VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

THOMAS LEONARD WATSON, PH. D.
DIRECTOR

Bulletin No. V

THE

Underground Water Resources

OF THE

Coastal Plain Province of Virginia

BY

SAMUEL SANFORD

PREPARED IN COÖPERATION WITH THE
UNITED STATES GEOLOGICAL SURVEY

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UNIVERSITY OF VIRGINIA
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LETTER OF TRANSMITTAL

VIRGINIA GEOLOGICAL SURVEY,
UNIVERSITY OF VIRGINIA,
CHARLOTTESVILLE, December, 1912.

To His Excellency, Hon. Wm. Hodges Mann, Governor of Virginia, and Chairman of the State Geological Commission.

SIR:—I have the honor to transmit herewith for publication, as Bulletin No. V of the Virginia Geological Survey Series of Reports, a report on "The Underground Water Resources of the Coastal Plain Province of Virginia," by Mr. Samuel Sanford of the U. S. Geological Survey.

This report has been prepared by the Virginia Geological Survey in coöperation with the U. S. Geological Survey and should prove of much value to the Tidewater section of Virginia. It forms a companion volume to Bulletin No. IV, entitled "The Physiography and Geology of the Coastal Plain Province of Virginia," published by the Virginia Geological Survey in January, 1912.

Respectfully submitted,

THOMAS L. WATSON,
Director.

UNDERGROUND WATERS OF THE COASTAL PLAIN PROVINCE OF VIRGINIA

BY SAMUEL SANFORD.

INTRODUCTION

Scope of Report.—This report deals with an investigation of the underground waters of the Coastal Plain Province of Virginia, a tract of country some 9,500 square miles in extent, which roughly corresponds with what has been known since Colonial times as Tidewater Virginia. The purposes of the investigation were to continue the study, begun by Darton, of the artesian waters of the Coastal Plain, and to examine the waters obtainable by open wells. Thus this report covers the occurrence and character of both shallow and deep waters; the geological relations of water beds; extent of artesian horizons and areas in which flowing wells can be had; methods and costs of developing underground water supplies; special adaptability of waters for domestic or medicinal use, and their application in agricultural and other industries; the relation of well and spring waters to the public health with particular reference to water-borne diseases; in short, the report is intended to answer those questions relating to underground water that would be most likely to occur to any one interested in the subject, whether resident, homeseeker, or promoter of industrial enterprises.

The facts presented were collected through correspondence with postmasters, drillers, and well-owners, and through field work. The correspondence includes the data received in answer to circular letters sent out in 1905. The field work was done by the writer in 1906, 1909, and 1910, chiefly in the fall of 1906.

Acknowledgments.—The writer is under obligations to N. H. Darton, geologist, U. S. Geological Survey, for hitherto unpublished data relating to a number of wells mentioned in the text. Grateful acknowledgment is made of suggestions from M. L. Fuller, formerly geologist, U. S. Geological Survey, regarding particular questions that came up in the progress of field work; and to many well drillers, especially J. H. K. Shannahan, Easton, Md.; R. H, Milligan, Crisfield, Md.; O. D. Hale, Whealton, Va.; I. B. Clark, Accomac, Va.; L. Rude, Tilghman, Md.; S. H. Fetterholf, Achilles, Va.; H. E. Shimp, Cappahosic, Va.; J. W. T. Robertson, White Haven, Md.; and J. V. Bray, West Point, Va., for information

regarding wells and the occurrence of artesian waters. Acknowledgment is also made to Froehling and Robertson of Richmond, Va.; W. H. Taylor of Richmond, Va.; the H. Bentley Smith Company of Philadelphia, Pa.; and the Sparrow's Point Boiler Company of Baltimore, Md., for kindly furnished copies of analyses of well waters. Many of the analyses were submitted to R. B. Dole and Chase Palmer of the U. S. Geological Survey, for recomputation to express results in the form adopted by the Federal Survey. Finally, the writer thanks the hundreds of persons who gave information regarding particular wells.

Literature.—Though many references to the wells and springs of Tidewater Virginia appear in narratives of travelers, in descriptions of various points of interest, and in accounts of military campaigns, the literature distinctly relating to underground waters is scanty, and is largely confined to the writings of Darton. His contributions comprise a paper before the American Institute of Mining Engineers,[a] a bulletin on Artesian Prospects in the Atlantic Coastal Plain,[b] and mention of underground waters in the Washington, Fredericksburg, Nomini, and Norfolk folios, Nos. 13, 23, 70, and 80, respectively, of the Geologic Atlas of the United States. By far the most important one of these is the bulletin on artesian prospects. It reviews the geologic relations of the water beds, contains a number of well records, many of which are reproduced in this report, and briefly indicates the outlook for artesian water in each of the Coastal Plain counties. Fuller and Darton[c] re-stated Darton's views in Water Supply Paper, No. 114, and Fuller summarized his own conclusions in a paper before the American Waterworks Association.[d] The conclusions of Darton and Fuller, chiefly those expressed by Darton in Bulletin No. 138 of the U. S. Geological Survey, have been briefly summarized by Watson[e] in a volume prepared for the Virgina Jamestown Exposition Commission.

The underground waters of the St. Mary's quadrangle, which includes a very small portion of Westmoreland County, are discussed by B. L. Miller in Folio No. 136 of the United States Geological Survey.

[a] Darton, N. H., Artesian Well Prospects in Eastern Virginia, Maryland, and Delaware, Trans. Amer. Inst. Min. Engs., 1905, vol. 24, pp. 372-397.

[b] Darton, N. H., Artesian Well Prospects in the Atlantic Coastal Plain Region, Bull. U. S. Geol. Survey No. 138, 1896, pp. 162-190.

[c] Fuller, M. L., and Darton, N. H., Underground Waters of Eastern United States, U. S. Geol. Survey, Water Supply Paper No. 114, 1905, pp. 127-135.

[d] Fuller, M. L., Artesian Waters of the Atlantic Coastal Plain, Amer. W. W. Ass'n, 1907.

[e] Watson, T. L., Mineral Resources of Virginia, 1907, pp. 268-275.

The publications mentioned deal chiefly with geologic conditions and particularly with artesian water; references to the composition of the waters are largely limited to an occasional analysis. W. B. Rogers[a] in his report for 1835 gives an analysis of a spring at Williamsburg. In the Norfolk Folio, Darton gives analyses of the water from two flowing wells. Fontaine[b] has mentioned an alum spring near Fredericksburg. Peale, in Bulletin No. 32 of the U. S. Geological Survey, gives the anaylsis of a spring near Richmond. Haywood, in Bulletin No. 91 of the U. S. Bureau of Chemistry, gives a detailed analysis of a spring in Alexandria County. Froehling and Robertson[c] have published anaylses of five springs, two of which are mentioned by Watson in the report already cited; and Fuller, in his paper before the American Water Works Association, briefly refers to the quality of the water from different horizons, and the general character of the mineralization.

Nowhere, so far as the writer is aware, have the characteristic features of the artesian waters of most of the Virginia Coastal Plain been discussed at length.

Results of investigation.—The study of the Coastal Plain formations in Virginia, the examination of springs and wells, and the analyses of the waters, have shown that plenty of water is to be had, and except in a limited area in the southeastern and eastern part of the Coastal Plain artesian supplies of abundant flow and excellently adapted for domestic purposes can be obtained without difficulty. Enough deep wells have been sunk to prove the existence of several widely extending series of beds containing water-bearing sands, and it is possible to say at what depth, at most localities, a particular series of beds can be found.

Dug wells are so cheaply sunk that they have become the main source of domestic supply. Many such wells from their location and the insufficient precaution against the entrance of water contaminated by organic wastes may frequently become dangerous to the public health. But dug wells properly located and protected will, in many places, yield entirely satisfactory supplies. The deposits underlying the terraces on which stand many of the towns and villages of the Coastal Plain transmit water readily, hence springs issuing from such terraces or shallow wells in the villages are easily polluted by filth from vault privies and from cesspools.

---

[a]Rogers, W. B., A reprint of Annual Reports and other papers on the Geology of the Virginias, 1884, p. 40.

[b]Fontaine, W. M., The Potomac Formation in Virginia, Bull. U. S. Geol. Survey No. 145, 1896, p. 68.

[c]Froehling, Henry, and Robertson, Andrew, A hand-book prepared for the Virginia Commission to the St. Louis Exposition, 1904, pp. 97-159.

The mineral content of the well and spring waters varies greatly at different localities, or even in the same locality, hence both the deep and the shallow waters are variously suitable for domestic use, boiler supply, or particular industries. The most striking characteristic of the artesian waters of certain formations on the west side of Chesapeake Bay is their relatively large content of sodium bicarbonate. In this aspect they differ from many deep waters.

TOPOGRAPHIC AND GEOLOGIC PROVINCES OF VIRGINIA

General statement.—The State of Virginia includes parts of three great topographic and geologic provinces which have been traced from New York to Georgia. In Virginia they are called the Allegheny Ridges, the Great Valley, the Blue Ridge region, the Piedmont Plateau, and the Coastal Plain. The approximate boundaries within the State of these provinces are indicated on the accompanying map. The two last are the only ones considered in this report. Because of the relations between these two provinces, certain features of the Piedmont Plateau are briefly mentioned here.

PIEDMONT PLATEAU

General description.—The Piedmont Plateau is a rolling plain that slopes gently eastward from the Blue Ridge mountains to where the hard rocks which underlie it are overlapped by the relatively unconsolidated deposits of the Coastal Plain. Where this plain now lies were once lofty hills and mountains, but weathering and the erosive action of the wind and the streams has reduced all great inequalities of surface. Since the deposition of the Coastal Plain sediments began, the area has been elevated, eroded, depressed and slightly tilted several times. It now stands higher than it did a geologically short time ago. The Piedmont rivers are actively deepening their channels, and are swift-flowing and unnavigable.

The rocks of the Piedmont Plateau comprise crystalline masses, granites, gneisses, and schists. The granites and some of the gneisses and schists crystallized from a molten state, but others of the gneisses and schists were once beds of sand and clay which after consolidating to hard rock lost all trace of original structure by mountain-building stresses in time long past. The ages of these rocks range from pre-Cambrian to Silurian. Among the crystalline masses are detached areas of comparatively little altered rocks, reddish, purplish and greenish sandstones, conglomerates and shales, intersected and parted by intrusions and flows of diabase, a heavy dark-greenish crystalline rock. These sedimentary beds and the diabase are of Triassic age, and the former belongs to the Newark series.

The eastward extent of the Piedmont rocks is unknown. They underlie the Coastal Plain and can be reached anywhere in Tidewater Virginia by wells of sufficient depth.

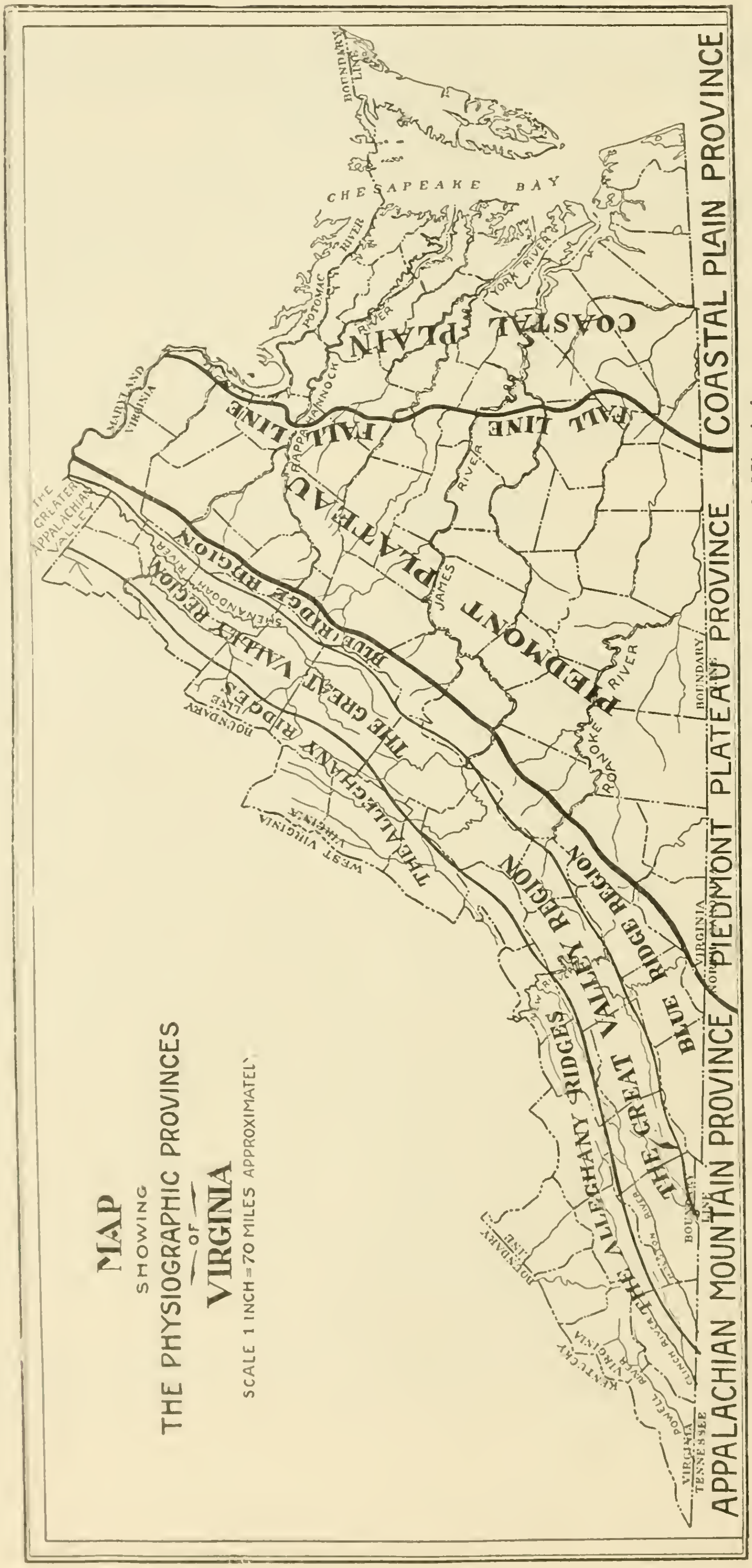

Fig. 1.—Sketch-map showing physiographic provinces of Virginia.
(After Watson, Mineral Resources of Virginia, 1907, p. 2.)

COASTAL PLAIN

General description.—Seaward from the Piedmont extends the lower-lying Coastal Plain characterized by its sluggish tidal rivers, stretches of flat land, and absence of hard rocks. Under the ocean the Coastal Plain beds reach the edge of the Continental shelf, a hundred miles off the Virginia coast.

Gravels, sands, clays, loams, and shell marls make up the great bulk of the Coastal Plain deposits in Virginia. In places some of the sands have been consolidated to sandstones and the clays to shales; in places, also, are shell beds so compact as to form lime rock, but there are no extensive areas of heavy-bedded limestones, such as are found in the Coastal Plain of North Carolina and of the states farther south. The "rocks" reported by drillers are mostly thin, irregular layers of limited extent. Some apparently are compacted shell beds but many are streaks or lumps of indurated sand in which the individual grains are cemented by silica or lime. The maximum thickness of the Coastal Plain formations in Virginia has not been determined. It may exceed 2,500 feet.

GEOGRAPHIC POSITION

The Coastal Plain of Virginia lies east of a line running through Emporia, Petersburg, Richmond, Fredericksburg and Alexandria, this line, from Emporia to north of Fredericksburg, corresponding nearly with the meridian of 77° 25′. Its length from the North Carolina line to the Potomac River at Alexandria is 185 miles. The maximum width, from Assateague Island to west of Milford, is about 115 miles. The total area is about 9,500 square miles.

CLIMATE

The climate of Tidewater Virginia is mild; nearness to the ocean tends to temper extremes of heat and cold. The following table gives mean annual temperatures for varying terms of years at a number of places, together with the mean monthly maximum and minimum temperatures.

Temperatures in Tidewater Virginia.

(Degrees Fahrenheit.)

Place	No. years obs. made	Mean annual	Month of maximum	Month of minimum
Ashland	15	56.7	July 77.7	Jan. 35.3
Cape Henry	32	58.7	" 77.0	" 40.2
Fredericksburg	17	55.8	" 77.5	Feb. 33.3
Hampton	23	58.9	" 79.2	" 39.9
Norfolk	36	59.0	" 78.5	Jan. 41.1
Petersburg	19	57.9	" 77.7	" 37.6
Quantico	9	54.1	" 77.4	Feb. 28.6
Richmond	27	58.0	" 78.2	Jan. 38.0
Spottsville	18	57.3	" 77.9	" 37.8
Warsaw			" 78.0	....
Williamsburg	15	56.3	" 78.0	Feb. 34.6
Washington, D. C.	36	56.3	" 77.3	Jan. 33.2

The climate is humid and the rainfall, which is so distributed through the year so as to favor the growth of vegetation, is abundant. The mean annual precipitation varies from 52 inches in the southeastern part of the province to 41 inches in the northwestern. The larger part of the precipitation is in the summer and spring, and comparatively little is in the form of snow.

The accompanying table shows the average precipitation at a number of places for various terms of years, and also the quarterly periods in which precipitation is greatest and least.

Precipitation in Tidewater Virginia.

Place	No. years obs. made	Mean annual	Mean quarterly maximum		Mean quarterly minimum	
		Inches	Quarter	Inches	Quarter	Inches
Ashland	15	41.75				
Cape Henry	32	52.34	Jul.-Sept.	15.72	Oct.-Dec.	11.21
Fredericksburg	15	42.25				
Hampton	23	43.60				
Norfolk	36	52.08	Jul.-Sept.	16.59	Oct.-Dec.	10.64
Petersburg	19	44.49				
Richmond	35	44.09	Jul.-Sept.	13.60	Oct.-Dec.	8.87
Spottsville	17	49.12				
Williamsburg	11	45.86				
Washington, D. C.	36	41.32	June-Aug.	12.57	Oct.-Dec.	9.36

A map (Chart 12) issued by the United States Weather Bureau from which the accompanying sketch map was made, shows how the rainfall diminishes in a northwest direction across Tidewater Virginia.

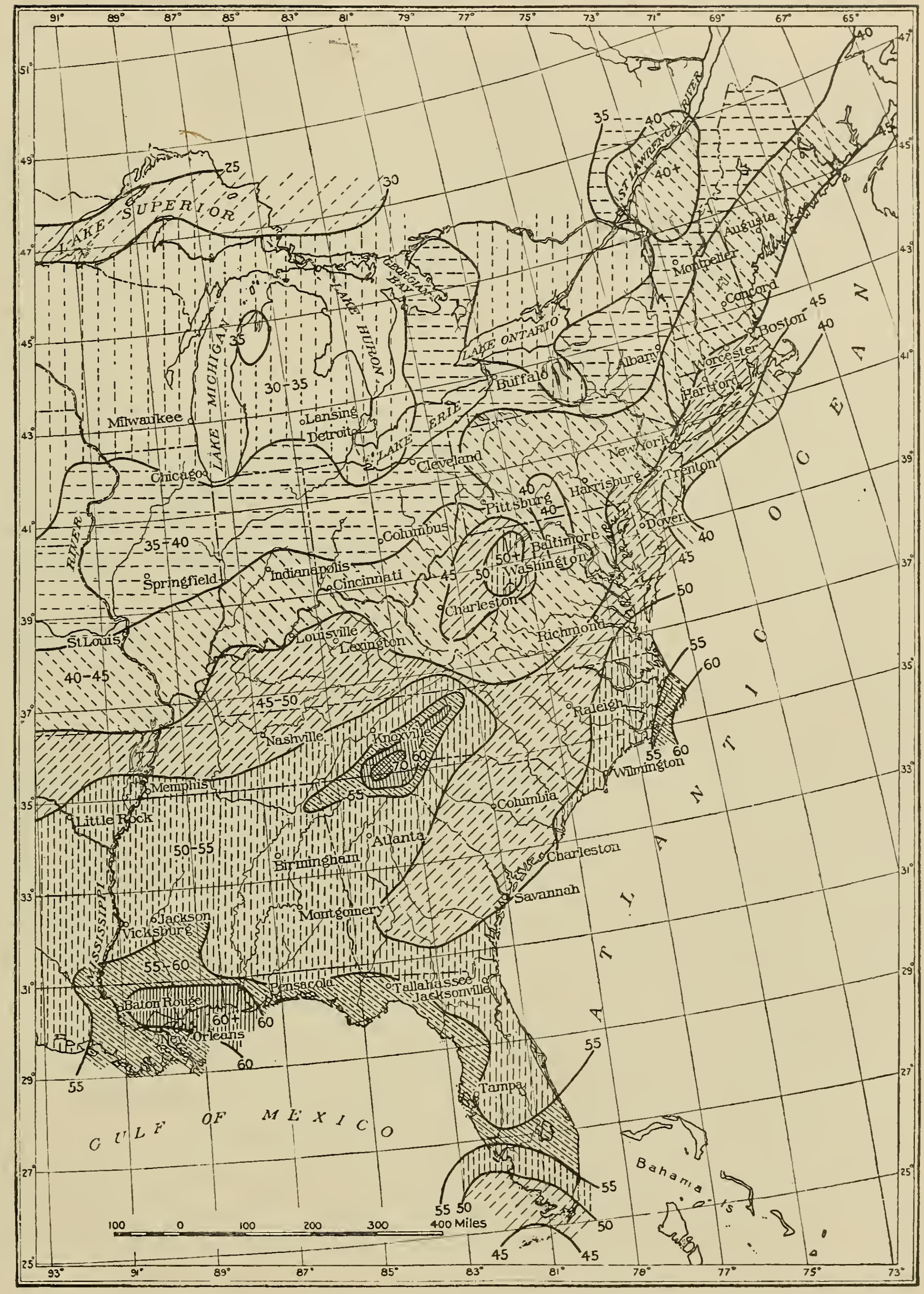

Fig. 2.—Sketch-map showing distribution of rainfall in eastern United States. (From U. S. Geol. Survey Water Supply Paper 223, p. 8.)

TOPOGRAPHY

General description.—The average seaward slope of the surface of the Coastal Plain of Virginia is about three feet to the mile. This slope is enough to cause rapid-flowing rivers, but the Coastal Plain rivers are sluggish because they flow through valleys that have been drowned by a recent depression of the land. Chesapeake Bay that crosses the eastern part of the plain from north-northwest to south-southeast is the drowned valley of a greater Susquehanna River that once flowed across the now submerged part of the plain to reach the ocean, then far east of the present shore line. Potomac, Rappahannock, and James rivers, the principal tributaries of Chesapeake Bay, are tidal estuaries to the western edge of the plain. Here the exposed crystalline rocks make rapids in the rivers; this zone of rapids has been called the "fall-line." Because sea-going vessels could not go farther inland, trading posts were established near the rapids on the different rivers in the early years of the colony, and these settlements have grown to the cities of Alexandria, Fredericksburg, Richmond, and Petersburg.

Terraces or terrace plains.—The seaward slope of the Coastal Plain, though gentle and as a whole uniform, is, in detail, step-like, broad terraces separated by more or less sharply defined scarps running along the river valleys and around intervening divides. The higher of these terraces or terrace plains, being oldest, are the more eroded; along river valleys and on narrow divides they have acquired a rolling surface and are sharply incised by the gorges of streams that head in springs or swamps. The lower and younger terraces have suffered less from stream attack. Near tide level in places the lowest terrace grades into salt marshes; inland in places it carries fresh water swamps, of which Dismal Swamp, lying on its widest portion, is the largest.

Topographic types.—Because of the varying elevation and width of these terraces and their manner of dissection, three types of topography may be distinguished in Tidewater Virginia. They are here designated as the eastern shore, the western shore, and the North Carolina.

The eastern shore topography is characterized by the low relief, under 50 feet, the slight erosion, and the gentle slope of the land toward tide level. Salt marshes fringe long stretches of the coast and tidal creeks reach inland up shallow channels.

The topography of the western shore is far more varied. Because of the narrow divides between the valleys of the Potomac, Rappahannock, York, and James rivers, and because along these rivers near the "fall-line" the highest of the terraces lies 200 to 400 feet above tide level, there are high cliffs and steep descents. The larger tributaries of the rivers have cut back into the divides. Their upper courses, locally called branches or runs, flow rapidly through narrow V-shaped valleys or shallow gorges, while the tidal lower courses, known as creeks, cross the youngest terrace by shallow partly drowned valleys. In places one terrace or another has been cut out by the rivers, so that here and there toward the fall line bluffs, or scarps, over 100 feet high mark the drop from a high terrace to tide level or the lowest terrace.

The part of the Coastal Plain south of James River has topography of the North Carolina type; that is, it resembles the topography of the northern portion of the North Carolina Coastal Plain. The stream valleys of the higher terraces are more open and have lower gradients than to the north; maximum elevations are less; the lower terraces are more extensive. The general slope of the surface is southeast and the rivers flow to the sounds of North Carolina. The above differences in topography determine differences in the occurrence of underground waters.

GEOLOGIC RELATIONS OF COASTAL PLAIN DEPOSITS

General description.—The generally unconsolidated deposits of the Virginia Coastal Plain rest on a floor of crystalline rocks that dips seaward. The beds just above bed-rock have an average inclination of about 30 feet to the mile; those laid down last dip 5 feet or less to the mile. Beds with steeper dips, 20° to 40°, have been noted in some of the formations, but such dips are local. The decrease in the dip from below upwards is a result of the initial seaward slope of the crystalline rocks and subsequent elevations and depressions. A succession of swings complicated by gentle bowings or warpings of the bed-rock has alternately carried the coast-line far to the eastward or brought it westward of its present position, so each great series or group of beds has been laid down on the beveled edges of the series below. As the tiltings have varied in direction, the overlap of one series has swung across the general strike of the beds in the preceding series, and as some formations overlapped unevenly eroded surfaces the boundaries on the west are quite irregular.

Thickness of deposits.—The maximum total thickness of the succession of formations is unknown. The deep well at Fort Monroe passed through 2,242 feet of beds; but the total thickness on the Eastern Shore is probably greater. At the big bend of Potomac River, northeast of Fredericksburg, the "fall-line"—the boundary between the Piedmont Plateau and Coastal Plain—curves to the east and takes a north-northeast course past Alexandria, Washington, and Baltimore. This may indicate a bowing of the crystalline rocks into a broad trough having an axis that dips southeast. Hence it is possible that at Franklin City, a well would go through 3,000 feet of sediments before reaching bed-rock.

CRYSTALLINE ROCKS

Character and extent.—The crystalline rocks along the western edge of the Coastal Plain comprise an extremely old (pre-Cambrian) series of gneisses, that originally were probably of igneous origin, intersected by intrusions of later granite, and large masses of gneisses and schists of doubtful origin, and age, though sedimentary in part and as late as upper Ordovician. These later gneisses and schists, like the older rocks, have been cut by igneous intrusions and the entire crystalline complex has been so mashed by pressure metamorphism, that much of the original structure has been obliterated and a complex system of folds and faults confuses rocks of widely different age and origin.

Slightly altered Triassic sandstones and shales with associated intrusions and flows of diabase underlie the Coastal Plain near Doswell and Ashland, but have not been found by deep borings elsewhere. This, however, is not surprising in view of the few holes sunk to bed-rock outside the immediate vicinity of Richmond and the probable limited extent of the Triassic rocks. The submerged portion of the Coastal Plain, which extends 100 miles east of the present shore line, is presumably underlain by crystalline rocks like those above described.

Bed-rock topography.—The Piedmont Plateau once extended far east of its present boundary as an undulating plain, in which scattered hills represented rock-masses that had best withstood the wear of wind and rain. The streams had reached their limit in down-cutting, and the bed-rock was deeply mantled with the products of decay. By a seaward tilting in early Cretaceous time, this mantle was worked over by streams and laid down as beds of sand, gravel, and clay. Since then earth movements have gently warped the crystalline floor into broad open troughs in some of which the succession of sediments is hundreds of feet thicker than on the ridges between. Hence, as the present rock-floor represents an original irregular rock surface, modified by what bending has taken place since sedimentation began.

depths to bed-rock vary at points equally distant from the "fall-line." The Fort Monroe record of 2,242 feet shows the average seaward slope between the well and the nearest point where crystalline rocks outcrop is 33 feet to the mile, but the slope is probably steepest near the "fall-line." North of Richmond, particularly along Potomac River, bed-rock slopes coastward at a greater rate, and a fall of 100 feet to the mile is indicated by the records of wells at Alexandria. This increase may mean that there has been faulting of the crystalline rocks near the "fall-line" north of Fredericksburg.[a]

WATER SUPPLIES

The crystalline rocks carry more or less water and along the western edge of the Coastal Plain deep wells have been drilled in them. The conditions governing the occurrence of water in crystalline rocks and in unconsolidated materials are so unlike, that the chief characteristics of the crystalline rocks as water bearers and the quality of their waters are discussed in a separate chapter (pages 83-97).

Although under special conditions water may travel through crystalline rocks for considerable distances, in general its circulation is limited. Where crystalline rocks are buried by water-filled porous beds, they contain, near the porous beds, water of the same general character as the latter. Hence it is not to be expected that wells sunk far east of the western margin of the Coastal Plain will obtain good water if the overlying unconsolidated beds carry water that is not potable.

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[a] Darton, N. H., Later Formations of Virginia and Maryland. Bull. Geol. Soc. Amer., vol. 2, p. 448.

SEDIMENTARY DEPOSITS

CRETACEOUS

LOWER CRETACEOUS

POTOMAC GROUP

Extent and character.—Immediately overlying the crystalline rocks throughout nearly all Tidewater Virginia is a great succession of gravels, cobble beds, sands, and clays classed as the Potomac group. This is exposed in stream gullies and railroad cuts along the western edge of the Coastal Plain from Alexandria to Fredericksburg, near Doswell, and in the valleys of James and Appomattox rivers south of Richmond and east of Petersburg. The smoothly rounded cobbles are of quartz, or dense vitreous quartzite, some dark, some light; cobbles of igneous rocks are rare. The sands frequently contain grains of feldspar, and where the feldspar grains are associated with angular quartz grains the sand becomes an arkose. The clays show great variety of color and texture. The proportion of coarse material is larger near the bottom of the succession of beds than near the top; also, the upper clays are often rather highly colored, red, yellow and brown, while those toward the bottom have more subdued tints, gray and dark green. The sands of the Potomac group, notably in exposures near Richmond and Petersburg, contain countless balls of clay that vary in diameter from an inch to a foot or more. They lie scattered through the sands and are even jumbled among hard quartzite boulders of equal diameter. Besides these balls the sands in places contain large sharply angular masses of clay that appear to have been torn from some bed. Sand and gravel beds compacted enough to make stone suitable for building rough walls are found on Aquia Creek and Appomattox River.

The Potomac beds show such local irregularities of dip that estimates of thickness based on dip can not be exact. It is probable that fully 350 feet of beds are exposed near Fredericksburg and at least 300 feet on Appomattox River. Under cover to the east, as shown by deep borings, the group thickens decidedly. The well at Fort Monroe went through 1,400 feet of material classed as Potomac by Darton.

The elevation of the lowest visible beds varies from sea-level at the "fall-line" to 250 feet in the divides between Potomac and Aquia creeks, Stafford County, and 300 feet on the hills northwest of Alexandria. The average eastward dip of the beds is from 30 to 60 feet to the mile.

The most striking characteristic of many Potomac outcrops is the heterogeneous mixture of materials. The sands are prevailingly cross-bedded; in places the minor beds are steeply inclined, but no bed is persistent for any great distance, and sections a few hundred feet apart in bluffs or railroad cuts show little correspondence. North of Fredericksburg and in the vicinity of Mount Vernon the upper part of the group is more evenly bedded.

Origin.—The fossils indicate that the Potomac beds as a whole were fresh water deposits and the varied aggregation of material in the lower beds shows that they were laid down by swiftly-moving currents. The fossils are mostly plant remains, impressions of leaves and seeds, with here and there lignitized or silicified wood. The animal remains include bones of dinosaurs.

DIVISIONS

The Potomac beds were first differentiated by W. B. Rogers[a] 70 years ago; he noted their composition and determined closely the boundaries of their outcrops. Since then they have been studied in greater or less detail by Fontaine, McGee, Ward, Darton, Clark, Bibbins, Miller, and Berry, and have been variously subdivided. Owing to the varying composition of the beds, distinctions based on lithologic character have proved unsatisfactory. On the basis of plant remains the Potomac in Virginia is divisible into two formations, an older and a younger. The older is known as the Patuxent and the younger as the Patapsco, from the typical exposures on Patuxent and Patapsco rivers in Maryland.[b]

Patuxent formation.—This, the lower of the formations, is traceable along river valleys near the "fall-line" from Alexandria to Petersburg. It comprises beds of cobbles, gravels and sands with discontinuous beds and lenses of clay and scattered clay balls. The sands are arkosic and cross-bedded. The clays are usually gray, drab, dark green, or chocolate in color. The fossils include plant remains of early Cretaceous types and bones of dinosaurs that have Jurassic affinities. The total thickness exposed north of Fredericksburg may be 250 feet. The formation dips east 30 to 60 feet to the mile.

Patapsco formation.—This formation has been recognized north of Fredericksburg and near Mount Vernon. South of Fredericksburg it is absent or is overlapped by Eocene and Miocene deposits. The Patapsco is

[a]Rogers, W. B., The Geology of the Virginias.
[b]Clark, W. B., and Bibbins, A., Jour. Geol. 1897, vol. 5, pp. 479-506.

clayey rather than sandy. The clays are bright-colored, and thicker and more evenly stratified than those in the Patuxent. The sands are less arkosic. The fossils comprise plant remains of Lower Cretaceous types. The exposed thickness of the Patapsco beds may be 150 feet. The formation dips east about 30 feet to the mile.

WATER SUPPLIES

Sandy beds in the lower formation of the Potomac group, the Patuxent, underlie almost all the Coastal Plain of Virginia and constitute vast reservoirs of water, but as they are deeply buried a short distance east of the "fall-line," making their development expensive, only a few wells draw on them. Most of these wells are near Alexandria. Near their outcrops the lower Potomac sands usually yield excellent water. Sands toward the top of the Patuxent seemingly are not so sure to yield good water. Far to the east the supplies become more mineralized and in the Norfolk area are too salty to be potable.

The significance of the disorder of the Patuxent sands to the well driller or geologist is that predictions of striking water at a given depth 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.

UPPER CRETACEOUS

The Upper Cretaceous does not outcrop in Virginia. The outcrops of Coastal Plain deposits show a well-marked break above the highest beds of the Potomac group. Formations belonging to the Pamunkey (Eocene) and Chesapeake (Miocene) groups cut across the feather edges of the Potomac formations from the northeast. In Maryland and in North Carolina beds of Upper Cretaceous age, sands, clays, and greensands, intervene between the Lower Cretaceous and the Eocene deposits. As these beds have not been recognized in Virginia in wells less than 30 miles east of the "fall-line," their extent under cover in this State is conjectural. However, the Magothy formation is found on the heights back of Anacostia, D. C., across Potomac River from Alexandria, and the Raritan a few miles farther east. Upper Cretaceous beds were penetrated by deep wells at Crisfield, Md., Fort Monroe and Norfolk, Va. Back of Anacostia the Magothy may be 10 feet thick. Data for estimating the thickness of the Upper Cretaceous formations under cover far eastward are not particularly reliable. Darton thought there were 60 feet of Magothy and 35 feet of higher Cretaceous beds at Crisfield, Md., and 120 to 140 feet of "Marine Cretaceous" beds at Fort Monroe and Norfolk.

The Raritan formation of Maryland includes clays much like those of the Patapsco with interstratified sands. The Magothy is of more variable composition. The Upper Cretaceous material from the deep wells of Crisfield, Md., included greensands, fine gray micaceous sands, and dark clays. In the Norfolk-Fort Monroe area the Upper Cretaceous deposits comprise gray micaceous sands, dark gray, red and green clays, and gray sandy clays. Upper Cretaceous fossils have been found north of Fort Monroe by deep wells near Selden, Gloucester County, and Fairport, Northumberland County.

TERTIARY

EOCENE

PAMUNKEY GROUP

Extent and character.—Along Potomac River between Aquia Creek and Matthias Point; on the divide between Potomac and Rappahannock rivers; along the latter from 3 miles southeast of Fredericksburg to 4 miles east of Port Royal; on Mattaponi River above Marricossick Creek; on the Pamunkey from Hanover to Piping Tree Ferry; on James River from Richmond to Coggins Point; and on the Appomattox between Petersburg and City Point, are exposures of sands, sandy marls and clays that contain abundant marine fossils, mostly shells of mollusks. The clays below tide-level are prevailingly dark-colored, usually greenish, but one, exposed in outcrops north of Fredericksburg and found by artesian wells along Potomac and Rappahannock rivers, is reddish to white. The sands range in color from light gray through bluish and greenish shades to almost black; many are composed of quartz grains with a varied proportion of the small irregularly-rounded dark green or black nodules of the mineral glauconite, a silicate of potash and iron. When these glauconite grains predominate the material becomes a greensand or what well drillers term "black sand."

In the sands are indurated streaks or nodules that form dense hard rock; these streaks are of irregular thickness and small extent. There are also hard beds composed largely of shells. At the base of the Pamunkey is a thin but rather persistent bed of dark pebbles or small cobbles.

The contact between the Potomac and the Pamunkey near the "fall-line" in places is decidedly uneven. There is evidence near Richmond and

Petersburg, where there are inliers of Pamunkey among hills of Potomac material, that the Pamunkey was laid down on an irregularly eroded surface having almost as much relief as the present topography. The total thickness of the Pamunkey beds exposed on Potomac River is 225 feet. Unlike the Potomac group, the Pamunkey does not thicken greatly under cover, and it thins out to the southwest. The well as Crisfield, Md., penetrated possibly 150 feet of it; the borings at Fort Monroe and Norfolk not over 250 feet and possibly less than 100 feet. South of Petersburg to the North Carolina line there are no definitely identified exposures of Pamunkey beds.

Since deposition the Pamunkey beds have been slightly tilted and now dip 10 to 15 feet to the mile east. Above water-level, owing to the proportion of iron in the glauconite and the easy decay of the mineral, the Pamunkey sands weather to shades of brown, buff and yellow; the clays also grow brighter, buff being perhaps the color most frequently seen in high-lying exposures.

DIVISIONS

Clark, who has described the Pamunkey in Maryland and along Potomac River in Virginia, divides the group into two formations, the Aquia and the Nanjemoy, of which the Aquia contains the greater proportion of sandy beds and the Nanjemoy the more clay. For a detailed account of the Potomac River exposures the reader is referred to reports of the Maryland and Virginia Surveys.[a]

Aquia formation.—This formation is typically exposed along Aquia Creek in Stafford County, where it is 100 feet thick. It comprises beds of greensand and greensand marls containing many marine shells of Eocene age. Southward it thins out, is overlapped by the Nanjemoy, and is exposed in few Pamunkey outcrops south of Richmond.

Nanjemoy formation.—This formation, named after Nanjemoy Creek in Maryland, outcrops in river valleys from the big bend of Potomac River to Petersburg. It does not outcrop further south and at the North Carolina line its western boundary may be 30 miles east of Emporia. It comprises beds of sand, greensand and clay, with numerous marine shells. A distinctive bed of clay, white at the top, pink at the bottom, marks the base on the divide between Potomac and Rappahannock rivers near Fredericksburg, and has been recognized in wells along those rivers to the east. The total thickness of Nanjemoy beds exposed on Potomac River is about 125 feet.

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[a] Clark, W. B., Maryland Geol. Survey, Eocene, 1901, pp. 59-71; Clark, W. B., and Miller, B. L., Bull. No. iv, Virginia Geol. Survey, 1912, pp. 93-96.

Brief descriptions of the Pamunkey beds under cover, as reported by drillers, are shown in the well records published on succeeding pages.

WATER SUPPLIES

Under much of Tidewater Virginia the Pamunkey group is an important source of deep water, though the porous sands which give flowing wells are relatively thin and few in comparison to the total thickness of sandy material and the number of sand beds seen in the outcrops. The glauconite sands, because of the proportion of interstitial space between the rounded granules of glauconite, give up water more easily than quartz sands and such open-textured beds full of the dark green or black glauconite are called "water sands" or "true water sands" by well drillers.

MIOCENE

CHESAPEAKE GROUP

Extent and character.—The irregular edge of the Chesapeake cuts across the Potomac and Pamunkey beds in a south-southwest direction, and south of Rappahannock River to the North Carolina line the Potomac and Pamunkey are exposed only in river valleys. On the divides the western edge of the Chesapeake rests directly on the crystalline rocks. East of the line along which the Pamunkey beds slope below tide-level the Chesapeake deposits are hidden only by a thin covering of Columbia material and are exposed to river bluffs and in creek valleys nearly to Chesapeake Bay. Thus the area in which the Chesapeake outcrops is much greater than the combined outcrop areas of the Potomac and Pamunkey.

The Chesapeake beds are prevailingly sandy, with a varying proportion of clay. They comprise pure quartz sands, glauconitic sands, sandy clays, and beds of marl; the latter, full of tightly packed marine shells, are widely distributed. Some of the sand beds contain glauconite in scattered grains only, others are almost as glauconitic as those in the Pamunkey. Streaks and nodules of hard, cemented sand or "rock" occur at many horizons, but individually are of small extent. The colors below water-level are subdued, varying from light gray through bluish and greenish shades to dark greenish gray.

Near the base of the Chesapeake are drab and gray beds of clayey or finely sandy material full of the minute siliceous tests of diatoms, forming diatomaceous earth. In places, as just below Wilmont Landing on the Rappahannock, these diatomaceous earth deposits are 50 feet thick.

On exposure the Chesapeake beds weather to brighter tints, buff and yellow predominating. The elevation of the highest lying beds ranges from 250 feet back of Brooke, to about 100 feet near the Virginia-North Carolina line. The maximum thickness of the group in Virginia may be 700 feet. The dips are southeast and east, about 6 to 10 feet to the mile. In places comparatively steep reverse dips up to 30° are seen, but these are of small extent.

DIVISIONS

Four divisions of the Chesapeake, based chiefly on differences in the abundant marine fauna, have been recognized in Virginia by Clark; these are the Calvert, Choptank,[a] St. Mary's and Yorktown. This fourfold division of the Chesapeake applies to the outcrops west of the bay. The relation of the formations far under cover in the eastern and southeastern parts of the State has not been established. Deep wells near Norfolk show a great thickness of dark, fine sandy clays and clayey sands, and few distinctive fossils that might serve as guides in correlating records have been saved in drilling.

Calvert formation.—This formation, the most clayey of the four, has been traced along the west edge of the Coastal Plain from Potomac River to south of Petersburg. Farther south it is overlapped by the St. Mary's. It is well exposed at several localities, notably the bluffs on Rappahannock River south of Port Conway. It contains thick diatomaceous earth deposits and shell beds with characteristic marine fauna. The maximum thickness exposed is 200 feet. The average dip is southeast and east about 10 feet to the mile. It is named from Calvert County, Maryland.

Choptank formation.—This formation is sandier than the Calvert but contains a considerable proportion of clayey beds as well as diatomaceous earth. It is not exposed anywhere in Virginia but may intervene between the Calvert and St. Mary's under cover in the Potomac Valley as it has been recognized and mapped in Maryland.

St. Mary's formation.—This formation consists of bluish and greenish sandy clays and gray sand, with many thick beds of shell marl. It is established as a separate formation by the predominance of certain marine shells. The thickness is 150 feet and the dip 8 or 10 feet to the mile eastward. It is named from St. Mary's County, Maryland.

Yorktown formation.—This formation succeeds the St. Mary's so conformably that no sharp dividing line has been determined. It is sandy,

[a]Not recognized in Virginia by Clark and Miller, Bull. No. iv, Virginia Geol. Survey, 1912, p. 140.

richly fossiliferous, and at the type locality, Yorktown, contains firm, fairly hard rock made up almost entirely of comminuted shells. Its total thickness is over 100 feet. As a whole it slopes seaward at the rate of 6 or 8 feet to the mile, but in places are fairly steep westward dips.

WATER SUPPLIES

From its extent, stratigraphic position, and sandy character, the Chesapeake group is a notable source of artesian water. It has been tapped by many hundreds of inexpensive wells and its deep supplies, except on the eastern shore of Chesapeake Bay and in a few counties on the western shore, are soft, "light," fresh, and excellently suited to domestic use. The shallow waters may be hard from lying in beds of shells or iron-bearing from the decay of glauconite.

PLIOCENE (?)

No beds containing distinctive Pliocene fossils have been found in Tidewater Virginia. There are such beds in the Coastal Plain of North Carolina and of other states southward, notably Florida. The Lafayette has been classified as a Pliocene formation. The lithologic resemblances between the Lafayette and the Sunderland formation in Virginia are great and there is no definite proof that the Lafayette is older than Quaternary. It is here called Pliocene (?).

Lafayette Formation[a]

Extent and character.—The Lafayette is a far-extending but relatively thin mantle of clay, sand, and cobbles, in which the finer-textured material has in places an orange or reddish tinge. This vast, blanket-like deposit, usually gravelly toward the base but loamy near the surface, has been traced along the higher portions of the Atlantic Coastal Plain from New Jersey to Florida and across the Piedmont to the Blue Ridge. It is characterized not only by the bright hues of its loams and clays but by the peculiarly irregular and confused arrangement of the materials in many of the coarser beds. The formation is high-lying, overlapping the Coastal Plain sediments only where they are much above sea-level, and nowhere in Virginia reaching tidewater, being cut off seaward or riverward by distinct slopes and well-marked scarps. Another peculiarity is a scarcity of fossils.

[a]The name Lafayette was proposed by Hilgard in 1891 from Lafayette County, Miss. Amer. Geol. 1891, vol. 8, pp. 129-131. Berry has recently shown that the so-called Lafayette of the type section in Lafayette County, Miss., is of Eocene age. Jour. Geol. 1911, vol. 19, pp. 249-256.

the organic remains being plant fragments and impressions of no determinative value. This far-spread mantle was first recognized as a distinct geologic unit by McGee[a] and named by him the Appomattox formation.

The total extent of the formation in Virginia has not been determined. It covers little of the tidewater country. Its cobbles and gravels rest on the crystalline rocks of the Piedmont, or on the edges of Potomac, Pamunkey, or Chesapeake beds. Usually not over 50 feet thick and nowhere filling the gorges, the Lafayette caps the higher interstream plateaus. Its base is 480 feet above tide at Peach Grove Hill in Fairfax County, and 200 feet near Fredericksburg. Whether it actually is present at the type locality of McGee's Appomattox formation, southeast of Petersburg, is uncertain.[b]

Along Potomac River north of the great bend the Lafayette is sharply interrupted or cut off by the river valley. South of the great bend to Petersburg the eastern limit of the formation is less clearly defined, but probably nowhere extends far east of the "fall-line." It has been traced inland back of Fredericksburg for 10 miles, and has been described by Shaler and Woodworth[c] in the Richmond coal basin at altitudes of 350 feet.

Origin.—The probable origin of the Lafayette has caused much discussion. Some geologists have called it a marine formation, others have said it was formed by streams. Further investigation may show that the term Lafayette has been applied to both marine and fluviatile deposits. A detailed discussion of the origin lies without the province of this report. In Virginia the field relations, varied lithology, heterogeneous assortment of materials, and lack of fossils, are evidence in favor of a fluviatile or estuarine rather than a marine origin.

WATER SUPPLIES

The Lafayette gravels are reservoirs of ground water for springs and dug wells. The supplies they furnish are generally limpid and soft, and in some places remarkably low in mineral content but, from the limited extent of the Lafayette in the Coastal Plain, are important in only a few counties.

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[a] McGee, W. J., Three Formations of the Atlantic Slope, Amer. Jour. Sci. 3rd ser., 1888, vol. 25, pp. 120-143.

[b] The writer is of the opinion that the Appomattox formation in the vicinity of Petersburg, as described by McGee, includes Columbia beds, and that the Lafayette has not been differentiated with exactness there.

[c] Shaler, N. S., and Woodworth, J. B., Geology of the Richmond Basin, Virginia, 19th Ann. Rept. U. S. Geol. Survey, Part 2, pp. 385-519.

PLEISTOCENE

COLUMBIA GROUP

Character and extent.—Over most of Tidewater Virginia, resting on Miocene, Eocene, or Cretaceous deposits, or on the crystalline rocks of the Piedmont, lies a mantle of loam, clays, sands, gravels and cobbles; the older strata cropping out on river bluffs, in stream gullies, and on eroded divides. Like the Lafayette, this mantle shows a prevailing assortment into coarse material at the bottom and fine at the top, and its component beds show great differences of color, texture, and arrangement. The clays have many hues, from dark gray through yellow or buff to orange and red; the coarse material comprises evenly stratified sands and mixtures of sands, cobbles, and boulders that seemed dumped in place.

The Columbia differs from the Lafayette in several details. While the latter mantled an undulating surface, the Columbia partly filled river gorges and capped intervening divides. The Lafayette forms a sloping plain cut off to the seaward and along river valleys by scarps or graded slopes; the Columbia comprises several terraces or terrace plains that slope seaward and toward river valleys. Large transported boulders are not found in the Lafayette, but are common on the river terraces of the Columbia toward the "fall-line." Some of these boulders are seven or eight feet long, have polished and striated faces, and have evidently been dropped by ice floes. The Columbia loams on the lower terraces are mostly light buff and yellow; on the higher terraces, buff and red; but south of James River bright-colored loams are not so common as along Potomac River. Even on the highest terrace they are often light buff and yellow rather than dark buff, orange, and red.

The landward elevation of the surface of the highest terrace along the "fall-line" varies from 300 feet west of Alexandria to about 150 feet south of Petersburg. The surface of the lowest terrace is less than 25 feet above tide and extends to sea-level in many places. The only fossils found in the clays of the higher terrace are plant remains. The lowest terrace contains plant remains and marine shells.

DIVISIONS

In Maryland, three terraces were distinguished by Shattuck[a] and traced across the State. He found that while each terrace sloped seaward and

[a]Shattuck, G. B., The Pleistocene Problem of the North Atlantic Coastal Plain, Amer. Geol., 1901, vol. 28, pp. 87-107; Maryland Geol. Survey, Pliocene and Pleistocene, 1906, 291 pp. lxxv plates.

toward river valleys, there was a remarkable uniformity of elevation at points on the same terrace many miles apart. The three terraces he named in order of age, from high to low, the Sunderland, Wicomico, and Talbot, and classified their materials as the Sunderland, Wicomico, and Talbot formations. This division of the Columbia he extended into Virginia.

In North Carolina six terraces with elevations varying from sea-level to 200 feet have been described.[a] Stephenson[b] discriminates five Pleistocene terraces in North Carolina. The names he gives them and the elevations above sea-level are as follows, in order of age: Coharie, 160 to 220 feet; Sunderland, 110 to 160 feet; Wicomico, 60 to 90 feet; Chowan, 30 to 50 feet; Pamlico, 0 to 25 feet. The Coharie has not been recognized north of North Carolina. The Chowan and Pamlico together correspond to the Talbot of Maryland and Virginia as described by Shattuck.

Clark and Miller[c] have recognized and traced three Columbia terraces in the Virginia Coastal Plain and have designated as formations the deposits that constitute them, the Sunderland, the Wicomico, and the Talbot.

The terraces as a whole slope east or southeast, but along the rivers each terrace slopes toward the river; on the divides the slope is seaward. Hence the elevation of each terrace is least toward the river or the ocean and greatest at the foot of the slope or scarp which marks the transition to the terrace above.

In general there is on each terrace a rough assortment of materials from coarse at the base, to fine near the surface. The proportion of very coarse material, gravel, cobbles and boulders, is greatest near the "fall-line." The basal sands are generally gray in color; the tints of the subsoil loams and clays range from dark gray with bluish, brownish or greenish hues, to bright red, orange and buff.

The thickness of each terrace formation varies from a thin edge near the scarp above to a maximum at varying distances riverward or seaward. The maximum thickness of the lowest formation is uncertain because in places on the western shore of Chesapeake Bay and along the bay side and ocean side of the Eastern Shore, a considerable part of the formation lies below tide-level and its materials have not been definitely distinguished from the Chesapeake (Miocene) beds on which they presumably rest.

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[a]Johnson, B. L., Pleistocene terracing in the North Carolina Coastal Plain. Science, 1907, vol. xxvi, pp. 640-642.

[b]Stephenson, L. W., Geology and Underground Waters of the North Carolina Coastal Plain. N. C. Geol. Survey. In press.

[c]Clark, W. B., and Miller, B. L., Bull. No. iv, Virginia Geol. Survey, 1912, p. 48.

Sunderland formation.—Maximum elevations of the Sunderland range from 300 to 220 feet on divides back of the "fall-line," to 90 feet at points along the rivers farther east. The Sunderland-Wicomico scarp extends along a northeast line, that is a line at right angles to the trend of the larger river valleys. The materials of the Sunderland terrace, which constitute the Sunderland formation, comprise cobble-beds, sands and gravels, bright-colored loam and clays, and near the "fall-line," large boulders. The thickness of the formation varies from a feather-edge to a maximum of 50 feet.

Wicomico formation.—The Wicomico terrace can be traced at intervals along the rivers to the "fall-line" and around the intervening divides from North Carolina to Potomac River. It is widest south of James River where it is 10 miles wide. On the divides between York, James, Rappahannock, and Potomac rivers, this terrace is not as pronounced a topographic feature as the terrace below it. The terrace materials comprise cobbles, gravel, sand, and bright-colored loams and clays, much like the Sunderland. The thickness varies from a feather-edge to about 45 feet.

Talbot formation.—The Talbot is the youngest and most easily distinguished of all the terraces.[a] It is 30 miles wide at the south and includes all of Princess Anne County, most of Norfolk, nearly all of Elizabeth City County, the east end of Gloucester County, and practically all of Mathews County. Reëntrants of this terrace extend up the river valleys. On the eastern shore the terrace probably includes all of Northampton County and most of Accomac County. The Talbot formation is composed of sands, gravels, clays and loams, with cobbles and ice-borne boulders along the river toward the "fall-line." The fossils comprise cypress stumps and other plant remains, and beds of marine or brackish water shells. The thickness of the formation ranges from a few feet to fully 40 feet on the western shore of the bay. On the eastern shore the thickness may exceed 50 feet.

The relations of the Columbia terraces and the terrace materials to the underlying deposits are shown in Fig. 5, page 52.

Origin.—While a marine or estuarine origin for the terrace formations has been advocated, the question is still in dispute. The 0-25 foot terrace underlain by beds containing marine and brackish water-shells at Newport News, east of Norfolk, and in the Dismal Swamp area, is indisputably marine or estuarine.

[a]The writer believes that the Talbot formation in Virginia, as described by Shattuck, comprises two formations; in other words, the Chowan and Pamlico formations of North Carolina extend into Virginia.

WATER SUPPLIES

The coarser beds of the several Columbia formations are important reservoirs of water in Tidewater Virginia, and are tapped by thousands of dug or driven wells. As the sands and gravels often rest on relatively impervious clayey beds of Miocene, Eocene, or Cretaceous age, and are exposed along scarps or in stream gullies, they are the source of countless springs. On the high terraces the ground water is mostly soft and of low mineral content. On the lower area and especially near tidewater it differs greatly; in most places it is limpid and soft and excellent for general use; here and there so mineralized as to be unfit for many purposes.

Undifferentiated Columbia Beds

Extent and character.—Beds of mud, sand, clay, and gravel underlie the lowest Columbia terrace, or the terrace now in process of formation, at places in the eastern part of Norfolk, Elizabeth City, Gloucester, Mathews and Princess Anne counties, and the whole Eastern Shore. The chief objections to including these beds in the Talbot formation are that their indicated thickness would make this formation much thicker than any of the older Columbia formations, and that there is nothing to show that all the beds accumulated while the Talbot terrace was forming. Some may antedate the Talbot terracing; some may even be of Pliocene age. In the localities mentioned the beds rest on Chesapeake sands and clays. As they do not outcrop but lie below tide-level they can be differentiated from the Chesapeake beds below and the Recent or Columbia beds above only by the study of well records and samples of drillings. As few samples have been saved the age remains in doubt.

These undifferentiated beds comprise soft, dark bluish or greenish and bluish-gray sands with rounded and sharply angular grains, and coarse gravel. Some of the beds contain many marine shells, some contain cypress stumps or logs.

The sands in which the shells lie, sparsely scattered or in distinct layers, are medium fine, and, when dry, light gray in color; when wet, dark bluish or greenish. They apparently form discontinuous bands or lenses of varying thickness, no single sand bed having been traced far. The sands are for the most part soft, and offer little resistance to the drill, but locally contain indurated streaks usually only a few inches thick that the drillers term rocks. The beds are separated by dark clays of bluish or greenish tinge, that vary in texture from tough and firm clay to soft mud in which the drill of a light jet rig will sink five or six feet in as many minutes.

The soft clays, those most frequently found, are described by drillers as "blue mud" or "blue marsh mud." The shell beds, logs and stumps found in these beds on the Eastern Shore all lie considerably below tide-level. The following list of localities and depths to shell beds nearest surface in Accomac and Northampton counties is given for its geologic interest:

List of localities and depths to shell beds nearest surface in Accomac County.

	Feet		Feet
Accomac	50	Hunting Creek	90
Belinda	80	Mearsville	117
Bloxom	83	Mears Wharf	75
Boggs	104	Mappsville	70
Cashville	100	Mesongo Creek	115
Chesconnessex	100	Mt. Prosperity, near Onancock	60
Craddocksville	140	New Church	120
Hallwood	110	Pungoteague	110
Harborton	126		

Northampton County: Charlton 63 feet, Upshur Neck 128 feet; throughout Northampton County generally, 60 to 90 feet.

A well near Onancock, sunk 110 feet, is reported by the driller to have struck a bed of "beach sand" containing small shells at 65 feet and to have been bottomed in shell-rock containing "oyster" and "clam" shells. "Pieces of bark and knots of wood" were reported between 60 and 100 feet.

Another driller, F. A. Merrill, of Onancock, reports striking in a well on Grapeland farm, on Occahonnock Creek, three quarters of a mile from Wardstown Post-office, a "stump" 70 feet below surface or 60 feet below tide-level. A well at the house of Tully Scott on Masitank Creek, three quarters of a mile west of Cashville, according to the owner, went through "pieces of wood" at 64 to 68 feet.

WATER SUPPLIES

On the Eastern Shore many flowing wells draw on these deep-lying Columbia sands. The heads are low and seem to be largely determined by local topography. Thus there are few flows along the bay shore near Saxis, Belinda, and Marsh Market in Accomac County where the Talbot terrace slopes gradually to the expanses of salt marsh that border the tidal inlets; the ground, as well drillers say, is "too low." But there are many flowing wells on the bay shore farther south, where, as about Onancock and Harborton, a terrace plain 15 to 20 feet high, often overlooks open water. Again there are more flowing wells in Accomac than in Northampton County where the general elevation of the surface is less than to the north.

It is not possible that the supplies of these Eastern Shore wells could have come from across the bay; the beds under the bay contain salt water at too great a depth to permit that. They are fed from ground water that is supplied by the rain and snow that fall on the Eastern Shore. The underground circulation is southward and from the higher land along the axis of the peninsula toward the bay and the ocean. The heads of the water in particular wells or groups of wells are closely related to the height above sea-level of the water table in the vicinity of the wells. Since the water beds lie comparatively near surface, are overlain by muds or soft clays and extend under tidal inlets, the flowing wells of the Eastern Shore all show tidal changes, but the lag is less than that of the deeper wells of the western shore.

No flowing wells that evidently draw on these sands have been reported in Mathews, Norfolk, and Princess Anne counties.

As the deep Columbia beds comprise both clean sands and swamp mucks the contained waters vary greatly. Some of the sands yield excellent water—clear, soft, and low in mineral content, while other beds yield waters that are highly colored, hard, contain iron and have a decided odor of sulphuretted hydrogen.

SUMMARY OF GEOLOGIC FORMATIONS AND THEIR WATER SUPPLIES.

The geologic relations of the various Coastal Plain formations, their constituent materials, and their importance as water-bearers are shown in the following table:

TABLE 1.—*Geologic relations and water supplies of Virginia Coastal Plain formations.*

System	Series	Group	Formation	Materials
Quaternary	Recent			Marsh and swamp muck, river silts and sands, beach and dune sands .... (1)
	Pleistocene	Columbia	Talbot	Sands and gravels, clays and loams, less brightly colored than those of older terraces, old cypress swamps and beds of marine shells; 0–40 feet .... (2)
			Wicomico	Cross-bedded sands; cobble beds and ice-borne boulders toward "fall-line"; clays and loams often bright-colored, some plant remains; thickness 0–40 feet........ (3)
			Sunderland	Cross-bedded sands; cobbles and boulders; bright-colored loams; thickness 0–50 feet .... (4)
Tertiary	Pliocene (?)		Lafayette	Cross-bedded sands, locally indurated, cobbles, and small boulders; bright-colored loams and clays; thickness 0 to 50 feet........ (5)
	Miocene	Chesapeake	Yorktown	Gray sands; beds of marine shells, locally indurated; thickness 0–150 feet .... (6)
			St. Mary's	Gray bluish or greenish sands and sandy clays and shell marls, weathering to bright hues; thickness 0 to 250 feet........ (7)
			Choptank (?)	Gray bluish and greenish sands, locally indurated, sandy clays and shell marls, not recognized in Virginia........ (8)
			Calvert	Gray bluish and greenish sands, locally indurated, sandy clays and shell marls, thick beds of diatomaceous earth, weathers to bright hues; thickness 0–300 feet........ (9)
	Eocene	Pamunkey	Nanjemoy	Gray and greenish sands, greensand marls, locally indurated, dark clays, shell beds, all weathering to bright hues; thickness 0–125 feet .... (10)
			Aquia	Gray and greenish sands, greensand marls locally indurated, dark clays, shell beds, all weathering to bright hues; thickness in outcrops 0–100 feet .... (11)
Cretaceous	Upper Cretaceous			Does not outcrop in Virginia, comprises, under cover, greensands, gray micaceous sands and dark clays; thickness uncertain, over 500 feet .... (12)
	Lower Cretaceous	Potomac	Patapsco	Bright-colored, evenly bedded clays, dark clays, arkosic sands, plant remains; thickness in outcrops 0 to 150 feet........ (13)
			Patuxent	Cross-bedded arkosic sands with pebbles and cobbles, in places sandstone, conglomerate and shale, clay beds and lenses, plant remains; thickness in outcrops 0 to 250 feet........ (14)

WATER SUPPLIES

(1) Not important.

(2) Coarser beds supply ground water to springs and shallow wells; contain artesian water on Eastern Shore.

(3) Coarser beds supply springs and shallow wells.

(4) Coarser beds supply springs and shallow wells.

(5) Coarser beds supply springs and shallow wells.

(6) Ground water to springs and shallow wells, artesian water to a few wells.

(7) Ground water to springs and shallow wells, artesian water to many wells.

(8) May supply artesian water to a few wells.

(9) Ground water to springs and shallow wells, artesian water to many wells.

(10) Ground water to springs and shallow wells, artesian water to many wells.

(11) Ground water to springs and shallow wells north of Pamunkey River; artesian water to some wells.

(12) Artesian water of varying quality to a few deep wells near Chesapeake Bay.

(13) Ground water to springs and shallow wells, artesian water of varying quality to a few deep wells.

(14) Ground water to springs and shallow wells, artesian water of varying quality to a few wells near the "fall-line," and near Chesapeake Bay.

UNDERGROUND WATERS

ORIGIN, OCCURRENCE, AND DISTRIBUTION.

General statement.—Of the moisture that falls on the land in the form of rain and snow, part returns directly to the air by evaporation, part flows directly away by streams, and part enters the soil. The total precipitation on any region is distributed variously among these destinations, the exact amount that goes to any one being determined by factors which interact in an extremely complex manner.

Evaporation.—The proportion of rainfall that returns to the air by evaporation from the leaves of plants, before or after reaching the ground, or from the surface of the ground itself, varies greatly under different conditions. The temperature, the wind velocity, the character of the vegetation, the nature of the soil, all affect it. Evaporation is less in a cool climate with light winds than in a hot climate where fresh winds prevail. It is less from sandy than from clayey soils. It is less from fields than from forests. Tidewater Virginia has hot summers with liberal precipitation; on the other hand the wind velocity is low. Estimated on the basis of measurements at Washington, D. C., and including the water returned to the air by plants, evaporation in the Virginia Coastal Plain amounts to more than 50 per cent of the rainfall.

Run-off.—That portion of the rainfall that the streams carry away from a given district is the run-off. It includes the over-surface flow and the water from seeps and springs; it is determined by measuring the discharge of the streams, and is expressed either in inches, like rainfall, or as a percentage of the rainfall. The chief factors controlling run-off are vegetation and temperature. This is shown by Hoyt[a] who finds that while the winter run-off in Vermont is 92 per cent of the rainfall and in Virginia is 63 per cent, the summer run-off is practically the same in the two states. No determination of annual run-off in the Virginia Coastal Plain has been made but it is probably less than in the Piedmont counties of the State, where it is 40 per cent of the rainfall.

Controlling factors in soil absorption.—The chief factors regulating the entrance of water into the ground are the slope of the surface, the rate of

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[a]Hoyt, J. C., Comparison between rainfall and run-off in the northeastern United States, Trans. Amer. Soc. Civ. Eng., vol. 59, pp. 431-520.

precipitation, the air temperature, and the texture of the soil. On steep hillsides much rain water runs off before the soil can take it up; similarly, if the rain falls in a heavy shower less of it enters the soil than if it falls more slowly, because every soil has a certain rate of absorption, and if this be exceeded the excess water runs off. A high temperature decreases the surface tension of water so that water passes more readily through the soil pores. Sands have much larger pore spaces than clays, hence sandy soils take up water more rapidly than clayey soils.

In the Virginia Coastal Plain the conditions favorable to the absorption of moisture reach a maximum on flat expanses of terraces with sandy soils during gentle rains in warm weather.

Storage capacity of soils.—The capacity of a soil to absorb water is a measure of its porosity. In sands, the evenness of size of the grains and their roundness of outline determine the proportion of voids, because if the grains are round the total amount of open space is independent of the diameter of the grains. A clean, evenly sized sand with well-rounded grains will absorb water equal to 40 per cent of its bulk; a cubic foot of such sand will absorb about 10 quarts. Sharp sands that pack closely and sands with grains of various sizes absorb less. On the other hand, loams have proportionally more pore space and greater absorption capacity. Some determinations made by King[a] showed that the percentage of pore space in clayey loams was about 44.5 per cent, and in sandy soils 30 to 35 per cent. Because of the great predominance of sands and sandy loams in the Virginia Coastal Plain, as shown in the table on page 29, it is probably safe to assume that the average absorption capacity of the soils is about 35 per cent.

SOILS AND SOIL SOLUTIONS.

Soils.—The soils of the Coastal Plain are derived almost wholly from unconsolidated beds of gravel, sand and clay, which in turn represent the washed-over debris of pre-existing unconsolidated beds, or the material worn from the hard rocks of the Piedmont Plateau. Since the Lafayette and Columbia formations lie blanket-like upon the older beds, and the latter are practically not exposed except where the Lafayette or Columbia beds have been removed by erosion, as on scarps, valley slopes, or narrow stream divides, the older beds are of less importance in the formation of soils. On the other hand the more or less weathered surfaces of the several Columbia formations form the cultivated soil of fully three-fourths of the Coastal Plain area.

[a] King, F. H., Nineteenth Ann. Report, U. S. Geol. Survey, pt. ii, 1897-98, pp. 213-214.

On the basis of origin, soils may be divided into two classes, residual and transported. A residual soil represents what is left from the decay of rocks, and rests where it formed. A transported soil is composed of material that has been moved by water, ice or wind. Residual soils characterize the Piedmont Plateau, transported soils the Coastal Plain. In the latter province the great agent of transportation has been water. There has been movement as dust but not enough to be of much importance in soil formation. There are accumulations of wind-moved sands, or dunes, back of some Chesapeake Bay or ocean beaches, notably at Cape Henry, but these are of little or no agricultural value. The water-moved rock particles were variously transported, some by streams and some by the waves and currents of the ocean or tidal inlets; they were deposited along river bottoms or on flood plains, in swamps or shallow bays, or in the ocean. Thus the finest of silts and the coarsest of gravel were laid down simultaneously in the formation of any one of the Columbia terraces. The terraces have been variously eroded since elevation above sea-level. Certain areas in all the terraces have been better drained than others, and the rate of decay of the soil particles has therefore not been the same. In consequence of original differences in mode of deposition and in material, and of subsequent differences in erosion and weathering, the soils vary decidedly within short distances and show very complex relationships.

Soils may be classified not only by origin but by topographic features, depth, suitability for certain purposes, and by physical characteristics. The latter are the most obvious guides. They comprise texture, as shown by the proportion of mineral particles of different sizes, structure (the manner of arrangement of the particles), and color. These physical properties form the basis of soil classification adopted by the U. S. Bureau of Soils, but other factors are considered. A soil class is based on texture, as shown by a mechanical analysis. Soils of different classes that are evidently related in origin, topographic position, and color, constitute a soil series. The structure and color determine with what series a soil can be correlated. The unit of a soil series is the soil type and the type is established by considering the physical properties and all other determinable factors that have to do with the relations of soils to crops.

In the Coastal Plain of Virginia the U. S. Bureau of Soils has mapped about 940,000 acres, and has discriminated 24 soil types in this acreage. The areas occupied by these types are shown in the following table compiled from figures published in 1909.[a] The areas cover parts of Chesterfield and

[a]Whitney, Milton, Soils of the United States, U. S. Bureau of Soils, Bull. 55, 1909, p. 233.

Hanover counties, all of Norfolk, Princess Anne and Warwick counties, and most of York and James City counties.

Area of soils surveyed in the Virginia Coastal Plain.

