation of deeper domestic flowing wells on very low ground, which

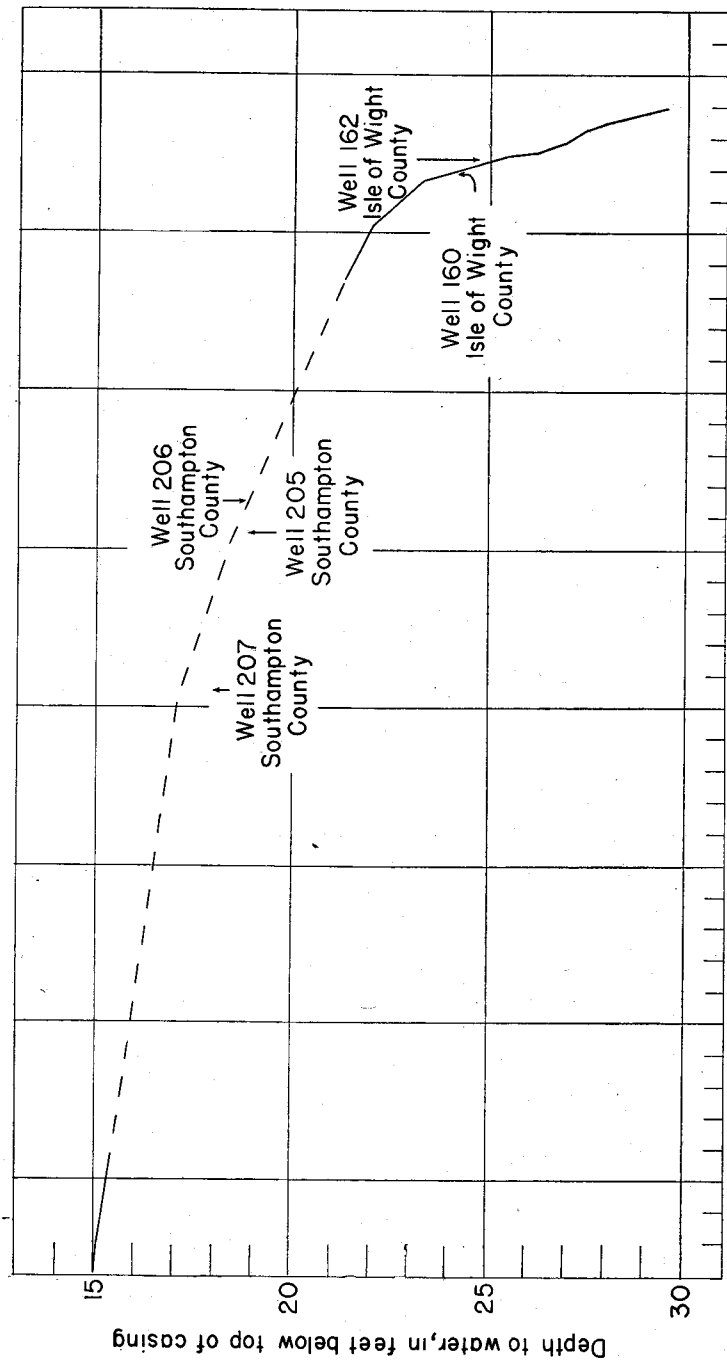


FIGURE 27.—Hydrograph showing decline of water levels at Sebrell, Southampton County, Virginia, and effect of large-yield wells at Franklin.

thereby kept pace with the declines which had already occurred, probably brought about further more rapid declines of water level.

From July 28, 1939, to September 26, 1941, the water level in the well at Sebrell declined 2.06 feet, an average of .65 foot per year, as compared with the average of .20 foot per year previous to 1938. With the installation and continuous operation of large yield wells at Franklin, water levels at Sebrell declined sharply (Pl. 31 and Fig. 27). From September 26, 1941, to November 4, 1943, the depth to water increased 5.89 feet, an average of 2.80 feet per year. More recently the curve has shown signs of flattening, since from November 4, 1943 to November 1, 1944 depth to water increased only 1.38 feet.

SAFE YIELD IN THE FRANKLIN AREA

The data resulting from deep drilling and heavy pumping at Franklin, in conjunction with the water-level observation program, are of particular value. It has been shown that very large quantities of water can be obtained from Coastal Plain deposits with relative ease in some places. Water-level observations to date show that in large developments care should be taken that safe yield is not exceeded. Data on safe yield may be obtained by drilling properly spaced observation wells and conducting pump tests, as in the case of the Bacons Castle test-drilling project, and by maintaining observation wells in and around the area of high discharge, as is being done at Franklin. Where wells are to be operated intermittently, as at Hopewell, the problem of safe yield is correspondingly less.

At present it is indicated that at Franklin the cone of depression will widen and deepen somewhat before equilibrium will be reached and the costs of lift will be correspondingly higher than when wells were first put into operation. Increasing the discharge by millions of gallons at Franklin would undoubtedly result in a marked additional decline of water levels over a wide area and might exceed safe yield.

WELL RECORDS AND ANALYSES

Records of wells in Isle of Wight County, available logs of wells, and analyses of water samples are listed in Tables 34-37, on the following pages. The locations of the wells are shown in Figure 26.

TABLE 34.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
1	1¼ miles north-northwest of Rushmere.	Warren Wilson, Jr.	J. Minton	1917	5	J
2	1 mile north-northeast of Rushmere.	Mark E. Holt	E. J. Cousins	.....	5	J
3a	¾ mile northeast of Rushmere.	S. B. Marshall	Mitchells Pump and Well Co.	1939	5	D
3b	¾ mile northeast of Rushmere.	M. L. Marshall	J. Minton	1911	9	J
4	½ mile northeast of Rushmere.	E. S. Wooley	J. Minton	1925	12	J
5	¾ mile southeast of Rushmere.	W. P. Wilson	J. Minton	1917	5	J
6	¾ mile southeast of Rushmere.	W. P. Wilson	J. Minton	1912	5	J
7	¾ mile north of Shoal Bay	H. W. Doughty	R. W. Sillings	1908	15	J
8	1 mile northeast of Shoal Bay	L. Turner	E. Evans	1908	12	J
9	1 mile west of Morgarts Beach	C. A. Snyder	W. Wilson	1908	8	J
10	1 mile west of Morgarts Beach	W. R. Weaver	J. Minton	1906	6	J
11	1 mile west-southwest of Morgarts Beach.	J. R. Barlow	J. Minton	.....	10	J
12	¾ mile west of Morgarts Beach.	B. M. Cooper	J. Minton	1928	18	J
13	¾ mile southwest of Morgarts Beach.	A. Streml	E. Evans	1912	9	J
14	½ mile west of Morgarts Beach.	F. H. Wells	J. Minton	.....	33	J
15	¼ mile west of Morgarts Beach.	Berryman	.....	.....	5	J
16	Morgarts Beach	Morgarts Beach Hotel	W. R. Sillings	1918	5	J
17a	Morgarts Beach	Roy Conklin	W. Wilson	1911	10	J
17b	Morgarts Beach	Roy Conklin	W. Wilson	1908	30	J
18	⅛ mile east of Morgarts Beach.	L. J. Upton	J. Minton	.....	7	J
19	1 mile south of Morgarts Beach.	J. B. Barlow	P. H. Haverty	1913	10	J
20	1⅓ miles south of Morgarts Beach.	W. H. Watkins	E. Evans	1912	8	J
21	1½ miles south-southwest of Morgarts Beach.	J. M. Mountjoy	E. Evans	1915	10	J
22	1¼ miles south-southwest of Morgarts Beach.	H. C. Haverty Estate	E. Evans	1912	10	J
23	1 mile southwest of Morgarts Beach.	H. C. Haverty Estate	E. Evans	1912	12	J
24	1¼ miles southwest of Morgarts Beach.	Lone Star Cement Co.	J. Minton	1929	9	J
25	2 miles southwest of Morgarts Beach.	Lone Star Cement Co.	R. W. Sillings	1917	12	J
26	2⅓ miles south-southwest of Morgarts Beach.	W. H. Sykes	J. Minton	.....	10	J
27	1 mile southeast of Shoal Bay.	T. L. Dashiell, Jr.	J. Minton	1917	15	7
28	¼ mile south of Shoal Bay	W. W. Gwaltney	E. Evans	1912	20	J
29	1⅛ miles northeast of Moonlight.	W. W. Barlow	.....	.....	77	Dug
30	Moonlight	T. H. Curtis	.....	.....	85	Dug
31	2½ miles west of Septa	E. M. Baker	.....	.....	85	Dug
32	1¼ miles west of Septa	G. L. Gwaltney	.....	.....	71	Dug
33	½ mile west of Septa	J. A. Thacker, Jr.	Owner	.....	86	Dug
34	Septa	C. H. Thacker	.....	.....	87	Dug
35	1 mile northeast of Septa	O. B. Edwards	.....	.....	85	Dug
36	½ mile south of Septa	M. E. West	.....	.....	75	Dug
37	1 mile north of Magnet	M. E. West	.....	.....	85	Dug
38	1 mile north-northeast of Magnet.	I. N. Jones	Owner	.....	80	Dug
39	½ mile north-northwest of Magnet.	Trinity School	.....	.....	86	Dug

Isle of Wight County, Virginia

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface[b]	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
365	2	+	.....	5	D S	.....	Temp. 64½° F.	1
.....	2	+	.....	.....	D	.....	.....	2
386	.....	+	.....	.....	D	.....	See log.	3a
350	2	+	.....	8	D	A	.....	3b
380	2	+	.....	[e]35	D	.....	Temp. 65° F.	4
325	2	+	.....	.....	D	.....	Temp. 65° F.	5
348	3	+	.....	.....	D	.....	Supplies 19 homes at Rushmere. See log.	6
321	2	+	.....	3	D S	.....	Flowed 20 gallons a minute in 1918.[f] See log.	7
321	2	+	.....	[g]20	D S	A	.....	8
338	2	+	.....	[g]15	D S	.....	Water head was 35 ft. above sea level in 1918[f]. See log, Table 35.	9
340	2	+	.....	.....	D S	.....	Flowed 30 gallons a minute in 1910.[g] Water head was 30 ft. above sea level in 1918.[e]	10
.....	2	+	.....	.....	D S	.....	Supplies 3 families.	11
340	2	+	.....	[g]5	D S	.....	.....	12
348	2	+	.....	[e]20	D S	.....	.....	13
375	2	−	.....	.....	D	.....	.....	14
.....	2	+	.....	[e]30	D	.....	.....	15
350	2	+	.....	[e]35	D	.....	.....	16
350	2	+	.....	[e]20	D	A	Flowed 30 gallons a minute in 1918.[f]	17a
375	2	−15	July, 1938	.....	Ab	A	Water head was 34 ft. above sea level in 1908[g] but less than 30 ft. in 1918.[f]	17b
375	2	+	.....	5	D S	.....	Glauconite sand at 275 to 310 ft.	18
345	2	+	.....	.....	D S	.....	.....	19
345	2	+	.....	[e]25	D S	.....	Water head was 25 ft. above sea level in 1918.[f]	20
340	2	+	.....	[g]35	D S	.....	.....	21
348	2	+	.....	[g]30	D S	.....	Glauconite sand at 330 to 345 ft.	22
360	2	+	.....	[e]20	D S	.....	.....	23
345	2	+	.....	[g]30	D	.....	.....	24
335	2	−	.....	.....	Ab	.....	Flowed 25 gallons a minute in 1918.[f] See log, Table 35.	25
350	2	+	.....	7	D S	.....	.....	26
340	2	+	.....	8	D	.....	.....	27
.....	2	[g]−1	1937	.....	Ab	.....	Originally flowed.	28
.....	1¼	−	.....	.....	D S	Hard	.....	29
12	.....	−1½	Dec. 3, 1937	.....	S	.....	.....	30
13	.....	−1	Dec. 3, 1937	.....	D S	.....	.....	31
9	.....	−3	Dec. 3, 1937	.....	D	Soft	.....	32
14	.....	−1	Dec. 2, 1937	.....	D S	.....	.....	33
13	.....	−1	Dec. 3, 1937	.....	D S	.....	.....	34
13	.....	−2	Dec. 3, 1937	.....	D	.....	.....	35
18	.....	−3½	Dec. 2, 1937	.....	D S	A	.....	36
14	.....	−2	Dec. 1, 1937	.....	D	Soft	.....	37
20	.....	−12	Dec. 1, 1937	.....	D S	.....	.....	38
9	.....	−¾	Dec. 3, 1937	.....	D	.....	.....	39

TABLE 34.—*Records of wells in Isle of*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
40	2¾ miles northwest of Smithfield.	J. N. Stringfield	J. N. Stringfield	1912	10	J
41	2¾ miles northwest of Smithfield.	Oliver Cox	J. N. Stringfield	1915	12	J
42	2¼ miles northwest of Smithfield.	J. M. Jones	R. W. Sillings	1918	6	J
43	1½ miles west-northwest of Smithfield.	N. G. Oberry	J. Minton	1912	6	J
44	1½ miles northwest of Smithfield.	W. F. Moody	J. Minton	1931	11	J
45	1¼ miles north-northwest of Smithfield.	T. L. Dashiell	J. Minton	1907	30	J
46	1½ miles northwest of Smithfield.	T. L. Dashiell	J. Minton	1908	12	J
47	North end of Pagan Creek bridge	Smithfield Ham Products Co.	J. Minton	1920	11	J
48	North end of Pagan Creek bridge.	Isaac Thomas	J. Minton	1934	5	J
49	1 mile north-northeast of Smithfield.	J. M. Batten	J. Minton	1936	11	J
50	North end of Pagan Creek bridge.	P. D. Gwaltney, Jr	J. Minton	1937	10	J
51	North end of Pagan Creek bridge.	P. D. Gwaltney, Jr	J. Minton	1935	10	J
52	1½ miles west of Battery Park.	H. Dashiell	R. W. Sillings	1916	12	J
53	¾ mile west of Battery Park	L. T. Gatling	J. Minton	1912	16	J
54	Battery Park	Battery Park Water Co	R. W. Sillings	1908	13	J
55	Goodwin Point, Rescue	C. L. Voight	J. Minton	1908	17	J
56	¼ mile south of Goodwin Point, Rescue.	R. S. Mountjoy	R. W. Sillings	1921	5	J
57	West bank of Jones Creek, Rescue.	R. S. Mountjoy	R. W. Sillings	1921	5	J
58	East bank of Jones Creek, Rescue.	L. Skeeter	J. Minton	.....	8	J
59	East bank of Jones Creek, Rescue.	J. H. Carter	J. Minton	1914	11	J
60	¼ mile east of Jones Creek, Rescue.	Rescue Water Co	R. W. Sillings	1917	6	J
61	Rescue	G. W. Watkins	J. Minton	1914	15	J
62	Near Jones Creek, Rescue	C. C. Driver	J. Minton	1911	15	J
63	On James River, Rescue	O. S. King	J. Minton	1923	17	J
64	On James River, Rescue	J. D. Tennis	E. Evans	1912	22	J
65	¾ mile southeast of Rescue	Martin Brothers	.....	.....	18	J
66	1 mile southeast of Rescue	S. R. Johnson	.....	.....	6	J
67	1½ miles southeast of Rescue	R. B. Cox	J. Minton	.....	10	J
69	1¾ miles south of Rescue	E. C. Mingea	J. Minton	1908	20	J
70	3 miles east of Smithfield	I. M. Scott	J. Minton	.....	17	J
71	Head of Morris Creek, Smithfield.	T. Powell	R. W. Sillings	1917	14	J
72	¾ mile southeast of Smithfield.	J. B. Grimes	J. Minton	1913	11	J
73	1 mile southeast of Smithfield	J. T. Grimes	J. Minton	.....	15	J
74	1 mile southeast of Smithfield	L. L. Chapman	J. Minton	.....	8	J
75	½ mile south-southeast of Smithfield.	C. S. Betts	J. Minton	.....	10	J
76	¼ mile east of Smithfield	Southern Oil Co	J. Minton	.....	3	J
77	Pagan Creek, Smithfield	G. W. Delk	.....	.....	6	J
78	Pagan Creek, Smithfield	P. D. Gwaltney, Jr	J. Minton	1909	5	J
79	Pagan Creek, Smithfield	P. D. Gwaltney, Jr	R. W. Sillings	.....	10	J
80	Pagan Creek, Smithfield	B. W. Godwin	J. Minton	1924	10	J
81	Pagan Creek, Smithfield	B. W. Godwin	R. W. Sillings	1914	10	J

Wight County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface[b]	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
350	2	+	.....	[g]20	D S	A	Flowed 40 gallons a minute in 1915.[g]	40
350	2	+	.....	[g]20	D	.....	.....	41
355	2	+	.....	[e]8	D S	.....	Temp. 64½° F.	42
360	2	+	.....	[e]10	D	.....	Flowed 35 gallons a minute in 1912. Temp. 64° F.	43
.....	.....	+	.....	[e]15	D	.....	Flowed 25 gallons a minute in 1931.[d] Temp. 65° F.	44
400	2	−	.....	.....	Ab	.....	Abandoned because no flow obtained.	45
350	2	+	.....	[g]15	D S	.....	Flowed 30 gallons a minute in 1908.[g]	46
410	2	+	.....	.....	D	.....	.....	47
340	2	+17½	July 30, 1938	[e]20	D	.....	.....	48
380	2	+	.....	5+	D S	.....	.....	49
361	3	+	.....	[g]25	D	.....	.....	50
360	3	+	.....	[g]25	D	.....	.....	51
340	2	+	.....	[g]15	D S	.....	.....	52
397	2	+	.....	[e]15	D	.....	Flowed 25 gallons a minute in 1912.[g]	53
350	2	+	.....	.....	M	.....	Flows only at high tide. Water head was 37 ft. above sea level in 1918 and flow was 30 gallons a minute.[f] See log.	54
400	2	+	.....	[e]10	D S	.....	Flowed 25 gallons a minute in 1908.[g]	55
385	2	+	.....	[g]30	D S	.....	.....	56
360	2	+	.....	[e]40	D	.....	.....	57
400	2	+	.....	[e]10	D	.....	.....	58
405	2	+	.....	[e]7	S	A	Temp. 65° F.	59
375	3	+	.....	.....	M	.....	.....	60
457	2	+	.....	[e]20	D	.....	.....	61
418	2	+	.....	7	D	.....	Flowed 25 gallons a minute in 1911.[g] Temp. 65½° F.	62
425	2	+	.....	[e]15	D	.....	Marked decrease in flow noted.[g]	63
375	2	±	Nov. 10, 1937	.....	D	.....	Flows only at high tide. Water head was 26 ft. above sea level in 1912.[g]	64
.....	2	+	.....	1½	D	.....	Temp. 66° F.	65
.....	2	+	.....	[e]7	D	.....	.....	66
.....	2	+	.....	.....	D	.....	.....	67
410	2	+	.....	[e]4	D S	.....	.....	69
385	2	+	Nov. 10, 1937	1	D S	.....	Flow is intermittent.	70
380	2	±	.....	2	D S	A	Marked decrease in flow noted.[g]	71
353	2	+	.....	[e]6	D S	.....	.....	72
360	2	+	.....	.....	D	.....	Supplies 6 families.	73
350	3	+	.....	[g]10	D S	.....	.....	74
350	2	+	.....	.....	D	.....	Supplies 9 families.	75
320	2	+14½	July 30, 1939	[e]25	D	.....	Temp. 67° F.	76
.....	.....	+11	July 30, 1939	[e]30	D	.....	Known locally as "the old ice plant" well.	77
340	2	+	.....	[e]10	D	.....	Flowed 35 gallons a minute in 1909.[g]	78
370	2	+	.....	5	D	.....	Known locally as the "old Peanut Company" well.	79
340	3	+	.....	.....	C	.....	Flowed 85 gallons a minute in 1924.[g]	80
350	2	+	.....	.....	C	.....	Flowed 95 gallons a minute in 1914.[g] See log.	81

TABLE 34.—*Records of wells in Isle of*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
82	Mason St., Smithfield	P. D. Gwaltney, Jr	Wilson	1908	11	J
83	Mason St., Smithfield	W. P. Warren	J. Minton	1912	10	J
84	Near High School, Smithfield	W. P. Warren	J. Minton	1923	15	J
85	½ mile southwest of Smithfield.	W. H. Sykes			30	Dv
86	½ mile southwest of Smithfield.	W. H. Sykes	J. Minton	1935	10	J
87	1 mile southwest of Smithfield.	Harold Little			60	Dug
88	¼ mile southeast of Mount Holly Pond.	E. V. Turner			62	Dug
89	Northeast of Mount Holly Pond.	Guy Stevens	J. Minton	1908	10	J
90	Northeast of Mount Holly Pond.	Guy Stevens	J. Minton	1914	10	J
91	Northeast of Mount Holly Pond.	Guy Stevens	J. Minton	1937	10	J
92	¾ mile east of Magnet	J. M. Cox			80	Dug
93	Magnet	W. R. Cox			85	Dv
94	½ mile southeast of Magnet	T. C. Chapman			85	Dv
95	1¼ mile southeast of Magnet	T. S. Brabrand			80	Dug
96	Four Square	W. M. Cobb			25	Dug
97	1 mile east of Four Square	Gus Edwards			80	Dug
98	2 miles southwest of Smithfield.	W. C. Whitehead			80	Dug
99	2 miles southwest of Smithfield.	Ida James			84	Dug
100	2½ miles southwest of Smithfield.	Caule Gale			84	Dug
101	2 miles south of Smithfield	G. W. Delk			35	Dug
102	1 mile south of Smithfield	E. B. Johnson			45	Dug
103	1¼ miles south of Smithfield	G. A. Barlow	J. Minton	1932	10	J
104	1½ miles southeast of Smithfield.	J. C. Mathews	J. Minton	1937	8	J
105	2 miles south-southeast of Smithfield.	Adeline Wilson	J. Minton		10	J
106	2 miles south-southeast of Smithfield.	J. M. Branch	J. Minton	1911	12	J
107	2 miles southeast of Smithfield.	M. R. Minton	J. Minton	1912	25	J
108	½ mile southwest of Fulgham Bridge.	S. W. Edwards	R. W. Sillings	1915	12	J
109	1¼ miles east-northeast of Puttins Bridge.	N. E. Simmons	J. Minton	1914	18	J
110	1½ miles east of Puttins Bridge.	L. Lyons	J. Minton	1915	10	J
111	End of James River Bridge	James River Bridge Corp	J. Minton	1927	3	J
112	1½ miles northeast of Carrolton.	J. W. Jordan	J. Minton	1910	24	J
113	2 miles east of Carrolton	A. O. Channel	J. Minton	1912	10	J
114	1 mile north-northeast of Chuckatuck Creek Bridge.	J. Q. Adams	J. Minton		12	J
115	½ mile north of Chuckatuck Creek Bridge.	W. G. Brennan	J. Minton	1937	96	J
116	End of Chuckatuck Creek Bridge.	J. Q. Adams	J. Minton		3	J
117	End of Chuckatuck Creek Bridge.	J. I. Davis	L. W. Brown	1911	20	J
118	½ mile northwest of Chuckatuck Creek Bridge.	J. Q. Adams	J. Minton		6	J
119	1¾ miles northwest of Chuckatuck Creek Bridge.	W. A. Daniels	L. W. Brown	1910	20	J
120	1¾ miles northwest of Chuckatuck Creek Bridge.	J. C. Ashby	L. W. Brown	1910	21	J
121	2¼ miles east-southeast of Carrolton.	James River Bridge Corp	J. Minton	1928	20	J
122	Carrolton	J. W. Jordan	J. Minton	1914	20	J
123	Carrolton	W. R. Norsworthy	J. Minton	1920	20	J

Wight County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface[b]	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
265	2	+	.....	2½	D	.....	Temp. 63½° F.	82
330	2	+	.....	[e]6	D	.....	.....	83
320	2	+	.....	[e]15	D	.....	.....	84
28	1¼	[g]−16	.....	.....	B	.....	Pumped 1,500 gallons a day during 1935-1940.	85
360	2	+	.....	[e]20	B	Foams	Foams in boiler.	86
18	.....	[g]−6	.....	.....	D S	.....	.....	87
12	.....	−5	Dec. 1, 1937	.....	D	A	.....	88
330	3	+	.....	.....	M	A	Flowed 70 gallons a minute in 1908.[g]	89
330	3	+	.....	.....	M	.....	Flowed 70 gallons a minute in 1914.[g]	90
380(?)	3	+	.....	.....	M	.....	Wells 89, 90, 91 supply Smithfield.	91
15	.....	−2	Dec. 5, 1937	.....	D	.....	.....	92
30	1¼	−	.....	.....	D	Iron	.....	93
20	1¼	−	.....	.....	D	.....	.....	94
23	.....	−17	Dec. 5, 1937	.....	D	Hard	.....	95
25	.....	−	.....	.....	D S	Soft	.....	96
25	.....	−22	Dec. 5, 1937	.....	D S	.....	.....	97
24	.....	−18	Dec. 6, 1937	.....	D	.....	.....	98
10	.....	− 1½	Dec. 6, 1937	.....	S	.....	.....	99
18	.....	− 3	Dec. 6, 1937	.....	D S	.....	.....	100
17	.....	− 4	Dec. 6, 1937	.....	D	Hard	.....	101
27	.....	−25	Dec. 6, 1937	.....	D	Soft	.....	102
360	2	+	.....	.....	D S	.....	Decrease in flow noted.[g]	103
385	2	+	.....	[g]22	D S	.....	.....	104
360	2	+	.....	[e]20	D S	.....	.....	105
400	2	+	.....	[g]15	D S	Corrodes aluminum	Flowed 30 gallons a minute in 1911.[g]	106
390	2	[g]−12	.....	.....	D S	.....	.....	107
385	2	+	.....	[e]8	D S	.....	Flowed 40 gallons a minute in 1912.[g]	108
450	2	+	.....	[e]5	D S	.....	Temp. 65° F. See log. Temp. 66¼° F.	109
.....	.....	+	.....	[e]15	D S	.....	Temp. 67¼° F.	110
457	3	+	.....	[e]25	D	A	Temp. 67° F.	111
350	2	−	.....	.....	D	.....	Originally flowed.	112
405	2	+	.....	[g]20	D S	.....	Flowed 40 gallons a minute in 1912.[g]	113
470	2	+	.....	[e]30	D S	.....	Temp. 69½° F.	114
480	2	+19	July 30, 1938	42½	D	A	Temp. 72° F.	115
520	2	+15	July 30, 1938	[e]20	D	.....	Temp. 71¼° F.	116
460	2	[g]− 4	.....	.....	D	.....	Water head originally was 12 ft. above surface.[g]	117
480	2	+	.....	25	D	.....	.....	118
418	2	+	.....	¼	D	.....	Drill lost in hole.[g]	119
428	2	[g]− 1½	.....	.....	D	.....	Originally flowed 30 gallons a minute.[g]	120
525	2	+	.....	.....	D	.....	Supplies 4 business places.	121
400	2	+	.....	6½	D	.....	Flowed 30 gallons a minute in 1914.[g]	122
400	2	+	.....	3	D	.....	Flowed 40 gallons a minute in 1920.[f]	123

TABLE 34.—*Records of wells in Isle of*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
124	Benns Church	B. Yoeman	R. W. Sillings	1915	18	J
125	2 miles west of Benns Church	S. A. Whittely	J. Minton	.....	4	J
126	1 mile west of Benns Church	S. A. Whittely	J. Minton	1936	5	J
127	2¼ miles west-northwest of Benns Church.	B. H. Copeland	J. Minton	.....	15	J
128	1¾ miles north of Carrol Bridge.	J. Gwaltney	.....	.....	80	Dug
129	2 miles southeast of Benns Church.	Junius Batten	J. Minton	1911	15	J
130	2½ miles southeast of Benns Church.	Ivy Turner	J. Minton	1915	3	J
131	2 miles southeast of Benns Church.	E. E. Holloway	J. Minton	1912	15	J
132	3½ miles south-southeast of Benns Church.	R. B. Wood	J. Minton	1914	10	J
133	Isle of Wight	Isle of Wight High School	J. Minton	1928	59	J
134	2 miles west of Isle of Wight	W. D. Joyner	J. R. McLane	1918	93	J
135	Zuni	M. T. Harris	R. W. Sillings	1924	30	J
136	Zuni	C. M. Joyner	R. W. Sillings	.....	30	J
137	Zuni	B. W. Ely	J. Minton	1931	40	J
138	Zuni	Columbian Peanut Co	R. W. Sillings	1925	41	J
139	Zuni	W. T. Hall	R. W. Sillings	1924	20	J
140	Zuni	Percy Bradshaw	R. W. Sillings	.....	30	J
141	Zuni	County Highway Dept	R. W. Sillings	1914	30	J
142	Zuni	P. H. Doles	R. W. Sillings	1927	18	J
143	1½ miles southeast of Zuni	Norfolk & Western Railway Co.	J. A. Coffman	1910	60	D
144a	Windsor	S. T. Holland	J. R. McLane	1936	85	J
144b	Windsor	Jenkins	J. Minton	1940	85	J
145	Windsor	High School	J. Minton	1933	85	J
146	1½ miles north of Walters	J. R. Boyette	J. R. McLane	1937	71	J
147	Walters	Mt. Carmel Christian Church.	J. Minton	.....	37	J
148	Walters	School	.....	1934	20	J
149	Walters	O. V. Joyner	J. R. McLane	1920	52	J
150	Carrsville	High School	J. Minton	1933	65	J
151	Carrsville	G. W. Wade	J. R. McLane	1928	60	J
152	Franklin	Chesapeake-Camp Corp	Mitchells Pump and Well Co.	1937	22	D
153	Franklin	Chesapeake-Camp Corp	Mitchells Pump and Well Co.	1938	20	D
154	Franklin	Camp Manufacturing Co	J. R. McLane	1927	10	J
155	Franklin	Camp Manufacturing Co	J. R. McLane	1931	10	J
156	Franklin	Camp Manufacturing Co	J. R. McLane	1937	10	J
157	Franklin	Hygeia Ice Co	J. R. McLane	1929	9	J
158	Franklin	Hygeia Ice Co	J. R. McLane	1930	9	J
159	Franklin	J. R. Boyette	J. R. McLane	1929	14	J
160	Franklin	Chesapeake-Camp Corp	Layne-Atlantic Co	1941	20½	D
161	Franklin	Chesapeake-Camp Corp	Layne-Atlantic Co	1941	15	D
162	Franklin	Chesapeake-Camp Corp	Layne-Atlantic Co	1941	6	D
163	Franklin	Airport	Sydnor Pump and Well Co	1942	30	D
164	Franklin	Airport	Sydnor Pump and Well Co	1942	30	D

[a]D = drilled. Dv = driven. Dug = dug. J = jetted.
[b]As of October and November, 1937, unless otherwise noted.
[c]A = air conditioning. Ab = abandoned. B = boiler feed. C = cooling; D = domestic. I = industrial. M = municipal. P = public school.

Wight County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level: Feet above (+) or below (−) surface[b]	Approximate Water Level: Date of measurement	Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
385	2	+	.....	[e]25	D	.....	Supplies 3 homes. No decrease in flow 1915-1940.[f]	124
375	2	+	.....	[e]20	D S	.....	.....	125
350	2	+	.....	[g]30	D S	.....	.....	126
.....	2	+	.....	[e]20	D S	.....	.....	127
18	.....	−8	Dec. 6, 1937	.....	D S	.....	.....	128
400	2	+	.....	[e]15	D	.....	Temp. 66¼° F.	129
.....	2	+15	July 30, 1938	[e]40	D S	.....	.....	130
375	2	+	.....	[e]10	D	.....	Flowed 20 gallons a minute in 1912.	131
475	2	+	.....	[e]15	D	A	Temp. 66° F.	132
444	3	−	.....	.....	P	A	.....	133
419	4	−	.....	.....	D	A	Temp. 61° F.	134
227	2	−	.....	.....	D	.....	Flowed until 1935. Temp. 61½° F.	135
.....	2	−	.....	.....	D	.....	.....	136
232	2	[g]−11	.....	.....	D	.....	Supplies 3 homes.	137
255	4	[g]−11½	.....	.....	B	Foams	.....	138
225	3	+	.....	[e]10	M	.....	Supplies 14 homes.	139
.....	2	+	.....	1	D	.....	.....	140
212	2	+	.....	1	D	.....	Flowed 20 gallons a minute in 1914.[g] Temp. 62° F.	141
210	2	+	.....	12	D	A	Temp. 61° F.	142
265	6	[g]−30	1910	.....	B	.....	See log.	143
430	3	[g]−55	1936	.....	M	.....	Supplies 9 homes.	144a
458	3	−	.....	.....	D	.....	See log.	144b
384	3	[g]−55	1933	.....	P	A	.....	145
337	2	−	.....	.....	D S	.....	See log, Table 35.	146
296	2	+ 2½	July 29, 1938	1	D	A	Temp. 61° F.	147
320	3	+	.....	[e]10	D	A	Temp. 63½° F.	148
302	2	[g]−13	1920	.....	D	.....	.....	149
430	3	−	.....	.....	P	A	.....	150
355	3	−	.....	.....	D	.....	.....	151
307	6	+	.....	26	Ab	A	From 1938 to 1941 supplied water for air conditioning, 140 gallons a minute. Temp. 62° F.	152
368	6	+	.....	.....	D	.....	Pumps 50 gallons a minute.	153
135	2	+	.....	.....	D	.....	.....	154
175	1¼	+ 8	July 20, 1938	5	D	.....	Supplies water to fountain near office. Temp. 62° F.	155
316	4	+	.....	[g]75	D	.....	.....	156
300	4	+	.....	[g]47	C	.....	Pumps 500 gallons a minute in summer and one-half as much in winter.	157
135	4	+	.....	[g]17	C	.....	.....	158
250	2	+ 9½	July 20, 1938	10	D	.....	Water level below surface in 1942. Temp. 62° F.	159
800	18-10	+	Nov., 1941	[g]200	I	A	See log. See text for discussion of yield.	160
605	6-4	+6.8	Nov. 27, 1941	.....	.....	.....	Used as observation well. See Plate 9. M. P. 25.3 above sea level. See log.	161
610	18-10	+	Dec. 25, 1941	.....	I	.....	See log.	162
180	8	−12½	Nov. 16, 1942	.....	D	A	Tested 45 gallons a minute with 87 ft. drawdown. Screen at 164 to 170 ft.	163
170	8	−14	1942	.....	D	.....	Tested 60 gallons a minute with 43 ft. drawdown. Screen at 155 to 161 ft.	164

[d]Analysis in Table 36 or 37.
[e]Estimated.
[f]Data collected by R. D. Mesler in 1918.
[g]Reported by owner or driller.

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia*

Well 3a, Rushmere; S. B. Marshall
(Log by Mitchells Pump and Well Co.)
Altitude, 5 feet

	Thickness (feet)	Depth (feet)
Undescribed	219	219
Chesapeake group (Miocene):		
Rock	1	220
Sand and rock	10	230
Pamunkey group (Eocene):		
Green sand and mud	70	300
Undifferentiated (Upper Cretaceous ?):		
Gray sand and mud	60	360
Potomac group (Lower Cretaceous):		
Gray and white sand, water	26	386

Well 7, Burwells Bay; H. W. Doughty
(Log by R. W. Sillings)
Altitude, 15 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Marl	12	12
Blue clay	248	260
Pamunkey group (Eocene):		
Black sand	45	305
Potomac (?) group (Lower Cretaceous):		
Fine white sand	14	319
Coarse sand, water	2	321

Well 25, 1¼ miles south of Morgarts Beach; Lone Star Cement Company
(Log by R. W. Sillings)
Altitude, 12 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Marl	60	60
Blue clay	205	265
Pamunkey group (Eocene):		
Black sand (glauconite)	30	295
Potomac (?) group (Lower Cretaceous):		
White compact sand	40	335
Loose sand and gravel, water	..	..

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia—Continued*

Well 54, Battery Park; Battery Park Water Company
(Log by R. W. Sillings)
Altitude, 13 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Shell marl	40	40
Blue clay and mud	220	260
Pamunkey group (Eocene):		
Black sand	25	285
Undifferentiated (Upper Cretaceous ?):		
Red tough clay	25	310
Potomac (?) group (Lower Cretaceous):		
Fine white sand	35	345
Coarse sand and gravel, water	..	..

Well 81, Smithfield; Smithfield Ice Plant
(Log by R. W. Sillings)
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Blue marl	60	60
Blue clay	180	240
Pamunkey group (Eocene):		
Black sand	50	290
Undifferentiated (Upper Cretaceous):		
Blue sandy mud	30	320
Potomac (?) group (Lower Cretaceous):		
Coarse white sand and gravel, water	1	321

Well 108, Carrolton; S. W. Edwards
(Log by R. W. Sillings)
Altitude, 8 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Red clay	15	15
Blue marl	245	260
Undifferentiated (Upper Cretaceous ?):		
Brown mud, hard clay	47	307
Bright-red clay	26	333
Potomac group (?) (Lower Cretaceous):		
Fine white sand	53	386
Coarse gravel and sand, water	4	390

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia—Continued*

Well 143, Dwight Siding; Norfolk & Western Railway
(Log by Norfolk & Western Railway Co.)
Altitude, 60 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	10	10
Sand	20	30
Chesapeake group (Miocene):		
Blue mud	30	60
Marl	80	140
Blue sand	55	195
Pamunkey group (Eocene):		
Black sand	25	220
Undifferentiated (Upper Cretaceous ?):		
Blue mud	40	260
Potomac (?) group (Lower Cretaceous):		
White sand, water	5	265

Well 144b, Windsor; Mr. Jenkins
(Log by Jesse Minton)
Altitude, 85 feet

	Thickness (feet)	Depth (feet)
Undescribed beds	300	300
Pamunkey group (Eocene):		
Black sand	25	325
Undifferentiated (Upper Cretaceous ?):		
Red clay	25	350
Blue clay	35	385
White arkosic sand, water	5	390
Black sand and mud	37	427
Fine green sand	3	430
White arkosic sand, water	13	443
Mixture of black sand and white sand	15	458
Potomac (?) group (Lower Cretaceous):		
White arkosic sand, water	10+	468+

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia—Continued*

Well 146, Walters; J. R. Boyette
(Log by J. R. McLane)
Altitude, 33 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	5	5
Yellow clay	15	20
Gravel	15	35
Chesapeake group (Miocene):		
Blue mud with shell layers	135	170
Sand and shells	10	180
Pamunkey group (Eocene):		
Black sand	30	210
Black clay or marl	10	220
Undifferentiated (Upper Cretaceous ?):		
Gray shell marl; layer of quartizite at 250 to 251½ feet	38	258
Variegated (white, pink, brown) clay	72	330
Potomac group (Lower Cretaceous):		
White sand, water	7	337

Well 156, Franklin; Camp Manufacturing Co.
(Log by J. R. McLane)
Altitude, ±20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	35	35
Chesapeake group (Miocene):		
Blue mud	85	120
Pamunkey group (Eocene):		
Black sand with 3 layers of rock, each about 1 foot thick	45	165
Undifferentiated (Upper Cretaceous ?):		
Gray sand	35	200
Dark chocolate-brown clay	55	255
Potomac group (Lower Cretaceous):		
White sand, water	61	316

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia—Continued*

Well 161, Franklin; Chesapeake Camp Corp.
(Log by Layne-Atlantic Company)
Altitude, 15 feet

	Thickness (feet)	Depth (feet)
Fine white sand	20	20
Blue clay	63	83
Fine black sand	12	97
Rock	3	100
Fine black sand[a]	100	200
Blue clay	85	285
Medium to coarse sand, water	165	440
Clayey sand	25	465
Sandy clay	35	500
Hard sticky clay	75	575
Sand, water	30	605

[a]Black sand probably does not extend below about 150 feet. In drilling this stratum caved badly.

Well 162, Franklin; Chesapeake Camp Corp.
(Log by Layne-Atlantic Company)
Altitude, 7 feet

	Thickness (feet)	Depth (feet)
White sand	25	25
Blue clay	75	100
Fine black sand[b]	116	216
Hard blue clay	65	281
Sand, water	35	326
Blue clay	14	330
Soft sand, water	93	423
Clayey sand; probably water bearing	67	490
Hard clay	41	531
Sand, water	11	542
Hard clay	16	558
Sand, water	49	607
Sandy clay	3	610

[b]Black sand probably does not extend below about 140 feet. In drilling this stratum caved badly.

TABLE 35.—*Logs of wells in Isle of Wight County, Virginia—Continued*

Well 163, Franklin Airport
(Log by Sydnor Pump and Well Co.)
Altitude, 30 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Gray sand and clay	12	12
Sand	7	19
Chesapeake group (Miocene):		
Blue clay	31	50
Very tough blue clay	28	78
Blue marl	17	95
Tough blue marl	10	105
Pamunkey group (Eocene):		
Glauconite sand	14	119
Poorly cemented glauconite sand and sea-green clay	4	123
Midway (?) group (Paleocene):		
Glauconite sand	23	149
Cemented shell stratum	1	150
Glauconite sand	3	153
Undifferentiated (Upper Cretaceous ?):		
Fine quartz and glauconite sand	5	158
Tough brown clay	6	164
Gray sand with a trace of glauconite, water	4	168
Tough brown clay	12	180

TABLE 36.—*Analyses of waters from Quaternary deposits in Isle of Wight County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 34)

	36	88
	Septa	Smithfield
Iron (Fe)	.....	.....
Bicarbonate (HCO_3)	1.0	48
Sulfate (SO_4)	1.0	15
Chloride (Cl)	8.0	4.0
Fluoride (F)	.0	.20
Nitrate (NO_3)	12	27
Total dissolved solids at 180°C	.....	.....
Total hardness as $CaCO_3$	10	70
Date of collection	Dec. 4, 1937	Dec. 4, 1937

Analyst: W. M. Noble.

TABLE 37.—*Analyses of waters from Cretaceous*

(Parts per million. Numbers in name column

	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Rushmere (3a)	.....	.....	.....	.....	.....	.....	410
Rushmere (3b)	.....	0.17	4.8	3.1	181		465
Shoal Bay (8)	.....	.....	.....	.....	.....	.....	383
Morgarts Beach (17a)	42	.08	3.4	.7	170		429
Morgarts Beach (17b)	.....	.....	.....	.....	.....	.....	409
Smithfield (40)	.....	.....	.....	.....	.....	.....	459
Rescue (59)	.....	.....	.....	.....	.....	.....	437
Smithfield (71)	.....	.....	.....	.....	.....	.....	410
Smithfield (89)	.....	.....	.....	.....	.....	.....	419
James River Bridge (111)	.....	.....	.....	.....	.....	.....	438
Chuckatuck Bridge (115)	.....	.....	.....	.....	.....	.....	452
Benns Church (132)	.....	.....	.....	.....	.....	.....	520
Isle of Wight (133)	.....	.....	.....	.....	.....	.....	312
Central Hill (134)	.....	.....	.....	.....	.....	.....	314
Zuni (142)	.....	.....	.....	.....	.....	.....	388
Windsor (145)	.....	.....	.....	.....	.....	.....	438
Walters (147)	.....	.....	.....	.....	.....	.....	513
Walters (148)	.....	.....	.....	.....	.....	.....	311
Carrsville (150)	.....	.....	.....	.....	.....	.....	274
Franklin (152)	.....	.....	.....	.....	.....	.....	290
Franklin (160)	31	.....	.3	.3	102	4.5	233
Franklin (163)	.....	.....	.....	.....	.....	.....	434

Analysts: 3b, Addie T. Geiger; 17, C. S. Howard; 147 and 152, Margaret D. Foster; 160, Margaret D. Foster and L. W. Miller; 163, F. W. Lohr; others by W. M. Noble.

deposits in Isle of Wight County, Virginia

refer to corresponding well numbers in Table 34)

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids 180°C	Total hardness as $CaCO_3$	Free carbon dioxide (CO_2)	Date of collection
2.0	12	3.6	0.35	.....	<5	.....	Nov. 10, 1937
7.2	13	.....	.38	568	25	.....	Oct. 19, 1918
4.0	6.0	3.4	.12	.....	<5	.....	Nov. 9, 1937
6.7	14	.....	Tr.	458	11	.....	Oct. 20, 1918
4.0	10	3.8	.40	.....	<5	.....	Nov. 10, 1937
5	4.0	3.9	.46	.....	<5	.....	Apr. 18, 1938
8.0	25	4.4	.48	.....	<5	.....	Nov. 10, 1937
5.0	8.0	3.7	.47	.....	<5	.....	Nov. 10, 1937
5.0	4.0	4.4	.55	.....	<5	.....	Nov. 20, 1937
8.0	55	4.9	.70	.....	<5	.....	Nov. 10, 1937
8.0	25	4.4	.05	.....	<5	.....	Nov. 10, 1937
3.0	5.0	5.0	.65	.....	<5	.....	Nov. 12, 1937
4.0	1.0	2.8	.33	.....	<5	.....	Nov. 20, 1937
3	2.0	1.9	.10	.....	<5	.....	Apr. 18, 1938
1	2.0	2.2	.10	.....	<5	.....	Nov. 20, 1937
1	4.0	4.0	.64	.....	<5	3.6	Apr. 18, 1938
1	3	.8	.0	.....	6	.7	Nov. 10, 1938
3	2.0	1.5	.10	.....	<5	5.0	Apr. 18, 1938
5.0	4.0	5.0	.30	.....	<5	.....	Nov. 11, 1937
7	4.0	4.2	.0	.....	<5	.....	Sept. 15, 1937
9.5	10	6.6	.15	282	2.5	.....	Nov. 27, 1941
1	4	2.1	.....	.....	14	.....	Dec. 6, 1943

NANSEMOND COUNTY

LOCATION AND DEVELOPMENT

Nansemond County extends as a narrow strip from the mouth of James River southward to the North Carolina State line. Isle of Wight County lies on the west and Norfolk County on the east.

The area of the county is 406 square miles, of which 56 per cent is classed as farm land. According to the Census of 1940, the population of the county was 34,076, of which almost a third was located in Suffolk. The rural section of the county is engaged mainly in the production and processing of food stuffs. A vegetable cannery is located at Drivers, and Suffolk is outstanding as a center for peanut products. Lumbering, sawmills and planing mills are of lesser importance. Marl is quarried near Chuckatuck for the manufacture of cement.

TOPOGRAPHY

That portion of the county which is west of Nansemond River and Dismal Swamp, is made up chiefly of the dissected Wicomico terrace, which lies about 70 to 80 feet above sea level, sloping gently southeastward. A large part of this area is nearly level but is broken where the terrace is crossed by tributaries to Blackwater and Nansemond rivers, and to Dismal Swamp.

The Wicomico terrace descends abruptly to a lower terrace, by a scarp which extends from the North Carolina State line northward through Suffolk and Chuckatuck. This lower or Pamlico terrace makes the fine farmlands in the northern part of the county. Dismal Swamp, which lies on the Pamlico terrace, occupies the eastern portion of the county and extends into Norfolk County, and also southward into North Carolina.

GEOLOGY

Depths to bedrock have not been determined anywhere in Nansemond County; but reasoning from data obtained at Mulberry Island and at Fortress Monroe across James River, it seems likely that at Suffolk in the central part of Nansemond County, bedrock may be about 1,400 feet below the surface.

The upper boundary of the Potomac group of alternating clays and sands is indeterminate from drillers' logs of most wells

in Nansemond County because, in the writer's opinion, Upper Cretaceous strata which are very variable in thickness and lithologic character are widely distributed and easily confused with Lower Cretaceous deposits.

It is likewise difficult to establish the upper and lower boundaries of the Eocene deposits because in some places characteristic glauconitic beds are seemingly absent, or Upper Cretaceous deposits similar in appearance to those of Eocene age may be present.

Careful logging of a test hole at Lake Prince has furnished a detailed record down to 905 feet below sea level. The strata present have been subdivided with reasonable accuracy on the basis of fossil evidence and the best procedure at this time, therefore, seems to be to discuss the section at Lake Prince (Pl. 34) and to compare logs of other wells in the county with it.

Deposits of the Potomac group penetrated in the test hole consist of 473 feet of alternating sand and clay strata. The deepest clay beds were tougher than those above. The thickest of these encountered were 28, 33, and 32+ feet. Sandy strata, on the other hand, were thicker, 42½, 40, 67 and 46 feet being the thickest penetrated. These made up 68 per cent of the deposits. Sand below 800 feet was more coarse than shallower sands and formed about as large a proportion of beds present higher in the hole (Pl. 36). There was no indication that additional permeable sands might not be found at still greater depths.

At comparable depths the Potomac (?) sediments in well 104 (Table 40), 1 mile northwest of Suffolk, contained much less sand. "Shells" reported in this well below 559 feet may have been washed down from higher horizons, since the well was drilled by the rotary method. It is not impossible, however, that Upper Cretaceous deposits extend to this depth.

In well 106, 1 mile east of Suffolk, the record seems reasonably comparable to the Lake Prince log. One hundred and fifty-five feet of Potomac (?) deposits contain only subordinate clay; much of the sand penetrated may be relatively fine, however. Potomac strata may be reached in well 109 at about 500 feet; the 103½ feet of strata below that depth contains slightly more clay than sand.

The presence of the gray clays and subordinate sandy strata of late Cretaceous age in Nansemond County is proved by the presence of a species of *Exogyra* found in wells at Lake Prince and Drivers (Pl. 35 and log of well 37, Table 40). The 100 feet of red

clay and the underlying thin blue clay stratum encountered in well 8 at Chuckatuck may be late Cretaceous in age, as may the 30 feet of red clay found at a similar stratigraphic horizon in well 106, east of Suffolk. Red gravel at 330 to 365 feet in well 115 at Cypress may also be of late Cretaceous age. Nothing similar to this red gravel has been reported in southeastern Virginia from formations of the Potomac or Pamunkey groups. It is thought that Upper Cretaceous formations are most likely logged in wells 104 and 109 (Table 40), but their separation from those of the Lower Cretaceous (Potomac group) below and the Eocene (Pamunkey group) above is impossible on the basis of data at hand.

At Lake Prince the Pamunkey group of Eocene age consists of 77 feet of highly glauconitic marl.

At Monogram Farm (37) the Eocene strata, from 315 to 373 feet, consist of glauconitic sandy marl and greenish clay.

"Black sand" of the Pamunkey group is reported in several wells near Chuckatuck and in well 106 east of Suffolk. "Black rotten rock" in the City of Suffolk test well (104, Table 40) is almost certainly of Eocene age but in the log of the Planters Nut and Chocolate Co. well (109) at Suffolk, it seems impossible on the basis of drillers' logs to designate any particular stratum as Eocene in age. Pamunkey deposits may be absent at Cypress; certainly highly characteristic glauconitic beds are absent there.

The base of the Chesapeake group of Miocene age (Fig. 6) is about 218 feet below sea level at Lake Prince and 295 feet at Drivers. At Chuckatuck the base of the Miocene appears to be 365 feet below sea level, and east of Suffolk (well 106), 333 feet below sea level.

As recognized at Bacons Castle, the Miocene consists of basal sandy marls, in places dull-brown or drab-olive-green in color, above which lies an intermediate zone of almost unfossiliferous blue or gray marls which are very tough in places. Sandy highly fossiliferous marls occur near the surface. These three lithologic units may correspond approximately with the Calvert, St. Marys and Yorktown formations. Fossils collected during the drilling of the Lake Prince test well are given in Table 9.

According to Mr. E. N. Woodward, Superintendent at the Chuckatuck quarries, the sequence of material is approximately as follows:

Material encountered in quarries near Chuckatuck, Va.

Material	Approximate thickness (feet)
Soil	2
Red clay	5
Gummy brown clay and marl, with a few shells	5
Red shell marl (coquina)	10
Stony shell marl (partly consolidated and cemented coquina)	0.5
Blue marl with shells	1 to 10
Blue marly clay	

The red shell marl and stony shell marl (Pl. 31) are quarried, and a little of the material above and below may also be taken. As calcium carbonate is the mineral desired, operations are limited by the amount of included clay and other siliceous material encountered, and the ease with which it may be removed. In a typical run, material containing 55 per cent or more of calcium carbonate and 13 per cent or less of silica may be quarried. After being milled the product contains 75 per cent or more of calcium carbonate and 6 per cent or less of silica.

The occurrence of these sediments appears to offer evidence of a considerable amount of secondary leaching by ground water. The uppermost red clay may be part of a Pleistocene terrace formation, but the clay and marl layer beneath, which is a dirty brown mixture containing many shell fragments, appears to be a weathered shell marl from which some of the shell material has been leached. The red marl is a very permeable coquina containing little other material. Its color is indicative of oxidation which could have taken place only when ground-water levels were lower than they are at present. The red marl lies upon a thin hard, stony layer, comparable to the zone of enrichment of metalliferous deposits, which presumably marks the ground-water level at which the deposition of calcareous material and oxide of iron cemented an open-textured layer of shells into a hard, less permeable rock. As this layer is now 5 to 20 feet below the water table, either subsidence of the land or rise in the water table has taken place since the stony layer was formed. The blue marl (Pl. 31) and blue clay beneath are unaltered sediments. Marl containing a high percentage of shells must have been present before such concentrations could take

place, and the thickness of the red marl may have been limited by some original characteristic of the formation. The marl deposits are of limited extent.

An excellent description of similar beds at Yorktown has been given by Roberts[89]. The terraces of Pleistocene age which cover the

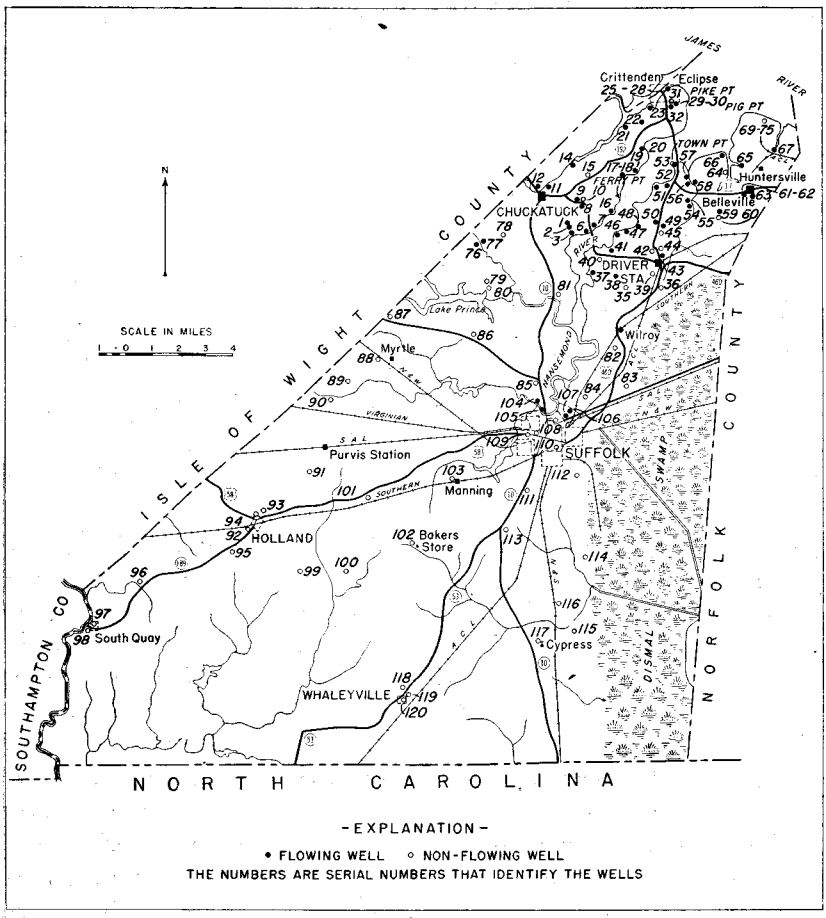


FIGURE 28.—Map of Nansemond County showing location of wells listed in Table 39.

greater part of the county, are composed of clay and sandy clay with thin beds and lenses of sand, the total thickness of which is generally less than 30 feet.

GROUND WATER

In Nansemond County, water is derived from three sources: the Columbia group of terrace deposits of Pleistocene age, the uppermost strata of the Chesapeake group of Miocene age, and the Potomac group of early Cretaceous age.

SHALLOW WELLS

In the western part of the county water is commonly obtained from dug or driven wells in the higher (Wicomico) terrace. The strata are similar to the clay and sand strata found in the terraces of the counties farther west. Ample supplies of water for domestic use are obtained from wells less than 30 feet deep. In most places only small amounts of water are pumped from these wells, and data on the maximum amount of water which might be obtained are not at hand. However, at the Hudnell Cedar Mill, 1¾ miles southeast of Suffolk, about 3 gallons a minute is obtained from each of two 1¼-inch driven wells (112, Table 39). At the mill of the Holland Lumber Co., 2½ miles south-southwest of Suffolk, a dug well 18 feet deep (113) yields about 5 gallons a minute.

The lower (Pamlico) terrace is made up chiefly of clayey and sandy material but it is also marly in places. In the vicinity of Drivers marl is reported to be close to the surface. Many wells, generally less than 30 feet deep, are developed in the sandy beds. A 1¼-inch driven well, 32 feet deep, three-quarters of a mile northwest of Drivers (42), obtains water from coarse sand near the base of the terrace, and is reported to yield a maximum of 25 gallons a minute. At Barretts Creek Dairy, 2 miles southwest of Huntersville, a 1¼-inch driven well, 27 feet deep (60), yielded 10 gallons a minute when pumped continuously for a period of several weeks. Water from the lower terrace is generally somewhat harder than that from the higher terrace, and a few wells yield water with a hardness of more than 200 parts per million. (See Table 41.) The hardness is present mostly as calcium bicarbonate.