Name	Area of types in series	Total for series and types	Per cent. of total
	Acres	*Acres*	
Coastal beach	....	12,376	1.3
Chesterfield gravelly sandy loam	....	34,304	3.6
Chesterfield sandy loam	....	95,680	10.2
Elkton fine sandy loam	....	14,656	1.6
Leonardtown loam	....	43,584	4.7
Norfolk gravelly loam	1,344		
coarse sandy loam	4,288		
sand	11,200		
fine sand	20,864		
sandy loam	214,976		
fine sandy loam	230,272		
loam	23,872		
silt loam	5,952		
clay loam	1,856	514,624	54.8
Portsmouth sand	2,048		
sandy loam	50,048		
fine sandy loam	29,760		
silt loam	55,488		
clay loam	2,176	139,520	14.8
Swamp, tidal swamp and marsh	....	67,072	7.1
Wickham sand	4,416		
sandy loam	5,120		
loam	5,952		
clay loam	2,176	17,664	1.9
Total number of acres mapped		939,840	

The table brings out the relatively small extent of many of the soils, the predominance of two series, and the proportionally great extent of two types, the Norfolk sandy loam and the Norfolk fine sandy loam, which together occupy over 47 per cent of the area mapped. A survey of all the Virginia Coastal Plain might show soil types not as yet recognized there, and would change the present rank of some of the types, but would not alter the rank of the Norfolk series nor of its two predominating types—chiefly because these types occupy areas on both high and low terraces, whereas the topographic distribution of the other types as a rule is more restricted.

For a description of the soils named in the preceding table and their suitability for particular crops the reader is referred to the government bulletins from which the tables were compiled. The Norfolk soil series is described as consisting of light-colored sandy soils underlain by yellow or orange sand or sandy subsoils, while the Portsmouth is characterized by dark gray to black surface soils underlain by yellow, gray or mottled yellow and gray subsoils.

As has been stated, the texture of a soil is determined by the proportion of the different sized mineral particles in it that are found by mechanical analysis. The U. S. Bureau of Soils recognizes seven grades, the limits of which are arbitrarily fixed. The texture of the Norfolk soil series is shown by the following table:

Textures of Norfolk soils.[a]

Name	Fine gravel (2–1 mm.)	Coarse sand (1–0.5 mm.)	Medium sand (0.5–0.25 mm.)	Fine sand (0.25–0.1 mm.)	Very fine sand (0.1–0.05 mm.)	Silt (0.05–0.005 mm.)	Clay (.005 mm. or less).
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Norfolk gravelly loam....							
soil	5	13	12	17	18	25	9
subsoil	3	9	11	14	18	27	17
Norfolk coarse sandy loam							
soil	9	24	14	10	10	22	9
subsoil	11	38	20	11	4	9	5
Norfolk sand							
soil	3	15	22	38	10	8	4
subsoil	3	16	21	37	9	8	5
Norfolk fine sand.........							
soil	0	3	10	56	14	11	5
subsoil	0	2	9	53	16	14	5
Norfolk sandy loam......							
soil	4	5	14	31	18	11	7
subsoil	4	12	10	22	12	12	26
Norfolk fine sandy loam...							
soil	1	3	5	38	24	22	8
subsoil	1	3	4	20	17	21	24
Norfolk loam							
soil	1	6	9	24	17	30	11
subsoil	1	6	9	20	15	29	19
Norfolk silt loam							
soil	1	3	4	10	14	54	12
subsoil	0	3	4	9	13	51	19
Norfolk clay loam.......							
soil	1	3	8	23	7	34	23
subsoil	0	4	6	18	7	32	33

[a]U. S. Dept. Agriculture, Bureau of Soils, Soil Survey Field Book, 1906, pp. 47-54.

Soil solutions.—The solubility of the mineral compounds in the soil, under local conditions of rainfall, temperature and drainage, and the chemical reactions which take place in the underground circulation determine the quality of the ground water. The Coastal Plain soils, deep as well as surficial deposits being included under this term, comprise sands, loams, clays, shell beds, and beds full of glauconite. The sand grains are composed chiefly of silica, but in some formations many sand grains are made up of compounds of silica, alumina, iron, lime, potash, and soda. The ease with which these compounds are dissolved is determined not only by the solubility of the compounds but by the fineness of the soil particles, hence the quality of the ground water, that is, the kind and degree of its mineralization, varies decidedly from place to place.

In general the reason for the variations is easily recognized; lime carbonate is readily dissolved, hence shell beds contain limy, or "hard," water. Many iron compounds dissolve without difficulty, and iron-bearing solutions precipitate iron on exposure to air or by mingling with oxygen-bearing waters. Thus along the western edge of the Coastal Plain the loams that contain grains of iron sulphide worn from the Piedmont rocks are the source of "iron" and "alum" and "sulphur" springs and seeps; beds of bog-iron form where such waters accumulate on the surface, and iron crusts and bands grow along the underground water courses. Hydrogen sulphide, the compound which gives so many Coastal Plain waters a "swampy" or "marshy" odor, is derived not only from the dissolving of iron sulphide but from compounds found in the organic matter contained in many Coastal Plain beds; it may also come from reaction between sulphate of lime, a common constituent of soils, and other compounds.

Although as above indicated the mineralization of a particular water may be from causes easily recognized or self-evident, the quality of another water may be due to reactions that cannot be definitely traced, or to long-past events in the geologic history of the region. Instances of these differences are the high percentage of bicarbonate of soda in many Coastal Plain waters and the saltness of others; in the one case we have to deal with a matter little understood, the selective interactions between certain mineral solutions underground; in the other with sea water which was originally in the beds or reached them after deposition.

GROUND WATER

Definition of ground water.—Of the water that enters the soil some is returned to the air through the capillary action of the soil particles and evaporation, some is absorbed by plant roots, stored in tissues, and ultimately returned by plant decay, or is given back to the air by transpiration from foliage; a little is taken up by the hydration or weathering of rock particles in the soil, and some reaches the ground water. By ground water is meant the water beneath the surface at any given point; its lateral extent and depth below surface are determined by several factors. Its lower limit may be at dense, impervious beds or there may be no sharp lower limit, the water filling crevices in rocks to an indefinite depth.

Water table.—The upper surface of the ground water is called the water table; it marks the water level in wells. Its depth below ground depends on topography, geology, and climate. In general the water table rises under hills and falls toward valleys. Under a level plain with soil of uniform texture, bounded by descents to lower ground, the convexity of the water table as a whole depends primarily on the texture of the soil and the difference in elevation between the plain and the lower ground. But the water table slope is modified by differences in soil texture, in the character and position of underlying rocks, in surface slope and in vegetation. It lies nearer the surface in fine textured soils than in coarse, and nearer under tilled fields than under forests. Where the water table cuts the surface of the slope there are seeps and springs; where confined hollows descend below the water table there are ponds. Under a flat expanse on a high terrace the water table may be at the surface, whereas near the scarp of that terrace it may be 50 feet below the surface of the ground.

Fluctuations of water table.—The water table rises after wet weather and falls after droughts, but these changes are not sudden. It takes a sensible period for the soil to absorb and transmit rainfall, so the water in wells may be low during a rainy period, in consequence of preceding drought, and may remain high long after rains have ceased. The seasonal differences in the height of the water table are the result of accumulative differences in the proportion of rainfall that reaches the ground, so that the period of lowest or highest ground water lags after the period of most or least rainfall, subject to superimposed modifications from evaporation and the growth of vegetation.

In Virginia the ground water is highest in the spring and lowest in the fall. These fluctuations are greater away from ravines and scarps than near them, because the water under a level stretch remote from any point of emergence moves very slowly and a rise in the water table of several feet increases the general slope toward the point of emergence but slightly, whereas near a scarp the water can run away so fast that the water table rises very little.

Besides being affected by the seasonal differences in rainfall, the water table is affected by other factors. Fluctuations in atmospheric pressure are among these. A rise of one inch shown by the barometer means an increase in air pressure equal to a foot of water. This load transmitted underground by wells can depress the well water by forcing it back into the sand and locally raising the water table. In the course of the field work for this report one instance of a dug well showing the effect of changes in air pressure was noted. This well, 26 feet deep, is near Potomac Mills, in Westmoreland County. The normal depth of the water in dry weather is about 2 feet. When the wind during such weather blows from the northwest, that is when the barometer is high, and the atmospheric pressure is heavier than the average, the level of the water in the well falls. With wind from the southeast, that is when atmospheric pressure is less, the water rises.

In very shallow wells changes in air temperature affect the surface tension of water. Cold increases the surface tension, hence if some of the ground water is near enough to surface (within a few feet) to feel the change, it rises into the partly saturated soil above the water table under the capillary attraction of the soil particles, thus lowering the level of the water in wells.

Change of level, due to natural or artificial causes, in nearby bodies of surface water—rivers, lakes, or the sea—may affect the water table decidedly. Where there is communication between such a body of water and nearby ground water, either through rock crevices or the pores between sand grains, a rise of the surface water raises the water table, either by direct transmission or by backing up the outward flowing ground water. Along Chesapeake Bay many shallow wells show tidal changes. These changes are not instantaneous since transmission through sands implies time, and along tidal bodies of water high water in a well occurs after high tide. The time difference or lag is governed by distance from shoreline and ease of communication below ground. It may amount to several hours.

Perched ground water.—Some accumulations of ground water are purely local. A sheet of clay may separate saturated sands from dry sands below, resulting in what is known as perched ground water. Such a condition may be found at many places in Tidewater Virginia, and is especially noticeable after prolonged wet weather. Boring a hole through the clay draws off the perched water. In this way some ponds or swamps may be drained.

Circulation of ground water.—Two factors, gravity and capillarity, control the movement of underground water. Downward percolation, as the drainage of a soil after a rain, is largely due to gravity and takes place chiefly through the larger openings in the soil. On the other hand the water evaporated from a soil is supplied from below either by the capillary movement through the finer openings or by the creeping of thin films of water around the soil particles. Gravity and capillarity act together where the movement is downward or are opposed when the movement is upward. They combine to bring water to the surface on a slope.

The texture of the soil determines the relative efficiency of the two factors, because the soil openings are many times larger in coarse sands than in silts or clays. Practically, the water returned to the air by plants as well as that evaporated from the surface of the soil is supplied by capillary action, whereas the water of springs and wells is supplied by gravity. The relative importance of gravity and capillarity in the movement of ground water is nearly equal, the proportion of the rainfall that ultimately reaches the surface again under capillary action, being little less than the proportion of gravitational or drainage water returned by springs.

The movement of gravitational water toward some point of escape is modified by differences in soil texture, the position and character of the rocks below the soil, and the slope of the surface. By reason of the variety of factors the course of a drop of water toward some spring may be changed from a straight line many times.

In granites and other dense igneous rocks, circulation is by joint cracks of which there are usually three systems, one parallel to the surface, the other two steeply inclined. In stratified rocks, circulation is of two orders. In sandstones and conglomerates there may be both direct movement along the bedding through openings between constituent grains, and cross circulation through joint cracks. In shales, circulation is practically limited to joint cracks and bedding planes. In limestone, as the rock is readily dissolved, openings of considerable size may grow along bedding planes or cross fissures and may become large enough to take the entire volume of small rivers. The freedom of movement through sandstones and conglomerates is seldom comparable to that through sands and gravels, because of many original voids being closed by the cement that binds the grains and pebbles.

Rate of movement of underground water.—In fine sands with rounded grains the openings between the grains are of capillary size, and the frictional resistance to the movement of water is great; in sharp sands that pack closely the resistance is still greater. In coarse sands the voids are many times larger than in fine sands and the water can move with much more freedom. Ease of transmission through a soil thus depends on the size, shape and evenness of assortment of the soil particles, there being all gradations between coarse gravel and clay. A coarse sand transmits water 100 times as freely as a fine sand. A clay absorbs water but its transmission capacity is practically zero.

In discussing the capacity of soils to transmit water, Schlichter[a] says:

> If the particles of sand or gravel which make up the water-bearing medium are well rounded in form, the pores are somewhat triangular in cross section and the diameter of the individual pores is only one-fourth to one-seventh the diameter of the soil particles themselves. Thus if the individual grains of sand average one millimeter in diameter the pores through which the water must pass will average only one-fourth to one-seventh of a millimeter in diameter. If to a mass of nearly uniform sand particles larger particles be added the effect on the resistance to the flow of water will be one of two kinds, depending principally upon the ratio which the size of the particles added bears to the average size of grains in the original sand. If the particles added are only slightly larger than the original sand grain the effect is to increase the capacity of the sand to transmit water, and the more particles of this kind are added the greater will be the menace in the capacity of the sand to transmit water. If, however, larger particles are added the effect is the reverse. If particles seven to ten times the diameter of the original sand grains be added, each of the new particles tends to block the passage of the water. Thus, for example, a large boulder placed in a mass of fine sand will tend to block the passage of the water. As more and more of the large particles are added to a mass of uniform sand, the rate of flow of water through it will be decreased until the amount of the large particles equals about 30 per cent. of the total mass. From this time on the adding of the large particles will increase the capacity of the whole to transmit water until, if a very large quantity of the large particles be added, so that the original mass of fine particles becomes relatively negligible, the capacity to transmit will approach that of the mass of the large particles alone. These facts have an important bearing upon the capacity of gravels to furnish water to wells or to transmit water in the underflow of a river. The presence of large particles is not necessarily to be interpreted as indicating a high transmission capacity of the material, for this is indicated only when the large particles constitute a large fractional per cent of the total mass, as would be the case where the large particles equal 40 or 50 per cent of the whole.

The rate at which water moves underground is controlled by the resistance of the soil openings and by the slope or difference in height between two given points in its course. Through such mixtures of sand, gravel and boulders in nearly flat beds as lie in the terraces of the Virginia Coastal Plain, the rate is to be measured by feet a day rather than by miles a day, as in a surface stream. On the south shore of Long Island are Coastal Plain

[a]Schlichter, C. S., Field measurements of the rate of movement of underground waters, U. S. Geol. Survey, Water Supply Paper No. 140, 1905, p. 10.

beds resembling in texture and inclination some of those underlying terraces in Virginia. Velocities have been measured there that range from 15 inches to 12 feet a day.[a]

Underground lakes and rivers.—The belief held by many persons that underground waters in places outside of limestone regions lie in lakes or move as rivers, has little foundation in fact. The lakes and streams reported by well drillers are merely beds of saturated sand. The rivers described with great particularity by some water finders often are pure fiction, the stated course of an underground river having no relation whatever to the geology of the district.

Ground water temperature.—Soils absorb and radiate heat readily but transmit it slowly, so that daily temperature fluctuations are felt only a very few feet underground; even the changes from summer to winter become imperceptible at less than 100 feet, and the unvarying temperature there corresponds very closely to that of the mean annual temperature of the particular locality. Several factors combine to determine the distance below surface of this zone of unvarying temperature. In Tidewater Virginia it apparently lies at about 60 feet. Thus the temperature of shallow wells or springs varies seasonably, that of deep wells is constant. At depths of 20 to 40 feet, depths equal to those of the average dug well in the Tidewater region, the cumulative results of the winter's cold and the summer's warmth are minimum temperature in the spring and maximum temperature in the fall, but the difference between maximum and minimum is slight. In shallow, open wells the temperature of the water may be modified by heat taken from or given to the air, and changed decidedly by the entrance of water from near the surface after heavy rains, but allowing for these contingencies, there is no ground for the belief of many a well-owner that the water from his well is cold in summer and warm in winter; a thermometer will show him his error.

Chemical composition of ground water.—Rain that falls at the end of a shower is practically pure water. In passing through the soil the rain-water takes up carbon dioxide gas and also various salts. It attacks and slowly breaks down the resistant particles of the hardest rocks, reduces dense granite to grains of quartz and particles of clay, and completely dissolves beds of shells.

The chemical composition of the ground water at any point is determined by the rainfall, the drainage, the climate, and the composition of the

[a]Schlichter, C. S., Op. cit. p. 67.

soil. Where precipitation is as abundant as in Tidewater Virginia and underground circulation is active, the soil at a certain point may be leached of easily soluble compounds in a time geologically brief; the ground water will thereafter have little solid matter in solution and will be soft and limpid. On the other hand, if the circulation is difficult the leaching will be less, and the mineralization of the water will persist for a longer period.

The soils of the higher terraces of the Coastal Plain of Virginia usually contain near scarps waters of extremely low mineral content; on the lower terraces the waters in places carry considerable iron or lime; on the lowest terrace, near the bay, where broad expanses of ground are covered by salt water during high spring tides, the ground water in places is distinctly brackish.

Few complete analyses of waters from dug wells are available, and the field assays presented in table 7 do not show the wide variety in quality of the waters. The analyses of spring waters (table 7) show the low mineralization of the waters from the sands of the high terraces.

Normal chlorine.—Chlorine, a constituent of common salt, is found in all surface and underground waters. It is derived from the sea as salt spray borne inland with dust particles by the wind and precipitated in rains, from the soil minerals, and from organic wastes. Hence the chlorine content of surface waters, other conditions not being considered, is greatest near the seashore and diminishes inland. The spring waters in table 7 show as a rule this chlorine decrease. In a given region the proportion of chlorine in the surface waters derived from soil minerals and from the sea is called the normal chlorine content of the waters. Any increase above the normal represents drainage from habitations, since the density of population on a given area has a direct bearing on the proportion of chlorine contained in the water flowing from that area. Hence, chlorine above normal in a surface water is taken as evidence that the water is or has been polluted.

Owing to variations in freedom of circulation and the composition of the soil, the normal chlorine content of the underground waters of a given region varies within wide limits, and a chlorine content above the normal of the surface waters does not necessarily denote pollution. A notable chlorine content in the waters from springs and shallow wells on high ground may indicate that the waters have been polluted, but many shallow wells near seashore tap waters that are normally brackish. High chlorine in the waters from a deep-drilled well is not necessarily evidence of pollution. In the water from a pumped well it may or may not be suspicious. Increase of chlorine in wells near the sea is not uncommon under heavy pumping.

Pollution of ground water.—Decaying organic matter carried in solution from the surface to the ground-water zone may make the water of wells or springs in the vicinity highly colored and offensive. Such discolored, ill-smelling water is rightfully viewed with suspicion, but a water that is clear, colorless or odorless may be much more dangerous. The menace to health is not the organic compounds in the water, but the microscopically small bacteria that cause specific diseases. These pathogenic germs may or may not be found in clear, refreshing spring waters having a local reputation for healthfulness or for curative properties.

A sanitary analysis of a ground water shows the proportion of compounds presumably of organic origin—nitrates, nitrites, and ammonia—and the proportion of chlorine. The proportion of organic compounds and of chlorine is taken to indicate the probable sanitary quality of the water. The value of such an analysis is disputed by many chemists.[a] In Tidewater Virginia the almost universal use of wood-curbing in dug wells, the practice of dosing such wells with lime and salt after cleaning, and the large variations in chlorine content of the ground water at places on the shores of inlets, combine to make the value of a sanitary analysis even more doubtful than for surface waters unless the chemist knows the local conditions. A bacterial examination of a suspicious water may be decisive, but in most cases no examination or analysis of a water is necessary to show its doubtful purity. A glance at the well surroundings, the nearby privy, pig-pen or slop-hole, or the leaky curbing that permits any kind of filth to be washed in at every rain, will suffice to show why the well water is to be regarded with suspicion.

Areal extent of pollution.—In sedimentary deposits like those of the Virginia Coastal Plain, the decaying organic matter and the disease-spreading bacteria that reach the ground water are carried along its upper surface toward the nearest point of escape. The distance they may travel before they are destroyed by filtration and oxidation depends on the rate of movement of the water table and the fineness of the sands. Some recent experiments in Germany[b] showed that heavy pumping could make bacteria from a polluted well 177 feet deep pass through 69 feet of sand and gravel (porosity 32 per cent) to an unpolluted well of equal depth in nine days; whereas if the bacteria were forced into the soil above ground water-level no pollution could be detected after prolonged pumping.

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[a] Leighton, M. O., The futility of a sanitary water analysis as a test of potability: Biological studies by the pupils of Wm. Thompson Sedgwick. Boston. 1906. pp. 36-53.

[b] Experiments on the passage of bacteria through soil. Engineering Record. 1909, Nov. 4, vol. 60.

Where, as on many terraces of the Coastal Plain, coarse sand and gravel or shell marls underlie a few feet of surface loam, and the water moves with comparative freedom toward springs that flow from the terraces, conditions are particularly favorable to the spread of pollution underground. Any shallow well or any spring in the village may come under suspicion. Where waters from a possible source of pollution must pass through 10 feet or more of loam and sand to reach the ground-water zone the danger is lessened, but in general the radius of safety between well and source of pollution is not less than 100 feet. A dug well and a vault privy within the limits of the average 25-foot building lot favor a quick transfer of water from the well to the house and back to the well, but a more unsanitary arrangement can hardly be devised.

EMERGENCE OF GROUND WATER.

Seeps.—A large proportion of the ground water is returned to the surface or escapes below water level by seepage. Seeps make wet and boggy spots on slopes or at the base of scarps, and supply imperceptibly much ground water to bodies of surface water. Seeps differ from springs in size and localization of flow. Springs mark the escape of ground water moving in a definite passage through the open-textured portions of a porous bed or along crevices and solution passages in hard rocks. In other words, a spring is seepage water emerging in sufficient volume at one point to form a rill. No sharp dividing line separates seeps and springs; the gradation in volume and localization of flow is gradual. Many so-called springs in Tidewater Virginia are basins or shallow wells fed by seeps.

Springs.—Speaking of the tidewater country in general, Hugh Jones,[a] an Englishman who visited Virginia early in the eighteenth century, said: "good springs abound everywhere almost." This statement holds true. Because of the liberal rainfall, the bedding of the Lafayette and Columbia sands, the manner in which pervious overlie less pervious deposits, and the many places at which the water table is exposed on bluffs and slopes or in gullies, springs of excellent water abound in most of the Coastal Plain counties. They are most numerous in the counties near the "fall-line." There are few where the surface is low and little eroded, as in Norfolk, Princess Anne, Mathews, Accomac and Northampton counties.

Because of its composition, extent, position, and great dissection, the Sunderland formation is the source of a majority of the springs.

[a]Jones, Hugh, The present state of Virginia, London, 1724; reprint, New York, 1865, p. 57.

TYPES OF COASTAL PLAIN SPRINGS.

Few of the Coastal Plain springs gush from rock crevices like the springs of the Piedmont region, or issue as giant flows from large cavities, like the springs of the limestone regions of the Great Valley. Instead the waters gently flow from the sands along terrace scarps or in ravines, and the volumes are small. In places where hollows in the surface of an impervious stratum, a bed of clay, a band of iron crusts, collect the water from a considerable area are springs of larger size. In places also springs of good size flow from open-textured beds of shell marl. Three types of springs are distinguishable. They may be termed normal, perched, and artesian or boiling springs, and their characteristics are shown in Fig. 3.

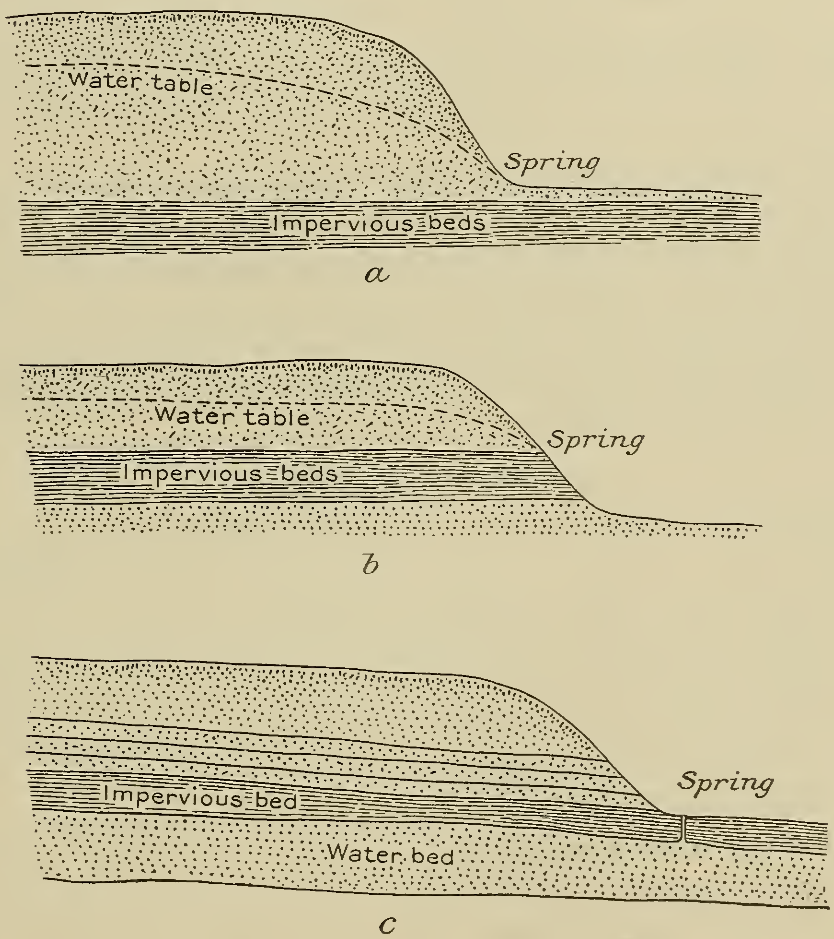

Fig. 3.—Diagrams illustrating types of Coastal Plain springs. (*a*) Normal spring. (*b*) Perched spring. (*c*) Artesian spring.

Normal springs.—Springs of the normal type are those that issue where the water table is exposed at ground-level. They are found in hollows on terraces along the bases of scarps, and on low terraces. Hence they are common to all parts of the Coastal Plain and flow from all the formations exposed. Many are of shallow source and go dry every year.

Perched springs.—This name has been proposed by Matson[a] for springs from perched ground-water, those that issue from above some impervious layer exposed in a stream gully or terrace scarp. The point of emergence may be 100 feet or more above the foot of the bluff, or the point at which the top of the main ground water supplies springs of the normal type. Perched springs are characteristic of that part of the Virginia Coastal Plain having topography of the western shore type—interstream divides sharply cut by V-shaped valleys of creeks, high scarps facing rivers—this area lying between Potomac River and the divide separating the Chesapeake from the Chowan drainage. Thousands of them issue from the base of the Columbia formations above sandy clays of the Chesapeake and Pamunkey groups.

Artesian springs.—While the waters usually seep or flow from a slope, the face of a bluff or the side of a gully, in places there are springs that are slightly artesian, the waters rising with force enough to lift sand grains in the spring basin. Such are known as boiling springs. As a rule the imprevious layer from under which the waters rise is less than 10 feet below the spring basin and at some springs is covered only by a thin wash of sand. In places the source is deeper.

SOURCES OF SPRING WATERS

In general the springs are fed by the rainfall on the particular terrace from under which they flow. As the terraces are cut up by stream valleys and the ground water takes the easiest course to its point of escape, in the majority of cases the water does not travel more than a mile or two underground, and in many places springs of some size flow from a narrow remnant of a Columbia terrace capping a divide, where the gathering area is less than a quarter of a mile wide.

The temperature of the spring waters shows that the springs are fed by the ground water of the terrace rather than from deep sources. Most "cold" springs have a temperature of about 58 to 60 degrees, or the mean annual temperature of the region. These "cold" springs flow from beds buried 50

[a] Matson, G. C., Water Resources of the Blue-grass Region, Kentucky, Water Supply Paper, U. S. Geol. Survey, No. 223, 1909, p. 40.

feet or more. Springs which show higher temperatures than the annual mean do not have this temperature the year round. The water gets warmer in summer because of the shallow cover of the source. No spring in Tidewater Virginia, so far as known, has throughout the year a temperature above normal, as have the deep flowing wells, and evidently no spring freely rises from a depth of several hundred feet. Those that are coldest in the fall have the deepest source, and this source is not deep enough to show the increase of temperature due to depth.

PERMANENCE OF FLOW

Many springs in the Coastal Plain fail in every dry summer. Many yield less water after several months of drought, and many show slight difference in volume. These differences represent differences in the magnitude of the fluctuations of the water table.

Near the edges of high terraces wells go deep for water, and the height of the water in the wells changes but little during the year; springs flowing from the scarps of these terraces have much more uniform flow than those in hollows on terraces away from scarps, where wells are shallow and are full in the spring and dry in the fall. Still there are springs having immediate shallow sources that flow the year through with little reported change in volume. Some such springs evidently are supplied by water that comes through a confined channel so small in proportion to its length that fluctuations of ground water level are minimized. Springs flowing from crevices in granite in hollows of high terraces are of this class, other springs which show little change in volume though having apparently shallow covers are fed by the water that comes from under a terrace above the one that seems to supply them.

PURITY OF SUPPLY.

Pollution of spring sources.—As most of the Coastal Plain springs flow from sandy beds covered by loams, surface waters undergo filtration in reaching the ground-water zone and in traveling to the point of emergence. Hence as a rule the springs of the Coastal Plain, if properly developed, are not likely to be the source of disease. On the other hand, where cities or villages stand on terraces having a thin cover of loams and coarse sands below, the ground water is easily contaminated by leakage from cesspools or sewers, or the impurities washed into dug wells, and springs flowing from the scarps of such terraces may be altogether unsafe no matter how clear, sparkling and refreshing their waters are.

Quality of spring waters.—The quality of the spring waters varies widely. As a rule the waters from the Columbia sands of the higher terraces are soft, contain little iron, and are suited for all domestic purposes. Springs from the lower terraces show greater differences. Many "marl springs" that flow from shell-marl beds in the Pamunkey or Chesapeake group, yield hard water. Here and there, particularly along the western edge of the Coastal Plain, are small springs whose waters contain sulphates of iron and alumina.

The analyses in table 6 show the characteristic differences in mineralization of the springs flowing from sands, from granite, and from marl, and the modifications resulting from topographic position. The granite, and the sand and gravel springs of Alexandria and Chesterfield counties contain less than 100 parts per 1,000,000 of total solids, and many are extremely soft, some containing less than 1 part per 1,000,000 of calcium. They are also low in chlorine. Evidently the sources of mineralization of the granite and the slightly mineralized sand springs are approximately the same, being derived from well-leached or relatively insoluble soils. On the other hand, the marl springs and the springs in low terraces near Chesapeake Bay show as a rule more total solids, more lime, and more chlorine. The most heavily mineralized waters in the table are those from two marl springs, one in Surry County and one in Sussex County.

DEEP AND ARTESIAN WATERS.

Function of ground water.—The greater part of the ground water in Tidewater Virginia does not rest on a clearly defined impervious floor, but lies above more or less pervious rock or unconsolidated material and there is no sharp line of demarcation between the ground water and what may be called, for convenience, deep or artesian water. Where, as in the Piedmont province, there is a mantle of rotted rock and residual soil, or where, as in the Coastal Plain, there are blanket-like formations of unconsolidated material, it is often convenient to take the top of solid rock or of beds older than those lying at the surface as the base of the ground-water zone and to regard the surface material as constituting a great sponge, its function being to absorb and store precipitation and slowly feed ground water to crevices and porous beds in the underlying formations.

Deep circulation.—Circulation below, as in the ground-water zone, is determined chiefly by gravity, but although in a general way influenced by topography, it is closely controlled by geologic structure. The porosity of the beds, their dip, the size and extent of cracks or fissures, are more important than topographic differences. So while the ground water flows down a valley, the deep water may move in a direction at right angles to the valley's trend.

The deep circulation may extend to far greater depth at one place than at another. Thus, where porous beds are steeply inclined or the continuity of rock masses is broken by profound fissures, water may circulate thousands of feet below the surface. On the other hand, where thick flat beds of shale lie near the surface there may be little or no deep water, as in certain regions of Pennsylvania and adjacent states.

While primarily governed by gravity, deep circulation may be assisted by the increase of temperature with depth; the waters from the surface working downward reach higher and higher temperatures until, through some comparatively free way of ascent, they rise and emerge at the surface as thermal springs. Also, deep waters may become so charged with gases that they rise more strongly than by difference of level alone.

In the Coastal Plain of Virginia deep circulation is along gently inclined porous strata and neither gain in temperature nor gaseous content is an important factor in the movement of the water. Flow down hill is sufficient to account for the facts observed. Yet, while the water moves down the dip of the porous beds toward the sea, the course of a single drop may be anything but a straight line. The beds are not of uniform texture for long distances. Instead, the water-bearing sands form irregular partly connected or discontinuous lenses, here coarse, here fine, and a drop following the line of least resistance may move down, across or even up the general dip of the beds. The limiting depth of active circulation is unknown, but the high mineralization of the deep waters in the Norfolk region indicates that their circulation is feeble.

Temperatures of deep water.—The thermal gradient, or rate of increase of temperature with depth, varies from place to place being most rapid in regions of recent volcanic activity. Unless running freely through open passages, underground water has the temperature of the material in which it is found. Hence temperatures of a large number of wells of varying depth show the temperature of the line of no change, its distance below the surface, and the increase of temperature with depth beneath.

Some observations in Tidewater Virginia indicate that the mean temperature of the line of no change is 56° to 59° and that the line lies at least 50 feet below surface; its exact depth was not determined because of the difficulty of getting the temperature of the water in the relatively small number of wells 50 to 100 feet deep.

Temperatures of flowing wells measured at the surface are subject to error. In most of the older artesian wells in Tidewater Virginia casing goes only to some dense bed below the Columbia sands and gravels. In some areas, as at West Point, two or even three deep water beds have been penetrated, and the flows from all the sources mingle, so that the temperature at a certain well is not the temperature of any one flow. Again in rising through several hundred feet of pipe water loses heat. Hence of two wells side by side tapping the same water bed, the one poorly sunk or cased that yields a mere dribble will show a decidedly lower temperature than its freely-flowing neighbor; for the same reason the flow of a 6-inch well will show the temperature of the source more accurately than that of a 2-inch well.

Temperatures of a considerable number of flows were taken in the course of field work, as shown in table 6. These temperatures are subject to the possible errors above stated, the most trustworthy figures being those of the freest flows.

In the following table are grouped the depth and temperature of flow of a number of wells:

Temperatures of artesian flows in Virginia Coastal Plain.

Location	Depth	Flow	Temperature of flow	Probable mean ann. temp. of locality
	(Feet)	*(gal. per min.)*	(°F)	(°F)
Mount Holly	153	15	63	
Chain Ferry	172	10	62	
Warsaw	188	16	62.5	
Coan	188	16	62.5	
Tappahannock	256	5.5	62.5	56
Boulevard	266	52	63	57.5
Jamestown	270 (6-inch well)	40	65	56.5
Bayport	300	20	64	56.8
Jamestown	300 (3-inch well)	78	64	56.5
Freeport	330	2	63	
West Point	335	37	66	
Curtis Point	361	2	67	56.6
Leehall	400	2	65	56.4
Urbanna	476	25	68	56.8
Irvington	580		69	56.3
Lamberts Point	616	51	72	59
Selden	716	52	70	57

The indicated average gradient of 1° for each 40 feet increase in depth is probably a close approximation to the truth.

The above table subject to the errors indicated may be used for roughly checking the depth of a well. For instance, the water from the bottom of a well 300 feet deep should have a temperature of about 64° F. This check however is of no value unless an accurate instrument is used. Many cheap thermometers are not correct within 2 degrees, and to use one of these is a waste of time.

Composition of deep water.—The substances in solution in the deep water at a given point necessarily bear some relation to the composition of the enclosing beds, to the depth below surface, and to the freedom of movement, but this relation is often extremely obscure. The chemical reactions that take place, under the conditions of circulation in solutions as dilute as most underground waters, are hardly comparable with the reactions observed in a chemical laboratory.

In Tidewater Virginia the mineralization of the deep waters increases toward the southeast. This change is not directly due to increase of depth, nor has it been shown to be due to changes in the composition of the enclosing beds. The rank of the controlling factors is discussed in the consideration of the artesian flows of the Norfolk-Newport News area. Defective circulation seems most important.

ARTESIAN WATERS

Definition of artesian.—The term artesian well has different meanings in different parts of the United States, being applied variously to all bored or drilled wells much deeper than the dug wells of the particular locality, to deep wells in which the waters rise, and to wells in which the waters rise and overflow. Even in Tidewater Virginia usage is not uniform. Both the deep drilled wells with water-level 100 feet below surface, at Richmond, and the much shallower flowing wells along river banks or the shores of Chesapeake Bay are called artesian. In this report the word artesian is used to designate the hydrostatic principle, the tendency of water to seek its level. Hence artesian waters are those which rise when the beds containing them are tapped. An artesian slope is a slope with artesian water below it, and an artesian well is one that taps artesian water. A well in which the water rises above ground-level is called a flowing well.

Artesian conditions.—Flat-lying ground water obviously cannot be artesian; the water in a well sunk to it will stand at the level of the water table. Difference of elevation is essential, the other conditions vary from place to place.[a]

[a] For a discussion of all the factors involved, see Summary of the Controlling Factors of Artesian Flows, by M. L. Fuller, U. S. Geol. Survey, Bull. 319, 1908, 44 pp.

In Tidewater Virginia the governing conditions are these:

(1) Sufficient rainfall.

(2) Porous beds that receive rainfall directly or indirectly.

(3) Differences of elevation.

(4) Sufficient slope to the porous beds to carry them below less pervious beds.

Coastal Plain an artesian slope.—The Coastal Plain formations dip seaward. They contain water-filled open-textured beds overlain by relatively dense beds. The confined waters are artesian, and the Coastal Plain is an artesian slope. Some conditions causing artesian water are indicated in Fig. 4.

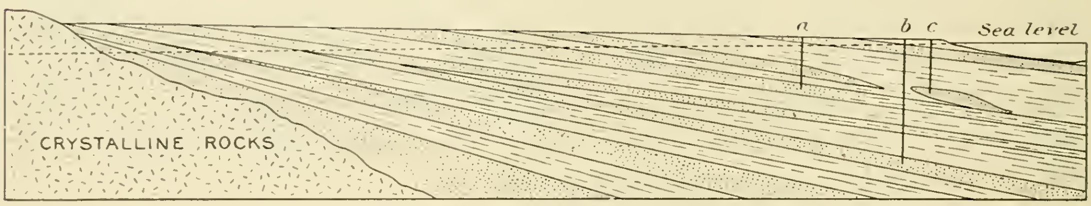

Fig. 4.—Diagram illustrating artesian conditions in the Coastal Plain Province of Virginia. (*a*) Well penetrating two artesian sands; strong flows because of sands pinching out or becoming clayey. (*b*) Well finding no water in beds penetrated by (*a*), but drawing on a water bed that does not outcrop. (*c*) Well to isolated sand bed, water under low head.

Source of artesian water.—To account for flowing wells some persons assume a great difference of elevation is necessary and say of the water gushing from a bore hole that it must "come from the mountains." They do not realize that there is no difference in principle between water rising in a well to 10 feet above the water bed and water rising to surface, nor do they realize that the heads of the flowing wells are low in comparison with the elevation of hills not far distant. The water that gushes from a well in Tidewater Virginia either entered the artesian bed at its outcrop or was fed to it from overlying beds. In either case the water entered the ground within the Coastal Plain. Some topographic relations of the artesian flows are shown in Fig 5.

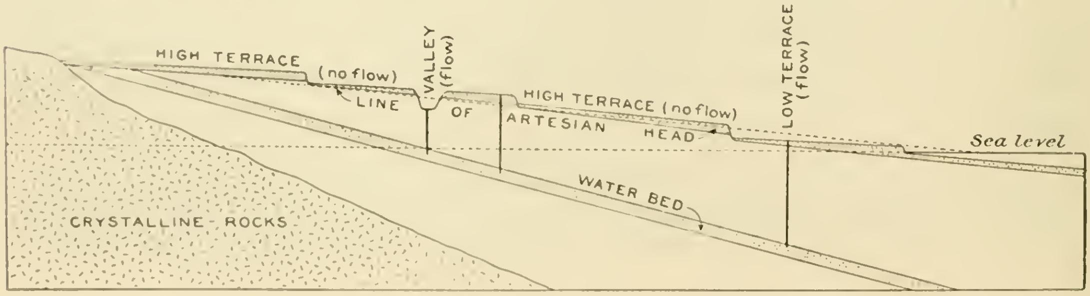

Fig. 5.—Diagram illustrating relations of head of artesian wells to topography in the Coastal Plain Province of Virginia.

Initial head.—As the Potomac, Rappahannock, Pamunkey, Mattaponi, and James rivers have cut valleys to the western edge of the Coastal Plain, the outcrops of beds or zones that carry artesian water to the east are exposed from tide-level almost to the tops of the interstream divides. Hence what may be called the initial head of the waters is not represented by the elevation of the porous beds at their edges on the divides nor by the height of the water table in deposits overlying the upper edges of the beds, for there is leakage toward the valleys.

Loss of head.—Ordinarily water never rises as high in a well as the level of the ground water supply of the artesian bed. This loss of pressure is due to the frictional resistance the water has met in passing through the sands, and to leakage in the journey to the well or down the dip of the beds beyond the well. Where water is confined under pressure in a widely-extending bed of uniform size sand grains through which the movement of water in any given direction is very slow, the flow to a well is along the bed from all directions at practically the same velocity, and the loss of head by frictional resistance during transmission from the distant source is small. Thus in that vast artesian reservoir of the Great Plains—the Dakota sandstone—the loss of head down the dip is only about 1 foot per mile. Water in beds of sand less evenly sized or less confined shows much greater loss of head, 100 feet per mile or even more.

In the Coastal Plain of Virginia are artesian sands in which the size, the angularity, the evenness of assortment, and the looseness of the component grains vary greatly, hence water circulates through them at various rates. On this account, and because of the uncertainty as to the probable initial head of the water found at any place, and because of errors in drilling and casing, it is difficult if not impossible with present records to determine the loss of head per mile of the water in a particular sand or connecting series of sands. In some places the more eastern wells show higher heads than do other wells to the west tapping the same formation at about the same horizon.

Ponded water.—Though the water that enters an artesian bed in the Coastal Plain deposits tends to move downward, that is seaward, toward some point of escape, ever getting deeper under cover, there are undoubtedly waters confined by sand beds pinching out or becoming clayey in all directions but one, and therefore practically stagnant. Such stagnant or ponded waters far below sea-level may be highly mineralized, because the sands in which they lie have not, since deposition in the sea ages ago, been thoroughly flushed by vigorous circulation, or because in depressions of the land the beds up the dip were saturated with sea water which displaced the fresh water below.

FLUCTUATION OF LEVEL IN ARTESIAN WELLS

Some agencies that cause fluctuations in the level of the upper surface of the ground water, the water table, cause fluctuations of the water in artesian wells. The most effective in Tidewater Virginia are changes of level in bodies of water on the surface. Since there can be no free communication between the deep and the surface water, otherwise the deep waters would not be artesian, there can be no direct transmission of water, nor of pressure, through porous beds. The pressure is transmitted through the relatively impervious beds that confine the artesian water. A river flood, a high tide, a flooded swamp means increased load; this pressure is transmitted downward to the covered sands through the saturated but impervious clays, causing a slight plastic deformation, and the water in wells sunk to the sands rises. In flowing wells this rise is shown by increased yield.

There are along Chesapeake Bay and its tributary rivers hundreds of wells showing marked tidal changes, some flowing only at and just after high water. In fact it is probable that all the deep wells on the shores of Chesapeake Bay or its tributaries show tidal changes, though in some the rise and fall of water are very slight and are not detected.

A change in atmospheric pressure can affect deep wells as it affects shallow ones. If the well flows, increased pressure may be shown by diminished yield. Near Sealston, in King George County, John Curtis has a 2-inch drilled well, 250 feet deep, that normally yields about two-thirds of a gallon per minute, the water rising only a few inches above the surface. This well flows most strongly before an easterly storm (when atmospheric pressure is less than normal) and during one period of cold weather with northwest winds (high atmospheric pressure) it ceased flowing for two days.

QUALITY OF ARTESIAN WATERS.

The wells drilled to the known Potomac sands are either near the western edge of the Coastal Plain or far to the east, there being none in the intermediate areas. Hence it is impossible to trace the changes in mineralization of the Potomac waters under cover. Similarly, as Upper Cretaceous beds have been recognized only in deep borings near Chesapeake Bay, nothing definite is known regarding the quality of the water in Upper Cretaceous beds further west. 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, like the waters in the Pamunkey and Chesapeake sands. 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. Such sodic bicarbonated waters are not peculiar to Virginia; they are found in other parts of the Coastal Plain, especially in South Carolina. But in Virginia they underlie the larger part of the Coastal Plain west of Chesapeake Bay, and are remarkable because they differ decidedly from the ground water from which they are derived, and because the change from the calcic bicarbonated (hard) ground water in the marl beds of the Chesapeake and Pamunkey groups to the sodic bicarbonated (soft) artesian waters, takes place during a relatively short underground journey. As a rule the artesian waters become more mineralized by taking up chlorine, bicarbonate, sulphate, and sodium radicles; that is, while there is a decided increase in the proportion of several acid radicles there is less increase in the basic radicles, except sodium.

At some places, as for instance, Hardings, Northumberland County, and Smithfield and Shoal Bay, Isle of Wight County, there are waters that are practically dilute solutions of sodium bicarbonate. Although chemists have reported high carbonate contents in the waters at several places, these waters may actually contain no carbonates, or little more than a trace. It is probable that at comparatively few places does the content of carbonates amount to over 30 parts per 1,000,000. The carbonate content reported in some analyses represents the chemist's opinion rather than the salts actually in solution.

Bicarbonated waters stimulate the growth of algæ. The difference in this respect between most ground waters and the soft artesian waters is striking. A heavy growth of "green moss" accumulates in troughs and about the mouths of flowing wells in many counties west of Chesapeake Bay.

Sodium bicarbonate waters have certain physiological effects and are not well adapted for all industrial purposes. Their healthfulness, their value in the treatment of disease, and their suitability for specific uses in the arts, are considered in another chapter.

ARTESIAN SANDS

Number.—It is extremely doubtful if there is a single water-bearing stratum in Tidewater Virginia that is of wide extent. The water beds are to be regarded as sands of varying porosity, laid down in interleaved lenticular deposits containing discontinuous streaks of hard rock. Thus while the wells along any given stretch of river may reach the same artesian zone, the depths to the points from which freest flows come may vary irregularly.

The total number of the artesian sands is unknown. Few wells have been sunk deep enough to prove all of them in the formations above the top of the Potomac group, and the Potomac, under cover the thickest of the groups, contains more sands than all the overlying formations combined. Yet except for what is told by the records of the Fort Monroe and Norfolk City Water Works wells nothing is known of the Potomac sands under cover far from their outcrops.

Potomac sands.—The Patuxent formation contains sands that under cover are probably as irregularly bedded as in their outcrops. Hence at one place the Patuxent may contain several beds freely yielding water, and at another not far distant show but one or two and these of feeble yield. Still, except in Norfolk, Princess Anne, Elizabeth City, and Mathews counties, and the eastern end of Gloucester County, good water is to be expected from the lower Potomac formation along the entire western shore of Chesapeake Bay, the mineralization increasing, deep under cover, toward the southeast corner of the State. The best chance for liberal yield is near bed rock rather than some distance above. On the Eastern Shore the Potomac lies so far below surface that there is little hope of getting good water from its lower beds. The most important wells drawing on the Patuxent are at Alexandria.

The Patapsco formation, or upper part of the Potomac group, contains water-bearing sands, though toward its outcrop only a few artesian wells are known to draw on them. Of the eastward extent of the Patapsco, as of the Patuxent sands, little is known. The upper part of the 1,300 feet or so of Potomac strata found in the Norfolk area has been shown to contain a number of water beds, and it is probable that under the whole of Tidewater Virginia, the upper Potomac contains artesian water, though the quality of the water is variable, and in the southeast part of the State is poor. On the Eastern Shore there is a possibility of getting fair water from the upper beds of the Potomac near the Virginia-Maryland line, but there is little chance of good water from the Patapsco formation in Northampton County.

For a fuller discussion of the quality of the supplies obtainable from the deep-lying Potomac beds the reader is referred to the account of the deep wells of the Norfolk-Newport News area in another chapter.

Pamunkey sands.—Though they vary irregularly in thickness, the water beds of the Pamunkey have much more continuous layers than those of the

Potomac, and because they lie nearer the surface have been drawn on by a far greater number of wells. They have been developed along the Potomac, Rappahannock, and James rivers, and reached by a few wells near Chesapeake Bay.

Of the two Pamunkey formations the Aquia is more important as an artesian reservoir than the Nanjemoy. The former underlies a wider area, and has been more developed along the Potomac and Rappahannock rivers.

The Nanjemoy formation is, however, an important water-bearer and near its base contains sandy beds that have been tapped by many wells between Potomac and James rivers. Little is known of the extent of the Nanjemoy formation south of the James; apparently it thins or is cut out along a northwest-southeast line so that few, if any, of the many wells in Southampton County draw on it.

Chesapeake sands.—In Tidewater Virginia the number of artesian wells drawing on Chesapeake sands is greater than the combined number of those drawing on Pamunkey or Potomac beds. This is because the artesian beds of the Chesapeake, in much the greater part of the area, yield fair to liberal supplies of good quality. Hence the beds below the Chesapeake have been explored only near or beyond the western edge of the Chesapeake outcrops, or where the Chesapeake supplies have been unsatisfactory.

Most of the artesian wells on the western shore of Chesapeake Bay in the territory lying east of a line running from Pope Creek, on the Potomac River, through Piping Tree, on the Pamunkey River, to Claremont, on the James River, draw on Chesapeake sands.

Well records along the Potomac and the Rappahannock rivers show a number of Chesapeake sands. They are thin and of varying persistency. The most persistent are in the lower half of the group in the Choptank (?) and Calvert formations, especially the latter. Those near the top, in the St. Mary's and Yorktown, are more patchy. Along York and James rivers the sands yield water less freely than to the north, and toward the mouths of these rivers the Chesapeake contains few sands that give flows and these are neither continuous nor regular.

On the Eastern Shore irregularly distributed sands near the top of the Chesapeake group, possibly high in the Yorktown formation, contain artesian water that supplies a few flowing wells along inlets from the bay or the ocean. This water varies in quality but on the average is very different from the artesian supplies found in Chesapeake beds on the western shore of the bay.

Columbia sands.—Generally thin, and for the most part lying above tide level, the Columbia sands on the western shore of Chesapeake Bay contain artesian water but rarely. Here and there "boiling" springs show artesian conditions but no flowing wells drawing on Columbia sands have been reported. On the Eastern Shore the Columbia sands are thicker and local conditions favor the storage of water under pressure in beds 50 feet or so below surface, which are here classed as Columbia.

The relation of some of the artesian water beds in the Potomac, Upper Cretaceous, Pamunkey, and Chesapeake groups are shown by the sections given in Fig. 6.

Flowing well areas.—As very few flowing wells in Tidewater Virginia have heads that are more than 35 feet above sea level, and heads on the Eastern Shore are under 10 feet, the flowing well areas are limited to the low ground bordering the bay or the ocean, and to strips of country of varying width along river and creek valleys. In other words, the flowing wells are confined to the shores, or to the terrace slopes. Enough drilling has been done to establish the extent of several artesian horizons west of Chesapeake Bay. It is certain that water which will rise above tide level can be had along the principal rivers from a short distance east of the "fall-line" to their mouths. Waters which will rise 25 feet above tide can be had along Potomac River east of Matthias Point, along the Rappahannock from 15 miles east of Fredericksburg, along the Mattaponi below Beverly Run, along the Pamunkey below Enfield, along York River, and along the James below Wilcox Wharf. Wells of high head can also be had around the east end of the peninsula between Potomac and Rappahannock rivers. Between Rappahannock and James rivers, however, in Mathews and Elizabeth City counties, several deep wells did not get flows and the yield of others has been disappointingly small. East of Norfolk, in Norfolk and Princess Anne counties, flows can be had, but the prospects for potable water from the formations which give fine flows to the west and northwest is distinctly unpromising.

Water that will rise 20 feet above tide, and in places even higher, can be had along Blackwater River south of McClelland, along Nottoway River south of Lumberton and along its principal tributary Assamoosick Swamp south of Littleton, along Three Creek east of Arringdale, and along Meherrin River from 15 miles below Emporia. As there are no topographic maps that show the lowest terrace along all the rivers, it is impossible to state the total extent of the area on the west side of Chesapeake Bay in which flows can be had.

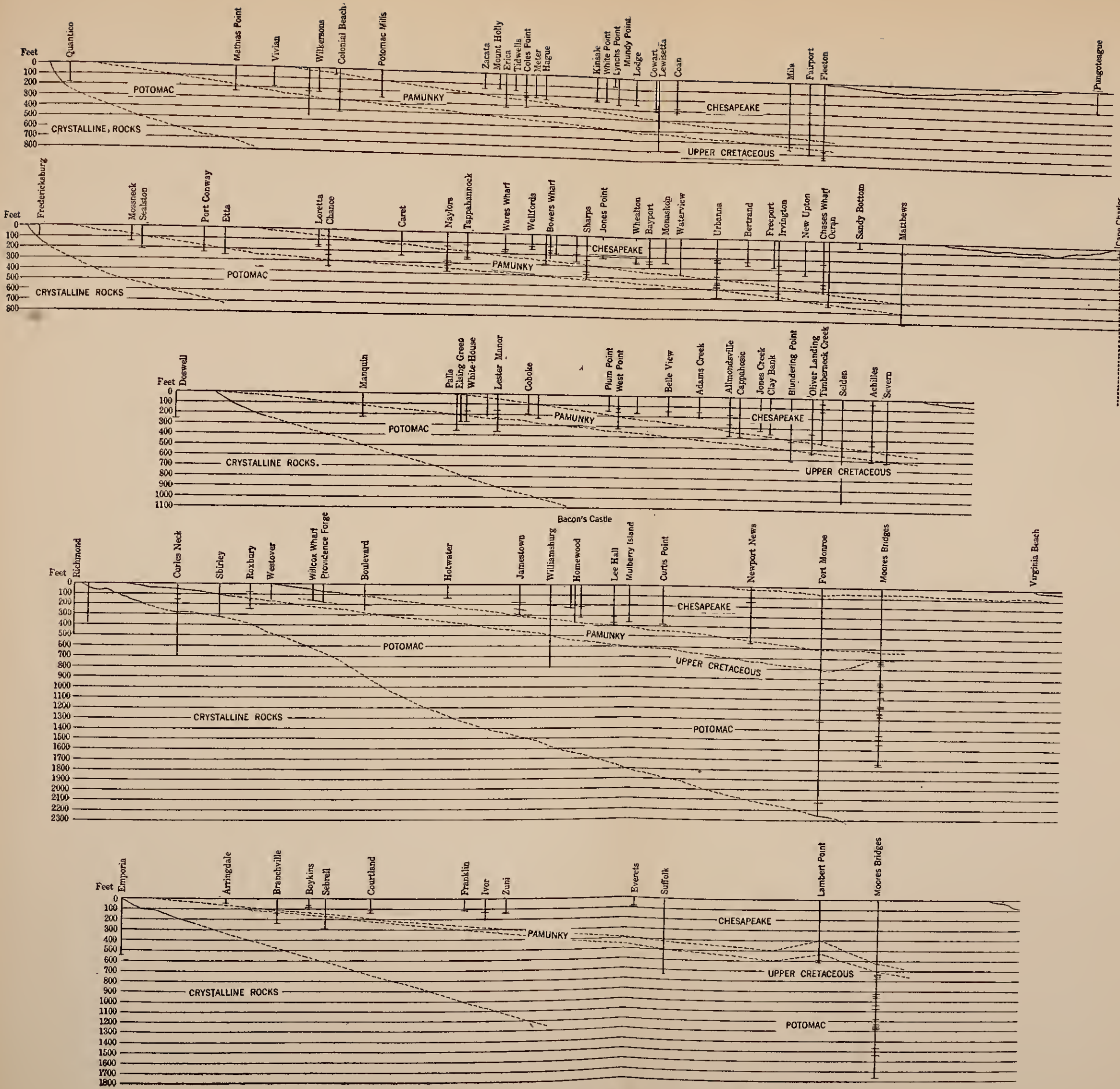

Fig. 6.—Sections across the Coastal Plain Province of Virginia, showing geologic relations of artesian sands and of wells drawing on them. Columbia formations not shown except in section from Richmond to Virginia Beach.

On the Eastern Shore, where the heads of the artesian waters are much lower, flows may be had along the shore in many places, as shown by the records in table 1. They can not be had at every place where the surface elevation is less than 5 feet, though it is probable that the flowing well areas will prove to be more extensive than the records indicate, particularly along the ocean side of the peninsula.

Some of the many flowing wells and the westward limits of flows from sands in the groups of formations are indicated in Plate I.

Conservation of artesian supplies.—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 head 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 at both Colonial Beach and West Point 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.

RECOVERY OF WATER

CISTERNS

The cistern is one of the oldest human devices for procuring a supply of drinking water, and it remains the most practicable source of supply in many localities. Cistern water is soft and is usually regarded as pure, hence cisterns are dug where ground waters are hard, irony or brackish, or are liable to pollution. In the Coastal Plain of Virginia there are some villages and many isolated dwellings that rely chiefly on cisterns. The sanitary quality of the water stored compares favorably with what is obtained by the ordinary type of dug well but is seldom as excellent as it is thought to be, since cisterns, like wells, may be polluted from below and from above. Some cisterns are not tight and impure ground water can find its way in when the level of the cistern water is below the water table. Many cisterns are not properly covered and back-yard dust and insects get in. The chief source of contamination, however, is from the roof. Dust, dead insects, and the droppings of birds fall on roofs and accumulate in eaves troughs to be washed into cisterns at the first shower. Where birds perch on buildings the danger of contamination is obvious, but even where such gross pollution is not apparent, danger may lurk. The small box filters of sand or charcoal, such as are often used, do little more than remove visible impurities: the bacteria that cause disease pass through. In fact, such filters, unless the contents are frequently renewed, may become breeding places for pathogenic germs.

Good cistern water is rain water properly collected and properly stored. Hence, cisterns should be tight, also they should be large, that only the best rainwater need be saved, that which falls at the end of showers when the air is free from dust and roofs and gutters are washed clean. There should be provision for diverting the water from the roof during the first part of a shower, and if filters are used they should be large so that the water will have to go through not less than 3 feet of fine sand before it reaches the storage chamber. In addition the cistern should be tightly covered and provided with a good pump. To allow farm laborers to bail water from a cistern is to invite infection.

SPRINGS AND SEEPS

Probably 90 per cent of all the springs in the Coastal Plain area issue as small flows from sandy beds in the Columbia formations, or from sands and marls in the Chesapeake. Some of the marl springs are of considerable volume although none are known that approach in size the large limestone springs of the western part of the State. In former days it was customary throughout Tidewater Virginia to supply the manor houses, when possible, with spring water—in fact the location of many houses was determined by the finding of a suitable spring. A wood or masonry basin and a wooden shelter as a spring house were the usual improvements, and buckets the means of conveyance, though sometimes a hand-power pump at the spring forced water to a tank in the house. It is no longer easy for the average household to obtain water in the old way, and the use of springs for household supply has greatly diminished.

Improvement of springs.—The improvements required at springs are few. A basin of tile or concrete, or even of wood, with a spout and a tight cover, are the chief requisites. The common arrangement of an open basin from which water is dipped, and steps leading down to the basin, facilitates pollution.

Use of rams.—To have a supply of spring water in a dwelling above the spring is in many cases neither difficult nor expensive. A ram costing perhaps $10 at point of shipment and a few hundred feet of pipe are the essentials. The yield obtainable is dependent on several factors—the fall from the spring to the ram, the height at which the water is to be delivered, and the distance of the ram from the spring and the point of delivery. A simple formula for rough calculations is one-seventh of the flow to four times the head—that is a ram fed by a flow of 7 gallons per minute under 7 feet head will elevate 1 gallon per minute to a height of 28 feet, or 2 gallons to a height of 14 feet. The smallest rams installed require at least 1½ gallons of water per minute for 3 feet of fall.

Objections are sometimes made to rams and tanks. The commonest is that by storage the water becomes unpalatable. Against this is the convenience of tap water. Between a well-situated spring and a dug well situated and curbed as too many are, the sanitary advantages are all with the spring. The main point in installing a ram is to have ram and pipe large enough to handle the water easily. Failure to measure the quantity of water available and the use of too small equipment are the chief causes of disappointment with new installations.

COLLECTING TUNNELS AND DRAINS

General statement.—The point where the upper surface of the ground water, or where some water-bearing sand reaches the face of a bluff or terrace scarp, is frequently more or less hidden by wash. Hence it has happened that a small visible flow has been utilized when a larger yield could have been had by a little digging in a better situated or more convenient place not far distant. Where seeps on the faces of bluffs cause landslides that may destroy the beauty of a dwelling site, or do other damage, a small outlay of labor may not only stop the danger but develop a liberal supply of water less liable to contamination than that obtained by dug wells on top of the bluff.

Mount Vernon collecting tunnels.—A good example of how to make the most of such springs is to be seen on the face of the 125-foot bluff at Mount Vernon, on the Potomac. Here small flows and seeps of water that emerge at 50 feet above tide from Potomac sands locally indurated to ferruginous sandstone, caused slips of overlying clay beds which threatened serious injury to the premises. The bluff shows the following section:

Section of the bluff at Mount Vernon on the Potomac.

Group and formation	Material	Thickness	Depth
COLUMBIA, Sunderland	Soil	1	1
	Gravel	7	8
POTOMAC	Dry red clay	20	38
	Brown and yellow clay	25	63
	Putty clay, pockets of water	2	65
	Sand and sandstone indurated by iron near face of the hill where tree roots reached water; water-bearing at base	10	75
	Dry blue clay	7	82
	Dry red clay	20	102
	Brown and yellow clay	10	112
	Dry putty clay	1	113
	Dry sandstone, no water at contact with clay below	4	117
	Blue clay	6	123

Under the direction of William Archer tunnels 6 feet high and 3½ feet wide were run nearly east and west in the 7-foot bed of blue clay below the sand and indurated sandstone. The first tunnel, which carried 2 feet of blue clay in the headings, was driven east 279 feet on a grade of 2 inches in 100 feet, and cut all seeps on clay level at right angles. At a sudden V-shaped depression, which carried much water, an underdrain 4½ feet deep and 2½ feet wide was dug. In this ditch 2-inch tiles were laid on 3 feet of rammed gravel, and covered with coarse washed gravel. Another tunnel was driven west 121 feet and filled with gravel. In August, 1906, the long tunnel was flowing 10,500 gallons in 24 hours, and the short tunnel 7,500 gallons.

The flows from the tunnels go to brick catch-basins, thence to two rams situated 18 feet below. With both rams running, 2,500 gallons a day are pumped to tanks 150 feet above river level.

According to Mr. Archer, the tunnels have dried the face of the bluff for twice their length, have stopped land slips, and are an unqualified success. They seem to drain the overlying Columbia gravels as well as the spring bed. A 20-foot dug well on the terrace, 80 feet above the ditch, is said to have gone dry since the completion of the tunnels, and the water in another dug well 100 feet from the bluff has been preceptibly lowered.

In ordinary practice there is no need of tunneling to develop hill-side springs. A gravel-filled trench to the bottom of the water-bearing bed, a covered catch-basin, a ram and pipe are enough. Since the work can be done when other farm duties are not pressing the labor expense may be small. There are many seeps and wet spots along the higher terrace scarps and river bluffs in Tidewater Virginia that can be developed by a little trenching.

WELLS

With the lessened use of springs as sources of domestic water supply there has been a great increase in the number of wells, until now, in most rural communities, every house has its well. As the wells are sunk to recover underground waters that are found under very different conditions, they vary greatly in depth, diameter, and yield, but may be divided into four classes as follows: (1) Dug wells; (2) Bored wells; (3) Driven wells; (4) Drilled wells.

Dug wells.—At present, chiefly because of its low first cost, the dug well is the mainstay of a majority of the inhabitants of the Virginia Coastal Plain. Except in a few counties, or in exceptional locations, enough good water for the needs of an ordinary household can be had by a dug well close to the house and less than 50 feet deep, and the labor cost of such a well, dug at a time when other farm work is not urgent, is more or less nominal. In most parts of the tidewater country the only laborer specially employed is the digger, and he may ask but $5.00 for digging 35 feet.

Wells dug for household supply are 3 to 6 feet in diameter. When sunk through firm loam and sandy clays that will stand without support, usually no lining is placed, except enough at the bottom to keep the sand in the water-bed in place. This lining is of 2-inch plank, 12 to 16 feet long. Where water lies near the surface the wells are often lined with plank or boards from top to bottom, and have circular, octagonal, or square cross-sections. In some localities the sandy soils will not stand and wells must be lined throughout, even though water lies 40 feet below the surface.

The total cost, labor and materials included, for many a 35-foot well, wood casing, curb, rope, and bucket, has been under $20.00. Wells cased with brick or tile cost more—the prices asked by well diggers for digging a well and placing brick, running from 50 cents to $1.00 per foot of depth.

The usual method of lifting water from the dug wells is by bucket with rope or chain, and windlass or pulley. At a few wells sweeps are still used. At an increasing number of wells are wooden lift-pumps or iron force-pumps, but the bucket is found in at least four-fifths of the country wells.

The great majority of the pumps are operated by hand-power. In some localities windmills are used, and here and there are gasoline engines.

Open wells of the sort most often seen rank among the most effective spreaders of disease. Wayfarers and transient laborers handle the bucket with their dirty hands, small animals fall in, and all manner of impurities, such as the droppings of fowls that have had access to privies, or filth from the feet of laborers who have been working about manure heaps, are washed in at every heavy shower. If a bed that is water-bearing in wet weather is met part way down the walls of the well heave at that point, the casing deteriorates rapidly, and in a few years a break comes, with a rush of sand. Repairs are troublesome and may be more expensive than digging a new well. In such a case the old well is often filled carelessly, adding to the unsanitary surroundings of the new one.

A well should be considered a permanent investment, and if not lined throughout with tile or cement should have a water-tight lining for several feet from the top. The top should be covered with a good sloping platform, and a pump that does not need frequent priming should be put in, to avoid the contamination of the well water by any water used for priming.

Bored wells.—This term is here applied to wells dug with an earth auger. Such wells are usually from 8 to 12 inches in diameter, and can be sunk cheaply where soils are free from large boulders. Most are covered, have pumps, and are, if curbed with tile, superior to wood-curbed dug wells. They are of course cheaper than dug wells curbed with large tile but their reserve capacity is smaller. While not so good for obtaining supplies from beds that transmit water slowly, bored wells are much less liable to serious pollution than dug wells.

Driven wells.—Driven wells consist essentially of an iron pipe with a pointed cap, are usually 1½ or 2 inches in diameter, and are driven to a water bed. They are particularly adapted to localities where soils are easily penetrated and water lies in loose, coarse, clean sands. Wells 10 feet deep or less may be driven by a maul. Wells over 20 feet deep are usually driven by a hammer worked by a block and fall. The extreme depth to which a pipe can be driven depends on the character of the soil, but may exceed 100 feet. If the subsoil clay is tough, an earth auger is used to make a hole for the pipe. The water enters the well through holes in the cap and near the bottom of the pipe. To keep out sand galvanized iron screens are sometimes used, and, if the sand is fine, screens of brass gauze as fine as 60 mesh may be needed.

Driven wells may be equipped with cheap pitcher pumps, costing \$2 to \$5, wood pumps, or force pumps, the latter worked by hand or by a windmill. The obtainable yield varies with the transmission rate of the water bed, depth to water, size of pipe, and the pump.

From a sanitary standpoint, a driven well is much superior to a dug or bored well. If the pipe is driven 10 feet or more below the lowest level of the water table, has a collar of concrete to hold it firmly and prevent surface water from working down along it, and is topped by a good pump, that does not need priming, a driven well is safe from surface pollution.

There are hundreds of driven wells 1½ or 2 inches in diameter and 5 to 50 feet deep in the low terraces of the Virginia Coastal Plain. They are very numerous in Norfolk, Princess Anne, Accomac, and Northampton counties. With an ordinary pitcher pump the average yield is about 3 gallons per minute. The total cost of a driven well varies with the depth and the equipment. For wells 5 to 50 feet deep the cost ranges from \$3 to \$40.

Drilled wells.—Under this head are included all wells sunk by drilling rigs, whether of jet, rotary or percussion types. Diameters range from 1 to 15 inches; depths from 50 to over 2,000 feet.

In the tidewater counties the deeper wells—most of those over 50 feet and very nearly all over 100 feet deep—have been sunk by rigs of the jet type. In these a stream of water is forced down a hollow drill rod and washes up the material loosened by the reciprocating bit. If the beds penetrated are loose, casing must be placed as the boring advances. In firm, compact sandy clays the hole will stand without casing. If no hard layers or loose sands are encountered progress is rapid, and by hand power alone a depth of 400 feet can be reached.

Hand power rigs have light derricks made of wood or of iron pipe, and are worked by two or more men pulling on a rope leading over a head pulley, the bit being rotated with a wrench. Two other men are needed to work a pump to force water down the rod through openings in the bit and up the casing, and wash out the drillings. In firm sands free from hard "rocks" a hand power jet rig put down a 1½ inch hole 150 feet in half a day, but should one or more "rocks" be encountered, even though these be but a foot or so thick, a driller may be a week or two in completing a well.

Drillers have sometimes substituted horse for man power, but practically all wells over 300 feet are now sunk by rigs with gasoline or steam engines. With these rigs, wells 2 or 3 inches in diameter have been sunk over 1,000 feet through the Coastal Plain beds. Various types of gear are used for giving a reciprocating motion to the drill rod. A rig capable of sinking a 3-inch hole 1,000 feet requires the services of a driller and a helper. The rate of progress, hence the total cost of drilling, depends largely on the skill and resourcefulness of the driller. Hard beds give trouble, but rapid progress is made through firm sands.

For wells of large diameter, such as are needed for city supply or for the equipment of manufacturing plants, three types of drilling outfits have been used in the Virginia Coastal Plain; the jet, the rotary hydraulic, and the standard cable. all of which require for heavy work a driller. a helper, and one or two laborers.