Water from shallow wells in Nansemond County contains as much as 100 parts per million of chloride, a greater amount than is generally found in wells in the higher terrace to the west. At and near Holland some wells (94, Table 41) yield water with objectionable amounts of iron, which may be due to the corrosive action of the water on iron pipes rather than from iron in the formation itself. Elsewhere iron has not generally been found in the water in objectionable amounts.

DEEP WELLS

WATER FROM MIOCENE DEPOSITS

Water from Miocene deposits is obtained in several parts of the county by driven or drilled wells, generally less than 100 feet deep. A few dug wells more than 30 feet deep may reach Miocene strata.

At Everetts Bridge, in northern Nansemond County, 2 flowing wells (76) obtain water from sand 54 to 84 feet below the surface. Each discharged less than 1 gallon a minute in 1939. Sanford[104] states that at Rieds Ferry, 5 miles southeast of Everetts, a well 150 feet deep did not obtain a satisfactory supply of water. A 188-foot well, 1 mile east of Chuckatuck, was likewise a failure. However, near Drivers, north of Suffolk, a good supply of water for irrigation was developed at the Kirschoff Gladiolus Farm, by wells 36 to 66 feet deep (40). The water is derived from a shell bed which may be similar to the strata quarried at Chuckatuck. The wells are 2½-inch driven wells with open ends. A battery of 10 of these wells yielded nearly 200 gallons a minute, the static water level, normally about 15 feet below the surface, being drawn down 8 feet.

At the Portsmouth Ordnance Depot, 7 wells, 8 inches in diameter, (69-75, Table 39) obtain water from Miocene strata. The wells range in depth from 81 to 105 feet (65 to 89 feet below sea level), and are reported to have yielded 60 to 140 gallons a minute each when they were drilled in 1918. In 1940 these wells were being pumped by suction from a central station, at the rate of not more than 50 gallons a minute per well. The total daily yield is probably not in excess of 100,000 gallons. It is of interest to note that there has been no indication of chloride contamination although several of the wells are very close to the brackish James River and have been in continuous use for many years. Chloride contamination will probably never become a problem here as long as the rate of pumping is not greatly increased.

An analysis (40, Table 41) of a water sample from the well at the Kirschoff Gladiolus Farm shows a total hardness of 349 parts per million. The hardness is mostly bicarbonate or temporary hardness, but the noncarbonate hardness is appreciable. Calcium is high and magnesium very low; sodium and potassium are also low. The sample contained 7.7 parts per million of iron. This amount would render the water objectionable for many domestic purposes. As the water contained no free carbon dioxide, the iron may have been derived from the water-bearing formation rather than from the casing. The fact that the shell bed contains iron is another point of similarity to the marl

beds in the Chuckatuck quarries, which are across Nansemond River from this locality.

Water at the Portsmouth Ordnance Depot is reported to contain somewhat less than 200 parts per million of total hardness, of which about one-third is noncarbonate hardness. Only a small amount of iron is reported to be present.

Analysis of a sample of water from the H. P. Harrell dug well (45, Table 41) shows it to be hard, and to contain sulfate in appreciable amounts. The water had a very high content of nitrate, suggesting pollution by surface drainage. This may also account for the high sulfate content and hardness of the water. It is thought that this water may be obtained from the terrace deposits (which is said to contain marl in this area), but the terrace beds may be thin in this locality and the well may actually be drawing water from the Miocene.

WATER FROM CRETACEOUS DEPOSITS

Deep drilled or jetted wells obtain water from the Cretaceous formations in many parts of the county. Most of such wells are located in the northern part of the county, on low ground bordering James River and its tributaries. A few deep wells are also situated in the southern part of the county, at Suffolk, Cypress, and Whaleyville. There are 2 deep wells at South Quay near the western border of the county.

At South Quay the first artesian water-bearing sand is encountered about 210 feet below sea level (wells 97, 98, Table 39). The water rises about 20 feet above sea level, but is within the cone of depression centering about Franklin (Fig. 9). At the Cedarbrook Farm, near Chuckatuck (well 8, Table 40), the first artesian water-bearing sand is encountered 540 feet below the surface. Many wells go deeper, however, and at Eclipse, 4½ miles northeast of Chuckatuck, the well of S. Q. Bunkely (29) reached a depth of 708 feet, or about 696 feet below sea level. The water-bearing sand in this area, and in the vicinity of Drivers and Town Point to the east, lies beneath red clay of late Cretaceous (?) age. This red clay is irregular in thickness; where it is thin the first water-bearing sand is encountered at a lesser depth below the surface. At Suffolk Lower and Upper (?) Cretaceous deposits as a group are predominantly clayey. However, water-bearing sand was found 487 to 517 feet and 533 to 550 feet below sea level, in the well of the Planters Nut and Chocolate

Co. (109, Table 40). In the municipal test well, 1½ miles north of Suffolk, water-bearing sand was found 481 to 496 feet, 551 to 561 feet, and 673 to 698 feet below sea level. The great thickness of water-bearing sands logged in the Lake Prince test hole is described below in this chapter.

At Whaleyville, in the southern part of the county, water-bearing sand was found 300 to 310 feet below sea level (well 118, Table 39). A well at Cypress (115, Table 40), at an elevation of 30 feet above sea level, encountered coarse white water-bearing sand from 365 to 380 feet below the surface, but the well was later deepened and sand at 410 to 420 feet supplied the water obtained in 1940.

ARTESIAN HEAD

In 1940, water rose about 20½ feet above sea level in a well 1 mile east of Glebe Point (41, Table 39). A measurement made west of Drivers gave a similar elevation for the piezometric surface. No measurements were made in the area from Chuckatuck to Crittenden and Eclipse.

At Lake Prince water rose to 19.7 feet above sea level in 1942. At Monogram Farm, Drivers, water stood about 13 feet above sea level in 1943. However, at Suffolk, water in the 560 foot well of the State Highway Dept. (105) rose about 27 feet above sea level in 1940, and water in the municipal well, 717 feet deep (104), rose about 32 feet above sea level. It was reported in 1926 that water rose to about 29 feet below the surface, or 27 feet above sea level, in the well of the Planters Nut and Chocolate Co. (110) in Suffolk. At Cypress water in the well of the Chesapeake-Camp Corp. (115) rose about 30 feet above sea level in 1940.

LOSS OF ARTESIAN HEAD

Diminution of flow and loss of artesian head has been noted since 1920 at a number of places in northern Nansemond County. A few wells, which once yielded an ample supply of water, have almost ceased to flow. At the Shamrock Farm, 1 mile east of Trottmans Wharf, the height to which water will rise (well 28) is reported to have fallen 2 feet since it was drilled (about 1930). In 1918 water flowed 25 feet above sea level at the Barretts Creek Dairy, 2 miles southwest of Huntersville (59), but the artesian head has since declined several feet. However, many individuals

have reported that no loss of head or flow seems to have taken place during the period 1920-1940.

It is probable that mutual interference of closely spaced wells along James River has brought about diminished yields, and it is also probable that regional loss of head has had an effect in decreasing the natural flow of many wells. It is believed that smaller losses of head have taken place in Nansemond County than in that part of Isle of Wight County which borders James River, because in Nansemond County the wells are located near the eastern limit of the James River artesian area. On the other hand, most of the wells in Nansemond County are located on low ground, where they obtained fairly large initial flows of 30 to 60 gallons a minute, and it seems probable that a decrease of several gallons a minute in flow would be less often noticed or considered as significant in these wells than would decreases of smaller amounts in wells which had initial yields of only 5 to 20 gallons a minute.

At Suffolk it appears that very little loss of artesian head has taken place. Sanford[103] reported in 1910 that, in a well 803 feet deep of the Portsmouth Traction Company at Suffolk, water rose to a level of 33 feet below the surface. As this well is at an elevation about 57 feet above sea level (Sanford states 63 feet), the water then rose about 24 feet above sea level. The more recent measurements at Suffolk do not indicate that any significant change in the artesian head took place between 1910 and 1940.

YIELD OF ARTESIAN WELLS

The pumping yield of artesian wells in Nansemond County is known at only a few places. The well of the Planters Nut and Chocolate Co. at Suffolk (110) is reported to have yielded 500 gallons a minute in a 24-hour test, with drawdown of 98 feet (to a depth 127 feet below the surface). The well therefore furnished about 5 gallons a minute for each foot of drawdown, or a somewhat greater amount than is yielded by the 3-inch and 4-inch flowing wells located along James River in Surry, Isle of Wight and Nansemond counties. The Burgess Lumber Co. at Suffolk pumps at a rate of about 50 gallons a minute from well 108. The artesian well (55) at the Eberwine canning factory north of Drivers is pumped at a rate of 100 gallons a minute during certain seasons of the year.

The favorable results of test drilling and possible high yields of deep wells in the Lake Prince area are discussed below.

Private well installations at 3 places (11, 48a, 48b, 106) in Nansemond County are so arranged that the pump draws from a collecting basin which is fed only by the natural flow from 1 or 2 artesian wells. The total amount available and the rate of pumping are thus limited. Direct pumping of the wells can not be done because they are not fitted with strainers, and heavy discharge from the wells would cause the casings to clog with sand and greatly impair the yield of the wells. It should be strongly emphasized that a newly drilled well should not be considered to be completed until it has been fitted with a suitable strainer, and the well has been pumped clear of all fine sand which might work its way through the strainer and collect in the bottom of the well. Although proper finishing increases the initial cost of a well, it is only by such means that the well owner can be certain that he will always have more than a few gallons a minute available. Several wells in the county which should easily furnish 100 to 200 gallons a minute furnish only a fraction of that amount and in addition require large storage tanks.

There are about 50 flowing wells in Nansemond County, (Pl. 12) most of which are located along James River or its tributaries. At the quarry of the Lone Star Cement Corp. at Chuckatuck, 3 wells each 3 inches in diameter (1, 2, and 3), flow respectively 125, 80, and 65 gallons a minute. Other wells on higher ground, of smaller diameter, or partly clogged with sand, have smaller flows, averaging about 26 gallons a minute.

Most of the wells are equipped with hydraulic rams which deliver a small part of the flow to residences at higher elevations. By such use of rams and the failure to shut off the overflow not passing through them, it is estimated that more than 1,500,000 gallons of water a day is wasted in the part of Nansemond County that is adjacent to James River.

QUALITY OF ARTESIAN WATER

Water from deep drilled wells in Nansemond County which reach Cretaceous strata is very soft but has a high mineral content in which sodium bicarbonate predominates. (See Table 42.) The analyses indicate that the bicarbonate content ranges from about 370 parts per million in the western part of the county to more

than 700 parts per million in some wells in the southeastern part, but most samples analyzed contain between 500 and 600 parts per million (Fig. 14.).

At South Quay the deeper of 2 wells (97) yields water containing slightly less bicarbonate than does the shallower well (98). At Chuckatuck a well 390 feet deep (11) yields water containing 593 parts per million of bicarbonate, but a well 580 feet deep (1) yields water containing only 447 parts per million of bicarbonate. A well 505 feet deep at Suffolk (108) yields water containing 628 parts per million of bicarbonate, but 2 wells more than 600 feet deep (104, 110) yield water containing respectively 524 and 530 parts per million of bicarbonate. At Lake Prince samples taken at 600, 810 and 852 feet contained respectively 408, 491 and 521 parts per million of bicarbonate.

The high bicarbonate content gives a taste to the water, which some people consider to be unpleasant; but similar and even more highly mineralized water from artesian wells in Warwick County, north of James River, is considered by many people to be quite palatable. The water is not suitable for boiler feed without treatment as it foams when used for steam making.

The deep-well water is very soft: most samples analyzed had less than 10 parts per million of total hardness, but a few had 20 to 30 parts per million. Water from 600 feet at Lake Prince contained 20 parts of hardness, but the sample from 852 feet contained only 10 parts total hardness. Sulfate ranged from 1 to 29 parts per million, but most of the samples analyzed contained less than 10 parts per million of sulfate. Sulfate increased with depth at Lake Prince, but no difference in sulfate was found in samples from 515 and 717 feet in the City of Suffolk test well.

With the exception of one sample (98) in the western part of the county which contained 0.8 part per million of fluoride, the fluoride content of the samples analyzed ranged from 3.5 parts per million to 7.5 parts per million. (See Fig. 16.) No marked differences due to differences in depth are apparent.

Few children in Nansemond County use only artesian water for drinking during the first 10 years of their life, and the incidence of mottled enamel may be somewhat less than in some other parts of southeastern Virginia.[53] However, in that part of Nansemond County which borders James River, a few children drink artesian water both at home and at school; and in these areas it would be desirable that a drinking water low in fluoride be made available.

Water which contains very little or no fluoride from shallow wells properly safeguarded against contamination, or some commercial bottled water, might be easily obtained and cheaply substituted.

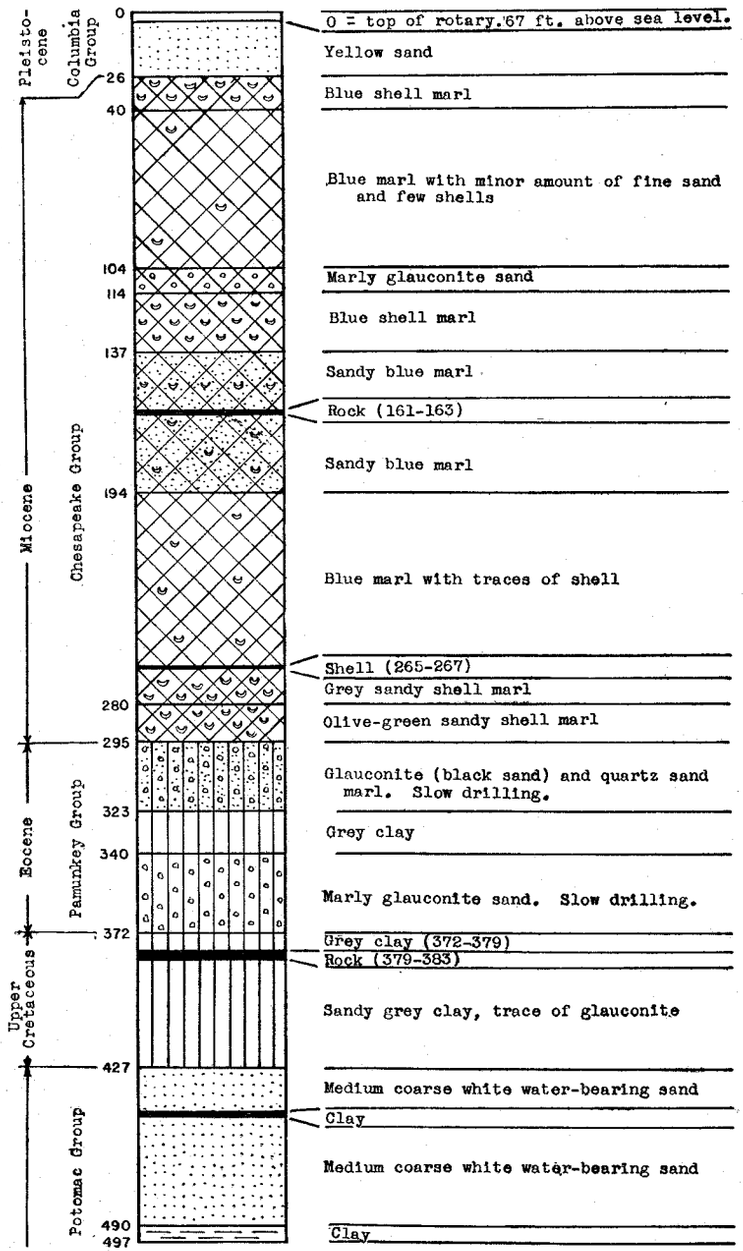
The probable beneficial effect of drinking water containing up to 1.0 part per million of fluoride is now recognized.[54]

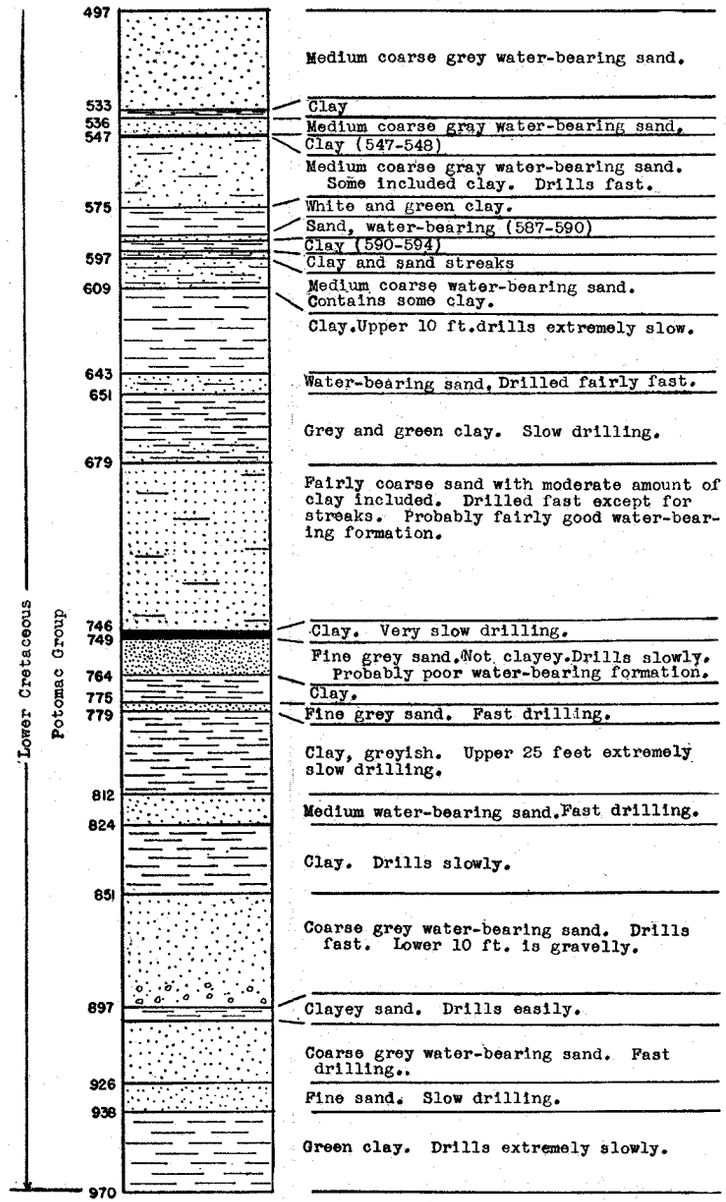
The chloride content of artesian water in Nansemond County is generally low. (See Fig. 15.) A few wells, however, yield water containing significant amounts of chloride. At Eclipse, a sample of water from the well of E. L. Murtig Co., 650 feet deep, (30, Table 42), contained 94 parts per million of chloride. A field test on water from the S. Q. Bunkley well, 708 feet deep (29, Table 39), showed the presence of 68 parts per million of chloride. The former well is pumped from time to time. At the Lassiter Farm, water from a well 550 feet deep (26) contains 67 parts of chloride, according to field test. Other wells of about the same depth in this vicinity yield water containing much less chloride.

Water from a large number of wells in the area northeast of Drivers has a moderate chloride content. A sample from the well at the Eberwine canning factory (55, Table 42) had a chloride content of 67 parts per million. This well is pumped at the rate of 100 gallons a minute at times. Nearly the same amount of chloride (68 parts per million) was found in a sample from the W. R. Old well (66). Both wells are 550 feet deep. At the Belleville Industrial School a well 536 feet deep (63, Table 39) yields water containing 72 parts per million of chloride, according to field test. Water from another well of the school, 547 feet deep (61), contained only 47 parts per million of chloride. Field tests of water from the Horace Dean well, 542 feet deep (67), showed a content of 118 parts per million of chloride.

The chloride content increases eastward, as shown in Figure 15, from about 200 parts per million near the western border of the county, to 300 parts per million at Lamberts Point, Norfolk.

The presence of high-chloride waters may be due to incomplete flushing of water-bearing strata since they were originally saturated with sea water. It is not believed that the artesian waters are underlain by sea water, although deeper wells may yield somewhat more mineralized water than is now obtained. The water having high chloride content may be localized in the area of flowing wells. At Suffolk, the well of the Planters Nut and Chocolate Co., 604 feet deep (110, Table 42), yields water con-





Graphic log of test hole at Lake Prince.
(Continued on next page.)

taining 13 parts per million of chloride; and a well, 717 feet deep, at the City Farm (104), yields water containing 26 parts per million of chloride. Although Suffolk is west and south of the localities where the artesian water has high chloride content, it can not be predicted that a well drilled 5 or 10 miles south of the James River artesian area and east of Suffolk will not yield water high in chloride.

It is believed that the chloride content of artesian water in northern Nansemond County is not changing appreciably.[21] Samples have been collected periodically from some wells in this area since 1938 in an effort to determine any change which might be taking place. Comparative data on 2 wells at Suffolk (104 and 109, Table 39) indicate that no change has occurred in chloride content in waters from those wells from 1929 and 1934, respectively, to 1939.

The continuous withdrawal of several million gallons of water a day from limited areas along James River would almost certainly result sooner or later in an increase in the chloride content. Installations intended to produce more than 1 million gallons a day should be located south and west of the bank of James River, in order to reduce to a minimum the possibility of chloride contamination. It might be safe to discharge 1 million gallons of water a day by pumps along James River, but even then it would be a wise precaution to draw the required amount of water from two or more wells spaced as far apart as possible.

TEST DRILLING AT LAKE PRINCE

GENERAL STATEMENT

On July 20, 1942, a request was received by the Washington office of the Geological Survey from the Navy Department that the Geological Survey undertake a survey of the ground water in the Lake Prince area, Nansemond County, Virginia. Funds were subsequently made available by the Navy Department for field work in connection with the investigation and for writing a memorandum report.[17]

On July 21, the writer discussed with officials of the Public Works Department, Naval Operating Base, Norfolk, the possibility of obtaining a supplementary ground-water supply at Lake Prince, and the various factors to be considered in alleviating the water shortage then threatening the City of Norfolk. On July 22, a conference was held with Mr. Walter Taylor, Director of Public Works, City of Norfolk,

at which time the steps which had already been taken by the City of Norfolk towards meeting the emergency and possible plans for further action were discussed.

CITY OF NORFOLK WATER SHORTAGE

In 1942 the City of Norfolk was supplied with water from the Moores Bridges and North Landing reservoirs in northeastern Norfolk and northwestern Princess Anne counties and from Lake Prince and Burnt Mills reservoirs in Nansemond County. The Nansemond County reservoirs supplied about three-fourths of the total demand of 22 million gallons daily used by the City of Norfolk at that time.

Drought conditions which prevailed from April 1941 through July 1942, had left reservoirs in a dangerously low stage. The accumulated departure for the year 1941 was —11.07 inches at Diamond Springs, Princess Anne County, and —13.59 inches at Williamsburg. By August 1, 1942, the accumulated departure had increased respectively to —19.19 inches and —24.49 inches at these stations. (The normal annual rainfall at the two stations is 46.01 and 45.84 inches.) On August 1, 1942, the Lake Prince reservoir was 12 feet below normal.

Work was begun previous to July, 1942, on a pipe line extending from the Lake Prince watershed to Nottoway River (Courtland, Southampton County), which was intended to bring new large supplies of water to the Norfolk watershed and eliminate any shortages which might develop from increases in war population and industries and from severe droughts.[a] This work was being carried out by the Federal Works Agency.

Completion of the pipe line, however, was not possible before August 15, if then, and it was obviously necessary that additional water be provided to meet the existing emergency.

GROUND-WATER RESOURCES OF THE LAKE PRINCE AREA

As a result of investigations made of the ground-water resources of southeastern Virginia by the writer from 1937 to 1940, as a cooperative project between the Federal and State Geological surveys, and other investigations, ground-water conditions in the Lake Prince area, as far as they could be judged by available data, were well known.

The records of the municipal and industrial wells at Franklin, the data resulting from the test drilling at Bacons Castle, detailed informa-

[a] In June, 1943, the City of Norfolk was still supplying its consumers with ample water using only the Lake Prince and Moores Bridges reservoir systems.

tion on wells at Lee Hall and Ft. Eustis, and other information led to the conclusion that the water shortage at Lake Prince could most probably be alleviated by installing wells and, further, that yields of about 1,000,000 gallons of water a day per well might be expected. It was pointed out that the water would probably be fairly high in bicarbonate and fluoride but would be low in chloride. Dilution of well water with reservoir water would probably bring the bicarbonate and fluoride content of the water down to within permissible limits.

The Layne-Atlantic Company of Norfolk, Va., was directed by the City of Norfolk to proceed with the construction of a test well. Drilling was begun on August 6th. The writer supervised the drilling, made a detailed record of the strata penetrated, collected samples of water from various depths, advised both Navy Department and City of Norfolk officials on progress of the work and made suggestions for further action toward obtaining a ground-water supply.

RESULTS OF TEST DRILLING

FORMATIONS PENETRATED

The hole was drilled by the hydraulic rotary method (Pls. 20 and 21) to a depth of 970 feet and penetrated 26 feet of Pleistocene sand deposits, 269 feet of Miocene shell marl, 77 feet of Eocene clay and glauconitic marl, 55 feet of Upper Cretaceous clay and 543 feet of alternating quartz sands and clays of early Cretaceous age (Pl. 34).

Pleistocene.—A fine yellow sand stratum, 26 feet thick, belonging to the Columbia group of Pleistocene age, was encountered immediately below the surface.

Miocene.—The Chesapeake group of Miocene age at Lake Prince is made up of blue and gray marl containing variable amounts of sand and shell. Some strata, a foot or two in thickness, were made up entirely of shell, but thicker strata generally contained less than 10 per cent shell material. The proportion of included quartz sand was generally small. One stratum, from 104 to 114 feet below the surface, contained a high proportion of glauconite sand. Strata between 163 and 218 feet below the surface contained very little shell or sand and were drilled very slowly; other strata were drilled easily and quickly.

Although most of the material was a nondescript gray or blue in color, an olive-green marl was penetrated from 280 to 295 feet below the surface. This stratum is similar in appearance to a stratum en-

countered in a comparable position near the base of the Miocene in some wells at Camp Peary, near Williamsburg.

Eocene.—The Pamunkey group of Eocene age was penetrated between 295 and 372 feet below the surface. The beds consist of black glauconitic marl and sandy marl and subordinate gray clay. Much of the clayey material was difficult to drill, but, where glauconitic (black sand) material predominated, the strata were penetrated more easily.

Upper Cretaceous.—The lower boundary of the Eocene is placed at 372 feet. An Upper Cretaceous index fossil, a species of *Exogyra,* is believed to have come from one of these strata and accordingly they are assigned to the Upper Cretaceous in this report. Upper Cretaceous foraminifera were identified from samples taken at 375 and 389 feet.

A 4-foot stratum of consolidated sediment ("rock") was penetrated at from 379 to 383 feet, but the true nature of the "rock" was indeterminate because only tiny fragments were brought up by the drilling fluid.

Lower Cretaceous.—Sediments of the Potomac group of early Cretaceous age were encountered at 427 feet below the top of the rotary. They consist of alternating clays and sands of various thicknesses.

From 427 to 575½ feet the material was almost entirely water-bearing sand. In the 148½ feet of sediments penetrated, 137½ feet was clean sand ranging from moderately coarse to moderately fine (Pl. 36) in grain size.

Between 597 and 824 feet, 7 sand strata, separated by clays, were present. Except for one stratum which was 4 feet thick, the strata varied from 8½ to 29 feet in thickness. The aggregate thickness was 104½ feet. The material ranges from moderately fine to coarse in texture; in much of the strata a little clay was present, largely in streaks. About three-fourths of the 104½ feet of sand strata appeared to be a reasonably good water-bearing formation.

Clean sand, ranging in texture from medium to coarse (gravel), was encountered at from 854 to 926½ feet. This 72½-foot thickness of good water-bearing sand was underlain by 11½ feet of fine sand.

In summary, 326 feet of sand was encountered between 427 and 938 feet below the surface, of which about 300 feet appeared to be highly permeable.

Most of the clays penetrated seemed to be gray in color although some green clays were recognized. They all drilled slowly, but from 779 to 804 feet and 938 to 970 feet progress was extremely slow.

Drilling was not continued below 970 feet because at that depth ample thicknesses of sands to justify the construction of a well had been found and, furthermore, the limit of the rig was being reached.

POSSIBLE YIELD

The test hole was not converted into a well, but comparison with records of the test well at Bacons Castle and the wells at the Chesapeake-Camp Corp. at Franklin indicates that 3,000,000 gallons of water a day or more might be obtained at Lake Prince from a well at the site of the test hole.

The data for comparison are given in tabular form below.

TABLE 38.—*Texture and thickness of water-bearing sands penetrated in deep wells in southeastern Virginia*

	Franklin 160	Franklin 162	Bacons Castle	Lake Prince
Fine sand	.....	.....	24 ft.	25½ ft.
Medium sand	26 ft.	153 ft.*		56 ft.
		160 ft.	160 ft.	159 ft.
Coarse sand	155 ft.			
Clayey sand	.....	67 ft.	42 ft.	49½ ft.
Total thickness	181 ft.	220 ft.	226 ft.	316 ft.
Yield, gallons per day	3,500,000	3,500,000	1,380,000	
Drawdown	90 ft.	90 ft.	22 ft.	.....

*Some coarse and fine sand may be included.

It would appear that the sands were not quite as coarse in the Lake Prince test hole as in the first large-diameter well at Franklin but are comparable to the sands present in the second well at Franklin and the well at Bacons Castle. In addition, the total thickness of sands at Lake Prince was much greater. There seems to be ample reason to believe that at Lake Prince a properly constructed well would yield at least 3,000,000 gallons of water a day with 100 feet of drawdown.

LATERAL VARIATIONS IN WATER-BEARING SANDS

It should not be assumed that, at every location in the vicinity of the Lake Prince reservoir, identical strata would be encountered upon deep drilling. Coastal Plain sediments vary markedly from place to

place and it would not be safe to assume that equally good water-bearing formations will be found everywhere.

For example, in the City of Suffolk test well, located 5 miles southeast of the Lake Prince well, 57 feet of water-bearing sand had been penetrated when 717 feet of hole had been drilled. At a comparable depth at Lake Prince, 204 feet of water-bearing sand had been penetrated.

At Franklin, relatively little variation is found in sediments penetrated in the two wells, 2,190 feet apart. At Bacons Castle, test hole No. 1 contained 182 feet of water-bearing sand, whereas test hole No. 2 (later converted into a test well), 3.2 miles to the south, contained 226 feet of water-bearing sand within a comparable depth; further, the sands in the second hole were somewhat cleaner (contained less interstitial clay) and slightly coarser on the average.

Hence, it would be safer to assume that the average yield of wells in the Lake Prince area would be somewhat less than the yield of a well at the test hole site, whatever that yield might prove to be. The thickness and character of sands encountered in the test hole were very promising, and it is difficult to believe that anything better would be found in the vicinity. Assuming a yield of 3 million gallons of water a day with a drawdown of 100 feet at the test-hole site, perhaps the average yield of wells of similar construction in the area would be 2 or 2½ million gallons a day with the same drawdown, or average drawdown would be greater than 100 feet to obtain an average of 3 million gallons a day.

If wells were spread over an area of several miles to eliminate mutual interference, chances of marked lateral variation would be much greater than if wells were located somewhat more closely together and further test drilling would be warranted before wells were installed.

Generally speaking, however, the results of the test hole were most encouraging, and there seems to be every reason to believe that the minimum requirement of 5,000,000 gallons of water a day could have been met and, in fact, that 10 million gallons a day could have been developed if needed.

QUALITY OF WATER

Samples of water were taken at 600, 810 and 852 feet. The results of preliminary analyses of these samples are given in Table 42.

Hardness.—The total hardness of all three samples taken is very low, and the water should be excellent for domestic purposes. The

sample from 600 feet contained the maximum hardness, 20 parts per million.

Bicarbonate.—The bicarbonate is fairly high and, if used without treatment, the water would probably be unsuitable in high pressure boilers. The analyses show that with depth the bicarbonate content increases from 408 to 521 parts per million.

Sulfate.—Sulfate is very low in all three samples but was higher, 15 parts per million, in the two samples from below 800 feet.

Chloride.—The chloride is very low in all samples. The sample from a depth of 852 feet contained 20 parts per million, only a very little more than the sample from 600 feet.

Fluoride.—The fluoride is high in all samples, ranging from 4.0 to 4.6 parts per million. It is known[53] that the presence of more than 1 part per million of fluoride in drinking water is detrimental to the teeth of children who habitually use such water. However, the presence of small amounts of fluoride in drinking water is desirable[54] in inhibiting dental decay. The addition of some fluoride-containing water to the Norfolk system might well have been considered a desirable thing in itself.

In summary, the ground water at Lake Prince contains objectionable amounts of bicarbonate and fluoride. If diluted with 4 parts or more of Lake Prince reservoir water, the resultant blend would be low in bicarbonate, necessitating little or no treatment for boiler use, and would contain a small but desirable amount of fluoride.

TERMINATION OF PROJECT

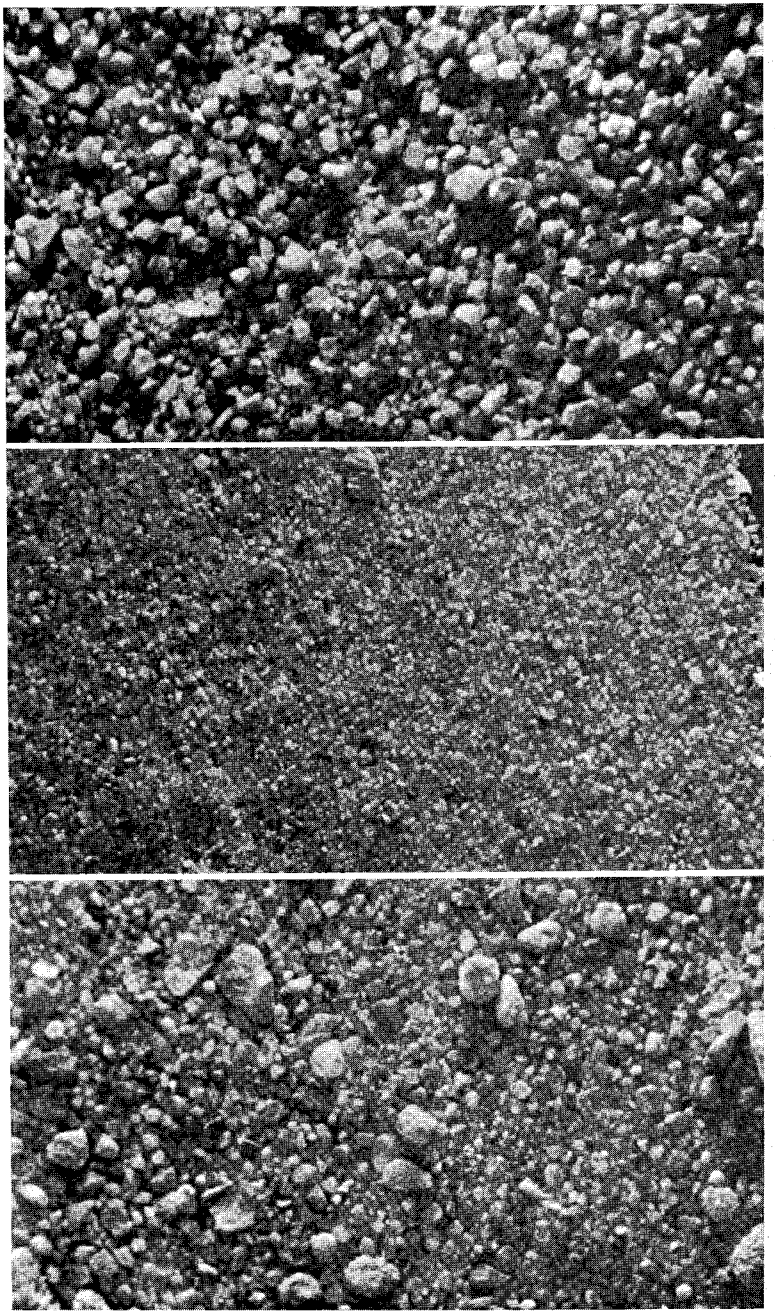
On August 11, 1942, rains began which in 52 hours amounted to 9.89 inches and gave Norfolk the worst drenching ever recorded. Total rainfall for August at Diamond Springs was 13.65 inches (9.37 inches above normal) and at Williamsburg 11.10 inches (5.27 inches above normal). The Lake Prince reservoir rose 2 feet immediately following the rains (Pl. 36) and it was decided that the need for wells no longer existed.

WELL RECORDS AND ANALYSES

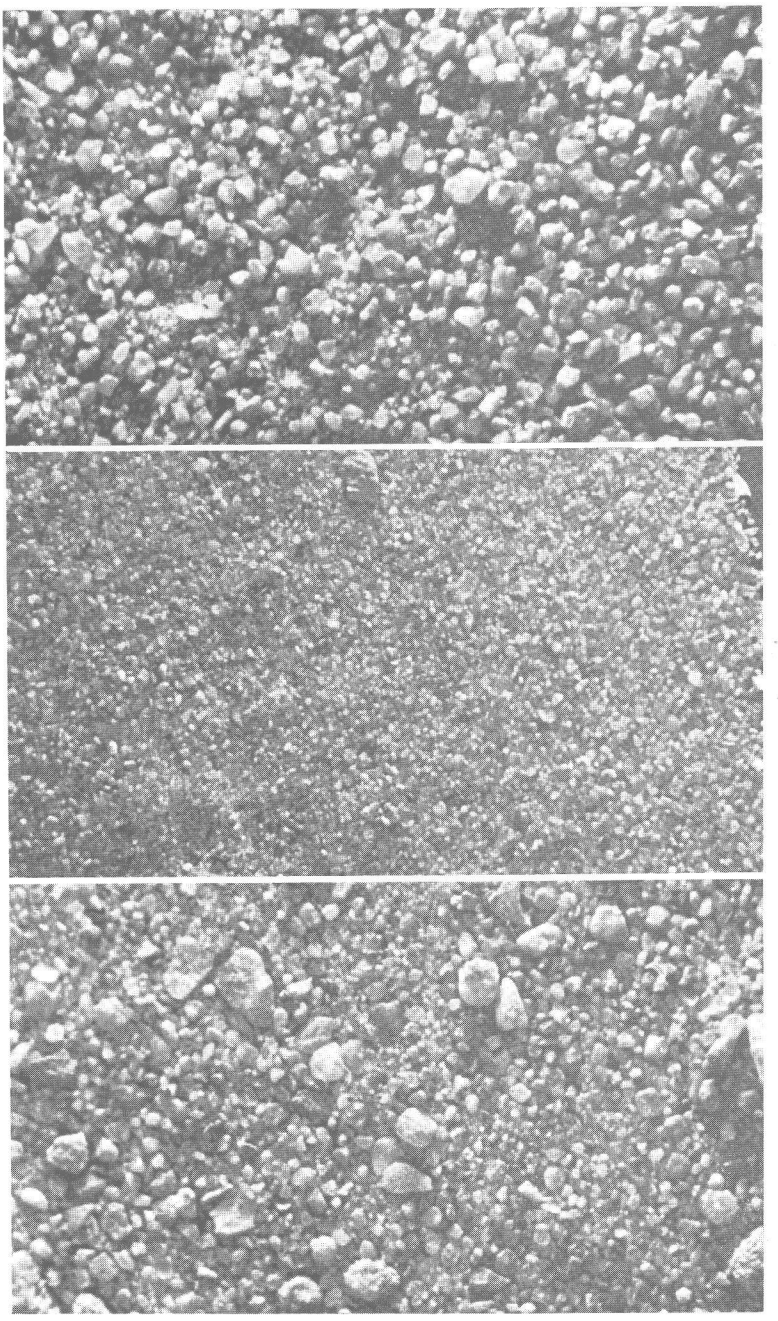
Records of wells in Nansemond County, available logs of wells, and analyses of water samples are listed in Tables 39-42, on the following pages. The location of the wells listed are shown in Figure 28.

TABLE 39.—*Records of wells in*

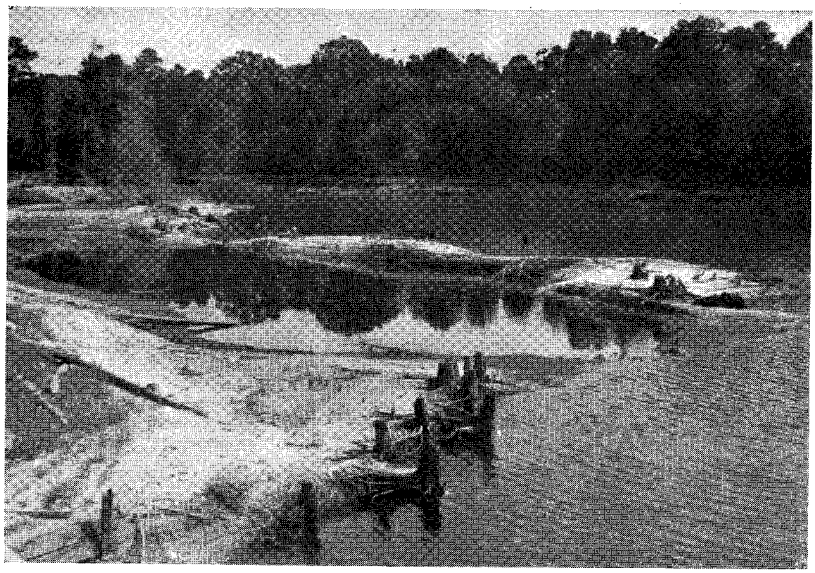
No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
1	½ mile west of Godwins Wharf.	Lone Star Cement Corp.	J. Minton	1937	12	J
2	½ mile west of Godwins Wharf.	Lone Star Cement Corp.	J. Minton	1937	12	J
3	½ mile west of Godwins Wharf.	Lone Star Cement Corp.	J. Minton	1939	12	J
6	Godwins Wharf, Nansemond River.	Kings Highway Bridge	J. Minton	1937	3	J
7	½ mile northeast of Godwins Wharf.	Holiday Point Farm	J. R. McLane	1927	16	J
8	¼ mile southeast of St. Johns Church.	Cedarbrook Farm	J. Minton		15	J
9	¼ mile west of St. Johns Church.	Meadowbrook Farm	J. Minton		15	J
10	¼ mile west of St. Johns Church.	Meadowbrook Farm			20	Dug
11	Chuckatuck	Chuckatuck Water Co.	J. Minton		10	J
12	Chuckatuck	B. W. Godwin	J. Minton		10	J
14	½ mile northwest of Dalys Store.	E. L. Pruden	J. Minton	1931	8	J
15	Dalys Store	W. C. Daly			26	Dug
16	Ferry Point	Ferry Point Farm	J. Minton		4	J
17	1½ miles east of Dalys Store	Barrett Creek Farm	J. Minton	1934	6	J
18	1½ miles east of Dalys Store	Barrett Creek Farm	J. Minton	1938	6	J
19	¾ mile northwest of Newmans Point.	G. F. Wilkerson	J. Minton	1915	8	J
20	Nix Wharf	Nix Farm	J. Minton		10	J
21	½ mile west of Hobson	Oliver Newman	J. Minton	1917	16	J
22	Hobson	Johnson Mercantile Co.	J. Minton		15	J
23	1 mile north-northeast of Hobson.	Adams Oyster Co.	J. Minton	1935	12	J
25	Crittenden	W. B. Healling	J. Minton	1910	14	J
26	Crittenden	Lassiter Farm	J. Minton	1925	12	J
27	Crittenden	Johnson and Cochran Shipyards.	J. Minton	1925	8	J
28	Crittenden	Dixon Oyster Co.	J. Minton	1930	7	J
29	Eclipse	S. Q. Bunkley	J. Minton	1924	12	J
30	Eclipse	E. L. Murtig Co.	J. Minton	1931	20	J
31	Eclipse	G. W. Dixon			20	Dug
32	Eclipse	J. R. Dixon	J. Minton		12	J
35	1¾ miles southwest of Drivers.	Hurff Farm			22	Dug
36	1 mile south of Drivers	J. C. Bailey			24	Dug
37	Trottmans Wharf	Monogram Farm	Sydnor Pump and Well Co.	1943	20	D
38	1 mile east of Trottmans Wharf.	Shamrock Farm	J. Minton		8	J
39	Drivers	Atlantic Coast Line R. R. Co.			22	J
40	Glebe Point, Nansemond River.	W. E. Kirchoff			20	J
41	1 mile east of Glebe Point	John Bryant	J. Minton		5	J
42	¾ mile northwest of Drivers	W. E. Kirchoff			22	Dv
43	Drivers	Public school	J. W. Brinkley		10	J
44	½ mile north of Drivers	Roy Jones		1920	15	Dv
45	2 miles north of Drivers	H. P. Harrell		1870	19	Dug
46	Sleepy Hole	A. Trottman	J. Minton		7	J
47	Sleepy Hole	Planters Club	J. Minton	1924	8	J
48a	½ mile northeast of Sleepy Hole.	A. Obici	J. Minton	1922	8	J
48b	½ mile northeast of Sleepy Hole.	A. Obici	J. Minton	1922	8	J



Water-bearing sands penetrated in test hole at Lake Prince, Nansemond County. Top, at 597 feet; middle, at 562 feet; bottom, at 860 feet. (Natural size.)



Water-bearing sands penetrated in test hole at Lake Prince, Nansemond County. Top, at 597 feet; middle, at 562 feet; bottom, at 860 feet. (Natural size.)



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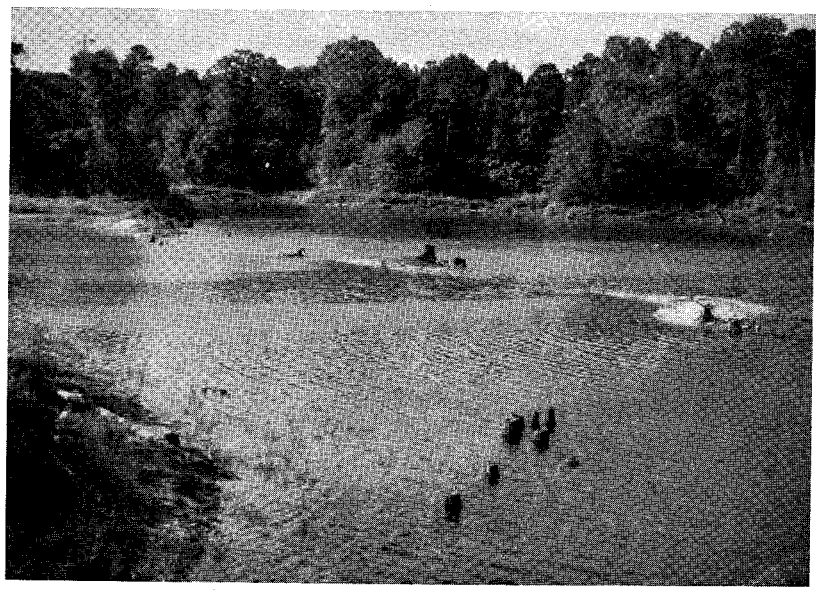
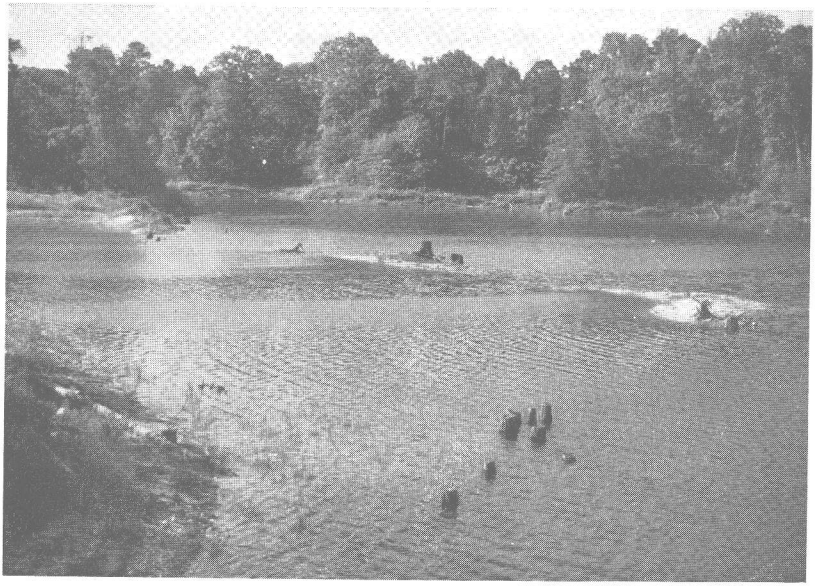


B.

A, Lake Prince reservoir during drought in July 1942. Photograph by M. Nicols. B, Lake Prince reservoir after heavy rains in August 1942.

A.



B.

A, Lake Prince reservoir during drought in July 1942. Photograph by M. Nicols. B, Lake Prince reservoir after heavy rains in August 1942.

Nansemond County, Virginia

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level[b]		Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
		Feet above (+) or below (−) surface	Date of measurement					
580	3	+	.....	[e]125	I	A	Water from wells 1, 2 and 3 is used in marl washing operations.	1
542	3	+	.....	[e]80	I	.....	.....	2
510	3	+	.....	[e]60	I	.....	.....	3
356	3	+	.....	10	D	.....	.....	6
433	3	+	.....	15	D S	.....	.....	7
550	2	+	.....	10	D S	.....	See log.	8
560	2	+	.....	7	D S	.....	.....	9
32	.....	−16	July 19, 1939	.....	S	Hard	Water from Miocene marl.	10
390	2	+	.....	[e]40	M	.....	Supplies 6 families.	11
450	2	+	.....	.....	D	A	.....	12
520	2	+	.....	20	D S	.....	.....	14
14	.....	[e]−7	.....	.....	.....	.....	.....	15
450	2	+	.....	.....	D S	Hard	Water from Miocene sandy marl.	16
560	2	+	.....	15	D S	Cl, 18	.....	17
510	2	+	.....	20	D S	.....	.....	18
585	2	+	.....	25	D S	.....	.....	19
488	2	+	.....	12	D S	.....	.....	20
377	3	+	.....	13	D S	.....	.....	21
520	2	+	.....	20	D S	.....	.....	22
525	2	+	.....	20	D	A	.....	23
570	2	+	.....	4	D	Cl, 20	Temp. 71° F.	25
550	2	+	.....	3	D	Cl, 66	.....	26
558	2	+	.....	15	D	Cl, 28	Temp. 73° F.	27
642	2	+	.....	30	D	Cl, 34	.....	28
708	2	+	.....	15	D	Cl, 68	.....	29
650	3	+	.....	5	M	A	Supplies 6 families.	30
28	.....	−15	.....	.....	D	Hard	.....	31
495	2	+	.....	12	D	Cl, 64	.....	32
24	.....	− 7½	Aug. 5, 1939	.....	D	TH, 150 Cl, 24	.....	35
16	.....	−11	.....	.....	D	Hard	.....	36
540	8	− 7	June, 1943	.....	D S	.....	Tested 76 gallons a minute with 81 ft. of drawdown. 30-slot screen from 515 to 531 ft.	37
480	2	+	.....	4	D S	A	Temp. 66° F.	38
72	3	−	.....	.....	D	TH, 190	Yields less than 1 gallon a minute.	39
36–66	2½	−15	.....	.....	Irr	A	Consists of a battery of 10 wells. Yields 200 gallons a minute with drawdown of 5 ft. Water from Miocene shell beds at various depths below 30 ft.	40
480	2	+15	July 25, 1939	30	.....	.....	.....	41
32	1¼	−	.....	.....	C	.....	Pumps 25 gallons a minute.	42
400	3	+	.....	15	P	A	.....	43
32	2	−	.....	.....	D S	TH, 160 iron	Water from terrace gravel.	44
30	.....	−	.....	.....	D S	A	.....	45
450	2	+	.....	.....	D S	Cl, 14	.....	46
450	3	+	.....	40	D	Cl, 18	Overflow from ram is pumped to swimming pool.	47
450	3	+	.....	85	D Irr	.....	Rams supply dwelling. Overflow from rams is pumped to 100,000-gallon tank for use in barns and for irrigation and fire protection.	48a
450	2	+	.....	35	D Irr	.....	.....	48b

TABLE 39.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
49	1¾ miles north of Drivers	K. E. Brinkley	A. Johannson	1928	16	J
50	2 miles north of Drivers	F. M. Warrenton	J. Minton	1939	4	J
51	1 mile southwest of Town Point, Nansemond R.	Industrial School Farm	J. Minton	1928	5	J
52	½ mile south of Town Point	L. C. March	J. Minton	1936	4	J
53	Town Point	Town Point Farm	J. Minton	1913	8	J
54	2 miles south-southeast of Town Point.	V. G. Eberwine	J. Minton	.....	7	J
55	2 miles south-southeast of Town Point.	Eberwine Cannery	J. Minton	.....	3	J
56	1¼ miles southeast of Town Point.	T. A. Jones	J. Minton	.....	10	J
57	1 mile southeast of Town Point.	Terese Nurney	J. Minton	1938	7	J
58	1½ miles southeast of Town Point.	W. E. Milteer	J. Minton	.....	7	J
59	1½ miles west of Belleville	Barretts Creek Dairy	J. Minton	1918	7	J
60	1½ miles west of Belleville	Barretts Creek Dairy	.....	.....	26	Dv
61	½ mile west of Belleville	Belleville Industrial School	J. Minton	1928	6	J
62	½ mile west of Belleville	Belleville Industrial School	J. Minton	1928	6	J
63	Belleville	Belleville Industrial School	J. Minton	1928	6	J
64	1½ miles west-southwest of Huntersville.	J. E. Brinkley	.....	.....	20	Dv
65	1¼ miles west of Huntersville.	John Ames	J. Minton	1914	10	J
66	1½ miles west-northwest of Huntersville.	W. R. Old	J. Minton	1915	15	J
67	1 mile northeast of Huntersville.	Horace Dean	J. Minton	1927	8	J
69	Pig Point	Portsmouth Ordnance Depot.	.....	1918	12.7	D
70					15.0	D
71					14.3	D
72					14.7	D
73					13.0	D
74					15.8	D
75					17.2	D
76	Everetts Bridge	H. Saunders	.....	.....	8	Dv
77	¼ mile east of Everetts Bridge.	H. Schram	J. Minton	.....	10	J
78	1 mile east of Everetts Bridge.	H. G. Griffin	.....	.....	70	Dug
79	2 miles south-southeast of Everetts Bridge.	G. W. Willman	Owner	.....	20	Dv
80	Lake Prince	City of Norfolk	Layne-Atlantic Co.	1942	63	D
81	Rieds Ferry	H. F. Oliver	.....	.....	25	Dug
82	½ mile south of Wilroy	M. R. Gregory	Owner	1938	20	Dug
83	2 miles south of Wilroy	Sequoia Farm	.....	.....	20	Dug
84	1½ miles north-northeast of Suffolk.	J. H. Parker	.....	.....	24	Dug
85	1½ miles north of Suffolk	Peanut City Inn	Owner	.....	40	Dug
86	½ mile west of Kings Fork	D. C. Clements	.....	.....	72	Dug
87	2 miles north of Myrtle	White Oak Tavern	.....	.....	74	Dv
88	Myrtle	J. H. Powell	.....	.....	76	Dug
89	1½ miles southwest of Myrtle.	John Ashburn	.....	.....	73	Dug
90	2 miles north of Purvis Station.	J. H. Wright	.....	.....	70	Dv
91	1 mile south of Purvis Station	W. M. Aston	.....	.....	78	Dug
92	Holland	S. W. Rawls	J. Minton	1942	82	J
93	Holland	Colonial Inn	.....	.....	82	Dv

Nansemond County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level[b]		Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
		Feet above (+) or below (−) surface	Date of measurement					
584	2	+	.....	1½	D S	Cl, 35	.....	49
560	3	+	.....	40	D S	Cl, 28	.....	50
542	3	+	.....	35	D S	A	.....	51
500	2	+	.....	25	D S	.....	.....	52
520	2	+	.....	20	D S	Cl, 28	.....	53
550	2	+	.....	[f]30	D	.....	.....	54
550	2½	+	.....	[f]60	I	A	Pumps 100 gallons a minute.	55
527	2	+	.....	25	D S	.....	.....	56
560	2	+15½	July 25, 1939	40	D	.....	.....	57
518	2	+	.....	20	D	.....	.....	58
548	2	+	.....	20	D S	Cl, 50	Originally flowed from tap 26½ ft. above sea level. Temp. 72° F.	59
27	1¼	−	.....	.....	C	.....	Water from coarse gravel near base of terrace. Pumps 10 gallons a minute.	60
547	3	+	.....	[f]47	P	Cl, 48	.....	61
542	2	+	.....	[f]43	P	.....	.....	62
536	2	+	.....	[f]36	P	Cl, 72	.....	63
25	1¼	−	.....	.....	D S	Hard, iron	Pumped by windmill.	64
600	2	+	.....	25	D S	A	.....	65
550	2	+	.....	.....	D S	A	.....	66
542	2	+	.....	30	D S	.....	.....	67
88	8	[e]−4.0	1918				In 1918, wells 69-75 pumped respectively 140, 113, 60, 115, 120, 115 and 115 gallons a minute; drawdown not known. A central suction pump draws 200 gallons a minute from the group.	69
81	8	[e]−3.3	1918					70
86	8	[e]−3.6	1918					71
90	8	[e]−4.2	1918	.....	D	TH, 170		72
91	8	[e]−5.0	1918			Cl, 14		73
105	8	[e]−3.8	1918					74
92	8	[e]−6.5	1918					75
85	1¼	+	.....	½	D	.....	Two wells; water in sand at 54-84 ft.	76
360	2	+	.....	20	D	A	.....	77
22	.....	[e]−14	.....	.....	D S	Soft, iron	Water from terrace sand.	78
22	2	−	.....	.....	D S	TH, 70	Water from terrace sand.	79
970	8	−43¼	Aug. 12, 1942	.....	T	A	See log, Pl. 35.	80
18	.....	[e]−10	.....	.....	D S	Soft	Water from terrace sand.	81
16	.....	[e]−10	.....	.....	D	Hard, iron	.....	82
20	.....	− 4	July 21, 1939	.....	D S	TH, 80 Cl, 18	.....	83
20	.....	[e]−17	.....	.....	D S	TH, 40 Cl, 10 iron	.....	84
12	.....	[e]− 3	July 28, 1937	.....	D	TH, 90	.....	85
35	.....	− 5	July 28, 1939	.....	D	TH, 80 Cl, 74	Water level usually about 10 ft. below surface.[e]	86
30	2	.....	.....	.....	D	Slightly hard	.....	87
30	.....	.....	.....	.....	D	TH, 80 Cl, 60	.....	88
32	.....	−15	.....	.....	D S	TH, 30 Cl, 18	.....	89
50	2	.....	.....	.....	D	TH, 80	Water from Miocene sand.	90
15	.....	− 1	July 28, 1939	.....	D S	.....	Water level usually about 5 ft. below surface.	91
470	3	[e]−52	June, 1942	.....	D	A	Supplies 12 families. Pumps 6½ gallons a minute.	92
28	2	− 5½	.....	.....	D	TH, 50 Cl, 18	Water from terrace sand.	93

TABLE 39.—*Records of wells in*

No.	Location	Owner or name	Driller	Date completed	Approximate altitude above sea level (feet)	Type of well[a]
94	Holland	J. P. Holland	Owner	.....	82	Dug
95	1 mile southwest of Holland	F. O. Forbes	Owner	.....	83	Dv
96	2½ miles northeast of South Quay.	W. B. Lewis	Owner	.....	60	Dug
97	South Quay	W. A. Jones	J. R. McLane	1922	30	J
98	South Quay	F. H. Johnson	J. R. McLane	1920	28	J
99	½ mile northwest of Noah Howell School.	B. E. Hedgebeth	.....	.....	75	Dug
100	3 miles west-southwest of Bakers Store.	S. T. Holland	.....	.....	75	Dug
101	2½ miles southeast of Purvis Station.	E. D. White	.....	.....	72	Dug
102	Bakers Store	O. L. Baker	.....	.....	69	Dug
103	Manning	J. E. Howard	.....	.....	70	Dug
104	1½ miles north of Suffolk	City of Suffolk	Layne-Atlantic Co	1929	20	D
105	1 mile north of Suffolk	State Highway Dept	J. Minton	1920	4	J
106	1½ miles northeast of Suffolk	Prudens Packing Co	J. Minton	1939	7	J
107	1 mile northeast of Suffolk	Travelers Rest	J. Minton	.....	16	J
108	Suffolk	Burgess Lumber Co	Virginia Machinery and Well Co.	1916	45	D
109	Suffolk	Planters Nut and Chocolate Co.	Sydnor Pump and Well Co.	.....	52	D
110	Suffolk	Planters Nut and Chocolate Co.	Virginia Machinery and Well Co.	1926	52	D
111	2¼ miles south-southwest of Suffolk.	J. E. Harrel	Owner	1935	62	Dv
112	1¾ miles southeast of Suffolk	Hudnell Cedar Mill	Owner	.....	48	Dv
113	2½ miles south-southwest of Suffolk.	Holland Lumber Co	Owner	1937	64	Dug
114	White Marsh School	D. L. Brinkley	.....	.....	50	Dug
115	1½ miles east of Cypress	Chesapeake Camp Co	J. R. McLane	1938	30	J
116	Saunders	J. E. Overman	.....	.....	54	Dug
117	Cypress	Public school	J. Minton	1927	60	J
118	Whaleyville	Public school	J. Minton	1931	70	J
119	Whaleyville	T. O. Knight	Mitchell Pump and Well Co.	1927	72	D
120	Whaleyville	H. B. Knight	.....	.....	69	Dv

[a]D = drilled. Dv = driven. Dug = dug. J = jetted.
[b]As of 1938, unless otherwise noted.
[c]B = boiler feed. C = cooling. D = domestic. I = industrial. Irr = irrigation. M = municipal. P = public school. S = stock. T = test.
[d]A: Analysis given in table of analyses. Figures refer to total hardness (TH) and chloride (Cl), in parts per million, as determined by field test.
[e]Data from owner or official in charge.
[f]Data from driller.