The rotary hydraulic rig has a revolving bit down which water is forced. It is particularly suited for rapid advance through soft or unconsolidated deposits. The chief objection to its use in a district where the water-bearing beds are thin and have not been definitely located, is that a sludge of mud and water is used to plaster the sides of the hole to prevent sand beds from running. By keeping pressure on a pump and forcing down mud a driller need not place casing and can therefore make rapid progress; this tempts him to neglect possible water beds, particularly if he is working at so much per foot. One well in Tidewater Virginia, said to have been sunk by this process 1,000 feet without casing, was not a success, though flows were found at lesser depths by other wells in its vicinity.

The standard cable rig, the best type, all things considered. for going through rock, is not particularly adapted for work in the Coastal Plain sands and clays. In most localities the casing has to follow the bit closely, and even a careful driller may have great difficulty in getting through loose sands which sometimes rise in the casing 100 feet over night. Sudden inrushes of sand may bury the drill, causing vexatious delays. Again the frictional resistance of the sands may prevent the casing. after several hundred feet are placed, from going down by its own weight; then it has to be driven and heavy driving may break it at some joint, causing its collapse and the loss of the well. All things considered the jet rig is perhaps the best of the types in use, though in places what is known as the California stove-pipe rig could be used to better advantage.

The actual cost of drilling a given well and the price asked by the driller may differ greatly. The driller assumes the risk of accidents and unforeseen delays, can not work all the year, and has to bear the expense of moving and setting up his rig. The drilling cost varies with depth, the rate of advance, the casing needed, etc. Where drilling is good the actual labor and power cost of a 1½-inch well 150 feet deep may be $10; if hard "rocks" are struck the cost may be $75. The cost of larger wells varies as widely. Under favorable conditions a six-inch hole can be sunk 1,000 feet for $1 per foot, excluding casing, but more than one driller has lost money contracting to sink 500 feet for $2 per foot.

The usual price for a cased six or eight inch well from 200 to 500 feet deep has been $3 per foot.

Most of the small diameter wells are sunk on a "flow or no pay" contract. Where a driller knows that at a certain depth water can be struck having sufficient head to rise above the well mouth he will contract at a low figure, whereas in territory that is new to him, or where the surface elevation makes a flow doubtful, he will ask much more. Large diameter wells are usually sunk at so much per foot, the price increasing below certain depths, or under a contract to get a flow and complete the well for a certain price. Whether the owner is liable to lose more at the hands of an unscrupulous driller by contracting for a flow at an unnecessarily high price than by having the driller working at so much per foot, pass by water beds to run up the total cost, is a question. The fairest contract, where conditions are unknown, is one which protects the driller from loss and stimulates him to do his best. Such a contract should be at a certain price per foot, with a bonus for obtaining the desired flow within a given time, or above a given depth.

Speaking generally, the cost of a well may run from 10 cents to $5.00 a foot, depending on the diameter of the well, the length of casing needed, and the material penetrated. The writer knows of a fine 1½-inch well 150 feet deep, that cost, casing and all, but $18, and of a 6-inch well 1,000 feet deep that cost $4,000.

The most expensive well ever drilled in Tidewater Virginia is the one sunk at Fortress Monroe in 1902. This had 15-inch casing to 720 feet, 12-inch casing to 1,200 feet, and 9-inch casing to 2,128 feet. From 2,128 to 2,250 feet no casing was placed. The contract price was $34,820.

MAGNETIC WELLS.

The only magnetized well in the tidewater region to come to the writer's notice is that of J. M. Shackelford at Severn, in Gloucester County. At first the casing is said to have had magnetism enough to hold up a 10-penny nail, but in November, 1906, two years after the well was drilled, the magnetism was just sufficient to draw from the perpendicular a small iron key suspended from a ring.

The reason for the magnetic action of the casing is simple. The earth is itself a great magnet; the drill falling at right angles to what are known as the lines of force becomes magnetic, the jar of the bit helping the particles of steel in it to become polarized. By the scraping of the bit on the casing the latter is magnetized in much the same way as a knife blade is by rubbing it on a pocket magnet. The duration of the magnetic effect depends on the physical structure of the metal in the casing and on the original intensity of magnetization.

Claims that magnetic waters flow from such magnetized wells have been made, but have not been verified. The casing of the well at Severn is said to have shown a stronger effect when the water was running than when the flow was shut off. That such was actually the case seems doubtful.

YIELD OF WELLS

When the water in an open well is lowered by bailing or pumping the upper surface of the ground water is locally depressed, and under continued pumping falls until the increased rate at which the water enters the well from the surrounding sands by reason of the pressure toward it, equals the rate of bailing or pumping. The rate at which water flows to the well depends on the difference in pressure between the water at the instant it enters the well and the water in the surrounding sands, as measured by the local depression of the water table, and the ease with which the sands transmit water. As has been stated, every soil has a certain porosity determined by the size of the voids between the soil particles, and every soil has, at a given temperature and a given difference of pressure, a certain rate at which it will transmit water, called its transmission constant. The conditions governing flow to wells have been studied by Schlichter, among others, who says:

"The amount of water yielded by a common well or by a non-flowing tubular well is dependent first of all upon the degree of fineness of the material in the various strata from which the water is obtained. The size of the soil grains not only determines the rate at which water can be transmitted to the wells under a given head but it also determines the proportion of contained water the soil will freely part with. The fine-grained soils retain a considerable proportion of the water of saturation as capillary water even after free means of drainage are established, so that fine-grained materials will not only deliver water slowly but will furnish only a small total amount. Some quicksand is so fine that the waters can be pulled away from the fine grains only with the greatest difficulty."[a]

The same general principles apply to artesian and flowing wells as to shallow open wells. The yield of water depends on the difference in pressure between the water in the well and the water in the sand, on the temperature (which for deep wells is unvarying), on the porosity, or rather the transmission constant of the sand, and on the thickness of the sand. These factors account for all the differences observed in the yield of flowing wells, except such as are due to faults in drilling or maintenance. Fine sands, imperfectly assorted sands, and clayey sands transmit water less freely than coarse, clean, evenly assorted sands, and coarse gravels transmit water still better. The boldest flows in the tidewater country come from beds of coarse, rounded sand or from beds of smooth gravel.

LOSSES OF HEAD OR YIELD IN FLOWING WELLS

Causes.—The commonest complaints of a well owner are that the water in his well will not rise as high as when the well was just completed, or that the yield is less, and that if he wants as much water as he had at first he must have a new well sunk. The causes of lower head and lessened yield are various, and the responsibility may rest on one or on many persons. The causes may be summarized thus:

(1) Faults in sinking; such as (*a*) improper casing, (*b*) lack of screens.

(2) Faults in maintenance; such as (*a*) neglect, (*b*) abuse.

(3) Interference.

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[a] Schlichter, C. S., Field measurements of the flow of underground water, U. S. Geol. Survey, Bull. No. 140, p. 87.

Faults in Sinking.

The desire of a driller to economize on casing has resulted in reducing the flow of many a well. Where the clayey Chesapeake or Pamunkey sands above the water bed would stand without casing it was customary for a driller to place casing through the overlying Columbia or Recent material and bottom it in the sandy clay, possibly using in all only a length, about 20 feet. Such work permitted (1) the sub-surface escape of water, by leakage, about the bottom of the casing, or the escape of water below the casing from a deep sand into a higher one; (2) the clogging of the well by material washed from the sides but too heavy to be carried up and discharged by the flow.

Some drillers instead of placing casing to the water-bed carry it down to an impervious layer, but leave a small pipe, usually the ¾-inch drill rod, in the well. This diminishes the danger of the well clogging but does not prevent possible leakage outside the pipe, which only half fills the hole of water from the deep sand into a sand nearer surface.

Screens have been little used in small flowing wells on the western shore of the bay. Their use might diminish the possible yield, but would maintain the flow, of many wells sunk into loose sands and showing low initial heads. On the Eastern Shore screens are used at many wells because the loose sands and soft clays soon clog unscreened wells, or because at pumped wells the sands damage pump valves and cylinders.

Faults in Maintenance.

Neglect.—Most flowing wells, like non-flowing driven or dug wells, receive too little care from owners. Many flowing wells, particularly those of low head tapping loose sands, need to be cleaned occasionally. The sand can be washed out with a good force pump and enough pipe to reach the bottom of the well. A well with a screen is sometimes clogged by sand grains packing against the screen. In such a case the flow may be restored by forcing water down the casing, thus loosening the packed sand.

Abuse.—Under the head of abuse come dropping in pebbles or other objects too heavy for the water to lift, attempts at cleaning with a sash weight and string (a plugged well may be the result) and momentarily stopping the flow by the hand or otherwise. A momentary stoppage of flow may have no effect on some wells, particularly properly cased wells with high head, but at others it may permit loose sand in the casing or the bore hole to pack, thus greatly reducing if not cutting off the flow. Any sudden interruption of flow in a well not cased to the bottom may loosen material above the water sand and clog the well.

Generally speaking, it is not advisable to shut off a flowing well, but where unrestricted flow may affect the head of nearby wells the flow may be reduced to a small fraction of the normal volume. The reason for not shutting off the flow entirely is that more than one well has had its flow reduced or cut off by children or older persons closing the pipe with their hands.

Interference.

The total supply of water in the artesian sands of the Virginia Coastal Plain is practically inexhaustible, but it is easily possible to draw so much water from a particular part of a bed, especially if the bed be thin, that the head of the water in that part of the bed is decidedly reduced. Such reduction of flow has happened at various places along the Rappahannock River; also, and especially, at Colonial Beach and West Point.

At Colonial Beach the first artesian wells found water, at a depth of about 200 feet, that rose fully 20 feet above tide level, or above the surface at the highest points in town. Possibly 200 wells have been drilled in an area 1½ miles long and half a mile wide. No restrictions have been put on flow and a few of the wells are pumped heavily. As a result the head of the water in the 200-foot sand has been so reduced that most wells in the center of the town do not flow at the surface, and many at lower elevations flow only at high tide. Many wells back from the water front have been cut off below the surface and now flow into basins 5 feet or so deep. The lowest wells, those along the shore, drain those on higher ground. The sinking of one well on the water front has stopped the flow of a neighboring well on ground a few feet higher. Many of the wells were poorly cased and there is probably much leakage underground. That this loss of head is purely local is shown by the high heads of wells tapping essentially the same horizon at points a mile or two from town.

At West Point where over 300 wells have been driven the loss of head has been even greater than at Colonial Beach, but conditions are more complicated. The city is on a point of land at the junction of the Mattaponi and Pamunkey rivers. There is a water-bearing sand at 120 feet and another at about 165 feet. Along the water front many wells have been drilled and allowed to flow without restraint. As a result wells on higher ground that formerly flowed now have to be pumped. The 120-foot sand that once furnished flows is now penetrated by many poorly cased wells sunk to the 165-foot sand, and the water flows down these holes to the 165-foot sand and escapes from the river-front wells tapping the latter sand. The maximum local loss of head in the 165-foot wells has been about 15 feet; in the 120-foot sand even more. According to E. W. Wilkinson, a well sunk in 1884, and one of the first if not the first in the town, flowed at an elevation of 14 feet above surface, or 20 feet above tide. After about a year and a half, when a number of wells had been drilled, the flow decreased and now the well is pumped. Isolated wells above the city or across the rivers show undiminished heads.

The manner in which poorly cased wells and wells near river level have reduced the head of the water in the 120-foot and 165-foot sands at West Point is indicated in Fig. 7.

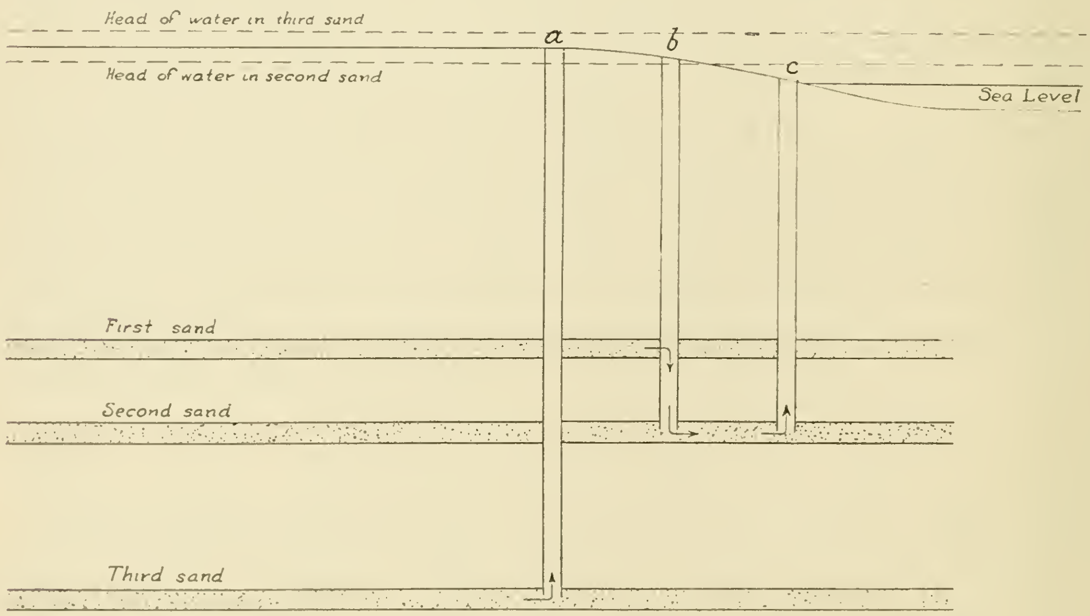

Fig. 7.—Diagram illustrating artesian well relations at West Point. *a*, properly cased well which obtains a flow from the third sand; *b*, improperly cased well on high ground, no flow; *c*, well at river edge; flows continually, draining third sand, also second sand through well *b*.

From an examination of several hundred flowing wells in the Coastal Plain of Virginia the writer ranks the causes of decline in yield as follows: (1) interference; (2) neglect; (3) improper casing; (4) abuse.

Utilization of Supply.

The great majority of the flowing wells in Tidewater Virginia are of small diameter, 2 inches or less, and yield about 2 gallons a minute at the well mouth. This yield with proper economy is liberal for an average household. In great manufacturing cities where the installation of meters on all service mains has reduced the consumption of water to actual requirements the daily consumption is as low as 50 gallons per capita. The average person drinks about 3 pints of liquids per day and 25 gallons per capita has been estimated as sufficient for all domestic needs. Hence a flow of 2 gallons per minute, or 2,880 gallons per day, if storage capacity is provided, will not only more than suffice for a household of average size, but the overflow piped to the barn will water many head of stock, allowing 8 gallons per head.

Yet at most places in Tidewater Virginia there is little effort toward economy. On the other hand, there are a few places, notably Tappahannock, where the superiority of the deep waters to those obtainable from dug wells is so much appreciated that wood or concrete tanks are built at some well mouths from which the water is piped to pumps or taps at two or three houses.

Rams at flowing wells.—Where a house and farm buildings stand on a terrace 25 feet or more above river or bay level and flows on the terrace are impossible, an abundant supply may be had for dwelling and barn by harnessing a hydraulic ram to a flowing well of good head below the terrace and piping the water to a tank. A flow of 5 gallons per minute at 10 feet above tide level can be had along many inlets on the lower courses of the rivers on the west side of Chesapeake bay. If properly placed and connected, to utilize 7 feet of this head, a ram costing possibly $15 will afford 1 gallon per minute at 40 feet above the ram. There is little difficulty in thus making a flowing well pump its own water. The most essential feature of the equipment is a basin, small tank, or stand-pipe between the well and the ram; the ram should never be connected directly to the well. There are in Tidewater Virginia a number of wells with rams that give satisfactory service. Some failures reported were due to not determining in advance the available head and flow and the amount that could be delivered at the desired point; other failures were due to improperly placed or connected equipment.

SANITARY PROTECTION OF WELLS

In drilled wells there is ordinarily slight danger of pollution except from the top, because the tight iron casing protects against sub-surface contamination. Yet one can see wells that cost $200 sunk to sands that yield beautiful water, into which all kinds of backyard refuse are washed at every rain, simply because the top of the casing or the pump chamber is not properly protected, a defect remedied at trifling expense. Flowing wells, such as those in the Virginia Coastal Plain, are practically unpollutable, and it is to this fact that the improved health of particular communities after the development of artesian supplies has largely been due.

The greater the number of people that may use a well the more urgent the need of the well water being free from disease germs. Also it is evident that if many people use an open well there is more chance of some person who carries disease germs handling the bucket and thus contaminating the well water. Consequently, wells at churches, camp-meeting grounds, courthouses, and schoolhouses need to be dug and protected with more than ordinary care. Many cases of typhoid fever have been traced to such public or semi-public wells, and yet the precautions taken against the pollution of well water at many gathering places in the tidewater country are practically of no account. Usually the most that is done before a camp meeting is to clean the dug well. This is a wise precaution but does not lessen the chance of the water being polluted during the meeting. Absolute safety means making pollution impossible. This implies location with regard to natural conditions of drainage—most church and courthouse wells in the tidewater country satisfy this requirement—and then, if water can not be had by a driven well and a deep drilled well would be too costly, providing a water-tight casing extending several inches above and at least 5 feet below ground level, a water-tight cover and a good pump. The open well and the oaken bucket may appeal to sentiment but the tightly cased well and the force pump are far more sanitary.

Even though a drilled or driven well is properly sunk and has a good pump, occasional inspection is necessary to make sure of an unpolluted supply. A virulent outbreak of typhoid at one locality in the tidewater country was traced to the schoolhouse well. This well had been sunk to an artesian sand, the water from which rose to within a few feet of surface. As the artesian water was known to be excellent the well was not suspected until the coming of the fever, which attacked 40 per cent of those who drank the well water. Investigation showed that the casing had rusted through at ground water level, a few feet below surface, and in consequence the well for an unknown length of time had not drawn on the artesian supplies but on a polluted source.

PUBLIC HEALTH AS RELATED TO UNDERGROUND WATER SUPPLY.

Without accurately kept mortality tables covering a term of years, it is practically impossible to prove or disprove statements regarding changes in the death rate or in the prevalence of particular diseases at specified communities. Hence, statements regarding the effects of changes in the conditions of living in the smaller settlements and the rural districts of the Virginia Coastal Plain are of value only in so far as they are put forth by persons who are familiar with the conditions and are competent to judge. For this reason the testimony of local physicians is of decided value. In their opinion changes in sources of water supply in towns, villages, and on farms have been followed by definite changes in the prevalence of specific diseases, more especially typhoid fever and malaria. Following the lessening use of springs as sources of supply and the increasing use of unprotected dug wells, there was a marked increase in typhoid. The substitution of driven and drilled wells for open wells at particular villages has notably diminished the prevalence of this disease and lowered the death rate. In addition physicians living in widely separated communities claim that the development of artesian supplies in the lowlands along the rivers has practically freed many tracts from the malarial fevers for which they were once notorious.

MUNICIPAL WATER SUPPLIES

SOURCE OF SUPPLY

Some of the towns and cities in the area covered by this report have waterworks that distribute surface water, a few have plants that draw on underground supplies. The surface water is variously obtained from rivers or ponds, the underground water from shallow or deep sources.

SURFACE WATER

Rivers and creeks are the more important sources of surface water. They are subject to great variations in volume of flow and quality of supply; at times of flood they contain much finely divided mineral matter in suspension or semi-solution, and are extremely turbid. Many of the surface waters are polluted; the large rivers by the sewage of cities, the creeks by drainage from privies, barnyards or cultivated fields. The ponds drawn on are as a rule less liable to pollution, but vegetable growths frequently make the water high-colored or give it an offensive smell and taste. In consequence, most of the public supply systems include equipment for rendering the water more acceptable, ranging from simple settling basins to elaborate filtration plants.

UNDERGROUND WATER

Though the porous sands of the various Coastal Plain formations form great underground reservoirs, they are much less important as sources of municipal water supply than rivers and creeks. This is because there are few cities or towns of large size along the middle portion of the Virginia Coastal Plain where the underground waters, and more especially the artesian waters, are most readily available. The cities are chiefly on the western edge of the Coastal Plain, where flowing wells can not be had and the ground water supplies are not sufficient for the needs of large cities; or towards the seaward edge where the deep artesian water is not well suited for municipal use, and satisfactory shallow water is restricted to certain areas.

SUITABILITY OF SURFACE AND UNDERGROUND WATERS FOR MUNICIPAL NEEDS.

The belief that underground water is better, that is more healthful, than surface water is widely held, but rests on the sparkle, clearness, coolness and taste of well and spring waters rather than on careful investigations of their merits.

Surface waters are often badly polluted but settling and filtration render them innocuous; the water furnished by the supply systems of the larger cities in eastern Virginia is, from a sanitary standpoint, altogether superior to that obtained from many dug wells in villages. The deep artesian waters are unpolluted, but under a considerable part of the Virginia Coastal Plain they contain enough mineral salts to make them less suitable for boiler supply and other industrial purposes than filtered surface water. The latter, as a rule, contains little lime and the addition of the chemicals for precipitating finely divided matter does not increase the mineral content enough to affect the industrial value of the water as distributed. In general it may be said that nearly all of the public supply systems distribute good water, that is, water which satisfies sanitary and industrial requirements. In fact, most of the cities of Tidewater Virginia have reason to be proud of the excellence of their public water supplies.

NOTES ON CITY AND TOWN SUPPLIES

The city of Richmond owns its water supply system. James River receives the sewage of several cities and towns and is often very turbid.

The water is collected in a settling reservoir above the city limits and after purification is pumped to the mains and to smaller distributing reservoirs on high points in the city. Careful determinations of the variations in turbidity, and chemical and bacterial quality of the water were made during a number of years, and on the basis of the results the city installed a sedimentation and coagulation plant. The water after treatment is remarkably clear. The municipal waterworks in Manchester distribute James River water, collected above the city at a point opposite the intake of the Richmond city waterworks and purified by sedimentation and mechanical filtration.

Barton Heights, a suburb of Richmond, was supplied in 1910 with water obtained from a spring and from a well 759 feet deep.

Norfolk gets water from three distributing systems. The city waterworks, which supply most of the city, draw on small lakes in low ground northeast of the city; the sanitary surroundings of these in 1906 were good. Complaints of color and odor, caused by vegetable growths, led to the installation of a coagulation and filtration plant, and the water supplied is now satisfactory. To meet the prospective needs of the city other sources of supply have been sought. Part of Norfolk and several suburban towns, Lambert's Point, Ocean View, Huntersville and Lindenwood, are supplied by the Norfolk County waterworks, which get most of their supply from a system of driven and dug wells on a tract of land near the lakes that supply the city works. This ground water is of good quality and is distributed by a direct pressure system without filtering. To supply an increasing demand the company has investigated the development of surface waters similar to those distributed by the Norfolk City waterworks. The eighth ward of Norfolk, formerly the city of Berkeley, is supplied by the Norfolk, Berkeley & Suffolk Water Co. Most of the water comes from a system of shallow driven wells on a tract of land not far from Berkeley, but part comes from Smith's Creek (Lake Kilby) near Suffolk. The well water is of satisfactory quality but the quantity obtainable on the tract near Berkeley is insufficient for the prospective needs of the community.

The cities of Suffolk and Portsmouth are supplied by the Portsmouth, Berkeley & Suffolk Water Co., with Lake Kilby water. The water of Lake Kilby is high-colored and at times has an objectionable smell. The water distributed passes through a coagulation and sand-filtration plant which reduces the color and removes the odor.

The city of Newport News, the city of Phœbus, the town of Hampton, the Hampton Agricultural and Collegiate Institute, the National Soldiers'

Home, near Hampton, and the military post of Fort Monroe, are supplied with water by the Old Dominion Water & Power Co. This company has a large reservoir in Warwick County, controls practically all the watershed (about 1,500 acres) of the creeks feeding this reservoir, and endeavors to protect the watershed from pollution. Because of complaints of high color and disagreeable odor the company installed a coagulation and filtration plant (mechanical filters) and the water is now satisfactory.

The city waterworks of Petersburg distribute surface water obtained from Livetenant Run, a creek that empties into Appomattox River on the east side of the city. The watershed of the creek is open to pollution from dwellings, but the creek water is passed through a settling and coagulation basin and is filtered before distribution, consequently its quality is satisfactory.

Fredericksburg owns its distributing system, which obtains water from a canal of the Rappahannock Power Co., supplied by a dam on Rappahannock River three miles west of the city. The river is often very turbid and local conditions do not tend to improve the quality of the water passing through the canal, but a collecting reservoir at the pumping station permits decided improvement by sedimentation. From the collecting reservoir the water is pumped to a distributing reservoir on the heights south of the city. A considerable number of people in the city obtain water from the mains of the Aqueduct Company. This water comes from several springs, none of large size, on the high ground south of the city, and is generally of satisfactory quality.

Alexandria has city waterworks that distribute water from Cameron's Run, a creek on the south side of the city. The water is collected three miles west of the city and brought by a canal to a pumping station, whence it is forced to settling and distributing reservoirs on Grimes' Hill. The run water is often turbid, the water shed is inhabited, and conditions along the canal are not altogether satisfactory. However, the quality of the water is decidedly improved by sedimentation in the settling reservoir.

The city waterworks of West Point draw on artesian wells that tap sands 330 feet below surface. The sanitary excellence of this supply is not disputed, but its industrial value would be greater were the water less mineralized; it contains considerable bicarbonate and sulphate of soda and in boilers has a tendency to foam.

The town of Franklin has a public supply system drawing on Blackwater River. The water is pumped from the river to a tank on a high tower; it is a good boiler water but at times is objectionable for drinking.

The Smithfield supply is from a pond on a small creek three miles west of the town. It is not filtered, but the small watershed of the creek is sparsely settled, and except for vegetable growths the quality is satisfactory.

The town of Emporia distributes Meherrin River water. An attempt to get water by a deep well gave unsatisfactory results.

Practically all the water distributed by the municipally owned system of the town of Cape Charles comes from driven wells varying in depth from 30 to 90 feet. The supply is not altogether satisfactory, partly because the wells are close to tidewater. The water is hard and forms scale in boilers.

The Onancock waterworks draw on driven and drilled wells less than 75 feet deep, and on a large dug well. The water, while slightly hard, works well in boilers, and except for the possibility of polluted water entering the dug well, the sanitary surroundings in 1906 were good.

The military post of Fort Myer, west of Alexandria, is supplied with filtered Potomac River water. Fort Hunt on Potomac River, below Alexandria, obtains excellent water from an artesian well.

A summarized statement of information collected regarding the public water supply systems of the Coastal Plain towns and cities appears in table 2.

TABLE 2.—*Municipal water supplies in the Coastal Plain Province of Virginia.*

City	Owner	Source	From what distributed	Capacity of reservoir *(gal.)*	Elevation of reservoir or standpipe above town *(feet)*	How distributed
Alexandria	City	Cameron Run	Reservoir	16,000,000	55–95	Gravity
Ashland		Wells	Standpipe			
Barton Heights	Town	Springs and wells	Standpipe	50,000	30–60	Direct pressure
Cape Charles	City	Wells	Standpipe	50,000	60	Direct pressure
Franklin	Town	Blackwater River	Standpipe	80,000	110–125	Gravity and direct pressure
Fredericksburg	City	Rappahannock River	Reservoir	4,000,000 11,000,000	125	Gravity and direct pressure
Manchester[a]	City	James River	Standpipe	128,000	20–240	Gravity and direct pressure
Newport News	Newport News Light & Water Co.		Standpipe	430,000,000	200	Direct pressure and gravity
Norfolk	Norfolk County Waterworks Co.	Wells	Standpipe	305,000	100	Direct pressure
	City	Lakes	Reservoir			Direct pressure
	Portsmouth, Berkeley & Suffolk W. Co.	Wells	Standpipe		100	Gravity and direct pressure
Onancock	Town	Wells	Standpipe	50,000	80	Gravity and direct pressure
Petersburg	City	Livetenant Run	Reservoir	3,000,000	40–150	Gravity and direct pressure
Portsmouth	Portsmouth, Berkeley & Suffolk W. Co.	Smith's Creek	Standpipe		100	Gravity and direct pressure
Richmond	City	James River	Reservoir and standpipe	150,000 40,000,000 9,000,000	285 15–155	Gravity
Suffolk	Portsmouth, Berkeley & Suffolk W. Co.	Smith's Creek	Standpipe		110–170	Gravity and direct pressure
Smithfield	Town	Creek	Standpipe		40–70	Gravity
West Point	City	Wells	Standpipe Cistern	65,000 20,000	70–90	Gravity and direct pressure

[a]Now a part of the city of Richmond.

TABLE 2. *(Continued.)—Municipal water supplies in the Coastal Plain Province of Virginia.*

City	Length of mains *(miles)*	No. of taps	No. of fire hydrants	No. people supplied	Population of city in 1910	Daily consumption *(gal.)*	Max. capacity of pumps *(gal.)*	Domestic pressure *(lbs. per sq. in.)*	Fire pressure *(lbs. per sq. in.)*	Purification system
Alexandria	17.3	3,520	160	3,300[b]	15,329	1,000,000	2,100,000	20–35	20–35	Sedimentation
Ashland	...	...	...	...	1,324	...	...	...	...	None
Barton Heights	...	...	...	...	1,388	...	...	...	...	None
Cape Charles	1.5	...	20	1,100	1,948	60,000	...	25	50 (?)	None
Franklin	3.5	150	57	1,000	2,271	80,000	1,440,000	50	125	None
Fredericksburg	28.0	1,431	92	1,560[b]	5,874	...	1,000,000	40–55	55–90	Sedimentation
Manchester[a]	16.0	1,730	75	...	9,715	1,435,770	2,250,000	49–90	49–90	Coagulation
Newport News		2,400	180	...	20,205	...	...	...	...	Coagulation and filtration
Norfolk	80.0	...	40	1,400	67,452	1,000,000	3,500,000	40	...	None
	...	...	...	...	...	...	22,000,000	30	...	None
	...	...	24	...	...	...	1,500,000	...	...	
Onancock	1.5	75	30	...	1,001	...	168,000	40–55	55–90	None
Petersburg	28.0	2,900	280	15,000	24,127	800,000	3,500,000	14–60	14–60	Sedimentation and coagulation
Portsmouth	75.0		220	...	33,190	...	10,000,000	...	...	Coagulation and filtration
Richmond	133.0	18,000	1,000	...	127,628	12,474,000	20,500,000	8–83	8–83	Sedimentation and coagulation
Suffolk			52	...	7,008	...	12,000,000	...	...	...
Smithfield				...	1,278	...	...	...	...	None
West Point	3.5	67	36	...	1,397	...	430,000	43	75 (?)	None

[a]Now a part of the city of Richmond.
[b]Rate payers.
[c]Population as of 1900 census.

MINERAL WATERS

The term, mineral water, as commonly used, implies either water having therapeutic value or water differing decidedly from that obtained from the springs or shallow wells of a given region. Some waters, classed as mineral, are very soft and pure, and owe the esteem in which they are held largely to their low mineralization. Others are so highly charged with various substances that they are offensive to taste and smell and have a powerful physiologic action.

As has been stated the potable underground waters of the Virginia Coastal Plain differ widely, the amount of dissolved mineral matter they contain varying from less than 50 to over 9,000 parts per 1,000.000. Many are especially light and pleasant table waters; a few are so strongly mineralized that they should be drunk only under the advice of a physician.

In general, the shallow waters differ more than the deep waters, yet they are distinguished by the predominance of calcium and magnesium salts. Some springs of shallow source contain iron and aluminum salts in sufficient quantity to have therapeutic value, others are notably free from such compounds. Most of the spring waters that have been marketed are of such low mineral content that they are to be classed as table rather than as medicinal waters.

Outside of Southampton and Alexandria counties and a part of Essex County the deep waters so far developed are characterized chiefly by the pressence of sodium and potassium salts, especially the bicarbonates. Few of these waters have been marketed, partly owing to lack of suitable transportation facilities. Some of those exploited contain sodium and potassium bicarbonates in sufficient proportion to be of therapeutic value.

The following list includes wells and springs from which water has been shipped in a commercial way at times during the past five years:

Beaufort Lithia Spring	Chesterfield County
Bellfont Lithia Spring	Chesterfield County
Buckhead Lithia Spring	Chesterfield County
Campfield Lithia Spring	Chesterfield County
Cappahonk Lithia Spring	Chesterfield County
Days Point Artesian Lithia Spring	Isle of Wight County
Diamond Spring	Princess Anne County
Erup Mineral Spring	Alexandria County
Fonticello Lithia Spring	Chesterfield County
Holly Lithia Spring	Chesterfield County
Hume Spring	Alexandria County
Landale Mineral Spring	Norfolk County
Mico Water	Alexandria County
Mulberry Island Chloride Lithia Water	Warwick County
Trepho-Lithia Water	Surry County
Powhatan Spring	Alexandria County
Virginia Lithia Springs	Chesterfield County
White Oak Spring	Norfolk County

Other springs and wells than those named have in years past furnished water for sale, and a few have been more or less extensively exploited.

The list of producers shows that mineral springs are apparently confined to a few counties, seven of the eighteen springs named being in Chesterfield County, four in Alexandria County, and two being in Norfolk County. This localization, however, simply means that most of the commercial springs are near cities in which there is a demand for agreeable drinking water. Thus the Chesterfield County springs had their commercial beginnings in shipments to Richmond, and those in Alexandria County in shipments to Washington, at a time when the public supplies of both Richmond and Washington were often turbid and were regarded with suspicion by many people. The chief market for the springs in Norfolk County is the nearby city of Norfolk.

There are few sanatoriums or large hotels utilizing the alkaline artesian waters for the treatment of disease, but a large amount of water that might be designated as "mineral" under any usage of that term, is obtainable from artesian wells along the lower courses of Potomac, Rappahannock, and James rivers, and at least one city, West Point, distributes by a public supply system an alkaline bicarbonate and sulphate water that is claimed to have decided merit in the treatment of certain disorders of the stomach, liver and kidneys.

VALUE OF MINERAL WATERS

The total value of the mineral water reported sold by the springs and wells named in the preceding list amounted to $33,000 in 1910. In addition to these sales several of the springs used large amounts in the manufacture of sweetened beverages.

DEEP WELLS IN CRYSTALLINE ROCKS.

General statement.—All the flowing wells of Tidewater Virginia tap waters that circulate through pervious beds in sedimentary deposits. Along the western edge of the Coastal Plain, a considerable number of wells have been sunk through the comparatively thin, sedimentary beds and have obtained water from the underlying crystalline rocks.

These rocks are hard, dense and without pervious beds. The water does not move through minute interstitial spaces but through relatively free passages, joint cracks which intersect the mass of the rock at various angles. The joints are of two orders, those roughly parallel to the upper surface of the rock or sheet joints, and those which are steeply inclined. Near surface the sheet joints are much nearer together and more open than at a depth of several hundred feet. The vertical joints do not disappear as rapidly with depth, but as a rule grow narrower below; yet they do not extend downward indefinitely. Since the water lies in cracks and crevices that intersect irregularly there is nothing regular in its occurrence. Success in drilling depends on striking a crevice, and the wider and longer the crevice, and the greater the number of crevices it intersects, the larger the yield. One well may find water at a certain depth, while another, a few feet distant, may go twice the depth and find none; one well may strike a crevice carrying water fed to it from some distance through a series of connecting crevices; another may strike at over 1,000 feet a crevice containing water that comes almost directly from the surface and possibly from close to the well mouth. The general character of the circulation in the crystalline rocks is shown by the accompanying diagram.

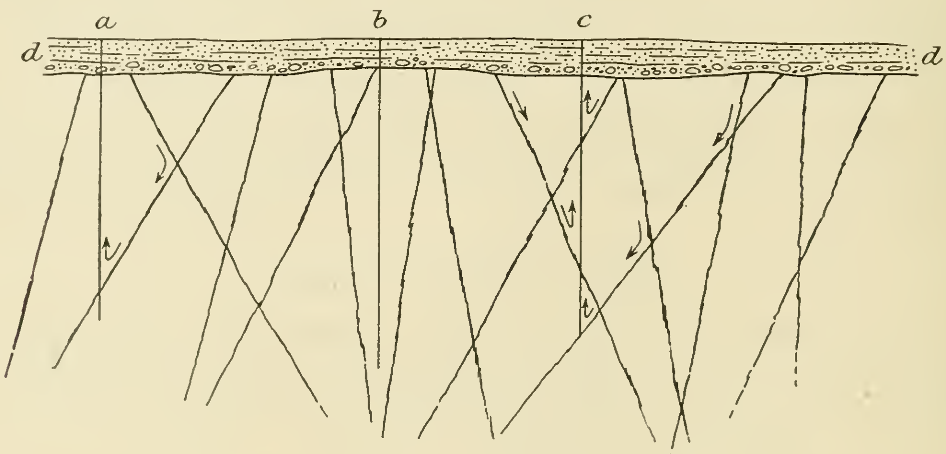

Fig. 8.—Diagram illustrating circulation of water in crystalline rocks, and well supply. (*a*) Deep well striking water that enters near well. (*b*) Deep well finding no water. (*c*) Deep well striking several crevices. (*d*) Unconsolidated material.

For the above reasons deep wells in crystalline rocks are considered by themselves, and facts relating to them are tabulated separately. Also, as the results of deep drilling in the vicinity of Richmond throw light on the occurrence of water in similar rocks and the prospects for deep wells in a strip of country extending from Maine to Georgia, some data collected in the course of field work are here discussed in detail.

WELLS NEAR RICHMOND

General conditions.—Richmond is situated at the "fall-line;" the resistant crystalline rock, a gray hornblende granite, outcrops in the bed of James River and causes rapids. In the low ground along Shockoe Creek and Gillies Creek the granite is overlain by Potomac sands and gravels; on the higher ground in the central and north parts of the city by Chesapeake dark sandy clays or marls, and along James River near the rapids by Columbia cobble beds and loams. The James is tidal to the foot of the rapids but the high Sunderland plain on which much of the city is built has an elevation of from 175 to over 200 feet. Hence, elevations of well mouths differ greatly and though a few wells were started almost directly on granite, others went through over 100 feet of loam, clay, and sand before striking hard rock.

Because of differences in surface elevation there are differences in the depth below surface at which water stands. In wells on high ground in the center of the city, water level is over 100 feet below surface. As most of the wells are pumped intermittently and few give large yields, deep well pumps are generally used. In some of the wells the pump barrel is 300 feet below the well mouth. The waters show wide differences in composition and have no general resemblance; two or three wells seem to draw on the same system of joint cracks, and one well yielded water unlike any other in Tidewater Virginia. Particulars are summarized in the accompanying table; only those wells that are of especial interest are discussed at length.

WELLS NEAR RIVER FRONT

Richmond Paper Co.—One of the first deep wells at Richmond was that of the Richmond Paper Co., drilled near the corner of Byrd and 9th Streets, in 1884. Water which rose to within 60 feet of surface, elevation 83 feet, was found at 250 feet, but it was sulphur-bearing, pitted boilers, and contained so much iron that it could not be used in bleaching rags, consequently the well was abandoned.

Albemarle Paper Co.—Another early well was that of the Albemarle Paper Co., on the river bank near Hollywood cemetery, put down like that of the Richmond Co., to get water more suitable for making paper than that obtained from the often-turbid James. It was started 10 feet above the river and found a small crevice at 225 feet from which water rose to about river level. The yield is so small, about 25 gallons per minute, that little use is made of the well except for drinking and washing filters. For boilers and for paper-making the company filters some 500 gallons per minute of river water.

Other wells.—In addition to the wells of the Albemarle and the Richmond paper companies, there are a number of others near the river, including those of Kingan & Co., the Merchants Cold Storage and Ice Co., and the Transparent Ice Co. Depths vary from 248 to 703 feet and yields from 15 to 210 gallons per minute, the deepest well giving the smallest supply. At the Kingan well, according to report, the drill dropped over 1 foot when the water-bearing crevice was reached. At these wells there is a relatively thin cover of earth, at some wells mostly made ground, above bed rock, and as suggested by Darton[a] they may yield surface water in part, though in most wells the character of the supplies indicates a deeper circulation. The waters contain enough lime and magnesia salts to make them bad for boiler use and they are utilized for condensing only. That from Kingan & Co.'s well has a sulphur odor, a flat taste, and is purgative; it is said to be so corrosive that ordinary casing lasts only 3 months and heavy galvanized casing but 3 years.

The analyst gave the following partial analysis with the results expressed as hypothetical combinations. The determinations have been recomputed to parts per 1,000,000.

Partial analysis of water from 428-foot well of Kingan & Co.

(Froehling & Robertson, analysts.)

	Parts per 1,000,000
Total solids	779.
Silica (SiO_2)	31.5
Alumina and iron oxides ($Al_2O_3 + F_2O_3$)	18.
Calcium carbonate ($CaCO_3$)	175.
Calcium chloride and sulphate ($CaCl_2 + CaSO_4$)	181.
Magnesium chloride ($MgCl_2$)	107.
Alkaline chlorides and sulphates	267.

WELLS NEAR THE CENTER OF THE CITY

Hotel Jefferson.—An interesting series of wells is that drilled on high ground, near the center of the city and northward, for the three hotels and the apartment house named below. All are 8 inches in diameter and range in depth from 365 to 702 feet. As the table shows, the depths to water and

[a] Darton, N. H., Artesian well prospects in the Atlantic Coastal Plain, U. S. Geol. Survey, Bull. No. 138, p. 178.

the height of the water level differ considerably, after due allowance is made for difference of elevation. The record of the Hotel Jefferson well is as follows:

Record of 445-foot well at Hotel Jefferson.

Group or formation	Material	Thickness	Depth
COLUMBIA			
Sunderland	"Drift soil"	41	41
	Gravel	2	43
CHESAPEAKE	Yellow clay	2	45
Calvert	Black clay	30	75
	Sand	15	90
	Sand, marine shells and a little water	12	102
	Blue clay	16	118
PRE-CAMBRIAN	Soft granite	5	123
	Hard and soft granite, water at 410 to 438 ft.	322	445

The well is said to be cased to 400 feet. The water rises to within 60 feet of surface, elevation 180 feet, but to obtain a yield of 60 gallons per minute the pump barrel had to be placed near the bottom of the well. The water is used at the table and for other purposes about the hotel but not for boiler supply. The following analysis, recalculated to express results in ionic form, was furnished by the manager.

Analysis of water from 445-foot well at Hotel Jefferson.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	173.
Silica (SiO_2)	38.
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	0.5
Calcium (Ca)	30.
Magnesium (Mg)	8.6
Sodium (Na)	6.2
Potassium (K)	1.2
Carbonate radicle (CO_3)	51.
Bicarbonate radicle (HCO_3)	not reported
Sulphate radicle (SO_4)	33.
Chlorine (Cl)	4.5

Chesterfield Apartments.—At the Chesterfield Apartments well, elevation 195 feet, the water, which was found at 230 feet down, stands 150 feet below surface but the yield is so free that the level is lowered only slightly by steady pumping. The apartments in 1906 used no city water at all. The following analysis, recomputed from one obtained from the manager, indicates that the well water contains bicarbonates of lime and magnesia as principal substances in solution, and considerable silica.

Analysis of water from 365-foot well at Chesterfield Apartments.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	287.
Organic matter	5.9
Silica (SiO_2)	47.
Aluminum (Al)	0.5
Iron (Fe)	0.5
Manganese (Mn)	0.17
Calcium (Ca)	29.
Magnesium (Mg)	12.
Sodium (Na)	18.
Potassium (K)	3.7
Lithium (Li)	0.01
Strontium (Sr)	0.24
Iodine (I)	0.009
Bromine (Br)	trace
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	138.
Sulphate radicle (SO_4)	26.
Phosphate radicle (PO_4)	0.8
Chlorine (Cl)	6.1

Murphy's Hotel.—At Murphy's Hotel are two wells; one is said to be 450, the other 702 feet deep. The second well had not been put in service when the data for this report were collected. The first well, elevation 175 feet, struck rock at a reported depth of 125 feet. The water level is given as 100 feet below surface and the yield as 40 gallons per minute. The well is said to be cased for 350 feet, and the pump plunger is at 390 feet. The water is used for drinking and cooking, and has been bottled for table and medicinal use as Granite Lithia Water; though used in a boiler it is not satisfactory for that purpose, foaming somewhat. A series of analyses made by Otto Meyer[a] in 1904 showed the presence of radium and traces of several rare earths and of tin, copper, and nickel. The principal substances in solution, however, seem to be bicarbonates of calcium and magnesium. In general the water is much like that from the Chesterfield Apartments well. The following analysis, recomputed from that furnished by the analyst, is given for comparison.

[a] Meyer, Otto, Radium in water from a deep well, Sci. Amer., 1904.

Analysis of Granite Lithia Water; well at Murphy's Hotel.

(Henry Froehling, analyst.)

Determination	Parts per 1,000,000
Total solids	196.
Organic matter	0.82
Silica (SiO_2)	34.4
Aluminum (Al)	0.3
Iron (Fe)	0.31
Manganese (Mn)	0.063
Calcium (Ca)	21.
Magnesium (Mg)	9.5
Sodium (Na)	21.9
Potassium (K)	5.9
Lithium (Li)	0.015
Strontium (Sr)	0.10
Barium (Ba)	0.04
Iodine (I)	0.002
Carbonate radicle (CO_3)	70.
Phosphate radicle (PO_4)	0.19
Sulphate radicle (SO_4)	24.
Nitrate radicle (NO_3)	0.15
Chlorine (Cl)	6.6

Richmond Hotel—The well at the Richmond Hotel, elevation 157 feet, struck a crevice yielding a large supply, said to be 300 gallons per minute; the depth to water could not be ascertained from the engineer in charge of the plant, but the pump plunger is 250 feet below surface. The water, which is used for all purposes, is more mineralized than that from the Chesterfield Apartments and Hotel Jefferson wells, containing more soda and potash as well as sulphates and bicarbonates.

Analysis of water from 572-foot well at Richmond Hotel.

(Froehling and Robertson, analysts.)

	Parts per 1,000,000
Total solids	702.
Silica (SiO_2)	28.
Aluminum (Al)	1.10
Iron (Fe)	0.18
Calcium Ca)	68.
Magnesium (Mg)	30.
Sodium (Na)	68.
Potassium (K)	29.
Lithium (Li)	0.01
Strontium (Sr)	0.02
Barium (Ba)	0.05
Manganese (Mn)	0.03
Iodine (I)	trace
Bromine (Br)	trace
Bicarbonate radicle (HCO_3)	182.
Sulphate radicle (SO_4)	232.
Phosphate radicle (PO_4)	0.25
Chlorine (Cl)	63.

WELLS IN THE NORTHWESTERN PART OF RICHMOND AND IN OUTLYING DISTRICTS TO THE NORTHWEST

A notable example of the uncertainty that attends the search for water in crystalline rocks is presented by three wells 550 to 650 feet deep at the Home Brewing Co. brewery, elevation 182 feet. These wells lie in a northeast line; the first well (8 inches), sunk in 1894, yields about 60 gallons per minute, and the barrel of the deep-well pump is over 400 feet below surface though normal water level is about 125 feet below; the second of smaller diameter (6 inches), 50 feet northeast of the first, sunk in 1899, gave but 5 gallons a minute when completed and has been dynamited several times at different depths without any increase in yield; the third (8 inches), 75 feet southwest of the first, is dry. The supply from the first two wells is used for condensing, brewing, and washing, but not in boilers as it scales badly. The company furnished an analysis of the water from the first well; this has been recomputed to express results in ionic form.

Partial analysis of water from 550-foot well of Home Brewing Co.

(First Scientific Station for the Art of Brewing, analyst.)

	Parts per 1,000,000
Total solids	448.
Organic and volatile	20.
Iron (Fe)	large traces
Calcium (Ca)	62.8
Magnesium (Mg)	12.6
Sulphate radicle (SO_4)	144.
Chlorine (Cl)	24.8
Nitrate radicle (NO_3)	none
Nitrite radicle (NO_2)	none

In the vicinity of the old State Exposition grounds are several wells of note. One, 8 inches in diameter, at the packing plant of W. S. Forbes, is said to be 400 feet deep and to yield, with the pump plunger 340 feet below surface, 300 gallons per minute. sufficient for all needs of the plant in 1906. The water is said to be remarkably good for boiler supply. A low mineral content is shown by the following analysis, recomputed from that furnished by the chemist.

Analysis of water from deep well of W. S. Forbes.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	92.0
Organic matter	8.0
Silica (SiO_2)	15.0
Iron (Fe)	0.4
Calcium (Ca)	4.0
Magnesium (Mg)	0.2
Sodium (Na)	22.0
Potassium (K)	not determined
Carbonate radicle (CO_3)	25.0
Bicarbonate radicle (HCO_3)	not determined
Sulphate radicle (SO_4)	12.0
Chlorine (Cl)	5.3

A well said to be 385 feet deep at the Richmond Union Stock Yards, about 250 yards east-northeast of the above well, obtained but 5 gallons per minute and is said to have been affected by pumping at the Forbes plant.

Another 8-inch well not far away, that of the Southern Stove Works, about 300 feet deep, is said to yield 200 gallons per minute of an excellent boiler water that is used for all purposes about the works. In recomputed form, an analysis made by Henry Froehling for the company shows the following radicles:

Analysis of water from deep well of Southern Stove Works.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	319.
Silica (SiO_2)	26.
Iron (Fe)	0.4
Aluminum (Al)	0.3
Calcium (Ca)	2.7
Magnesium (Mg)	0.7
Sodium (Na)	76.
Potassium (K)	3.6
Lithium (Li)	trace
Carbonate radicle (CO_3)	not determined
Bicarbonate radicle (HCO_3)	183.
Sulphate radicle (SO_4)	17.
Arsenate radicle ($As O_4$)	trace
Nitrate radicle (NO_3)	0.8
Chlorine (Cl)	8.5
Bromine (Br)	trace
Iodine (I)	trace

Northwest of the city, in the vicinity of Ginter Park, several deep wells have been sunk which vary in the amount of water obtained. One on the estate known as Westwood went 900 feet, passing through Columbia and Chesapeake deposits to 108 feet and through granite below. The yield was but 5 gallons per minute; another on the same estate after going through 118 feet of sedimentary beds and 350 feet through granite obtained 50 gallons. At the estate known as Westbrook a well 306 feet deep obtained 50 gallons per minute of good water after going through sedimentary beds for 96 feet and granite for 210 feet; whereas another well, 322 feet deep, on the Bloomingdale Stock Farm, got 25 gallons per minute after passing through 123 feet of Coastal Plain deposits and 199 feet of granite.

The best well in this section supplies Ginter Park. It is 8 inches in diameter and 357 feet deep. Granite was struck at 123 feet. In 1906 about 60,000 gallons daily were pumped from the well for residences and for the Union Theological Seminary. The water was tried at a large laundry but proved unsatisfactory because of its hardness; it contains a considerable amount of sulphates. An analysis made for the owner, recomputed to express results in ionic form, follows:

Analysis of water from deep well at Ginter Park.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	626.
Total scale-forming matter	219.5
Organic and volatile matter	6.6
Silica (SiO_2)	28.
Oxides of iron and alumina ($Fe_2O_3 + Al_2O_3$)	1.2
Calcium (Ca)	55.2
Magnesium (Mg)	11.1
Sodium (Na)	128.
Potassium (K)	8.5
Chlorine (Cl)	37.0
Carbonate radicle (CO_3)	87.
Sulphate radicle (SO_4)	263.
Nitrate radicle (NO_3)	0.18

WELLS SOUTH OF RICHMOND.

At the works of the American Ether Co. just south of the city, a 407-foot well on low ground near Almond Creek is said to have gone through "earth" for 117 feet and "rock" for 293 feet. Potomac cobble beds and soft sandstones outcrop nearby in the creek bed, and the greater part of the "earth" is probably Potomac material. The well developed a large supply, reported to have been 200 gallons per minute. This water at first was good but after some time became remarkably saline, and so corrosive that it could not be used even for condensing. The following analysis, recomputed from one made by the former chemist of the company, shows the unique character of the water:

Water from 410-foot well of American Ether Co.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	1610.
Sand and silica	32.
Oxides of iron and alumina ($F_2O_3 + Al_2O_3$)	16.
Calcium (Ca)	16.
Magnesium (Mg)	8.9
Sodium (Na)	580.
Carbonate radicle (CO_3)	86.
Sulphate radicle (SO_4)	93.
Chlorine (Cl)	778.

An 8-inch well at Curle's Neck, 15 miles south of Richmond, went through Coastal Plain deposits to 311 feet, and into granite 414 feet; when completed it yielded only 9 gallons per minute. It was dynamited with the result that steady pumping for three weeks at the rate of 100 gallons a minute lowered the water level only a little. A sanitary analysis made for the owner contained these determinations:

Partial analysis of water from 710-foot well of C. H. Senff at Curle's Neck.

(J. A. Deghuee, analyst.)

	Parts per 1,000,000
Total solids	234.
Volatile solids	12.
Hardness, equivalent to $CaCO_3$, before boiling	6.0
Hardness, equivalent to $CaCO_3$, after boiling	6.0
Chlorine	37.5

EMPORIA.

At Emporia on a river terrace 40 feet above sea level, just outside the western edge of the Chesapeake deposits, is an 8-inch, 600-foot well sunk for town supply. The well entered granite at 6 feet and struck crevices at 62, 370 and 470 feet, the last being the most important. The water is reported to stand 10 feet below surface. The supply is said to be free; pumping at the rate of 100 gallons per minute lowered the water 20 feet. Only 28 feet of casing, it is stated, was put in the well. The quality of the water is reported to have been unsatisfactory and the town is supplied with river water.

PROBABILITY OF FINDING WATER BY DEEP WELLS.

The accompanying list undoubtedly omits some rock wells 200 feet deep or over that have been drilled in and near Richmond; but it probably includes the majority, and the omissions are chiefly unsuccessful wells. Drillers are liable to omit mention of dry holes when telling of the wells they have sunk, and some pursue the mistaken policy of claiming, if there is a chance of closing a contract at so much per foot with no guarantee as to yield, that they can get water anywhere. Owners do not advertise a failure and the present holder of a property may have no knowledge of a well drilled some years ago. Hence the total number of unsuccessful wells is hard to ascertain. The list tabulated, however, is long enough to serve as a basis for estimates valuable to persons contemplating deep wells for considerable supplies of water at points along the western edge of the Coastal Plain where crystalline rocks occur having the general character of those near Richmond. The facts are as follows:

(1). Of the deep wells in crystalline rocks 2 were dry or gave too little water to be of use; 7 gave, estimated or measured, 5 to 25 gallons; 16, 26 to 100; 4, 101 to 200; and 2 over 200 gallons per minute. Or, 5 gave 5 gallons or less, making the proportion of commercially successful wells over 80 per cent.

(2). Of the 22 more successful wells, 15 or nearly 70 per cent went less than 500 feet into "granite" and 1 went less than 200 feet.

(3). Of the 17 wells yielding 50 gallons per minute or over, 6 were on high ground, 6 on low ground, and 5 on hillsides, showing that yields bear little relation to the situation of wells.

ANALYSES OF WATERS FROM WELLS IN CRYSTALLINE ROCKS NEAR RICHMOND.

The following table gives all the available analyses of the wells mentioned; it includes partial analyses and determinations of chlorine, total and volatile solids, and hardness from sanitary analyses. That some of the waters may show, when the wells are pumped heavily, a very different composition from that indicated by the table is altogether possible, as the heavy pumping of wells in crystalline rocks may modify the circulation of the water for a considerable distance.

TABLE 3.—*Details of Deep Wells in Crystalline Rocks.*

County and Place	Owner	Year completed	Elevation of surface	Depth	Diameter of casing	Depth to chief supply	Depth to other supplies	Length of casing	Depth to rock	Water stands below surface	Yield to pump	Temperature	Use	Quality	Remarks
			Ft.	*Ft.*	*In.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Gal.*	*°F.*			
DINWIDDIE:															
Petersburg	J. B. Worth & Co.	....	20	150	8	.....	.....	.....	5	.....	50	59	Ice making		
GREENESVILLE:															
Emporia	Town	1906	60	600	8	470	370	28	6	10	100	.....	Town supply	Hard, irony	Abandoned
HENRICO:															
Barton Heights	Town	1909	150	759	8	759	200	....	115	.....	40	.....	Town supply		
Curle's Neck	C. H. Senff	1900	26	726	8	357	26	315	311	26	100	.....		Soft	
Ginter Park	L. Ginter Land & Imp. Co.	1898	200	357	8	.....	.....	.....	123	40	166	.....	Town supply	Hard	
Ginter Park	Bloomingdale Stock Co.	....	.....	322	.....	.....	.....	.....	123	.....	25	.....			
Ginter Park	"Westbrook"	....	.....	306	.....	.....	.....	.....	96	.....	50	.....			
Ginter Park	"Westwood"	....	.....	900	6	.....	.....	.....	108	.....	5	.....			
Ginter Park	"Westwood"	....	.....	468	6	468	.....	.....	118	.....	50	.....			
Richmond	American Ether Co.	1900	25	407	6	405	.....	80	117	20	175	.....	Condensing	Salt	Abandoned
Richmond	Albemarle Paper Co.	1886	10	225	6	.....	.....	200	5	10	25	.....	Drinking, washing		
Richmond	A. D. Atkinson (Richmond Hotel)	1905	157	572	8	.....	.....	196	.....	.....	300	.....	Hotel supply		
Richmond	Chesterfield Apartment Co.	1904	195	365	8	230	.....	.....	.....	150	48	.....	Drinking, boiler		
Richmond	W. S. Forbes	1903	180	400	8	.....	.....	.....	.....	.....	300	.....	Boiler and washing		
Richmond	W. S. Forbes	....	180	250	.....	.....	.....	.....	.....	.....	25	.....	Boiler and washing		
Richmond	Home Brewing Co.	1894	182	550	6	.....	.....	.....	98	125	50	62	Brewing	Hard	
Richmond	Home Brewing Co.	1899	182	550	8	.....	.....	.....	98	.....	5	.....	Brewing	Hard	
Richmond	Home Brewing Co.	1899	182	650	8	.....	.....	.....	98	.....	0	.....			Dry hole
Richmond	Jefferson Realty Co.	1895	180	425	4	410	.....	.....	123	.....	.....	.....			Not used in 1906
Richmond	Jefferson Realty Co.	1896	180	445	8	425	.....	400	123	60	60	62	Hotel	Soft	
Richmond	Kingan & Co.	1893	.....	428	6	.....	.....	149	23	20	60	62	Condensing	Corrosive	
Richmond	Kingan & Co.	....	180	300	8	.....	.....	.....	.....	.....	.....	.....	General		
Richmond	Murphy Hotel Co.	1904	175	450	8	250	.....	150	125	100	45	.....	Hotel, medicinal		Pumping 50 gal. p. m. lowers water 50 feet.
Richmond	Murphy Hotel Co.	1906	175	702	8	650	.....	169	125	.....	65	.....	Hotel		
Richmond	Merchants Cold Storage & Ice Co.	1901	95	248	8	.....	.....	.....	.....	.....	120	62	Condensing		
Richmond	Richmond Paper Co.	1884	83	256	6	250	.....	.....	.....	60	20	.....		Irony	Abandoned
Richmond	Richmond Union Stockyards Co.	1899	.....	385	8	.....	.....	180	.....	.....	5	.....	Watering stock		
Richmond	Seaboard Air Line	1900	200	500	8	.....	.....	200	.....	.....	0	.....			Dry hole
Richmond	Southern Stove Works	1892	.....	300	6	.....	.....	.....	.....	.....	200	.....	Boiler, drinking		
Richmond	Transparent Ice Co.	1900	105	703	6	.....	.....	47	.....	15	60	.....	Ice making		Plant idle in 1906
Richmond	Virginia State Penitentiary	....	115	248	6	240	.....	.....	38	.....	150 to 70	.....	General		
Richmond	Virginia Union University	....	.....	200	6	.....	.....	.....	.....	40	30	.....			
School	Laurel Reformatory School	1905	.....	300	8	.....	.....	33	23	25	60	.....	General		

TABLE 4.—*Analyses of well water from crystalline rocks.*

(Parts per 1,000,000)

Locality	Owner	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Lithium (Li)	Arsenic (As)
Catman	O. H. Senff	234	12.0	......	......	......	......	......	......	......	......	......	......	......	......
Ginter Park	Lewis Ginter Land and Improvement Co.	620	6.6	28.0	1.2	......	......	......	55.2	11.0	......	128.0	8.5	......	......
Richmond	American Ether Co.	1610.	......	32.0	16.0	......	......	......	16.0	8.9	......	580.0	......	......	......
Richmond	Chesterfield Apartments	287.	5.9	47.0	......	0.5	0.5	.17	29.0	12.0	.24	18.	3.7	.01	......
Richmond	Hotel Jefferson	173.	......	38.0	0.5	......	......	......	30.0	8.6	......	6.2	1.2	......	......
Richmond	Home Brewing Co.	448.	20.0	......	......	tr.	......	......	63.0	12.6	......	......	......	......	......
Richmond	Kingan & Co.	779.	......	31.5	0.9	......	......	......	......	27.0	......	......	......	......	......
Richmond	Kingan & Co.	260.	58.0	......	......	......	......	......	0.8	2.2	......	74.0	......	......	......
Richmond	Murphy Hotel Co.	196.	0.82	34.4	......	0.31	0.3	.063	21.0	9.5	.1[a]	21.9	5.9	.015	......
Richmond	Richmond Hotel	702.	......	28.0	......	0.18	1.1	.03	68.0	28.0	.02[b]	69.0	28.0	.01	......
Richmond	Southern Stove Works	319.	......	26.0	......	0.1	0.3	......	2.7	0.7	......	76.0	3.6	tr.	tr.
Richmond	Southern Stove Works	271.	28.0	......	......	......	......	......	......	......	......	......	......	......	......
Richmond	State Penitentiary	190.	20.0	20.0	......	......	......	......	8.6	0.98	......	46.0	......	......	......
Richmond	W. S. Forbes	92.	8.0	15.0	......	0.4	......	......	4.0	0.2	......	22.0	......	......	......
Richmond	Virginia Union University	559.	207.0	40.0	......	......	......	......	82.0	12.0	......	7.6	......	......	......
Sherwood Park	......	66.7	......	27.0	2.9	......	......	......	7.0	1.3	......	......	......	......	......
School	Laurel Industrial School	392.	......	......	......	......	......	......	26.0	8.6	......	106.0	......	......	......

[a]Water also contains .05 parts barium (Ba).
[b]Water also contains .041 parts barium (Ba).

TABLE 4. (*Continued.*)—*Analyses of well water from crystalline rocks.*

(Parts per 1,000,000)

Locality	Owner	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Phosphate radicle (PO_4)	Bromine (Br)	Iodine (I)	Chlorine (Cl)	Nitrate radicle (NO_3)	Analyst and date
Catman	C. H. Senff	......	......	......	0.0	......	......	37.5	0.0	J. A. Deghuée
Emporia	......									
Ginter Park	Lewis Ginter Land and Improvement Co.	87.0	......	263.	......	......	......	37.0	0.18	Froehling, 1902
Richmond	American Ether Co.	86.0	......	93.0	......	......	......	778.0	......	Froehling, 1892
Richmond	Chesterfield Apartments	......	138.0	26.	0.8	tr.	.009	6.1	......	Froehling & Robertson, 1904
Richmond	Hotel Jefferson	51.0	......	33.0	......	......	......	4.5	......	Froehling, 1896
Richmond	Home Brewing Co.	......	......	144.	......	......	......	25.0	0.0	First Scientific Station for the Art of Brewing
Richmond	Kingan & Co.	105.0	......	......	......	......	......	......	......	Froehling, 1893
Richmond	Kingan & Co.	......	......	105.0	......	......	......	113.0	......	H. Bentley Smith Co., 1904
Richmond	Murphy Hotel Co.	70.0	......	24.0	.19	......	.002	6.6	0.15	Froehling & Robertson, 1904
Richmond	Richmond Hotel	......	182.0	232.0	.25	tr.	tr.	63.0	......	Froehling & Robertson, 1906
Richmond	Southern Stove Works	......	183.0	17.0	......	tr.	tr.	8.5	0.8	Froehling, 1902
	Southern Stove Works	......	......	......	......	......	......	12.0	0.25	H. Bentley Smith Co., 1904
Richmond	State Penitentiary	57.0	......	12.0	......	......	......	13.0	......	Froehling, 1903
Richmond	W. S. Forbes	25.0	......	12.0	......	......	......	5.3	......	
Richmond	Virginia Union University	96.0	......	10.0	......	......	......	35.4	68.0	H. Bentley Smith Co., 1905
Sherwood Park	......	4.2	......	......	......	......	......	......	......	Froehling, 1897
School	Laurel Industrial School	54.0	......	101.	......	......	......	96.0	......	H. Bentley Smith Co., 1907

A comparison of the analyses shows that the total solids range from 66 to 1,600 parts per million; the calcium from 1 to 70 parts; the magnesium from 0.2 to 28 parts; the sodium from 6 to 580 parts; the carbonates and bicarbonates from 4 to 180 parts; the sulphates from 10 to 260 parts; and the chlorine from 4.5 to 780 parts. The differences are explained by differences in the underground circulation.

Changes in quality of the water.—Little can be foretold regarding the bacterial purity of the supplies from wells in granite underlying a densely populated area. Where the surface drainage is good, the soil cover on the rock thick, and the well casing tight, conditions which may obtain at all wells on high ground in Richmond, the danger of contamination is remote. But heavy pumping can produce such changes in the circulation of granite waters that the waters from wells which are seemingly not exposed to contamination may be easily polluted. After being in use a year, a deep well at Atlanta, Ga., was fouled by impure waters that may have entered the well at a depth of several hunderd feet. Hence it is advisable to analyze periodically the water of a deep well that is heavily pumped.

At Richmond the joint cracks of the granite may be filled either with river water, with ground water slightly filtered, or with water that has soaked through many feet of stratified material of varying composition. These waters may mingle after a relatively short journey under ground, or after having passed through a long series of intersecting joints and having descended hundreds of feet. A particular well may draw on one crevice or a series of connecting crevices, and hence the quality of the water from nearby wells may differ greatly.

An erratic well water, like that of the American Ether Company, obviously must be local. Various explanations have been suggested for the saline character of somewhat similar waters found in granite. A reasonable explanation for the Richmond area is that sea-water accumulated in crevices at a time when the James was salt as far west as the rapids; an alternative is derivation from water that did not come from the surface but ascended from a great depth in the earth's crust.

DEEP WATERS OF THE NORFOLK-NEWPORT NEWS AREA

General statement.—The possibility of obtaining artesian water by deep drilling near the mouth of the James first attracted attention 65 years ago when Government authorities were looking for something better than cistern or shallow well water for the supply of Fort Monroe. Since then wells have been drilled near Fort Monroe; on Back River, 7 miles north of the fort; at Newport News, 7 miles west; and in the vicinity of Norfolk, from 8 to 15 miles south and southeast. In all, fully 10 wells have been put down and not one has been considered a complete success. Some did not find flows, some found flows that were too salty for drinking or boiler supply, and some found little water.

Because a great number of successful wells have been drilled elsewhere in Tidewater Virginia, and because drillers and others have claimed that it is possible to get artesian water in the vicinity of Norfolk and Newport News, the questions whether there is a possibility of finding such water and why the wells thus far drilled have been unsuccessful merit detailed answers. Besides, although Norfolk and Newport News had in 1906 good public supplies the number of manufacturing establishments near the mouth of James River that may desire to procure for industrial purposes cheaper water than that furnished by public service systems is large, and some may attempt to find it by deep drilling. As enough work has been done to permit definite answers to some questions that would arise in the mind of any one investigating artesian possibilities, whether well owner or driller, a review of the results of deep work in the Norfolk-Newport News area and what these results indicate may save misdirected effort and wasted money. In fact, the reason for the failures to get good artesian water about Norfolk was the most important problem that came up for investigation in the course of the field work for this report.

Limits of area.—By the term Norfolk-Newport News area is meant Elizabeth City County and the south end of Warwick County, which are north of James River and Hampton Roads, and the north part of Norfolk and Princess Anne counties which lie south and southeast of the mouth of the James. The area is thus defined not because its deep wells show features which are not presented by wells elsewhere, but because of its population (over 75,000) and because it is destined to be of increasing importance as a manufacturing district. As has been indicated in the general discussion of artesian conditions in the Virginia Coastal Plain and as the accounts of work in other counties show, no flows, scanty flows, or highly mineralized water seem to be characteristic of the deep wells (more than 400 feet) in a considerable area, one that probably embraces most of Norfolk, all of Princess Anne County, the east end of Gloucester County, part of Mathews County, the east end of Middlesex County, most of Accomac and all of Northampton County.

DEEP WELLS NORTH OF JAMES RIVER

Fort Monroe.—The first deep boring in the Norfolk-Newport News area, the first in Tidewater Virginia and one of the first in the entire Atlantic Coastal Plain—the first probably being the unsuccessful well at Charleston, S. C., sunk in 1823 to a depth of 335 feet—was begun by the Government in 1864 to obtain a supply to supplant or supplement the cistern water used at the post. A previous attempt, in 1845, had reached a depth of 168 feet. In spite of the great advance in the art of well-drilling between 1845 and 1864, rigs and tools for rapid work in the soft unconsolidated beds of the Coastal Plain had not been devised at the latter date, nor were drillers generally aware of the troubles that await the man who, skilled in drilling rock wells, undertakes with such experience as a guide to sink through clays and quicksands. So it is not surprising that the well was abandoned in 1869 at a depth of 907 feet. The attempt proved of decided value to science, because the samples of the strata penetrated were examined by Rogers[a] in 1869 and later by Fontaine and Darton, and the records compiled from this study (which have been published by Darton[b]) gave the first information on the total thickness far under cover of the Miocene and Eocene deposits in Virginia. Practically, the well was a failure; several sands containing water under so low a head that it would not rise to surface may have been penetrated, but the only water noted in the record was struck in gray sand at 599 feet. This water had head enough to rise above the level of the parade ground, 3 feet above tide, but was "very saline."