Nansemond County, Virginia—Continued

Depth of well (feet)	Diameter of well (inches)	Approximate Water Level[b]		Yield as flow (gallons a minute[b])	Use of water[c]	Reported quality[d]	Remarks	No.
		Feet above (+) or below (−) surface	Date of measurement					
35	.....	[e]− 7	.....	.....	D S	A	.....	94
32	1¼	[e]− 5½	.....	.....	D S	Very irony	.....	95
25	.....	−20	July 29, 1929	.....	D	TH, 60 Cl, 104	.....	96
437	2	− ¼	July 29, 1939	.....	D	A	Temp. 62½° F.	97
230	2	[e]− 2	1922	.....	D	A	.....	98
.....	.....	−	.....	.....	D	TH, 60 Cl, 130	.....	99
.....	.....	− 4	July 29, 1939	.....	D	.....	Water level usually about 7 ft. below surface.[e]	100
14	.....	−	.....	.....	D S	TH, 60 Cl, 170	.....	101
14	.....	−	.....	.....	D S	TH, 80 Cl, 58	.....	102
20	.....	− 5	July 28, 1939	.....	D S	TH, 50 Cl, 18	.....	103
717	8	+11½	Aug. 8, 1939	60	S	A	Temp. 71¼° F.	104
560	2	+23	July 27, 1939	20	D	A	Temp. 69½° F.	105
.....	.....	+	.....	.....	I	.....	.....	106
560	2	+	.....	5	D	.....	.....	107
520	8	−	.....	.....	I	A	Temp. 69° F.	108
578	10–8	−	.....	.....	C	A	Pumps 150 gallons a minute.	109
604	8	−21	Nov., 1936	.....	C	A	Pumps 300 gallons a minute.	110
50	2	−	.....	.....	D	TH, 85 Cl, 66	Pumps 8 gallons a minute.	111
34	1¼	−	.....	.....	B	A	Two wells yield 3 gallons a minute each.	112
18	.....	− 6	.....	.....	B	TH, 50 Cl, 16	Pumps 5 gallons a minute.	113
16	.....	−12	July 31, 1939	.....	D	TH, 50 Cl, 24	.....	114
420	3	− ½	.....	.....	D	A	.....	115
14	.....	− 5	July 31, 1939	.....	D	TH, 35 Cl, 24	.....	116
340	3	−30	1927	.....	P	A	.....	117
380	3	−	.....	.....	P	.....	.....	118
365	4	−	.....	.....	D	A	.....	119
30	1¼	−	.....	.....	D S	Hard, iron	.....	120

TABLE 40.—*Logs of wells in Nansemond County, Virginia*

Well 8, Chuckatuck; Cedarbrook Farm
(Log by Jesse Minton)
Altitude, 15 feet

	Thickness (feet)	Depth (feet)
Undescribed deposits:	380	380
Pamunkey group (Eocene):		
Black sand	50	430
Undifferentiated (Upper Cretaceous ?):		
Red clay	100	530
Blue mud	10	540
Potomac group (Lower Cretaceous):		
Sand, water	10	550

Well 40, Drivers; Monogram Farm
(Log by Sydnor Pump and Well Co. and D. J. Cederstrom)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow sand and clay	8	8
Brown sand, gravel and clay	37	45
Chesapeake group (Miocene):		
Sandy blue clay	15	60
Blue clay	231	291
Blue sandy marl, trace of glauconite	14	305
Dark-gray sandy clay	10	315
Pamunkey group, Jackson (?) formation (Eocene):		
Glauconitic sandy marl, phosphatic pebbles, sharks' teeth, quartz pebbles, pelecypod shells	49	354
Pamunkey group, Aquia (?) formation (Eocene):		
Hard gray-green clay, minor glauconite, quartz sand, fish bones, pyrite	19	373
Undifferentiated (Upper Cretaceous ?):		
Hard sandy gray clay, trace of glauconite	80	452
Hard fine white sand	19	471
Hard gray sandy clay	9	484
Stiff mixed clay	5	489
Pasty gray sandy clay	20	509
Potomac group (?) (Lower Cretaceous):		
Medium coarse gray clayey sand, water	12	521
Gray sand, water	14	535
Blue clay	5	540

TABLE 40.—*Logs of wells in Nansemond County, Virginia—Continued*

Well 104, Suffolk; City of Suffolk
(Log by Layne-Atlantic Co.)
Altitude, 19 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil and clay	8	8
Yellow sand	10	18
Sandy clay	7	25
Chesapeake group (Miocene):		
Blue marl and shells	40	65
Soft shell marl	30	95
Hard marl	5	100
Fine sand	12	112
Marl and shells	23	135
Hard marl and shells	25	160
Blue clay	25	185
Soft sandy muck	15	200
Hard blue clay	20	220
Hard clay	20	240
Soft sandy muck	8	248
Sand	6	254
Blue marl	11	265
Hard brown sandstone	2	267
Coarse gray sand	5	272
Brown sandy clay	15	287
Pamunkey (?) group (Eocene):		
Black rotten rock (soft glauconitic limestone ?)	40	327
Undifferentiated deposits:		
Blue-green clay	25	352
Soft blue clay	15	367
Tough blue clay	21	388
Rock (sandstone?)	1	389
Tough blue clay	25	414
Conglomerate	1½	415½
Tough blue clay	20½	436
Soft dark clay, with stones	22	458
Soft brown clay, and sand	35	493
Fine gray sand	2	495
Coarse gray sand, water (?)	5	500
White sand, water	15	515
Sticky gray clay	23	538
Sticky clay, and gravel	21	559
Soft blue clay and shells	11	570
Coarse gray sand, water	10	580
Blue clay, sand and shells	30	610
Fine blue-gray sand, with marl	24	634
Fine blue-gray sand, with marl and shells	42	676
Fine sand, marl and shells	16	692
Sand, water	25	717

TABLE 40.—*Logs of wells in Nansemond County, Virginia—Continued*

Well 106, Suffolk; Pruden Packing Co.
(Log by J. Minton)
Altitude, 7 feet

	Thickness (feet)	Depth (feet)
Chesapeake group (Miocene):		
Gray sand	40	40
Shell marl	10	50
Blue mud	290	340
Pamunkey group (Eocene):		
Black sand	20	360
Undifferentiated (Upper Cretaceous ?):		
Blue mud	60	420
Red mud	30	450
Potomac (?) group (Lower Cretaceous):		
White sand, not much water	92	542
Black greasy mud, not glauconitic	18	598
Coarse white sand, water	45	643

Well 109, Suffolk; Planters Nut and Chocolate Co.
(Log by Virginia Machinery and Well Co.)
Altitude, 52 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow clay	20	20
Chesapeake group (Miocene):		
Blue clay, sand, shells and gravel	30	50
Blue marl and shells	150	200
Blue marl	80	280
Brown sandy marl and shells	27	307
Sand and shell rock	5	312
Brown sandy marl	15	327
Undifferentiated deposits:		
Blue marl	29	356
Blue sandy marl	20	376
Blue marl	27	403
Blue marl with stones	35	438
Hard rock (sandstone ?)	½	438½
Blue marl	63½	502
Yellow-gray marl	10	512
Red-brown marl	22	534
Gray sandy marl	5	539
Gray sand, water	30	569
Gray sandy clay	16	585
Gray sand, water	17	602
Blue marl	1½	603½

TABLE 40.—*Logs of wells in Nansemond County, Virginia—Continued*

Well 115, Cypress; Chesapeake-Camp Corp.
(Log by J. R. McLane)
Altitude, 30 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Sand	12	12
Blue mud	20	32
Chesapeake group (Miocene):		
Fine blue sand with shells	20	52
Sandstone	1½	53½
Fine blue sand, mud	86½	140
Gray sand	10	150
Sand and blue mud	75	225
Blue mud	55	280
Fine sand and dark mud	30	310
Rock	1	311
Undifferentiated deposits:		
Yellow clay	19	330
Red gravel	35	365
Coarse white sand, water	15	380

TABLE 41.—*Analyses of waters from Miocene and Quaternary deposits in Nansemond County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 39)

	Miocene	Quaternary			
	40	45	94	[a]94	112
	Glebe Point	Drivers	Holland	Holland	Suffolk
Silica (SiO_2)	11	.....	.....	.....	.....
Iron (Fe)	7.7	.....	.....	.....	.....
Calcium (Ca)	125	.....	.....	.....	.....
Magnesium (Mg)	9.0	.....	.....	.....	.....
Sodium (Na)	10	.....	.....	.....	.....
Potassium (K)	3.7	.....	.....	.....	.....
Bicarbonate (HCO_3)	246	110	7.0	.....	7
Sulfate (SO_4)	105	100	1	1	9
Chloride (Cl)	22	24	23	19	22
Fluoride (F)	.0	.0	.0	.0	.1
Nitrate (NO_3)	38	133	27	24	8.3
Total dissolved solids at 180°C	464	330	.....	.....	.....
Total hardness as $CaCO_3$	349	330	48	.....	21
Free carbon dioxide (CO_2)	.0	.....	.....	64	.....
Date of collection	Sept. 1, 1939	Aug. 5, 1939	Aug. 5, 1939	Oct. 4, 1939	Aug. 13, 1939

[a]Acid., pH — 4.4.

Analyst: Margaret D. Foster.

TABLE 42—*Analyses of waters from Cretaceous*

(Parts per million. Numbers in name column

	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
Godwins Wharf (1)	17	0.05	1.2	0.7	174	6.4	447
Chuckatuck (12)	.....	.....	.....	.....	.....	.....	593
Hobson (23)	.....	.....	.....	.....	.....	.....	457
Eclipse (30)	.....	.....	.....	.....	.....	.....	470
Trottman Wharf (38)	.....	.....	.....	.....	.....	.....	578
Drivers (43)	.....	.....	.....	.....	.....	.....	580
Town Point (51)	.....	.....	.....	.....	.....	.....	514
Town Point (55)	.....	.....	.....	.....	.....	.....	544
Huntersville (65)	.....	.....	.....	.....	.....	.....	496
Huntersville (66)	.....	.....	.....	.....	.....	.....	561
Everetts Bridge (77)	.....	.....	.....	.....	.....	.....	556
Lake Prince (80)[a]	.....	.....	.....	.....	.....	.....	408
Lake Prince (80)[b]	.....	.....	.....	.....	.....	.....	491
Lake Prince (80)[c]	.....	.....	.....	.....	.....	.....	521
Holland (92)	.....	.....	.....	.....	.....	.....	564
South Quay (97)	.....	.....	.....	.....	.....	.....	384
South Quay (98)	.....	.....	.....	.....	.....	.....	416
Suffolk (104)[d]	12	.02	4.7	1.9	242	7.6	638
Suffolk (104)[e]	21	.20	2.3	.8	213	6.7	518
Suffolk (104)[e]	.....	.....	.....	.....	.....	.....	524
Suffolk (105)	.....	.....	.....	.....	.....	.....	591
Suffolk (108)	.....	.....	.....	.....	.....	.....	628
Suffolk (109)	.....	.....	.....	.....	.....	.....	594
Suffolk (110)	.....	.....	.....	.....	.....	.....	530
Cypress (115)	9.9	.07	2.3	3.3	311	12	775
Cypress (117)	.....	.....	.....	.....	.....	.....	659
Whaleyville (119)	.....	.....	.....	.....	.....	.....	549

[a]Sample taken at 600 feet.
[b]Sample taken at 810 feet.
[c]Sample taken at 852 feet.
[d]Sample taken at 515 feet.
[e]Sample taken at 717 feet.

Analysts: 1, 23, 55, 115 and 117, Margaret D. Foster; 12, 30, 38, 43, 51, 65, 66, 92, 97, 98, 108, 109, 110 and 119, Margaret D. Foster and J. D. Hem; 80 (at 600, 810 and 852 feet), E. W. Lohr; 77, W. M. Noble; 104 (1929), William L. Lamar; 104 (1939) and 105, Margaret D. Foster and G. J. Petretic.

deposits in Nansemond County, Virginia

refer to corresponding well numbers in Table 39)

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids 180°C	Total hardness as $CaCO_3$	Free carbon dioxide (CO_2)	Date of collection
3.8	8.2	3.5	0.58	439	5.9	.....	Aug. 4, 1939
2	7	5.2	.....	.....	10	.....	Aug. 4, 1939
10	15	6.0	.....	.....	<5	4.7	Oct. 3, 1939
25	94	4.3	.....	.....	12	.....	Aug. 4, 1939
6	11	6.6	.....	.....	6	.....	Aug. 5, 1939
7	16	5.0	.....	.....	<5	.....	Aug. 5, 1939
7	16	4.3	.....	.....	14	.....	Aug. 6, 1939
25	67	7.4	.....	.....	7.5	5.0	Oct. 4, 1939
29	87	3.6	.....	.....	<5	.....	Aug. 6, 1939
17	68	5.8	.....	.....	20	.....	Aug. 6, 1939
3.0	7.0	6.0	.88	.....	<5	.....	Nov. 12, 1937
5	5	4.0	.....	.....	20	.....	Aug. 19, 1942
15	15	4.0	.....	.....	14	.....	Aug. 20, 1942
15	20	4.6	.....	.....	10	.....	Aug. 22, 1942
8	11	6.5	.0	.....	15	.....	July 6, 1942
18	34	6.3	.....	.....	16	.....	Aug. 6, 1939
1	4	.8	.....	.....	30	.....	Aug. 5, 1939
13	18	.....	.21	636	20	.....	Aug. 8, 1929
13	25	.....	.06	549	9.0	.....	Sept. 14, 1929
8	26	6.4	.....	.....	9	2.9	Aug. 5, 1939
5	15	7.5	.....	.....	9	1.4	Aug. 5, 1939
5	30	6.8	.....	.....	9	.....	Aug. 4, 1939
8	19	6.8	.....	.....	9	.....	Aug. 3, 1939
6	13	6.2	.....	.....	15	.....	Aug. 3, 1939
16	26	6.4	2.5	782	19	.....	Aug. 4, 1939
15	12	5.6	.....	.....	10	2.9	Oct. 3, 1939
3	7	5.0	.....	.....	22	.....	Aug. 4, 1939

NORFOLK COUNTY

LOCATION AND DEVELOPMENT

Norfolk County extends from Hampton Roads southward to the North Carolina State line. Its greatest importance is due to large commercial, industrial, and military and naval establishments that are located in and about the cities of Norfolk and Portsmouth. The county embraces an area of 410 square miles, 33 per cent of which is classed as farm land. The rural population of the county was 35,828, the City of Norfolk, 144,332, South Norfolk, 50,747, and Portsmouth, 80,038, according to the Census of 1940.

Although the value of farm products is approximately the same as that of other counties described in the present report, the value of manufactured goods is far in excess of that from farm products and is given as about $99,000,000 as compared to about $3,000,000 for farm products. Based on the number of persons employed in each, the most important industries are the manufacture of iron and steel products (railroad and naval supplies), and chemicals (fertilizers and cements). Sawmills and planing mills, other woodworking industries and textiles are of lesser importance.

Norfolk is near Hampton Roads, gateway to Chesapeake Bay and the Atlantic shipping lanes. Its harbor and docks provide facilities for the fueling, provisioning and repairing of ocean vessels and the transshipment of goods. It is a terminal of 6 interstate railroads: the Atlantic Coast Line, the Southern, the Seaboard Air Line, the Virginian, the Norfolk and Western, and the Norfolk and Southern. By ferry Norfolk is connected with the Chesapeake and Ohio Railroad terminating at Old Point Comfort and with the Pennsylvania Railroad terminus at Cape Charles. Greater Norfolk is, therefore, an important port of entry and departure through which domestic and foreign trade moves.

MUNICIPAL WATER SUPPLIES

In 1940 the city of Norfolk[132] obtained its supply of water from a chain of impounding reservoirs known as Lake Wright, Lake Taylor, Little Creek, Lake Lawson, Lake Smith and North Landing Lake, most of which lie in northwestern Princess Anne County. In 1940 a maximum of 8,000,000 gallons a day was used from these sources.

Approximately an equal amount of water was obtained from Lake Prince in Nansemond County, 18½ miles southwest of the city of Norfolk. In 1942 a small additional supply was obtained from the near-by Burnt Mills reservoir, and in 1943 an additional supply was made available from Nottoway River. A pipe line extends from Courtland, Southampton County, to Lake Prince.

The municipal water supply of Portsmouth[134] is also surface water. It is obtained in large part from Lake Kilby, 18½ miles to the southwest, in Nansemond County. Lake Cahoon, 2 miles north of Lake Kilby, is held in reserve to supplement the Lake Kilby supply, when necessary. The capacity of the filter plant of the system is rated at 12,000,000 gallons a day.

TOPOGRAPHY

The Pamlico terrace, from 22 to 15 feet above sea level, forms the surface of most of the county. Although many streams are present, the relief is necessarily small. Much of the area is poorly drained, and ditches have been constructed to augment the natural drainage. The Dismal Swamp Canal is the longest of these ditches. It enters the county along the eastern edge of the swamp and empties into Deep Creek and the inland waterway system. The area about the city of Norfolk faces Hampton Roads, and a depth of 20 feet of water extends for some distance up the Southern and Eastern branches of Elizabeth River. The northern part of the county borders Chesapeake Bay. There wind and ocean currents have formed a long even coastline ending in Willoughby Spit. The entire length of this coast is bordered by sand dunes.

GEOLOGY

Depth to bedrock has not been determined in Norfolk County. Darton[49] reported that a well which was drilled in 1890 at the Norfolk city waterworks (Pl. 10B), to a depth of 1,762 feet just east of the county line in Princess Anne County, failed to reach bedrock, but bedrock may be present at a slightly greater depth.[22] Ewing[59], by seismic investigation, found that near Cape Henry the basement rock is 2,900 feet below the surface.

Sediments of the Potomac group, of early Cretaceous age, rest upon the basement rock and may be more than 1,000 feet thick. They consist of alternating beds of sand and clay. A few layers of indurated sand are reported from place to place, and the

sand varies from very fine to coarse-grained. The strata in the well of the Norfolk City Waterworks (well 20, Table 44) are gray down to a depth of 1,190 feet. Below that depth buff and brown sand and brown and red-brown clay are reported.

Above the Lower Cretaceous strata is 70 feet of gray sand and clay, in which are included green clay and a little glauconite sand. Fossils found in these strata show that they are of late Cretaceous age and that they were deposited in a marine environment, in contrast to the Lower Cretaceous strata, which are continental deposits.

Glauconitic quartz sand strata, 127 feet thick, of Eocene age, were penetrated in a well (9, Table 44) of the Norfolk and Western Railway Co. at Lamberts Point. In a well at the Norfolk City waterworks at Moores Bridges (20) the Eocene deposits consist of about 80 feet of more or less glauconitic marl. At Fentress (63) 72 feet of glauconitic strata were penetrated below 578 feet in a well recently drilled by the Layne-Atlantic Co.

Sediments of Miocene age do not crop out in Norfolk County but have been encountered in many wells. They consist of a maximum of 650 feet of gray to blue clay and fine sand. The record of the Lamberts Point well shows more sand than clay, but few sand strata are reported in the log of the Norfolk City Waterworks well.

In southeastern Virginia the Miocene sediments have been divided into 3 formations the uppermost of which, the Yorktown,[88] consists of shell marls, sands, and beds of sand and shells. It is penetrated by many relatively shallow wells in Norfolk County.

Pleistocene deposits making up the Pamlico terrace are found at the surface throughout most of the county. They consist chiefly of light-colored sand and clay, but blue clay, and marly beds containing shells, are also present. They are probably not more than 50 feet thick in most parts of Norfolk County, and in some areas they are considerably thinner. In many places it is difficult to distinguish in the well logs the boundary between the uppermost Miocene and the base of the Pleistocene. Hence, it is a possibility that wells less than 60 feet deep in Norfolk city and in Portsmouth (north of the Navy Yard) may be sunk in Pleistocene instead of in Miocene sediments. The sand deeper than 30 feet below sea level is referred to the Miocene, however, because it occurs at the same depth as Miocene coquina beds a few miles to the south; and because the Yorktown formation is known to be

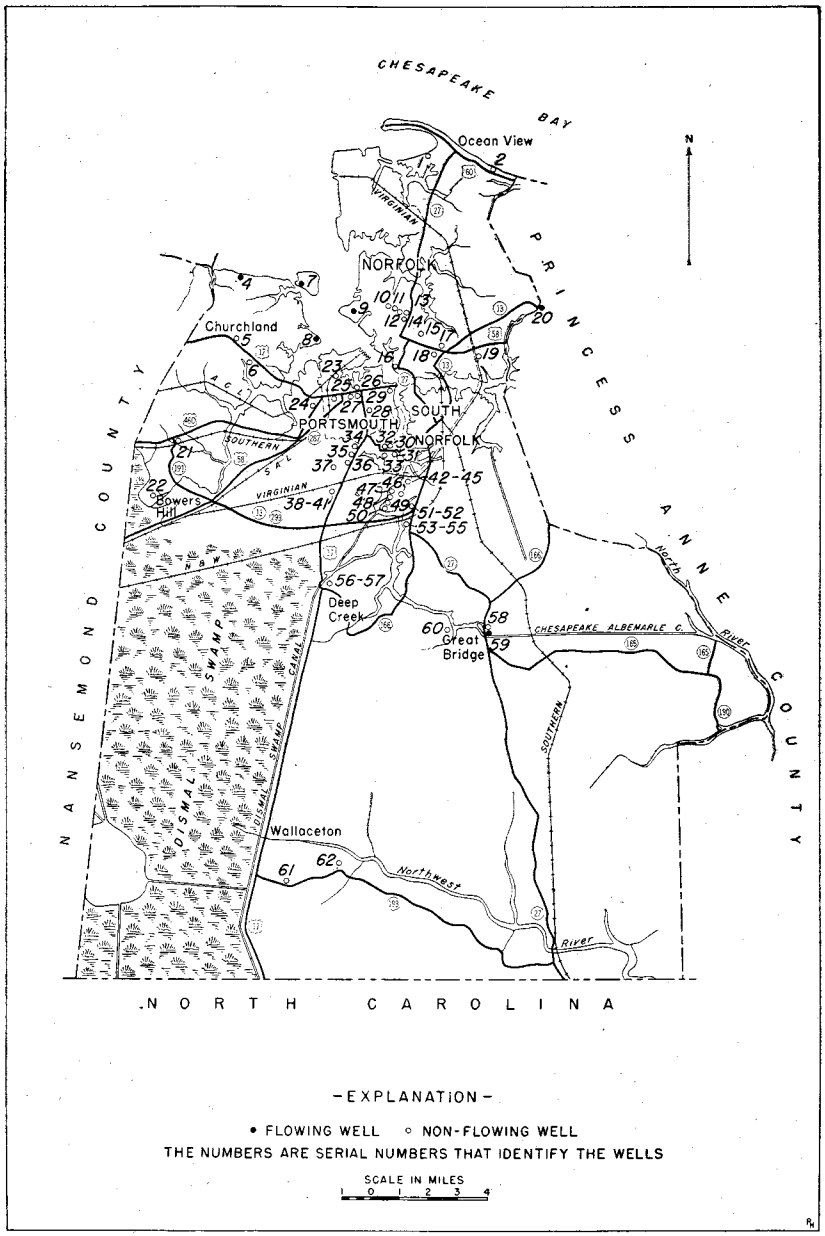


FIGURE 29.—Map of Norfolk County showing location of wells listed in Table 43.

quite sandy in places. Darton[50] has placed the base of the Pleistocene at above 7 feet below sea level at Lamberts Point. Logs that show the character of the Pleistocene deposits a few miles east of Norfolk are included in the description of Princess Anne County.

Willoughby Spit is made up of sand deposited by waves and currents, and along Hampton Roads from Willoughby Spit to the northeast corner of the county sand dunes are well developed.

GROUND WATER

SHALLOW WELLS

Only a few industrial firms in the vicinity of Norfolk use water from shallow wells. The use of water from wells sunk in the terrace sand is largely confined to the strictly rural portions of the county. However, about 1910 a number of concerns obtained moderate supplies of water from batteries of shallow wells, described by Sanford[105] as follows:

"The pumping plant of the Portsmouth, Berkeley & Suffolk Water Co. draws on some 35 6-inch wells, 25 feet deep, about 3 miles south of Berkeley. The wells obtain water from a bed of gray sand below blue mud. The water level of the wells varies considerably. At times it is within 3 feet of surface . . .

"At Port Norfolk, the Norfolk & Portsmouth Traction Co. has, at a power plant at the corner of Mount Vernon Street and Florida Avenue, a mile south of Elizabeth River, 24 wells, 22 of which are 1½ inch in diameter and 16 feet deep, and two are 2 inches in diameter and 50 feet deep. In 1906, these supplied . . . . in all about 55,000 gallons daily.