In the report, dated 1876, by S. T. Abert[c] on the survey of a line to connect the waters of the Cape Fear and Neuse rivers and for a connection by water between Norfolk harbor and Cape Fear River appears this record of borings 313 feet deep at Fort Monroe. The object of the work is not stated and no mention is made of water.

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[a]Rogers, W. B., Geology of the Virginias, 1885, p. 733.

[b]Darton, N. H., Artesian Water Prospects in the Atlantic Coastal Plain, U. S. Geol. Survey, Bull. 138, pp. 168-169.

[c]U. S. War Dept., 44th Congress, 1st Session, Senate Doc. No. 35, p. 16.

Record of borings at Fort Monroe, Va.

(Authority, U. S. Engineer's Office.)

Materials	Thickness *(Feet)*	Depth *(Feet)*
Marsh soil	5½	5½
Fine clean dark sand	12½	18
Angular light-colored sand, containing coarse sand, round pebbles and mud	10	28
Sand and mud, different layers	12	40
Some stone, sand and mud	5	45
Miocene marl	200	245
(The lowest layer of the last showed some greensand and shells, next hard stone full of shells)		
Sand, bluish-gray, mixed with mud	16	261
Same, fragments of shell marl, stone harder	9	270
Softer marl, sky blue	43	313
A note says "fossil shells or continuous marine deposits were 224 feet in thickness."		

A final and decisive attempt to find potable artesian water at Fort Monroe was made in 1902. This well, sunk within the fort, started at an elevation of about 3 feet, passed through all underlying formations of the Coastal Plain, struck crystalline bed rock at 2,240 feet below mean high tide, and was sunk in this rock 8 feet, making its total depth 2,251 feet—the deepest well in the entire Atlantic Coastal Plain from New York to northern Florida. A hydraulic jet rig was used and progress was rapid in spite of the large diameter; 15-inch casing was placed at the start and 12-inch to 1,200 feet; below 1,200 feet the driller had so little trouble that 9-inch casing was used down to 2,128 feet; beyond that depth the well was not cased. Drilling began January 25, and on April 21 the well was down 2,200 feet.

Some samples of borings were saved during the progress of the work and the driller noted the general character of the beds. The type of the rig and possible errors in labelling the samples make the borings of slight determinative value, and the driller's notes are not detailed enough to be of value in discriminating formations. Hence an accurate record of this well is not available.

According to Capt. C. P. Townsley, U. S. A., while boring was in progress nothing could be told about any water bed struck except by casing to it and bailing the well. This was done at 1,317 and 2,128 feet, and at both depths the water was very salty. Evidences of water appeared at 1,520, 1,630, 1.915, and 1,939 feet, but were not tested. The head of the water at 2,128 feet was 20 feet below surface and the yield was so small that with an 8-inch boiler 21 feet long the water was easily lowered 1,000 feet in the 9-inch casing in 10 hours. The most promising horizons between 1,320 feet and 2,128 feet were at 1,640 feet and 1,915 feet. According to another officer, who happened to be at the fort in 1902 and speaks from memory, the largest flow found had head enough to just run over the casing, elevation about 6½ feet above mean tide. Efforts to develop flows of potable water at points above 2,128 feet by the use of dynamite proved unavailing; in consequence the 12-inch casing down to 600 feet and the 9-inch down to 1,200 feet were removed and no use whatever has been made of this well.

No quantitative analyses of the water from any flow appear to have been made; if any were, there is no record of them.

Newport News.—In 1882, the Old Dominion Land Company which had undertaken extensive real estate developments at Newport News, began a search for artesian water there. Unfortunately drilling began on ground 31 feet above sea level, so that the prospects for a flowing well, as subsequent work has shown, were not bright. Work started March 9, with a standard cable rig. The driller met with many accidents, in repairing some of which he had more than average good luck. At a depth of 329 feet, reached on March 31, it was found impossible to drive the 8-inch casing farther; a series of accidents followed the resumption of work with 6-inch casing, and after this casing had broken in several places, the well was abandoned on July 28, after it had been sunk 582½ feet.

The following log is compiled from the record preserved by the company.

Record of well of Old Dominion Land Co., Newport News, Virginia.

(Authority, Old Dominion Land Co.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand "6 kinds"	18	18
Sand and yellow clay	15	33
Sand and hard tough blue clay	36	69
Hard blue clay containing sand with shells; clay, dark blue but soft, with few shells at 106 feet	37	106
Blue clay	19	125
Quicksand	7	132
Greenish sandy clay, or marl, with numerous large shells; hard bluish sand-rock at 184½ to 186 feet; water below rock rose high enough to be seen by looking down pipe	121	253
Greenish or bluish clay, free from sand	253	270
Hard stiff tough blue clay	69	339
Bluish "soapstone"	70	409
Lighter more sandy clay which "changes" at 414 and 420 feet	14	423
Coarse sand; water rose to within 10 feet of the surface	3	426
Shells, stone and sand	2	428
Sand, which rose nearly 150 feet in pipe over night	9	437
Sand with streaks of cement rock	18	455
Sand, clayey towards bottom	38	493
Heavy brownish clay, gravelly towards bottom	14	507
Clay with stones	39	546
Clay and sand	36	582

Water was struck at two horizons in the Chesapeake group, namely, below a rock stratum at 186 feet and in a bed of coarse sand at 422 feet; neither horizon was given a good test; the water in the 422-foot bed rose perhaps 21 feet above sea level. It is unfortunate that no note was taken of the quality or volume of this water; it might have yielded a good flow at a lower elevation.

In 1907, H. E. Shimp began a well for the Old Dominion Brewing Co. at Newport News, but stopped work at a depth of about 500 feet. He did not keep a record of the section shown by the drill, and the samples he saved were lost before they could be examined by a geologist.

Back River.—A deep well was sunk in 1886 at the site of a contemplated fish factory on the tip of the sand spit, known as North End Point, on the south side of the entrance to Back River, about 7 miles north-northeast of Fort Monroe. This well reached a depth of 1,172 feet; there the drill struck a very hard stratum, which the driller thought was granite; the drill rod broke and work was abandoned. The notable thing about this well is that no water worthy of mention was found except in two beds of gravel, between 1,000 and 1,007 feet, in the Potomac group. Whether water in sufficient quantity might have been found by properly testing some of the sandy beds penetrated is uncertain. Darton has published the following record.[a]

Record of well at North End Point.

(Authority, C. C. Knox)

Material	Thickness *(Feet)*	Depth *(Feet)*
White sand and gravel	75	75
Blue clay	5	80
White sand	20	100
Thin layers of sand and blue clay	30	130
Blue or gray sand	25	155
Quicksand	10	165
Hard white sand	5	170
Loose white sand	15	185
Black marl	12	187
White sand and marl	162	249
Rock	1	250
Blue clay	17	267
Stone	1	268
Hard sand	7	275
Blue clay with thin marl layers	55	530
Hard blue clay	70	600
Quicksand	18	618
Stone or bowlder	2	620
White sand	5	625
Yellow sand	1	626
Clay and sand mixed	29	695
Gravel and clay	1	696
Hard and soft layers of blue clay	4	740
Very hard clay	8	748
Soft blue clay	165	913
Hard blue clay	7	920
Coarse sand	6	926
Sandstone	3	939
Hard sandstone	16	955
Hard sand with few gravels	18	973
Hard sandstone	27	1000
Sandstone with two veins of gravel and some water	7	1007
Alternate layers of sand and sandstone 3 to 4 feet thick	8	1015
Alternate layers of sand and sandstone 3 to 15 feet thick	65	1080
Very hard white sand	80	1100
Sandstone	155	1155
Red sandstone	5	1160
Hard sandstone	10	1170
Hardest kind of stone or granite; here drill rods broke and work was abandoned	2	1172

[a]Darton, N. H., Artesian Well Prospects in the Atlantic Coastal Plain, U. S. Geol. Survey, Bull. 138, pp. 171-172.

Another attempt to get water on North End Point was made in 1896. R. H. Milligan, the driller, used a hollow-rod, jet outfit and had little difficulty in sinking a 3-inch hole 1,035 feet. No water that would flow at surface was found, but in conversation with the writer Mr. Milligan has stated that he thinks, in the light of his experience with deep wells at other points near the shore of Chesapeake Bay, that there are at the mouth of Back River deep-lying sands which will yield flows to a well sunk with regard to the local conditions. Though this is not impossible, the writer is inclined to regard the prospects for obtaining a good flow of potable water from depths below 500 feet at North End Point as distinctly unfavorable.

Hotel Chamberlain.—After the unsuccessful attempt in 1864-69 no further efforts to get artesian water in the vicinity of Fort Monroe appear to have been made until 1896, when a well was sunk at the Hotel Chamberlain. The well started at an elevation of 4 feet above high water, on made ground near the sea wall in the rear of the hotel, and reached a depth of 945 feet.

The following record of the well compiled from a study of the borings and notes furnished by the contractor and his foreman has been published.[a]

[a]Woolman, Lewis, Artesian Wells, Geol. Survey, N. J., Ann. Rept. 1898, pp. 122-125.

Record of artesian well at Chamberlain Hotel, Old Point Comfort.

Material	Thickness (Feet)	Depth (Feet)
Surface sand	10	10
Sand with minute fragments of shells	20	30
Dark gray sand, spines of sea urchins plentiful	10	40
Sand, lighter in color	10	50
Sandy clay with Miocene shells	10	60
Greenish sandy clay	30	90
Sandy clay with Miocene shells	10	100
Greenish sandy clay, a few shells	20	120
Greenish sandy clay, with shells in great number	10	130
Fine dark gray sand, sea urchins spines abundant	30	160
Dark brownish sandy clay, with shells	20	180
Dark greenish clay (marine shells, Miocene age, at 190, 200, 270 feet)	100	280
Dark greenish clay, more sandy, but without shells	60	340
Dark greenish clay, not so sandy, still without shells	190	530
Dark bluish-green diatomaceous clay	30	560
Dark clay, not diatomaceous	30	590
Dark brownish sandy clay	20	610
Greenish clayey sand, with a large admixture of greensand grains and some foraminifera	50	660
Greenish sandy clay with green sand and foraminifera	50	710
Brownish sandy clay	710	800
Gray sand, mixture of greensand grains and pure quartz grains	20	820
Brownish clayey sand, also contains a mixture of greensand and quartz grains	20	840
Calcareous rock crust and pebble conglomerate with some wood and shells	10	850
Dark sandy micaceous clay	55	905
Fine gray sand	15	920
Coarse gravel, water-bearing	25	945

The well gives a rather small flow, inasmuch as the inner casing is 4 inches in diameter, of the saltest and most mineralized water yielded by any flowing well in the Norfolk-Newport News area. Though the log makes no mention of water above 945 feet, it is likely that several sandy beds were penetrated which contained water under insufficient head to flow at surface. The driller gave the estimated yield as 50 gallons per minute[a] and the head as over 17 feet above surface or about 22 feet above sea level. In 1906, according to the engineer of the hotel power plant, the flow, at surface, was "a ¾-inch pipe full" and the head was 14 feet above tide. The flow at 5 feet elevation is certainly not over 25 gallons per minute. The water has so much mineral matter in solution that it is not used except for flushing; it is too salty for drinking or for boiler use and is so

[a] Darton, N. H., U. S. Geol. Survey, Folio No. 80, 1902.

iron-bearing that, though perfectly clear when fresh from the well, it soon becomes turbid and deposits much ferric hydrate. Hence it is unsuitable for bathing or for laundry use.

The following analysis made in March, 1906, shows that though highly mineralized, the flow resembles the excellent water from artesian wells to the west in containing much soda and comparatively little lime or magnesia, in proportion to the total solids. Much of the increased mineralization is probably in the form of common salt, sulphates of soda, potash, lime, and magnesia, and iron compounds.

Analysis of water from 945-foot well at Hotel Chamberlain, Fort Monroe.

(W. H. Taylor, analyst.)

	Parts per 1,000,000
Total solids	9248
Silica (SiO_2)	14
Aluminum (Al)	23
Iron (Fe)	16
Calcium (Ca)	97
Magnesium (Mg)	44
Sodium (Na)	3268
Potassium (K)	87
Lithium (Li)	trace
Bicarbonate radicle (HCO_3)	433
Sulphate radicle (SO_4)	265
Chlorine (Cl)	4978

The following sanitary analysis, also made in March 1906, shows some additional characteristics of this water:

Sanitary analysis of water from 945-foot well at Hotel Chamberlain.

(Penniman and Brown, analysts.)

	Parts per 1,000,000
Total solids at 200° F.	9145.
Volatile solids	188.
Chlorine	4940.
Nitrogen as free ammonia	1.50
Nitrogen as albumenoid ammonia	0.16
Nitrates	trace
Nitrites	none

DEEP WELLS SOUTH OF JAMES RIVER

General statement.—In that part of the Norfolk-Newport News area south of James River and Hampton Roads, at least six wells over 200 feet deep have been sunk, but detailed records of only two are available.

However, the results of the borings are sufficient to determine the prospects for getting potable artesian water from deeply buried beds. As will be seen, though no waters are known to have been found as highly mineralized as the flows tapped by the borings near Fort Monroe, particularly the Hotel Chamberlain well, the flows all contain large amounts of solids in solution, are not what would ordinarily be called good potable water, and are not suited for boiler supply.

Virginia Beach.—One of the earlier borings for deep water in the southern part of the area under discussion was made in the winter of 1888-1889 at the Princess Anne Hotel at Virginia Beach. The elevation of the surface was possibly 7 feet. According to F. O. Clebourne, who was at the time in the employ of the company that had the work done, the well was sunk 600 feet and found no water below 73 feet. No record of the beds penetrated was kept, nor is any information available to show whether possible water-bearing beds were properly tested, but it is probable that no bed which would have yielded a flow was penetrated.

Masons Creek.—George S. Bunting states that in 1890, using a hand rig, he drilled a 1½-inch well 575 feet deep near Masons Creek, a short distance west of the present post-office of Rixton. Mr. Bunting kept no record but remembers that he cased the well to 260 feet and drilled from there to the bottom without casing. At some point below 260 feet, he struck a weak stream which did not give a flow though the elevation of the surface is not over 10 feet. A bed of shells was struck at 200 feet and shell beds or hard layers were struck at 160, 252, and 500 feet, but from 260 to 575 feet nearly all the material was fine, bluish sand.

Money Point.—South of Norfolk, on Elizabeth River, at Money Point, two deep wells were bored, but no record of either seems to have been preserved. One well has been long abandoned; the other, 562 feet deep, is said to flow 30 gallons per minute of brackish irony water at an elevation of 5 feet above tide. The flow is not suited for boiler use but is reported to be drunk as a mineral water by some people in the vicinity of the well.

Lambert Point.—In 1891 a well was completed near the pier at the Norfolk and Western Railroad terminal on Lambert Point, north of Norfolk. The well, which is close to the shore and was drilled for boiler supply, reached a reported depth of 616 feet. It struck a strong flow, 65 gallons per minute, at 610 feet in a coarse micaceous sand; and a weak flow, about 1 gallon per minute, at 603 feet in another sand bed. The driller kept a record and saved samples. Records compiled from an examination of the samples have been published by Darton[a] and by Woolman.[b] The following log is given in slightly different form.

Log of well on Lambert Point.

Material	Thickness *(Feet)*	Depth *(Feet)*
Slightly yellowish sand, shell fragments	17	17
Bluish clay, shell fragments	27	44
Gray, fine micaceous sand, shell fragments	139	183
Greenish gray, sandy clay	8	191
Gray micaceous sands	42	233
Greenish gray fine sand and clay; tough when dry (fossil shells)	31	264
Gray or bluish clay	22	286
Gray or bluish fine sand, shell fragments	69	355
Gray or bluish clay	22	377
Gray, fine sand, shell fragments	20	397
Dark gray or bluish clay	10	407
Gray moderately coarse sand, some glauconite	19	526
Small gravel, shell fragments	8	534
Gray or bluish clay	23	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
Small gravel in gray sand, shell fragments, water	3	606
Rock, shell fragments	4	610
Gray, fine to moderately coarse micaceous sand, oyster shells	6	616

In the Norfolk folio of the U. S. Geological Survey Darton gives a list of shells and diatoms found in the borings. These show the water-bearing sand to be of Upper Cretaceous (Matawan) age.

The flow from the 610-foot sand was, when tested in 1898, 65 gallons per minute through the 6-inch casing at an elevation of 7 feet above surface, or 15 feet above mean high tide; the head was about 30 feet above sea level. Tests in 1906 showed that the well was yielding 51 gallons per minute. The temperature of the flow is 72° F.

The water is drunk by some employees at the terminal and by many people in the vicinity, but while it undoubtedly has medicinal value it is rather too mineralized for steady drinking. The prime reason for classing the well as unsuccessful, however, is that the railroad company has made little use of it except for washing cars and cleaning up around the piers. In a boiler the water foams badly and rapidly corrodes stay bolts. It

[a]Darton, N. H., Op. cit. p. 172.
[b]Woolman, Lewis. Ann. Rept. N. J. Geol. Survey, 1899, pp. 87-92.

probably contains considerable common salt and bicarbonate of soda (though no bicarbonates are reported) and some sulphate of soda. It contains very little lime. The following analysis was made in 1891:

Analysis of water from 616-foot well of Norfolk and Western Railroad, Lambert Point.

(C. W. Shepard, analyst.)

	Parts per 1,000,000
Total solids	1093.
Silica (SiO_2)	10.
Oxides of iron and alumina ($Fe_2O_3 + Al_2O_3$)	0.91
Calcium (Ca)	5.0
Magnesium (Mg)	1.7
Sodium (Na)	415.
Potassium (K)	21.
Sulphate radicle (SO_4)	43.
Carbonate radicle (CO_3)	245.
Chlorine (Cl)	351.

Whether better water could have been had by deeper drilling is doubtful. It is barely possible that water a little less mineralized might have been found above 1,000 feet; below that depth, judging from the results of other borings, it is likely that the water obtained would have been more saline.

Moore's Bridges.—A well was sunk at Moore's Bridges, 5 miles northeast of Norfolk near Diamond Springs post-office, by the Norfolk City Water Department in 1890, to a depth of 730 feet; it found salty water. The next and the most important well in the southern part of the Norfolk-Newport News area was sunk in 1896-98 at Moore's Bridges, to test all the water-bearing sands found down to bed rock. A standard cable rig was used. Partly on account of the rig, work progressed slowly, and operations were finally abandoned at 1,760 feet below surface, elevation about 8 feet above sea level.

The following log has been slightly changed from the form in which it was published by Woolman[a]. References to the microscopic organisms noted by Woolman are omitted.

[b]Woolman, Lewis, Ann. Rept. N. J. Geol. Survey, 1899, pp. 92-102.

Record of Norfolk City Well near Waterway.

Material	Thickness (Feet)	Depth (Feet)
Light buff sandy loam	3	5
Fine light sand	13	18
Sand, water-bearing	3	21
Bluish clay, fossiliferous	44	65
Bluish clay, not fossiliferous; small streak of gravel at 80 feet	20	85
Gray clayey sand and gravel; scallop shell (Miocene), at 105 feet	20	105
Gray clayey sand, fossiliferous and containing rather large white quartz pebbles at 110 to 115 feet. *Rangia cuneata* shell at 125 feet	20	125
Gray clayey sand, with comminuted shell	40	165
Fine bluish clay, scallop shell (Miocene) at 185 feet	85	250
Gray clay, with much sand; full of shells about 5 inches long, boring had to be cased	10	260
Dark greenish sandy clay	25	285
Soft clay which ran into boring	20	305
Greenish gray clay	5	310
Gray sandy clay, very sandy clay had to be cased off, 310-320 feet	65	375
Light fine less sandy clay	70	445
Light gray fine clay, comminuted shell at 465-475 feet	135	580
Slightly lighter, fine clay, called "brown mud" by driller	45	625
Green sand marl (glauconite) mixed with white quartz sand	10	635
Dark greenish clay	30	665
Dark sticky hard clay	20	685
Gray sticky hard clay, with glauconite described by driller as "sand gravel and marl"	20	705
Lighter gray sticky fine clay; much comminuted shell at 715 feet	23	728
Gray sand, small flow of salty water	2	730
Soft sandy clay, with much comminuted shell	5	735
Small gravel (and clay), flow of salty water	10	745
Very sandy greenish clay, micaceous sand, fossil shell 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 water at 780 to 783 feet[a] Upper Cretaceous shell	18	783
White, very light gray, sticky clay	2	785
Gray quartzose sand, some mica, no glauconite; slightly salty water, flow 35 gallons per minute at surface, 786 to 805 feet	30	815
Decidedly darker gray sand, no glauconite	20	835
Lighter gray sand	35	870
Gray very sandy clay	20	890
Black sticky mud (no sample)	8	898
Clayey sands or alterations of gray sands and clays, sands micaceous; lignite at 925 and 965 feet, quartz pebbles at 925-935 feet; slightly salt water; flow 75 gallons per minute at 950 feet; 10 gallons per minute at 975 to 980 feet; 15 gallons per minute at 985 feet	93	991

[a]All sands between 750 and 783 feet are said to have flowed into the well. This indicates the sands were loose, but not, as Woolman suggests, strongly water-bearing.

Record of Norfolk City Well near Waterway—(Continued).

Material	Thickness (Feet)	Depth (Feet)
Slightly yellowish (greenish when fresh) sandy clay........	42	1.033
Gray sands, some micaceous, pebbles at 1,060-1,070 feet; flows of salt water, 25 gallons at 1,038 feet; 150 gallons at 1,070 feet	45	1.078
Gray sands, clayey and micaeous above 1,100 feet	32	1.120
Darker gray fine to coarse sands, heavy pebbles at 1.130 feet; coarse gray sand lignite at 1,160 feet; heavy pebbles and water at 1,190 feet. yield of water by bailing 350,000 gallons per 24 hours; said to have been fresh at first, afterwards salty	30	1.190
Reddish and reddish yellow or buff clays and clayey sands, heavy 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
Slightly yellowish-olive somewhat micaceous sand; "some water"	35	1.290
"White marl" (no sample)	5	1.295
Reddish yellow and gray clays and sandy clays called "red marl," but not glauconite; fossil shell (Upper Cretaceous) reported from 1,320 feet..........	35	1.330
Alternations of sands (micaceous 1,320-1,340 feet; not micaceous below) and clayey sands varying from white or light gray to yellowish in color; heavy pebbles at 1,470-1,480 feet and 1,540-1,570 feet. Clay beds (no samples), 1,356-1,358 feet; 1,400 to 1,410 feet; 1,557-1,560 feet; 1,568-1,571 feet; lignite at 1,500 feet; salt water, good flow at 1,480 feet; flows at 1,510-1,517 and at 1,535 feet..........	250	1,580
Dark slightly variegated clay..........	20	1,600
Reddish or slightly reddish coarse sands and clayey sands; beds of clay (no samples) probably not glauconitic but bluish 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
Reddish variegated clay	42	1,742
Loose sand which ran up 150 feet in casing; evidently water-bearing (no sample)	20	1,762

Darton[a] states that water beds were found at 783, 805, 950, 975, 984, 1,038, 1,072, 1,190, 1,220, 1,227, and 1,480 feet, and at the bottom, which yielded from 10 to 150 gallons per minute under the pump. One or two of the beds may have given more but no flow of fresh water was struck. The water from the 1,190-foot bed did not quite overflow; at 1,220, 1,227, and several points below small volumes of salt water were found, and at

[a]Darton, N. H., Geologic Atlas of United States, Norfolk Folio, No. 80, p. 4.

1,480 feet a large volume of very salt water. Twelve-inch casing was used to 778 feet, 10-inch to 1,208 feet, 8-inch to 1,539 feet, 6-inch to 1,730 feet, and 4½-inch to 1,750 feet.

The well was dynamited at 1,072 feet and possibly at other points, and nothing definite is known of the source of the present flow. It is supposed to come from about 680 feet but the temperature indicates a greater depth. The yield amounts to 75 gallons per minute through a 4½-inch pipe, the well mouth being 11 feet above tide. The flow, said to have a head of 20 feet, has a temperature of 76° and a decided sulphur odor, is saline and contains sodium bicarbonate as shown by the following field assay made by the writer in November, 1906.

Field assay of water from deep well at Norfolk City pumping station.

	Parts per 1,000,000
Iron (Fe)	trace
Calcium (Ca)	little
Chlorine (Cl)	1,000.
Bicarbonate radicle (HCO_3)	620.
Sulphates, as SO_4	110.
Total hardness, as $CaCO_3$	7.5

A sample collected in November, 1904, and analyzed by Dr. Sheperd, city bacteriologist of Norfolk, contained 920 parts of chlorine per 1,000,000.

Had the well been sunk deeper, even to bed rock, the probabilities are that all water found would have been more saline than that struck at 1,072 feet. In fact salinity apparently increased with depth. The sodium chloride content for three flows, from partial analyses made while drilling was in progress, as given by Darton in the Norfolk folio of the Geologic Atlas of the United States, compare thus:

Sodium chloride and total solids in deep waters from Norfolk City well.

(Henry Froehling, analyst)

Parts per 1,000,000

Flow	Total mineral matter	Sodium chloride
730 feet	2,578	1,926
1,038 "	3,345	2,723
1,070 "	3,652	2,830

In 1906 the flow ran into the clear water basin at the pumping station. There is of course not the slightest possibility of the well water being polluted.

COMPARISON OF RECORDS.

The scanty observations recorded by some drillers and the varying terms used in describing what were probably similar deposits makes correlation of the well records difficult. Samples saved from the wells at Fort Monroe, Moore's Bridges and Lambert Point were examined by Woolman and by Darton and the records prepared by them were based largely on the samples. The best series were from the Hotel Chamberlain and Norfolk City wells. In all except the Norfolk City well water-bearing beds may have been passed which were not noted by the driller.

A comparison of the records shows that the Chesapeake group in the Norfolk-Newport News area, considering its thickness, is very poor in water-bearing beds. There is one midway in it at the last well at Fort Monroe, one at the base in the old well, and one near the base at the Money Point well. The Pamunkey is thin and unimportant. Water was found near the top in the last Fort Monroe well and probably at Newport News. Upper Cretaceous beds proved prolific water carriers at the Hotel Chamberlain, Fort Monroe (1902), Lambert Point, and the Norfolk City wells. The Potomac group at Fort Monroe was fully 900 feet thick, and contained many water beds.

The least mineralized water found below 200 feet by any well is the Lambert Point flow, which according to the 1891 analysis contained 1,091 parts per million of total solids of which 518 parts per million, according to a hypothetical combination given by the analyst, were sodium chloride. In comparison, the 738-foot flow of the Norfolk City well, which is presumably from the same group of beds though not necessarily from the same horizon, contained 1,923 parts per million of sodium chloride. Here is a decided increase of salinity in a distance of 10 miles eastward, a fact in harmony with the general increase of mineralization of deep waters toward the ocean, elsewhere noted. The Lambert Point well is the farthest west of the wells in the Norfolk-Newport News area south of James River, its water is least mineralized and comes from the Upper Cretaceous at a depth of only 616 feet. These details are important.

The results obtained from the work here noticed indicate that it is altogether probable that waters found between 500 and 700 feet at Newport News will be less saline than those from beds of corresponding age at Fort Monroe and in character will approach the Lambert Point flow. North of James River the best chances for finding flows of potable artesian water near Newport News are at elevations less than 20 feet and at points west of a north and south line running through that city; eastward, probabilities rapidly become unfavorable and in the eastern part of Elizabeth City County deep drilling will probably prove a waste of time and money.

South of James River the best prospects are west of a north-northwest line through Lambert Point with diminishing chances of success eastward. In Princess Anne County efforts to get good water by deep boring will, in all probability, be of no avail, and within the city limits of Norfolk there are small chances of getting water better than the Lambert Point flow at depths below 500 feet.

CAUSES OF MINERALIZATION.

The Norfolk-Newport News area, as previously stated, is not exceptional in the character of its deep waters. In fact it forms part of a much larger area which may include the whole Eastern Shore of Virginia and certainly extends south and east into northeastern North Carolina. The possible causes of the high mineralization, saltness, and other characteristics of the deep waters of this large area will not be discussed here. It is enough to say that the saltness is not due to sea waters included in the beds when first deposited, since the flows do not resemble sea water in composition, and there are salt flows from Potomac formations, which are not marine. The increased mineralization probably results from several causes. One is difficult circulation due to the decreased permeability of the water beds down the dip; for horizons which yield bountiful flows farther west are not water-bearing in this area and at some localities, as at Back River, water-bearing beds seem to be lacking through 1,000 feet of strata. At the same time, since coarse sands yielding free flows, under good heads, of water too saline for boiler use have been encountered, the texture of the beds can not be the sole factor. Besides increased fineness of sediments, or pinching out of water beds locally or to seaward (causing slow circulation and ponded water), the more effective factors have been long confinement under pressure and, particularly, 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.

FRESHENING OF DEEP WATER.

That wells which yield saline water may, by heavy pumping or unrestricted flow, come to yield fresh water is a possibility that has attracted the attention of geologists. Instances of freshening have been reported but whether or not the improvement was due to the replacement of the contained salt water in the water bed by fresh water from up the dip can not always be determined from the evidence available. Fuller[a] noted some instances of a change from salt to fresh water in wells near the mouth of Cape Fear River, N. C., and concluded that the freshening represents such a replacement.

In objection to this view it may be said that a well might penetrate a bed containing salt water and one containing fresh. In such a well the yield of the water beds, the heads of the water they contain, the tightness of the well casing, and the possible clogging of the well at one horizon by sand, are factors that would determine the quality of the water obtained.

Permanent freshening with no marked decrease in flow has not been observed, so far as known at any well in the Norfolk area, but it is possible that there has been a very slight decrease in the mineralization of the water from the Lambert Point well, though analyses extending over a period of 18 years, during which time the well has flowed without restraint, show little betterment. A marked decrease in mineralization and in volume of flow was noted in June, 1909, but after the flow was restored by cleaning out the well its quality was substantially the same as before. The important determinations, total solids and chlorine, are given below:

Variations in mineralization of water from Lambert Point well.

(Parts per 1,000,000.)

Date	Total solids	Chlorine
1891	1,091	350
1906, Dec. 15	1,421	290
1909, June 17	86	23
1909, July 6	1,128	290

The freshening of the water in June, 1909, was evidently due to the main flow being cut off or greatly reduced by sand; the quality of the water as shown by the analysis dated June 17, given in table 10, is not at all like that of any deep well in the Norfolk-Newport News area, but resembles that from wells less than 200 feet deep. There was evidently no detectable change in chlorine content between 1906 and 1909; the indicated change between 1891 and 1906 rests on a single analysis, and is not large enough to be entitled to much consideration. Making

[a]Fuller, M. L., Instances of Improvement of Water in Wells, U. S. Geol. Survey, Water Supply Paper, 160, pp. 96-99.

allowances for differences in analytical methods and in statements of results by different chemists, the variation in chlorine content between 1891 and 1909 is so small that one may fairly assume that it would not pay to drill a well to a known salt-water horizon in the Norfolk-Newport News area in the hope that by unrestricted flow the water would become fresh enough for boiler use.

SUMMARY.

(1). In the Norfolk-Newport News area the prospects for obtaining good boiler water by deep drilling are poor.

(2). The chances of obtaining such water improve west of Newport News and Elizabeth River.

(3). Mineralization increases toward the east and with depth.

(4). Better water is found above 1,000 feet than below.

(5). The high mineralization of the deep waters has been caused by factors affecting a large extent of country.

(6). A flow of salty water may become fresher by allowing the water to run without hindrance, but in this area the decrease in salinity is too gradual to be worth consideration in determining the sinking of a deep well as a business venture.

UNDERGROUND WATER SUPPLIES BY COUNTIES

ACCOMAC COUNTY

General description.—Accomac is the larger of the two counties covering the Virginia portion of what has long been known as the Eastern Shore, the peninsula between Chesapeake Bay and Atlantic Ocean. The county is about 45 miles long by 15 wide and has an area of 478 square miles. Although in 1900 but two counties in the state had a larger population per square mile, there was not within the county in that year a settlement with a population of over 1,000 people. The two incorporated towns, Onancock and Bellehaven, had populations of 938 and 331.

The surface has slight relief and is monotonously level. Except in some small areas, elevations are below 25 feet, hence the surface is mostly part of the Talbot terrace.[a]

There are few fresh water streams of any size or even stream valleys. Along the ocean side and on many stretches of the bay side are wide expanses of salt marsh or land flooded at high spring tides. The ocean side is characterized by many off-shore sandy islands of the barrier beach type, of which Chincoteague is the most important. Back of these islands are shallow bays where miles of mud or sand flats lie bare at low tide.

The surface soil, a light warm sandy loam, is in many places underlain by from 2 to 6 feet of buff or light-brown sandy clay and this in turn by a varying thickness of coarse white, gray, yellowish or occasionally brownish sand that contains scattered lenses of gravel and thin beds of light-colored clay with darker beds below.

UNDERGROUND WATERS

Distribution and quality.—The Eastern Shore term for a water-bearing horizon is a spring, and drillers speak of the first, second, third, and fourth "springs" found at such and such depths; the "first spring" being at the water table. The fluctuations of the water table from rainfall are spoken of as the rise and fall of the "springs" and on Chincoteague Island one is told that "the water springs" (stands higher) in shallow wells after wet weather. The "first spring" is in the yellow Columbia sands. As a rule, the second, third and fourth "springs" are in the beds that underlie

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[a]The author believes that the terrace here termed the Talbot is in large part to be correlated with the Pamlico of North Carolina.

the yellowish or reddish beds of the Columbia, though in places the second "spring" is the sand and gravel at the base of the light or bright-colored beds, separated from the first "spring" by clays or loams yielding little or no water to a driven well.

The first "spring," the water not being confined, affords no flowing wells, though shallow dug wells in hollows may be full to overflowing after prolonged rains. The "springs" below, the water being confined under relatively impervious beds of clay yield in many places flowing wells at low elevations.

The quality of the underground water varies. Nearness to inlets from the sea or bay is an important factor in the quality of supplies. In general, the water from dug wells or from pumps driven to the first "spring" does not contain as much lime or magnesia as that from the second or third spring; it is also less alkaline. On the other hand, it is rather more likely to be iron-bearing. Probably the best water for general use comes from 50 feet or more below surface. Along the coast and on the islands many shallow wells yield brackish water and many are salted by unusually high tides. Wells 25 to 200 feet on small islands are more apt to yield brackish water than those on the mainland.

Springs.—There are no true springs of commercial importance. In places water seeps from the creek banks at points where the water table curves down to the creek; such springs often disappear in dry weather. There are, however, springs of perennial flow and a few are used for household supply. What is said to be the largest spring in the county flows from the foot of a bluff on the shore of Chincoteague Bay, 2 miles north of Sinnickson. Another spring at Drummonds Mill, near Grape post-office, was once of local repute because its iron-bearing waters were believed to have medicinal value.

Wells.—The commonest type of well is a shallow hole dug to the "first spring." The deepest dug wells are near Assawoman, where some go 40 feet to water, but the depth of the average dug well in the county is about 10 feet. Buckets with chain or rope, or windlass or pulley, lift the water from the well. Here and there are wells with the old-time sweep and bucket. The perishable nature of wood casing and the many sanitary objections to it have led to the introduction of tile, 20 to 24 inches in diameter. The labor cost of digging a well varies according to the depth to water, but seldom exceeds $5.

Driven wells or "pumps" as they are called, are easily sunk, much used, and give satisfaction. Wells to the "first spring" are often put down by the owner, a piece of $1\frac{1}{2}$-inch or 2-inch pipe with a pointed cap being driven by a maul; if the clay subsoil is tough, a hole may be bored through it with an earth auger. Many wells over 20 feet deep are sunk by the jet process, as are nearly all wells over 50 feet deep. Most drillers use hand-power rigs, though the driller who has done the most work in the county has a small gasoline engine. Probably no county in Tidewater Virginia has more driven or drilled wells 50 to 100 feet deep. Their usual diameter is $1\frac{1}{2}$ to 2 inches. For such wells hand-power pumps, either iron pitcher pumps, wood pumps, or force pumps, are generally employed, though many residences have wind mills. One driller in 1906 gave the following as his usual charges for putting down driven wells, or, as it is called, "cutting pumps."

10-foot well	pitcher pump	$8
	wood pump	$12
30-foot well	wood pump	$20
	force pump	$22
50-foot well	wood pump	$30
	force pump	$32
100-foot well, no pump, about		$75

This driller has sunk a 103-foot well and finished it with a pitcher pump for $50. It is usually understood that the owner will furnish free such extra labor as a driller may need.

LOCAL SUPPLIES

New Church.—At this village near the northern line of the county, dug or driven wells to the "first spring" average 12 to 15 feet deep. The water is generally hard. In some wells it is so iron-bearing that it is not fit for laundry use, while in others it contains little iron. The "second spring" from 30 to 35 feet, is also decidedly iron-bearing in most wells. The "third spring" has been developed by two wells, both of which yield excellent water. One of these, owned by J. E. Johnson, is 125 feet deep and draws on water in a bed of shells in dark bluish sand; this water rises to within 4 feet of surface. An ordinary pitcher pump easily supplies 8 gallons per minute. The record of the beds penetrated is as follows:

Record of well of J. E. Johnson, near post-office at New Church.

(Authority, I. B. Clark, driller.)

Material	Thickness (Feet)	Depth (Feet)
Soil	1	1
Pipe clay (light gray clay)	7	8
Yellow sand, small pebbles and gravel with plenty of water of poor quality, "first spring"	6	14
Blue mud	30	44
Sand, a little water, "second spring"	3	47
Blue mud	73	120
Dark, bluish sand with small shells, excellent water, "third spring"	5	125

The owner has at his saw-mill nearby a well to the "second spring" which yields a fair boiler water, and a well to the "first spring" at his store. Results of field tests of samples from a 12-foot driven pump and the 135-foot well at J. E. Johnson's store, and the 34-foot well at the mill, made by H. N. Parker, are given in table 7, to show how great are local variations in quality.

The tank of the New York, Philadelphia & Norfolk Railroad is supplied by a pump drawing from eight 2-inch points driven 30 feet, or to the "second spring." These yield fairly good boiler water.

Franklin City and Greenbackville.— These villages are on or near a strip of salt marsh bordering Chincoteague Bay. At Franklin City there are no dug wells as the town site is inundated at high tides. Pumps to the "first spring" yield brackish water. Fairly good water, which rises to mean high tide level, is obtained by driving 30 to 70 feet.

At Greenbackville, where fresh water is found at 6 feet and even less, pumps are driven 10 to 45 feet and obtain water of varying quality. That from some wells is high in iron, lime, and chlorine; that from others is less mineralized. The water tank of the New York, Philadelphia & Norfolk Railroad is supplied by three driven wells 25 feet in depth, which are said to yield a sufficient supply of satisfactory boiler water. At a canning factory nearby, water is obtained by wells driven 15 feet. One well was driven 80 feet but obtained no water below 50 feet. In the thickly settled portion of the village the "first spring" at 5 to 15 feet, supplies most pumps, but is regarded by local physicians with suspicion on account of possible pollution from stables and privies; much of the water obtained at 10 to 12 feet is iron-bearing and brackish. According to T. F. Mumford, who has driven many wells, excellent water is obtained from some wells not over 40 feet deep, while others yield water containing considerable quantities of mineral salts, chiefly composed of lime, iron, and sodium.

Dr. H. C. Mallory gave the writer samples of residue obtained by evaporating water from three wells at Greenbackville: Those of Elihu Tull, 18 feet; James Chapman, 22 feet; and J. T. Sharpley, 45 feet. These were qualitatively analyzed by R. B. Dole, assistant engineer of the Water Resources Branch of the U. S. Geological Survey, with the following results:

Analyses of residue from well waters at Greenbackville, Va.

	E. Tull	J. Chapman	J. T. Sharpley
Silica	high	moderate	moderate
Iron	high	moderate	low
Calcium	high	moderate	low
Magnesium	high	low	low
Sodium	moderate	moderate	trace
Potassium	low	low	moderate
Sulphates	moderate	low	low

Field tests of samples from the wells of Elihu Tull (18 feet) and J. T. Sharpley (45 feet) at Greenbackville, and James Chapman at Franklin City, showed notable variations in mineralization. (See table 7.)

Drillers charge about $25 for a 40-foot well and $35 to $70 for a 70-foot well.

Chincoteague.—Chincoteague Island and its larger neighbor, Assateague, are growing in popularity as summer resorts and are known to many sportsmen for the duck-shooting on Chincoteague Bay and its connected inlets. The village of Chincoteague has a summer population of over 1,500, and the question of water supply is of increasing importance. Both islands are low and sandy—a succession of beach ridges under 10 feet high, except for a few small dunes that may rise above 15 feet. On Chincoteague water is obtained from dug and driven wells 3 to 14 feet deep, the best water being found in white sand in the higher parts of the island. Only two attempts to find water at greater depth, previous to 1906, are reported. James Williams drove 70 feet on the outskirts of Chincoteague village some years ago without result, and the United States government attempted to get deep water at the lighthouse on Assateague. This last trial was abandoned when a pipe had been driven to a reported depth of 135 feet.

The quality of the water from the dug and driven wells varies considerably, and is said to be better after a long spell of wet weather than during a drought. The water level in the interior of the islands fluctuates a couple of feet with the seasonal variations of rainfall, and when the "springs are low" in dry weather many wells yield brackish water.

In the village of Chincoteague driven wells are almost the sole source of supply, not over 25 cisterns being reported in use in 1906. Near the water front many wells have been salted by unusually high tides. Much of the well water is highly colored by iron or organic compounds, but there is great irregularity in this respect—the water from wells less than 20 feet apart differing decidedly in appearance. A sample said to represent a fair average of the wells in town was taken from a tank at the store of D. J. Whealton. This water is drawn by a wind pump from three points driven 14 feet. The results of a field test are given in table 7.

As the demand for domestic purposes is increasing, and present sources of supply at Chincoteague are not altogether satisfactory, the possibility of getting better supplies by wells deeper than any yet sunk calls for investigation. However, it is not likely, in view of what is known regarding the deep flows of the mainland, that good water will be found at great depths, 1,000 feet or more; and the prospects for potable water between 100 and 1,000 feet are not promising.[a]

With ordinary precautions against pollution the driven pumps now used will suffice for isolated dwellings. The use of water from surface ponds near dwellings for "drinking" (floating) oysters is decidedly objectionable.

Wells on the bay side at Saxis, Belinda, Marsh Market, and Grotons.—A large number of wells have been driven near Saxis, Belinda, Marsh Market, Grotons, and Justisville and a few of these flow. Details regarding some appear in table 5. The supplies are in some places excellent and in others so hard and iron-bearing as to be unsuited for household use. One well on the steamboat pier at Saxis found water in a bed of coarse gravel under 2 feet of bluish sand indurated enough to be called rock by the driller. The record is as follows:

Well of Baltimore, Chesapeake & Atlantic Steamboat Co., at Saxis.

(Authority, I. B. Clark, driller.)

Material	Thickness (*Feet*)	Depth (*Feet*)
Water	6	6
Blue mud	87	93
Bluish rock	2	95
Gravel, with pebbles as large as marbles, water-bearing	2	97

[a] A deep well is reported to have been drilled in 1910 for a projected fish factory on Assateague Island. The depth of the well and the quality of the water found are not known to the writer.

The water, which is of good quality, rises to tide level.

At a saw mill half a mile east of Belinda belonging to Ross & Hall, two 1½-inch wells were driven, 44 and 46 feet respectively, to the "second" spring" to get enough water for a 50-horse power boiler. The water was hard and formed scale. Wells to the "first spring," 8-10 feet, did not get water enough. Half a mile northwest of Belinda a well was driven to the "third spring" finding water in a bluish gray sand containing small bivalve shells. Those washed up by the drill were not identifiable.

A well at the oyster house of M. L. Hall on the outer edge of a wide strip of marsh facing Mesango Creek was driven 64 feet, stopping on "rock." It yields brackish water high in iron that is used for washing oysters and has been tried in a boiler. An 84-foot well at Belinda post-office found water which rose to above tide level, but contained so much iron as to be unfit for domestic use.

At the mill of J. A. Hall at Marsh Market a 2-inch well driven 92 feet struck water which rose to 4 feet above tide or 1 foot below the surface. The yield was insufficient and a 1½-inch well had to be sunk to the sands at 48 feet to get water enough for a 50 horse-power boiler.

Wells on the bay side farther south.—Farther south on the bay side of the county a considerable number of flowing wells, ranging in depth from 36 to 160 feet, have been sunk along Muddy, Hunting, Deep, Chesconnessex, Onancock, Pungoteague, and Nandua creeks, there being probably 30 on Hunting Creek alone. As a rule these wells yield good water which may have (when fresh from the well) a faint odor of sulphur; in places the water is slightly hard and iron-bearing. Details of many wells are given in table 5.

A well on Muddy Creek near Mearsville showed the following succession of materials:

Record of well of W. J. Somers, one mile south of Mearsville.
(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Sand	4	5
Blue mud	75	80
Bluish sand, poor water	4	84
Blue mud	33	117
Sand with small shells, good water	1	118

This 1½-inch well, according to the driller, flows at an elevation of 6½ feet above tide 1½ gallons per minute.

Between Chesconnessex and Deep creeks, where the ground is so low that shallow wells are liable to be salted by high tides, several deep wells have been driven yielding water of fair quality. The following succession of beds was reported from a well near Deep Creek:

Record of well of Bailey East, one-half mile north of Chesconnessex.
(Authority, Bailey East, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Yellow sand	19	20
Black, bluish, and slate-colored marsh mud	19	39
Bluish gray sand; a little water	1	40
Loam with smooth pebbles, yellow, gray, black and white: water at base	3	43
Bluish sand, water at base	32	75
Coarse gravel, no large stones; water	4	79
Bluish sand, with shells at 95-99 feet; water at 37 and 100 feet	58	137

The water from all the four "springs" rose to the level of mean high tide, or within 18 inches of it, and is slightly irony.

Onancock, on Onancock Creek, has a public supply system, but most persons get water from driven wells, many of which go only to the "first spring" at 16 feet. In 1906, seven 2-inch wells at the town waterworks reached various depths—two 16 feet, two 30 feet, and three 50 feet. They were fitted with slotted brass strainers and were, except one, connected to a triplex pump driven by a 7 horse-power gas engine that lifted the water to a 50,000-gallon tank on a steel tower 65 feet high. The wells are driven over a roughly circular area 90 feet in diameter, about 18 feet above mean high tide. The head of the water in the points is said to be about 5 feet above tide. In addition, water is pumped from a dug well 20 feet in diameter and 16 feet deep, in which one of the points to the 50-foot sand is driven. The yield from the driven wells is small and much of the water used comes from the dug well, which serves both as well and reservoir. The total yield is given as 35 gallons per minute.

The following record of one of the pumping-plant wells was given from memory:

Record of well at waterworks, Onancock.

(Authority, F. A. Merrill, driller.)

Material	Thickness (*Feet*)	Depth (*Feet*)
Soil	1	1
Red clay	3	4
Yellowish sand at base, gravel containing pebbles one-half inch in diameter; water-bearing	12	16
Bluish sand and mud	14	30
Bluish gray sand, water	5	35
Blue mud	15	50
Coarse gray sand with pebbles up to one-half inch; water	5	55

A field assay of water drawn directly from the points, and another, by H. N. Parker, of water presumably taken from the dug well are given in table 7.

The water is used in the boiler of vessels belonging to the State oyster navy and in those of steamers running to Baltimore. The bacterial purity of the supplies from the 50-foot bed should be unquestionable but in 1906 contamination of the open well was possible.

In 1906, about one-third of the estimated population, 1,200 people, used this water, the remainder getting supplies from driven wells 16 to 25 feet deep. The yield of the 25-foot wells was said to be small, but the water was pronounced very good.

Several attempts to supply the town from other wells than those now used have been made and two deep wells have been sunk without success. One drilled in 1890 by H. K. Shannahan found water at 90 and 140 feet, and more below to a depth of 486 feet. The casing was broken in an attempt to withdraw it, and the water from the 140-foot sand which rose nearly to surface was used for a few years by means of a wooden pump. The yield was 5 to 10 gallons per minute. The water was not liked because of its "sulphur" odor and the well has been abandoned for years. Another well was sunk in 1895 to about 600 feet without getting a satisfactory supply.

The following incomplete log of the well drilled by Mr. Shannahan is from that published by Darton.[a]

[a]Darton, N. H., Artesian well prospects in the Atlantic Coastal Plain, U. S. Geol. Survey, Bull 138, p. 131.

Partial record of well at Onancock.

Material	Thickness (Feet)	Depth (Feet)
No record	150	150
Shells in gravel and sand	25	175
No record	5	180
Fine sand; no water	25	308
Hard rock 9 inches; clay 2 inches; rock 5 inches; clay 5 inches	2	310
Clay and sand	23	333
Clay and sandy clay	147	480

The 50-foot sand tapped at the waterworks is reported to be water-bearing and to yield no water within short distances. The flowing well of H. L. Hurst, on the edge of the creek, 50 yards from the waterworks, is only 34 feet deep and evidently taps this sand.

At Finney, back of Onancock, are several wells over 50 feet deep. The 83-foot well of W. T. Rogers, according to the owner, went through hard black mud from about 50 to 75 feet, below that dark sand, and below that light sand containing half-inch pebbles. The water does not rise 3½ feet above tide. The head is greatest at high tides or when nearby marshes are flooded after heavy rains. In the springhouse, at the well, are two cement basins from one of which the water is pumped by wind power to a tank. The water fresh from the well, though perfectly clear, has a slight "sulphur" odor; that from the tank is odorless.

At Cashville, south of Onancock, a number of wells from 80 to 100 feet deep have been sunk. The following record is reported.

Record of well of S. Crockett, on Masitank Creek.

(Authority, Bailey East, driller.)

Material	Thickness (Feet)	Depth (Feet)
Soil, clay and sand	20	20
Mud	25	45
Blue sand	65	110
Blue sand and clam shells	1	111

This well does not flow, though the water rises to within 1 foot of surface; elevation 6 feet.

The elevation of the higher ground about Cashville is 8 to 10 feet. Dug wells 8 to 15 feet deep yield water of varying quality; those near the creek are sometimes salted by high tides. The water from the deep wells is satisfactory. Most of the drilled wells cost $35 to $40, including the 1½-inch pipe.

At Harborton, which has a population of about 450, are perhaps 20 wells that will flow at an elevation of 8 feet above mean high tide. They all tap a bed of coarse sand and gravel at 140 feet. The water is soft and excellent, but at some wells it has a slight "sulphur" odor. A well at Allen & Lenner's fish factory, used for boiler supply at the factory and on fishing steamers, may be the oldest flowing well on the Eastern Shore. The water is said to be satisfactory, the boiler being in good condition after 16 years' use. A field analysis of a sample from this well is given in table 8.

The following record is reported by a local driller. Much the same succession was found in other wells in Harborton.

Record of well of J. W. Adams, Harborton.

(Authority, J. W. Adams, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Red clay	4	5
White and yellow sand; water at 12 feet	11	16
Blue creek mud	24	40
Gray sand and gravel; water-bearing	11	51
Tough blue clay	74	125
Gray sand, fine at top, coarser below, contains hard streaks and shells; water-bearing	15	140

The deeper wells at Harborton have a 4-foot galvanized iron strainer on the 1½-inch pipe. The casing is usually just long enough, 50 to 55 feet, to cut off the water in the second sand. In a few wells casing is carried to the bottom because of running sand. At a number of the wells are wood or cement tanks into which the water rises and from which pitcher pumps lift it to sinks, etc.

One driller, who furnishes all labor and necessary tools and works on a "water or no pay" basis, charges 45 cents per foot for the first 100 feet and 35 cents for each additional foot. Another driller charges $50 for sinking 140 feet.

A well at Boggs Wharf about one-half mile above Harborton passed through beds of the same general character as those at Harborton, as indicated by the record below.

Record of well of H. Battail, near Boggs.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Red clay	3	4
White sand; poor water	6	10
Blue mud	34	44
Blue sand; very little water	1	45
Blue mud	59	104
Shells in bluish sand rock	8	112
Blue mud, shells and sand rock, four layers of rock in all	38	150

In a moderately coarse greenish-gray sand, not glauconitic, at 150 feet were small bivalve shells. Specimens of these examined by Dr. W. H. Dall were pronounced probably Miocene. The water rises about 4 feet above surface or about 9 feet above mean tide. The quality is good.

Another well a few hundred yards distant showed much the same succession of material.

Record of well of Richard Taylor, at Boggs.

(Authority, I. B. Clark, driller.)

Material	Thickness (Feet)	Depth (Feet)
Soil	1	1
Red clay	4	5
Yellow sand	5	10
Blue mud	94	104
Bluish gray sand with small shells	1	105

At the mouth of this well is a cement tank. The head is about 8 feet above mean tide.

At Pungoteague village, population about 350, several dug and driven wells sunk to the "first spring," 10 to 18 feet, came under suspicion during an outbreak of typhoid fever, and a number of deeper wells have been put down since. One of these, 210 feet deep, or 190 feet below tide level, is the deepest in use in Accomac County. It cost $120. The driller reported the following succession of beds:

Record of well of S. W. Ames, Pungoteague.

(Authority, I. B. Clark, driller.)

Material	Thickness (Feet)	Depth (Feet)
Soil	1	1
Yellow sand	15	16
Blue mud, at 40 feet, and 60 feet, slightly sandy, with a little water, at latter point; bluish sand with shells	94	110
Blue mud	3	113
Bluish sand with shells and wood	95	208
Sand; good water	2	210

The well throws considerable sand when pumped hard. The sand is fine, white, well rounded and contains bits of lignitic material. A complete analysis of a sample of water from this well is given in table 8.

There are known to be five water-bearing horizons of varying extent at Pungoteague: the first, at 15 to 25 feet, gives plenty of "medium soft" water containing little iron; the second, at 30 to 40 feet, gives hard, iron-bearing water; the third, at 62 feet, yields water containing little iron; the fourth is at 110 feet; and the fifth at 208 feet gives good water.

Near Craddockville are several flowing wells. The following is a log of one of them.

Record of well of L. J. Nielson, Allen Farm, 2 miles northwest of Craddockville.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Blue mud	140	140
Blue sand and shells	33	173

This well was dry when completed, and the water at 170 feet broke in some 48 hours after the driller had stopped work.

Wells along the line of the New York, Philadelphia & Norfolk Railroad.—At the villages south of New Church driven wells reach the "first spring" at 10 to 15 feet; most of them find soft water, but some find decidedly iron-bearing water. The deeper sands frequently yield better supplies.

At Hallwood are two wells over 100 feet deep. The log of one is given below.

Record of well of Jas. A. Hall, at Hallwood.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Pipe clay, sand and gravel, with water below 10 feet	29	30
Blue mud	80	110
Bluish sand with shells; small yield of good water	40	150
Blue mud	36	186

The yield by a pump was so small that though the water was of good quality, the well was abandoned.

A tank of the New York, Philadelphia & Norfolk Railroad is supplied from a dug well 12 feet deep and from sixteen 2-inch points driven to varying depths. An analysis of the water from the dug well is given in table 7. A partial analysis made by C. B. Dudley for the Pennsylvania System showed 4.91 grains per gallon of total solid residue consisting chiefly of sulphate of lime and magnesia with no carbonates; a slightly corrosive water.

Parksley, one of the largest villages along the railroad, population 500, has no public supply system; nor were drilled wells over 40 to 50 feet deep reported from the village.

At Accomac, the county seat, water is obtained from three sandy beds lying 12, 30, and 50 feet respectively below surface. The water from the first is soft, but that from the second is iron-bearing, and that from the third is soft. The following generalized section is given by a driller who has sunk many wells in the county.

General section at Accomac.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Red clay	3	4
Yellow and white sand; surface water at 12 feet, better water at 32 feet	28	32
Sticky blue mud	18	50
Coarse bluish sand, gravel, and small shells; good water	1	51

Field assays of samples from three wells are given in table 7.

Near Tasley dug and driven wells average 10 to 15 feet deep and many get water that contains a little iron. Water of better quality is said to be found at 20 feet. The railroad tank is supplied from eighteen 2-inch points driven to varying depths, said to be 22, 35, and 50 feet.

A partial analysis by C. B. Dudley, of water from a well 12 feet deep, showed 4.21 grains of total solid residue per gallon, consisting chiefly of sulphates of lime and magnesia with some chlorides and no carbonates; a slightly corrosive water.

No wells over 55 feet deep had been driven at Onley, 3 miles south of Tasley, and there were only two over 50 feet; most were 10 to 20 feet deep. The following record shows the character of the materials overlying the "second spring."

Record of well of I. W. Rogers at Onley.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Light gray clay	9	10
Yellow sand, full of water	8	13
Blue mud	35	53
Coarse gravel and pebbles; water-bearing	2	55

About Keller dug wells get water at 8 to 10 feet and are nearly full in wet weather. Driven wells tap sandy beds at 8 to 20 feet. One taps a sand at 60 feet.

Wells on the ocean side south of Chincoteague Bay.—On the ocean side of the county, south of Chincoteague Bay, flowing wells have been drilled along the inlets, the best flows, as on the bay side, being at the base of steep slopes facing open water or marshes. The first attempt it is said, was at the residence of B. T. Gunter, 4 miles southeast of Accomac, in 1899. This well gets water, which rises about 3 feet above the level of mean high tide, from a sand bed at 122 feet below surface. A windmill elevates the water to a tank whence it is piped to the house.

Another flowing well on Custis Neck, ¾-mile southeast of the well just mentioned, is 104 feet deep and flows 100 gallons an hour at an elevation of 1 foot above the surface or about 4 feet above mean high tide; the following record was given by the driller.

Record of well of G. L. Dougherty, one and one-half miles north of Locustville.

(Authority, I. B. Clark, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil, sand, clay; surface water	20	20
Blue mud	35	55
Sand; flow of salt water	5	60
Blue mud	40	100
Sand; flow of good water	4	104

At Wachapreague, on the head of Wachapreague inlet, east of Keller, practically all the driven wells get water from the "first spring" at about 10 feet. Along the edge of the marsh at the head of the inlet this water is brackish. A large hotel supplies cistern water for drinking.

Wells on islands in Chesapeake Bay.—The Chesapeake Bay islands included in Accomac County are low, like those on the ocean side; and some are mere patches of salt marsh. The largest of the islands, Tangier, has a population of over 1,200 persons. Most of the dug wells on this island are less than 9 feet deep. The water at some wells is soft and at others, particularly near the shoreline, hard or irony. These shore wells frequently get brackish in droughts or after unusually high tides. Shallow driven wells which yield water of much the same quality as the dug wells are preferred for sanitary reasons.

The only attempt at deep drilling reported is a well driven to 250 feet for J. J. Daly near the center of the island in 1906. A bed of very fine sand 65 feet thick containing salty water which rose to within a few inches of the surface was struck at 141 feet; "rock" at 165 feet, and black mud, "rotten sea-grass and clam shells" at 200 feet and below. No large supply of water was found below 141 feet, and the sand at that depth clogged the pipe.

On Watts Island the deepest well in 1906 was about 70 feet and on Fox Island the deepest was 76 feet. On the latter island a number of wells have been driven by William Ellinger for use at oyster houses. The following carefully kept record shows the character of the beds penetrated:

Record of well on Fox Island.

(Authority, William Ellinger, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Marsh sod	1	1
Marsh mud	6½	7½
Stiff, yellowish-red clay	4½	12
Blue mud	15	27
Conglomerated shells, pebbles and gray limy clay	7	34
Stiff, gray clay	15	49
Hard substance called "coral rock" by driller	1	50
Tough gray clay	13	63
Sand and clay	5	68
Sharp gray or white, fine to coarse quartz sand	6	74
Coarse gravel; water	2	76

The water which rises to within 2 feet of the surface of the marsh, the level fluctuating with the tide, is hard and slightly iron-bearing. The yield with a No. 3 pitcher pump is 10 to 15 gallons per minute. The quality of the water is shown by the field assay in table 7.

The chances of getting plenty of deep water on these bay islands, particularly on Tangier, is so promising that a test by deep drilling should be made. The fine wells on the Great Wicomico River, Virginia, and at Crisfield, Maryland, indicate that abundant flows may be had at about 1,000 feet below sea level in the Upper Cretaceous beds. The water will probably be fully as mineralized as that at Crisfield and may be salty.

Some shallow-well details reported by postmasters are summarized below:

Details of shallow wells in Accomac County.

Post-office	Depth of wells (*Feet*)	Material of water bed	Quality of water
Assawoman	10–25	sand	soft
Atlantic	10–25	clay and sand	hard
Bullbegger	8–25	sand	bad, irony
Fairoaks	8–16	sand	
Graysville	8–12	sand	soft, bad, salty
Horsley	10–40		shallow, irony; deep, good
Leemont	10–18		ditto
Onley	10–28	sand and gravel	soft
Parksley	8–16		hard, irony
Poulson	5–20	sand	
Sinnickson	6–40	clay and sand	poor
Temperanceville	10–25	sand	fair, irony

Conclusions.—By sinking to one or another of the sandy beds above 300 feet it is possible at most places to get supplies of water of satisfactory quality. Owing to their easy pollution dug wells are objectionable. Driven wells can be sunk cheaply and water from those 30 feet or more deep should be free from disease germs.

The outlook for satisfactory water from beds in the Chesapeake deposits 300 feet or more below surface is not especially good. On the mainland in the northern part of the county there is a chance of getting potable water at greater depth, 1,000 to 1,500 feet in the Raritan, but drilling in the hope of reaching better supplies in the Potomac beds, 2,000 feet more below surface, is not advisable. In the southern part of the county deep well prospects are less promising than in the northern.

ALEXANDRIA COUNTY.

General description.—This county, once part of the District of Columbia, is the smallest and most densely populated county in Virginia. The area is 32 square miles. The topography is varied, elevations ranging from sea level to over 400 feet. In places on the heights above 300 feet are remnants of the Lafayette terrace, and several of the Columbia terraces are plainly traceable, particularly the Sunderland at 260 feet near Ballston and Glen Carlyn. The city of Alexandria stands on a somewhat eroded terrace 40 to 50 feet high.

The crystalline rocks, mostly granite and gneiss, outcrop and are quarried along the river above Rosslyn and are exposed in ravines in the western part of the county.

The cobbles, sands, and clays, of the Patuxent formation (Potomac group) outcrop here and there. Northwest of Alexandria the higher (Patapsco) beds rest on gneiss and granite at elevations up to 250 feet above tide, whereas the base of the Patuxent is over 450 feet below tide at the river front in Alexandria.

The Columbia formations contain characteristic cobble beds, sands, and loams. The more highly colored loams of the Lafayette formation are found on the remnants of the high plain between Cherrydale and Falls Church, at Upton Hill, and elsewhere.

UNDERGROUND WATERS

Occurrence and quality.—In Alexandria County water is obtained from the crystalline rocks, from their decayed upper surface, and from Potomac, Lafayette and Columbia sands. Because of this difference of origin the quality varies. Generally the waters are soft; in places they are hard and some deep wells and occasional shallow wells have found water containing considerable iron. In general the water of the deep drilled wells, particularly those at Alexandria, is beyond suspicion, but into many open shallow wells, in places where there is lack of proper curbing, surface impurities are washed at every rain.

Springs.—As a result of an abundant rainfall, and a deeply scored topography, Alexandria County has many springs. They issue from hollows, from hillsides, in ravines, or at the base of terrace scarps. Most of them flow from sandy beds in the Columbia, but a few flow from hard rock. Many of the springs are utilized for household supply or for watering stock, while three are, or have been, of commercial importance. These are the Hume, near St. Asaph, the Erup near Glencarlyn, and the Powhatan south of Upton.

Hume.—This spring or springs, for there are two distinct sources, in the valley of Four Mile Run, is said to have been discovered by troops during the Civil War. It has been improved by a concrete basin, piping, etc. The flows issue from Columbia sands on a terrace. The principal flow, about 10 gallons per minute, is said not to vary with the seasons. The water contains iron and according to some persons, has a slight sulphur odor. It is not sold by the owner, but has been collected and sold by others.

Erup mineral spring.—This spring, about half a mile south of Glencarlyn Station, issues from a high-lying sand and cobble bed. The flow is about 1 gallon per minute. Over the spring is a frame spring house, adjoining this is a frame bottling house with cement-lined iron tanks. The water, which is clear, colorless and odorless, is said to carbonate well. It has been shipped to Washington and sold there, plain or carbonated, for table or medicinal use.

The water has been analyzed several times; the following analysis shows its low mineral content.

Analysis of Erup mineral spring water.

(J. K. Haywood, analyst.)

	Parts per 1,000,000
Silica (SiO_2)	7.9
Sulphuric acid radicle (SO_4)	3.3
Bicarbonate acid radicle (HCO_3)	9.1
Chlorine (Cl)	6.3
Bromine (Br)	none
Iodine (I)	small amount
Iron (Fe)	.1
Manganese (Mn)	none
Calcium (Ca)	2.9
Magnesium (Mg)	1.8
Potassium (K)	1.5
Sodium (Na)	5.7
Lithium (Li)	trace
Oxygen to form oxide of iron (Fe_2O_3) and silicic acid radicle (SiO_2)	1.2
Total	38.8
Total solids	47.8
Hypothetical Combination	
Lithium chloride (LiCl)	trace
Potassium chloride (KCl)	2.9
Sodium chloride (NaCl)	8.1
Potassium iodide (KI)	small amount
Sodium sulphate (Na_2SO_4)	4.6
Magnesium sulphate ($MgSO_4$)	.3
Magnesium bicarbonate ($Mg(HCO_3)_2$)	10.2
Calcium bicarbonate ($Ca(HCO_3)_2$)	.8
Calcium silicate	7.9
Silica (SiO_2)	3.8
Ferric oxide (Fe_2O_3)	.2
	38.8

Powhatan.—This spring is situated about three-eighths of a mile south of Kearney station on the Washington, Alexandria & Great Falls electric railway. It issues from the south side of a ravine, the valley of a small rill that empties into Four Mile Run less than half a mile east of the spring. A dark granite outcrops in the ravine, and the spring is probably of the crevice type, though the point of emergence from the rock is not visible. The coolness of the water indicates a source deeper than that of many hillside springs. The flow is about 10 gallons per minute; the quality clear, tasteless, and odorless. The spring basin is protected by a masonry chamber; there are no possible sources of pollution near, and the sanitary conditions are good.

There is a masonry bottling house at the spring from which water has been shipped to Washington. The following analysis was made by the Bureau of Chemistry.[a]

Analysis of Powhatan spring water.

(J. K. Haywood and B. H. Smith, analysts.)

	Parts per 1,000,000
Silica (SiO_2)	12.0
Sulphuric acid radicle (SO_4)	1.2
Bicarbonate acid radicle (HCO_3)	12.0
Nitric acid radicle (NO_3)	1.55
Nitrous acid radicle (NO_2)	.016
Phosphoric acid radicle (PO_4)	none
Metaboric acid radicle (BO_2)	none
Arsenic acid radicle (AsO_4)	none
Chlorine (Cl)	3.8
Bromine (Br)	none
Iodine (I)	trace
Iron and aluminum (Fe + Al)	.2
Manganese (Mn)	none
Calcium (Ca)	1.6
Magnesium (Mg)	1.2
Potassium (K)	1.2
Sodium (Na)	3.7
Lithium (Li)	none
Ammonia (NH_4)	.069
Oxygen to form Fe_2O_3	.10
Total	38.435
Free ammonia	.065
Albuminoid ammonia	none
Nitrogen as nitrates	.350
Nitrogen as nitrites	.005
Oxygen required	.45

[a] Haywood, J. K., and Smith, B. H., Mineral Waters of United States, Bull. 91, Bureau of Chemistry, 1905, p. 43.

Analysis of Powhatan spring water—(Continued).

HYPOTHETICAL COMBINATION	Parts per 1,000,000
Ammonium chloride (NH_4Cl)	0.207
Potassium chloride (KCl)	2.3
Sodium chloride ($NaCl$)	4.3
Potassium iodide (KI)	faint trace
Sodium sulphate (Na_2SO_4)	1.8
Sodium nitrate ($NaNO_3$)	2.12
Sodium nitrite ($NaNO_2$)	.024
Sodium bicarbonate ($NaHCO_3$)	2.9
Magnesium bicarbonate ($Mg(HCO_3)_2$)	6.0
Calcium bicarbonate ($CaCO_3$)	6.5
Ferric oxide and alumina ($Fe_2O_3 + Al_2O_3$)	.3
Silica (SiO_2)	12.0
Total	38.451

Public supplies.—The city of Alexandria, population about 17,000, is supplied with water taken from a creek, Cameron Run, about 3 miles above the city. The military post of Fort Myer is supplied with water from Potomac River.

LOCAL SUPPLIES

Alexandria.—There are a number of dug wells owned by the city and many privately owned ones. These wells 20 to 40 feet deep get water from sandy and gravelly Columbia beds. In 1906 some were liable to pollution from leaky sewers or cesspools.

Deep wells have been drilled for the Robert Portner Brewing Co., the Mutual Ice Co., the Alexandria Fertilizer and Chemical Co., and the Belle Pré Bottle Co. At the Portner brewery, on a slope 40 feet above tide, are four 8-inch wells down about 400 feet and one 6-inch well down 61 feet, the greatest depth of well reported being 430 feet. The wells are pumped by air lift. The water is low in lime but alkaline enough to make an admirable boiler water. It is used for brewing, for ice-making, and for washing as well as for steam production. A number of families in the vicinity of the brewery get the water for drinking. The water from the 61-foot well contains considerable iron and is used only for cooling condenser coils and washing the outside of kegs and barrels. Analyses of water from two of the deep wells, made in 1903, are given below. Well No. 1 had been in use 20 years; well No. 2 had just been completed.

Analyses of water from wells of Robert Portner Brewing Co., Alexandria.

(First Scientific Station for the Art of Brewing, analyst.)

	Parts per 1,000,000	
	No. 1	No. 2
Total solids	118.0	170.0
Organic and volatile matter	12.0	14.0
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	trace	4.0
Calcium (Ca)	.....	.....
Magnesium (Mg)	.....	.....
Chlorine (Cl)	24.8	19.5
Alkaline carbonates	114.4	109.0
Sulphuric acid (SO_3)	11.6	12.0
Nitric acid	0.0	0.0
Nitrous acid	0.0	0.0
Free ammonia	trace	trace
Albumenoid ammonia	small trace	small trace
Total hardness	15.6	20.0

A later analysis made by the United States Geological Survey is given in table 11.

The 8-inch well of the Peoples Ice Company is on the river front. It is 401 feet deep and cased to the bottom. The water rises about to tide level, 12 feet below the top of the well. Pumping 90 gallons a minute lowers the water to 60 feet from the top. The water, like that from the Portner wells, is colorless, odorless, and tasteless. It is used for making ice and has been bottled and sold for table use under the name of Mico water. An analysis furnished by the company but recalculated to express results in the form adopted by the U. S. Geological Survey shows the following mineral content:

Analysis of Mico Water.

(J. D. Hird, analyst.)

	Parts per 1,000,000
Total solids	176.
Organic matter	0.
Silicia (SiO_2)	21.
Calcium (Ca)	trace
Magnesium (Mg)	1.4
Sodium (Na)	49.
Bicarbonate radicle (HCO_3)	39.
Sulphate radicle (SO_4)	36.
Chlorine (Cl)	32.

A well sunk in 1906 at the plant of the Alexandria Fertilizer and Chemical Co., on the water front a quarter of a mile north of the well of the Peoples Ice Co., illustrates the variability of the Patuxent sands as water bearers, the poor quality of the water in some of the sands and the difficulties that beset a driller unaccustomed to working in the Potomac sands and sandy clays.

A standard cable rig was used and rapid progress made for the first 250 feet. Below 300 feet progress was slower and the 8-inch casing after a series of accidents finally collapsed at 397 feet. An attempt to go deeper with 6-inch casing resulted in reaching a total depth of 445 feet, beyond which it was impossible to drive the casing, though this was heavy pipe, without its collapsing. Little water was found and none that would flow at surface, 10 feet above tide. Dynamiting at 350 feet gave a small yield which rose to 80 feet of surface. Dynamiting at 225 feet gave water which rose nearly to tide level. The yield is 60 gallons per minute, by air lift, the end of the air pipe being 215 feet down the well.

The water from the sand and gravel at 225 feet has not improved in quality under heavy pumping. It is clear and colorless when fresh from the well but becomes turbid and deposits iron on standing. It has an acid reaction and is not suitable for boiler use. A partial analysis showed solids amounting to 1,265 parts per million, chiefly sulphates.

A 6-inch well drilled for the Belle Pré Bottle Co., half a mile northwest of the brewery, is 185 feet deep; the water, from a sand bed in the Patuxent formation, rises to 25 feet of surface, elevation 40 feet; pumping 65 gallons lowers it 10 feet. It is used for boiler supply, though it forms a tough hard scale, and for other purposes at the company's glass works. The analysis in table 11 was made by the U. S. Geological Survey in 1910. The difference between this water and that from the deeper wells is marked.

Other localities.—On the heights west of Alexandria most residences get water from dug wells; a few have drilled wells. The supplies come from Columbia or Potomac sands and cobble beds. Depths to water and quality of supplies vary. Thus a drilled well about 125 feet deep on the southeast slope of Shooter Hill obtains iron-bearing water that rises to 60 feet of surface from a Patuxent sand bed; whereas about 100 yards east, and a little higher up the hill, a well only 20 feet deep yields an abundant supply of soft clear water. At most wells the water is soft.

The irregular occurrence of water in crystalline rocks in the western part of the county is shown by the following records furnished by N. H. Darton. The second well is 150 feet east of the first.

Record of well of G. N. Saegmuller, Chain Bridge.

(Authority, W. C. Miller, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Micaceous red clay	60	60
Soft micaceous rock	10	70
Gneiss	485	555

A little water, about 2 gallons per minute, was found at 80 feet and no water below.

Record of well of G. N. Saegmuller, Chain Bridge road.

(Authority, W. C. Miller, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Micaceous red clay	60	60
Soft micaceous rock	11	71
Gneiss	10	81

The yield of this well was 8 gallons per minute.

The record of another well that obtained water from granite is given below.

Record of well of A. M. Lathrop, Upton Hill, near Fostoria.

(Authority, W. C. Miller, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Micaceous red clay	60	60
Soft micaceous rock; small supply of water at 60 feet	34	94
Soft gneiss	80	172

According to the driller, this well, when completed, yielded 15 gallons per minute of excellent water.

About Addison and Arlington Junction are many dug wells and a few drilled wells. The dug wells are 15 to 25 feet deep. The drilled wells vary greatly in depth. One at the power house of the Washington, Alexandria & Mt. Vernon railway, near Luna Park, yields a small flow of good water from a sand bed reported to be but 36 feet below surface. The comparatively high head of the flow, about 20 feet, is explainable by the water bed receiving supplies from the hill on the Luna Park grounds, and thus having an initial head of possibly 100 feet. At the plants of the Standard Brick Co., and of the New Washington Brick Co.

near Addison are wells 140 feet and 131 feet deep respectively, tapping Patuxent beds. The water is used for boiler supply and for drinking. An analysis of the water from one of the wells appears in table 11.

There are no deep drilled wells at Rosslyn. Most dug wells obtain soft water from Columbia or Potomac sands and cobble beds. Depths range from 15 to 40 feet.

On the terrace near Ballston, Clarendon, Veitch and Kearney, dug wells about 20 feet deep are practically the sole source of supply. The water lies chiefly in Columbia sands or cobble beds and is soft at most wells; a few wells yield hard water and a few water that is irony.

About Glen Carlyn dug wells are 20 to 35 feet deep. The water, in Columbia cobble beds, is soft as a rule.

Falls Church lies chiefly in Fairfax County and its water supply is described under that county.

Conclusions.—The underground water resources of Alexandria County are considerable and can meet far greater demands than those at present made. At Alexandria and along the river front northward, it will probably pay any concern using large amounts of water to have a competent driller make a test to bed rock. Exact prediction of depth to good boiler water at a particular point is impossible. It is probable that such water will be found within 100 feet of bed rock, that a deep well will penetrate a number of water-bearing sands, and that wells a short distance apart will get water of different quality from about the same depth.

Deep drilling on the higher terraces to develop water in the crystalline rocks is a more uncertain venture. It will often be justified by sanitary considerations.

CAROLINE COUNTY.

General description.—Caroline County, formed in 1727 from portions of Essex, King and Queen, and King William counties, lies in the western part of the Coastal Plain between Rappahannock and Mattaponi rivers and extends into the Piedmont region.

The topography is of the western shore type. On the highest terraces are patches of swamp in which head sluggish brooks that meander to the edge of the terrace, then descend rapidly through sharply cut valleys to the lowest terrace. Elevations range up to 250 feet. The Lafayette terrace caps divides in the western end and the Sunderland terrace occurs on the divides in the eastern end of the county. Lower terraces make the second and first bottoms of Rappahannock and Mattaponi rivers.

The oldest rocks exposed at the surface within the Coastal Plain part of the county are the Triassic sandstones and shales in the valley of the South Anna River. The sands, gravels, sandstones, and clays of the Potomac, the greensands of the Pamunkey, and the clays and sands of the Chesapeake all outcrop.

UNDERGROUND WATERS

Because of the topography and because of the variability in composition of the surficial deposits, the depth to the water table and the character of the ground water vary greatly. On projecting headlands of the Lafayette or Sunderland terraces dug wells may have to go 60 feet to get water, while on level interstream areas of the same formation wells may find sufficient supplies within 12 feet of surface and be full to the top after prolonged rains. On the lower terraces the differences in depth to water are less but the wells are more apt to go dry in drought. The sands of the high terraces yield water that is mostly soft but in places it is hard. Waters in the lower terraces are more apt to be hard or iron-bearing. Wells sunk through the terrace formations or through valley wash into the Chesapeake deposits obtain water that may be soft; if the water comes from a bed of shell marl it may be decidedly hard. Supplies may be scanty, though the wells penetrate the clayey sands for 50 feet. The Potomac and Pamunkey sands, tapped by drilled wells along Rappahannock River, yield flows of soft water of good quality that has a faint "sulphur" odor.

Springs.—Because of the topography Caroline County contains many springs of the Coastal Plain type. They are comparatively little used for household supply and none is of commercial importance. One near Guineys has a local reputation for yielding water of theraputic value.

Wells.—Dug wells, most of them having a wood curbing at the bottom, are the chief source of supply. There are comparatively few driven wells in the county and perhaps 10 drilled wells along Rappahannock River.

The usual price for digging a well is $5. This does not include extra labor needed and lumber used for curbing.

LOCAL SUPPLIES

Bowling Green.—Practically all the water used in this village, the county seat, is obtained from dug wells 25 to 35 feet deep which give enough water for household use, but few withstand continued heavy pumping after prolonged dry weather. Some of the wells are poorly located.

According to R. P. Vincent, there are about 60 dug wells in the village. He gives the following as an average section of the materials penetrated.

Generalized section at Bowling Green.

(Authority, R. P. Vincent.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Red loam	7	7
Red loam and pebbles	7	14
Yellow sandy clay, with seeps of water	12	26
Gray sand, main supply of water	6	31

The supplies show unexpected variations in quality, due either to the chaotic assortment of materials in the basal beds of the Sunderland formation or to some wells striking shell beds in the Chesapeake. The water from the public well in front of the old courthouse is soft and contains little iron, while almost directly across the street, the well of R. P. Vincent gives water that is hard and contains iron. The village has a reputation for healthfulness, so the supplies obtained from the dug wells are presumably satisfactory from a sanitary standpoint.

Results of field assays of the water from neighboring wells appear in table 7.

Other localities.—At Milford on Mattaponi River the dug wells average 20 feet deep, and get water from sandy and gravelly Columbia beds. The water in a number of the wells is decidedly irony.

The dug wells at Port Royal go deeper than at Milford; some pass through the Columbia sands and get hard water in the Pamunkey greensands at 20 to 25 feet. The artesian wells at or near Port Royal tap coarse greensands and gravels at the bottom of the Aquia formation. The water is beautifully limpid, has a faint "sulphur" odor and is distinctly alkaline.[a] One of these wells, owned by the corporation of Port Royal, is on the river edge just below the steamboat landing. It is 272 feet deep, 1½ inches in diameter, and flows 2 gallons per minute, the flow varying slightly according to the stage of the tide. An attempt to get a supply on the terrace, elevation 20 feet, by a ram, proved disappointing and was abandoned. The other wells at and below Port Royal get water from the Aquia. A few wells farther up stream get water from "quicksand" in the Potomac. One of these wells at Hayfield farm near Horseneck is 169 feet deep and just flows at an elevation of 25 feet above tide. The driller reported the following log:

[a]For field assay of water, see table 9.

Record of well of A. B. Lewis, 9 miles southeast of Fredericksburg.
(Authority, Geo. Heflin, driller.)

Material	Thickness (Feet)	Depth (Feet)
Red clay and gravel	20	20
Blue marl; water at bottom; this water cased off	80	100
Quicksand, "green with white spots"; main flow at 167 feet	67	167

The following summarized statement shows the variations in depth to water and quality of supplies at several localities dependent on dug wells. The data are from reports by postmasters and others.

Details of dug wells in Caroline County.

Post-office	Depth of wells (Feet)	Water bed	Quality of principal supply
Brandywine	25 to 45	....	Hard, soft
Central point	40	....	....
Chilesburg	16 to 24	Clay and gravel	Soft
Delos	10 to 20	Sand	Soft
Edgar	25 to 40	Iron crusts	Shallow, soft; deep, hard
Ezra	30 to 50	Gravel	Soft
Golansville	16 to 50	Gravel	Soft
Guineys	15 to 25	Sand, blue clay	Fair, irony
Milford	10 to 60	Sand, gravel	Soft, irony
New London	30 to 35	....	....
Penola	10 to 75	....	....
Return	40	....	....
Rappahannock Academy	20 to 45	....	....
Woodford	12 to 30	Gravel	Soft

Conclusions.—Except at a few villages present supplies of water are equal to local demands. Water that is above suspicion of pollution can be had from the Pamunkey and the Potomac sands by properly drilled wells, but flows are not to be expected at over 25 feet above sea level.

At Bowling Green excellent water for domestic use can be had from the Pamunkey at a probable depth of 400 feet. As this water will not rise within 100 feet of surface, the well would have to be pumped, hence should be of sufficient diameter. At Milford a flow at the surface from either Pamunkey or Potomac sands is doubtful. Enough water to keep fire tanks full and supply several buildings can be had on the terrace at Port Royal by attaching a hydraulic ram to a carefully drilled and cased well of larger diameter than those now in use. On the Mattaponi no artesian wells have been sunk, but flows may be struck at 300 feet below tide level at the east line of the county. In general flows are not to be expected and supplies that will rise 20 feet above river level are unlikely. There is a good prospect for flows at less elevation east of Penola. The Newark rocks on the North Anna River are uncertain water-bearers, as shown by the deep well at Doswell.

CHARLES CITY COUNTY.

General description.—Charles City County, one of the original shires of the colony of Virginia, was formed in 1634. It extends along the north side of James River to the eastern end of the peninsula between James and Chickahominy rivers.

Away from the rivers the western end of the county has a gently rolling surface, cut here and there by some tributary of the James or the Chickahominy. An altitude of 200 feet is reported just south of Roxbury. This high point is a remnant of the Lafayette terrace, and other remnants of the Lafayette terrace may be seen northeast of Malvern Hill. The lower terraces are plainly evident in the east end of the county. On the James the development of the Wicomico terrace gives the topography a peculiar, drowned look; red hills, remnants of the Sunderland terrace, project above the buff loams and clays of the Wicomico plain. This is particularly noticeable on the road from Charles City to Richmond, between the Willcox Wharf road and Herring Creek. Along the Chickahominy which, above Providence Forge, flows for 40 miles through a narrow swamp, a low terrace is well developed.

The Columbia or the Lafayette overlies the clays, sands, and marls of the Chesapeake, on the higher land in the eastern part of the county. The Chesapeake is probably not more than 120 feet thick, thinning toward the west. Along James River, from the west line of the county to Herring Creek, the greensands of the Pamunkey lie just below the Columbia and are exposed in bluffs. The Chickahominy has not cut its way down to the Pamunkey, though at Roxbury the cover of Chesapeake is less than 50 feet thick.

UNDERGROUND WATERS

Occurrence and character.—Supplies of underground water sufficient for the needs of farm houses can be obtained on the terraces from wells sunk in the Lafayette or the several Columbia formations. The depth to the water table varies according to topography, depth of the surficial deposits, freedom of ground water movement, etc. Some anomalous conditions result. For instance, near Shirley some wells on projecting headlands of a Sunderland plain get water at 15 feet in loam, while on the Wicomico terrace 50 feet below and not over 300 yards distant, wells go 30 feet to water. The quality of the supplies from the Sunderland and Wicomico formations varies, but is generally soft. On the stretches of a low-lying terrace near James River, excellent water can be had by driven points 20 to 30 feet deep. Water from shallow wells in the Chickahominy valley has a bad reputation, being thought to cause malaria, and intestinal diseases. Part of this ill-repute is no doubt due to the use of dug wells.

Springs.—Charles City County has its share of springs, most of which are of the ordinary Coastal Plain type, flowing from terrace gravels above Chesapeake or Pamunkey beds of sandy clay. The flows are small, probably averaging less than 5 gallons per minute, but the waters are soft. No spring is the site of a health or pleasure resort, and from none is water shipped in commercial quantities. A few that are noticeable for one reason or another are those of John Ruffin, 6 miles west of Charles City; E. A. Saunders at Buckland Farm in the same section; and R. W. Swift 2 miles southeast of Elko. The last, situated in a hollow by a run that empties into Chickahominy River, has a fine flow of 20 to 25 gallons per minute from clayey and sandy beds near the bottom of the Wicomico formation. Other good springs are found along the same run. The water from Mr. Swift's spring is clear and sparkling, and is used for all domestic purposes. A field assay is given in table 6.

Wells.—The dug well, cased with wood, is the chief source of underground water supply. In places on the lower terraces along James River driven wells are used. There are few deep drilled wells, though water-bearing beds in the Pamunkey or Potomac underlie the entire county.

LOCAL SUPPLIES

Of the deep wells reported, one 280 feet deep, near the Chesapeake & Ohio railroad station at Roxbury, on the edge of the cypress swamp along Chickahominy River, was drilled for T. L. Watson to furnish drinking water of better quality than could be procured by dug wells, and to supply a mill boiler. The water rises to within 2 feet of surface, or about 40 feet above mean high tide in James River. According to unverified reports a small flow was struck at 70 feet, but was cased off. The main flow is from a Potomac gravel bed. The water, pumped by a windmill, is clear and soft with a very slight sulphur taste. It works nicely in a boiler, and is called an excellent table water.

One of the finest wells in the section along James River was sunk for W. M. Ramsey, on the famous estate known as Westover. The well, which is 10 inches in diameter and 139 feet deep, found water in a bed of gravel and black sand (basal Pamunkey) at 132 feet; this water rises to 10 feet of surface, or 10 feet above mean high tide. Pumping 70 gallons per minute lowers the water 8 feet. A 4 horse-power gas engine belted to a horizontal pump, forces the water to a tank whence it is piped to the house, stables, and other buildings. The water is clear, tasteless, and odorless.

At Bucklands stock farm, near Bucklands Landing on James River, are 6 flowing wells ranging in depth from 168 to 184 feet that reach Pamunkey sands. The flows are free, ranging from 6 gallons through a 2-inch pipe, at the well on the highest ground, elevation 24 feet, to 80 gallons per minute at a well by the river. The reported head of the flows is about 32 feet above river level. (See table 5.)

Near Charles City dug wells are found 25 to 40 feet deep, averaging 30 feet, and ordinarily contain 4 or 5 feet of water. In most wells the water is called hard.

The following section in a road cut at Courthouse Creek shows the general character of the Columbia and Chesapeake beds reached by dug wells.

Section at Courthouse Creek, Charles City.

Material	Thickness *(Feet)*	Depth *(Feet)*
Gray, buff, and red loam and clay	10	10
Discontinuous band of cobbles	1	10
Gray sand	3	14
Iron crusts and sand	2	16
Coarse yellow and orange sand	10	26

Near Binn's Hall dug wells are 12 to 60 feet deep, most being from 12 to 25 feet; the water in the shallow wells is soft, in the deep hard. Near Oldfield the wells average around 30 feet and yield soft water; near Sturgeon depths range from 20 to 70 feet, averaging 50 feet. The water is soft. On the terrace back of Wilcox Wharf wells are 30 to 45 feet deep. One on the bluff, belonging to T. W. Hubbard, went 12 feet through red and buff clay and 31 feet through sand, gravel, and iron crusts, with pebbles near the bottom. The water is soft and excellent for domestic use. (See analysis, table 8.)

At Eppes Island on James River, driven wells get good water from the Talbot formation at 15 feet. At and near Shirley are a considerable number of driven wells. They are from 27 to 35 feet deep. H. S. Saunders gives the following average record for wells at Upper Shirley.

Generalized section at Upper Shirley.

(Authority, H. S. Saunders.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	3	3
Tough gray clay	10	13
Reddish sandy clay	15	28
Cobble bed	4	32
Coarse gravel, water-bearing	1	33

A field assay of a sample of water from a 30-foot well is given in table 7.

This well, driven some 15 years ago, is situated in a slight hollow of a terrace about 25 feet high. To guard against surface water working down along the pipe a hole 4 feet in diameter and 1 foot deep was dug about the pipe and filled with concrete. A deep well drilled for Mr. Saunders struck bed rock at 350 feet. It did not get a flow.

Near Malvern Hill post-office wells are from 20 to 70 feet deep; some of the deeper ones go down into "marsh-mud," probably fine dark clays of the Pamunkey, and obtain little water. A well at the post-office, said to be 50 feet deep, though nearly full in wet weather, is said to go dry in droughts; it evidently gets little water except what comes in near the surface. In the neighborhood are several 8-inch wells bored by an earth auger and cased with 12-inch tile. One of these owned by J. M. Gill, 70 feet deep, cost $15 to bore. This well is said to be sunk through "marsh-mud" below the surface sands and loam. The depth from which the main supply of water comes in wet weather is uncertain. The character of the water in 1906 is indicated by the field assay in table 8.

Data regarding dug wells at a number of places in the county are presented in the accompanying table.

Details of dug wells in Charles City County.

Post-office	Depth of well *(Feet)*	Water bed	Quality of principal supply
Binn's Hall	12–60	Sand and marl	Hard and soft
Holdcroft	13–30	Sand	......
Oldfield	35	Sand	......
Lent	30–75	Marl	Hard
Lamc	30	Sand	Soft
Sturgeon Point	15–60	Sand and clay	Soft

Conclusions.—Good water can be had by dug, driven, and drilled wells in Charles City County. On the low ground along Chickahominy River where the shallow water is regarded with suspicion, plentiful supplies can be had from Pamunkey sands 150 to 300 feet below sea level; along the tidal portion of the river, south of Boulevard, basal sands of the Chesapeake group 100 to 150 feet below sea level, may yield small flows at elevations less than 10 feet. Along James River in the eastern half of the county good flows can be had from the Pamunkey, but heads 25 feet above river level should not be expected.

CHESTERFIELD COUNTY.

General description.—Chesterfield County, formed from Henrico County in 1748, is bounded on the north and east by James River and on the south and west by Appomattox River, but only that part of the county east of a line from Richmond to Petersburg lies within the geologic province considered in this report. In this part of the county elevations range up to 210 feet. James River and Appomattox River have cut gorges nearly 200 feet deep in what was a gently rolling plain, and tributary creeks have V-shaped valleys. Near the rivers the Columbia terraces have been largely removed, but remnants of the Sunderland and Wicomico terraces are traceable back of Manchester and along the road from Manchester to Petersburg. The Talbot terrace is nowhere conspicuous.

A gray granite, in places gneissoid, outcrops about Manchester and causes rapids in James River. It also outcrops near Ettricks on Appomattox River. The sand, sandstone, and cobble beds of the Patuxent formation are exposed in places along James River and are conspicuous on the north bank of Appomattox River. The dark green glauconitic sands of the Nanjemoy formation outcrop at Powhatan and elsewhere on Appomattox River. The sands and diatomaceous clays of the Calvert overlap the Nanjemoy, resting on that formation, the Patuxent, or the granite. The yellow, buff, and reddish loams of the Lafayette and Sunderland formations mantle the divides.

UNDERGROUND WATERS

Occurrence and character.—Ground water, stored in the coarser beds of the Lafayette and of the various Columbia formations, is the chief source of supply. Depths to the water table show the usual variations characteristic of the western edge of the Coastal Plain and range from 5 to 50 feet. The water as a rule contains little mineral matter in solution and is clear and soft.

Springs.—Chesterfield County contains many springs. As fastidious people in Richmond desired water of better appearance and greater purity than the supplies that were, until the installation of purification plants, furnished by the city waterworks, some of the owners of conveniently situated springs have sold large quantities locally, and have extended business to points outside the State. Some of the important springs are outside the Coastal Plain area, and flow from crevices in crystalline rocks; others, just within it, issue from gravelly beds in the surficial loams of the Lafayette or the Sunderland terrace. All the springs of note are mentioned here. Five of these springs have been advertised more or less extensively; the waters from several others have been sold or have been used in the manufacture of ginger ale and other sweetened beverages.

Perhaps the longest known of the springs is the Fonticello, situated in Swansboro, a suburb of Manchester, on a tract of land that is said to have been an Indian camp ground during the time of Powhatan. The spring issues from a crevice in the granite-gneiss exposed by a slight hollow in the red cobbly Lafayette loam that mantles the high ground west of Manchester for an undetermined distance. It flows from the cleft in the rock at the rate (estimated) of 18 to 19 gallons per minute and, according to the proprietor, shows no seasonal changes in flow. The water is pumped from a cement basin in the stone spring house to the bottling room. The overflow from the basin supplies a small pond. The grounds about the spring are laid out as a park. Care has been taken to exclude surface water by digging a blind ditch around three sides of the spring and laying tile drains. The source of the flow is uncertain, but the location of the spring, in a hollow on high ground, the temperature of the flow, 61° F. in October, 1906, the manner of emergence, and the character of the water indicate that the source is not deep. The water probably accumulates in the gravels of the Lafayette on the higher ground to the west and flows by connecting joints in the underlying granite to the outlet.

Fonticello Lithia water, as the output of the spring is called, is shipped in bottles and carboys. It is sold for table use and as a light bicarbonated alkaline water for disorders of the liver and kidneys.

The following analysis is recomputed from that given in circulars sent out by the proprietor.

Analysis of Fonticello Lithia water.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	46.
Silica (SiO_2)	14.
Iron (Fe)	1.6
Aluminum (Al)	0.07
Calcium (Ca)	2.0
Magnesium (Mg)	0.61
Sodium (Na)	3.5
Potassium (K)	1.5
Manganese (Mn)	trace
Lithium (Li)	0.08
Arsenic (As)	trace
Bromine (Br)	trace
Bicarbonate radicle (HCO_3)	13.
Sulphate radicle (SO_4)	2.5
Phosphate radicle (PO_4)	0.04
Chlorine (Cl)	5.4
Free carbon dioxide (c. c. per liter)	30.

Not far from the Fonticello, in Manchester, on a hillside pasture lot in the shallow valley of a small run, is another spring flowing from a cleft in granite. This spring, known as the Bellfont, has been less advertised than the Fonticello, and the water is sold chiefly for table purposes in Richmond.

The water is clear, tasteless, and odorless. There were, in 1906, no buildings on the slope above the spring for 200 yards or more, and the sanitary surroundings were good. The flow, estimated at about 20 gallons per minute, is said not to vary during the year. The only improvements at the spring at the time it was seen were a cement basin and a small frame springhouse. In essential characteristics of origin and emergence, this spring resembles the Fonticello; and the water has much the same composition. The following analysis was furnished by the former proprietor, Clarence Vaden, of Manchester.

Analysis of Bellfont Lithia water.

(W. H. Taylor, analyst.)

	Parts per 1,000,000
Total solids	44.
Silica (SiO_2)	14.
Iron (Fe)	1.0
Calcium (Ca)	1.9
Magnesium (Mg)	0.4
Sodium (Na)	3.8
Potassium (K)	2.9
Lithium (Li)	0.03
Bicarbonate radicle (HCO_3)	5.3
Sulphate radicle (SO_4)	10.
Chlorine (Cl)	5.8

About 1 mile southeast of Swansboro post-office, in a tract of land partly wooded, partly open, is a group of springs from which water has been sold from time to time. In 1905 the title passed to people who made extensive improvements with the apparent intent of having more ornate surroundings there than at any spring near Richmond. The spring-house, open at the sides, has a concrete floor, the basin is walled with slabs of white marble, and a niche of similar slabs surrounded by an ornamental iron screen is built above it. These springs, known as the Holly Lithia springs, are situated in a slight hollow of the almost level surface of the plain. The chief spring is a "boiling spring," the water rising from a bed of coarse sand, gravel, and cobbles beneath a few feet of surface soil and loam. Dug wells in the vicinity strike granite at from 5 to 30 feet below surface. The water is clear, tasteless, and odorless, and contains free carbon dioxide, bubbles of which can be seen rising in the basin. When the spring was inspected there were no dwellings nor other buildings so situated that contamination of the spring water from them was possible. The source of the water is evidently shallow, as indicated by the temperature, 62½° F., in October, 1906. The present volume of flow was determined, it is said, by the improvements made; a flow sufficient to fill a 4-inch pipe was obtainable by lowering the level of the water in the spring basin 2 feet.

The output has been sold for table use almost exclusively. The following analysis, furnished by the manager, J. P. Carson, of Richmond, shows a lower mineral content than the Fonticello and Bellfont springs, but the same type of mineralization. An analysis made thirteen years before, by Chas. H. Chalkley, agrees closely with the later analysis.

Analysis of Holly Lithia water.

(Froehling & Robertson, analysts.)

	Parts per 1,000,000
Total solids	35.4
Silica (SiO_2)	11.
Iron (Fe)	0.35
Aluminum (Al)	0.8
Calcium (Ca)	1.4
Magnesium (Mg)	0.35
Barium (Ba)	0.008
Sodium (Na)	4.6
Potassium (K)	1.
Lithium (Li)	0.033
Bicarbonate radicle (HCO_3)	4.8
Sulphate radicle (SO_4)	4.3
Phosphate radicle (PO_4)	0.029
Nitrate radicle (NO_3)	2.7
Iodine (I)	trace
Chlorine (Ca)	4.4

Three miles south of Manchester, at Swineford Station, on the Atlantic Coast Line Railroad, is the spring formerly known as Swineford's spring, and now called the Lion Lithia spring. It is owned by the Virginia Lithia Springs Co. It is a boiling spring, the water rising through coarse gravels in a terrace slope west of the railroad. The flow, which is said not to vary with the seasons, is about 10 gallons per minute. Its temperature when measured, October, 2, 1906, was 63° F. The owners do not claim for the water, which is clear and bright, without color, taste, or smell, any therapeutic value, but simply state that it is a good table water. Part of the output is sold still in carboys, part is carbonated and sold in bottles, and part is used for making ginger ale. The following analysis is recomputed from one furnished by the company.

Analysis of Lion Lithia water.

(Froehling & Robertson, analysts.)

	Parts per 1,000,000
Total solids	28.1
Silica (SiO_2)	10.
Iron (Fe)	0.11
Manganese (Mn)	0.022
Aluminum (Al)	0.18
Calcium (Ca)	1.0
Magnesium (Mg)	0.40
Lithium (Li)	.011
Sodium (Na)	3.
Potassium (K)	1.2
Bicarbonate radicle (HCO_3)	3.9
Phosphate radicle (PO_4)	0.035
Sulphate radicle (SO_4)	4.1
Arsenate radicle (AsO_4)	0.039
Chlorine (Cl)	3.6
Iodine (I)	trace
Bromine (Br)	trace
Free carbon dioxide, 54 c. c. per liter.	

When the writer saw the spring there were no buildings above it for a considerable distance, and the chances of pollution were remote. The spring house had a tile floor, concrete walls, and an open roof. From the basin the water flowed to the bottling house, a two-story frame building 400 feet distant, which contained carbonators, automatic washing machines, etc.

Four miles west of Manchester, in a shallow ravine, is a spring with a flow of 25 to 30 gallons per minute, known as the Beaufont. It issues from a cleft in granite, and is covered by a frame spring house with cement floor. The water, which is clear and without taste or odor, had, when the spring was visited on October 2, 1906, a temperature of 57° F. It flowed through a tile pipe line to a bottling house by the roadside, 100 yards or more from the spring. Most of the output was said to be used in making ginger ale. The following analysis, furnished by the proprietor, has been recomputed to express results in standard form.

Analysis of Beaufont Lithia water.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	63.
Silica (SiO_2)	16.
Iron (Fe)	0.25
Aluminum (Al)	8.4
Calcium (Ca)	1.4
Magnesium (Mg)	1.0
Sodium (Na)	4.0
Potassium (K)	2.1
Manganese (Mn)	trace
Lithium (Li)	0.07
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	15.
Sulphate radicle (SO_4)	1.3
Phosphate radicle (PO_4)	0.04
Chlorine (Cl)	5.2
Iodine (I)	0.06
Bromine (Br)	trace
Free carbon dioxide (CO_2)	37 c. c. per liter

In 1906 the land about the spring was largely wood-covered; there were no dwellings near, and pollution was improbable.

Situated at Buckhead Springs Station, on the Seaboard Air Line Railroad, about ½ mile east of Centralia, at the head of a run that empties into Proctor Creek, are the Buckhead springs, a group of three, with a total flow of about 2½ gallons per minute. The water, which comes from sandy beds in the Sunderland formation, is bright and sparkling, without taste or odor. The flow is said not to vary in volume or temperature throughout the year. The proprietor has taken strict precautions to insure the sanitary excellence of the spring surroundings. The residences and farm buildings on a small area of level ground, a remnant of a high Columbia terrace, are about 300 yards from the springs. Concrete walls and tile drains about the springs prevent the entrance of surface water. The water flows from the concrete basin at the spring-house through an enamel pipe to an enamel filling basin in the bottling house, a frame building, 60 by 20 feet, near the railroad track, where it is at once securely sealed. The output has a wide sale as a table and as a medicinal water. It contains free carbon dioxide, hence is light and pleasant. The following analysis, recomputed from one furnished by the proprietor, Thos. S. Wheelwright, of Centralia, shows a low mineral content.

Analysis of Buckhead Chloride Lithia water.

(Froehling & Robertson, analysts.)

	Parts per 1,000,000
Total solids	43.
Silica (SiO_2)	7.4
Iron (Fe)	0.1
Aluminum (Al)	0.53
Calcium (Ca)	1.4
Magnesium (Mg)	2.5
Sodium (Na)	3.6
Potassium (K)	2.3
Lithium (Li)	0.001
Manganese (Mn)	0.009
Barium (Ba)	0.02
Arsenic (As)	faint trace
Bicarbonate radicle (HCO_3)	3.1
Sulphate radicle (SO_4)	0.72
Nitrate radicle (NO_3)	8.80
Phosphate radicle (PO_4)	0.009
Chlorine (Cl)	11.
Free carbon dioxide (CO_2), 15 c. c. per liter.	

About 5 miles south of Manchester, near Temple's station, is the Campfield spring or well. It is situated in a hollow. The water flows from a bed of gravel covered by sand and loam. The water is shipped to Richmond, Norfolk, and other points, and is sold for table and medicinal use.

The following analysis is recomputed from that supplied by the company owning the spring.

Analysis of Campfield Lithia water.

(N. B. Tucker, analyst.)

	Parts per 1,000,000
Total solids	28.
Silica (SiO_2)	5.3
Iron (Fe)	0.3
Aluminum (Al)	0.11
Manganese (Mn)	trace
Calcium (Ca)	0.8
Magnesium (Mg)	0.9
Barium (Ba)	trace
Sodium (Na)	3.2
Potassium (K)	1.9
Lithium (Li)	0.05
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	8.0

Analysis of Campfield Lithia water—(Continued).

	Parts per 1,000,000
Sulphate radicle (SO_4)	2.4
Phosphate radicle (PO_4)	0.03
Chlorine (Cl)	5.2
Bromine (Br)	trace
Iodine (I)	trace
Free ammonia	0.002
Albuminoid ammonia	0.009
Nitrogen as nitrates	0.0
Nitrogen as nitrites	trace (?)
Free carbon dioxide gas, 27 c. c. per liter.	

Besides these springs several others in eastern Chesterfield County are or have been of commercial importance, including the Urquhart Lithia spring, 4 miles from Richmond, and the Rocky Run south of Wiseville. A partial analysis of the water from the latter, furnished by the proprietor, David Adkin, is appended in recalculated form.

Partial analysis of Rocky Run Lithia water.

(Analyst unknown.)

	Parts per 1,000,000
Calcium (Ca)	40.
Magnesium (Mg)	0.46
Sodium (Na)	1.1
Potassium (K)	1.6
Iron (Fe)	1.1
Lithium (Li)	0.07
Carbonate radicle (CO_3)	1.2
Sulphate radicle (SO_4)	6.3

In the southern part of Chesterfield County are several springs from which water is or has been sold in Petersburg. One of these, the Patrol Oaks Mineral spring, three-quarters of a mile northeast of Ettricks, is a well rather than a spring. The water is clear, tasteless, and odorless; the flow is about 6 gallons per minute.

Another spring just north of the Powhatan highway bridge across Appomattox River is owned by a company and was once an important source of drinking water in the city of Petersburg. It is known as the Aqueduct spring. The water is still sold in the city, being delivered to houses at a nominal charge, and is the chief drinking water in Powhatan.

There are several springs along the valley side near Powhatan, some of the water coming from the Pamunkey (the contact of the basal pebble bed of this formation with dark clays of the Potomac being exposed just below the springs), and some of the water coming from under the Columbia loam which hides the older formations. The water is tasteless and odorless, clear and soft, and the slope above the springs has been so sparsely inhabited that the possible contamination of the sources has not called for investigation.

Wells.—Dug wells are almost the sole source of underground water for domestic supply. There are few drilled wells. The large manufacturing concerns and the railroad yards in Manchester either use city water or pump their own supplies from James River.

LOCAL SUPPLIES

Manchester, now a part of Richmond, owned its waterworks in 1906 and distributed filtered James River water. In the outskirts of the city, particularly to the west, are many shallow dug wells. The suburb of Swansboro, for instance, with a population of several thousand people, had no public supply system in 1906. The wells were dug through Lafayette cobble loams and decomposed granite, some obtaining water from the Lafayette and some from the granite. In places where firm granite comes near the surface more or less blasting has been done, usually with indifferent success. Where the cover of loam is thin, dug wells in such a thickly settled area are particularly liable to pollution; where 25 feet of loam, sand, and rotten granite are found above water, there is less danger; but wells should not under any circumstances be located within 75 feet of cesspools, privies, and other sources of contamination, and should be properly protected. In Manchester the local authorities have been closing dug wells as city service is extended.

At Bermuda Hundred on the bank of James River dug wells average 15 feet deep; the supply is not considered as satisfactory as that from springs, of which there are several along the foot of the low bluff facing the river. One of these, on property of the Farmville & Powhatan Railroad, has a bold flow of soft water, sufficient for the needs of several families.

At Centralia dug wells go down 18 to 20 feet, and obtain soft water from Columbia sands and clays.

There are in Chester about 50 dug wells 25 to 40 feet deep which get water from Columbia sands. Neither at Centralia nor Chester do wells go to hard rock.

At Ettricks, just across Appomattox River from Petersburg, dug wells are 12 to 45 feet deep, averaging 20 feet. They are not sunk to rock, but get water of varying quality, mostly soft, from beds in the Columbia.

Dug wells in Powhatan are sunk in Potomac and Columbia sands and gravels. They are about 20 feet deep, and some yield water of suspicious quality. Much of the drinking water used is taken from the Aqueduct Spring, previously mentioned.

Conclusions.—Satisfactory supplies for isolated residences and farm buildings can be had from dug wells. In thickly settled areas water much less liable to pollution can be had from drilled wells. Owing to the dissection of the Coastal Plain formations by the gorge of James River, flowing wells are not to be expected.

DINWIDDIE COUNTY.

General description.—Dinwiddie County, formed in 1752 from Prince George County, lies between Appomattox River and Nottoway River. Only a narrow strip along the east line of the county, which contains the city of Petersburg, is included in the Coastal Plain.

Most of this area has an elevation of more than 150 feet, and is included within the Lafayette and Sunderland terraces. Small patches of the Wicomico and lower terraces are found along Appomattox River near Petersburg. From an elevation of nearly 300 feet within a few miles of Petersburg there is an abrupt descent north to Lieutenant Run and Appomattox River, and a gentle slope southeastward. The southward-flowing streams which head in the divide, tributaries of Blackwater River, flow through swampy valleys.

Geology.—Crystalline rocks underlie the Coastal Plain section of the county at no great depth. Potomac, Pamunkey, and Chesapeake beds are all exposed in the immediate vicinity of Petersburg, but elsewhere are usually hidden by the Lafayette or the Columbia formations. The three, however, may be seen along Livetenant Run. Potomac arkosic sands and cobble beds are exposed near the mouth of the run at the crossing of the Norfolk & Western Railroad; Pamunkey greensands are visible at the east end of the dam at the city pumping station; and light-colored diatomaceous clays and dark greenish sandy clays of the Chesapeake, full of clam and scallop shells, are to be seen along the run and in its bed as far west as the Seaboard Air Line Railroad. Both the Potomac and Pamunkey are barely thicker than feather edges near Petersburg. The Chesapeake overlaps them and may have an extreme thickness of more than 100 feet at the eastern end of the county.

UNDERGROUND WATERS.

Occurrence and character.—All the Coastal Plain formations carry ground water, but the depths to the water table and the character of the water vary greatly. The chief sources of supply are the Lafayette and Sunderland formations, though a considerable number of wells are sunk in the Talbot and Patuxent sands and gravels near Appomattox River.

Springs.—There are numerous springs along hillsides and stream valleys, but they are usually small and of little importance, except for watering stock. No mineral springs from which water is shipped on a commercial scale are reported.

Wells.—Dug wells are the principal source of supply. Throughout the rural districts wood curbing is commonly used, but near Petersburg many dug wells are curbed with brick or stone. There are very few deep drilled wells in the Coastal Plain portion of the county.

LOCAL SUPPLIES.

The public supply system of the city of Petersburg gets water from Livetenant Run. There are, in the outskirts of the city, many shallow dug wells that vary greatly in depth and in probable freedom from pollution. Some dug wells in the city are used for boiler supply and other industrial purposes.

The only deep wells reported are those of J. B. Worth & Co., near the river. They are 100 and 150 feet deep, respectively, and yield under a pump 50 gallons of water per minute, which is used for condensing because of its temperature, 59° F.

Near Rowanta wells are 20 to 60 feet deep, most of them being about 25 feet. The deeper wells in this part of the county go through the Sunderland formation and get water, which is apt to be hard, from shell marl beds in the Chesapeake.

Conclusions.—In the rural districts dug wells not near sources of pollution, if properly protected against the entrance of surface impurities, will yield satisfactory supplies. In the city of Petersburg and its more thickly settled suburbs drilled wells are preferable for sanitary reasons. Flowing wells are not to be expected anywhere in the county.

ELIZABETH CITY COUNTY.

General description.—Elizabeth City County, formed in 1634 as one of the eight original shires of the Virginia colony, covers the tip of the peninsula, the strip of land between James and York rivers. The county contains the towns of Hampton and Phœbus, and the military post of Fort Monroe, near Old Point Comfort. At Old Point Comfort is the

Chamberlain Hotel, a famous health and pleasure resort; near Phœbus is a National Soldiers' Home; and at Hampton is the Hampton Normal and Agricultural Institute.

The county has a flat ill-drained surface, most of it being within the area covered by the lowest of the Columbia terraces, the Talbot. Elevations of about 30 feet are found in the low terrace along the Warwick County line. This plain grades very gently east to the salt marshes and mud flats of the shores.

Geology.—The yellow, buff, and gray loams and sands of the Talbot cover practically the entire surface of the county. The maximum thickness of the Talbot on the east side of the county is uncertain, but may amount to 50 feet. Below the Columbia lie Chesapeake, Pamunkey, Upper Cretaceous, and Potomac beds. The base of the Chesapeake beds on the east side of the county is about 600 feet below sea level. Beneath are about 150 feet of Pamunkey, 500 feet of Upper Cretaceous, and 900 feet of Potomac beds, the crystalline rocks lying perhaps 2,250 feet below sea level.

UNDERGROUND WATERS.

Distribution and quality.—The water table lies near the surface, and dug and driven wells get water at from 5 to 15 feet. The quality of the ground water is variable. Along the shores wells are liable to become salty under heavy pumping, and where the surface loams and sands are thin, wells go down into shell beds which yield hard water. The Chesapeake sands are uncertain water-bearers. The sands are local and seldom yield free flows. The water is iron-bearing in the upper beds and brackish in the deeper ones.

Springs.—There are no springs of commercial importance in the county. Most of the so-called springs are very shallow wells, dug in hollows where the water table is but a foot or two below the surface; many used for stock and household purposes have unsanitary surroundings and are liable to be badly polluted.

Wells.—Dug wells are mostly used, but there are many driven wells in the county. The deep drilled wells have been mentioned in the discussion of the Norfolk-Newport News area on pages 97-116.

LOCAL SUPPLIES.

Hampton obtains water from the Newport News Light & Water Co., a corporation that supplies surface water from a watershed in Warwick and

York counties to Newport News, Phœbus, the National Soldiers' Home, Hampton Normal and Collegiate Institute, and Fort Monroe. Within the corporate limits of Hampton are perhaps 3,000 persons, of whom fully one-half used this water in 1906. Another company, the Peninsula Pure Water Co., proposed to supply Hampton, Phœbus, Old Point Comfort, and the lower part of the county generally. The water was to come from ponds near Bethel, 9 miles from Hampton.

In the suburbs of Hampton about nine-tenths of the population use driven wells which get water at 10 to 12 feet in blue and white sands and marls. Much of the well water in Hampton is too hard for laundry use, while that near the shore is brackish; hence there are many cisterns. Near the Courthouse a well, elevation about 5 feet above mean high tide, dug for fire protection, is 25 feet in diameter and 22 feet deep; it passed through marl for 16 feet. It is now used for watering horses.

In the suburbs of Hampton some dug wells were still used as a source of drinking water in 1906, but their use was condemned by local health officials.

At Hampton Normal and Collegiate Institute most of the water used is supplied by the Newport News Co. There are several dug wells 10 to 15 feet deep, cased with 16-inch tile. The elevation of the Institute grounds, which border a tidal inlet, does not average over 5 feet; hence the well water has a high chlorine content. It is examined frequently for indication of possible contamination. The following determinations, made by W. S. Sweetser of the Institute, show the character of water from the better wells near the shores of lower Elizabeth City County.

Analyses of water from wells on grounds of Hampton Normal and Agricultural Institute.

(W. S. Sweetser, analyst.)

Location of well	Parts per 1,000,000	
	Chlorine	Total solids
Machine shop	59.4	265.0
Hospital	45.3	373.0
Trade school	28.8	401.0[a]
Whittier School	24.7	———

A well just outside the Institute grounds, close to the shore, gave water which contained 111 parts of chlorine per 1,000,000, but this water was pronounced dangerous.

[a] High in nitrates; not used.

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A 12-foot well dug on the Hemenway farm 6 miles from Hampton on Back River obtains water from a marl bed. The well is about 500 feet from salt water; the elevation is 6 feet, and depth to water 3 to 6 feet. The following partial analysis was made by the chemical laboratory of the Institute.

Analysis of water from well on Hemenway farm.

(W. S. Sweetser, analyst.)

	Parts per 1,000,000
Calcium (Ca)	188.
Magnesium (Mg)	16.5
Sulphates as SO_4	32.
Total hardness, as $CaCO_3$	38.4
Chlorine	113.

The Soldiers' Home, officially designated the Southern Branch of the National Home for Disabled Volunteer Soldiers, is just outside the municipal limits of Phœbus. Over nine-tenths of the water used is obtained from the Newport News Co. A few driven wells about the grounds furnish drinking water. Cistern water is used for flushing, and salt water for flushing and for fire protection.

In Phœbus there are many driven wells 13 to 15 feet deep which get water in Columbia gravels, under quicksand and yellow loam. The water is generally hard, but is used for all household purposes. In 1906 probably three-fourths of the population used such wells, the remainder taking Newport News water.

The Hotel Chamberlain uses some 60,000 gallons of water daily, about half of which is furnished by the Newport News Co., and half obtained from two dug wells 10 feet in diameter and 14 feet deep just outside the municipal limits of Phœbus on the Soldiers' Home grounds. The elevation of the surface at the wells is 8 feet above mean high tide. The wells are bricked, and the water rises from sands of the Talbot formation, normal water level being about that of mean high tide. Either well can be pumped dry in two hours by a 4 by 6 inch duplex steam pump running 60 strokes per minute, and to get the most water the wells are pumped together about 8 hours out of the 24. The wells were dug for the old Hygeia Hotel, which had to get water by boat from Norfolk. The well water, though slightly hard, is used as it comes from the well for all purposes except drinking; for drinking it is distilled. The flow from the deep artesian well at the hotel (see page 105) is used for flushing only.

At Fort Monroe three attempts to get good water by deep drilling ended with the well sunk to granite in 1902 (see page 100). About 1894 the

Government drove a series of wells on the mainland from which water was pumped to the fort by a pipe under the creek. The supply was satisfactory for a while, but other wells were driven nearby the city of Phœbus, and under heavy pumping the wells all became salty and were abandoned. In 1906, the post used for all purposes about 300,000 gallons of fresh water daily, supplied by the Newport News Co. Salt water is used for fire protection.

Conclusions.—Dug wells in places where the water table lies as near the surface as in Hampton County are peculiarly liable to be polluted, and their use on landholdings as small as the average house lot is altogether objectionable. Driven wells that go at least 10 feet below the water table are much to be preferred. The prospects for getting water of good quality by deep drilled wells in the eastern part of the county are decidedly unfavorable.

ESSEX COUNTY.

General description.—Essex County, formed in 1692 from Rappahannock County, lies on the south side of Rappahannock River, in the western part of the Coastal Plain.

Topographically the county resembles many other counties of the Coastal Plain. A high terrace, the Sunderland, with a slightly rolling surface, forms the divide between Rappahannock and Mattaponi rivers. Near Rappahannock River this terrace is deeply cut by creek valleys. Where the Wicomico terrace is missing bold headlands of the Sunderland overlook the river, and are noticeable features of the topography. The height of the Sunderland plain at the northwest end of the county is about 180 feet; at the southeast end about 150 feet.

Underlying the loams and gravelly beds of the Columbia terraces, the sandy and diatomaceous clays, clayey sands, and shell beds of the Chesapeake group can be seen in many road cuts. The basal part of the Chesapeake carries many indurated layers from a few inches to a few feet thick that are a source of trouble to well drillers. The dark greensand marls of the Pamunkey underlie the Chesapeake, but are not exposed at the surface anywhere in the county. The top of the Pamunkey is near sea level at the west end of the county, and 300 feet below at the east end.

UNDERGROUND WATERS.

Character and extent.—The chief sources of ground water are the sands of the Sunderland and Talbot terraces. Wells in headlands of the Sunderland formation, near Caret, Upper Mount Landing, and Dunnsville, are 50 to 60 feet deep, while back from the valley front and away from stream gulleys, as at Center Cross, are wells 15 feet deep or even less. On the low terraces along Rappahannock River dug wells are 10 to 25 feet deep, and in the lowlands at the head of Pianketank River are even shallower. The quality of the well waters varies greatly. The waters from the Columbia formations are generally soft and low in iron, but wells that strike the Chesapeake shell marls, either near surface or beneath the Columbia, get hard water.

Springs.—Springs are abundant, but only a small proportion are used for household supply, and none is of commercial importance. Practically all the springs are of the usual Coastal Plain type and most of them flow from the contact between the Chesapeake sandy clays and the clean, sharp sands of the Columbia formations.

None of the springs is now of commercial importance, though two have attracted attention. One of these, near Dunbrooke, is situated in a little hollow. Iron crusts lie about the spring and the water rises from a bed of sand in the Sunderland formation. The water is perfectly clear when fresh, but contains iron enough to leave a slightly yellow deposit about the spring. It has some local repute for medicinal value, but lack of convenient transportation facilities has retarded efforts to put it on the market.

Two springs, one of which was formerly a resort, are on land near Meade, owned by Charles C. Tombs, and now used as a camp-meeting ground. One is called a sulphur, the other a lithia spring, but both are of the same type and the waters are much alike. Meade camp-meeting ground is on the Sunderland plain in a grove of young hardwood. Spring-fed tributaries of a creek are eating into the plain, and just south of the camp-meeting grounds one of these has made a gulley some 40 feet deep. At the head of the gulley is the so-called lithia spring. It trickles from between dark greenish Chesapeake clay and overlying gray sands and iron crusts at the base of the Sunderland formation. The flow is not large, possibly two gallons per minute. In 1906, a shallow basin, 5 feet long, with wood sides, was the only improvement at the spring. The water is soft, contains a little iron, and is clear and odorless, with a very slight "iron" taste. The thickness of the overlying loams, the excellent surface drainage, the short time the grounds are frequented, and the sanitary precautions taken should keep the spring from becoming polluted.

The other spring, situated at the foot of a slope on the west side of the camp-meeting grounds, is now known as the iron spring but was called a sulphur spring. It flows from sands beneath a ledge of iron-stone near the base of the Sunderland formation. The water is perfectly clear and colorless in the basin, but contains a little iron, as is shown by yellow stains on the wood trough. It is said to have had a decided "sulphur odor," but this is now barely perceptible. Sixty years or more ago this spring was made a resort, and a hotel erected. The improvements have disappeared, and, though the water has a considerable reputation as a remedy for various complaints, it is not sold, though more or less is taken away by visitors. Field assays of the water of the two springs are given in table 6.

Other springs of note from their size, quality of water, or improvements, are owned by Armistead Ransome, of Dunnsville; J. H. Allen, of Layton; and Clayton Stafford, of Bowler's Wharf. Mr. Ransome's spring is said to flow 30 gallons per minute of soft water. The water from Mr. Allen's spring was once shipped to Washington, D. C., for use by a druggist. Mr. Stafford's spring flows 8 gallons per minute of clear water from the base of the Sunderland scarp. It is equipped with a hydraulic ram for household supply.

Wells.—Dug wells are the chief source of supply. In the Sunderland formation they are usually curbed with wood for 16 feet at the bottom; in the Talbot they are often curbed to the top.

Wells drilled deep enough to reach the water-bearing sands interstratified with rocky layers at the base of the Chesapeake are numerous along the Rappahannock River, there being fully 30 in the town of Tappahannock alone. They are mostly bored to get flows sufficient for domestic use, hence are of small diameter, usually 1½ inches. The reported depths vary from 250 to 270 feet below mean high tide; the reported heads vary from 10 to 30 feet above it.

LOCAL SUPPLIES.

At Tappahannock many dug wells get hard water at 12 to 15 feet. Nearly all the water now used for domestic purposes is obtained from flowing wells that strike sands underlying "rocks" at the base of the Calvert formation at a depth of 270 feet below mean high tide. The wells are mostly 1½ inches in diameter with a 2-inch casing driven through the Columbia sands and loams into the Chesapeake clays; the later wells frequently have a ¾-inch pipe to the bottom. The elevation of the terrace on which the town stands is 28 feet, but the flows, which vary with the tide, are usually small, from 1 to 2 gallons per minute. At no place in Tidewater Virginia, however, is there more economy in the use of water. Some wells supply two and even three houses, the water being piped in some instances several hundred feet, either directly from the well or from a tank at the well. There is no public supply system, but, as a safeguard in case of fire, a number of masonry tanks have been constructed by the town which are kept full by the overflow of certain wells.

The water is clear, and, though containing more lime than some Chesapeake flows, it is soft, adapted to all household purposes, and an admirable table water; a slight "sulphur" odor quickly disappears when the water stands in an open vessel. The temperature at the well mouth averages 61° F. A canning factory and a large pickling house use the water.

There are about 30 wells in or near the town, and, according to the driller who has sunk most of them, the succession of materials is as follows:

Generalized section at Tappahannock.

(Authority, O. D. Hale, driller.)

Material	Thickness (*Feet*)	Depth (*Feet*)
Sand and light clay	65	65
Blue clay with rock layers ½ inch to 6 inches thick; a little water at 135 feet	135	180
Mixed clay and sand	93	273
Thin crust of shell rock; variegated sand below; water-bearing	1	274

A noteworthy feature of the Tappahannock wells is the cypress "logs" which drillers report at about 60 feet; some of them, said to be several feet thick, cause much trouble in drilling.

Of the individual wells, the one at the pickle house of Donaldson & Shultz has the freest flow; it is on the river edge, and the mouth of the well is only 4 feet above tide. The flow in 1906 was 5½ gallons per minute, but is said to have been 12 gallons. Another good well is at the residence of B. P. Brockenborough on the edge of the terrace overlooking the river. It is cased with 2-inch pipe to the bottom, 272 feet, and has a 3-inch casing down 150 feet. The water, which is said to rise 16 feet above surface and more than 30 feet above mean high tide, is piped to the residence.

The following partial analysis of water from the well of R. T. Cauthorn shows how free from organic matter is the water from the principal water bed. Field assays of water from wells at Tappahannock and other places are given in table 9.

Partial analysis of water from well of R. T. Cauthorn, Tappahannock.

(G. H. Lehmann, analyst.)

	Parts per 1,000,000
Total solids	494.
Volatile matter	48.
Chlorine	1.95

Partial analysis of water from well of R. T. Cauthorn, Tappahannock—(Continued).

	Parts per 1,000,000
Nitrogen, as free ammonia	0.
Nitrogen, as albuminoid ammonia	0.
Nitrogen, as nitrates	0.
Nitrogen, as nitrites	0.
Sulphates, as SO_4	34.
Hardness	25.

Just north of Tappahannock, R. B. Brockenborough has four artesian wells at his large stock farm. One of these, at the manager's home, is used for domestic purposes; the other three, at barns and outbuildings, are for watering stock. In volume of flow and quality of water the wells resemble those in the village of Tappahannock. Up the river there are wells at the farms of J. P. Taliaferro and C. B. Mallory, southeast of Caret, and still farther upstream are those of Joseph Baker, J. H. C. Beverly, Mrs. M. S. Sale, and H. K. Baylor, all of which tap the same water bed.

West and south of Tappahannock artesian wells on Hoskins and Piscataquis creeks and along the Rappahannock include those of John Bradley, G. F. Croxton, and J. L. Kriete.

The first important group of wells down the river is at Ware's Wharf, where there are 5 which, though shallower than those at Tappahannock, going to an average depth of 185 feet below sea level, yield water of the same general character. The flows at individual wells vary with the tide, but range from ½ to 2 gallons per minute, with heads as high as 16 feet above sea level. The following record of one well was given from memory.

Record of well of R. L. Ware estate, Ware's Wharf.

(Authority, R. L. Ware.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Surface soil, clay and sand	30	30
Marl	140	170
Rocks	35	205

Another important group of wells is at Bowler's Wharf, 3 miles below Ware's Wharf. Here 10 wells get water from varying depths, the main flows being at about 165 to 180 feet below mean high tide. The water-bearing sand contains many rocky streaks, and the flows of nearby wells differ, the distribution of these impervious layers being a determining factor. Above the main flow is a weak one at about 130 feet, and below the main flow is another at about 240 feet. The record of the well drilled at the steamboat wharf ran about as follows:

Record of well of Garrett & Hunt, Bowler's Wharf.
(Authority, I. W. Hunt, owner.)

Material	Thickness (Feet)	Depth (Feet)
Water	10	10
Sand and gravel	15	25
Blue clay with shells	123	148
Sand	1	149
Strata of rock 1 to 9 inches thick and 6 inches to 4 feet apart; blue mud and shells, gray and red sand, and gravel between rocks; increased flow with each sand bed penetrated	18	167

This well, situated at an oyster house on the end of the wharf, flows a full 2-inch stream, 30 gallons per minute, at an elevation of about 5 feet above mean high tide and has a head of over 15 feet. It is one of the finest wells on Rappahannock River. In 1906, the flow was used as a table water on the steamboats plying between Fredericksburg and Baltimore, and for washing oysters.

Another fine well, at the canning factory of the Claybrook & Neale Packing Co., has a larger flow than that of Garrett & Hunt, namely, 45 to 50 gallons per minute at 5 feet elevation. Another well, with a flow of 17 gallons per minute at an elevation of 10 feet, is used by C. P. Garrett.

On the river shore 3 miles south of Bowler's Wharf, two wells have been drilled near a canning factory owned by Latimer Kriete to depths of 190 and 195 feet, respectively, and reach the same horizon as the wells at the wharf. One of the wells has a head of 30 feet above mean high tide, and flows 32 gallons at an elevation of 4 feet; the flow of the other was reduced by an accident in drilling. In a boiler the water has a tendency to foam and is said to form a white scale.

Just below Mr. Kriete's house, which stands on a projecting headland of the Sunderland terrace, a well was drilled to a depth of 300 feet, but, as the surface elevation is fully 65 feet, no flow was obtained.

Near Jones Point, 7 miles below Bowler's Wharf, are several flowing wells. One of these, owned by Garrett & Taylor, is 1½ inches in diameter and 221 feet deep. It flows 20 gallons per minute at 5 feet above mean high tide. The following record is reported:

Record of well of Garrett & Taylor on Jones Point, northwest of Butylo.
(Authority, I. W. Hunt, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand and clay	15	15
Gravel, surface water	3	18
Blue mud with beds of marl	107	125
Alternating layers of sand and rock; 22 rocks in all; first flow of water at 127 feet; main flow at 181 feet	106	231

Of the villages in the country using dug wells as sources of supply, Center Cross is one of the most important. The wells are sunk in the Sunderland formation to depths of 15 to 35 feet, and as a rule yield soft water. Information regarding dug wells at various places in the county is given in the following table:

Details of dug wells in Essex County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Banks	20–60	....	Soft
Dunnsville	32–80	....	Soft, hard
Caret	25–48	....	....
Center Cross	12–60	Loam and sand	Soft
Howertons	12–30	....	....
Laytons	15–30	Sand	....
Lloyds	25–30	....	....
Loretto	18–20	....	Soft
Mount Landing	10–60	Sand	....
Meade	20–50	....	....
Pedro	20–50	Sand	....

Conclusions.—Dug wells on high ground, if precautions are taken in locating and protecting them against the entrance of surface impurities, will yield satisfactory supplies. On the low terrace along Rappahannock River and its tributaries, flows of excellent water for domestic use can be had at comparatively low cost. There is a possibility of getting flows along Pianketank River, but the chances for flows at over 30 feet above sea level are poor. Flows of good quality and of equal or larger volume can undoubtedly be had from sands below those already developed.

FAIRFAX COUNTY.

General description.—Fairfax County, formed in 1742 from Prince William County, is in the northern part of the State, and is bounded on the east by Potomac River. The Coastal Plain portion along Potomac

River is about 16 miles long, but nowhere more than 6 miles wide. In it is Mount Vernon, the residence of General Washington.

The topography is rolling and broken as a whole. Along Potomac River are some nearly level stretches on low terraces, with elevations of 20 to 60 feet. Along the deeply scored sides of the Potomac valley, at higher elevations, are remnants of older terraces. An inlier of the Lafayette formation covers a considerable area north of Weddeburn and Dunn Loring, and caps the highest point in the county, Peach Grove Hill, at an elevation of 500 feet. The principal creeks in the Coastal Plain section of the county, Cameron Run, Accotink Creek, and Pohick Creek, are 8 to 15 miles long.

Back from the river the crystalline rocks are exposed in creek beds and on the valley slopes above. Near the river the sands, gravel beds, and clays of the Potomac group outcrop. The contact between the crystalline bed rock and the Potomac dips east fully 40 feet to the mile, so that at Mount Vernon the Potomac has a thickness of 525 feet. The Patuxent formation with its characteristic arkosic sands and dark clays includes fully 350 feet of the total thickness of the Potomac.

The maximum thickness of the Lafayette formation on the inlier north of Dunn Loring may be 40 feet. The Columbia formations vary in thickness from a thin edge to more than 35 feet.

UNDERGROUND WATERS.

Occurrence and character.—The decayed top of the crystalline rocks and the Potomac, Lafayette, and Columbia beds above contain ground water. The depth to water and the quality of the supplies vary greatly with the location of the wells and the character of the formations penetrated. One well may find plenty of water in Columbia gravel within a few feet of the surface, while another on a nearby slope, where the Columbia beds have been removed, may have to go deep into the Potomac beds or the granite to get a sufficient supply.

As in other counties along the "fall line," the water from the Lafayette and the higher-lying formations of the Columbia group is generally soft and slightly mineralized. On the lowest of the Columbia terraces the ground water in some places contains much iron; in others, it is excellent. The Potomac sands contain much water, but the sands that yield water freely are of irregular extent and the quality of the water varies. On high ground the crystalline rocks as a rule carry good water.

Springs.—Springs are numerous, but most of them are of small flow; only a few are of fair size. The waters are usually soft and pure and are often used for household purposes. From a few springs water has been shipped, but none is now of commercial importance.

Wells.—Dug wells, the main source of domestic supply, are frequently lined with stone and brick. Some are cased with large tile. Depths to water and the yield vary widely. Many wells are so situated and protected that there is little chance of pollution; others, particularly some on level stretches of the lowest terrace, have insanitary surroundings. Nearly all the drilled wells are 6 inches in diameter. Those on the lowest terrace get water from sands in the Patapsco or Patuxent formations of the Potomac group. Those on the high ground go into decayed or solid granite or gneiss. On the high ground no wells over 200 feet deep have been reported, but there are several of greater depth near Potomac River. The yield of the deep wells on high ground is seldom large, but nearly always sufficient for domestic purposes. Of the wells sunk on low ground to the Patuxent sands some yield large supplies, others only enough for the needs of a household of average size.

LOCAL SUPPLIES.

At the military post of Fort Hunt on Potomac River, 8 miles below Alexandria, all the water used is obtained from an 8-inch well sunk to a 13-foot bed of white sand in the Potomac group, 202 to 215 feet below the level of the terrace. The following record was obtained by Darton:

Record of well at Fort Hunt.

(Authority, W. C. Miller, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Yellow clay	24	24
Blue clay	15	39
Heavy sand and gravel, with little water	3	42
Red, blue, and yellow clays; streak of sandy blue clay with a little water at 122 feet	80	122
Red and blue clay	80	202
Coarse white sand with large supply of good water rising within 17 feet of surface	202	215

Pumping 53 gallons per minute lowers the water 15 feet. The water is pumped by an air lift to a cistern and is forced thence by a steam pump to a tank on a steel tower. The water is colorless, tasteless, and odorless. According to W. New, of the U. S. Surgeon-General's Office, the mineral matter is chiefly sodium sulphate with traces of calcium, magnesium, and iron salts. A partial analysis showed 342 parts of total solids and 5.14 parts of chlorine per million of water.

About a mile southwest of Fort Hunt, at the residence of Dr. Bliss, is a 65-foot drilled well that gets soft but slightly iron-bearing water from a Potomac sand or gravel bed. Dug wells in the vicinity get water from Columbia loams and sands at depths of from 15 to 25 feet.

A mile northwest of Fort Hunt, at Riverside Park near the mouth of Little Hunting Creek, on property owned by the Riverside Brick Co., are two 6-inch wells which get water from Potomac beds. They are said to be over 100 feet deep. Neither gives a flow, the elevation of the surface being about 20 feet. Each affords a fair supply of good, though slightly iron-bearing water. Near Hunters station, on the Washington, Alexandria & Mount Vernon Railroad, a drilled well gets good water from a bed of white Potomac sand at 165 feet.

At Arcturus station, on the same road, household supplies are obtained from dug wells. The deepest of these, about 30 feet, owned by H. C. Pilling, strikes a bed of sand and mud containing "logs," and yields water high in iron. A gasoline engine pumps the water to a tank.

At Mount Vernon water for domestic purposes is obtained from an 8-inch artesian well 525 feet deep. The well is near the edge of the river, the well mouth being about 7 feet above high tide level. Little water was found in the basal beds of the Patuxent formation, and the casing was pulled back. The present supply, which rises within 6 feet of the surface, its level fluctuating with the tide, comes from a sand and gravel bed at 345 feet. The following log, kept by W. H. K. Shannahan, the driller, was furnished by William Archer, of Mount Vernon.

Record of well at Mount Vernon.

(Authority. J. H. K. Shannahan, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Blue and red clay	10	10
Gray clay	15	25
Hard green and blue clay	25	50
Hard green, blue, and brown clay	25	75
Sandy brown clay	25	100
Coarse green water-bearing sand; bad water, has the odor of marsh water, very unpleasant	25	125
Brown and green clay and gray sandy clay	25	150
Marsh clay	50	200
Very hard and dry brown, green and blue clays	100	300
Light green sandy clay	25	325
Light green sand, water-bearing below 340 feet, source of present supply	25	350
Clays	165	515
Sand, little or no water, and that sulphur-bearing	10	525
Bed rock	525	

The water supply is good. A steam pump lifting 50 gallons per minute from the well to a tank on top of the bluff, 175 feet, lowers the water about 9 feet. The water is soft and works nicely in a boiler, making little scale.

Water for washing, flushing, and greenhouse use at Mount Vernon is obtained from springs developed by drains along the face of the river bluff. The mode of development is described on page 62.

On Sandy Point a deep well was sunk for H. L. Cranford some years ago. The following record has been published:[a]

Record of well on Sandy Point, 2 miles southwest of Gunston.

(Authority, L. W. Shepard, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
White and yellow clay	20	20
Very soft blue swamp muck	80	100
Gravel and sand; water	15	115
Clay	15	130
Gravel and sand; water	10	140
Clay	10	150
Fine sand and clay; water	60	210
Clay	20	230
Fine sand and clay	25	255
Clay	9	264
Small pebbles and lignite	6	270
Clay	15	285
Soft rock; no water	5	290
Rock	270	560

The well was dynamited at 265 feet. The water from this point rose within 24 feet of the surface or about mean high tide level, and, according to the driller, showed tidal fluctuations of 3 feet.

Near the village of Accotink dug wells vary from 15 to 90 feet in depth, according to location, and get water of varying quality from Columbia and Potomac sands and pebble beds. The deepest of these dug wells is owned by J. P. H. Mason. It is on a hill 1½ miles north of Accotink and about 180 feet above tide level. The well, which is 91 feet deep, went through these materials.

[a]Darton, N. H., Artesian water prospects of the Atlantic Coastal Plain, Bull. U. S. Geol. Survey No. 138, p. 178.

Record of dug well one and one-half miles north of Accotink.

(Authority, J. P. H. Mason, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Very hard red gravel	18	18
"Fullers earth"	10	28
Light bluish sandy clay	16	44
White clay and sand, a little water	5	49
Light bluish sandy clay; water at 88 feet	42	91

Another well, 300 yards east of this, found a little water at 56 feet and no water below for 60 feet.

On the inlier of Lafayette formation that extends from near Dunn Loring to Peach Grove and Freedom Hill, dug wells are from 20 to 40 feet deep. The water, which is generally soft, is obtained from the Lafayette, and where that formation is thin, from decomposed crystalline rock. The deepest well reported in this section, 130 feet, is that of R. H. Watts, about 1½ miles east of Freedom Hill. It is said to have been drilled through clay and gravel and to have struck no rock. The first water was struck at 30 feet, but the main supply, about 10 gallons a minute, comes from 120 feet.