"At Lambert Point . . . . the first water, at 10 to 12 feet, is called poor; . . . . The Norfolk and Western Railway Co. . . . . once procured water from a system of driven wells 2 miles east of the Point. . . . .

"At Sewell Point [site of the Navy Base] water can be obtained almost anywhere by driving a pipe down 8 or 10 feet. This water is not considered good. . . . . At Ocean View and on Willoughby Spit . . . . water is obtained from driven wells. On the Spit the wells are 20 or 25 feet deep. The water is apt to be irony. At Ocean View station wells are about 12 feet deep, and yield better water than along the beach, where they average 18 to 20 feet and yield irony water.

"At Great Bridge a dug well struck a shell bed containing 'large oyster shells' at 20 feet. Water was found at about 30 feet which quickly filled the well. The owner uses the water for irrigation, and reports pumping 214 gallons per minute without lowering its level."

All these early wells are believed to have been abandoned prior to 1938. However, a few establishments in Norfolk County draw upon shallow terrace sand for their water supply. The Planters Manufacturing Co. in Portsmouth obtains water for boiler feed from fourteen 1½-inch to 2-inch driven wells (23, Table 43). The battery supplies about 40 gallons a minute and is operated continuously. The water has a low total hardness. It is treated with boiler compound to prevent corrosion, and the boiler is blown down frequently to prevent scale.

In conjunction with 15 deeper wells, the Barnes Lumber Co. at Buell (Pl. 16B) pumps 20 wells (43b) which are about 15 feet deep. The maximum yield of the battery is probably not much more than 80 gallons a minute. The water is treated with soda ash to check corrosion in the boilers.

DEEP WELLS

WATER FROM MIOCENE DEPOSITS

Water from the Miocene deposits is used by a large number of homes, dairies, farms and small industrial concerns for drinking, washing, cooling, boiler feed and irrigation. Most of the wells are "home-made" and of small diameter; consequently only low yields are obtained. Where more than 2 or 3 gallons a minute is needed, batteries of 2 to about 40 wells are driven or jetted down.

PORTSMOUTH

In Portsmouth and in the area to the south of Portsmouth, wells developed in the Miocene strata are generally 40 to 60 feet deep. A few are as much as 70 feet deep, and 1 well in the city (33, Table 44), 144 feet deep, obtains water from strata 51 to 93 feet below the surface. Most of the wells are in batteries. Well batteries supplying small industrial concerns with water for cooling (Pl. 17A) consist of 5 wells or less and generally yield not more than 20 gallons a minute from each well. At the factory of Proctor and Gamble, however, 6-inch wells are installed, some of

which obtain water from more than one stratum, and an average yield of 90 gallons a minute from each well is obtained. These wells are pumped continuously 5 days a week. The temperature of the water is about 61° F. or 62° F.

A test well at the Norfolk Navy Yard (30) yielded about 25 gallons a minute with 2 feet of drawdown. Water was obtained from a thick bed of fragmented shell (Pl. 38). In this test water was pumped from open hole 72 to 89 feet below the surface, and that part of the water-bearing stratum from 45 to 72 feet was cased off. It seems likely that hundreds of gallons a minute might be obtained from properly constructed 10- to 12-inch diameter shallow wells where this shell formation is as much as 30 feet thick. Continuous pumping at a high rate would probably exceed safe yield, but such installations might be advantageous for fire protection and other uses where large quantities of water are needed for short periods of time. In continuous use, however, the wells might yield less than 100 gallons a minute.

Sanford[107] reported that the Seaboard Air Line Railway formerly obtained its water supply from fourteen 2½-inch wells and twelve 4-inch wells, 60 to 64 feet in depth. The water was obtained from a sand bed 44 to 50 feet below the surface. This was probably the water-bearing sand that supplies many of the present wells in Portsmouth. Although some difficulty was experienced with clogging by sand, these early wells furnished 200,000 gallons daily.

A number of farms south of Portsmouth and at Deep Creek are irrigated by well water (Pl. 17B). The wells are 1½-inch or 2-inch drive-point wells that range in depth from 40 to 70 feet. Various yields are reported, but it appears that such wells generally yield 5 to 10 gallons a minute although some wells may yield as high as 25 gallons a minute. Each battery consists of 4 to 24 wells, and the total yield from the battery may be from 40 to more than 100 gallons a minute. A few farms have two batteries of wells.

Mr. R. F. Hanberry reported that the spring irrigating period is of about 2½ months duration and lasts from April through the first half of June. Water is pumped 6 to 14 hours a day during that period. At the end of the irrigating season the yield of his wells (38, Table 43) is generally less than one-half that which was obtained at the beginning of the pumping period. At the farm of the

F. W. Richardson estate (36) the yield is reported to have decreased one-third by the end of the spring pumping season. Mr. H. E. Trent at Deep Creek (56), reported that no decrease in yield was observed after a long period of pumping.

In Portsmouth the irrigated farms vary in size from 8 to 24 acres. Water is applied to the land as a spray, by means of elevated 1-inch pipe lines 32 feet apart, upon which nozzles are set every 2½ feet. The amount of water used varies with the local rainfall, but is generally not more than 8,000 gallons daily for each acre. In some years the success of such crops as parsley, peppers, beets, cucumbers and celery is totally dependent upon irrigation; the development of this practice has eliminated much of the risk of this type of farming.

The irrigation wells and small industrial wells in the Portsmouth area thus far mentioned derive water from strata variously described as marl, shells, and sandy marl, or sand and shells. These strata are similar to the Yorktown formation of the York-James Peninsula and probably belong to that formation (Pl. 38).

The static water level in wells which reach Miocene strata is generally a few feet above sea level. In most places this is less than 15 feet from the surface, and, where the land is very low, water may stand only a few feet from the surface.

SOUTH NORFOLK

On the east bank of Southern Branch of Elizabeth River, in the vicinity of South Hill, Buell and Money Point, a number of industrial concerns have developed ground water from the Miocene deposits. The wells range in depth from 50 to 125 feet and, as in the Portsmouth area, most of them are drive-point wells of small diameter. Where water is used for purposes other than sanitation, batteries of 4 to 6 wells are needed. The E. N. Barnes Lumber Co., however, has a battery of 15 wells (43a, Table 43) 80 feet deep, used in conjunction with 20 wells only 15 feet deep, in the terrace deposits. The yields of the deeper wells vary considerably but are reported to be rather high. Perhaps a maximum individual yield of about 30 gallons a minute is obtained from these 2-inch and 2½-inch wells. In an 8-inch well drilled at the Smith-Douglas Fertilizer Co. in 1941, water-bearing beds at 90 to 95 feet and at 113 to 118 feet below the surface furnished 180 gallons a minute with 41 feet of drawdown in a 2-day pumping test. These wells draw water from Miocene sand and shell beds or coquina.

In 1910 the Pocomoke Guano Co., at South Norfolk, obtained water from a well 86 feet deep. The Roanoke Railroad and Lumber Co., near by, obtained water from a similar well 63 feet deep. The logs of these wells, as recorded by Sanford,[106] are given in Table 44.

NORFOLK

In the city of Norfolk groups of 2 to 6 wells supply water to small industrial concerns. Most of the wells are of small diameter and many are equipped with drive-point strainers. Individual wells of small diameter may yield as much as 20 gallons a minute. At the plant of the Liquid Carbonic Co. two 8-inch wells (18a, 18b) are reported to have a combined yield of 85 gallons a minute when pumped continuously. Well 18c yields 60 gallons a minute with 41 feet of drawdown. Water is obtained from a sand bed 43 to 50 feet below the surface. At the plant of the Truckers Ice Co. near by, two 3-inch wells (17) yield about 90 gallons a minute and are pumped continuously. In the spring of 1940 a gravel-packed well of large diameter (13) was constructed at the Home Steam Laundry, the yield of which is probably a good measure of the maximum amount obtainable in this limited area. Sand was encountered at 45 to 51 feet below the surface and was underreamed to a diameter of approximately 40 inches. An 8-inch screen, 5 feet in length, was set opposite the sand, and the remaining space outside the screen was packed with gravel. An 8-hour pumping test showed a yield of 77 gallons a minute with drawdown of 26½ feet. The installation supplies the laundry with 65 gallons of water a minute.

Shortly after the Home Steam Laundry well was completed, an effort was made to secure a larger supply of water at the Ideal Laundry. A test hole, 170 feet deep, was drilled about 100 feet from well 10a but no water-bearing strata were encountered deeper than 18 feet below the surface. As the existing wells presumably obtain water at 2 or more horizons between 40 and 135 feet below the surface, it would appear that the occurrence of shallow water-bearing strata in Norfolk is very variable.

As indicated by the log of the well of the Liquid Carbonic Co. (18a, Table 44) and other data, a sand stratum 35 to 60 feet below the surface is the source of supply of most of the establishments using ground water in the city of Norfolk. A shell bed at 96 to 103 feet is also drawn upon at the plant of the Liquid Carbonic Co. and perhaps also at the Ideal Laundry.

However, it is reported that no relatively shallow water-bearing strata were encountered at the office of the Old Dominion Peanut Co. (14), about one-quarter of a mile from the Home Steam Laundry. Therefore, the possibility of failure to encounter water-bearing strata a short distance from existing wells must be taken into account if ground-water supplies in Norfolk are contemplated in unproven parts of the city.

NORFOLK COUNTY

Wells about 60 feet deep furnish water to a few individuals in Churchland, northwestern Norfolk County. A well 71 feet deep of the Pine Grove Dairy (21, Table 43) obtains water from a gravel and shell stratum 35 to 40 feet below the surface.

At Great Bridge, 10 miles south-southeast of Norfolk, several wells 65 to 70 feet deep develop water from Miocene strata. One well (59), 5 feet above sea level, flows 10 gallons a minute.

The Richmond Cedar Works, 1 mile west of Great Bridge, pumps about 60,000 gallons daily from eight 2-inch wells (60, Table 43), ranging from 50 to 90 feet in depth. The water is used for boiler feed. It is considered very hard, and a boiler compound is used to render the water more suitable for steam making. It is reported that this water becomes brackish during periods of very high tide. This is an uncommon condition in the area, and it seems possible that saline uppermost ground water may be leaking into some of the wells and causing the high chloride content.

QUALITY OF WATER

The water obtained from the Miocene deposits in Norfolk County is considered hard by all consumers. The total hardness ranges from 117 to 228 parts per million in samples analyzed, as shown in Table 46. It is present largely as calcium bicarbonate. The chloride content is less than 100 parts per million in most places, and, with the one exception noted, no difficulty with salty water or brackish water has been reported. Iron in the water is troublesome in some places, but in most places it is not present in sufficient amounts to cause difficulty. The water sample from the 135-foot well of the Ideal Laundry (10a, Table 46) contained 15 parts per million of free carbon dioxide. Silica is said to be present in undesirable quantities in many well waters near Norfolk which are used for boiler feed.

Although the water from the Miocene deposits is hard and may contain undesirable amounts of silica and iron, it is successfully used for boiler feed by 8 firms in South Norfolk and by 1 firm in Portsmouth. The water forms scale if used raw, so all these firms treat the water before using it for steam making and the boilers are frequently blown down to minimize the strong tendency to form scale. More thorough treatment is practiced in other places by adding other chemicals, or boiler compounds, to the water. Water from the Miocene strata that is used by 2 laundries in Norfolk is softened by zeolites before use.

According to Scofield's formula,[116]

$$\frac{Na(+K) \times 100}{Ca+Mg+Na(+K)} = \text{per cent of sodium}$$

in which the basic constituents are expressed as equivalents per million, if the percentage of sodium is 50 or less, the water is safe for irrigation. On this basis, the hard water from the Miocene deposits of the Norfolk area is well suited for irrigation. No complete analyses of the water used for irrigation in the Portsmouth area are at hand, but a complete analysis of a similar water from Great Bridge indicates that the ratio of sodium to total bases is 33 per cent, which is within the permissible limit. A partial analysis of an irrigation water from Deep Creek indicates that it is of a similar type. Water from the Miocene sediments is also used for irrigation at one locality in Nansemond County. A complete analysis shows that this water has an even more favorable ratio of sodium to total bases. The fact that water from the Miocene strata has been successfully used for a number of years is conclusive evidence of its fitness for irrigation.

WATER FROM CRETACEOUS DEPOSITS

ARTESIAN HEAD

The height to which water will rise in deep wells in various parts of Norfolk County is not known. Static level was 24 feet above sea level (in 1944) near Fentress, south of Norfolk, but it seems probable that water will not rise more than about 15 feet above sea level in the vicinity of Norfolk. As water rose about 33 feet above sea level in the Lamberts Point well (9) in 1898, a considerable loss of head since that time is indicated.

YIELD

Since only a few wells are developed in Cretaceous strata in Norfolk County not a great deal is known of the yield. The Lamberts Point well (9) flowed about 65 gallons a minute in 1898, at which time the piezometric level was 19 feet above the outlet of the well. By 1906 the yield had decreased to 51 gallons a minute. It was not possible to measure the flow in 1939. The flow of the H. L. Trottman well (4) was estimated to be about 30 gallons a minute in 1939. This is about one-half of the quantity discharged when the well was drilled in 1916.

The 4-inch well of the Virginia Smelting and Refining Co. (8) is pumped by air lift and yields a maximum of 285 gallons a minute during 15 hours a day, for a period of 3 weeks each year. The average amount pumped is somewhat less.

It would appear that moderate quantities of water may be obtained from wells less than 650 feet deep in many parts of Norfolk County, particularly in the city of Norfolk and in the area farther west. The more westerly and shallower wells will obtain the better water. It seems to the writer that, with few exceptions, the Cretaceous sands between 500 and 700 feet below the surface have been neglected as a source of water supply in this area. In some places they might be developed with difficulty, or might not be under sufficient head to cause the wells to flow at the surface. Although the water is more or less mineralized, as discussed below, it is used for drinking purposes at Craney Island (7) and elsewhere (4) and water from the well of the Virginia Smelting and Refining Co. (8) is treated and used for boiler feed. The temperature of water from these depths is considerably higher than that of shallower waters and may be as high as 72° F. However, water of this temperature might be economically used for cooling. Water from Cretaceous sands, however, is entirely unsuited to irrigation because of its low hardness and high sodium content.

QUALITY OF ARTESIAN WATER

In northwestern Norfolk County a well 520 feet deep (4, Table 47) yields water containing 196 parts per million of chloride. A 590-foot well (7) at the Navy Fuel Depot at Craney Island and a 600-foot well (8) at the office of the Virginia Smelting and Refining Co. in Port Norfolk yield water containing respectively 258 and 260 parts per million of chloride. At Lamberts Point, the Norfolk and Western Railway Co.'s well, 616 feet deep (9), supplies water containing 300 parts

of chloride, and a well 720 feet deep, at the office of the Old Dominion Peanut Co. (14), yields water containing 408 parts per million of chloride.

Several water-bearing strata in the Cretaceous sediments were penetrated between 730 and 1,762 feet below the surface in the Norfolk City Waterworks well[a]. Water from a depth of 730 (?) feet contained 1,030 parts per million of chloride. At 1,038 feet and 1,070 feet the water contained respectively 2,723 and 2,830 parts per million of chloride. Where quality of water at other horizons is mentioned in the log, the water was recorded as salty or slightly salty.

At Fentress, 10 miles south-southeast of Norfolk, water from basal Miocene and Eocene strata contained 1,300 parts of chloride, according to a commercial analysis.

The meager data at hand seem to indicate, therefore, that water which contains less than 300 parts per million of chloride may be obtained from Upper Cretaceous strata in northwestern Norfolk County; but in that part of the county east of Elizabeth River and Dismal Swamp the chloride content may be materially greater in water from such beds. Wells 500 to 650 feet deep between Churchland and Norfolk yield water that is satisfactory for many purposes, but east of Norfolk there is a sharp increase in mineral content of the water. In Nansemond County, adjoining Norfolk County on the west, only a few of the many deep wells yield water containing more than 50 parts per million of chloride. (See Fig. 15). The progressive increase in mineral content eastward due to greater chloride and sodium content is apparent.[21]

The data at hand indicate that the chloride content of water in deep strata in Norfolk County is not increasing. It is reported that the chloride content of water from the well of the Virginia Smelting and Refining Co. (8, Table 47) has not increased since the well was drilled in 1922. Sanford[115] published analyses made in 1891 and 1906 of water from the Lamberts Point well (9), showing contents of 351 and 291 parts per million of chloride. A sample collected from this well in 1939 contained 300 parts per million of chloride. A sample of water collected in 1906 from the Norfolk City Waterworks well was analyzed by Dr. Shepard, City Bacteriologist of Norfolk, and found to contain 1,030 parts per million of chloride (24, Table 47). A sample collected in 1939 contained 1,080 parts per million of chloride. It is probable that water enters this well from several horizons. Since loss of head in water from the upper horizons would admit more brackish water from

[a] This well is near the Norfolk-Princess Anne County boundary in Princess Anne County. For the sake of unity it is included with the discussion of deep wells in Norfolk County.

greater depths, the small increase in chloride content may not indicate that the upper strata are now yielding water more saline than when the well was drilled.

WELL RECORDS AND ANALYSES

Records of wells in Norfolk County, available logs of wells, and analyses of water samples are listed in Tables 43-47, on the following pages. The locations of the wells listed (except 63) are shown in Figure 29.

TABLE 43.—*Records of wells in*

No.	Location	Owner or name	Type of well[a]	Depth of well (feet)	Diameter of well (inches)	Number of wells[b]	Character of water-bearing material
1	East shore of Willoughby Bay.	Capt. C. H. Stanwood.....	D	20	2	1	Terrace sand
2	1 mile east of Cottage Park...	Dr. J. A. Jones.....	D	18	1¼	1	Dune sand
4	1 mile north of Twin Pines....	H. L. Trottman.....	J	520	2	1	Sand
5	Churchland.....	J. S. Wright.....	D	62	2	1	Sand
6	½ mile southeast of Churchland.	B. B. Ferguson.....	D	60?	1¼	1	.....
7	Craney Island.....	Navy Fuel Depot.....	D	590	8	1	Sand
8	West Norfolk.....	Virginia Smelting and Refining Co.	D	605	4	1	Sand
9	Lambert Point.....	Norfolk and Western Ry. Company.	.....	.....	.....	.....	Sand
10a	26th St. and Hampton Blvd., Norfolk.	Ideal Laundry.....	D	135	6	1	Sand
10b	26th St. and Hampton Blvd., Norfolk.	Ideal Laundry.....	Dv	40–100	2	7	Sand
11	25th St. and Colley Ave., Norfolk.	Nehi Bottling Co.....	Dv	55	2	3	Sand
12	25th and Llewellyn Ave., Norfolk.	Orange Crush Bottling Co..	Dv	55	2	3	Sand
13	25th St. and Omohundred Ave., Norfolk.	Home Steam Laundry.....	D	51	8	1	Sand
14	Omohundred Ave. and Norfolk and Western Ry., Norfolk.	Old Dominion Peanut Co...	D	720	6	1	Sand
15	Church St. and Lexington Ave., Norfolk.	Southern Brewery Co.....	D	155	8	2	Sand
16	Water St., Norfolk.....	Spicuzza Fruit Co.....	.....	60	2	1	Sand
17	Truckers Ice Co.....	Truckers Ice Co.....	.....	.....	3	3	.....
18a	1180 Calvert St., Norfolk.....	Liquid Carbonic Co.....	D	108	8	1	Sand and shells
18b	1180 Calvert St., Norfolk.....	Liquid Carbonic Co.....	.....	55	8	1	Sand
18c	1180 Calvert St., Norfolk.....	Liquid Carbonic Co.....	D	50	8	1	Fine to coarse sand
19	Broad Beach Road and Virginian Ry., Norfolk.	Milwaukee Bottling Co....	.....	50	.....	1	Fine to coarse sand
20	Moores Bridges (Princess Anne County).	Norfolk City Waterworks..	D	1750	10 to 4½	1	Sand
21	2 miles west of Bowers Hill....	Pine Grove Dairy.....	Dv	71	2	1	Gravel and shells
22	2¼ miles west of Bowers Hill..	R. T. Shay.....	J	40	2½	5	Shell bed
23	South of intersection of A. C. L. and Belt Line R. R., Portsmouth.	Planters Mfg. Co.....	Dv	20–25	1½–2	14	Terrace sand
24	Highway U. S. 58 and Belt Line R. R., Portsmouth.	Portsmouth Lumber Co....	Dv	50–60	3	4	Sand
25	Highway U. S. 58, Portsmouth.	Portsmouth Coal and Ice Co.	D	.....	6–4	1	.....
26	Highway U. S. 58, Portsmouth.	Norman Packing Co.....	J	40–65	3	5	Sand and shell
27	Highway U. S. 58, Portsmouth.	Maupin Ice Co.....	Dv	60	4	1	Fine sand
28	Highway U. S. 17 and Seaboard R. R., Portsmouth.	Consumers Ice Corp.....	J	48–60	2	3	Shells
29	South of Portsmouth-Norfolk Ferry Slip.	Isaac Fass.....	Dv	65?	2	1	Sand
30	Southeastern Portsmouth.....	Norfolk Navy Yard.....	D	90	8	1	Shells
31	½ mile south of Navy Yard, Portsmouth.	Wycoff Creosote Company..	Dug	12	.....	1	Terrace sand
32	¼ mile southwest of Navy Yard, Portsmouth.	D. H. Gowing Veneer Co...	D	105	4	1	.....
33	¼ mile southwest of Navy Yard, Portsmouth.	Proctor and Gamble.....	D	44–250	6	5	Terrace sand

Norfolk County, Virginia

Geologic age[c]	Approximate Water Level: Feet above (+) or below (−) surface[d]	Maximum daily consumption (thousands of gallons)	Use of water[e]	Reported quality[f]	Remarks	No.
P	−15	.....	D	A	.....	1
R	−	2	D	A	Supplies "Tiny Town".	2
C	+	.....	D	A	Jetted by J. Minton in 1916. Flows 30 gallons a minute. Temp. 69½° F.	4
M	−	.....	D	A	Driven by B. Carney.	5
.....	−	2	S	TH, 130 Cl, 20	Driven by B. Carney.	6
C	+	1	D	A	Drilled by Sydnor Pump and Well Co.	7
C	+	50	B	A	Drilled by Sydnor Pump and Well Company. Pumps 285 gallons a minute. Temp. 68° F.	8
C	+	.....	D C	A	Drilled by Sydnor Pump and Well Company.	9
M	−	10	Ind	A	Water softened before using. Drilled by A. Johannson.	10a
M	−	5	Ind	TH, 115 Cl, 63	Water softened before using. Drilled by A. Johannson.	10b
M	−	20	C	TH, 180	Driven by W. R. Jones. Temp 61½° F.	11
M	− 8	20	C	TH, 190 Cl, 34	Temp. 62½° F.	12
M	−14½	20	Ind	Hard	Water softened before using.	13
C	+	2	C	A	Drilled by Sydnor Pump and Well Co. in 1938. Flows 8 gallons a minute.	14
M	−	.....	C	TH, 266 Cl, 52	Water from yellow shell at 45 to 50 ft. and from sand at 150 to 155 ft.	15 15
M	−	.....	C	Hard	Pumps 4 gallons a minute.	16
.....	−	120	C	.....	Temp. 62° F.	17
M	−18.0	100	C	.....	Drilled by A. Johannson in 1930. Screens set at 38 to 43 ft. and 98 to 103 ft. Water level Aug. 22, 1931.	18a
M	−	.....	C	.....	.....	18b
M	−20½	.....	C	.....	Drilled in 1943 by Sydnor Pump and Well Co, yields 60 gallons a minute with 45 ft. drawdown. Strainer at 43 to 50 ft.	18c
M	−	.....	C	.....	.....	19
C	+13½	.....	D	A	Water level measured Aug. 12, 1939. Temp. 75° F. Flows about 60 gallons a minute.	20
M	−	9	D S	Moderately hard, iron	.....	21
M	−8	.....	Irr	.....	Combined yield 100 gallons a minute.	22
P	−	50	B	A	Equipped with drive points; water treated before using.	23
M	−	5	B	Hard	Open-end wells; water is treated before using.	24
.....	−	60	C	.....	.....	25
M	−15	45	C	Hard, iron	.....	26
M	−18	30	C	Hard	Temp. 62° F.	27
M	−	70	C	.....	.....	28
M	−	.....	Ab	.....	Pumped sand until the ground settled and damaged a brick storehouse.	29
M	−12	.....	T C	A	Yielded 25 gallons a minute with 2 feet of drawdown. See text.	30
P	−5	.....	C	Hard, corrosive, brackish	.....	31
M	−	10	C	TH, 188 Cl, 40	Drilled by A. Johannson in 1915.	32
M	−	500	C	TH, 103 Cl, 114	Wells respectively 44, 60, 85, 125 and 250 ft. deep. Shell bed with much water at 51 to 62 ft. Water also from sandy and shelly material below 120 ft.	33

TABLE 43.—*Records of wells in*

No.	Location	Owner or name	Type of well[a]	Depth of well (feet)	Diameter of well (inches)	Number of wells[b]	Character of water-bearing material
34	Shell Road and Paradise Creek, Craddock.	Edwards and Jackson Truck Farm.	J	45	2	18	Hard fine sand
35a	Shell Road and Paradise Creek, Craddock.	Edwards and Jackson Truck Farm.	J	70	1¼	24	Gravel and shells
35b	½ mile south of Paradise Creek on Shell Road.	R. F. Hanberry	J	55	2	24	Sand and shells
36	¾ mile south of Paradise Creek on Shell Road.	F. W. Richardson Estate	J	60	1¼	10	Sand
37	Deep Creek Blvd., 1 mile north of Virginian Ry.	W. S. Parker	J	55	2	16	Sand
38	Shell Road and Virginian Ry.	R. F. Hanberry	J	58	2	16	Sand
39	Deep Creek Blvd. and Virginian Ry.	B. C. Hayes	J	52	2	7	Sand and shells
40	Deep Creek Blvd., near Virginian Ry.	E. C. Jackson	Dv	40–85	2	18	Sand
41	Deep Creek Blvd., ⅓ mile south of Virginian Ry.	W. C. Parker	J	62	2	7	Sand and shells
42	South Hill, 5 miles south of Norfolk.	Amoco Petroleum Corp.	Dug	20	.....	1	Terrace sand
43a	South Hill, 5 miles south of Norfolk.	E. N. Barnes Lumber Co.	J	80	2–2½	15	Shells
43b	South Hill, 5 miles south of Norfolk.	E. N. Barnes Lumber Co.	Dv	15	2–2½	20	Terrace sand
44	South Hill, 5 miles south of Norfolk.	Republic Creosote Co.	.....	65	2	4	Shells
45	South Hill, 5 miles south of Norfolk.	The Texas Company	.....	80	.....	2	Sand
46	Buell, 5 miles south of Norfolk.	Smith Rowland Company	.....	40	.....	1	Sand
47	Buell, 6 miles south of Norfolk.	Norfolk Creosote Co.	J	65	2	6	Sand
48	Buell, 6 miles south of Norfolk.	F. S. Royster Guano Co.	.....	125	2½	1	Sand
49	Buell, 6 miles south of Norfolk.	Davison Chemical Co.	.....	85	.....	1	Sand
50	Money Point, 6½ miles south of Norfolk	Norfolk Tallow Co.	D	60	.....	4	Sand
51	1 mile east of Gilmerton	Chilean Nitrate Sales Corp.	.....	87	.....	1	Sand
52	1 mile east of Gilmerton	Southern States Fertilizer Co.	.....	85	2	1	Sand
53a	1 mile east of Gilmerton	Smith Douglas Fertilizer Co.	.....	125	2	4	Sand
53b	1 mile east of Gilmerton	Smith Douglas Fertilizer Co.	D	118	8	1	Shells and sand
54	1 mile east of Gilmerton	Colonial Oil Company	Dv	115	2	1	Sand
55	1 mile east of Gilmerton	Weaver Fertilizer Co.	.....	50-100	2	5	Sand
56	Deep Creek	H. E. Trent	J	70	2	4	Sand and shells
57	Deep Creek	H. E. Trent	J	40	2	4	Sand and shells
58	Great Bridge	T. H. Old	.....	60	1¼	1	Sand
59	Great Bridge	State Highway Dept.	.....	64	3	1	Sand
60	½ mile west of Great Bridge	Richmond Cedar Works	Dv	50-90	2	8	Sand
61	Wallaceton	Ballyhock Farm	.....	60	.....	1	Sand
62	2½ miles east of Wallaceton	C. L. Garrett	Dv	15	2	1	Terrace sand
63	Near Fentress	Oak Manor Farm	D	650	8	1	White sand Black sand

[a]D = drilled. Dv = driven. Dug = dug. J = jetted.
[b]Number of wells operated as a unit.
[c]R = Recent. P = Pleistocene. M = Miocene. C = Cretaceous. E = Eocene.
[d]Reported by owner as average water level.