Near Springman dug wells are 20 to 60 feet deep, about 50 feet being the most common depth and the one at which most water is obtained. At Pohick, Springman post-office, a well at the Methodist Church is 80 feet deep, obtaining water at 70 feet, but the church is on top of a hill.

The town of Falls Church had no public water supply system in 1906. The inhabitants relied chiefly on dug wells 10 to 35 feet, most of which yielded soft water.

At West Falls Church a 120-foot well, drilled for the Washington, Alexandria & Falls Church electric road, obtained in "granite" an irony water which is not used.

Particulars regarding dug wells at some villages are given below:

Details of dug wells in Fairfax County.

Location	Depth *(Feet)*	Water bed	Quality of water
Accotink	25–91	Sand and clay	Hard
Dunn Loring	20–65	....	Soft
New Alexandria	10–20	Sand and loam	Soft
Lorton Valley	20–50	Sand and gravel	Soft

Conclusions.—Good water can be had in the Coastal Plain portion of Fairfax County by both dug and drilled wells. At most places the former will furnish ample supplies for ordinary purposes, and if properly located and cased will be safe. Drilled wells near Potomac River will find good supplies in the Patuxent sands. Flowing wells, except at the water edge, are not to be expected.

GLOUCESTER COUNTY.

General description.—Gloucester County, formed from York County in 1861, lies between York River and Pianketank River.

Topographically the county is one of the most interesting in Tidewater Virginia. Part of the surface is included in the Sunderland terrace. The highest points in this terrace, about 125 feet, are in the northwest corner of the county; the lowest points have an elevation of 100 feet. The Talbot[a] terrace covers most of a triangular area between Severn River, Mobjack Bay, York River, and a line from Gloucester Point past Hayes' Store and Roanes to Pianketank River; this line follows a sharply defined scarp, the most marked and unmistakable terrace scarp in the Virginia Coastal Plain. From the foot of this scarp at an elevation of about 25 feet the Talbot terrace slopes very gently eastward to sea level, fading away in strips of salt marsh and wet ground.

Geology.—The Columbia formations are prevailingly loamy at top and sandy below; along York River large ice-borne boulders are found in the lower formations. Beneath the Columbia are the sandy clays, sands, and marl beds of the Yorktown and St. Mary's formations of the Chesapeake group. The marl beds weather light- or bright-colored, but are dark greenish or bluish below water level. The total thickness of the Yorktown formation may be 100 feet. The thickness of the other Chesapeake formations under cover, the St. Mary's, Choptank, and Calvert, is not determinable from the well records available, but the base of the Chesapeake lies about 200 feet below sea level at the western corner of the county, and 300 feet deeper on the shore of Mobjack Bay. Below the Chesapeake lies 150 to 200 feet of Pamunkey greensands, the more glauconitic and porous making the "black sand" of well drillers, while below these are the Upper Cretaceous formations.

UNDERGROUND WATERS.

Distribution and quality.—Both the surficial deposits and the deep sands, except at the east end of the county, contain abundant supplies of

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[a] The writer believes that the terrace that occupies the greater part of the area mentioned is to be correlated with the Pamlico terrace of North Carolina.

water. The quality varies greatly; probably no county in Tidewater Virginia can show more variety. On high ground the shallow water is soft and low in iron, except in Chesapeake marl beds. Near Mobjack Bay and at some points along York River the shallow water is of indifferent quality, very hard, high in iron or brackish; at some places it is excellent. The artesian waters show as great variation. At the west end of the county they are soft, clear, and fresh; at the east end they are barely potable, containing salt, sulphate and bicarbonate of soda, and at some wells iron. They are as a rule sulphur-bearing.

Artesian waters under moderate cover, 50 to 100 feet, are found in the eastern end of the county. They have low heads, 2 to 5 feet above mean high tide, and lie in irregular and discontinuous sand and shell beds in the Yorktown formation. The waters as a rule are clear and bright, but more or less limy, and in places very hard and iron-bearing. The deeper sands of the Chesapeake group give higher heads, up to 35 feet, and at some places larger flows. Very soft waters, resembling those of the basal Chesapeake beds, are found in the Pamunkey under the western part of the county, but to the east the Pamunkey sands, like the Chesapeake, as suggested by Darton,[a] probably become too fine to transmit water readily. The flows decrease in volume and cease, no flow being known from the Pamunkey east of Gloucester Point. Little is known of the Upper Cretaceous formations, but in the eastern portion of the county deep wells get waters presumably from these formations, that vary in character from the soft, alkaline, slightly sulphur-bearing flow at Gloucester Point to the highly mineralized, saline, ferruginous waters found near Severn River. The Potomac beds have not been tapped within the county west of Selden. They undoubtedly contain potable water in abundance as far east as Claybank.

Springs.—Springs are abundant. Most of them flow from Columbia sands; some from Chesapeake marl beds. Yields are generally small, averaging at such springs as are in any way improved, 5 to 10 gallons per minute; flows as large as 20 gallons per minute are rare. A considerable number are still used for household supply. No spring yields water for shipment in commercial quantities, and none is a health or pleasure resort. A few that have attracted notice by reason of size, location, or quality of water are owned by Dr. C. H. Bradford, near Dutton; F. E. Du Val, near Cash, a large marl spring; Thos. Dixon, Jr., 2 miles west of Dixondale, a bold flow of soft water known as the Cow Spring; C. J. Roane, near Woods

[a] Darton, N. H., Artesian water prospects of the Atlantic Coastal Plain, Bull. U. S. Geol. Survey, No. 138.

Cross Roads, irony water; W. R. Stubbs, near Pinetta, hard, iron-bearing water; and G. P. Brown, near Wan.

At Gloucester Point a spring of soft water rises through surface sand from shell-rock in the Yorktown formation. The water is much used by fishermen for boat supply, as it is said to keep well. The flow is about 1½ gallons per minute.

Wells.—Dug wells are practically the sole source of supply on ground over 40 feet above tide level. On lower ground are also dug and driven wells, the latter being particularly numerous toward the east end of the county.

LOCAL SUPPLIES.

At Gloucester are some 15 dug wells from 25 to 40 feet, most of which are lined with brick. There are no springs close to the Courthouse, which is on a ridge, but there are plenty with perennial flow along neighboring creeks. Owing to good drainage, the thick cover of loam, and the depth to water table, dug wells at Gloucester are not likely to be polluted if ordinary precautions are taken to prevent the ingress of surface water.

Near Achilles a number of deep driven wells that do not flow yield water of varying quality. One owned by B. A. Rowe gives water that is reported to work well in a saw-mill boiler. The water may come from beds of Chesapeake age.

The wells along York River from Puropotank Creek to Gloucester Point tap the Chesapeake, Pamunkey, and Upper Cretaceous sands. In general the wells flow soft, alkaline water suitable for all household purposes. The height to which water rises varies; the Chesapeake sands give heads of from 10 to 30 feet, but the Pamunkey gives reported heads of 35 feet at Cappahosic and of 25 feet at Timberneck Creek. The flow from the Upper Cretaceous sand, at Gloucester Point, has a head of but 10 feet.

A well 3 miles southwest of Signpine, on a tidal inlet, found salt water at 13 feet, brackish water at 33 feet, and good artesian water at 196 feet, as shown by the following log:

Record of well of R. C. Coleman, 3 miles southwest of Signpine.

(Authority, R. C. Coleman, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Yellow sand, salt water at 13 feet	13	13
Lighter colored sand, white at base; brackish water at 33 feet	20	33
Blue marl or "marsh mud"	155	188
Quicksand	9½	208½
Hard shell-rock	½	210
Sand; main flow	1	211
Elevation of surface 3½ feet.		

At Allmondsville several wells have been sunk for oyster houses and boiler supply. The reported depths are about 300 feet, the flow coming from Chesapeake sands. The alkaline water has a slight sulphur odor; it neither pits nor scales a boiler, but has a tendency to foam. A field analysis of the water from one well is given in table 8.

On Jones Creek, B. B. Weaver has a 336-foot well that flows 5 gallons at 5 feet above mean high tide. The water comes from medium fine quartz sand containing much dark green glauconite. The owner dammed a small run and put in a water wheel which he belted to a "bulldozer" pump that forces the water to a tank on a tower near the house; the house is 25 feet above the spring, and the total lift to the tank about 50 feet. Table 8 contains a field assay of a sample of the water.

The well at Cappahosic, 415 feet deep, found no flow in the Chesapeake sands, and the Pamunkey flow is of moderate volume. The owner has harnessed the well to a small ram, a flow of 3 gallons per minute, with a drop to the ram of 6 feet, being sufficient to lift all water needed for domestic use to a tank in the house 40 feet above the river. The overflow from the ram is piped to neighbors' houses, one being 300 yards distant.

The decrease of yield in the Chesapeake and Pamunkey sands near the mouth of York River is shown by a well sunk for James Brown by a driller familiar with local conditions. This well, on Carter Creek, about half a mile from the mouth, found water from 60 to 80 feet in coarse gravel, and no more till a very weak flow at 535 feet; sinking to 610 feet brought no increase in flow and the well was abandoned.

Near Timberneck Creek are artesian wells which get water from the shell beds in the Yorktown formation. One of these, 65 feet deep, at the residence of Charles Catlett, is used for household supply; two other wells sunk to the Pamunkey gave flows of sulphur-bearing water. The flow from the shallow well has a head of 4 feet and shows large tidal fluctuations. The water is clear but hard.

On the beach at Gloucester Point is a well 690 feet deep which gets water from the Matawan; no flows were found, according to the driller, in the Pamunkey or Chesapeake beds, and the Matawan flow is small (2 gallons), and of low head, 10 feet. The well was sunk for public use. The water has a slight sulphur odor, is alkaline, and contains more salt, sulphate of soda, and lime than the wells up the river. In a boiler it foamed badly. A field analysis is given in table 10.

The following record is reported from one of the flowing wells on Pianketank River. The water is probably from the base of the Chesapeake group.

Record of well of R. J. Bristow, 3 miles east of New Upton, on Pianketank River.

Material	Thickness (Feet)	Depth (Feet)
Sand, water at 8 feet	15	15
Clay	15	30
Sand	4	34
Blue sand marl; water at 42 to 46 feet	201	235
Sand, very small flow of water	2	237
Marl	148	385
Soft rock; flow of water, about ¼ gal. per minute, at 415 feet	30	415

Near Severn River are several deep wells notable for their highly mineralized waters. All the flows contain considerable salt in addition to sodium carbonate or bicarbonate, and some of the flows are decidedly iron-bearing. The yields vary decidedly, but as a rule are scanty.

At Eagle Point, the country seat of the late Joseph Bryan, several attempts were made to get a sufficient flow of potable water. The most important attempt was a 6-inch well 1,004 feet deep. It penetrated several water-bearing beds but found no water that would overflow, though the elevation of the surface is but 5 feet above tide. Another well, 900 feet deep, yields a scanty flow of clear, saline, alkaline water. (See table 11 for field assay.) A well 100 feet deep gets a flow of decidedly hard water from a shell bed in the Yorktown formation. Cistern water is used for most purposes. Nearby at the residence of A. W. Withers is a 6-inch well 605 feet deep, that taps Upper Cretaceous beds. It flowed, at an elevation of 6 feet above tide, 69 gallons per minute of salty, ferruginous, bicarbonated water that readily corrodes steel pipe. The water is too salty to be palatable. (See table 10.)

At Severn a well 610 feet deep found water at the base of the Pamunkey. The owner gave the following record from memory:

Record of 610-foot well of J. N. Shackelford, near Severn, Gloucester County.

Material	Thickness (Feet)	Depth (Feet)
Clay	1	1
White sand	6	7
Yellow and reddish sand; water	1	8
Blue shell marl, small shells	10	18
Dark gray sand, water-bearing; "water contained lime but washed well"	6	24
Dark marl and sand mixed	46	70
Light bluish marl containing a few shells, and mud	355	425
Fine black sand "almost as dark as gunpowder" with one white grain in 50 black; water-bearing but water did not rise to surface	15	440
Soft dark or greenish mud, very few or no shells	135	575
Black sand in hard layers, water-bearing, flow 1 gallon in 5 minutes at 5 feet elevation above tide	55	610
Below the rock was clean gravel "like fine hail" pebbles size of wheat grains, clear or occasionally bluish; this gravel contained water but the gravel and sand choked the pipe and it was pulled back to 575 feet		

The water is clear, but highly mineralized, containing considerable salt. It has been drunk as a medicinal water. (See table 10.)

Some particulars of dug wells, reported by postmasters, at various points in the county are shown below in tabular form:

Details of dug wells in Gloucester County.

Location	Depth (Feet)	Water bed	Quality of water
Belroi	10–20	Sand	Hard and soft
Cash	30–45	Sand and marl	Hard
Dutton	18–50	Sand	Soft
James Store	25–50	Sand	Soft
New Upton	35–40	Sand and marl	Soft and hard
Ordinary	10–35	Sand	Hard and soft
Pinetta	25–40	....	....
Roanes	20–30	Sand and marl	Hard
Signpine	40	Sand and marl	....
Woods Cross Roads	30–50	Sand and marl	Soft and hard
Whitmarsh	18–60	Sand	Soft
Wicomico	10–40	Sand and gravel	....

Conclusions.—Artesian water can be had under the whole of Gloucester County, but the wells already dug demonstrate that liberal flows of good quality can not be expected east of Gloucester Point. Excellent water can be had in the western part of the county under heads of 30 to 35 feet above tide. At Gloucester Courthouse soft alkaline water can be had by a well less than 500 feet deep, but a deep well pump must be used as the water will probably not rise to within 40 feet of the surface.

GREENESVILLE COUNTY.

General description.—Greenesville County includes the extreme southwest corner of the Virginia Coastal Plain, south of Meherrin River, and its southern boundary is the North Carolina-Virginia state line. The Coastal Plain portion of the county lies east of the Atlantic Coast Line Railway, and has an area of about 70 square miles.

The surface shows considerable diversity of relief but much of it is low, and is included within the valleys of Meherrin River, Fontaines Creek, and tributary swamps. The general slope is east. Along Meherrin River the lower Columbia terraces are extensive. The maximum elevations of the Coastal Plain area in this county have not been determined, but the Sunderland terrace is a less important feature of the topography than in counties to the north. Elevations above sea level range from 200 feet, west of Jarratt, to 20 feet along Meherrin River.

Geology.—Granite outcrops in the bed of Meherrin River near Emporia, and lies less than 50 feet below the surface in the town. Near the river the granite is overlain by Columbia gravels, sands, and loams, which also mantle the surface in the vicinity of the town and along the railroad to the south.

Potomac sands overlie the granite a short distance east of Emporia, but are not exposed along Meherrin River nor anywhere within the county. There is nothing to indicate the presence of Upper Cretaceous or of Pamunkey (Eocene) beds. Chesapeake marls are exposed in places by pits from which the marl was dug.

UNDERGROUND WATERS.

Distribution and quality.—The Columbia and the underlying Chesapeake or Potomac sands carry waters that show considerable variation in quality. Sufficient water for household needs can be had anywhere in the Coastal Plain portion of the county at small cost. For larger supplies groups of driven or bored wells have been put down in the Columbia sands, and at least one well has been drilled deep into granite.

LOCAL SUPPLIES.

At Emporia water for boiler supply has been obtained from dug, bored or driven wells. The Emporia Manufacturing Co., in 1905, had 6 bored wells, 24 feet apart, with 4½-inch casing, and a 2-inch suction pipe having a slotted brass strainer 2 feet long inside the casing; the yield was about 60 gallons per minute of hard water. Soft water was found at 22 feet. The company had also a series of 20 bored wells 16 feet apart, 2 inches in diameter, with 18-inch screens, and only about 22 feet deep. The water normally stood within about 10 feet of surface and the combined yield to pump was 70 gallons per minute. Granite is found at 32 feet.

The town of Emporia has a 600-foot drilled well, described on page 93; it furnished unsatisfactory water from crevices at several depths.

HANOVER COUNTY.

General description.—Hanover County, formed in 1720 from New Kent County, lies between Chickahominy and Pamunkey rivers, but only that part east of the Richmond, Fredericksburg & Potomac Railroad is within the Coastal Plain province. This part, probably 100 square miles in extent, contains several important settlements, the largest being Ashland.

The topography has the varied aspect common to other counties along the "fall line." The Lafayette and older Columbia terraces have been deeply trenched by tributaries of Chickahominy and Pamunkey rivers; maximum elevations are 200 to 225 feet near Ashland, Merryoaks, and Ashcake, while the swamp along Chickahominy River is 50 to 80 feet, and the flood plain or first bottom along Pamunkey River, is 10 to 30 feet above sea level. The Sunderland plain east of Ashland may be 160 to 180 feet high. The Wicomico plain lies along Pamunkey River from near Hanover to Doswell. At the latter place it forms the "second bottom" at an elevation of 60 to 80 feet above tide. A lower plain is well developed near New Castle bridge, where its surface is 25 to 40 feet above sea level. The Wicomico is not well shown in the Chickahominy valley.

Geology.—Granite underlies the Columbia deposits south of Ashland, and the Triassic sandstones outcrop north of Ashland, near North Anna River. Above this basement to the east are Potomac, Pamunkey, and Chesapeake deposits. The Potomac at Belamar is represented by a few feet of dark bluish shale, and on the North Anna near Doswell by arkosic sands and sandstones of the Patuxent formation. The exposures of Eocene deposits along Pamunkey River from Wyckham to Piping Tree Ferry were visited by Conrad and by Rogers over 70 years ago, and have been examined by many geologists since. The beds consist of dark green sands containing fossil shells which in places form shell-rock. Most of the material exposed is part of the Aquia formation. No Pamunkey (Eocene) beds are exposed in the Chickahominy valley. The Chesapeake (Miocene) beds, chiefly of the Calvert formation, overlap the Pamunkey. They comprise dark greenish sandy clays, which in places contain many fossil shells and in places are full of diatoms. The thickness of the Chesapeake beds varies from a feather edge to possibly 100 feet on the east side of the county.

The Lafayette and Sunderland formations overlap the granite and the Cretaceous, Eocene or Miocene beds to the west, the Lafayette extending an unknown distance westward. The Sunderland contains numerous large boulders of crystalline rocks, evidently ice-borne, and near Wyckham its scarp is as thickly strewn with boulders as a New England hill pasture. On the Wicomico plain along Pamunkey River these sub-angular boulders of gneiss and schist are dug out in tilling fields and used for well-casing, foundation-stone, flagging, etc.

UNDERGROUND WATERS.

Distribution and character.—Water-bearing beds occur in the Potomac, Pamunkey, Chesapeake, and Columbia deposits. The deeper Potomac and Pamunkey waters, as indicated by wells in King William County, are probably of good quality. The water from the Columbia sands is as a rule soft.

Springs.—Springs of the usual Coastal Plain type are numerous, but comparatively few are used for household supply and from none is water sold regularly. The quality of the spring waters varies from hard or iron-bearing to very pure and soft.

One spring of note is near the residence of T. A. Taliaferro about 1½ miles southeast of Pole Green. This spring rises as a bold flow from a bed of white sand (Sunderland) near a little run tributary to Beaver Dam Creek. The spring is said to rise from a depth of at least 20 feet, as a pole can be forced down into the sand to that depth. The flow, about 15 gallons per minute, is clear, soft, and light. The owner furnished an analysis that has been recomputed to express results in the form used by the Federal Survey.

Analysis of water from spring of T. A. Taliaferro, southeast of Pole Green, Hanover County.

(Henry Froehling, analyst.)

	Parts per 1.000.000
Total mineral solids	19.
Silica (SiO_2)	6.2
Iron (Fe)	0.08
Aluminum (Al)	0.11
Manganese (Mn)	0.02
Calcium (Ca)	0.7
Magnesium (Mg)	0.3
Sodium (Na)	2.2
Potassium (K)	0.8
Lithium (Li)	0.01
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	2.7
Sulphate radicle (SO_4)	2.3
Phosphate radicle (PO_4)	0.03
Chlorine (Cl)	3.1
Iodine (I)	trace
Free carbon dioxide gas 64 c. c. per liter.	

No improvements had been made at this spring when it was inspected, nor was the water being sold.

Other springs of more or less note in the Coastal Plain section of Hanover County are those of H. Carter Ridd, of Beaver Dam; of M. C. and C. H. Tate, at Ruel, which give iron-bearing water; and a small spring of E. G. Gwathmey, near Taylorsville, said to yield sulphur water.

LOCAL SUPPLIES.

Dug wells at Hanover average 20 to 30 feet deep, though one was dug 60 feet. The water from most of the wells is called "medium soft." The deeper wells go through the Columbia gravels and sands into the Chesapeake beds, and if they strike shell marl the water becomes hard. The 60-foot well found a little hard water at 20 feet on top of a dark, greenish sandy clay of the Chesapeake group, but none for 40 feet below.

At Ashland most of the water used is obtained from dug wells; enough for a family of ordinary size can be obtained by digging 18 or 20 feet. Because of the level surface of the ground and the shallow depth of the water table there is danger of pollution; hence some people use only cistern water for drinking. At Randolph-Macon College cisterns of large size, kept securely locked, are filled during late fall, winter and early spring; the supply being accumulated after leaves have fallen and migratory birds have left the region.

Where there is no danger of pollution from nearby cesspools or wells with unsanitary surroundings, good water from dug wells is had by digging to below water level, dumping in several feet of clear, coarse gravel, and using tile curbing with tightly cemented joints, the top length projecting a foot or so above surface.

Several attempts to get water by drilling have been made at Ashland. One well at Randolph-Macon College, sunk about 100 feet, furnished satisfactory supplies for about ten years, and then was abandoned because an influx of sand choked the pump. A deep well intended to furnish a supply for the college and the town is on the grounds of the Henry Clay Inn. This well, 365 feet deep, went through the Lafayette and obtained its supply from the sandstones of the Newark. The following record is that furnished by the driller:

Record of deep well of Ashland Water and Light Co., at Henry Clay Inn, Ashland.

(Authority, Sydnor Pump and Well Co., drillers.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Earth	64	64
Rock	77	181
Sandstone	26	307
Soft brown shale	58	365
Slate	——	365

The following record of a well near Ashland is from Darton's bulletin.[a]

Record of well near Ashland.

Material	Thickness *(Feet)*	Depth *(Feet)*
Clay and soil	20	20
Gravel and sand	22	42
Blue clay with beds of fine sand	37	79
Stratum of sandstone	6	85
Disintegrated stone, with water in its upper portion	35	120
Granite	20	140

In 1910, a public supply system, taking water from two deep wells, was installed.

On the lower terrace near Pamunkey River many shallow wells 10 to 15 feet deep get water enough for family use, but are frequently filled by

[a]Darton, N. H., Op. cit. p. 179.

surface water during rains, and are not considered wholly safe. A deep well sunk for locomotive supply by the Richmond, Fredericksburg & Potomac Railroad, near Doswell, elevation 55 feet, obtained, from the Newark rocks at a depth of about 300 feet, hard water, which rose to within 3 feet of the surface. The supply was either insufficient or unsatisfactory, for the well was abandoned by the railroad company and later covered in widening the grade.

About Wyckham, wells on the Sunderland plain get soft water at depths of 30 feet or less. Near Wyckham station on the scarp above the Wicomico plain an attempt to get water by digging into the Chesapeake marls and clays was unsuccessful. The following section was furnished by W. W. Dyson, superintendent of Hickory Hill farm.

Record of 75-foot well at Hickory Hill, Wyckham.
(Authority, W. W. Dyson.)

Material	Thickness (Feet)	Depth (Feet)
Loam and pebbles	5	5
Red clay	4	9
White "fuller's earth"	10	19
White and purplish "fuller's earth" with iron stains	10	29
Dark bluish black "fuller's earth"	8	37
Blue gravel and sand, pebbles large as hens' eggs	3	40
Blue sand	2	42
Shell marl, very hard, full of scallop and clam shells and sharks teeth	11	53
White sand, water-bearing	1	54

The water rose to the top of the marl. It tasted strongly of iron, and was so hard that it could not be used for washing, consequently the well was filled.

Shallow well conditions at a number of points in the Coastal Plain section of the county are given in the following table:

Details of dug wells in Coastal Plain portion of Hanover County.

Location	Depth (Feet)	Water bed	Quality of water
Belamar	12–100	Sand and rock	Soft and hard
Doswell	15–35	Sand	Soft
Beaverdam	15–30	Sand	Soft
Pole Green	30	Sand	Soft
Ruel	30	Sand	Soft

Conclusions.—There is little chance in Hanover County for artesian water that will rise above tide level, but in the eastern part of the county water of good quality and softer than that obtained by dug wells can be had by drilling. The Newark rocks are uncertain water-bearers, and though water can probably be had from them the quality and yield can not be predicted; both may be good, as at Ashland, or poor, as at Doswell.

HENRICO COUNTY.

General description.—Henrico County, formed in 1643 as one of the original shires of Virginia, lies between James and Chickahominy rivers, part of the county being in the Coastal Plain and part in the Piedmont Province. Richmond, the capital of Virginia, a prosperous manufacturing city, had a population of 127,628 in 1910. The area of the Coastal Plain portion is about 350 square miles. Outside the city limits are a number of suburbs, chiefly residential, such as Barton Heights, Brookland, Ginter Park, and Highland Springs. The population of the county, exclusive of Richmond, was 23,437 in 1910.

Away from the railroads and the immediate vicinity of Richmond the county contains few villages of importance. Along the James River are several famous estates, and one of the largest single farms in the State, measured by land under cultivation, is about 15 miles below Richmond.

As Henrico County lies partly in the Coastal Plain and partly in the Piedmont Plateau the topography is characterized by the gently undulating remnants of the high Lafayette or Sunderland plains on the interstream areas, with precipitous scarps along the gorge of James River, the gorge at Richmond being nearly 250 feet deep. The Lafayette plain has an elevation of 200 to 225 feet. The lower terraces are not well developed near Richmond, but can be traced along the James River valley below.

The Coastal Plain area contains few creeks or runs more than a few miles long. Those emptying into the James such as Shockoe, Gillies, and Almond creeks, have cut sharp valleys which are marked features of the topography. Along Chickahominy River is a cypress swamp, lying 50 to over 100 feet above tide level and in places over a mile wide.

Geology.—The gray granite-gneiss over which James River flows at Richmond is exposed at higher elevations in railroad cuts west of the "fall-line," as at Glen Allen. It dips eastward from the "fall-line" about 40 feet to the mile, and above it lie Potomac, Pamunkey, and Chesapeake beds, all of which outcrop in the city limits of Richmond. The Patuxent formation, with arkosic, incoherent or indurated sands full of pebbles, cobbles, and clay balls, may be seen along Gillies and Almond creeks. The Pamunkey greensands and the Chesapeake diatomaceous clays are exposed at the famous outcrop on the west bank of Shockoe Creek, just below the plant of the American Locomotive Works, where, in a bluff about 40 feet high, dark argillaceous Pamunkey greensands of the Nanjemoy formation grade into dark diatomaceous clayey Chesapeake sands of the Calvert formation. Higher up the run are many outcrops of the Calvert formation full of shells. North of the city, near the State Fair grounds, dark fossiliferous Chesapeake marls and clays rest directly on the granite. Along James River, south of Richmond, notably at Dutch Gap, many outcrops of Potomac sands and standstone can be seen. In Chickahominy valley the dark, sandy clays of the Chesapeake beds are exposed along the creeks and runs. From feather edges on the west, the Potomac, Pamunkey, and Chesapeake beds thicken rapidly down the dip, and at the eastern edge of the county the Potomac may be 300 feet thick, and the Pamunkey and Chesapeake, each 100 feet.

UNDERGROUND WATERS.

Distribution and character.—The occurrence of water in the granite has been described on pages 83-97. The Potomac beds are prevailingly coarse-textured, and contain much water that is available to wells. The Chesapeake sandy clays are dense and the Calvert formation is probably a poor water-bearer within the county limits. The loams and sands of the Columbia contain large supplies of ground water, the depth of the water table below surface depending on the topography. The shallow waters are for the most part soft. Little is known of the quality of the water to be had by deep wells sunk to the Potomac beds.

Springs.—Springs abound. Most are small seeps from beds of sand but a few are of considerable size. One of the largest in the county, known as the Tucker or Bonanza spring, is near Highland Springs on land owned by E. S. Reed. It is situated in a hollow near a small run that flows into Chickahominy River. The water rises from sands and gravel, evidently slope wash, and the geologic relations of the spring are not evident. The water probably comes from near the contact between the Chesapeake and the overlying Columbia sands. The flow, about 28 gallons per minute, is said not to vary during the year. The water is soft, clear, tasteless, and odorless, has been used for drinking purposes by several families at Highland Springs, and has been shipped to Richmond.

Situated a few miles west of Highland Springs, in the Sunderland scarp facing James River, is Como Lithia Spring, the water of which is sold for medicinal and table use. The spring issues from sand beds at the base of the Sunderland formation. The water is clear and sparkling, tasteless and odorless, and contains free carbon dioxide which makes it agreeably light. The following analysis, recalculated to express results in standard form, was furnished by the proprietor of the spring, I. M. Hawks.

Analysis of Como Lithia water.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	34.
Organic matter	slight trace
Silica (SiO_2)	5.4
Iron (Fe)	0.1
Aluminum (Al)	0.53
Calcium (Ca)	0.86
Magnesium (Mg)	1.1
Sodium (Na)	4.7
Potassium (K)	2.1
Lithium (Li)	0.07
Iodine (I)	0.39
Bromine (Br)	trace
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	7.9
Sulphate radicle (SO_4)	0.41
Chlorine (Cl)	10.
Free carbon dioxide gas, 31 c. c. per liter.	

The spring is in a park with no buildings near, and pollution by contaminated surface waters is improbable. The only improvements at the spring, when inspected, were a bricked pool from which the water was pumped, and a rustic spring house.

Other springs of more or less note in Henrico County are those of E. G. Hopkins, at Glen Allen; of William Dean, on the edge of a slope from the Sunderland plain, 2 miles northeast from Fair Oaks; of A. A. Carlough, half a mile south of Elko; of J. W. Francis, 3½ miles south of Chickahominy; of J. T. Brown, on the Sims place, 3 miles south of Laurel station; and a spring on the Crenshaw tract, 1½ miles east of Laurel. The spring that supplies Barton Heights is mentioned on page 190.

Wells.—While the larger proportion of the dug wells in the rural parts of Henrico County are curbed with wood, there are many, especially near Richmond, that are bricked. Most of the bricked wells are covered and have pumps. There are some driven wells, but outside of Richmond there are few drilled wells.

LOCAL SUPPLIES.

The city of Richmond owns waterworks which distribute James River water. In or near Richmond a number of deep wells have been sunk by hotels and industrial concerns. These wells get water from fissures and joints in the granite, and are of much interest because of the wide variation in yield and quality of water. They are discussed in detail under the heading "Wells in crystalline rocks," on page 83.

A dug well 12 feet in diameter and 112 feet deep at Benjamin Davis' brickyard in the north part of the city is situated just on the edge of the Sunderland plain above Bacon Quarter Branch. It went through Columbia cobble beds and loams and the Chesapeake sandy clays to decomposed granite, but struck nothing that could be identified as Potomac material, and yields little water.

In the Brookland district, which includes residential and manufacturings sections, northwest and north of the city, and had a total population of 10,068 in 1910, water is obtained chiefly from dug wells 10 to 40 feet deep, though there are many drilled wells and some cisterns.

Within a mile of Highland Springs there are over 100 dug wells, which obtain supplies of soft water from sand beds, and range in depth from 20 to 27 feet with an average of about 32 feet.

In Glen Allen dug wells are 20 to 35 feet deep, and most of them strike granite at about 20 feet. The Old Dominion Excelsior Co. has two wells 8 feet square and 22 feet deep that go to the granite, and are connected by a crosscut at the bottom.

Barton Heights, a suburb of Richmond, with a population of 1,388 in 1910, has a public supply from the Mitchell Spring and an adjacent dug well 15 feet in diameter and 44 feet deep, in the scarp back of the spring. The yield reported is about 100 gallons per minute. Some characteristics of the water, which is considered good, are shown by the following sanitary analysis:

Sanitary analysis of water from Mitchell Spring.

(E. C. Levy, analyst.)

	Parts per 1,000,000
Total solids	106.
Loss on ignition	42.
Alkalinity	0.0
Chlorine (Cl)	16.5
Nitrates (NO_3)	0.445
Nitrites (NO_2)	0.0
Iron (Fe)	0.03
Total hardness	32.5

To supplement the supply from this well and spring, the town, in 1909, had a deep well sunk on the east side of the valley of Bacon Quarter Branch. This well, 759 feet deep, yields to a pump 40 gallons a minute of excellent water.

The drilled wells at Barton Heights go through Columbia and Chesapeake beds, getting water from crevices in the granite-gneiss. Most of the drilled wells are from 50 to 150 feet deep, though a few are much deeper.

At Fort Lee, dug wells 15 to 25 feet deep go through red clay into blue marl and then into water-bearing sand. The cost of digging such wells has been $6 or $7. Some of the wells seen were liable to pollution because of insufficient protection at the top.

At Chestnut Hill and Highland Park nearly all householders have dug wells 20 to 40 feet deep, averaging about 30 feet at Highland Park. The water generally is soft.

At Ginter Park most houses are supplied from the deep well described on page 92. Dug wells are 20 to 35 feet deep. One at the Jefferson Laundry yielded water that was too hard for laundry use. Analyses of water from these wells are given in tables 4 and 7.

No account of deep wells in Henrico County would be complete without mention of the boring at Curle's Neck, the 7,000-acre farm of C. H. Senff. This well near James River where the Talbot terrace plain has a maximum elevation of about 30 feet, went through Columbia, Chesapeake, Pamunkey, and Potomac deposits, striking granite at 310 feet. According to Mr. Bedell, superintendent at Curle's Neck, a little sulphur-bearing water was found at 125 and 250 feet, and drilling was continued to 725 feet. In the granite water was struck at various depths, better in quality but less in volume than that above, and at 710 feet the well was temporarily abandoned. After remaining idle for a year, it was tested and the most that could be had was about 10 gallons per minute. As a last resort six or seven charges of dynamite, some 45 pounds in all, were exploded at various depths in the granite, with complete success. Mr. Bedell said that pumping at the rate of 100 gallons per minute continuously for three weeks lowered the water level but a few inches. The water, which is piped to several houses for domestic use and is drunk by 75 to 100 persons, is soft, clear and colorless, without taste or odor.

The depths of dug or driven wells, character of water bed, and quality of water at a number of places in the county are summarized below:

Details of dug wells in Henrico County.

Location	Depth of well (Feet)	Water bed	Quality of Water
Elko	15–25	Sand and gravel	Soft and hard
Fair Oaks	18–22	Sand	Soft
Glendale	15–60	....	Soft
Highland Park	20–25	Loam and sand	Soft
Highland Springs	20–40	Sand and gravel	Soft
School	20–50	Rotten granite	Soft
Seven Pines	About 20	Sand	Soft
Varuna Grove	About 30	Sand	Soft

Conclusions.—As the Lafayette and higher Columbia terraces have a thick covering of clay loam it is probable that dug wells, even when houses stand closely, will be satisfactory from a sanitary standpoint, provided that wells are properly protected, and provided they are not sunk close to cesspools or privies. Drilled wells properly cased are, however, preferable. Good water can probably be had by wells drilled to the Potomac beds in the eastern part of the county, but the prospects for flows, even at an elevation of less than 10 feet above tide level, are poor.

ISLE OF WIGHT COUNTY.

General description.—Isle of Wight County, formed in 1634 as one of the original shires of Virginia, lies south of James River and east of Blackwater River. Smithfield, with a population of 1,278 in 1910, is the only incorporated town.

The general slope of the surface is southeast. It varies from flat to gently undulating, though the Columbia terrace plains are somewhat sharply cut along the north and east by creeks flowing to James and Nansemond rivers, of which Pagan Creek is the most important. The creeks in the western and southern parts of the county drain to Blackwater River, have open valleys, and flow sluggishly through cypress swamps. The divide between the James River and Blackwater River drainage runs through the center of the county. Along James River and Pagan Creek the descent from the Wicomico plain to tide level is generally abrupt, there being bluffs along the James 50 to 80 feet high. The slope southwestward from the Blackwater-James divide is gentle, Moonlight having an elevation of 85 feet and the Blackwater bottoms opposite Franklin 30 feet.

Noteworthy features of the topography in the northwest corner of the county, commented on by Rogers,[a] are the wide, poorly drained tracts known as pocosons.

Geology.—The mantle of Columbia loams and sands hides the older beds except along the river and creek valleys. The Potomac and Pamunkey deposits are deeply buried, and the only outcropping Chesapeake formations are the Yorktown and St. Mary's. The sands, clays, and shell marls of the former in places constitute the whole thickness of the bluffs along James River, and at some localities, for instance near Fort Boykin, are beds crowded with marine shells that here and there form hard rock. The thickness of the Yorktown may be 100 feet; of the St. Mary's about 250 feet. The formations are much alike, being differentiated by fossils. The top of the Pamunkey is from 200 to 400 feet below tide level. Nothing positive is known of the Upper Cretaceous beds nor of the Potomac.

UNDERGROUND WATERS.

Distribution and quality.—The Potomac, Pamunkey, and Chesapeake groups contain artesian water. The coarser sands will yield supplies at any point in the county, and along James River will give flows at elevations below 25 to 35 feet. Nothing is known of the quality of the Potomac and Pamunkey waters, but there is every reason to believe that they are potable. The artesian waters in the Chesapeake beds are soft, alkaline, and adapted to domestic use. The shallow water varies in quality from soft in the Columbia sands to hard in the Chesapeake shell marls.

Springs.—There are many springs along tributaries of James and Blackwater rivers, but few of especial importance. Most springs flow from Columbia sands, and a few from the top beds of the Chesapeake.

Near St. Luke's church, built in 1632 (Benn's Church post-office), is a wayside spring of good flow, about 10 gallons per minute, that has been used by wayfarers for nearly 300 years. Its clear, fresh, but hard water flows from shell marls in the Yorktown formation.

Wells.—Dug wells with wood-lining are most widely used. In some places, particularly in the northern part of the county, curbing of 24-inch tile is being substituted for wood. The shallower wells, as a rule, reach Columbia sands and loams; the deeper wells penetrate Chesapeake sand or marl. There are some driven wells scattered in the county, and there are many drilled wells along James River, Everets Creek, and Blackwater River.

[a]Rogers, W. B., Geology of the Virginias, 1885.

The drilled wells are nearly all of small diameter, 1½ or 2 inches. Depths range from 40 to over 300 feet. Some have but 20 feet or so of casing; others, and especially those drilled recently, are cased to the bottom.

LOCAL SUPPLIES.

Flowing wells along James River.—The town of Smithfield is supplied with water from a creek 3 miles to the west. In the town are a few dug wells which get hard water, and a considerable number of cisterns. A drilled well 300 feet deep found a fine flow of soft alkaline water in the basal Chesapeake (Calvert) beds that are tapped by some wells a few miles farther up the river.

Along James River, above Smithfield, are several flowing wells about 300 feet deep. A part of the flow from one of the wells at a hotel near Day's Point is bottled and sold by the owner as a table and medicinal water. It belongs to the sodic alkaline bicarbonated class, and like waters of this class in the tidewater country, contains little lime in proportion to the total solids in solution. As a table water it is light and pleasant. The mineral content is shown by the following analysis:

Analysis of Day's Point Artesian Lithia water.

(Froehling and Robertson, analysts.)

	Parts per 1,000,000
Total solids	434.
Silica (SiO_2)	12.
Iron (Fe)	0.19
Aluminum (Al)	0.53
Manganese	.008
Calcium (Ca)	2.6
Magnesium (Mg)	1.1
Sodium (Na)	169.
Potassium (K)	6.2
Manganese (Mn)	0.008
Iodine (I)	0.004
Lithium (Li)	0.008
Bromine (Br)	0.36
Arsenic (As)	trace
Carbonate radicle (CO_3)	204.
Sulphate radicle (SO_4)	11.
Phosphate radicle (PO_4)	0.85
Chlorine (Cl)	25.
Carbon dioxide (CO_2) combined	165.
Free carbon dioxide (CO_2) 2.6 cu. in. per liter.	

A well near by, owned by J. P. Tower, is said to penetrate the following succession of beds:

Record of well of J. P. Tower, 3 miles east of Shoal Bay.

Material	Thickness (Feet)	Depth (Feet)
Soil	1½	1½
Yellow sandy clay	10½	12
Yellow shell marl	18	30
Blue shell marl	140	170
Reddish or "liver-colored" mud	4	174
Blue marl with sandy beds, rocks at base	106	280
Black sand	4	284
Rock	3	287
Blue marl, water	16	303

These wells are on a bluff 30 feet above James River, hence they yield small flows.

The flowing wells near Everets tap local sands high in the St. Mary's formation. The flows are weak, but the water is of good quality—a little harder and less alkaline than that from the deeper Chesapeake (Calvert) beds along James River. The wells were inexpensive, costing only 10 cents per foot for the driller's time, the owner providing the necessary extra labor and the pipe.

Flowing wells along Blackwater River.—On the west side of the county, in the bottom lands along Blackwater River, flowing wells have been drilled from north of Zuni to the south end of the county below Franklin. The wells tap sands lying in the Chesapeake group (St. Mary's formation) about 150 feet below tide level. Most of these wells are of small diameter (2 inches), and are used for household supply or for watering stock. There are several near Zuni. At the plant of the Shaw Lumber Co., at Ivor, elevation 60 feet, a 6-inch well supplies water for a number of houses; because of the elevation the water does not rise to the surface and a pump is used. For details of other wells, see table 5.

Conditions at some of the villages depending chiefly on dug wells are noted in the following summary, compiled from reports of various persons:

Details of dug wells in Isle of Wight County.

Location	Depth of wells (Feet)	Water bed	Quality of water
Benn's Church	12–20	Sand	Soft and hard
Bobs	12–40	Sand and marl	Soft and hard
Carrsville	15–24	Sand and clay	Soft
Chuckatuck	18–20	Marl and blue clay	Hard
McClelland	10–30	Sand and marl	Soft and hard
Moonlight	12–15	Sand	Soft
Raynor	10–100	....	Fair
Wells Corner	12–16	Sand	Soft
Windsor	12–18	Clay and sand	Soft, irony
Whitely	10–15	Sand	Soft

Conclusions.—While more care than formerly is now being taken in the location and protection of dug wells, there are many that are liable to pollution. Artesian water of satisfactory quality can be had anywhere in the county at a maximum depth of 300 feet below tide, but to drill with the expectation of getting flows at points higher than 35 feet above sea level will probably prove a waste of effort, except near James River, where carefully cased wells may find water that will rise 40 feet above sea level. Potable water can be found at greater depths, and the Potomac group in particular contains vast supplies. These is nothing to indicate that the Potomac water will not be potable at 1,500 feet below surface, though in the northeast corner of the county these very deep waters are liable to be more mineralized than those obtained from the Chesapeake beds.

JAMES CITY COUNTY.

General description.—James City County, one of the original eight shires of the colony of Virginia, lies north of James River and Chickahominy River, and south of York River. Historically, the county is noteworthy for containing Jamestown, the site of the first permanent settlement of English-speaking people on the American continent, and Williamsburg, the first incorporated city in Virginia. At Williamsburg is William and Mary College, the original charter of which antedates that of Harvard College, making it the oldest chartered institution of learning in the United States.

Situated between York and James rivers, the county has characteristic topography of the western shore type; the Sunderland terrace forms the divide but has been dissected by streams flowing to the rivers on either side. The principal streams are Diascond Creek, a tributary of Chickahominy River; Ware and Taskinash creeks, which empty into York River; and Warwick River, a tributary of York River, which separates the county from Warwick County on the northeast. The greatest elevation of the Sunderland plain is in the northern part of the county between Ware and Diascond creeks, where it is about 130 feet high. Along York River there are only small patches of the Wicomico terrace, but along James River, and particularly along Chickahominy River, there are some wide stretches of it having an altitude of from 50 to 80 feet. The lowest plain is better represented along James River than along York River, and is especially conspicuous in the vicinity of Jamestown Island.

Geology.—The Potomac and Pamunkey beds lie below tide level. The top of the Potomac or Upper Cretaceous is 320 feet below tide level at the west end of the county, and 580 feet at the east end. The top of the Pamunkey is 180 to 380 feet below sea level. Of the Chesapeake formations only the Yorktown and St. Mary's outcrop. Their characteristic dark greenish or bluish sands and sandy clays and included beds of shell marl, weathered to reddish, buff and yellowish tints, are seen at marl pits. The total thickness of the St. Mary's exceeds 200 feet, but is not exposed above tide water within the limits of the county.

UNDERGROUND WATERS.

Distribution and quality.—Ground water, found in the Columbia and Chesapeake formations, is mostly soft, but in places marl beds yield hard, irony water. The water from the Pamunkey and Chesapeake beds has all the characteristics of that from corresponding horizons in adjoining counties. It is beautifully clear and slightly alkaline, but at some places is sulphur-bearing. Though plenty of potable water can undoubtedly be obtained from the Potomac beds little is known of their possibilities.

Springs.—There are a great many springs in the county, but none of commercial importance. They are used to some extent for household supply, but mostly for watering stock. The waters resemble those obtained from shallow wells in being clear and soft when flowing from Columbia sands, and hard or even iron-bearing when issuing from Chesapeake marl beds. Springs of perennial flow are numerous, but flows of more than 10 gallons to the minute are few.

Wells.—Dug wells are the chief source of domestic supply. Some drilled wells have been sunk near Williamsburg and along the river, but the number is not large. The prices for sinking these have varied according to the diameter, etc. A number of 3-inch wells near Jamestown cost about $1 per foot, complete.

LOCAL SUPPLIES.

Williamsburg, with a population of 2,044, had no public water supply system in 1906; the inhabitants relied chiefly on dug wells, though there were some cisterns in the town. The deeper dug wells get hard and irony water from the Chesapeake marls. As the town was without sewers, and the location and surroundings of some wells made their pollution easy, and as water from these wells may travel through the marls a considerable distance without undergoing purification, the quality of the water from the dug wells in the central part of the town was not above suspicion.

The deep wells at William and Mary College, the Eastern State Hospital for the Insane, the ice plant, and the knitting mill, particulars of which are given in table 5, tap coarse greenish sands full of shell fragments near the base of the Chesapeake. The water rises about 35 feet above mean high tide in James River, and as the surface elevation is 60 to 80 feet, pumping is necessary. At William and Mary College, the knitting mill, and the ice plant, deep well pumps are used; at the Eastern State Hospital an air-lift. Two wells supply the hospital; one is 8 inches in diameter; the other, owned by the Marshall estate, is 6 inches. The supply from the first is about 50 gallons per minute and from the second 100 gallons per minute. Thirty-five horse power is required to drive a duplex air compresser (air cylinders 18¼ by 12¼ by 12 inches), which furnishes air under a pressure of 75 pounds per square inch to both wells. The water runs to a reservoir, whence it is forced by a steam pump to an elevated tank. Both wells still throw considerable sand containing fragments of Miocene shells up to several inches in diameter, though the wells have been pumped steadily for over 10 years. The water is used by about 1,000 persons. An analysis made by Dr. W. H. Taylor, State chemist, is given in recalculated form in table 8. An increased supply for the asylum, if needed, can be obtained without great difficulty by deepening the present wells, or by sinking new wells 200 feet or so deeper.

The well at William and Mary College has a deep well pump, geared to a 4-horse power gasoline engine. The yield is about 50 gallons of water per minute. The water is forced to a 30,000-gallon tank on a steel tower 75 feet high. About 200 people used this water in 1906.

The general similarity of the water from the Williamsburg wells is shown by the analyses in table 8. Except for a tendency to foam it works well in a boiler, neither forming scale nor corroding. In the open air it corrodes iron, and tanks on steel towers need to be kept tight to prevent damage to the towers.

Of the wells on York River, one of the most notable is that of W. H. Davis, 235 feet deep, on Taskinash Creek, 2 miles north of Croaker. The water has been sold in small amounts for medicinal and table purposes. An analysis, recalculated from one furnished by the owner, is given in table 8.

A flowing well on Chisholm Creek, 8 miles southwest of Lightfoot, owned by the Powhatan Fish and Gun Club, gets water from a mid-Chesapeake bed at 148 feet.

The flows from recent wells near Jamestown Island deserve particular notice because of their volume and head. The wells (see table 8) get water between 270 and 300 feet below mean high tide in greensands that in places contain pebbles over a half inch in diameter. One of these wells, that of W. H. Ayers, is but 3 inches in diameter yet flows 85 gallons per minute at an elevation of about 15 feet above high tide; the head is 43 feet. This well, at the time it was completed, had perhaps the best flow of any in Tidewater Virginia having the same diameter. The greensand of the water bed contained pebbles of quartz and silicified limestone nearly 1 inch in diameter. Frank Carman, the driller, procured from a nearby well belonging to Chas. Babcock a series of samples, from which and his notes the following log has been compiled:

Record of well of Charles Babcock, 1 mile north of Jamestown.

(Authority, Frank Carman, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil and red clay (no sample)	6	6
Reddish sand (no sample); water at 15 feet	10	16
White sand and small gravel; water at 45 feet	39	54
Dark bluish clay (dark greenish, slightly sandy, micaceous clay, with shell fragments)	45	99
Grayish sand	10	109
Shell marl, hard layer of shell rock, drill drops in going through	30	139
Grayish sand	10	149
Light-colored mud, soft at top, tough at bottom	13	162
Very hard gray sand, light stream of water at about 170 feet, would not rise to surface (sample at 173 feet contained glauconite)	16½	178½
Coarse gray sand	2½	181
Coarse black sand (quartz sand full of dark green to black glauconite; sharks tooth at 193 feet; light stream of water at 190 feet, rose to 10 feet of surface)	45	226
Blue mud (dark sandy clay, slightly glauconitic)	25	251
Blue marl, at wells nearby a stiff red clay which choked pipe	3	254
Black sand (coarse quartz sand full of dark glauconite) runs badly and clogs drill pipe, water at 260 feet	26	280
Shell bed in sand	5	285
Sand and shells	4	289
Sand rock	21	310
Sand, with coarse gravel; water-bearing	10	320

Other fine artesian wells in the immediate vicinity are owned by J. H. Franklin and S. W. Grimes. On Jamestown Island, in the rear of the ruins of the old church, a well 6 inches in diameter was sunk in 1905 for the Society for the Preservation of Virginia Antiquities, that owns the ground on which stands the ruins of the church and of Lord Ware's residence. The well flows about 40 gallons per minute at an elevation of 8 feet above high tide. The greensand water bed contains large pebbles.

The water from all the wells near Jamestown Island resembles that from the wells at Williamsburg. A field assay of a sample from the well of W. F. Ayers is given in table 8.

The villages in the county, except Bacon, Jamestown, and Iola, stand on high ground near the line of Chesapeake & Ohio Railway, and get water from dug wells. In places, as near Iola, a spring yields hard water, while a well nearby gives soft water. Such an occurrence of soft water below hard is to be explained by inequalities in the contact between the Chesapeake and the overlying beds. The spring flows from a marl bed in the Chesapeake, while the well on the terrace below does not reach the Chesapeake. The well showed the following section:

Record of well at Iola.

Material	Thickness (*Feet*)	Depth (*Feet*)
Yellow loam and clay	20	20
White sand	2½	22½
Yellow sand	2½	25
Sand, pebbles, and cobbles; water	5	30

The depths of wells, character of water bed, and quality of water at several post villages are shown in the following table:

Details of some dug wells in James City County.

Location	Depth (*Feet*)	Water bed	Quality of water
Bacon	10–15	Sand	Soft and hard
Diascond	15–62	Sand and clay	
Ewell	30–40	Sand and marl	Soft and hard
Iola	10–30	Sand and marl	Soft and hard
Toano	20–40	Sand and gravel	Soft

Conclusions.—Good artesian water can be had nearly everywhere in James City County, but flows can not be expected at elevations greater than 30 feet above tide level. The entire practicability of supplying Williamsburg with soft water free from bacteria is shown by the deep wells already drilled. Larger flows than those now obtained can be had by going to sands 200 feet deeper.

KING AND QUEEN COUNTY.

General description.—King and Queen County, formed from New Kent in 1691, lies north of York and Mattaponi rivers. Walkerton, the largest village, has a population of about 250.

Most of the southern part of the county lies between Mattaponi and Pianketank rivers, but much the larger portion of this part and all the northern part drains to the Mattaponi River, Forge Mill Swamp, and Chesetank Creek being the most important tributaries of the Mattaponi rising within the county. Pianketank River, which rises in Dragon Swamp, is peculiar in having no important tributaries throughout its course. The general relief of the county is like that of much of Tidewater Virginia. The divide between Pianketank and Mattaponi rivers is formed by the undulating Sunderland plain, which is deeply trenched by tributaries of the latter stream. Lower terraces are found along the rivers. The maximum elevations of the Sunderland range between 180 feet at the northwest end of the county, and 100 feet near the southeast end.

Geology.—The greensands of the Nanjemoy formation (Pamunkey) and the sands of the Calvert and Choptank formations (Chesapeake) are exposed along Mattaponi River. The Pamunkey greensands and shells show above low tide level from Beverly Creek to above Walkerton.

The Potomac beds are deeply buried. Of the surficial formation of the Coastal Plain, the Lafayette does not reach as far east as the western end of the county, but all the Columbian formations are present, their clayey and sandy loams forming much the greater proportion of the soils. These formations, the Sunderland especially, are more pebbly toward the western end of the county.

UNDERGROUND WATERS.

Distribution and quality.—The existence of water-bearing sands in the Chesapeake, Pamunkey, and Potomac formations has been proved by artesian wells along Mattaponi River. Most of the wells, at Walkerton and below, get water from Pamunkey greensands, or possibly sands of Matawan age, though in the lack of fossil evidence it is not possible to say that Upper Cretaceous beds extend as far west as King and Queen Courthouse. None of the sands tapped gives flows at over 40 feet above sea level.

All the artesian waters are soft and alkaline from bicarbonate of soda. The iron and lime content are generally low; the proportion of common salt present is remarkably low under the western part of the county, but increases a little toward the east. Most of the flows are not noticeably sulphur-bearing.

The shallow waters vary; most of those in the Sunderland and Wicomico formations are soft. Shallow water in Chesapeake beds is liable to be hard.

Springs.—Springs are numerous, as stream valleys and gullies cut through the Sunderland and later Columbia formations and expose the less permeable beds of the Chesapeake. Many of these springs are of fair size, but none is of commercial importance.

Wells.—Dug wells ranging in depth from 10 to 40 feet are the principal sources of domestic water supply. Driven wells are comparatively few. Along Mattaponi River is a considerable number of drilled wells, 120 to 300 feet deep.

LOCAL SUPPLIES.

At Walkerton dug wells were for many years the sole source of domestic supply. Now there are only three or four dug wells, which are mostly at barns. They get water at depths of 18 to 25 feet in the terrace above Mattaponi River. Water for drinking and household purposes, also for a pickle house, is obtained from artesian wells of which over 20 have been put down. All but one or two get water from Pamunkey sands which lie 200 feet or more below tide level. The deepest well, that of John A. Mitchell, was bored for coal which was supposed to underlie the village. It went down 372 feet but found no coal and no flow below a free one at about 250 feet. The shallowest well, that at the steamboat wharf, is said to be but 180 feet deep, yet it flows a good stream. One well owned by the Mattaponi Pickle Co. gets its flow from the Potomac at a depth variously stated as 330 and 350 feet, but found several flows above the one developed.

No records of the Walkerton wells were kept, but all the beds went through "rock" and found water in black or gray sand below. One well drilled in 1906 flowed a little sand for a few months after it was completed. This sand which came up through a ¾-inch pipe extending to the bottom of the well, 235 feet, consisted of medium fine quartz grains with black and dark green granules of glauconite.

The later wells at Walkerton have casing to the first rock struck or have pipe to the bottom, but the earlier wells were cased only about 20 feet. Many of these wells undoubtedly leak below the casing, have become clogged by sand, and have had their yields reduced by wells at lower elevations, tapping the same bed. Some wells on the terrace, 30 feet above the river, flow very weakly at high tide and at low tide barely drip, though when first completed they flowed strongly. The original head of the deeper Walkerton wells was probably 35 to 40 feet above mean high water.

All the wells yield alkaline water, which at most wells has a faint sulphur odor. The field assay in table 9 shows the softness, the low chlorine content, and the decided alkalinity, characteristics of the flows. This water can be used in a horizontal boiler, but foams badly in a vertical boiler.

Above Walkerton on Mattaponi River is a fine well, drilled at the bottom of a bluff in front of the residence of A. B. Gwathmey. It is but

190 feet deep, but flowed at an elevation of 8 feet, fully 35 gallons per minute. The head is 35 feet, so that while the water will not rise to the level of the ground on which the house stands, 40 feet above the river, it can easily be raised by a ram. The water bed is described as black and green sand below a rock. Samples showed the rock to be a medium-coarse, indurated sand, containing much dark glauconite and many shell fragments; it might be termed a glauconitic sandstone. At a 275-foot well, owned of John N. Ryland, half a mile from the river, the water rises to 17 feet from surface or about 40 feet above tide, and has to be pumped.

Below Walkerton, near the mouth of Mantapike Creek, a 150-foot well, owned by the Mantapike Canning Co., flows 20 gallons per minute of excellent water from basal Chesapeake beds. The actual cost of sinking was about $35.

At King and Queen Courthouse a deep well, owned by the county, formerly flowed, but in 1906 was pumped, the water rising about to the surface. It threw much fine sand which contained grains of glauconite.

Along Mattaponi River below the Courthouse and along York River are many flowing wells. At Chain Ferry are two about 168 feet deep. The flow comes from the same Chesapeake beds that supply most of the many wells at West Point, and the waters are of essentially the same quality, soft, alkaline, and slightly sulphuretted. (See field assay in table 8.)

Near the east end of the county a well near Gressitt, belonging to W. F. Anderson, is cased to rock, and after being in use 11 years flowed 8 gallons per minute at 11 feet above tide. It taps the same beds as the wells at Chain Ferry, and the water is of the same general quality.

A number of villages report the data shown in the following table:

Details of dug wells in King and Queen County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Biscoe	10–50	Clay, sand and gravel	Soft
Box	30–75		Soft
Carlton's Store	20–60	Sand	Soft
Cologne	20–50	Sand	Soft
Cumnor	20–40	Sand and marl	Soft to hard
Dragonville	10–40		Hard
Edna	15–50	Clay and sand	Soft and hard
Elsom	30–40	Gravel and sand	Slightly hard
Favor	30–50	Marl	Hard
Indian Neck	30–50	Sand	
Little Plymouth	25–40	Sand	Hard to soft
Plainview	20–30	Sand and marl	
Shackelford	14–24	Gravel	Soft to hard
Shanghai	15–25	Sand	Soft
Stevensville	22–45	Marl and sand	Hard

At Edna the deeper wells go through soil, yellow clay, and thin beds of white and yellow sand to about 35 feet, finding water in white sand and small gravel below iron crusts.

At Favor the average section of 35-foot wells shows red and yellow loam, black "fullers earth," "rock," and shell marl; while at Plainview wells go through loam, clay, white sand, and fullers earth, below which is shell marl.

Conclusions.—Artesian water of good quality can be had under the whole of King and Queen County, but flows can not be expected at elevations of over 30 feet above tide. In places where the interference of wells has resulted in diminished yield, more water under higher heads can be had by going deeper. Places on high ground can avail themselves of the soft, germ-free artesian waters by pumps, but at elevations above 50 feet the wells should be of sufficient diameter to permit the use of pump barrels inside the casing.

KING GEORGE COUNTY.

General description.—King George County, formed from Richmond County in 1720, occupies the west end of the Northern Neck, the peninsula between Potomac and Rappahannock rivers. The county contains no large towns and no large villages. Some of the farms are owned by men of wealth who are remodeling the old mansions and installing water supply plants drawing on artesian flows.

Lying near the western edge of the Coastal Plain, and having tidal rivers on two sides, King George County has greater relief than most counties of Tidewater Virginia. As a rule the divide between the rivers is rather narrow, and is much dissected; it comprises portions of the Lafayette and Sunderland plains. The Lafayette plain has an elevation of 220 feet near Boscobel farm. King George Courthouse stands on the Sunderland plain at an elevation of 130 feet.

Geology.—Potomac, Pamunkey, and Chesapeake deposits underlie King George County; the first are not exposed, but the Pamunkey clays and greensands are exposed along Potomac River from the county line to Mathias Point, and along Rappahannock River from 10 miles below Fredericksburg to 4 miles below Port Royal. At the western side of the county the Pamunkey beds rise 125 feet above tide level; at the eastern side their surface is just below tide level. Their total thickness is 200 to 250 feet, and the Potomac-Pamunkey contact dips east 12 to 25 feet to the mile, its depth below tide varying from 50 to 220 feet.

The Calvert formation of the Chesapeake contains much diatomaceous material, especially in the southeast corner of the county near Wilmont Landing on the Rappahannock, where dry fragments of the light-colored diatomaceous clays float when they fall into the river from the conspicuous bluffs.

The Chesapeake sands, clays, and marls are mantled by the buff and yellow Lafayette and Columbia loams with beds of sand, gravel, and cobbles. Boulders 5 feet or more long are found in the lower terraces.

UNDERGROUND WATERS.

Distribution and quality.—The waters in the Columbia sands vary in quality from clear and soft to irony and hard. Although the Potomac sands underlie the whole county, and undoubtedly contain much water, few wells have been sunk to them. The basal sands of the Aquia formation of the Pamunkey contain supplies of soft water. The Chesapeake, as it lies above sea level, contains no sands that yield flows. The shallow Chesapeake waters are generally hard.

Springs.—Because of the dissection of the surface the county contains many springs, mostly of small size. A few are used for domestic supply. None of commercial importance has been reported.

Wells.—Dug wells with wood lining are the main source of domestic supply. Because of imperfect drainage, wells located on the lower and flatter terraces are particularly liable to contamination by surface water, and some of the backyard wells with decayed lining, through which all manner of filth drips at every rain, are a continual invitation to visitations of typhoid fever. Driven wells are much preferable from a sanitary standpoint, and the deep flowing wells are inexpensive in comparison with the security they give.

LOCAL SUPPLIES.

Rappahannock River.—Two miles east of Sealston is a 250-foot flowing well drawing on Potomac beds, owned by John Curtis. It is on a terrace at an elevation of about 35 feet above tide, and flows two-thirds of a gallon per minute. It is noteworthy for showing variations of flow, due to fluctuations of atmospheric pressure, as stated on page 38. The water, used for drinking, is not so soft as the Pamunkey flows, but is of excellent quality. No record was kept of the formations penetrated; the well was driven to 247 feet and drilled below. The flow is from "quicksand."

At or near Port Conway are several flowing wells drawing on the sands at the base of the Pamunkey or on Potomac sands. One supplies water for a canning factory; another at the residence of R. V. Hunter is harnessed to a small ram that supplies the house; and a third at Oakenbrow farm, owned by Dr. J. H. Low, flows only about 2 gallons per minute at the level of the terrace on which it stands, but by a gasoline engine and pump 200 gallons per minute can be forced to a tank at the residence, on a bold headland of the Sunderland terrace, 100 feet above the well.

The character of the material penetrated at Port Conway is indicated by the following generalized section:

Record of well of R. V. Turner, Port Conway.

(Authority, O. D. Hale, driller.)

Material	Thickness (Feet)	Depth (Feet)
Sand and gravel	12	12
Light and dark clay (blue and lead-colored)	212	224
Sand; water-bearing	8	232

The flows of the Port Conway wells are clear and soft. The water has a slight odor of "sulphur" when fresh from the well. (For field assays see table 8.)

The exact depths of the wells at Wilmont Landing could not be ascertained, but they probably tap the sands near the base of the Pamunkey about 275 feet below sea level.

On the wide terrace along Rappahannock River, near Sealston, is a considerable number of driven wells. From one the following record was reported:

Record of well of Frank Taylor, 2 miles south of Sealston.

Material	Thickness (Feet)	Depth (Feet)
Red loam	3	3
Red clay	3	6
Fine red sand	6	12
Fine gravel	4	16
Gravel and small rock	2	18
Boulders and cobbles	3	21
Marl, black sand		

This section is said to be characteristic of driven wells in the vicinity.

Potomac River.—Several flowing wells have been drilled along Potomac River from Chatterton east. The waters are from near the base of the Aquia formation of the Pamunkey, or from the Potomac.

A well on Mathias Point is reported to have shown the following section:

Record of well of C. H. Pemberton, Mathias Point.

Material	Thickness (Feet)	Depth (Feet)
Sandy clay	30	30
Black shell marl	35	65
Red clay with shells	56	121
Gravel and sand	20	141
Rock and clay	30	171
Blue clay	30	201
Sandstone and clay; stone at 227 feet, water at 236 feet	35	236

This well has only 16 feet of casing, but a 1-inch pipe runs to the bottom. The water, soft and clear, is used for household purposes. A field assay of a sample is given in table 9.

Near Pluck, Dido, and Vivian are several flowing wells that were drilled at oyster and fish-packing houses. The reported depths range from 175 to 300 feet, but most of the wells probably draw on the Aquia sands. A flowing well near Pluck is but 50 feet deep, and its irony water evidently comes from a bed high up in the Nanjemoy.

At King George Courthouse are 7 or 8 dug wells, 40 to 50 feet deep, that get water from yellowish sands at the base of the Sunderland formation, or at the top of the Chesapeake beds. The quality is fair. Conditions at some of the settlements dependent on dug wells are shown below:

Details of some dug wells in King George County.

Location	Depth (Feet)	Water bed	Quality of water
Edgehill	25–60	Sand	Soft
Hampstead	60–100	Clay and sand	Good in deep wells
Passapatanzy	18–90	Clay, sand and marl	Hard in deep wells
Rollins Fork	40–65	Gravel	Soft
Shiloh	30–50	Sand and marl	Soft

Near Hampstead dug wells penetrate 25 feet of loam and clay, 15 feet of gravel and sand, and find water on the top of the Chesapeake marl. Here and at a number of other points in the county digging into the dark bluish, sandy clay or "marl" of the Chesapeake obtains a scanty supply of water of poor quality for domestic use.

Conclusions.—Good artesian water, soft but alkaline, that will rise 20 to 30 feet above sea level can be had at nearly all places in the county.

KING WILLIAM COUNTY.

General description.—King William County lies between Mattaponi and Pamunkey rivers, extending some 30 miles northeast of the point where they unite to form York River. At the junction of Pamunkey and Mattaponi rivers is the city of West Point, with a population of 1,397 in 1910. The county is rather sparsely inhabited and contains few large villages, some of the larger being Lester Manor, Cohoke, King William, and Aylett.

Topography.—The topography is diversified. The northwestern portion of the county approaches the western edge of the Coastal Plain, and the Lafayette terrace extends into it, but most of the surface is formed by the Sunderland terrace, which is deeply cut by stream valleys. Along both Pamunkey and Mattaponi rivers are expanses of the Wicomico and lower terraces, especially the Wicomico, which contain much good farming land. The elevation of the Lafayette terrace is about 200 feet, while that of the Sunderland is 180 feet in the northwestern part of the county, and 110 feet in the southeastern part. The Wicomico terrace varies in elevation from 50 to 90 feet, and the other lies below 60 feet.

Geology.—Potomac. Pamunkey, and Chesapeake beds underlie the county, but the Potomac beds are not exposed. The top of the Potomac may be 200 feet below tide level on the northwestern boundary of the county, and 400 feet below at West Point.

The greensands of the Aquia and Nanjemoy formations of the Pamunkey group outcrop along the Pamunkey River from the west end of the county to Piping Tree Ferry, where they disappear below the tide level. Above the Pamunkey are Chesapeake sands and clays more or less covered by Lafayette or Columbia gravels, sands, and loams. The base of the Chesapeake is 20 feet above tide level on the Pamunkey near Hanover Courthouse, and 180 feet below at West Point. The base of the Pamunkey group is 150 to 350 feet below. In the Wicomico and Talbot formations of the Columbia, particularly along Pamunkey River, are many large subangular boulders.

UNDERGROUND WATERS.

Distribution and quality.—Ground water that supplies springs and shallow wells is found in the Pamunkey in the western part of the county, in the Chesapeake in the eastern, and in the Lafayette and Columbia terrace materials. Its quality generally is excellent. Artesian waters underlie the whole county. The Chesapeake and Pamunkey groups furnish fine flows in the eastern part of the county. At the western end of the county, where the Chesapeake lies above tide level, water that will rise above tide level can be had from the Potomac, but few wells have been drilled to it.

The Pamunkey and basal Chesapeake waters differ but little, being delightfully soft, and more or less alkaline from the presence of bicarbonate of soda; some are slightly sulphur-bearing.

Springs.—There are many springs in King William County, but few that are of especial note and none of commercial importance.

Wells.—Dug wells are the main source of supply over most of the county; but, except Southampton County, there is no county in Tidewater Virginia having more drilled wells, as a large number have been sunk in the city of West Point. The drilled wells are nearly all of small diameter and the great majority draw on Calvert beds. The flows of properly drilled and cased wells are generally free, but the waters do not rise more than about 35 feet above tide level, hence there are not many wells on the 30 to 50 foot terrace along Pamunkey River above Elsing Green.

LOCAL SUPPLIES.

Aylett, on Mattaponi River, noted in colonial times for its export shipments of corn, has only three dug wells, which are from 20 to 65 feet deep; two sunk over 60 feet obtained scanty supplies of hard water. Several families use the water from a spring just below the terrace on which the village stands.

Two artesian wells on the terrace, 25 feet above the river, get clear, soft water in basal Pamunkey beds at 160 feet below mean high tide. One of these wells, owned by J. C. Fox, was put down at a total cost of but $40. The small flow, one-third of a gallon per minute, is due to the elevation, and possibly also to there being only 20 feet of 2-inch casing in the well, but the flow suffices for domestic purposes and for 20 head of stock, the overflow from a tank at the well being piped to the barn. This well is said to have gone through 20 feet of Columbia loam and sand, some 60 feet of "fullers earth" or fine dark clay, and then through beds of shell marl and rock, five or six "rocks" in all, before finding water in a gray sand. No flows were found above the one used, and the head of this is about 35 feet above mean high tide in the Mattaponi. A complete analysis of a sample of water from this well appears in table 8.

The other well, owned by Dr. J. B. Moore, also has only 20 feet of casing, but a ¾-inch pipe goes to the bottom of the water-bearing sand at 190 feet.

West Point is situated on low land, mostly not over 15 feet high. Along the rivers were formerly open marshes. Owing to the low elevation, a water table near the surface, and a sandy soil, the dug wells or driven pumps which were once the chief source of supply, were particularly liable to pollution, and the city once had a reputation for malaria and typhoid fever. Since the introduction of artesian water there has been a great improvement in public health, and local physicians claim that cases of typhoid fever originating in the city are practically unknown. The total number of drilled wells may be 300. They range in depths from 110 to 360 feet, but all draw on one or more of three water beds; the first at 110 to 120 feet, the second from 160 to 170 feet, and the third from 320 to 340 feet. The first, low in the Chesapeake, yields scant supplies of water having a decided sulphur odor and is now little used. The second, in basal Chesapeake beds, yields water that has a very slight sulphur odor, and to it the great majority of the wells in the city have been drilled. The third, in the Pamunkey, yields water much like that from the second, but it has been tapped by comparatively few wells. The two upper horizons once had strong heads, 15 to 25 feet, but the drilling of many poorly cased wells, and the constant flow from wells near the shore but a few feet above tide, have greatly lowered the heads in both sands, so that wells to the 120-foot sands will not flow at more than 4 or 5 feet above tide, and those to the 165-foot at not over 10 feet. This loss of head through interference has been discussed on page 71. Wells driven to the third flow are put down with care, and are usually cased to the bottom. The head of this flow is about 30 feet above tide.

All the West Point wells feel the rise and fall of the tide, and many flow at high water and do not at low water. The largest well at West Point was put down for the Southern Railway. The record was destroyed by a fire, and detailed records of the many small wells have not been kept.

The following generalized section was given by one of the most careful drillers in the city:

Generalized section at West Point.

(Authority, J. V. Bray, driller.)

Material	Thickness (*Feet*)	Depth (*Feet*)
Loam or marsh mud	10	10
Fullers earth	100	110
White sand and shell, water in shells	11	121
Shells, no sand	5	126
White sand	20	146
Greensand	6	152
Shells, second flow at 160 feet	8	160
Thin bed of reddish clay	1	161
Black sand and gravel, third flow in gravel at 320 feet	160	321

Another record of a well drilled near the post-office is as follows:

Record of well of Wm. Wheeler, West Point.

(Authority, J. Frank Smith, driller.)

Material	Thickness (Feet)	Depth (Feet)
Fullers earth	90	90
Fine white sand, small stream of sulphur water at 112 feet	35	125
Fullers earth	15	140
Shells, with good water at 150 feet	40	180
Black sand with "beautiful gravel" at 316 to 320 feet	140	320
Rocks with sand below	80	400

Artesian water is used at West Point for all domestic purposes and for boiler supply. The large number of wells drilled and their low cost, drillers asking but $50 for a 2-inch well to the second flow, delayed the installation of a public waterworks system. The present system, described on page 78, distributes water from wells tapping the 325-foot flow. The bacterial purity of this water is beyond question, and the quantity obtainable with ordinary care in development should be sufficient for years to come. Field assays of the water from several wells in West Point, and a complete analysis of water from the 165-foot flow, taken from a well at Beech Park, the property of the Southern Railroad Co., are given in tables 8 and 9. The water is notable for the percentage of sulphates.

The water from both the 165-foot and 325-foot wells has a tendency to foam in a boiler, and works best in horizontal boilers. It is, nevertheless, used in vertical marine boilers by tugs and other river craft. With a horizontal boiler it is the custom to blow off some water every few days to prevent the water from becoming too concentrated. The artesian water is much used at the large oyster houses for washing oysters. For this purpose it is most admirably suited, its bacterial purity making it especially desirable for washing shucked oysters.

In or near Lester Manor about 10 drilled wells find flows in fine to coarse Pamunkey sands that contain much dark green glauconite, and many shell fragments, a greensand marl. The following generalized record was furnished from memory:

Record of well of John G. Robins, 3 miles west of Lester Manor.

(Authority, H. E. Shrimp, driller.)

Material	Thickness (Feet)	Depth (Feet)
Clay	60	60
Shell rock	50	110
Fullers earth	90	200

The water bed at this well is a medium quartz sand containing much glauconite.

On Pamunkey River above Lester Manor, wells have been driven at Elsing Green, near Palls, and southeast of Manquin. The driller gave from memory the following record of one of the wells at Elsing Green:

Record of well of Roger Gregory, at Elsing Green.

(Authority, H. E. Shrimp, driller.)

Material	Thickness (Feet)	Depth (Feet)
Loam and gravel, surface water	10	10
Bluish sandy clay	50	60
Rock, full of fossil shells	30	90
Bluish slightly sandy clay, lighter than clay above, water at bottom	180	270
Soft greenish rock, sandy in places, no shells in it	30	300

A sample from a reported depth of 300 feet was a coarse quartz sand containing much glauconite.

The wells southeast of Manquin may draw on the Potomac flows; one of these, owned by C. B. Chapman, 6 inches in diameter and 237 feet deep, yields 6½ gallons per minute of soft water that is piped to half a dozen places about the farm buildings, and is used in steam boilers (for analysis see table 10). The following record was furnished from memory by Edward Williams:

Record of well of C. B. Chapman, 1 mile south of Manquin.

Material	Thickness (Feet)	Depth (Feet)
Loam, clay and sand	10	10
Marl and greensand with shells	175	185
Stiff blue clay	40	225
White sand with water	12	237
The water sand is medium coarse and contains flakes of mica.		

Several flowing wells have been drilled at Cohoke to the Pamunkey horizon tapped at Lester Manor. The driller gave the following record of one:

Record of well of J. N. O. Johnson, near Cohoke.

(Authority, H. E. Shimp, driller.)

Material	Thickness (Feet)	Depth (Feet)
Clay and sand	100	100
Shell rock	52	152
Hard rock	88	240
Quicksand, water		240

The water bed is a medium coarse quartz sand containing much dark green glauconite, and many fragments of shells.

On Mattaponi River opposite Walkerton are wells which draw on horizons tapped at Walkerton, mentioned in the description of King and Queen County.

An attempt was made about 20 years ago to obtain artesian water at King William Courthouse. A well some 350 feet deep found water, but, since the courthouse stands on the Sunderland terrace at an elevation of 135 feet above tide water, no flow was obtained and the well was abandoned. It is stated that the water rose to within 17 or 18 feet of the surface, but since the heads of the flows at Walkerton, a few miles away, are under 40 feet, this seems altogether unlikely.

At some of the villages in King William County which depend on dug wells conditions are summarized as follows:

Details of dug wells in King William County.

Locality	Depth of wells *(Feet)*	Water bed	Quality of water
Beulahville	19–75	....	Hard
Duane	20–40	Sand and gravel	Fair
Enfield	.....	....	....
Lanesville	15–25	Clay and sand	Soft
Mangochick	20–40	....	....
Manquin	20–45	Sand	Soft
Sykron	15–80	Clay and sand	Soft to hard

Conclusions.—Enough wells have been driven to show the entire practicability of getting flows of soft alkaline water at elevations of less than 35 feet over nearly all of the eastern part of King William County. Where wells have been closely driven and have been allowed to flow without restraint, as at West Point, resulting in general loss of head, more abundant flows under higher head of as good water can be had by going deeper.

On high ground, as at King William Courthouse, flows are impossible, but the artesian water can readily be obtained by the use of deep well pumps. At King William a well 450 feet deep will reach the sand supplying the Walkerton wells, but the water from these will not rise to 50 feet of surface.

LANCASTER COUNTY.

General description.—Lancaster County, formed in 1651, lies on the north side of Rappahannock River near its mouth, occupying the southern part of the end of the peninsula between Rappahannock and Potomac rivers. The principal settlements are Irvington and Weems.

The topography, though the greater elevations are less than in counties to the west, shows considerable variety. A high terrace with an undulating surface cut by V-shaped creek valleys extends eastward nearly to Kilmarnock. Lancaster Courthouse stands on it. The maximum elevation in the northwest end of the county is 90 feet. Lower terraces are traceable along Rappahannock River and face Chesapeake Bay. The drainage is mostly to the Rappahannock, the county line on the northeast following the Potomac-Rappahannock divide. Along the bay coast are many tidal inlets and the shoreline is extremely irregular.

Geology.—Though the sandy loams of the Columbia (Pleistocene) formations cover most of the surface, shell beds and sands belonging to the St. Mary's formation of the Chesapeake (Miocene) group are exposed in headlands along Rappahannock River and in creek gullies.

The bottom of the Chesapeake lies 360 feet below tide level at the Richmond County line and nearly 600 feet below at Windmill Point. So far as can be determined from well records the underlying Pamunkey (Eocene) group is about 100 feet thick, its base lying 480 feet to 700 feet below tide. At Windmill Point the top of the Potomac group (Lower Cretaceous) is fully 800 feet below sea level, and crystalline bed rock over 1,000 feet deeper.

UNDERGROUND WATERS.

Distribution and quality.—The Columbia sands and the top beds of the Chesapeake contain much ground water; the quality differs from place to place, here soft, there hard or irony. On low tracts near tidal inlets the ground water is at times brackish.

Artesian waters underlie all the county. The water bed most widely developed is a coarse sand in the Calvert formation, lying about 240 feet below tide at Whealton and 320 feet below at Irvington. The water is alkaline, soft, and sulphur-bearing. This sand either thins out or becomes too clayey to transmit water a few miles east of Irvington, and attempts to get water from it have had little success. Flows have been obtained from Pamunkey sands that lie 500 to 700 feet below sea level, and from Upper Cretaceous deposits. The Pamunkey sands, like the Chesapeake, are less freely water-bearing toward the east end of the county.

Springs.—Below the scarp of the high terrace are springs of the usual Coastal Plain type, few of which are of especial importance.

Wells.—Open dug wells, driven wells, and drilled wells are in use. The driven wells are mostly in the eastern end of the county, the drilled wells along inlets from Rappahannock River and Chesapeake Bay. Depths of dug wells vary from 8 to 50 feet, of driven wells from 10 to 20 feet, and of drilled wells from 100 to over 500 feet. Dug wells in lowlands in the east end of the county are sometimes salted by high tides.

LOCAL SUPPLIES.

At and near Whealton artesian wells, drawing on the Calvert sands at 240 feet below river level, supply drinking water for 200 people, and are claimed to have effected a marked improvement in the general health. The water is used not only for domestic purposes but also at a tomato canning plant and an oyster packing house. The wells are 1½ or 2 inches in diameter. The flow from one well is fed to a ram with 4½-foot fall; the ram elevates enough water 40 feet to keep full a tank in a dwelling house.

The following generalized record is reported:

Record of well of Lewis-Lankford-Tull Co., Whealton.

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand	22	22
Fullers earth or blue clay	192	214
Rocks and sand, rocks one-half to two inches thick; water at 251 feet	42	256

This well has 214 feet of 1½-inch casing; the flow is given as 16 gallons per minute at 8 feet above the river.

O. D. Hale, who has drilled many wells along Rappahannock River, reports the following generalized section:

Generalized section at Whealton.

(Authority, O. D. Hale, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand and light clay	65	65
Fullers earth or blue clay	70	135
Rocks and sand, rocks ½ inch to 6 inches thick	45	180
Clay and sand	93	273
Thin rock, with varicolored sand below, water		273

Essentially the same beds are tapped by wells farther down the river near Monaskon.

Near Bertrand, Millenbeck, Weems, and Irvington, perhaps 30 wells from 270 to 580 feet deep, have been drilled for domestic supply and other purposes. The wells at Bertrand, used for washing oysters and for household supply, get water from sands in the Calvert formation about 265 feet below river level. The water is soft and slightly sulphur-bearing. At Millenbeck and Merry Point the wells reach water of about the same quality at 200 to 210 feet. At Weems and Irvington most people get water from dug wells 15 to 35 feet deep. The towns are on a terrace with maximum elevation of about 30 feet. The wells at Weems go through sandy loams and clays and find water, soft, hard, and irony, at 12 to 20 feet, in a thin sand bed that overlies a black mud or clay. A mile west of Weems a dug well found this black clay 20 feet thick. Near the edge of the terrace at Irvington the dug wells, 25 to 35 feet deep, get soft water. About 70 per cent of the wells in the town are bricked, 20 per cent cased with tile, and 10 per cent with wood. The recent wells are nearly all cased with tile. There are many driven wells in the vicinity of the town, most of them about 20 feet deep. Some wells close to the inlets get brackish water.

The drilled wells near Irvington and Weems penetrate two important water sands, one about 330 feet below sea level in the Chesapeake group (Calvert formation), and the other between 200 and 240 feet deeper in the Pamunkey group. The wells driven to the first sand are 1½ inches in diameter and yield small flows, ½ to 2½ gallons per minute, of soft, alkaline water having a decided sulphur odor; the head is low, possibly 10 feet. A 3-inch well at a fish factory at Irvington and another at a country residence across Carters Creek from Weems get excellent water, under a head of about 35 feet above tide, that has no sulphur odor. The well at the fish factory is said to have flowed 58 gallons per minute at an elevation of about 5 feet when first completed; this flow was cut down to about 40 gallons by screening. The water keeps well in vessels and is said to work well enough in a horizontal boiler, but primes in a vertical boiler. The well on the Francis estate had in 1906 a measured flow of about 35 gallons per minute at 6 feet elevation. It is used for general purposes. Field assays of samples from several wells are given in tables 8 and 9.

The following partial analysis of the water at a 330-foot well at the fish factory in Irvington was furnished.

Partial analysis of 330-foot well Carters Creek Fish Guano Co., Irvington.

(Analyst unknown)

	Parts per 1,000,000
Calcium carbonate ($CaCO_3$)	14.0
Calcium sulphate ($CaSO_4$)	4.7
Magnesium carbonate ($MgCO_3$)	8.4
Sodium chloride (NaCl)	122.0
Iron oxide (Fe_2O_3)	12.0
Sand, clay, etc.	41.0
Organic matter	68.0

The prices for drilling at Irvington have varied. Some 1½-inch wells to the first flow cost $100; the 3-inch wells to the deeper flow cost about $2 per foot.

Along the river below Irvington, at Whitestone and Westland, two attempts to get flows resulted in failure, the drillers not having had strong enough rigs. Northeast of Irvington on inlets from Chesapeake Bay at Chase's Wharf, Ocran, and near Kilmarnock, are flowing wells that get water 400 to 650 feet below tide level in basal Chesapeake and Pamunkey or Upper Cretaceous beds. The water is used for various purposes. The flow near Kilmarnock, when the well was just completed, was given at 140 gallons per minute through a 3-inch pipe. It supplies a fish factory.

A 660-foot well at Ocran yields an alkaline water that is used for boiler and other purposes at a fish factory. A partial analysis made by the Hartford Steam Boiler Insurance Co., and kindly furnished by Lawford and McKim, of Baltimore, Md., showed each 1,000,000 parts of the water to contain 616 parts of total solids, which included 548 parts of readily soluble matter and 56 parts of silica. The soluble constituents were carbonate of soda (large amount), chloride of soda (considerable), and some sulphate of soda and carbonate and chloride of potash.

The following record of a well on Dimer Creek, probably at Chase's Wharf, has been published by Darton.[a]

[a]Darton, N. H., Op. cit., p. 176.

Record of well on Dimer Creek.

Material	Thickness (Feet)	Depth (Feet)
Tough blue clay, with 3-inch sand bed at 170 feet	237	237
Marl with shells and gravel	2	239
Gravel with good supply of water which rises to within 10 feet of surface	2	241
Blue clay	7	248
Rock, underlain by coarse sand mixed with yellow and green clay	2½	250½
No record	2½	153
Clay	132	385
Rather coarse dark sand	3	388
Blue clay	47	435
Sand, fairly coarse, dark buff and white below, 7-gallon flow of water	8	443
Hard rock, very rough, porous	21	464
Coarse sand mixed with clay and mica, 5-gallon flow of water	10½	474½
No record	1½	476
Rock, quite hard	3	479
Blue clay and sand	28½	507½

At Lancaster Courthouse, elevation about 75 feet, an attempt to get a flow some years ago naturally resulted in failure. Dug wells in the vicinity of the Courthouse are 30 to 60 feet deep. The following record of the Courthouse well has been published.[a]

Record of well at Lancaster Courthouse.

Material	Thickness (Feet)	Depth (Feet)
Bright orange sand, moderately coarse	30	30
Gray sands, moderately coarse with shell fragments	45	75
White and yellow sand intermixed, moderately fine	40	115
Gray sand moderately coarse, some glauconite grains, few shells and thin ferruginous crusts	45	160
Greenish-gray fine sands, mud with some mica and many shell fragments, some glauconite	20	180
Clay, light brownish-gray in color, few sandy streaks, shell fragments	70	250
Clay, light greenish-gray in color	50	300

Some data reported regarding the shallow wells at a number of villages are summarized thus:

[a] Darton, N. H., Op. cit., p., 176.

Details of shallow wells in Lancaster County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Alfonso	24–60	....	Soft and hard
Fisherman	8–15	Sand	Brackish
Litwalton	65–70	....	Soft
Millenbeck	10–30	Sand	Poor
Monaskon	10–70	....	Soft and hard
Ottoman	10–60	Shallow, sand; deep, clay and rock	....
Rehoboth Church	10–90	....	Shallow, poor; deep, good
Westland	5–15	Clay and sand	Soft or brackish
Whitestone	8–18	Shallow, sand; deep, clay	Good, soft

Conclusions.—While the mid-Chesapeake sands tapped by the 330-foot wells at Irvington can not be depended on for flows or satisfactory yields farther east, carefully drilled wells can get plenty of water at greater depths even as far east as Windmill Point. There is nothing to show that the water will be too highly mineralized for general use. At points above Irvington where flows from the first sand have been reduced by drilling several wells within a small radius, more water, probably of better quality, can be had by going deeper. Pumping will be required to get water at Lancaster Courthouse from either the Chesapeake sands, about 400 feet below the Courthouse, or the Pamunkey sands 200 feet deeper.

MATHEWS COUNTY.

General description.—Mathews County ranks next above Alexandria County in small area and in density of population. It occupies the peninsula between Pianketank River, Chesapeake and Mobjack bays, and has an extremely irregular outline. There are many villages but no incorporated towns.

The surface of Mathews County is monotonously level, nearly all of it lying within the Talbot plain.[a] From a maximum elevation of about 30 feet near the Gloucester County line the surface gradually slopes east and south to tide level. Along the eastern shores wide stretches of salt marsh fringe the inlets, and the surface slopes so gradually below sea level that heavy easterly gales drive the bay water far inland.

[a]The writer believes that most of the surface of Mathews County forms part of a terrace that is to be correlated with the Pamlico terrace of North Carolina.

Geology.—In the northwest part of the county gray Chesapeake sands of the St. Mary's formation are here and there exposed in the bluffs along Piankctank River; elsewhere in the county only Columbia or Recent material is visible. Near the west side of the county yellow buff and reddish loams, seen in road cuts and ditches, overlie more sandy beds. Eastward these bright-colored loams grow thinner and disappear, the sands become marly, and along the bay front mud and marl predominate. Near Port Haywood and elsewhere, dark, ill-smelling mud containing tree roots is found at depths of 15 to 25 feet and deeper, and the thickness of Columbia material may be 50 feet.

The bottom of the Chesapeake lies 500 to 600 feet below the surface, and the bottom of the Pamunkey 100 feet deeper. Evidence as to the presence of the Upper Cretaceous is lacking, and nothing is known of the Potomac. Crystalline bed rock is probably 2,000 feet below the surface.

UNDERGROUND WATERS.

Extent and character.—Because of the slight elevation and the nature of the beds the abundant shallow waters in the Columbia sands are not satisfactory at many points in the county, being high-colored, ill-smelling, and even brackish. In the western part of the county near North River dug and driven wells go through a foot of soil, 12½ feet of "yellow" clay, and 4 feet of red clay, finding water in sand below. On ground 20 feet or more high, the water is soft and sweet, while on flats the water is poor. Many of the shallow wells on higher ground go dry in times of drought. Waters from sands at a depth of 100 feet or so vary in quality and in the yield to driven or drilled wells; in places these sands afford plenty of excellent water, in places they supply but little, and this is irony or otherwise objectionable.

Artesian waters under heads sufficient to give surface flows underlie most of the county, but those so far found are not satisfactory. The Chesapeake and Pamunkey, beds which afford such abundant supplies in counties to the west, apparently are too fine-grained under Mathews County to transmit water readily; the waters are under lower head and are more sulphur-bearing and irony.

Springs.—Except in the western part of the county there are few springs large enough to be used for household supply. At Dixie, on Piankctank River, however, several seeps and springs emerge from a bluff of loam and sand. Their total volume is problematical, but two flows, one about 10 feet above the other, caught by wood basins, supply a saw-mill and a tomato canning factory on the shore below. The water is soft, free from iron, and works well in a boiler. Near Hudgins are two springs used for domestic supply and for stock. One owned by N. C. Miller is said to be used by neighbors when their wells go dry.

Wells.—There are many driven wells in the county, conditions favoring their use. In places, however, the fine sands of the water-bed clog pipes and cut the valves of pumps, and dug wells are favored.

LOCAL SUPPLIES.

At Mathews most of the water is from dug wells 8 to 12 feet deep, which, as the surface elevation is about 6 feet, seldom go dry, though wells close to the river get brackish after unusually high tides. Some of these wells are liable to pollution by surface drainage.

Besides the dug and driven wells there are a few cisterns in the village. Several attempts to get artesian water at the Courthouse have not resulted satisfactorily. The last well found water between 100 and 150 feet, and, according to the driller, a stronger flow at 817 feet. The water has a head of only 6 feet, and the yield in September, 1906, was 1 gallon per minute at an elevation of 4 feet. The water has a decided sulphur odor and is little used. The flow is said to have nearly ceased during the summer of 1905. The low head, the temperature, and the quality of the flow, as shown by the field assay in table 11, indicate that much of the water may come from the higher sands of the Chesapeake rather than from Potomac strata.

Near Port Haywood several drilled wells have found at about 100 feet water that is considered soft, and is used for household purposes or for boiler supply. It comes from sands high in the Chesapeake group.

Over much of the county, dug wells fill nearly to the top in wet weather. Where the water is high in iron, ill-smelling or salty, cisterns are much used. On Gwynn's Island, where about 600 people live, wells average only 7 to 9 feet deep.

Particulars regarding dug and driven wells at a number of places are thus summarized:

Details of dug wells in Mathews County.

Location	Depth (*Feet*)	Water bed	Quality of water
Blakes	8–16	Sand	Soft
Cardinal	8–16	Sand	Shallow wells, soft, brackish: deep wells, hard.
Cobbs Creek	8–10	Sand	Fair
Diggs	7–12	Sand	Soft
Dixie	12–40	Sand and marl	Soft
Grimestead	7–10	Sand	Good
Hudgins	6–10	Sand and clay	Poor
Mathews	7–12	....	Shallow, soft; deep, brackish.
New Point	5–8	Sand	....
North	6–15	Clay and sand	Hard, brackish
Port Haywood	7–25	Mud, shell beds, and sand.	Shallow, soft; deep, hard, and irony.
Susan	6–12	Clay and sand	Shallow, soft; deep, hard.
Tabernacle	6–8	Marl	Good
Williams Wharf	6–12	Shells and sand	Fair

A 70-foot driven well at Port Haywood entered "blue mud and shells" at about 20 feet and struck "soft rock" at 40 feet, but found no water worth mentioning. A driven well 110 feet deep at Fitchett's found water too salty for use. The pipe was pulled back to 50 feet and water was obtained that though a little brackish could be used in a boiler.

Conclusions.—While the Chesapeake beds under eastern Mathews County are apparently fine and clayey, small flows of hard or iron-bearing water may be had from discontinuous sand beds near the top of the group. The prospects of obtaining water of good quality from the Pamunkey beds or below at points east of Mathews Courthouse are doubtful: the odds favor highly mineralized water containing salt, iron and sulphur. Near the Gloucester County line prospects are much better.

MIDDLESEX COUNTY.

General description.—Middlesex County, formed from Lancaster in 1675, lies on the south bank of Rappahannock River, near its mouth, and north of Pianketank River.

The topography is diversified. The Sunderland terrace, elevation 90 to 120 feet, forms the divide between Rappahannock and Pianketank rivers, and is deeply cut by creeks flowing to the Rappahannock. Along this river a bold scarp marks the drop from the Sunderland to the Talbot terrace, and at the east the Wicomico terrace terminates in the scarp that is traceable across the counties south to the North Carolina line. In Middlesex, as in Essex County, to the northwest projecting headlands of the highest terrace give magnificent views of Rappahannock River valley.

Geology.—The Columbia loams, clayey and bright-colored on the high terraces, and of subdued tints along the low terraces, mantle the surface. No beds older than those of the Chesapeake group (Miocene) outcrop anywhere in the county. Shell beds and gray sands of the St. Mary's formation are exposed beneath Columbia sands in low bluffs along Rappahannock River and in the gorges of the larger creeks. The Chesapeake-Pamunkey contact lies at about 300 feet below sea level at the northwest end of the county, and about 600 feet below at Stingray Point. The thickness of the Pamunkey may be 100 to 150 feet. It is probable that marine Cretaceous beds underlie most of the county, but they can not be sharply differentiated on the evidence of such well records as are available. There are no records of wells sunk to Potomac beds, but it is likely that at Urbanna the top of the Potomac group is over 800 feet below sea level.

UNDERGROUND WATERS.

Distribution and quality.—Both the Columbia formations and the topmost beds of the Chesapeake contain ground water. The quality shows the usual variations. The artesian waters in the lower Chesapeake and in the Pamunkey sands are soft, but as a rule more highly mineralized than in Essex County. East of Urbanna the Chesapeake and Pamunkey water beds become gradually finer, the heads of the flows decrease and the mineralization of the water increases. A characteristic of the Chesapeake flows along Rappahannock River is a decided sulphur odor; this soon disappears, but makes the water when fresh from the well offensive to some persons. The deeper flows seem freer from sulphur. The heads of the different flows show local variations, but as far east as Urbanna properly driven wells, where there is no interference, yield waters from basal Chesapeake (Calvert) beds that rise 15 feet above mean high tide; the Pamunkey flows rise 10 feet higher.

Springs.—Along the gorges of the creeks that flow into Rappahannock River, near the foot of the Sunderland scarp, and in Pianketank River valley, there are many springs. Some are of considerable size, flowing 10 gallons or more per minute. A few are used for household supply. None is of commercial importance.

At the head of a small run on the old Fauntleroy place near Saluda, now owned by J. C. Gray, several springs issue from above dark sandy clay, or from marl beds, belonging to the Chesapeake group. Part of the flow of the highest spring supplies a ram that forces water to a tank in the house, 300 feet distant.

Another spring that gushes from a marl bed on a steep slope to Piankatank River, at the residence of J. E. Blakey, 3 miles southwest of Saluda, supplies the house and barn by means of a ram.

Wells.—Dug wells, the chief source of water supply, vary greatly in depth. Most of them have no lining except plank near the bottom; a few are bricked, and a few cased with tile. In places along the lowest terrace there are drilled and driven wells, nearly all of small diameter. Dug wells, bricked, have been completed for 40 cents per foot.

LOCAL SUPPLIES.

Urbanna in 1906 had no public waterworks, but water from a number of artesian wells was given away by the owners to all persons desiring it. A well intended to supply water for a distribution system was drilled to a depth of 590 feet. The record is of interest as the well is one of the few that have been drilled below 500 feet in this part of the Coastal Plain.

Record of waterworks well, Urbanna.

(Authority, R. H. Milligan, driller.)

Material	Thickness (Feet)	Depth (Feet)
Clay, sand, and gravel	25	25
Marl	175	200
Hard, bluish black clay	20	220
Sand, very light flow of sulphur water, flow not tested	18	238
Rock	1	239
Marl	21	260
Thin rocks, 6 to 8 inches thick, in marl	30	290
White chalky deposit, "neither sand nor clay"	2	292
Marl[a]	108	400
Bluish clay	45	445
White sand, very light flow of sulphur-bearing water	3	448
Coarse gray sand and white gravel	7	455
Hard sand, no water	10	465
Bluish clay	27	492
Sand, water-bearing, flow small but not tested	8	500
Marl	22	522
Hard red clay, "red as paint"	18	540
Softer pink and brownish clay which caved easily	7	547
White loose sand with thin crusts, sand often in little balls easily crushed by fingers, no clay; good flow of water, volume not tested	42	589

[a] Bones and small teeth are reported to have been struck at 400 feet in blue marl.

This well went through both Miocene and Eocene into Upper Cretaceous beds. The quality of the water from the last flow is said to have been excellent. The well, when seen by the writer, was flowing 3 gallons per minute from the sand at 492 feet; the bottom flow had been shut off by the clay beds caving.

A well near by passed through the following strata, according to the driller:

Record of well of G. W. Hurley, Urbanna.

(Authority, R. H. Milligan, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil, sand, and clay	25	25
Black mud	100	125
Marl	96	221
Rock	2	223
Coarse sand, flow of sulphur water, volume not tested, possibly 1 gallon per minute at surface	7	230
Soft marl, shelly at top	40	270
Light marl, containing thin layers of rock	15	285
Green marl	5	290
Black sand, not water-bearing, and marl	30	320
Soft blue clay	132	452
Sand, water-bearing; flow not tested	1	453
Rock	1	454
Sand containing bits of lignite, water-bearing; flow at 3 feet above high tide 105 gallons per minute through a 3-inch pipe, head over 30 feet	22	476

The water from this well, together with that from several wells tapping the sulphur water at 225 feet, is used at an ice plate. It is said to work better in a boiler than the water from the 225-foot wells, having less tendency to foam. Like practically all the deep artesian waters of the Virginia mainland, it contains little volatile organic matter, and hence makes excellent ice.

Other flowing wells at Urbanna are said to range in depth from 227 to 290 feet, but probably draw on sands 220 to 235 feet below high tide level. One of the shallowest, that of G. V. Wagenen, was sunk by the owner in less than a day, no rock being encountered. The flow at first was 5 gallons per minute, but had fallen to about 2 gallons in 1906. The water is used at a canning factory. The well of the Urbanna Manufacturing Co. is worthy of note as it is used to supply the cottages of employees, the water being pumped to an elevated tank. The depth of this well could not be ascertained, but the water has a decided sulphur odor and probably comes from the sand at 220 to 235 feet. Field assays of samples from various wells at Urbanna are given in tables 8 and 10.

Above Urbanna, along Rappahannock River, artesian wells have been drilled at Bayport and several other places. The reported depths of the Bayport wells vary from 260 to 300 feet, and the water probably comes from Calvert, basal Chesapeake, sands. The water is used for domestic purposes and for washing oysters. The following generalized section is reported:

Record of well of Bland Brothers, Bayport.

(Authority, O. D. Hale, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand	24	24
"Fullers earth" or blue clay	176	200
Alternating strata of rock and sand, rock layers from ½ inch to 10 inches thick, water at 242 feet	48	248

The well has 218 feet of 1½-inch casing. The reported flow is 16 gallons per minute at 7 feet above Rappahannock River.

A driven well at Sandy Bottom, in the east end of the county, found water in deep Columbia beds. The following record is reported:

Record of 78-foot driven well of D. A. Taylor, Sandy Bottom.

(Authority, D. A. Taylor, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
No record	30	30
Old wood and shells, blue mud	10	40
White sand	½	40½
Blue mud	32½	73
Gravel, principal water bed	2	75
Blue mud	25	100

Dug wells in Middlesex County, as previously noted, differ greatly in depth and in quality of supplies. Wells on high ground near a terrace edge go deep, usually yield soft water, and seldom if ever, go dry; while wells away from the terrace edge are shallower and more liable to go dry. Many wells go through the Columbia sands and get hard water from the Chesapeake shell beds. Conditions reported from various places in the country are briefly summarized thus:

Details of dug wells in Middlesex County.

Location	Depth *(Feet)*	Water bed	Quality of water
Butylo	40–60	Sand and clay	Good
Church View	20–50	Sand	Fair to good
Dew	15–45	Sand and marl	Hard or irony
Freeshade	12–40	....	Fair
Enoch	10–16	Sand	Hard
Lot	16–35	Sand	Soft to hard
Ruark	10–35	Clay	Shallow, poor; deep, good.
Saluda	40–55	Marl and red clay	Hard and soft
Streets	22–60	Sand	Soft
Urbanna	18–30	Marl	Hard, brackish
Warner	8–32	Red clay	Shallow, poor; deep, good.
Waterview	15–60	Shallow, sand; deep, rocks.	Fair to good
Wilton	15–60	Shallow, sand, deep, rocks.	Fair to good

Conclusions.—Over most of Middlesex County dug wells will remain the chief source of supply because of the cost of developing the artesian sands. Plenty of soft alkaline water can be had from the latter, and if the higher sands at any point yield insufficient flows better yields can be had by going deeper. From none of the sands are heads of more than 35 feet above tide to be expected. Hence wells of sufficient diameter to permit the use of deep well pumps will be required to supply villages on high ground. At Saluda, elevation about 75 feet, flows are impossible; the water will rise to about 40 feet of surface.

NANSEMOND COUNTY.

General description.—Nansemond County lies south of James River near its mouth, and extends from the river to the North Carolina line. The surface of the county is rather even, except for the abrupt descents to creeks and inlets in the northern part of the county, and for the scarp that separates the low ground, in which lies the Dismal Swamp, from the higher ground to the west. The principal stream is Nansemond River, a branch of James River. Jones Creek also flows into the James. Most of the southern part of the county drains to Blackwater River, while the southeastern is included within the Dismal Swamp. Much of the surface is part of the Wicomico plain, at elevations between 60 and 90 feet. The abrupt scarp separating the Wicomico from a lower terrace extends from the North Carolina line northward past Suffolk and Chuckatuck. Lake Drummond, part of which is in Nansemond County, has an elevation of 22 feet above sea level.

Geology.—Over nearly the whole county the Columbia sands and loams are the only beds that can be seen. North of Suffolk, along the banks of Nansemond River and its branches, the underlying dark greenish or bluish sandy clays of the Chesapeake, often filled with shells, are exposed in many places.

In the eastern portion of the county thick beds of mud and sand, which contain shell marl, have been cut by the canals leading to Lake Drummond. These beds, as shown by their fossils, are of Pleistocene age, and are included in the Columbia group.

Other formations, belonging to the Pamunkey, Upper Cretaceous, and Potomac groups, underlie the Chesapeake but are known only from the records of deep wells. The base of the Chesapeake is 350 to 500 feet below surface, and the base of the Pamunkey lies 450 to 600 feet deep.

UNDERGROUND WATERS.

Extent and distribution.—The water table throughout most of the southern and eastern parts of the county lies very near surface, and in wet weather many wells are full to overflowing. The supplies are generally soft, but because of the liability of pollution are not highly valued. In the northern and western parts of the county where the land lies higher, many wells near the edges of terraces are 30 feet deep or more. The supplies obtained are generally soft. Artesian waters underlie the whole county and attempts to get flows have been made at a number of places, but the only artesian wells in use in 1906 were at Suffolk and Everets. At the former place water is obtained from sandy beds high in the Upper Cretaceous; at the latter place from beds of sand and gravel near the top of the Chesapeake. The Upper Cretaceous water is soft and alkaline, the Chesapeake is less mineralized. Artesian water has been reported found near Chuckatuck, but no particulars as to quality are available.

Springs.—Springs are not especially abundant in Nansemond County, although there are some along the branches of James and Blackwater rivers. None of commercial importance has been reported. A spring of good flow, known as the Buckhorn, one-half mile north of Windsor, yields iron-bearing water.

Wells.—Though there are a considerable number of driven wells in the county, dug wells are far more plentiful. There were in 1906 not over 15 drilled wells in use. The dug wells are usually lined with wood, and, on wide, flat stretches where water is close to surface and surface drainage is defective, are not ideal sources of supply. The driven wells and nearly all the drilled wells are of small diameter. They are much preferable to the dug wells, and when conditions are favorable, that is, where the water lies in soft sand close to surface, driven wells with pitcher pumps attached cost but $5 or $6. The cost of drilled wells depends on their depth and diameter; 2-inch wells near Everets were sunk under contract for $1 per foot to depths of 50 feet or more.

LOCAL SUPPLIES.

Suffolk is supplied with water from Lake Kilby, which in 1906 was distributed by the Portsmouth, Berkeley and Suffolk Water Co. A summary of the supply system is given on page 77.

Various manufacturing concerns use or have used water from dug wells. This is hard and of indifferent quality for boiler supply as it forms scale, and the use of a softening plant or of boiler compounds is necessary. Up to the time of the field work for this report attempts to get artesian water at Suffolk had, with one exception, been failures. This was not because artesian water can not be had but because the wells did not go deep enough. There is a great thickness, probably not less than 300 feet, of Chesapeake sandy clay underlying Suffolk, in which there seem to be no beds that yield water freely. The successful well, that of the Norfolk & Portsmouth Traction Co., is reported to be 803 feet deep. Possibly it might have obtained water enough at a higher level, but the drillers were seeking a flow (an impossible undertaking as the elevation of the well is 63 feet), and continued drilling. The yield is small and the well has given more or less trouble ever since its completion. Apparently the water-bearing sand is fine. The water rises to 33 feet of surface and a deep well pump obtains 11 gallons per minute. The water is said to work well in a boiler if not allowed to become too concentrated, and to be good for ice-making.

The following analysis shows its softness, low lime content, and alkalinity; the chief substance in solution undoubtedly is bicarbonate of soda.

Analysis of water from deep well of Norfolk & Portsmouth Traction Co., Suffolk.

(First Scientific Station for the Art of Brewing, analyst.)

	Parts per 1,000,000
Total residue	596.0
Loss by calcination	20.0
Residue after calcination	576.0
Iron (Fe)	large traces
Lime (CaO)	4.0
Magnesia (MgO)	2.9
Carbonate of soda (Na_2CO_3)	493.0
Chlorine (Cl)	23.0
Nitrate radicle (NO_3)	0.0
Nitrite radicle (NO_2)	0.0
Free ammonia	0.0
Albumenoid ammonia	0.0
Oxygen required	0.02
Total hardness	128.0

Deep wells north of Suffolk.—A group of artesian wells has been sunk near Everets, on Everets Creek. Some are just at the foot of the Wicomico scarp and their heads, as they are of shallow depth, little over 50 feet, are due to the level of the water in the Wicomico plain to the west. In 1906, there were about 8 of these wells, the deepest being down 110 feet. The heads range from 4 to 10 feet above the creek, which is tidal. The following record of one of the wells shows the general character of the beds overlying the water-bearing sand:

Record of well of T. J. Saunders, Everets.

(Authority, T. J. Saunders, owner.)

Material	Thickness (Feet)	Depth (Feet)
Clayey soil on marl	8	8
Blue marl, with few shells	16	24
Black sand, with hard layers or "rocks"	2	26
Blue sand, lighter colored at base	28	54
White sand	30	84

Efforts to find the same flow farther southeast have not been successful; the water-bearing sand probably thins out or becomes clayey, though as the sand dips to the east it is barely possible that the wells did not go deep enough. At Reids Ferry, on Everets Creek, 5 miles southeast of Everets, a 150-foot well sunk for the Nansemond River Brick and Tile Co. did not find water, nor did a well 188 feet deep, a mile east of Chuckatuck, which when the driller stopped work was in black and white sand. A later and deeper well east of Chuckatuck is reported to have found a flow. The general character of the flows at Everets is shown by the field assay in table 7b.

Shallow well conditions near various villages in the county are summarized in the following table, most of the data being obtained from postmasters.

Details of dug wells in Nansemond County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Cleapur	16–90	Shallow, sand; deep, clay.	Shallow, soft; deep, hard.
Copeland	10–25	Sand	Soft
Hobson	16	Blue mud	Soft
Holland	10–34	Sand	Soft
Savage Crossing	8–30	Shallow, sand; deep, blue marl and "black dirt."	Shallow, poor; deep, good.
Valeria	6–10	Shallow, sand; deep, clay.	Shallow, poor; deep, good.

Conclusions.—There is undoubtedly plenty of artesian water under Nansemond County, but conditions are not so favorable for free flows of good water as in counties to the west. The upper Chesapeake sands are patchy and their limits can be determined only by drilling. The sands lower in the Chesapeake, and those in the Pamunkey, are uncertain water-bearers, but may yield flows with heads of 30 feet above tide through wells carefully drilled and screened. The quality of all the artesian waters deteriorates toward the east and near James River, and in the northeast corner of the county the deep flows may be too mineralized for domestic or industrial purposes.

NEW KENT COUNTY.

General description.—New Kent County, formed in 1654 from York County, lies between Chickahominy and Pamunkey rivers.

The topography is much like that of Charles City County. The highest of the terraces, the Sunderland, has an undulating surface sharply cut by stream valleys. Its greatest elevation is 140 feet. The Wicomico plain is developed along Pamunkey River, as is the lower Talbot, the latter comprising much of the land embraced in the wide meanders of the river. Both Chickahominy and Pamunkey rivers have few tributaries rising in the county; the largest of these, Diascond Creek, empties into the Chickahominy and forms part of the eastern boundary of the county. The divide between Chickahominy and Pamunkey waters crosses the northern part of the county, New Kent Courthouse being on it.

Geology.—Columbia loams mantle the surface. On neither Chickahominy nor Pamunkey rivers are Pamunkey (Eocene) beds exposed, the highest formation visible below being the St. Mary's formation of the Chesapeake (Miocene) group. Its dark, greenish sandy clays are exposed along stream gullies and in bluffs on the south side of Pamunkey and York rivers. The base of the Calvert formation of the Chesapeake group lies above tide level along the western boundary of the county and 180 feet below at Plumpoint. The base of the Pamunkey lies possibly 200 feet below tide water in the western side of the county, and 350 feet below in the east. Whether Upper Cretaceous (Matawan) beds extend as far west as the eastern side of the county is doubtful. Unquestionably, there is a considerable thickness, possibly over 600 feet of Potomac (Lower Cretaceous) beds above bed rock.

UNDERGROUND WATERS.

Distribution and quality.—New Kent County is well watered. Numerous rills and creeks are fed by springs. The ground water in the sands of the Columbia formations is generally abundant and soft. The artesian sands in the Pamunkey group carry plenty of soft water that gives flows up to 26 feet above tide. The Calvert sands at the base of the Chesapeake yield light flows in the eastern part of the county, and, if reports are to be trusted, in the Chickahominy valley as far west as Roxbury. Little is known of the Potomac waters, but they are undoubtedly abundant and generally good.

Springs.—There are many springs in the county, some of which have attracted notice by reason of their size or the quality of their waters. A few are used for domestic supply and one or two are thought to have medicinal value. A spring, or shallow well, 3 miles north of Talleysville, flows about 1 gallon per minute of water that has been sold as Belmont Lithia water. The water comes from marl, and the chief substance in solution is bicarbonate of lime. The appended analysis, furnished by the proprietor, R. E. Richardson of Talleysville, has been recalculated to parts per. 1,000,000.

Analysis of Belmont Lithia water.
(W. H. Taylor, analyst.)

	Parts per 1,000,000
Total solids	221.
Calcium bicarbonate ($CaH_2(CO_3)_2$)	135.
Ferrous bicarbonate ($FeH_2(CO_3)_2$)	15.
Magnesium bicarbonate ($MgH_2(CO_3)_2$)	11.
Manganese bicarbonate ($MnH_2(CO_3)_2$)	0.5
Sodium bicarbonate ($NaHCO_3$)	15.
Lithium bicarbonate ($LiHCO_3$)	0.1
Sodium chloride ($NaCl$)	3.4
Potassium chloride (KCl)	1.2
Ammonium chloride (NH_4Cl)	trace
Potassium sulphate (K_2SO_4)	6.3
Calcium phosphate ($Ca_3(PO_4)_2$)	0.6
Calcium nitrate ($Ca(NO_3)_2$)	trace
Alumina (Al_2O_3)	0.1
Silica (SiO_2)	33.
Sulphuretted hydrogen (H_2S) 0.88 cubic inches per imperial gallon.	

Wells.—Dug wells, usually cased with wood, are practically the sole source of water supply on the higher terraces. On the lower terraces are some driven wells. The drilled wells are practically confined to the low ground along Pamunkey and Chickahominy rivers. Nearly all are of small diameter; the depths reported range from 150 to 260 feet.

LOCAL SUPPLIES.

More wells have been driven at Plumpoint than at any other place in the county. They all draw on the Calvert, basal Chesapeake, sands reached by the 165-foot wells at West Point, and yield water of the same quality. Heads are about 20 feet above mean high tide. Above Plumpoint at Whitehouse possibly 10 wells have been driven, all of which draw on the same beds, basal Pamunkey, as the wells at Lester Manor in King William County. The heads range up to 35 feet above mean high tide. The flows, where proper care has been taken in casing, equal the average of Pamunkey wells of equal diameter, being about 5 gallons per minute.

The following generalized record of a well at Whitehouse was published by Darton:[a]

[a]Darton, N. H., Op. cit., p. 174.

Record of well at Whitehouse.

(Authority, P. H. Sweet. driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	15	15
Yellow clay	10	25
Blue fullers earth	40	65
Several thin rock strata, one 18 inches thick	5	70
Soft sand rock	25	95
Red clay	20	115
Greensand marl (?)	50	165
Black sand; water at 210 feet	45	210

Along Chickahominy River wells have been sunk at Providence Forge and near Windsor Shades (Boulevard P. O.). No records were kept of any of these wells, but all obtain water from practically the same horizon in the Pamunkey. At Providence Forge several wells have been drilled; one owned by Col. E. B. Townsend is 216 feet deep, and flows 10 gallons per minute at an elevation of 20 feet above sea level. A field assay of the water is given in table 9. Another well, that of R. E. Richardson, is 215 feet deep; it flowed at first but later had to be pumped. The loss of flow is explained by insufficient casing.

The well at Boulevard is probably the finest in the county. It is 260 feet deep, 4½ inches in diameter, and flows 52 gallons per minute at an elevation of 22 feet above mean high tide. This large flow is probably due not so much to the diameter of the well as to the character of the water bed, which, according to report, was a gravelly sand, whereas at Providence Forge the water bed is finer textured. An analysis of the water from the well at Boulevard appears in table 9. The water is noteworthy for the small proportion of mineral matter it contains.

For the supply of temporary saw-mills dug wells are used. In 1906, there were possibly a dozen such mills in the county, obtaining water from wells 25 to 50 feet deep. Information regarding dug wells at a number of villages is given in the following summary:

Details of dug wells in New Kent County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Barhamville	12–30	Loam and marl	Shallow, soft; deep, slightly hard.
Dash	18–60	Iron crusts, sand	Hard
Oak	20–60	Shallow, loam; deep, clay.	Soft
Plumpoint	10–15	Sand and gravel	Hard
Providence Forge	10–50	Shallow, loam; deep, marl	Shallow, fair; deep, good.
Tunstall	10–20	Shallow, clay; deep, marl.	Soft and hard

Conclusions.—To properly cased wells the Pamunkey sands will furnish supplies far in excess of present draughts. The Potomac group undoubtedly contains numerous sands that will yield ample flows with heads of 30 feet or more, and recourse can be had to them in case the head of the Pamunkey waters at any place is lowered by the interference of wells drilled too closely or allowed to flow without restraint.

NORFOLK COUNTY.

General description.—Norfolk County, formed in 1697 from Lower Norfolk, extends from the mouth of James River southward to the North Carolina line. In or near Norfolk are many large manufacturing establishments and no less than five railroads have terminals on Elizabeth River.

Almost all the surface of the county forms part of the Talbot terrace, which has a maximum elevation of about 25 feet, hence there are wide expanses of practically level ground and considerable swamp land. Most of the swamp is in the southwestern part of the county, and is part of the great Dismal Swamp of Virginia and North Carolina. The surface of this swamp slopes slightly to the northeast and southeast from the foot of the Wicomico-Talbot scarp which forms its western boundary. Lake Drummond, the only considerable body of fresh water in the State of Virginia, is near the center of this swamp. Its surface is 22 feet above tide level. The principal streams, Elizabeth River and North River, are shallow inlets which head in marshy creeks; Elizabeth River empties into James River and North River into Currituck Sound.

Geology.—The vari-colored loams of the Talbot formation are exposed here and there in shallow road cuts, and except for swamps or marshy tracts and strips of dune sand the Talbot loams form the soils. Below lie soft blue clays and bluish sands containing here and there beds of marine shells of Pleistocene age. The Talbot varies in thickness from 5 feet to perhaps 75 feet; it can not, by available well records, be sharply differentiated from the topmost beds of the Chesapeake group (Miocene). The maximum thickness of the Chesapeake group is not less than 600 feet. The topmost formation of the Chesapeake contains water-bearing beds which have been found by driven or drilled wells of moderate depth. The lower formations of the Chesapeake seem to have few beds coarse enough to convey water readily. The relations of the Chesapeake to the underlying Pamunkey, and the evidence of the deep wells, are discussed elsewhere (see page 97 et seq.).

UNDERGROUND WATERS.

Distribution and quality.—The chief sources of domestic water supply in Norfolk County are the gravels and sands in the Talbot formation, from 5 to 50 feet below surface. The water from the shallow beds at most places is soft, but at many is iron-bearing; and at some, near bodies of salt water, is brackish. The deeper beds give hard water which in some places is iron bearing. The discontinuous sand beds in the upper portion of the Chesapeake yield supplies that are, as a rule, iron-bearing and hard, in fact too highly mineralized for general domestic use.

Springs.—There are in Norfolk County comparatively few springs, but three have been developed on a commercial scale. Two, the White Oak and Landale, front inlets from Mason's Creek, 5 to 5½ miles north of Norfolk. They yield soft, clear water from the Talbot sands. The output has been sold in Norfolk. At the Landale Spring the water issues from the sands just above tide level, and comes from some distance below the surface. The flow varies slightly with stages of the tide. The spring is some distance from the nearest house and the sanitary conditions, when the spring was inspected, were excellent. The following analysis, recalculated to express results in standard form, was furnished by the owner, W. J. Land.

Analysis of Landale Mineral Spring water.

(Henry Froehling, analyst.)

	Parts per 1,000,000
Total solids	87.
Silica (SiO_2)	5.3
Iron (Fe)	0.06
Aluminum (Al)	0.18
Calcium (Ca)	5.8
Magnesium (Mg)	2.5
Sodium (Na)	14.
Potassium (K)	1.3
Lithium (Li)	0.01
Iodine (I)	0.009
Bromine (Br)	trace
Manganese (Mn)	trace
Arsenic (As)	trace
Bicarbonate radicle (HCO_3)	9.2
Sulphate radicle (SO_4)	28.
Nitrate radicle (NO_3)	5.5
Chlorine (Cl)	13.

The White Oak Spring is situated near the Landale, and the water probably comes from the same horizon. The following analysis, which has been recalculated, was furnished by the company putting the water on the market.

Analysis of White Oak Mineral water.

(W. H. Taylor, analyst.)

	Parts per 1,000,000
Silica (SiO_2)	5.4
Iron (Fe)	trace
Calcium (Ca)	21.0
Magnesium (Mg)	2.8
Sodium (Na)	14.0
Potassium (K)	3.6
Bicarbonate radicle (HCO_3)	55.0
Sulphate radicle (SO_4)	29.0
Chlorine (Cl)	15.0

Another spring, owned by Joseph Freitas, on Mason's Creek about 1½ miles due west of the two springs mentioned, has shipped water from time to time.

Wells.—There are probably more driven wells in Norfolk County than in any other county in Virginia. Most of them are shallow, going to the first water-bearing sand. There are many dug wells, most of which are not over 15 feet deep, and a few drilled wells. In some places cisterns are used. The more important deep wells have been mentioned on pages 97 to 116.

LOCAL SUPPLIES.

The city of Norfolk is supplied with water by three distributing systems owned by the city, the Norfolk County Water Co., and the Portsmouth, Berkeley & Suffolk Co. The size, capacity, and general equipment of the different supply system are described on pages 75-81.

In the outskirts of the city are many driven wells. G. B. Todd of Norfolk, who has driven a large number, states that east of Elizabeth River in Norfolk County are two water beds; one at 10 to 15 feet, yields water that is generally soft but is irony in places; and the second at 35 to 100 feet, yields water that is generally harder and is irony at a few places. The following records, furnished by Mr. Todd, show the character of the Talbot beds of the Columbia group.

Record of test-boring, corner of Brooke Avenue and Brush Street, Norfolk.

Material	Thickness *(Feet)*	Depth *(Feet)*
Made ground	4	4
Moist sand	3½	7½
Mud with some sand	7	14½
Mud	6½	21
Yellow clay and mud	7	28
Soft mud	8	36
Fine sand	2	38

This well was driven on made ground, formerly a marsh.

Record of test-boring on Reeves Avenue at river bank, Norfolk.

Material	Thickness (Feet)	Depth (Feet)
Made ground	3½	3½
Gray sand, water-bearing	8½	12
Yellow sand, almost dry	11	23
Blackish mud, very soft, mixed with fine sand	17	40
Solid coarse sand, water-bearing		40

At Lambert Point, a suburb which in 1906 had a separate government, Norfolk County water is used by nine-tenths of the inhabitants. There are, however, numerous cisterns and some driven wells. The latter find two sources of supply; the first water, at 10 to 12 feet, is called poor; deeper water, at 45 feet, is hard, and in places too iron-bearing for domestic use. The Norfolk & Western Railway Co. has used Norfolk County water largely at its yards and terminal on the Point. It once procured water from a system of driven wells 2 miles east of the Point, and subsequently tried a shallow well 30 feet in diameter about a half mile east of its yards. The water from the deep well, mentioned on page 107, is too highly mineralized for boiler use.

At Sewell Point, the site of the Jamestown Exposition, water can be obtained almost anywhere by driving a pipe down 8 or 10 feet. This water is not considered good. The Exposition grounds were supplied by the Norfolk County Co. At Ocean View and on Willoughby Spit, where there are many suburban residences and summer cottages, water is obtained from driven wells. On the Spit the wells are 20 to 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. A few wells, from 20 to 30 feet deep, strike water in a blue sand below a blue mud. The water has a slight sulphur taste and at some wells is irony. A driller reports that in the vicinity of Ocean View a bed of shells is occasionally struck in the blue sand above the blue mud at a depth of 8 feet. This shell bed is probably of Pleistocene age and part of the Columbia group.

Darton[a] has published records of several borings made by the city of Norfolk in search of shallow water east of the city. The two following are given in slightly modified forms to show the general character of the Columbia materials, and the depth to the main water beds.

[a]Darton, N. H., Norfolk folio, U. S. Geol. Survey, 1902, p. 4.

Poorhouse tract swamp.

Material	Thickness (Feet)	Depth (Feet)
Muck	4	5
Firesand	4	9
Sand and clay	23⅔	32⅔
Blue clay	1½	35⅙
Sandy clay	3¼	38 5-12
Sand and clay	7½	45½
Gravel, with water, on sand	6⅓	51⅚

Drummond woods.

Material	Thickness (Feet)	Depth (Feet)
Sand	3	4
White sand	9	13
Sand and clay	8	21
Clay and sandy clay	9½	30½
Sandy clay	5⅔	36⅙
White sand	2⅙	38⅓
Gravel, with water, on sand	5⅔	44

South of Norfolk, along the South Branch of Elizabeth River, wells have been put down for the boiler supply of mills. Most yield fair water. The E. S. Barnes Co., at its plant on the east bank of the South Branch, 2 miles above the Norfolk Navy Yard, has 10 wells 72 to 86 feet deep. A partial analysis by the Hartford Steam Boiler Co. showed 648 parts of solid matter per 1,000,000, considerable soda, lime, magnesia, chlorides, and sulphates, some silica and potash, and a little iron; the chief substance in solution was sodium chloride, with "traces" of calcium and magnesium sulphates, a rather poor boiler water. Another well, 120 feet deep, yielded somewhat similar water, containing 652 parts of solid matter per 1,000,000. A group of 14 wells, 15 feet deep, at the same plant, yielded water that contained only 164 parts of solid matter per 1,000,000, a good boiler water. In this water the hardness was chiefly temporary, from carbonates of lime and magnesia.

The Pocomoke Guano Co. obtains water from a well 86 feet deep, near Elizabeth River. The following record was furnished by the company:

Record of 86-foot well of the Pocomoke Guano Co., near Elizabeth River.

Material	Thickness (Feet)	Depth (Feet)
Hard black dirt	3	3
Soft fresh mud, swamp muck	9	12
Blue marl and mud	68	80
Shells, sand and gravel, water-bearing		80

A partial analysis of the water from this well (table 7) shows an unusually high percentage of organic matter.

Another well, that of the Roanoke Railroad & Lumber Co., not far from the two plants previously mentioned, penetrated the following beds, according to the company.

Record of well of Roanoke Railroad & Lumber Co.

Material	Thickness *(Feet)*	Depth *(Feet)*
Surface soil and sand	15	15
Clay, sands at base, water	10	25
Black mud with fine shells, clear water at about 53 feet	28	53
Black mud	10	63

The water is said to be slightly salty and to scale badly in a boiler.

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, but under heavy pumping falls to 17 feet. In 1906, there were no buildings on the tract and the possibility of pollution was remote. The water is said to be slightly hard. A partial analysis furnished by the American Waterworks & Guarantee Co. of Pittsburg, Pa., given in table 7, shows a chlorine content of 17 parts per 1,000,000, about the average in Norfolk County for unpolluted shallow waters at points away from salt creeks or arms of Chesapeake Bay.

At Oaklet, southeast of Norfolk, two water-bearing sands are tapped by the driven wells: The first, 12 to 18 feet below the surface and 8 to 10 feet thick; the second, about 40 feet below the surface, and separated from the first by blue clay. A well driven 124 feet proved a failure, finding no water at that depth. The water from the 40-foot sand is considered more healthful than that from the 15-foot.

The city of Portsmouth is supplied with water from Lake Kilby by the Portsmouth, Berkeley & Suffolk Co. Probably nine-tenths of the inhabitants of Portsmouth use this water, the remainder using driven wells and cisterns.

At the Scottsville yards of the Seaboard Air Line Railway, 1½ miles west of Portsmouth post-office, there are 14 2½-inch wells and 12 4-inch wells, all 60 to 61 feet deep. The elevation of the ground at the wells is about 10 feet. The following record was furnished by the company:

Record of driven wells at yard of Seaboard Air Line Railway, Portsmouth.

Material	Thickness *(Feet)*	Depth *(Feet)*
Fine gray sand	4	4
Very fine gray quicksand with bits of rotten wood and tree trunks at 18 to 20 feet	31	35
Bluish-gray clay from 8 to 10 feet thick	9	44
Very fine light buff sand, water-bearing	6	50
Hard, coarse gravel	10	60

No shell beds were found. The wells have double points, and are driven into the gravel because points in the soft sand corrode quickly. The yields are comparatively free, though the 2½-inch wells are sometimes choked by sand. The draught in 1906 was 200,000 gallons of water daily, which was used for locomotive supply and general purposes. It is considered a good boiler water. Analyses of water from the old and new wells are given in table 7.

The old wells comprise 14 2½-inch and 2 4-inch wells, nearer the creek than the new wells (10 4-inch), and the water consequently contains more sodium chloride. Pumping for several months had slight effect on the quality, as is shown by the analyses.

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 all the water for the boilers, rated at 950 horsepower, also for washing cars and for fire protection, in all about 55,000 gallons daily. The water is stated to work well in a boiler, forming but little scale. The water from the deep well is said to be harder than that from the shallow wells. A partial analysis furnished by the company, recomputed to standard form, is given in table 7.

Near the Norfolk & Portsmouth Co.'s power house the Air Line Manufacturing Co. had, in 1906, 5 1½-inch wells 38 to 40 feet deep, which supplied water for a boiler capacity of 160 horsepower. The following record is reported:

Record of wells of Air Line Manufacturing Co., Port Norfolk.

Material	Thickness *(Feet)*	Depth *(Feet)*
Clay and sand with water at 8 to 14 feet	14	14
Blue mud	20	34
Sand, water-bearing	4	38

The water was considered hard and a boiler compound was used to prevent scale. A partial analysis, recomputed, is given in table 7.

At the U. S. Naval Hospital in the southern part of the city 4 driven wells, 2½ inches in diameter and 35 feet deep, were sunk 400 feet back from Elizabeth River. The maximum yield obtained by pumping was 50 gallons per minute. The water, which rises to 8 feet of surface, or about tide level, is rather hard and is not used in boilers at the hospital. A partial analysis, furnished by the medical inspector in command, is given in table 7. In the same table appears an analysis of water from a shallow well owned by the Portsmouth Knitting Mills.

In the rural sections of Norfolk County, driven as well as dug wells generally go only to the first water-bearing sand, but some driven wells are 40 to 80 feet deep. The quality of the water varies from place to place, but, except close to tidal inlets, is usually soft. Near the Dismal Swamp, where the water table is almost at the surface, the water is apt to be highly colored and of poor quality.

Data collected regarding shallow wells at a number of places are summarized below:

Details of shallow wells in Norfolk County.

Locality	Depth of well (Feet).	Water bed	Quality of water
Cornland	8–45	Sand	Deep, good
Deep Creek	6–12	Sand	Good
Fentress	10–30	Sand	Shallow, soft, or salty; deep, irony
Gilmerton	8–10	....	Bad
Grassfield	8–14	Sand	Poor to good
Great Bridge	10–15	Sand	Hard
Hickory	10–30	Sand	Soft to hard
Indian Creek	8–12	....	....
Link	8–18	....	Shallow, soft; deep, hard.
Oaklet	12–18	Sand	Shallow, poor; deep, good
Piney Beach	10–15	Clay, sand and gravel.	Brackish
Port Norfolk	10–35	Marl	Not good
Pughs	25–30	Sand	Soft
Sewell's Point	10–50	Sand	Soft, irony, hard
Tanners Creek	10–12	Sand	Soft
West Norfolk	20–30	Sand	Hard

At some places where the shallow water is poor, cisterns are more or less used.

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.

Conclusions.—Ground water suitable for household and domestic use can be had at many places in Norfolk County at slight cost. Because of the easy pollution of dug wells, unless protected with more than average care, driven wells are to be preferred; water from 25 to 50 feet is less liable to pollution than that from 5 to 20 feet below surface. The best water will be found on dry tracts 10 to 30 feet above sea level, the poorest on lower ground along tidal inlets. Deep artesian water can be had under the whole county; its quality is problematical. Flows of such clear, soft water as are found in counties to the west are not to be expected.

NORTHAMPTON COUNTY.

General description.—Northampton County covers the southern part of the peninsula known as the Eastern Shore. The topographic aspects of the county are much like those of Accomac. Low islands or barrier beaches fringe the eastern coast; behind these are broad, shallow lagoons, mud flats bare at low tide, and wide stretches of salt marsh. On the bay side the shoreline is sharper. The surface elevations apparently lie below 35 feet and the surface is included in the lower Columbia terraces.

Geology.—Reddish buff to yellow clay loam underlies the sandy soil, and is underlain in turn by white and yellowish sands with occasional beds of light clay. The maximum thickness of these beds may be 40 feet. Beneath are the same series of silver-gray or bluish-gray sands, shell beds, and soft, dark clays, that are found in Accomac County, and are regarded as part of the Columbia group. Fewer drilled wells have been sunk in Northampton than in Accomac County, hence information regarding beds of fossil shells is scant, but they evidently occur at varying depths, the least depth reported being 30 feet, near Brighton. There is no evidence available for sharply separating the bottom of the Columbia (Pleistocene) from the top of the Chesapeake (Miocene), but the Columbia may be 100 feet thick. Pliocene beds may be present but have not been recognized.

UNDERGROUND WATERS.

Distribution and quality.—Good water has been found at most places. The depth to the water table, the "first spring," may be 20 feet in places, but usually is decidedly less and probably averages not far from 10 feet. The water table after prolonged wet weather comes to the surface on many flat stretches of land. The water from the deeper sands, the "second and third springs," contains, as a rule, more lime and less iron than that from the "first spring," and, if proper care is taken in its recovery, is practically above suspicion of pollution from surface sources.

Springs.—There are very few springs in the county. One 6 miles east of Chesapeake is reported to flow 1 gallon of clear, soft water per minute.

Wells.—The dug well is still the most widely used source of water supply. Wood casing is being supplanted by tile. Driven wells are becoming more and more popular. It is claimed by some persons that since driven wells came into general use there has been a marked improvement in the public health.

Most of the driven wells get water from the "first spring" and are not over 20 feet deep, but may go down 50 or 60 feet, and some drilled wells go to depths of 100 feet and more. The usual charge for "driving pumps" (putting down 1¼-inch driven wells), is about 30 cents per foot, the point and pump being priced separately. The type of point most used is 3 feet long with 60-mesh gauze screens; gauze as fine as 90-mesh being rarely used.

Wells of 1¼-inch diameter are almost invariably driven. Sometimes the pipe strikes "rocks" so dense that a 75-pound hammer falling 15 feet will not start it, but where conditions are favorable 125 feet of pipe can be driven in 1½ days. Drilled 2-inch wells are put down by the wash process, charges varying from 50 cents to $1 per foot, with point and pump included. These wells often have 6-foot Cook strainers.

LOCAL SUPPLIES.

At Exmore supplies are obtained from the "first spring," wells averaging 10 to 20 feet deep . The tank of the New York, Philadelphia & Norfolk Railroad is supplied with water from a 14-foot dug well, 18 feet in diameter, supplemented by points driven to the "second spring" at 30 to 40 feet. A partial analysis of the water from the 14-foot, 30-foot. and 40-foot wells is given in table 7. The analyses are chiefly interesting for the increase in hardness and in chlorine with depth. An analysis of water from a 12-foot well, made by C. B. Dudley for the Pennsylvania System, showed 8.4 grains of total solid residue per gallon, consisting principally of lime and magnesia sulphate with no carbonate, a slightly corrosive water.

The water in most of the village wells is soft and contains little iron. The pumps and dug wells at Nassawadox and Franktown show wide variations in supplies. At Nassawadox, drillers know 4 "springs" at depths of 8, 18, 28, and 38 feet. Water from the first is considered fairly good, that from the second and third irony, while that from the fourth has a decided sulphur odor. At Franktown, pumps are driven to two water beds, at 20 and at 35 to 40 feet. Both furnish soft water that is not irony, but local physicians prefer water from the deeper bed.

At Eastville, water is found at approximate depths of 10, 30, and 40 feet. Most driven wells go to the 30-foot bed which yields a soft, slightly iron-bearing water. One well driven 105 feet found no water below 33 feet. A well at the Courthouse, much used by the public, is driven 40 feet, and yields good water. (For field assay, see table 7.) The tank of the New York, Philadelphia & Norfolk Railroad has been supplied from a 14-foot dug well that gives a satisfactory boiler water. A partial analysis appears in table 7. Another analysis made by C. B. Dudley showed 11.01 grains per gallon of total solid residue, consisting chiefly of lime and magnesia sulphates, with considerable chlorides.

At Cheriton most pumps get water at 16 or 30 feet; it is said to be medium soft and is more or less iron-bearing, though at some wells it contains very little iron. Water having a decided sulphur odor was found at 63 feet in a well at Huff Brothers' store, and is no longer used. The record of this well is as follows:

Record of well at Cheriton.

(Authority, Huff Brothers, owners.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil	1	1
Yellow and gray sand, with water at 14 to 16 feet and 29 to 30 feet	29	30
Blue marsh mud	32	62
Sand and shells; sulphur water	1	63

There are many flowing wells in the county but not nearly so many as in Accomac. Most of them are on the ocean side, several being on Upshur Neck. One of these, on Brownsville Creek, driven by W. M. E. Tilghman, of Nassawadox, for Thomas Upshur, is 127 feet deep, 1¼ inches in diameter, and flowed 1½ gallons per minute at an elevation of 5½ feet above mean high tide. At Oyster, 5 1½-inch wells were drilled some years ago for W. T. Travis. They are said to range in depth from 175 to 225 feet and to strike silver gray sands containing marine shells. The flows are about 1 gallon per minute at 3 feet above mean high water, and about one-third more at high tide than at low. The water has a faint sulphur odor but is excellent and is used for domestic supply and on fishermen's boats. A field assay of water from one well is in table 7.

Cape Charles is the only town in Northampton County having a public supply system. The supply in 1906 came from an open well, 20 feet in diameter and 20 feet deep, and 17 3-inch points, 3 driven to 40 feet, and

14 to less depths. Twelve of these points were owned by the city and 5 by an ice plant. Owing to the steady draught the water table, normally about 8 feet below surface, has been lowered over a considerable area about the points, so that the 12-foot well is ordinarily entirely dry, and contains a few inches of water only after prolonged wet weather. The water from the points which tap the "second spring" in the Talbot sands makes good ice, but forms scale in boilers. In 1906, about three-fourths of the town's population used city water, the remainder using pumps driven to the "first spring."

At the shops of the New York, Philadelphia & Norfolk Railroad are 22 40-foot points and 4 90-foot points directly connected to a steam pump. The log of the deeper wells, situated at 4 feet above mean high tide, is as follows:

Record of well of New York, Philadelphia & Norfolk Railroad, at shops, Cape Charles.

(Authority, Geo. Russell. superintendent motive power, N. Y. P. & N. R. R.)