Norfolk County, Virginia—Continued

Geologic age[c]	Approximate Water Level: Feet above (+) or below (−) surface[d]	Maximum daily consumption (thousands of gallons)	Use of water[e]	Reported quality[f]	Remarks	No.
M	—	80	Irr	.....	.....	34
M	—	80	Irr	.....	.....	35a
M	—	130	Irr	.....	Two pumping units of 12 wells each. Total yield 10,000 gallons an hour. After pumping 2½ months the yield of each unit is 2,000 gallons an hour.	35b
M	—	70	Irr	.....	.....	36
M	—	130	Irr	.....	.....	37
M	—	70	Irr	.....	.....	38
M	−3	40	Irr	.....	Irrigates 15 acres.	39
M	−7	120	Irr	.....	Two pumping units of 9 wells each. Greatest amount of water obtained at 55 to 62 ft. Wells are equipped with screens.	40
M	−6	80	Irr	.....	No decrease in yield noted at end of 3 months heavy pumping, according to owner.	41
P	—	4	B	Soft	.....	42
M	—	60	B	TH, 200 Cl, 24	Not equipped with screens.	43a
P	—	.....	B	.....	Equipped with drive-point screens.	43b
M	−14	30	B	A	.....	44
M	—	12	C	Hard	.....	45
M	—	6	B	A	.....	46
M	−2	3½	B	TH, 94 Cl, 177 Fe, 1.9	.....	47
M	—	.....	D	Hard	.....	48
M	—	2	D	Hard, iron	.....	49
M	—	.....	B	Cl, 348	Drilled by A. Johannson in 1932.	50
M	—	.....	D	Hard, iron	.....	51
M	—	.....	D	.....	.....	52
M	—	8	B	TH, 220 Cl, 98 Fe, 2.4	.....	53a
M	−8	.....	B	.....	Yields 180 gallons a minute with 41 ft. drawdown. Drilled in 1941 by J. Lundquist. Water-bearing strata at 90 to 95 and 113 to 118 feet.	53b
M	—		Ind	TH, 180 Cl, 160	.....	54
M	—	5	B	TH, 228 Cl, 19	.....	55
M	—	15	Irr	Hard	.....	56
M	−5	15	Irr	A	.....	57
M	−1	.....	D	.....	Temp. 61½° F.	58
M	+½	.....	D	A	Flows 10 gallons a minute. Water head 3½ ft. above sea level Aug. 29, 1939.	59
M	—	60	B	Very hard	Boiler compound used.	60
M	—	.....	D	TH, 205 Cl, 43	.....	61
P	—	.....	D	TH, 65 Cl, 20	.....	62
M, E	+4	.....	T Ab	Cl, 1,300 Total dissolved solids, 3,209	Water level as of Oct., 1939. Strainers at 556 to 566 feet and 621 to 631 feet.	63

[e]Ab = abandoned. B = boiler feed. C = cooling. D = domestic. I = industrial. Irr = irrigation S = stock. T = test.
[f]A: Analysis given in Table of Analyses. Figures refer to total hardness (TH), chloride (Cl) and iron (Fe), in parts per million, as determined by field test or commercial analysis.

TABLE 44.—*Logs of wells in Norfolk County, Virginia*

Well 9, Lamberts Point; Norfolk & Western Railway Co.
(Log by N. H. Darton)[49]
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Yellow sand, shell fragments	17	17
Chesapeake group (Miocene):		
Blue clay, shell fragments	27	44
Fine gray micaceous sand, shell fragments	139	183
Gray-green sandy clay	8	191
Gray micaceous sand	42	233
Gray-green fine sand and clay, tough when dry (fossil shells)	31	264
Gray or blue clay	22	286
Gray or blue fine sand, shell fragments	69	355
Gray or blue clay	22	377
Fine gray sand, shell fragments	20	397
Dark-gray or blue clay	10	407
Pamunkey (?) group (Eocene):		
Coarse gray sand, some glauconite	119	526
Fine gravel, shell fragments	8	534
Undifferentiated (Upper Cretaceous ?):		
Gray or blue clay	29	563
Rock, shell fragments	1	564
Dark hard fine micaceous sandy clay, well laminated	4	568
Rocky strata, with thin layers of clay and shell fragments	35	603
Fine gravel in gray sand, shell fragments; water	3	606
Rock, shell fragments	4	610
Gray fine to coarse micaceous sand, oyster shells	6	616

Well 18a, Norfolk; Liquid Carbonic Co.
(Log by P. M. Weinstein)
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Blue clay	20	20
Gray sand	5	25
Sandy clay and shell	11	36
Gray and yellow sand; water[a]	9	45
Chesapeake group (Miocene):		
Blue mud and shells	51	96
Gray sand, shells, and gravel; water[a]	7	103
Blue mud	5	108

[a]Strainers at 38 to 43 and 98 to 103.

TABLE 44.—*Logs of wells in Norfolk County, Virginia—Continued*

Well 20, Moores Bridges; Norfolk City
(Log by N. H. Darton),,
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Light buff sandy loam	5	5
Fine light sand	13	18
Sand, water	3	21
Blue clay, fossiliferous	44	65
Blue clay, not fossiliferous; small streak of gravel at 80 feet	20	85
Chesapeake group (Miocene):		
Gray clayey sand and gravel; scallop shell at 105 feet	20	105
Gray clayey sand, fossiliferous and containing large white quartz pebbles at 110 to 115 feet; *Rangia cuneata* shell at 125 feet	20	125
Gray, clayey sand, with comminuted shells	40	165
Fine blue clay; scallop shell at 185 feet	85	250
Gray clay, with much sand; many shells about 5 inches long, well had to be cased	10	260
Dark-green sandy clay	25	285
Soft clay which ran into well	20	305
Green-gray clay	5	310
Gray sandy clay; very sandy clay (had to be cased off) 310-320	65	375
Light fine less sandy clay	70	445
Light-gray fine clay, comminuted shells at 465-475 feet	135	580
Lighter fine clay	45	625
Pamunkey group, Jackson (?) formation (Eocene):		
Greensand marl (glauconite), with white quartz sand	10	635
Dark-green clay	30	665
Dark-sticky hard clay	20	685
Pamunkey group, Aquia (?) formation (Eocene):		
Gray sticky hard clay, with glauconite	20	705
Light-gray clay	10	715
Undifferentiated (Upper Cretaceous ?):		
Light-gray shell marl	13	728
Gray sand, small flow of salt water	2	730
Soft sandy clay, with comminuted shells	5	735
Small gravel (and clay); flow of salt water	10	745
Very sandy green clay, micaceous sand, fossil shells (Upper Cretaceous) at 755 feet to 765 feet; water at 740 to 750 feet	20	765
Gray micaceous sand with a little glauconite; flow of salt water at 780 to 783 feet	18	783
Light-gray, sticky clay	2	785
Potomac group (Lower Cretaceous):		
Gray quartzose sand, some mica, no glauconite; slightly salt water at 786 to 805 feet, flow 35 gallons a minute	30	815
Dark-gray sand, no glauconite	20	835
Light-gray sand	35	870
Gray very sandy clay	20	890
Black sticky mud (no sample)	8	898
Clayey sand or alternations of gray sand and clay, micaceous sand; lignite at 925 and 965 feet, quartz pebbles at 925-935 feet, slightly salt water, flow 75 gallons a minute at 950 feet, 10 gallons a minute 975 to 980 feet, 15 gallons a minute at 985 feet	93	991

TABLE 44.—*Logs of wells in Norfolk County, Virginia—Continued*

Well 20, Moores Bridges; Norfolk City—Continued

	Thickness (feet)	Depth (feet)
Potomac group (Lower Cretaceous)—Continued		
Yellow sandy clay (green when fresh)	42	1,033
Gray sand, some micaceous, pebbles at 1,060-1,070 feet; flows of salt water, 25 gallons a minute at 1,038 feet, 150 gallons at 1,070 feet	45	1,078
Gray sand, clayey and micaceous above 1,100 feet	42	1,120
Dark-gray fine to coarse sand, pebbles at 1,130 feet; coarse gray sand, lignite at 1,160 feet; pebbles and water at 1,190 feet; yield of water by bailing 350,000 gallons in 24 hours, said to have been fresh at first, afterwards salt	70	1,190
Red and yellow or buff clay and clayey sand; pebbles at 1,210 feet	40	1,230
Dark fine clay and micaceous sand, called "black marl" by driller but not a greensand (glauconite) marl; lignite at 1,250 feet	25	1,255
Yellow-olive micaceous sand	35	1,290
White marl (no sample)	5	1,295
Yellow and gray clay and sandy clay called "red marl", but not glauconite; fossil shell (Upper Cretaceous) reported from 1,320 feet	35	1,330
Alternations of sand (micaceous 1,320-1,340 feet, not micaceous below) and clayey sand varying from white or light-gray to yellow; pebbles at 1,470-1,480 feet and 1,540-1,570 feet; clay (no samples) at 1,356-1,358 feet, 1,400-1,410 feet, 1,557-1,560 feet, 1,568-1,571 feet; lignite at 1,500 feet; salt water flow at 1,480 feet, 1,510-1,517 feet and 1,535 feet	250	1,580
Dark slightly variegated clay	20	1,600
Red or pink coarse sand and clayey sand; clay (no samples) probably not glauconitic but blue when wet, at 1,640-1,647 feet, 1,650-1,654 feet, 1,677-1,680 feet	80	1,680
Dark coarse very sandy clay, slightly variegated with red, similar to that from 1,580-1,600 feet but more sandy; probably dark clay beds at 1,683-1,685 feet and 1,693-1,695 feet	20	1,700
Red variegated clay	42	1,742
Loose sand which ran up 150 feet in casing; evidently water bearing (no sample)	20	1,762

Well 22, Bowers Hill; R. T. Shay
(Log by owner, from memory)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	2	2
Hard clay	3	5
Sand	7	12
Blue mud	23	35
Shell marl, water	5	40

TABLE 44.—*Logs of wells in Norfolk County, Virginia—Continued*

Well 33, Portsmouth; Procter and Gamble Co.
(Log by A. Johannsson)
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil	2	2
Yellow sand	3	5
Gray sand	9	14
Blue sand	2	16
Sandy blue mud	3	19
Blue mud	13	32
Fine gray sand	2	34
Yellow sand, water	6	40
Light clay	4	44
Brown clay	2	46
Chesapeake group (Miocene):		
Sandy marl	5	51
Shell and marl, much water	11	62
Dark gray sand and shells, some water	31	93
Dark gray sandy clay and shells	51	144

Portsmouth; Seaboard Air Line Railway Co.
(Log by S. L. Sanford[108])
Altitude, 10 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Fine gray sand	4	4
Very fine gray quicksand with bits of rotten wood and tree trunks at 18 to 20 feet	31	35
Chesapeake group (Miocene):		
Bluish-gray clay	9	44
Very fine light buff sand, water	6	50
Hard coarse gravel, water	10	60

South Norfolk; Pocomoke Guano Co.
(Log by S. L. Sanford[106])
Altitude, 6 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Hard black soil	3	3
Soft fresh mud, swamp muck	9	12
Chesapeake group (Miocene):		
Blue marl and mud	68	80
Shells, sand and gravel, water	6	86

TABLE 44.—*Logs of wells in Norfolk County, Virginia—Continued*

South Norfolk; Roanoke Railroad & Lumber Co.
(Log by S. L. Sanford[96])
Altitude, 6 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Soil and sand	15	15
Clay, sand at base, water	10	25
Chesapeake group (Miocene):		
Black mud with fine shells, clear water at 53 feet	28	53
Black mud	10	63

Well 63, near Fentress; Oak Manor Farm
(Log by Layne-Atlantic Co.)
Altitude, 20 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Top soil	4	4
Sand and blue clay	3	7
Brown clay	2	9
Brown sand with mud	62	71
Chesapeake group (Miocene):		
Blue clay with trace of shells and sand	13	84
Shells	16	100
Shells and shell rock	15	115
Blue clay and shells	18	133
Blue clay	15	148
Gray clay and shells	62	210
Fine silty sand, gray	20	230
Blue clay	12	242
Blue clay and shells	9	251
Blue clay	161	412
Soft blue clay with trace of fine sand	144	556
Medium-coarse quartz sand in hard and soft streaks, water	16	572
Sandstone (?), drilled hard and slow	3	575
Fine sand	3	578
Jackson (?) group (Eocene):		
Fine hard-packed black sand	6	584
Fine soft black sand	2	586
Fine soft black sand; drilled slow	28	614
Medium-coarse black sand, drilled rough and fast, water	14	628
Black sand in fine and coarse streaks	11	639
Slightly feldspathic quartz sand containing 40% glauconite; pyritic	11	650

TABLE 45.—*Partial analyses of waters from Quaternary deposits in Norfolk County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 43)

	1	2	23
	Ocean View	Cottage Park	Portsmouth
Iron (Fe)	.32	.....	.....
Bicarbonate (HCO_3)	8	20	37
Sulfate (SO_4)	65	9	27
Chloride (Cl)	38	7.0	50
Fluoride (F)	.0	.3	.....
Nitrate (NO_3)	33	8.6	.....
Total hardness as $CaCO_3$	102	24	41
Date of collection	Aug. 31, 1939	Aug. 31, 1939	Nov. 23, 1938

Analysts: 1 and 2, Margaret D. Foster and G. J. Petretic; 23, American Colloid Corporation.

TABLE 46.—*Analyses of waters from Miocene deposits in Norfolk County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 43)

	5	10a	44	46	57	59
	Churchland	Norfolk	South Hill	Buell	Deep Creek	Great Bridge
Silica (SiO_2)	.....	.....	.....	.....	.....	27
Iron (Fe)	.....	7.2	.....	.....	2.2	.67
Calcium (Ca)	.....	.....	.....	.....	.....	68
Magnesium (Mg)	.....	.....	.....	.....	.....	4.9
Sodium (Na)	.....	.....	.....	.....	.....	41
Potassium (K)	.....	.....	.....	.....	.....	2.6
Bicarbonate (HCO_3)	178	160	240	230	269	243
Sulfate (SO_4)	36	23	6	18	1	5.0
Chloride (Cl)	27	44	89	84	11	54
Fluoride (F)	.5	.3	.....	.....	.2	.6
Nitrate (NO_3)	.5	.85	.....	0	.0	.0
Total dissolved solids at 180°C	.....	.....	.....	.....	.....	325
Total hardness as $CaCO_3$	164	117	157	228	201	190
Free carbon dioxide (CO_2)	.....	15	.....	.....	.....	2.5
Date of collection	Aug. 5, 1939	Aug. 31, 1939	Jan. 28, 1939	July 21, 1937	Aug. 28, 1939	Aug. 28, 1939

Analysts: 5, Margaret D. Foster and J. D. Hem; 10a and 57, Margaret D. Foster and G. J. Petretic; 44, 46 and 59, Margaret D. Foster.

TABLE 47.—*Analyses of waters from Cretaceous deposits in Norfolk County, Virginia*

(Parts per million. Numbers at heads of columns refer to well numbers in Table 43)

	4	7	8	9	9	9	14	20[a]	20
	Twin Pines	Craney Island	Port Norfolk	Lambert Point			Norfolk	Moores Bridges	
Silica (SiO_2)	12	.....	11	10	16	.....	.....	.....	.....
Iron (Fe)	.04	.....	.....	.....	.....	.....	.....	.....	.....
Calcium (Ca)	2.5	.....	.....	5	5.2	.....	.....	.....	.....
Magnesium (Mg)	1.6	.....	.....	1.7	2.4	.....	.....	.....	.....
Sodium (Na)	344	.....	.....	415	459	.....	.....	.....	.....
Potassium (K)	12	.....	.....	21					
Bicarbonate (HCO_3)	555	542	627	497	601	613	616	620	637
Sulfate (SO_4)	31	36	32	43	43	40	65	110	110
Chloride (Cl)	196	258	260	351	291	300	408	1,000	1,080
Fluoride (F)	4.8	2.8	.....	.....	.....	4.8	4.8	3	2
Nitrate (NO_3)	1.8	.....	.....	.....	.....	.....	.....	.....	.....
Total dissolved solids at 180°C.	880	.....	1,145	1,093	.....	.....	.....	.....	.....
Total hardness as $CaCO_3$	13	6	21	18	23	18	12	7.5	33
Free carbon dioxide (CO_2)	.....	.....	.....	.....	.....	0	1.4	.....	0
Date of collection	Aug. 6, 1939	Nov.4, 1939	1938	1891	1906	1939	Aug. 31, 1939	Nov. 1906	Aug. 30, 1939

[a]Well 20 is located in Princess Anne County but is listed with Norfolk County.

Analysts: 4 and 7, Margaret D. Foster; 8, W. F. Pond; 9 (1891), Shepard Laboratory; 9 (1906), Norfolk & Western Railway; 9 (1939), 14 and 20 (1939), Margaret D. Foster and G. J. Petretic; and 20 (1906), S. Sanford.

PRINCESS ANNE COUNTY

LOCATION AND DEVELOPMENT

Princess Anne County lies east of Norfolk County and is bordered on the north by the mouth of Chesapeake Bay, known as Lynnhaven Roads, and on the east by the Atlantic Ocean. It extends southward to the North Carolina State line. It is the smallest county considered in the present report, having an area of only 267 square miles of which about 50 per cent is classed as farm land. The population of 19,984 in 1940 was greater than that of Surry, Sussex, or Isle of Wight counties, however. Farming, dairying, and activities connected with the resorts centering at Virginia Beach, furnish the main occupations. The resort business is based on hotels and inns located along fine beaches, the facilities for fishing parties, various points of historical interest, and amusements. Fort Story, part of the coastal defense system, is located at Cape Henry; and Camp Pendleton has been recently established a few miles south of Virginia Beach.

MUNICIPAL WATER SUPPLIES

Lake Smith and other small lakes in northwestern Princess Anne County furnish 6,000,000 to 8,000,000 gallons of water a day to the city of Norfolk. The treating plant which handles this water is also located within Princess Anne County, 3 miles southwest of Lake Smith.

Virginia Beach is furnished with surface water[139] from the municipal supply of Norfolk, and several smaller communities between Norfolk and Virginia Beach, as Oceana and Lynnhaven, also use this supply.

TOPOGRAPHY

The surface of Princess Anne County, like that of Norfolk County, is largely formed by the Pamlico terrace, less than 20 feet above sea level. Inland bays, produced by the drowning of small valleys by the rise of sea level, are present along the northern coast. The work of ocean currents has been important, and cut-and-fill action has created a long even coastline, which is in part erosional and in part depositional. Bays have become land locked in the southern part of the county, by deposits brought by ocean currents; and similar action has formed new land about

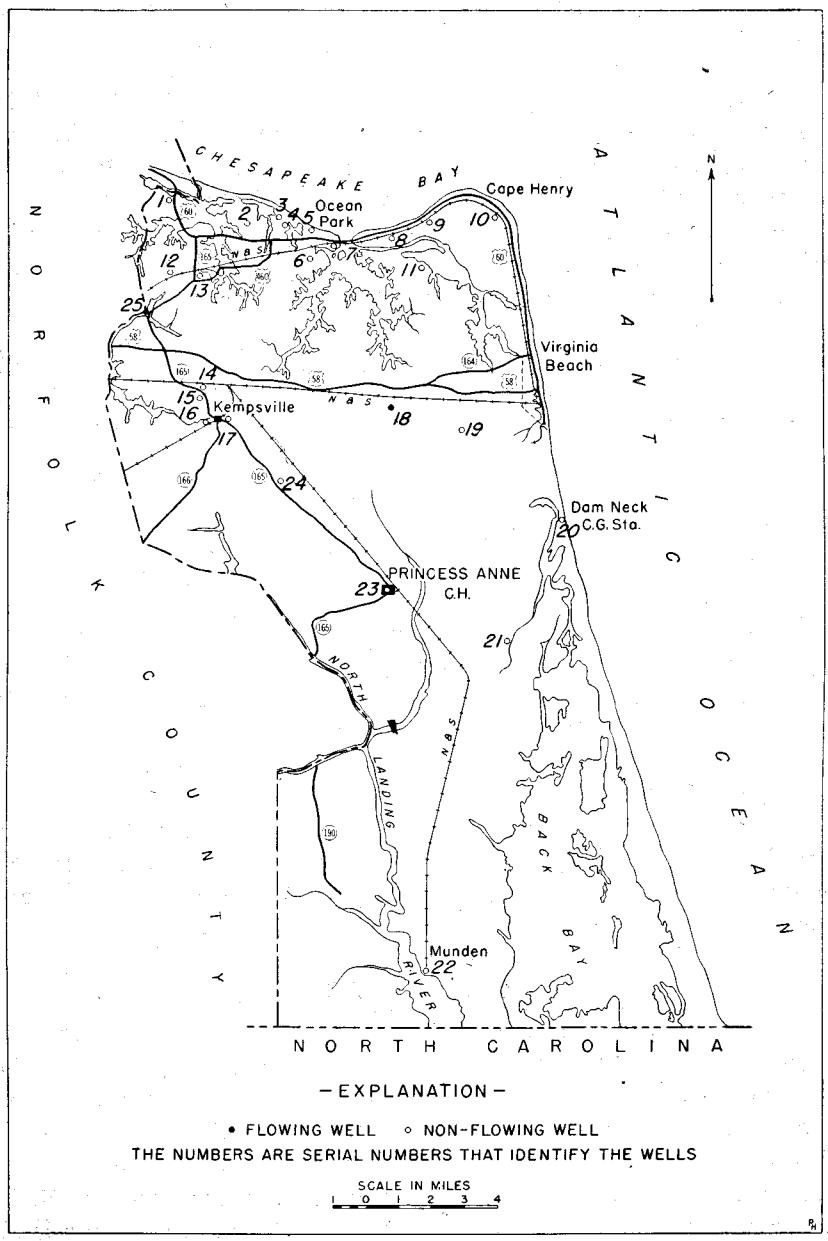


FIGURE 30.—Map of Princess Anne County showing location of wells listed in Table 48.

Cape Henry. Picturesque sand dunes flank the coast everywhere but attain their greatest development near the Cape, where the dune area is known as "The Desert."[47]

GEOLOGY

Very little is known of the strata which lie at depths greater than 100 feet below the surface in Princess Anne County.

Ewing[58] determined by seismic methods that bedrock lies 2,900 feet below the surface at Ocean Park (Cape Henry Station of Ewing). (See Plate 1.) The character of the Lower Cretaceous and Upper Cretaceous sediments throughout most of the county is not known. However, Upper Cretaceous sediments were encountered at 685 feet in the Norfolk City Waterworks well (25, Fig. 30) and Lower Cretaceous sediments were encountered at 815 feet. The sediments penetrated in this well have been discussed in the chapter on Norfolk County and a log is given in Table 44.

As in Norfolk County, Miocene sediments do not crop out in Princess Anne County and are known only from well logs. The Miocene is reported by Darton[50] to be within 50 feet of the surface in eastern Princess Anne County. The strata have been described by Sanford[109] as dark sandy clays which contains intercalated sand beds and beds of shell marl. A well at Virginia Beach encountered "marl" at 53 feet (45 feet below sea level), but it is probable that few other shallow wells in the county enter the Miocene deposits.

The Pamlico formation of Pleistocene age is found at or near the surface throughout the county. It consists of light yellow and red sand, sandy clay, and clay. Gravel is present near the base of the formation, and thin beds of blue clay are present in some places. Clark and Miller[39] report that Pleistocene shell beds occur in the Dismal Swamp, but, according to C. W. Cooke, these may be in the Croatan sand of Pliocene age.

Prior to 1902 the city of Norfolk bored a series of shallow test wells in western Princess Anne County in connection with studies for increasing the city water supply. The logs of two of these test holes, as recorded by Darton[50], show the character of the terrace deposits, and are included with the logs of wells in Table 49.

Recent sand dunes are well developed along the northern border of the county on Chesapeake Bay, and along the Atlantic Ocean on the east. They attain an altitude of 75 feet in the vicinity of the Cape

Henry "Desert," but elsewhere their crests are generally less than 50 feet above sea level. Migrating dunes have invaded farms and woodlands in the vicinity of Cape Henry. Much damage is done by shifting sands during severe storms. Wave action has been instrumental in the building of Cape Henry and marine-laid sand extends for some distance below sea level, as shown in Figure 31.

GROUND WATER

SHALLOW WELLS

WATER FROM RECENT DUNE SAND

Water in small quantities is obtained from shallow wells in dune sand in a number of places in Princess Anne County. At Seaside State Park 15,000 gallons a day is furnished by nine 2-inch driven wells (9, Table 48), 15 feet deep. At Fort Story sixty 2-inch wells, 15 feet deep (10), can supply more than 150 gallons of water a minute. In

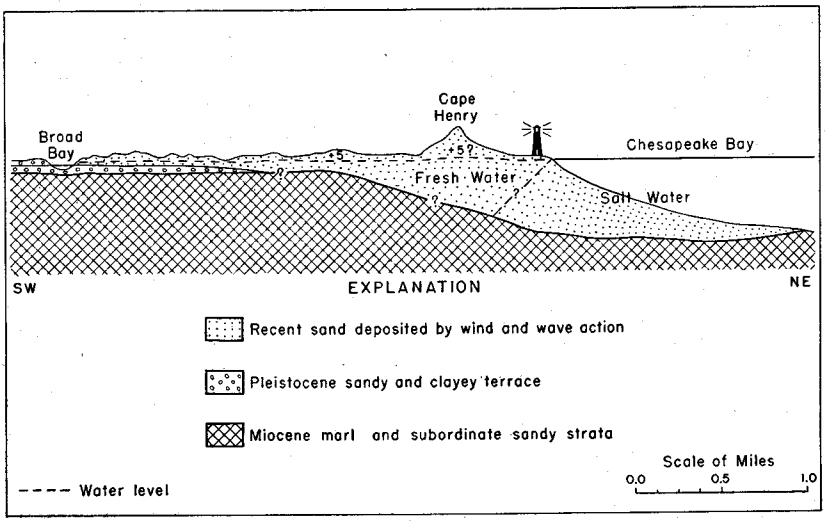
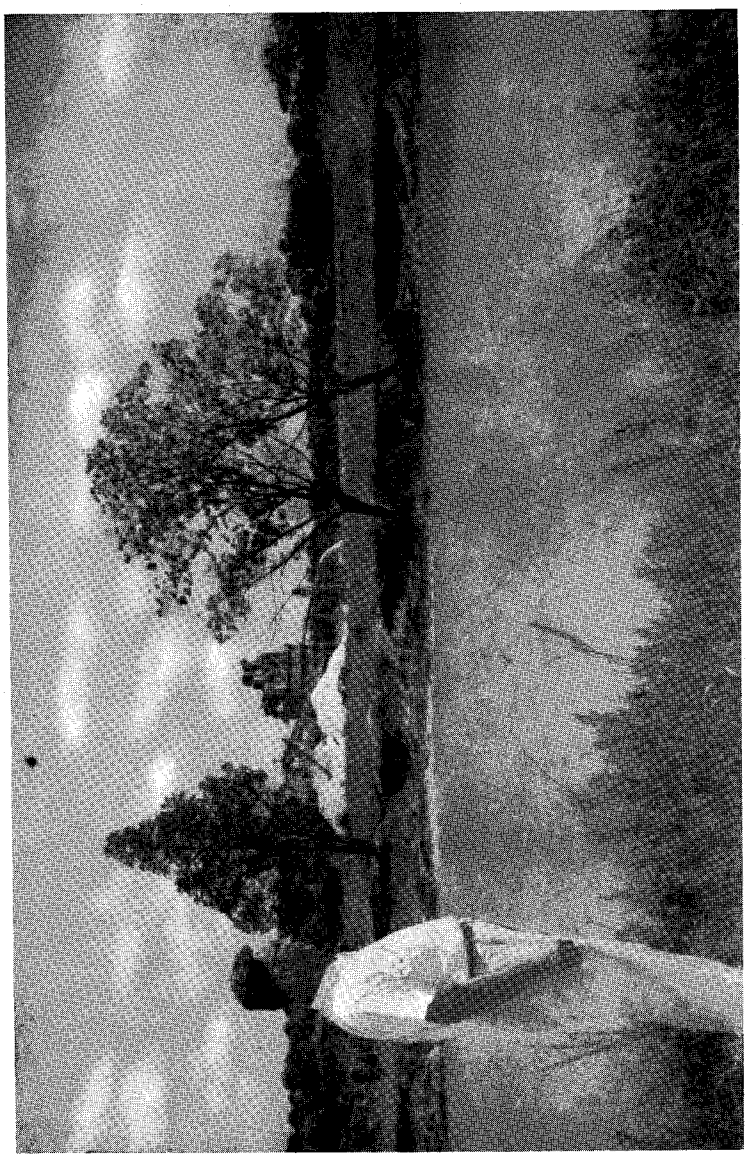


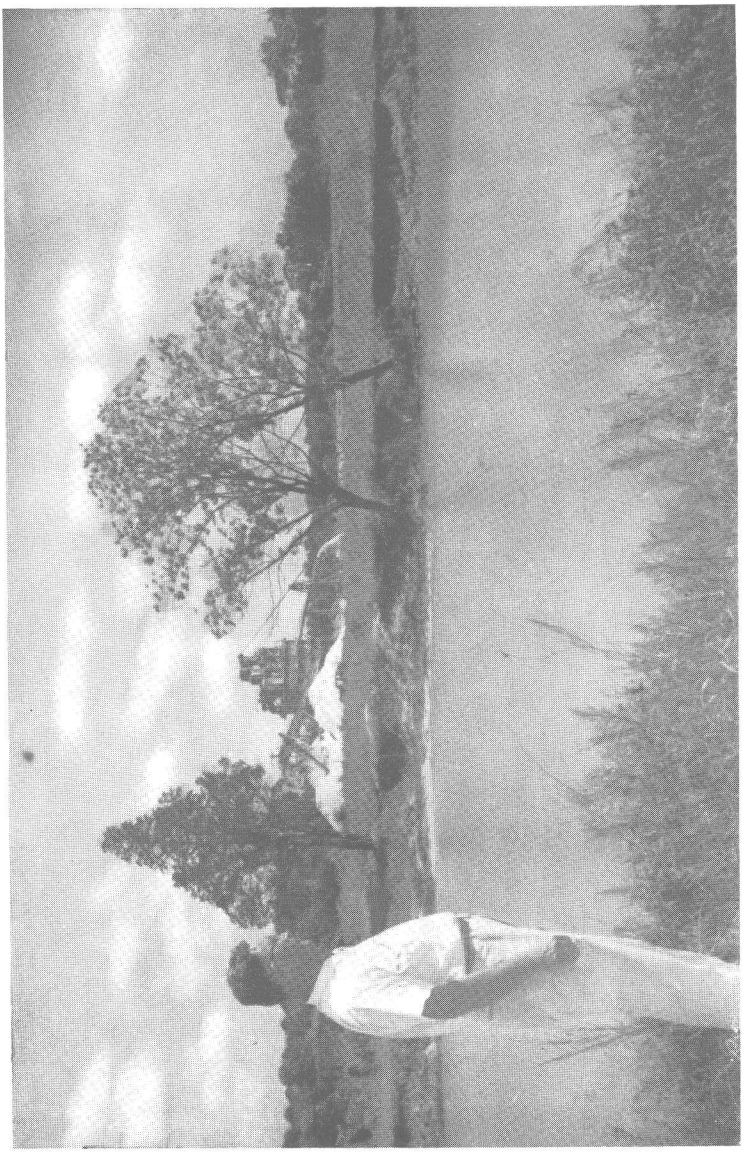
FIGURE 31.—Geologic section across Cape Henry, Virginia, showing the relation of fresh ground water to salt water.

the period January 1-June 30, 1940, these wells furnished 6,726,000 gallons of water to the post, or an average of 37,000 gallons a day. Dam Neck Coastguard Station also obtains its supply of water from shallow wells in dune sand (20).

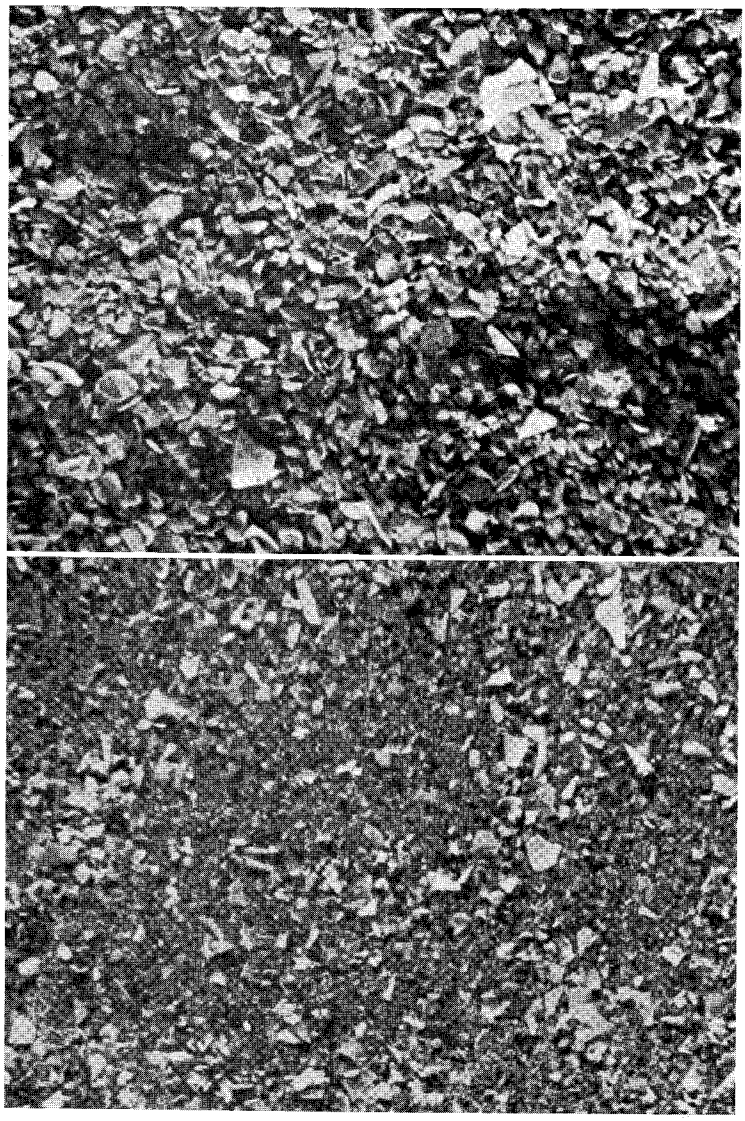
It seems likely that somewhat larger supplies of water can be obtained from the deeper sands at Cape Henry than are developed at



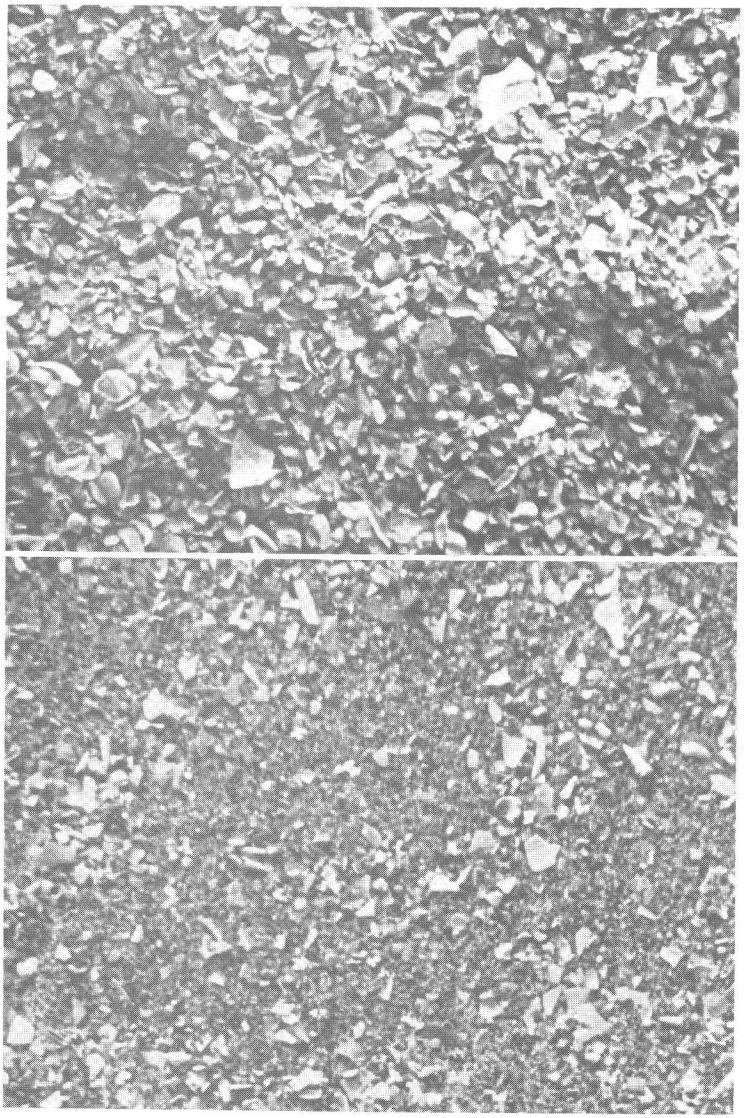
Gravel pit near Diamond Springs excavated below ground-water level. Photograph taken during the drought of 1941.



Gravel pit near Diamond Springs excavated below ground-water level. Photograph taken during the drought of 1941.



Miocene water-bearing sediments from Warwick County. Upper, sized shell-fragments stratum (from a core). Lower, a fine-grained gray sand containing subordinate amounts of shells and black sand. Sediments of this type furnish water to shallow drilled wells in the Norfolk area. (Natural size.)



Miocene water-bearing sediments from Warwick County. Upper, sized shell-fragments stratum (from a core). Lower, a fine-grained gray sand containing subordinate amounts of shells and black sand. Sediments of this type furnish water to shallow drilled wells in the Norfolk area. (Natural size.)

present (Fig. 31). However, the danger of pumping too heavily in this area and creating an intrusion of salt water is readily apparent.

Water from the dune sand generally contains an undesirable amount of iron and may also be colored brown from plant matter. Free carbon dioxide was found to be high in water from Seashore State Park (9, Table 50), and it is probable that other wells in dune sand also yield water high in free carbon dioxide. The total hardness is generally moderate or low.

At Seashore State Park the well-water supply is chlorinated; at Fort Story the water is passed through sand filters to remove the iron and then treated with lime and alum to reduce the hardness.

WATER FROM TERRACE DEPOSITS

A large number of dug and driven wells throughout the county, generally less than 50 feet deep, obtain water from the terrace deposits of the Talbot formation.

Moderate supplies of water are easily obtained in many places. At Ocean Park 60 gallons a minute is obtained from seven 1½-inch wells, 30 to 38 feet in depth (5a, 5b, Table 48).

Shallower strata also furnish moderate supplies of water. At the Diamond Springs Ice Co. east of Norfolk, the larger part of a yield of 90 gallons a minute was obtained from sand 20 to 30 feet below the surface. A battery of 32 closely-spaced 2-inch wells (13a) equipped with drive points furnished the water. These wells cause much difficulty, as the well points clogged with fine sand, and in 1940 a battery of 4 gravel-packed wells (13b) was constructed. The wells were underreamed to a diameter of 36 inches, and 5 feet of 8-inch screen was set. The first well produced 50 gallons a minute; the 4 wells have yielded a total supply of 180 gallons a minute. The materials penetrated are shown in the log of one of these wells (13b, Table 49). The static water level is about 14 feet below the surface; the amount of drawdown, limited by the intake pipe in the well, does not exceed 9 feet.

Darton[50] reports that 1 mile northwest of the Diamond Springs Ice Co., the Norfolk County Water Co., prior to 1902, drove or dug 36 wells, varying in depth from 30 to 40 feet. Water normally stood 9 to 17 feet below the surface. The site, an undissected terrace of moderate extent, 15 to 25 feet above sea level, was chosen because of the yield and quality of the water obtainable. The logs of 2 of the test wells which were sunk are given in Table 49. The marl reached at the bottom of each of these test wells is probably the uppermost bed of the Miocene deposits.

The Virginia Experimental Truck Farm, at Burtons, on the site of the old waterworks, obtains 30 gallons a minute from four 4-inch drilled wells, 26 to 30 feet deep (12, Table 48). The yield is limited by the capacity of the pump, however.

Gravelly beds in the terrace formation near Burtons are being quarried at present (Pl. 37); these strata may have furnished water to the old Norfolk County shallow well system. In the drought of 1941 and 1942 ground water was pumped from these pits at a rate of 50 or 60 gallons a minute for several weeks with no observable drawdown. A fairly large supply of water might be obtained from shallow gravel deposits but, unfortunately, gravel occurs very sparingly in the terrace formations in Princess Anne County.

Small dairy farms, near Kempsville, obtain their water supplies from 2-inch driven wells about 15 feet deep (14, 15). A small sawmill at Salem is supplied by 2 shallow driven wells (24). A camp of the Civilian Conservation Corps at Pungo has been supplied by four 2-inch driven wells (21) 14 feet deep, which furnish a total of 5,000 gallons a day.

Water obtained from the Pleistocene terrace sands and gravels generally has less than 75 parts per million of hardness, present as carbonate or temporary hardness. In the water from well 14 (Table 50) near Kempsville, however, the hardness (50 parts per million) is mainly noncarbonate, or permanent hardness. Iron is reported to be troublesome in places. A sample from Ocean Park (5) had an iron content of 5.6 parts per million. Two of three waters examined had high free carbon dioxide content and in some places, therefore, water from terrace deposits may be corrosive. Chloride is generally low.

DEEP WELLS

WATER FROM MIOCENE DEPOSITS

A few wells in Princess Anne County obtain water from Miocene strata. A 2-inch well (2, Table 48) near Little Creek Ferry obtained a yield of 10 gallons a minute from fine sand 54 to 80 feet below the surface. The well was equipped with 3 feet of 1½-inch drive point strainer. At Bayville Farms, near Lynnhaven, about 80 gallons a minute is obtained from one 6-inch well 75 feet deep (6, Table 49). Yellow sand and gravel were penetrated at 63 to 75 feet below the surface. The water has a low hardness, 34 parts per million, and a low chloride content but has 21 parts per million of free carbon dioxide (Table 50). At the Yoder Dairy near Kempsville, 23 gallons a minute is furnished

by a 2-inch well which encountered white sand 70 to 82 feet below the surface. Eight feet of 1½-inch drive point was installed. Water from this stratum is hard, 176 parts per million, and has rather high chloride content, 178 parts per million. The iron which is present, .48 part per million, is not troublesome (17, Table 50). Mr. C. B. Owens stated that at London Bridge a stratum of fine sand and large shells at 100 feet furnished a flow of 18 gallons a minute to a 2-inch open end well (18). No other water-bearing strata were penetrated at lesser depths.

Data at hand indicate that the prospects of obtaining more than moderate quantities of water in the Miocene deposits are not favorable. The Miocene sand and shell strata of South Norfolk and Portsmouth, which yield excellent supplies to small-diameter wells less than 80 feet deep, may be correlated with the water-bearing strata discussed in the preceding paragraph.

Throughout the county water-bearing deposits are present; they are patchy in distribution and it is frequently necessary to drill in two or more places before a successful well is had. However, there is a reasonable possibility of obtaining up to 1,000,000 gallons a day in many places. Where fairly large quantities of water are needed, inexpensive test holes should be drilled before large-diameter wells are constructed in order that the cost of exploratory drilling be kept at a minimum and needless "dry wells" be avoided entirely.

WATER FROM CRETACEOUS DEPOSITS

Although Cretaceous deposits may be encountered at depths generally greater than 700 feet below the surface, there seems to be little prospect of obtaining fresh water from them. In the chapter dealing with Norfolk County and also in the discussion of chloride, it was pointed out that the chloride content of water in the Cretaceous strata increases eastward. In eastern Norfolk County the water from Lower and Upper Cretaceous strata contains more chloride than is desirable in water for ordinary uses. There seems little likelihood of encountering fresh water in either Lower Cretaceous or Upper Cretaceous sands in Princess Anne County, as the available data indicate that the chloride content of water in these deep strata is even greater than it is in Norfolk County.

WELL RECORDS AND ANALYSES

Records of wells in Princess Anne County, available logs of wells, and analyses of water samples, are listed in Tables 48-50, on the following pages. The locations of the wells listed are shown in Figure 30.

TABLE 48.—*Records of wells in*

No.	Location	Owner or name	Type of well[a]	Depth of well (feet)	Diameter of well (inches)	Number of wells[b]	Character of water-bearing material
1	3 miles east-southeast of Ocean View.	H. A. Hewitt	Dv	22	2	.....	Dune sand
2	Near Little Creek Ferry	J. Sadler	D	80	2	.....	Fine sand
3	Chesapeake Beach	F. L. Lumsford	Dv	18	2	.....	Terrace sand
4	Chesapeake Beach	T. F. May	Dv	45	1½	.....	.....
5a	Ocean Park	Ocean Breeze Park	Dv	30	1½	2	.....
5b	Ocean Park	Ocean Breeze Park	Dv	38	1½	5	.....
6	Bayville	Bayville Farms	D	75	6	.....	Sand
7	Ocean Park	W. J. Hall	Dv	8	2	.....	.....
8	2 miles east of Ocean Park	Clydes Restaurant	Dv	31	2	.....	.....
9	3 miles east of Ocean Park	Seashore State Park	Dv	15	2	9	Dune sand
10	Cape Henry	Ft. Story	Dv	15	2	60	Dune sand
11	Southwest shore of Broad Bay	John Day	Dug	22	.....	.....	Terrace sand
12	Burtons	Virginia Experiment Truck Farm.	Dv	26	4	.....	.....
13a	¾ mile east-southeast of Burtons.	Diamond Springs Ice Plant.	Dv	20–30	2	32	Terrace sand
13b	¾ mile east-southeast of Burtons.	Diamond Springs Ice Plant.	D	26	8	4	Terrace sand
14	1 mile northwest of Kempsville.	Lloyd Yoder	Dv	15	2	.....	Terrace sand
15	¾ mile northwest of Kempsville.	N. W. Yoder	Dv	15	1½	.....	Terrace sand
16a	Greenwich, near Kempsville	Norfolk & Southern Railroad Co.	Dv	19	2	.....	Terrace sand
16b	Greenwich, near Kempsville	Norfolk & Southern Railroad Co.	Dv	65	2	.....	Sand and shells
17a	Kempsville	Yoder Dairies	Dv	70	2	3	Sand and shells
17b	Kempsville	Yoder Dairies	D	82	2	.....	Sand
18	London Bridge	B. F. Owen	Dv	100	2	.....	Fine sand and shells
19	1 mile south of Oceana	D. S. Potter	Dv	23	1½	3	Terrace sand
20	Dam Neck	Coast Guard Station	Dv	10	2	.....	Dune sand
21	Pungo	CCC Camp	Dv	14	2	4	Terrace sand
22	Munden	Norfolk & Southern Railroad Co.	Dv	20	2	.....	Sand
23	Princess Anne C. H.	Court House	Dv	15	2	.....	.....
24	Salem	Wood Sales Co.	Dv	13	2	2	Terrace sand
25	Moores Bridges	Norfolk City Waterworks	D	1,750	10–4½	.....	Sand

[a]Dv = driven. D = drilled. Dug = dug.
[b]If more than one well comprises pumping unit.
[c]C = Cretaceous. M = Miocene. P = Pleistocene. R = Recent.
[d]Reported by owner as average water level.
[e]B = boiler feed. C = cooling. D = domestic. S = stock.
[f]Figures refer to total hardness (TH) and chloride content (Cl), in parts per million, as determined by field analyses. "A" indicates that an analysis is given in Table 50.

Princess Anne County, Virginia

Geologic age[c]	Approximate Water Level: Feet above (+) or below (−) surface[d]	Maximum daily consumption (thousands of gallons)	Use of water[e]	Reported quality[f]	Remarks	No.
R	−19½	2	D	TH, 125 Cl, 250	Supplies tourist camp.	1
M	.....	.....	D	.....	Well yields about 10 gallons a minute. Drilled by A. Rudder in 1941.	2
P	− 6	.....	D	TH, 110 Cl, 50	.....	3
M	.....	1	D	Hard, iron	.....	4
M	.....	12	D	.....	.....	5a
M	.....	12	D	A	.....	5b
M	−13	20	C D S	A	Drilled by Sydnor Pump and Well Co.	6
R	.....	.....	D	A	.....	7
.....	.....	.....	D	Iron	.....	8
R	.....	15	D	A	Normal summer use is about 7,000 gallons a day. Water chlorinated.	9
R	− 5	100(?)	D	Moderately hard, iron	Consists of 3 pumping units. Water treated and chlorinated.	10
P	−19	.....	D	Fairly soft, iron	.....	11
.....	.....	.....	D S	TH, 65, iron	Drilled by A. Johannson in 1933.	12
P	.....	120	C	TH, 60 Cl, 24	.....	13a
P	.....	200	C	.....	Battery yields 180 gallons a minute. Drilled by Layne-Atlantic Co.	13b
P	.....	1	D S	A	.....	14
P	− 8	1	D	.....	.....	15
P	.....	.....	D	.....	Wells 16a and 16b together yield 50 gallons a minute. Water is used to wash vegetables.	16a
M	.....	.....	.....	.....	.....	16b
M	.....	22	C	A	Temp. 61½° F.	17a
M	.....	22	C	.....	Well yields 23 gallons a minute. Drilled by A. Rudder.	17b
M	+	.....	D	.....	Well flowed 18 gallons a minute at first.	18
P	− 5	1	D	Moderately hard	.....	19
R	.....	.....	D	A	.....	20
P	.....	.....	D	.....	.....	21
R(?)	.....	.....	B	.....	Well sunk on river flood plain.	22
P	.....	.....	D	A	.....	23
P	.....	.....	B	.....	Frequent blowdowns necessary.	24
C	+13½	.....	D	A	Well discussed with other deep wells in chapter on Norfolk County. Also listed as well 20, Table 43.	25

TABLE 49.—*Logs of wells in Princess Anne County, Virginia*

Well 6, Lynnhaven; Bayville Farms
(Log by Sydnor Pump and Well Co.)
Altitude, 18 feet

	Thickness (feet)	Depth (feet)
Columbia group (Pleistocene):		
Red sandy clay	4	4
Red and yellow sand	8	12
Light-gray sand, water	13	25
Dark-yellow sandy clay	6	31
Light-yellow sand	12	43
Chesapeake group (Miocene):		
Blue sticky mud	6	49
Gray sand with some mud	14	63
Dark-yellow sand and small gravel,[a] water	12	75
Mud	1	76

[a]Strainer placed at from 68 to 75 feet below the surface.

Well 13b, Diamond Springs; Diamond Springs Ice Co.
(Log by Layne-Atlantic Co.)
Altitude, 21 feet

	Thickness (feet)	Depth (feet)
Pleistocene:		
Soil	14	14
Sand, water	12	26
Blue mud	..	..

Test wells by Norfolk City Water Department
(Logs by N. H. Darton[50])

	Thickness (feet)	Depth (feet)
Poorhouse Tract Turnpike		
Sand	18	18
Blue clay	13	31
Sandy clay	3½	34½
Loose sand	8	42½
Gravel, water	7½	50
Marl	..	..
Lake Lawson		
Yellow clay with gravel streaks	10	10
Sand	14½	24½
White sand	6½	31
Sandy clay	6	37
Coarse sand, water	1	38
Marl	..	..

TABLE 50.—*Analyses of waters from Quaternary and Miocene deposits, Princess Anne County, Virginia*

(Parts per million. Numbers at heads of columns refer to corresponding well numbers in Table 48)

	5b	6	7	9	14	17a	20	23
	Ocean Park	Bay-ville	Ocean Park	State Park	Kemps-ville	Kemps-ville	Dam Neck	Princess Anne
Silica (SiO_2)	16	.....	.....	11	.....	.....	.....	.....
Iron (Fe)	5.6	0.08	.....	3.7	.....	0.48	1.8	2.1
Calcium (Ca)	5.4	.....	.....	2.9	.....	.....	.....	.....
Magnesium (Mg)	6.8	.....	.....	2.1	.....	.....	.....	.....
Sodium (Na)	50	.....	.....	11	.....	.....	.....	.....
Potassium (K)	3.5	.....	.....	1.2	.....	.....	.....	.....
Bicarbonate (HCO_3)	47	39	49	5.0	5	281	35	126
Sulphate (SO_4)	3.1	6	20	5.1	34	1	9	1
Chloride (Cl)	81	18	40	21	18	178	24	13
Fluoride (F)	.....	.5	.....	.5	.4	.9	.5	.0
Nitrate (NO_3)	1.0	.85	.40	.20	20	.0	1.7	.25
Total dissolved solids at 180°C	210	.....	148	63	.....	.....	.....	.....
Total hardness as $CaCO_3$	41	34	54	16	50	176	27	86
Free carbon dioxide (CO_2)	32	21	.....	45	57	1.1	.....	6.5
Date of collection	Aug. 30, 1939	Aug. 30, 1939	Aug. 31, 1939	Aug. 30, 1939	Aug. 28, 1939	Aug. 29, 1939	Aug. 24, 1939	Aug. 28, 1939

Analysts: 5b, 7 and 9, Margaret D. Foster; 6, 14, 17a, 20 and 23, Margaret D. Foster and G. J. Petretic.

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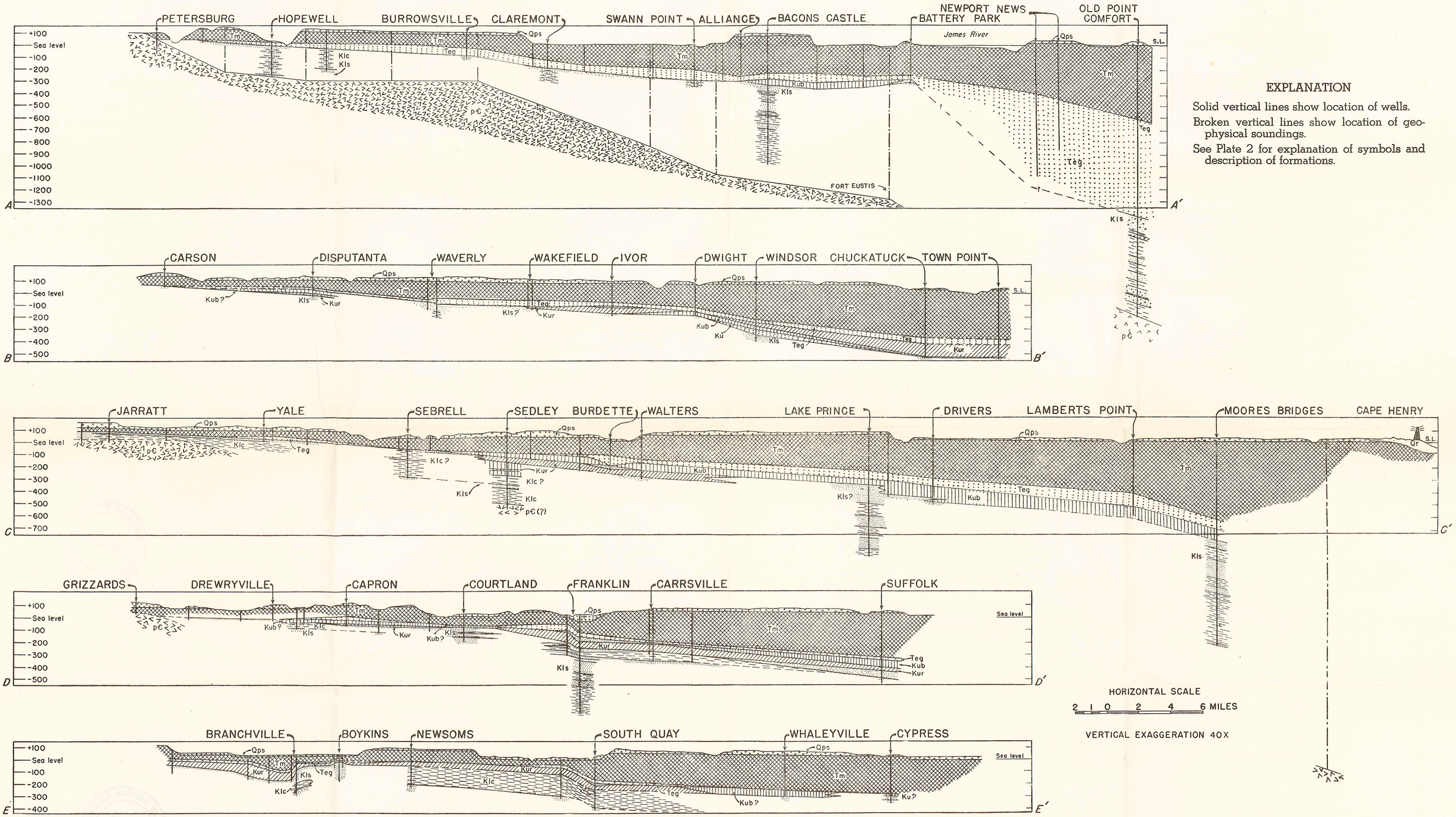

EXPLANATION

Solid vertical lines show location of wells.

Broken vertical lines show location of geophysical soundings.

See Plate 2 for explanation of symbols and description of formations.

GEOLOGIC CROSS SECTIONS OF THE COASTAL PLAIN IN SOUTHEASTERN VIRGINIA.

By D. J. CEDERSTROM

The contrast between the thickness of the Eocene formations south of James River, generally less than 100 feet, and the thickness north of James River at Newport News and Old Point Comfort (section A–A′), about 800 feet, should be noted.

Qr, Recent sands; Qp, Pleistocene terrace formations; Tm, Miocene marl; Teg, Eocene glauconitic formations; Kub, Upper Cretaceous blue clay; Kur, Upper Cretaceous (?) red, brown and variegated clay; Klc, Lower Cretaceous clay; Kls, Cretaceous sands; p€, pre-Cambrian granite.