Material	Thickness (Feet)	Depth (Feet)
Surface soil	1	1
Buff sandy clay	4	5
Yellow sand, water at 10 feet	10	15
White sand, quicksand with water	25	40
Gravel and pebbles, pebbles yellow, white, red, and black	3	43
Pea-green marl, no shells	10	53
Black mud with rotten wood, no shells	17	70
Shells and sand; good water at 90 feet which rises to 6 feet of surface	25	95

An attempt to get a flow by drilling deeper, made some 20 years ago, proved a failure, no freely water-bearing beds being found to a depth of 300 feet, but the character of the rig used prevented this test from being decisive. In 1910, the railroad had a well sunk over 1,500 feet by a careful driller, but found no strongly water-bearing sand between 40 and 1,520 feet.

The water from the driven wells is used in stationary boilers, also by locomotives and steamboats. It forms a hard scale. At the shops the boilers are run in weekly alternation and thoroughly cleaned when idle. Soda ash caused priming and various boiler compounds tried were too costly for the results obtained. Analyses of water from a 14-foot dug well and from a 90-foot point are given in table 7. It is not impossible, in view of the depression of the water table by pumping and the situation of the wells near the bay, that salt water may gradually work inland and impair the quality of the present supplies at the shops.

The conditions governing the underground occurrence of fresh water on the low islands along the coast have already been discussed (page 117). To get water other than rain water is a matter of considerable importance because of the growing popularity of the islands as resorts. Water from shallow driven pumps is the most available, though this is as a rule high-colored, irony, and, after high tides or dry weather, brackish. Wells sunk 100 to 250 feet may give better supplies, much depending on the location of the island with reference to catchment areas on the mainland.

The conditions on several of these islands are summarized below:

Details of wells on islands of Northampton County.

Island	Deepest well *(Feet)*	Level of water above or below surface *(Feet)*	Yield *(Gal. p. m.)*	Quality	Use
Bone	160	9	3	Irony	Domestic
Mockhorn	185	—1½	....	....	Domestic and stock
Fisherman's	14	....	....	....	Abandoned
Sandy, or Cherry-stone.	169 (?)	+1½	10	Slightly saline	Boiler

No records of the materials passed through have been kept, but water-bearing sands of the Columbia group (Pleistocene) supply the shallow wells, and Chesapeake (Miocene) sands the deep wells.

The well on Sandy Island is of interest on account of the small area and slight elevation (less than 5 feet) of the island, which is nearly covered by a large fish factory. The well supplies 20,000 gallons per day, the flow at 1¼ feet above tide varies from nothing to 10 gallons per minute, but, by pumping, 80 gallons per minute can be obtained. The water, though brackish, is used for drinking and cooking and to supply 7 tubular boilers, rated capacity 800 horsepower. Three fishing steamers owned by the company also use the water. It forms a hard, white scale. A field assay is given in table 8.

The wells on Fisherman's Island were driven to supply the Quarantine Station, the points became clogged by rust, and the wells were abandoned. The Bone Island well was sunk for a club-house and other buildings. The water is used for drinking and other purposes, but contains a rather large percentage of chlorine and is high in iron.

Data regarding wells at other places in the county are summarized below:

Details of wells in Northampton County.

Location	Depth of well (Feet)	Water bed	Quality of water
Birdsnest	8–30	Sand	....
Capeville	14–18	Sand	Shallow, fair; deep, good.
Chesapeake	10–60 driven and drilled 12–30 dug	....	Shallow, fair, deep, good.
Dalleye	12–50 driven 10–15 dug	....	Shallow, salty; deep, better.
Eastville	12–15 dug 20–35 driven	Shallow, sand, deep, sand and gravel.	Good
Franktown	10–60	....	Good
Mashipongo	12–18	Sand	Fair to good
Reed's Wharf	4–25	Sand	Poor to fair
Stewart's Wharf	6–30	Sand	Salty to good
Wardtown	10–20	....	Poor to fair
Willis' Wharf	8–25	....	Shallow, soft; deep, hard.

Conclusions.—At most points in the county driven wells, 30 to 50 feet deep, are preferable for sanitary reasons to those 10 to 20 feet deep; and for the same reason driven wells are much preferable to dug wells. Artesian waters that will rise 3 to 5 feet above tide level can be had by wells 75 to 100 feet at many places, but the sands are not continuous, and depths to flows can not be predicted if no drilling has been done in the vicinity.

While the lower formations of the Chesapeake group (Miocene) and the sands of the Pamunkey group (Eocene) may contain beds that will give flows at elevations less than 10 feet, and while the Upper Cretaceous and the Potomac undoubtedly contain such beds, sinking to depths of over 500 feet is not advisable. As indicated by wells in Gloucester County on the west and across the Maryland line on the north, these deep waters are in all probability highly mineralized.

At Cape Charles the quality and volume of the water obtainable near the water front to a depth of 1,500 feet have been proven. Better water can probably be had by wells 20 to 80 feet deep driven east of the town, and larger yield by placing points at least 50 feet apart. The water found at 250 feet in sinking the deep well may repay investigation.

On the off-shore islands along the coast deep water prospects are not so promising as on the mainland, and on some of these islands cisterns will prove more satisfactory than wells.

NORTHUMBERLAND COUNTY.

General description.—Northumberland County, formed in 1648, occupies part of the eastern end of the Northern Neck, the peninsula between Potomac and Rappahannock rivers. The county faces Potomac River on the north and Chesapeake Bay on the east, and has a decidedly irregular outline.

Much of the county has the topography peculiar to the greater part of the Sunderland plain, a gently undulating surface, sharply cut by creek gorges. Altitudes on this plain are nowhere above 120 feet. Practically all streams draining the county flow to Potomac River or Chesapeake Bay, the county line on the south following the Potomac-Rappahannock divide.

Geology.—Columbia deposits mantle the surface. Miocene beds belonging to the St. Mary's formation are exposed at many points near Yeocomico, Great Wicomico, Little Wicomico, and Coan rivers. They are prevailingly sandy, gray to greenish or bluish in tint, and contain beds of shells. The Pamunkey, the Upper Cretaceous, and the Potomac beds are not exposed within the county; well records indicate that the bottom of the Chesapeake group lies 320 feet below tide water on the western boundary of the county and 600 feet below at Fleet Point. The base of the Pamunkey is 500 feet blow tide water at Kinsale and 700 feet below at Fleet Point. The crystalline bed rock may be 1,500 feet below sea level at Kinsale.

UNDERGROUND WATERS.

Distribution and quality.—Ground water, abundant and potable, is found in the Columbia sands and in the top beds of the Chesapeake under most of the county. On the lower terraces many shallow wells go dry in time of drought. The quality of the water varies from soft and sweet to hard, irony, or brackish.

The deeper Chesapeake sands and the Pamunkey sands carry soft water under the whole county. There are artesian sands at the base of the Calvert, in the Nanjemoy formation, and in still lower beds, possibly Matawan. The heads of the flows range from 10 to 35 feet above sea level. The Chesapeake flows are soft, alkaline, and slightly sulphur-bearing. The Pamunkey waters much resemble the Chesapeake but have less sulphur odor. The Upper Cretaceous waters are harder than the Chesapeake and Pamunkey, and contain more lime salt.

Springs.—There are many springs of the usual Coastal Plain type along scarps, and in gorges and gullies. The majority flow from Columbia sands, a few from shell beds in the Chesapeake group. The great majority are without improvements and are used only for watering stock. From none is water sold.

Wells.—On the higher terraces dug wells are lined with planks at the bottom and at the top, since the loams near surface are sandy. On the lower terraces wells are lined with planks or boards throughout. A small proportion of the wells are lined with brick; very few are cased with tile. On the lower terraces are a few driven wells, and along inlets from Potomac river and Chesapeake bay are many drilled wells. Most of these are of small diameter, under 2 inches, and go only to the first sand that will yield a flow. A few are of larger diameter, 2 to 6 inches, and go down more than 500 feet.

LOCAL SUPPLIES.

At Heathsville, the county seat, all the water used is obtained from dug wells 25 to 45 feet deep; in some wells it is hard.

On Yeocomico and Coan rivers most of the flowing wells get water from Calvert sands at 250 to 320 feet. A field assay of water from the Calvert flow at Coan on Coan River is given in table 8.

The wells on the Great Wicomico are among the most notable in Tidewater Virginia. They range in depth from 590 to nearly 700 feet, and are 2 to 6 inches in diameter. Most of them were drilled by the same contractor, R. H. Milligan, of Crisfield, Md. Through the kindness of Mr. Milligan the following record of a well at Reedville is published:

Record of 698-foot well of J. C. Fisher, Reedville.

(Authority, R. H. Milligan, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil, sand, gravel etc.	60	60
Sandy clay	20	80
Blue clay	50	130
Dark marl (clay and sand, full of shells)	133	263
Shell rock	8	271
Hard dark marl	101	372
Rock	2	374
Sand, water-bearing; sulphur water, flow not tested	26	400
Soft dark clay	8	408
Dark marl with thin crusts of rock	68	476
Hard rock	4	480
Tough dark clay	210	690
White micaceous sand, contains lignite, water-bearing; flow 18 gallons through a 2-inch pipe at 30 feet above tidewater	8	698

Mr. Milligan also furnished the following notes on the formations penetrated below 670 feet by the well at Fleet Point.

Partial record of well of Fleeton Development Co., Fleeton.
(Authority, R. H. Milligan, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
No record	672	672
Hard white sand containing a little water	20	692
Hard marl, with green clay below	17	709
Sand, water-bearing, flow at surface 15 gallons per minute through 3-inch pipe	1	710
Dark clay or marl	10	720
White sand, water-bearing, flow not tested	1	721
Red clay (a streak not over 1 foot thick and "red as paint" at 725 feet) turning brownish below	19	740
White sand lying in crusts, comes up in balls easily crushed with the fingers, water-bearing; flow 30 gallons per minute through 2-inch pipe	5	745

The red clay and the white sand below it correspond to those struck at Urbanna, in Middlesex County, at 520 to 590 feet.

The water from the deep wells on the Great Wicomico is used for general household purposes, but particularly for boiler supply and for cleaning at the fish factories.

The conditions reported at some places in Northumberland County, where dug and driven wells are the sole sources of supply, are summarized as follows:

Details of wells in Northumberland County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Blackwells	35–72	Sand and rock	Good
Brown's Store	20–35	Sand	Shallow, salty; deep, good.
Coan	8–80	Sand	Soft to hard
Cowart	10–14	Sand and gravel	Soft
Callao	35–50	Sand	Slightly hard
Fleeton	18	Sand	Soft, brackish
Hyacinth	40–50	Iron crusts and clay.	....
Lottsburg	25–60	Iron crusts and sand.	Soft
Dynhams	8–20	Sand	Soft
Mila	14–50	Sand and marl	....
Reedville	10–15	Sand	Soft
Rainswood	15–25	Sand	Soft
Sampson's Wharf	12–50	....	Soft and hard
Tibitha	7–15	Sand	Good
Wicomico Church	10–80	....	....

Conclusions.—In Northumberland, as in other counties in the Virginia Coastal Plain, the development of ground water by dug wells is not always done with proper care. Though most wells, except those in villages, are not situated dangerously near privies and other sources of pollution, the protection of the wells at surface is usually altogether too slight. An abundant supply of artesian waters that will rise 35 feet above sea level can be had anywhere in the county by properly drilled and cased wells. The development of this water merits more attention than it has received, in spite of the many flowing wells in the county. At Heathville, soft water can be had by drilling 340 feet; it will have to be pumped as it will rise only to within about 40 feet of the surface.

PRINCE GEORGE COUNTY.

General description.—Prince George County, formed in 1702 from Charles City County, lies south of James River and the tidal portion of Appomattox River, east of Petersburg. The most thickly settled portion of the county is near Petersburg, which city is just across the county line in Dinwiddie County.

The county is near the western edge of the Coastal Plain, but, except along James River where the more important creeks, Baileys, Graves, and Chipoak, have cut short valleys, the topography differs from that of counties along the "fall-line" to the north. The headwaters of Blackwater River are only 5 miles from Appomattox River. Blackwater River flows into the Chowan, which empties into Albemarle Sound 150 miles to the southeast. Except near their mouths, the creeks flowing to the James have steep gradients; those flowing to the Blackwater and Nottoway have flatter gradients. The larger streams flow through narrow swamps 30 to 60 feet below an undulating sandy plain. The valley slopes are without steep descents. The highest points in the county are just south of Petersburg and have an elevation of 200 feet, but most of the county is comparatively low, a considerable portion being less than 100 feet above sea level. Terraces are clearly traceable along Appomattox and James rivers, but along the tributaries of Blackwater and Nottoway rivers the terraces grade into each other by slopes; scarps are not prominent. The greater part of the high ground of the county is included in the Sunderland terrace.

Geology.—The oldest visible formation within the county limits is the Patuxent of the Potomac group (Lower Cretaceous). Its characteristic arkosic sandstones and incoherent sands containing pebbles, cobbles, and clay balls, are exposed near Livetenant Run, a tributary of Appomattox

River, in the northwest corner of the county, and in various places near Appomattox River for 4 or 5 miles northeastward. The greensands and shell beds of the Aquia formation of the Pamunkey group (Eocene) outcrop on Livetenant Run near the Petersburg waterworks pumping station and at several places on James River, as in the bluffs at City Point. The Calvert formation of the Chesapeake group (Miocene) containing dark and light diatomaceous clays, and dark and light sandy clays, with shell beds, overlaps both the Pamunkey and Potomac. The base of the Chesapeake is 5 feet above sea level at Coggins Point, but is about 150 feet below at the mouth of Chipoak Creek, 10 miles southeast. Near Petersburg, the base of the Pamunkey is about at sea level, whereas at City Point, 6 miles northeast, it is about 20 feet below, and between is a wide stretch of country where Potomac beds are 50 feet above sea level. The base of the Pamunkey at the mouth of Chipoak Creek is about 300 feet below sea level.

UNDERGROUND WATERS.

Distribution and quality.—An abundance of water is stored in the Columbia sands and the upper beds of the Potomac and Pamunkey groups in the western part of the county, and the upper beds of the Chesapeake in the eastern and southern portions. The quality shows wide differences, but the water generally is soft. Relatively few deep wells have been drilled in the county, and little is known of the quality of the Patuxent and Potomac waters under more than 100 feet of cover.

Springs.—Prince George County contains numerous springs, but none of commercial interest. Some are used for household supply. One of the most noted is at City Point; it really consists of several springs developed by digging along the face of the bluff, and once supplied the hospital of Grant's army. It is now used by several families. The total flow is perhaps 50 gallons per minute. The water is clear, tasteless, and odorless, but, as it comes from shell beds in the Pamunkey, is slightly hard.

At Coggins Point a spring that flows from sand beds near the top of the Chesapeake supplies the residence of David Dunlop. The water is pumped by a gasoline engine from an enclosed masonry basin to an elevated tank, and is distributed thence to the dwelling house and other buildings. The flow is 25 gallons per minute. The water is clear, tasteless, odorless, and low in lime (for field assay see table 6).

Two springs are worthy of note. One, having a flow of 25 gallons per minute, is 2 miles west of Disputanta, the other is at Warwick Church a mile farther west. Both springs flow from surface sands a foot or two above the level of the water in Warwick Swamp. Field assays of the waters are given in table 6. A spring near Garysville has been utilized for household supply by means of a ram.

Wells.—Dug wells that draw on water-bearing sands in the Columbia formations are the chief source of supply in villages and on farms. Most of them are cased with wood, a few with tile; near Petersburg are many deep, bricked wells. The cost of dug wells varies. At City Point the cost of wells 20 to 50 feet deep is $2 per foot for digging and bricking. There are some driven wells and some bored wells. In places ordinary driven wells are unsatisfactory because of fine sand clogging the pipes and cutting pump valves.

LOCAL SUPPLIES.

At Prince George Courthouse only dug wells are used. These yield water that is said to be slightly hard. The lower part of Blandford, a suburb of Petersburg, is supplied with surface water from the Petersburg system. The dug wells on the high ground are 40 to 60 feet deep, and usually get soft water. On the lowland near Appomattox River driven wells get water of varying quality at depths of 20 to 25 feet, from Columbia or Potomac sands and gravels. At City Point, where dug wells 20 to 50 feet deep get hard water, a drilled well 112 feet deep obtains from Potomac gravels plentiful supplies of soft water that is sometimes turbid from clay in the water bed. Samples saved from this well served for the following record:

Record of well of the Misses Epes, City Point.

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil, clay and sand (no sample)	40	40
Fine to coarse quartz sand with a little dark clay and much glauconite	15	55
Quartz sand, glauconitic, and coarse gravel, in light clay	20	75
Fine to coarse white gravel with a little arkosic sand, some glauconite	14	89
Fine gravel in white clay	33	112
Gravel and well-rounded pebbles up to 2 inches in diameter, with a little white clay; water-bearing	....	112

A complete analysis of this water, of interest because of the location of the well, is given in table 11.

At Coggins Point a well 307 feet deep passed through several water-bearing beds between 60 feet and the bottom, but could not get a flow, as the elevation of the well mouth is 63 feet above mean high tide in James River.

At Disputanta, people rely on dug wells about 14 feet deep which get soft water from red, buff and yellow loams of the Columbia group. As the loams stand well, many of the wells are not cased, having only 2 or 3 feet of wood curbing at the top. The average depth of the wells within a mile of Disputanta is 20 feet; the deepest well is 35 feet. In the vicinity of Wall's Store wells on slopes get hard water at 10 to 15 feet in marl, while those on high ground get soft water at 22 to 25 feet in white sand under red clay.

Information regarding dug wells at other points in the county is summarized herewith:

Details of dug wells in Prince George County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Academy	15–20	Loam and sand	Soft
Brandon	.....	....	....
Burrowsville	15–40	Shallow, sand; deep, marl.	Good and bad
Harrison Grove Corner	32	Sand	Soft
Edlow	20–30	Sand	Soft
Garysville	20–40	Sand	Soft
Templeton	15–40	....	Irony
Spratleyville	30	Sand	Soft
Youngblood's Store	20–35	Sand	Soft

At Spratleyville a bored well near the store went through soil 2 feet; variegated clay, 15 feet; yellow sand, 18 feet; coarse white gravel—water-bearing—1 foot. Near Garysville wells on high ground go through soil, 1 foot; red clay, 10 feet; yellow sand with cobbles, 3 feet; "pipe" clay and red clay, 10 feet; and get water from white sand.

Conclusions.—As the western side of Prince George County is near the edge of the Coastal Plain, there is slight chance of obtaining flowing wells except along James River east of City Point. Flows with heads of 10 to 25 feet above tide can be had from Pamunkey and Potomac beds on low-ground near the river east of Baileys Creek.

At Prince George artesian water can be had from the Potomac beds by pumping; the water will rise to about 35 feet below the level of the Court-house. At Disputanta, the artesian waters in the Pamunkey and Potomac sands will rise to about 40 feet below the level of the railroad station. Hence there is no chance of getting flows.

PRINCESS ANNE COUNTY.

General description.—Princess Anne County, formed in 1691 from Norfolk County, is bounded on the north by Chesapeake Bay, on the east by the Atlantic Ocean, on the south by the North Carolina line, and on the west by Norfolk County. The only incorporated town in the county is Virginia Beach, a noted resort.

The surface of Princess Anne County is flat and is included in a low terrace. At the northwest, between the eastern branch of Elizabeth River and Lynnhaven Inlet, the surface in places rises 25 feet above mean sea level, but much the greater part of the county has an elevation of less than 20 feet. The highest points are on the sand dunes near Cape Henry, over 75 feet high. The county contains considerable tracts of swamp and marsh land. Shallow lagoons with wide stretches of salt marsh lie back of the barrier beach that extends from a few miles south of Virginia Beach to the North Carolina line. The principal streams are tidal and have marshy shores.

Geology.—No formations older than Columbia beds are exposed. The youngest Columbia formation, as shown by well records, is probably 75 feet thick. It comprises buff loams and light-colored sands, underlain below water level by soft, dark clays, termed marsh mud by well drillers, sands and shell beds.

Below the Pleistocene beds lies the Chesapeake group, the upper part of which shows by well records not less than 250 feet of dark, sandy clay, which contains continuous sand beds and beds of shell marl, but in general is dense and impervious. Pamunkey, Upper Cretaceous, and Potomac beds underlie the Chesapeake in order. Crystalline bed rock is over 2,200 feet below sea level.

UNDERGROUND WATERS.

Distribution and quality.—Water lies near the surface in Princess Anne County, and abundant supplies can be had almost everywhere, but the quality at many places is not satisfactory. The shallow water where the water table is just below the surface is in many places of objectionable color or odor, and is not considered healthful. In some places this water is iron-bearing, and, along tidal inlets and on the barrier beaches, it is brackish. The waters, 15 to 50 feet below surface, are less liable to be polluted and are preferred. In places they are irony or brackish, and as a rule are hard. The discontinuous sands near the top of the Chesapeake group have been little prospected. The quality of the deeper flows, as shown by the well at the Norfolk City Waterworks pumping station, has already been discussed. (See page 110 et seq.)

At their best, the Columbia supplies are soft and clear, and as good drinking water as can be desired. At their worst, they are so highly colored, hard, iron-bearing, and salty as to be unsuited for most purposes.

Springs.—There are few springs in Princess Anne County; one of commercial importance is Diamond Spring, situated on land owned by C. F. Hodgman, a quarter of a mile east of Waterway. The water issues from Talbot sands at the foot of a slight descent to an arm of Lake Lawson, and the flow is said to vary but little during the year. The water has been sold in Norfolk. The following sanitary analysis was furnished by the owner:

Analysis of water from Diamond Spring near Waterway.

(C. F. Chandler, analyst.)

	Parts per 1,000,000
Total solids	36.4
Organic and volatile	12.5
Chlorides	10.5
Chlorides as sodium chloride	17.4
Phosphates	0.0
Nitrogen as nitrates and nitrites	1.55
Permanent hardness, equivalent to $CaCO_3$	13.1

The sanitary surroundings of this spring in 1906 were excellent.

Other springs are those of E. B. Macon and W. B. Strong, 2 miles west of Virginia Beach, which have been used for domestic supply.

Wells.—Driven wells are the principal source of water supply. Many of them are inexpensive, being driven by a maul to the first water-bearing sand and finished with a pitcher pump. The yields vary greatly. Where the ground water is iron-bearing and corrosive the yield is much reduced within a few years by rust clogging the pipe. Wells finished with brass gauze, or slotted brass screens, and good pumps maintain their yield much longer.

Dug wells are used chiefly for stock; because of their easy pollution they are reccommended only for irrigation. Several deep wells have been drilled in the county; particulars of some are given in table 5.

LOCAL SUPPLIES.

The Norfolk County Water Co., which supplies part of the city of Norfolk and several suburban settlements, has its pumping plant on a tract of land containing about 275 acres, some 5 miles northeast of Norfolk, and a mile east of Moore's Bridge. Here the company had driven or dug, previous to December 1, 1906, 36 wells, varying in depth from 30 to 40 feet; all cased with iron. Thirty of the wells are 6 inches in diameter, and 6 are 54 inches. Water normally stands 9 to 17 feet below the surface, which has an elevation of 15 to 25 feet. Below the light-colored Talbot sands are bluish sands containing shells and some dark bluish clay. One well driven 50 feet as a test found no water in these beds. The following average section was given from memory:

Average record of wells of Norfolk County Water Co., Waterway.

Material	Thickness (Feet)	Depth (Feet)
Soil	1	1
Fine yellowish sand	3½	4½
Yellow and brownish coarser sand with some gravel	10	14½
Fine white sand	2½	17
Medium coarse light yellow sand	16	33
Fine bluish sand with shells, sticky bluish mud below	17	50

Before locating its pumping plant, the company tested several tracts of land north and east of Norfolk, driving possibly 30 wells in all. The present site was selected because of the yield and quality of the water obtainable. An analysis in table 7 shows, according to the company, the average quality of the ground water in the vicinity of its wells.

The pumping plant of the Norfolk City Waterworks is a little more than a mile southeast of the Norfolk County plant. The supply is from shallow ponds, connected by canals. These canals in places went through shell beds lying apparently from 5 to 10 feet below water level. At the pumping station is a deep, artesian well, described on page 110.

At Virginia Beach, which has a population of possibly 5,000 during the height of the bathing season, several attempts to get artesian water have been made. One in 1890 found no water that would rise 10 feet above sea level though the well went down 350 feet. Another well driven some years later at the Princess Anne Hotel obtained water of fair quality at 90 feet. This water did not rise to surface, but to about sea level. In 1906, supplies at the Beach were obtained from shallow wells driven 5 to about 30 feet, estimates of maximum depth varying considerably. The first water is found in sands below buff or yellow clay. The following record was given as a fair average of the materials penetrated:

Well at Virginia Beach.

(Authority, J. L. Walker.)

Material	Thickness (Feet)	Depth (Feet)
Sandy soil	1	1
Yellowish and reddish clay	10	11
White sand and blue clay in alternating strata, 2 to 4 feet thick	16	27

Most of the wells have hand pumps, some have wind pumps, and a few steam or gasoline pumps.

Some wells yield soft and some yield hard water. Many, near the ocean, yield slightly brackish water. At nearly all wells the water contains some iron, at a few it contains little. Cistern water is largely used for drinking. A field assay of a sample from what was said to be one of the best wells on the beach appears in table 7.

At Cape Henry driven wells, 10 to 20 feet deep, and cisterns are used. Some of the wells yield soft water, but at most the water is highly colored and at some brackish. Along the ocean beach from a few miles south of Virginia Beach to the North Carolina line there is no good well water. Between Lynnhaven and Broad bays clear, soft water is reported at 15 to 25 feet, in sand below red clay and sandy surface soil. Dug and driven wells at other points obtain supplies that vary in quality from place to place. Some conditions reported are here recorded:

Details of wells in Princess Anne County.

Location	Depth of well (Feet)	Water bed	Quality of water
Bonney	12–15	Sand	Good
Herbert	25	Sand	Irony
Jacksondale	8–30	Sand	Shallow, soft; deep, hard and irony.
London Bridge	10–20	Sand	Shallow, irony; deep, good.
Lynnhaven	10–18	Sand	Soft, hard, irony
Mapleton	10–15	Shallow, clay and sand; deep, mud.	Shallow, good or brackish; deep, hard and irony.
Nimmo	10–15	Sand	Good
Sigma	20–25	....	Slightly brackish

Conclusions.—Enough driven and drilled wells have been sunk in Princess Anne County to show average prospects. Excellent water can be had near the surface at many points, at other points cistern water or water from ponds or lakes will be found more satisfactory. More attention should be given the location of shallow wells, and the indiscriminate driving of wells 10 to 20 feet deep in the immediate vicinity of privies and cesspools should not be tolerated. Deep drilling in the hope of finding potable water from the basal Chesapeake (Calvert), Pamunkey, Upper Cretaceous, or Potomac sands is inadvisable; in fact, will in all probability prove a waste of effort.

At Virginia Beach the possibility of getting water of satisfactory quality from driven wells in vacant land away from tidal inlets had received little attention up to 1906. The supply of the town must come either from such shallow wells or from ponds.

An adequate supply for the municipal waterworks of Norfolk can be more easily and cheaply obtained from streams than from wells.

PRINCE WILLIAM COUNTY.

General description.—Prince William County, formed in 1730, lies on the west side of Potomac River above the big bend. Only a small part of its area, a strip along the river containing about 80 square miles, lies within the Coastal Plain province.

Lying on the slope from the Piedmont Plain to Potomac River, with differences of altitude of over 300 feet, the Coastal Plain area has been deeply eroded and the topography is rough and broken. Except for a few strips on the lower terraces near the river there is little level ground. Patches of the Lafayette terrace back of Quantico are 300 feet above sea level, but intermediate terraces are traceable with difficulty. The drainage in the Coastal Plain section is in creeks tributary to Potomac River, of which Occoquan Creek, which forms the northern boundary of the county, is the most important.

Geology.—Overlying the crystalline bed rock, which is exposed along the upper courses of the creeks, are the gray arkosic sands and sandstones, and drab and brown clays of the Patuxent formation of the Potomac group (Lower Cretaceous). Except for small scattered patches the Pamunkey (Eocene) greensands and clays have been removed by erosion, and the Chesapeake (Miocene) beds have been entirely removed. The cobble beds, sands, and bright-colored loams of the Columbia formations, and the Lafayette, hide the Potomac beds in many places.

UNDERGROUND WATERS.

The Patuxent formation, as shown by deep wells near the river, contains water-bearing sands that vary in thickness, lateral extent, and yield to wells. At most places one or more sands yield good water freely. Ground waters reached by dug, bored, or driven wells, lie in Columbia, Lafayette, or Potomac sands, at varying depths according to the location of the wells. As a rule the water is soft.

Springs are numerous. Little use is made of most of them and none are now of commercial importance. One, that of J. R. King, a mile north of Dumfries, was a resort of some note 50 years ago.

LOCAL SUPPLIES.

Artesian wells have been sunk at Myron (Cherry Hill), Quantico, and at a point 5 miles north of Quantico. The following record of the well at Myron was obtained from N. H. Darton.

Record of well at Cherry Hill.

(Authority, W. C. Miller, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Top soil	2	2
Sand and gravel	41	43
Sandy clay	47	90
Yellow sand and gravel with water	22	112
No record	15	127
Yellow sand and gravel, some water	6	133
Blue clay mixed with sand, some water	8	141
Blue and brown clay	16	157
Blue sandy clay	8	165
No record	2	167
Fine sand with water	18	185
Blue clay, mixed with a little sand	53	238
Coarse sand with gravel, plenty of water	14	252
Blue clay and sand with rock (?) at 257 feet	5	257

The well yielded 50 to 60 gallons per minute during an 8-hour pumping test.

The water is soft and slightly iron-bearing, a yield by pumping of about 320 gallons per minute through a 4-inch pipe is reported.

The well at Quantico is 210 feet deep. Darton[a] has published this record:

[a]Darton, N. H., Op. cit., 1896, p. 177.

Record of well at Quantico.

Material	Thickness (Feet)	Depth (Feet)
White clay	22	22
Fine gravel	6	28
Red clay	25	53
Fine red sand	5	58
Very hard blue clay	28	86
Fine sand	3	89
Dark clay	35	124
Coarse dark sand	3	127
Light-colored clay	78	205
Very coarse sand and water	5	210

This well, 4 inches in diameter, flowed 30 gallons per minute at 10 feet above the river. The head is said to have been 22 feet. The water is used by a number of families in the village.

The well 5 miles north of Quantico was sunk for the projected town of Barrow, and is little used. Water was struck in a bed of sand, or sandstone, at 143 feet. The following record has been published:[a]

Record of well at Barrow.

Material	Thickness (Feet)	Depth (Feet)
Clay and marl	10	10
Gravel	10	20
Clay	10	30
Sandstone	14	44
Coarse sandstone, water-bearing	1	45
Sandstone	12	57
Bluish sandy clay	1	58
Brown clay	15	73
Bluish sandy clay and fine sand	40	113
Sandstone, large supply of water	30	143
Yellow clay	4	147
Sand with pebbles	13	160
Yellow clay	5	165
Brown clay	30	195

Some reported depths of dug wells and the supplies obtained are as follows:

Details of dug wells in Prince William County.

Location	Depth of wells (Feet)	Water bed	Quality of water
Agnewville	25–65	Gravel	Soft to irony
Dumfries	20–80	Shallow, iron crusts; deep, clay	Soft, hard, irony
Neabsco	20–30	Sand	Soft

[a]Darton, N. H., Op. cit., 1896, p. 177.

RICHMOND COUNTY.

General description.—Richmond County, formed in 1692 from old Rappahannock County, is in the Northern Neck, the peninsula between Potomac and Rappahannock rivers. The more important creeks, Monatico and Totuskey, drain into the Rappahannock. The topography resembles that of many counties north of James River. The creeks head in sharply cut valleys and are tidal and bordered with salt marshes along their lower courses. The maximum altitude of the Sunderland plain is about 150 feet, near Farmers Fork, and 100 feet near Downings.

Geology.—The loams of the Columbia formations are exposed in many road cuts. The dark, clayey sands of the St. Mary's formation of the Chesapeake group (Miocene) outcrop at numerous points along Rappahannock River and its tributary creeks. Pamunkey (Eocene) beds are not exposed, the base of the Chesapeake lying about 50 feet below tide in the northwestern corner of the county, and 300 feet below near Simonson in the southeastern part. Upper Cretaceous beds probably underlie the Pamunkey and are in turn underlain by Potomac. The bottom of the Pamunkey is probably 300 feet below tide at Carter's Wharf, and 450 feet below at Simonson. Bed rock lies fully 1,000 feet deep.

UNDERGROUND WATERS.

Distribution and quality.—The sands of the Columbia formations and the highest Chesapeake beds contain ground water that varies in quality from soft and clear to hard and irony. Near the middle of the Chesapeake in the Choptank formation and toward its base in the Calvert formation are coarse sands that yield artesian water. Other sands lie in the Nanjemoy formation of the Pamunkey. Heads vary from 20 to 35 feet above tide. Chesapeake and Pamunkey waters are soft and limpid, but the former have as a rule a slight odor of sulphur. The Chesapeake waters, as in Essex County across the Rappahannock, are less alkaline and contain more lime than farther east. At a number of places the substitution of artesian for shallow well water is said to have resulted in a marked improvement of the public health.

Springs.—Richmond County abounds in springs, but little use is made of them, except by stock. The springs are of small volume, seeps rather than bold flows, relatively few exceeding 5 gallons per minute. One owned by A. J. Snyder, near Blantyre, flows about 5 gallons per minute of soft water from iron crusts at the base of the Sunderland formation. There is no spring in the county from which shipments of water are reported, or is a resort.

Wells.—Dug wells are almost the sole source of supply on high ground. Many are cased with wood from top to bottom. At some of the old churches and at old manor houses are bricked wells. Many of the shallow wells fail in prolonged droughts. Along Rappahannock River and tributary creeks are a considerable number of drilled wells, practically all of small diameter. The contract price for sinking about 275 feet ranges from $50 to $75. The actual labor cost of sinking, if everything goes nicely and no hard beds or "rocks" are encountered, may be $25.

LOCAL SUPPLIES.

At Warsaw, on the Sunderland plain, water is obtained from dug wells 35 to 50 feet deep, of which there are about 30. The following is an average section of the beds penetrated:

General section at Warsaw.

Material	Thickness (*Feet*)	Depth (*Feet*)
Soil	5	5
Red clay	17	22
White sand	14	36
Red sand and clay	3	39
Rock, iron crusts	2	41
Fullers earth, dark blue clay	....	....

The white sand bed halfway down gives much trouble to wells cased with plank in the usual way. The average life of the plank, as it is above water level, is but 6 or 7 years, and replacing the casing when decayed is more or less troublesome.

Along Rappahannock River not less than 50 artesian wells have been driven, there being at least 17 at Sharp's Wharf alone. Depths vary from 165 to 366 feet, but most of the wells draw on sands in the Calvert formation 160 to 300 feet below tide. Summarized information is given in table 5.

The following record of a well at Naylor's Wharf is given by Darton[a]:

Record of 366-foot well at Naylor's Wharf.

Material	Thickness (*Feet*)	Depth (*Feet*)
Surface deposits	20	20
Fullers earth	100	120
Marl	15	135
Rock strata, 1 to 15 feet apart, containing water	20	155
Black sand	15	170
Blue fullers earth	90	260
Dark orange-colored loam	15	275
Black sand, full of water, which rises to 35 feet above tide	50	325
Blue fullers earth, underlain by a soft rock layer, with water that rises to 45 feet above tide	60	385

[a] Darton, N. H., Op. cit., p. 175.

This well is used for domestic supply and by a canning factory. The quality of the water, which rose from a black sand in the Aquia formation, is shown by the field assay in table 9.

At Sharp's Wharf, one of the most important oyster-shipping points on Rappahannock River, most of the flowing wells go about 240 feet below tide and get water in the Calvert formation, from the same sand beds that are tapped by the wells at Bowler's Wharf on the opposite shore of the Rappahannock. A few go 360 feet to the Nanjemoy, and at least one reaches an Upper Cretaceous (?) sand at 440 feet. The head of the 240-foot wells was originally 24 feet, that of the 320-foot wells is about 30 feet above tide. The water is used for removing the mud from oysters as they are brought from the beds, and for washing shucked oysters. The flows are also utilized to keep oysters from freezing in winter, a pile of several hundred bushels being kept through the sharpest frosts without injury by allowing the water, which has a temperature of 63° F., to flow over them.

At one of the wells near Wellford's Wharf, which draws on Choptank sands, the following beds were penetrated:

Record of 165-foot well of Frank Garland at Wellford's Wharf.
(Authority, Frank Garland, owner.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Sand	5	5
Blue mud or "marl"	30	35
Gravelly sand	50	85
Thin strata of rock	55	140
Sand and rock, with hard rock stratum at 163½ feet; water in shell rock at 156 feet	25	165

This well, at an elevation of 6 feet, flows 24 gallons per minute. The head is about 22 feet above mean high tide, and is a foot lower at ebb than at flood tide.

Near Whealton are several wells that tap deeper sands in the Calvert formation.

Near the bridge across Totuskey Creek east of Warsaw, several flowing wells draw on Calvert sands at about 180 feet. The water is used for domestic purposes, in saw-mill boilers, and at a canning factory. It is called a fairly satisfactory boiler water though having a tendency to foam. Field assays are given in table 8.

The following record of a well higher up Totuskey Creek is of interest from the occurrence of a sand yielding artesian water at a depth of only

65 feet. This sand, which was found also in a dug well, is probably of limited extent.

Record of well of W. E. Garland, near head of Totuskey Creek, 5 miles east of Warsaw.

Material	Thickness *(Feet)*	Depth *(Feet)*
Surface wash	8	8
Blue marl, water at 65 feet	157	165
Rock	2	167
Blue marl	17	184
Rock	3	187
Sand (composed of medium quartz grains with much dark green to black glauconite): water, head at 30 feet	1	188

The flow is 16 gallons per minute through a 1½-inch pipe at 8 feet above river. This well was put down by the owner in less than a day. The water is used for household purposes. The overflow, received in a cement basin protected by a small building, prevents viands from freezing in winter and keeps them cool in summer.

Data collected at various places in the county regarding dug wells are given below:

Details of dug wells in Richmond County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Blantyre	20–50	Clay or sand	Hard
Carters Wharf	16–50	Loam and sand	Soft.
Downings	35–45	....	....
Farmers Fork	25–60	....	Good
Farham	.....	Sand or clay	Soft to hard
Haynesville	12–60	....	Shallow, soft; deep, hard.
Ivondale	12–65	....	Shallow, hard to soft: deep, hard.
Newland	18–45	Clay	Soft
Sharps	18–20	Clay and sand	Hard
Wellford	15–22	Sand	Soft

Conclusions.—Water that is perfectly healthful, so far as freedom from disease germs is concerned, can be had by dug or bored wells less than 50 feet deep at many points in the county, provided the wells are not located near sources of pollution, and are properly cased or lined, preferably with tile. Soft, iron-free, artesian waters can be had anywhere, but pumping will be necessary at places more than 20 to 35 feet above sea level.

At Warsaw, elevation 105 feet, good supplies can be had by sinking a 6-inch well to the Calvert sands about 300 feet below the level of the Court-house. There is also a possibility of obtaining water in the sands at 225 feet down. From neither of these sands will the water rise to 50 feet of surface.

SOUTHAMPTON COUNTY.

General description.—Southampton County, formed in 1784 from Isle of Wight, lies between Sussex County and the North Carolina line, its north end being 30 miles southeast of Richmond.

The county has a rolling surface. It is traversed by Blackwater and Nottoway rivers, which unite to form the Chowan at the southeast corner of the county, and is bounded on the southwest by Meherrin River. These streams flow through rather open valleys and meander across low terrace plains, and their tributaries are called swamps. A large part of the surface is included in the Sunderland and Wicomico terraces. Later Columbia terraces can be traced along the river valleys, but their total extent is undetermined. The maximum elevation of the highest terrace is about 110 feet near Joyner, Ivor, in the northern part of the county, has an elevation of about 90 feet. The highest ground in the vicinity of Franklin is 84 feet above sea level. In the valleys of Meherrin, Nottoway, and Blackwater rivers in the southern part of the county, a low Columbia terrace, with an elevation of 20 to 25 feet above tide water, covers large areas. The extent of the low terraces, those less than 40 feet above tide, is an important question since it is along them that flowing wells are to be had.

Geology.—The sandy loams of the Columbia formations hide the older deposits over nearly all the county, the Chesapeake (Miocene) sands and marls being exposed here and there on valley slopes. The base of the Chesapeake is about 20 feet above sea level in the west end of the county and 120 feet below near Franklin, evidently dipping eastward about 4½ feet per mile. The Chesapeake thins to feather edges at the west, but is 200 feet thick on high ground in the northeast end of the county. The Pamunkey (Eocene), Potomac (Lower Cretaceous), and Upper Cretaceous beds underlie the Chesapeake group under part of the county, but toward the southwest the Pamunkey beds thin out and disappear and the Chesapeake rests directly on the Potomac. Even at Franklin there is no positive evidence that the Pamunkey is present. At Emporia, in Greenesville County, 2 miles west of the west corner of Southampton County, crystalline bed rock comes above sea level, so that the thickness of the

Potomac and Upper Cretaceous beds in Southampton County varies from almost a feather edge to possibly 900 feet at Franklin.

UNDERGROUND WATERS.

Distribution and quality.—The Columbia sands carry plenty of water, which at many places is hard; in low ground the shallow water is not considered healthful. The depths to the water table vary with differences in topography, but in general water lies not more than 20 feet below surface. In the southern, eastern, northern, and western parts of the county artesian waters under heads of 25 to 50 feet above tide are found, in the sands of the Potomac group or of the Upper Cretaceous; well drillers say the sands at Arringdale, Hugo, Branchville, Boykins, Delaware, Courtland, and Franklin are white and contain much mica, and more or less lignite, called "wood" or "coal." In places the sands are apparently arkosic. As no fossils have been saved from bore holes, the exact age of the sands is in doubt. Similar sands are reported at Margaretsville, on Meherrin River in North Carolina. The artesian waters show considerable differences. In general they are soft and alkaline and well adapted to household use, but at some places they contain iron and have a distinct sulphur odor.

Springs.—While there are in the aggregate many springs along the creeks of Southampton County, most of them issue as seeps rather than strong flows, and in some sections of the county springs are relatively scarce. A few are used for household supply but none are of commercial importance.

Wells.—Southampton County probably contains more drilled wells than any other county of Tidewater Virginia except King William. The total number may exceed 300. Nearly all are 1½ or 2 inches in diameter. Depths range from 75 to 344 feet, and costs from 25 to 50 cents per foot. On the higher ground dug wells are the main source of supply for farms and villages. The usual price for digging is $5 for 30 feet. There are some bored wells and many driven wells in the county.

LOCAL SUPPLIES.

At Branchville are about 17 wells that develop a water-bearing sand in Potomac or Upper Cretaceous beds. The depths range from 130 to 250 feet and the heads are 45 to 50 feet above sea level, the level of the railroad station being taken as 46 feet. The flows are from 1 to 8 gallons per minute. As many as four flows have been found by one well.

The following general section at Branchville is reported by R. G. Ellis & Son, well drillers.

General section at Branchville.

Material	Thickness (Feet)	Depth (Feet)
Surface soil, sand and clay	10	10
Yellowish sand, water	11	21
Soft blue mud	13	24
Blue marl, with shells	17	41
Sand, with lignite	9	50
Red and white clay, with sand layers	60	110
White sand, contains mica and lignite and at some wells much kaolin, water-bearing	45	155

Other water-bearing sands lie below, separated by clayey beds. The well of T. J. Harrell found flows at 90, 110, 160, and 207 feet.

The artesian water is of good quality, although having a faint sulphur odor and being slightly iron-bearing at some wells.

At Boykins, 3 miles east of Branchville, about 25 wells, mostly for household supply, have been driven to Upper Cretaceous or Potomac beds, the succession of surface soil, clay, sand, blue mud, marl, reddish clay, and sand being much the same as at Branchville. The wells range in depth from 85 to 130 feet. The water is soft, but at some wells carries a little iron and is sulphur-bearing. An idea of its mineralization may be had from the field assays in table 8.

Near Arringdale are several small diameter wells that get flows from white micaceous sands below clay and marl. The wells go 70 to 75 feet below the surface of a swamp, elevation about 70 feet. They are used for household supply and for stock.

The Tidewater Railway Co. (Virginian Railway) has at Sebrel the largest and deepest well reported in the county. It is 10 inches in diameter and goes down 344 feet. It probably draws on Potomac sands. The following record was kept by the driller:

Record of well of Tidewater Railway Co., Sebrel.

(Authority, Tidewater Railway Co., owner.)

Material	Thickness (Feet)	Depth (Feet)
Clay	10	10
Clay and sand	20	30
Light blue mud	21	51
Blue mud and sand	10	61
Blue mud	51	112
Sand and gravel	10	122
Blue clay	32	154
Sand and clay	13	167

Record of well of Tidewater Railway Co., Sebrel—(Continued).

Material	Thickness *(Feet)*	Depth *(Feet)*
Blue clay	8	175
Fine yellow sand	11	186
Blue clay and sand	5	191
Coarse sand and gravel: water	21	201
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 water-worn gravel with pebbles the size of a small egg: water-bearing	....	342

The water level of this well when completed was 21 feet below surface, elevation 55 feet. For a test the well was pumped steadily 18½ hours at the rate of 106 gallons per minute. This lowered the water to 48 feet below surface, but after pumping ceased the water rose gradually to within 15 feet of surface. The well was drilled for locomotive supply. The water contains sodium bicarbonate, as indicated by the analysis in table 7d, and has a tendency to foam. The water at 191 to 202 feet rose to 30 feet of surface.

At Ivor on high ground, 4 miles west of Zuni, the Shaw Lumber Co. sunk a deep well to procure supplies to supplement those obtainable from dug wells. It draws on Upper Cretaceous or Potomac sands. The following log is reported:

Record of well of Shaw Lumber Co., Ivor.

(Authority, Shaw Lumber Co., owners.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Earth, marl, quicksand and blue mud	106	106
Blue mud and clay	89	195
Green mud	6	201
Black sand and gravel, with a small supply of water	19	220
White sand and small gravel	17	237
White sand with layers of blue mud	19	256
Water-bearing sand	31	287

The water from the bottom rises to 35 feet of the surface; the yield by air-lift is 55 to 60 gallons per minute. The 6-inch casing is finished with a No. 6 Cook strainer, 20 feet 6 inches long.

At Courtland are many flowing wells, possibly 75. T. J. Moore, of Storeys, reports having put down more than 50. Yields average about 10 gallons through a 2-inch pipe at surface, but vary from 1 to 50 gallons, depths and yield depending partly on the elevation of the well. Where wells are thick, yields and heads have been reduced by interference, those on low ground draining those on higher ground. The original head was about 27 feet above sea level, and on the high ground, elevation about 30 feet above the Nottoway River, wells have to be pumped. The following general record is reported by Mr. Moore:

General section at Courtland.

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil, clay and sand; water at 6 feet	13	13
Blue mud	23	36
Marl and blue mud	60	96
Yellow pipe clay	24	120
White micaceous sand with "wood," water-bearing, water rising about to surface	2	122
Yellow pipe clay	8	130
White micaceous sand with "wood"; water at 130 feet rising 12 feet above surface	15	145

A 2-inch well at the level of the main street, about 20 feet above Nottoway River, flows 25 gallons per minute. The artesian water is of excellent quality for household use, containing very little iron and having no sulphur odor. In a boiler it foams. Results of a field assay appear in table 8.

At Franklin a large number of wells have been put down, perhaps 150. Depths average 130 feet, but vary since surface elevations in the town range from 10 to 35 feet above river level. The water comes from higher sands than those tapped by the Courtland wells, and are presumably of Upper Cretaceous age. The following succession is reported by T. J. Moore:

General section at Franklin.

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil clay and sand	15	15
Blue mud	20	35
Blue marl and shells	40	75
Blue pipe clay	25	100
Hardpan or marl rock; drilled 14 inches in 3 days	1	101
Dark clay, like blue mud above	30	131
Hardpan or marl rock	½	131½
Clay and sand	8½	140
Hardpan or marl rock	½	140½
White micaceous sand, with "chunks of wood," water-bearing	24½	165

The average flow of 2-inch wells at the level of the main street, 20 feet above high tide in Blackwater River, is 4 gallons per minute. On "the ridge," the higher ground in town, elevation over 34 feet, the wells have to be pumped, as the water will not rise over 26 feet above high tide.

Flowing wells have also been drilled on Meherrin River west of Branchville, at Hugo, and south of Boykins, on Nottoway River several miles north and south of Courtland, and on Blackwater River as far north as Zuni, though no wells are reported on the Blackwater between Zuni and 5 miles from Franklin; south of Franklin deep wells are reported for 5 miles.

The following statement summarizes the information collected regarding dug wells at various places in the county:

Details of dug wells in Southampton County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Aidyl	15–30	....	Soft
Assamoosick	6–60	Loam, sand and marl.	Soft
Conley	15–20	....	Fair to good
Ivor	10–17	Blue clay	Soft
Maury	10–40	....	Soft
Newsoms	10–30	....	Soft
Sunbeam	15–25	....	Soft, hard; deep, irony.
Unity	12–16	Sand and marl	Soft to hard
Worrells	22	Sand	....

Conclusions.—Enough drilling has been done to indicate that flowing wells of good water can be had in this county on the low terraces along Blackwater River below McClelland, along Nottoway River below 10 miles north of Courtland, and along Meherrin River below 10 miles east of Emporia. Flows are not to be expected on the higher divides between the main rivers, but can be had up many tributaries for considerable distances. Where, as at Courtland or Franklin, heads have fallen and flows grown smaller by allowing wells to run without restraint more water can be had by going deeper.

SPOTTSYLVANIA COUNTY.

General description.—Spottsylvania County, formed in 1720 from Essex, King William, and King and Queen counties, lies between Rappahannock and North Anna rivers. Only a small part of the county near the eastern border is included in the Coastal Plain. The topography of this portion of the county is as a whole hilly, but there are extensive level stretches 50 to 70 feet high along Rappahannock River, and also on the high Lafayette plain, which has an elevation of 250 feet south of Fredericksburg.

In the valleys of the main streams west of Fredericksburg the crystalline gneisses and granites are exposed. They are overlain by the arkosic gravels and sands of the Potomac (Lower Cretaceous) and further south by the sandy clays and sands of the Chesapeake (Miocene). Near Massaponax Creek, Pamunkey (Eocene) greensands weathered to reddish and buff tints separate the Potomac from the Chesapeake beds. The Columbia cobble beds, sands, and loams rest in places directly on bed rock, in places on Potomac, in places on Pamunkey, and in places on Chesapeake beds. The Potomac group has a maximum thickness of 300 feet in the extreme northeast corner of the county. The Pamunkey and Chesapeake are thinner. The Chesapeake is everywhere above sea level, and only a small portion of the Pamunkey is below.

UNDERGROUND WATERS.

Distribution and quality.—The coarser beds of the Lafayette and the several Columbia formations are the most important reservoirs of ground water. The supplies generally are soft and slightly mineralized, but in places the water in the 60-foot terrace formation is decidedly iron-bearing. In the Pamunkey and Chesapeake sands the water varies from hard to soft. Little is known of the Potomac sands below tide level.

Springs.—Because of the water-bearing sands in the Lafayette and lower-lying terrace formations being uncovered along scarps, springs are numerous. Most of them are small, a few show bold flows and several in the vicinity of Fredericksburg have been long used by the public. Two of these, known as the Mint and the Gunnery springs, are owned by the city. They have covered masonry basins which exclude trash and surface wash during storms. Each spring flows from the base of a terrace, and the terrace immediately back of each spring is rather densely populated. The water from neither spring can be regarded as safe from pollution, though the danger at the Gunnery spring is less than at the Mint spring. In 1906, the water from both springs was drunk by a considerable number of people, particularly in the summer, because of its coolness and clearness.

Another spring, known as the Silk Mill spring, issues from the base of the same terrace, near the river, in the northwest part of the city. It has been used more or less by people living in the vicinity, but an investigation by the local Board of Health in 1905 indicated that the spring water was dangerous and should not be drunk unless boiled.

Besides these springs, several near the base of the Lafayette scarp on the heights a mile west of the city are utilized for public service by the Aqueduct Water Co. The water is clear and soft.

Wells.—Dug wells are the main source of supply. Depths vary greatly; in hollows on the top of the high Lafayette terrace are wells less than 15 feet deep, while near the edge of the terrace depths range up to 40 feet. Along lower slopes depths are from 20 to 30 feet.

On the broad terrace plain along Rappahannock River southwest of Fredericksburg, wells are dug to depths of 10 to 15 feet. In Fredericksburg is a number of dug wells 20 to 40 feet deep. Several near the river front, used for boiler supply, obtain rather hard water from Potomac beds.

In 1906, there was but one deep well in the city of Fredericksburg, that owned by E. D. Cole. This well is 120 feet deep and yields water of low mineral content. Mr. Cole uses the water for household purposes and furnishes it for drinking to neighbors who desire water more refreshing and less liable to pollution than that from the turbid Rappahannock. An analysis furnished by the owner, but recalculated to standard form, appears in table 11.

Fredericksburg is supplied with raw Rappahannock River water distributed by the city waterworks. In addition a private corporation, the Fredericksburg Aqueduct Co., distributes the water from the springs on the heights back of the town to a limited number of subscribers. This company is one of the oldest water companies in the United States giving an uninterrupted service, the springs having been developed as far back as 1823. Water was distributed for many years through bored logs and lead pipes. With ordinary care in maintaining the pipes leading from the springs to the supply basin, and in protecting the latter, these springs can furnish a drinking water of satisfactory quality, so long as the terrace above them is sparsely inhabited; but the flow is so small that the use must be limited.

Conclusions.—The gravels and sands, and even the non-clayey beds on the terraces along the river and on the divides, yield water in sufficient quantity for all the requirements of isolated dwellings and farm supply. Deep wells at and southeast of Fredericksburg will probably get good water from the Potomac beds. Flows can not be expected on the 60-foot terrace, though the water may rise above tide level.

STAFFORD COUNTY.

General description.—Stafford County, formed in 1765 from Westmoreland County, lies on the west bank of Potomac River north of Rappahannock River which forms its southern boundary. The Coastal Plain portion is a narrow strip along Potomac River.

Valleys deeply cut by Potomac, Aquia, and other creeks emptying into Potomac River give a rugged topography with comparatively few stretches of level ground. The maximum elevation, a little over 250 feet, is on a patch of the Lafayette plain, northeast of Fredericksburg. There are some level stretches on a low Columbia terrace along Potomac River, with elevations of 35 to 45 feet. Near the mouth of Aquia and Potomac creeks are cliffs 50 to 100 feet high.

Geology.—The soil over most of the Coastal Plain portion of Stafford County is derived from the Potomac (Lower Cretaceous) clays, shales, sands, and gravels. In places the Pamunkey (Eocene) greensands, weathered yellow, orange, and red, form the surface material, the largest area of Pamunkey being in the extreme southeast corner of the county. In this same part of the county a thin sheet of the Chesapeake (Miocene) rests on the Pamunkey, the only occurrence of Chesapeake beds in Stafford. The Lafayette and Columbia cobble beds, sands, and loams, as a rule brightly colored, rest on Potomac, Pamunkey, and on Chesapeake beds. The maximum exposed thickness of the Potomac is about 250 feet, and its thickness in the southeast corner of the county may be 350 feet. Nearly all the Pamunkey beds lie above sea level and no Chesapeake beds extend below it.

UNDERGROUND WATERS.

Springs are numerous but few are of especial note. They and dug wells are the sources of domestic supply. Depths to water and quality of water vary from place to place; in general the ground water is good. Excellent water can be obtained, no doubt, from the Potomac beds, but no deep wells have been sunk to determine the depth to water-bearing sands or the quality of the water. Flows are not to be expected.

Dug well conditions at a few points in the Coastal Plain portion of the county are summarized as follows:

Details of dug wells in Stafford County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Brooke	15–40	Sand and marl	Soft to slightly hard.
Falmouth	15–30	Sand	Soft to hard
Leeland	20–50	Sand	Soft
Millin	20–100	Soft rock and sand	Soft
Stafford	25–50	Sand and rock	Soft and hard

SURRY COUNTY.

General description.—Surry County, one of the original eight shires of Virginia, lies south of James River, in the western part of the Coastal Plain. Most of the surface of the county is included in the Sunderland plain and is rolling, with a gentle slope to the southeast. Near the northern edge of the county Chipoak, Grays, and other creeks flowing to James River have cut sharp valleys. As in Prince George County to the west, the southward flowing streams, such as Cypress Swamp, tributaries of Blackwater River, have open valleys. The divide is but a few miles back from James River. The Sunderland plain is, as a rule, below 100 feet high, its maximum elevation near Ruffins and Spring Grove being 130 feet. Low terraces occupy a very small part of the county. They are most noticeable south of Hog Island. For considerable distances, the southern bank of the James is steep and high, and the river cuts directly into the Sunderland terrace, as at Claremont.

Geology.—The Columbia (Pleistocene) formations cover most of the county. The Chesapeake (Miocene) group outcrops in the bluff at Claremont and is exposed in creek gullies. South of the divide the Chesapeake shell beds have been dug for marl in pits along tributaries of Blackwater River. The maximum thickness of the Chesapeake group in the western corner of the county is probably 150 feet, its base lying 50 feet below tide. In the eastern part of the county near Hog Island the base of the formation may be 350 feet deep. The Pamunkey does not outcrop within the county limits. Its base is about 350 feet below sea level at Claremont and 500 feet below at Homewood. The Potomac is over 500 feet thick and crystalline bed rock is fully 800 to 1,500 feet below sea level.

UNDERGROUND WATERS.

Distribution and quality.—Surry County is well watered by its numerous creeks. The ground water in the Columbia beds is generally soft, but in places is of indifferent quality. Ground water in the Chesapeake marls is at many places hard. Depths to water vary greatly. In the wide pocosons on the east side of the county the water rises to the surface after wet seasons, and is never more than 10 feet below it, while on high ground overlooking James River the water table may be 40 feet below the surface.

Plenty of artesian water underlies Surry County in the Chesapeake, Pamunkey, and Potomac sands. Both the Chesapeake and Pamunkey waters are soft and are more or less alkaline. No attempt to reach Potomac sands is reported, but it is altogether probable that they will yield plenty of water.

Springs.—Surry County is abundantly favored with springs, nearly all the creeks and branches being spring fed. Many of the small springs and seeps fail in time of drought, but the deeper springs in the northern part of the county and the "boiling" springs in the southern part are perennial. Most of the springs are little used except by stock, but a few furnish household supplies. Near Claremont are several with bold flows. Some from beds of marl yield water that is slightly hard and is said to have a marly taste. There are people who consider such water unhealthful, but where the ground above the spring is thinly settled, the marl bed overlain by a thick layer of loam, and surface waters can not reach the sources of the spring through poorly protected dug wells, there is no reason for judging the healthfulness of the water by the taste. A complete analysis of water from a marl spring south of Claremont, given in table 6, shows that the water contains notable amounts of bicarbonate of soda. A marl spring north of the village supplies several families. Another spring just east of the city has been improved by the owner, E. E. Harry, who markets the water as Trepho Lithia water. This spring flows from iron crusts and sands in the Sunderland formation. Various improvements have been made at this spring, and precautions have been taken to maintain the sanitary excellence of its surroundings. The following analysis is recomputed from one furnished by the owner:

Analysis of Trepho Lithia water.

(J. B. Weems, analyst.)

	Parts per 1,000,000
Total solids	573.
Silica (SiO_2)	34.3
Aluminum (Al)	1.95
Iron (Fe)	2.88
Calcium (Ca)	115.
Magnesium (Mg)	3.22
Sodium (Na)	11.2
Potassium (K)	2.12
Lithium (Li)	0.03
Bicarbonate radicle (HCO_3)	395.
Sulphate radicle (SO_4)	3.82
Chlorine (Cl)	3.46
Free carbon dioxide (CO_2), 3.5 c. c. per liter.	

A group of marl springs just south of Dendron was, at one time, used for boiler supply at the mills of the Surry Lumber Co., but the water was so limy and formed so much scale that the springs were abandoned. Other springs in the county deserving note are one, 2 miles southeast of Anchor, and one 2 miles northeast of Surry, on the road to Scotland. A few springs supply houses by rams; there is one at Bacon's Castle.

Wells.—Open dug wells, often provided with the old-time sweep and bucket, constitute the most important source of water for household use. Prices for digging these average about $5. Most of them have no lining but a wood "curb" at the bottom. The cost of such wells complete has often been less than $15. A few of the dug wells are bricked or cased with tile; the proportion of the latter is increasing. In dry seasons many of the shallow wells fail. There are some bored wells and some driven wells, and along James River a few drilled wells. At a number of points near the river the ground waters are so limy or irony that cisterns are used.

LOCAL SUPPLIES.

At Dendron most people obtain water from dug wells, 14 to 20 feet deep. There is also a considerable number of driven wells 18 to 20 feet deep, the water from which is considered better than that from dug wells. Both dug and driven wells get water from sands in the Sunderland formation. This water is soft and adapted to household use. A well drilled some years ago for the Surry Lumber Co. to a depth of 386 feet was abandoned as unsuccessful because it did not give a flow.

At and near Surry Courthouse dug wells average about 20 feet deep. Ordinarily they have from 5 to 8 feet of water in them, but in wet seasons some of the shallow ones are filled to the surface. Most of the wells are lined with wood, though a few are cased with tile. The following section is reported:

Section at Sunny Courthouse.

Material	Thickness (*Feet*)	Depth (*Feet*)
Soil	1	1
Yellow clay	12	12
Slate-colored, sandy clay	8	20
Vari-colored clay, pebbles at 35 feet	20	40
Marl	3	43
White gravel; water	4	47

At Claremont, situated on a headland of the Sunderland plain, dug wells are from 20 to 40 feet deep. These yield water of varying quality; some is from shell beds and so hard as to be unsatisfactory for domestic use. Some of the wells are liable to contamination because of insufficient protection at the surface, others because of seepage from old polluted wells nearby. In 1906, cisterns were used by fully one-half of the population; about one-fifth used wells; the balance used spring water. At some of these springs are rams supplying tanks at dwellings. The water is generally soft.

On Homewood plantation on Hog Island in James River are 6 flowing wells, all sunk 20 years ago. Their depths are variously stated, but all draw on Chesapeake beds. A 6-inch well is said to have been sunk 317 feet, and to have struck a strong sulphur water at 270 feet, and a good flow, 40 gallons per minute, in a shell bed at the bottom.

The following record of one of the wells has been published by Darton[a]:

Record of well at Homewood.

Material	Thickness *(Feet)*	Depth *(Feet)*
Clay and loam	15	15
Gravel with surface water	10	25
Clay, blue below	60	85
Shell marl with hard crust of shell at base, flow of ferruginous water at 112 feet	37	112
Marl	108	220
Rock	1½	221½
Blue clay with flow of water at 222 feet, water better than at 112 feet, and greater flow	67½	289
Hard rock	2½	291½
Black, water-bearing sand; fine water, flow at surface 30 gallons per minute through 1½-inch pipe, head 40 feet	....	291½

It is not possible to determine to which of the wells at Homewood this record refers.

A complete analysis from a well in the southeast corner of the plantation appears in table 8. The water has a faint sulphur odor when fresh. The well is said to be 219 feet deep; it may be deeper.

Another well south of Homewood and 4 miles east of Bacon's Castle was sunk for a brickyard, since abandoned. It is said to be 400 feet deep, but the water has all the characteristics of the Chesapeake flows. An attempt to get a flow at Bacon's Castle was unsuccessful, the elevation of the post-office being 84 feet above tide.

Shallow well conditions at a number of villages in Surry County are summarized below:

[a]Darton, N. H., Op. cit., p. 174.

Details of shallow wells in Surry County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Alliance	15–40	Marl	Shallow, soft; deep, hard.
Anchor	12–35	Sand	Shallow, soft; deep, soft to hard.
Bacon's Castle	15–40	Sand and marl	Soft to hard
Cabin Point	16–30	Sand	Soft to hard
Claremont	40–60	Sand and marl	Hard
Dendron	12–26	Shallow, clay; deep, clay and marl.	Shallow, soft; deep, hard.
Elberon	8–25	....	Fair to good
Hargrave	20	Sand	Soft
Ingenall	50	Marl	Hard, cistern
Ruffins	8–40	Sand and marl	Deep, hard
Savedge	10–24	Clay	Fair to good
Scotland	60–80	Iron crusts and marl.	Limy and irony
Spottsville	10–80	Shallow, sand; deep, marl.	Shallow, soft; deep, hard.
Surry	15–40	Sand, marl	Soft
Wiedman	35–45	Sand and marl	Hard

Conclusions.—Plenty of good water can be had in Surry County by dug, driven, or drilled wells. Artesian waters that will rise 20 to 35 feet above sea level can be had anywhere. Their quality will be found excellent for most purposes, but toward the east side of the county they may not be altogether satisfactory for certain industrial uses.

At Dendron, where the question of obtaining better water than that afforded by shallow wells will demand attention with the growth of the town, plenty of water can be had from the basal Chesapeake sands at 300 feet, or the Pamunkey sands at 550 feet, by 8-inch wells and pumps or air-lifts. Flows are impossible. In the swamp along Blackwater River south of the town, the Pamunkey waters may rise to surface. Flows are impossible at Surry, the elevation of the ground at the Courthouse being about 100 feet. By drilled wells and pumps soft alkaline water can be had at about 400 feet.

In case artesian water is sought for town supply at Claremont, a well or wells near the foot of the bluff will probably be more satisfactory than wells in the center of the town. In the latter situation flows can not be had, the altitude being 90 feet, but flows can probably be had near the river and it will be more economical to locate a pumping station there than to use deep well pumps.

SUSSEX COUNTY.

General description.—Sussex County, formed in 1754 from Surry County, is separated from the latter by Blackwater River. It extends from Blackwater River to Nottoway and Meherrin rivers, and is about 40 miles long from its northeastern to its southwestern corner. The southwestern corner of the county lies west of the Piedmont-Coastal Plain boundary. The two most important towns are Waverly and Wakefield.

The topography varies from slightly rugged in the southwest to undulating in the northeast. The larger portion of the surface is included in the Sunderland terrace. The maximum elevation reported is near Jarratt, 155 feet; the minimum is on the banks of Meherrin River near Emporia, 25 feet. The general slope of the surface is southeast. Coppahaunk Swamp and Warwick Swamp flow northeast to Blackwater River; Joseph's Swamp, Stony Creek, Roaring Creek, Poplar Spring, and Assamoosick Swamp flow south or southeast to the Nottoway.

Geology.—While the Chesapeake (Miocene) clayey sands and marl beds underlie practically all the county as far east as the Atlantic Coast Line Railway they are seldom exposed, owing to the coating of Columbia (Pleistocene) loams and sands. On the west the St. Mary's formation of the Chesapeake overlaps the Potomac beds and rests directly on the crystalline rocks. Its shell or marl beds have been opened by many small pits and dug for fertilizer. Pamunkey (Eocene) beds probably underlie the Chesapeake east of Sussex but are not known to outcrop anywhere in the county. At Bolling's Bridge on Nottoway River is an outcrop of a bed of cobbles and pebbles that has been regarded as a basal bed of the Potomac group, Lower Cretaceous; it may belong to the Chesapeake. From feather edges the Chesapeake and older formations thicken eastward and at Wakefield the base of the Chesapeake is probably 300 feet below the surface, the base of the Pamunkey 50 feet deeper, and the crystalline bed rock not less than 700 feet below. The surficial sands, gravels, and loams belong to the Sunderland, Wicomico, and Talbot formations of the Columbia group.

UNDERGROUND WATERS.

Distribution and quality.—The abundant ground water in the Columbia sands and Chesapeake sands and marls varies in quality from soft to hard, and in places is irony. Artesian waters underlie the eastern half of the county. Little is known of them, but it is safe to say that they are of excellent quality. There are no flowing wells in the county but it is likely that some artesian waters will rise to the level of the swamps along Nottoway River south of Lumberton.

Springs.—There are numerous springs and seeps along the rivers and their tributaries. Nearly all issue from the white sands which mantle the valley slopes and their geologic source can not be determined by inspection. Most are of small flow and many fail in droughts. The springs are little used except for watering stock. The only one in the county of commercial note is the Coppahaunk on Coppahaunk Swamp, about 1½ miles south of Waverly. It has had considerable repute and is now owned by persons who bottle and ship the water. The flow is free, about 25 gallons per minute. The water rises through sand and probably comes from a Chesapeake shell bed; it is iron-bearing and is said to have slight sulphur taste when fresh from the spring. The following analysis is recomputed from one furnished by the company:

Analysis of water of Coppahaunk Spring, Waverly.

(Froehling & Robertson, analysts.)

	Parts per 1,000,000
Total solids	293.
Silica (SiO_2)	23.
Iron (Fe)	0.7
Aluminum (Al)	9.9
Manganese (Mn)	trace
Calcium (Ca)	93.
Magnesium (Mg)	1.5
Strontium (Sr)	0.1
Barium (Ba)	0.15
Zinc (Zn)	faint trace
Sodium (Na)	5.4
Potassium (K)	2.9
Lithium (Li)	0.19
Arsenate radicle (AsO_4)	0.034
Phosphate radicle (PO_4)	0.12
Carbonate radicle (CO_3)	143.
Sulphate radicle (SO_4)	1.6
Iodine (I)	trace
Bromine (Br)	trace
Chlorine (Cl)	11.

Wells.—Dug wells, generally cased with wood, are the main source of supply at most farms, and in many villages. The cost of digging these is low. There are some bored wells and at Waverly and Wakefield many driven wells. No deep drilled wells are reported.

LOCAL SUPPLIES.

At Wakefield there are a few dug wells and over 75 driven wells, the latter from 19 to 22 feet deep. They get soft water in sands underlying loam. A peanut mill gets water from an 80 horsepower tubular boiler from two dug wells about 15 feet deep. The supply is fairly good for boiler use though it has a tendency to form scale. (See table 7.)

At Waverly, where are large lumber mills, nearly all the water for both boiler and domestic supply is obtained from driven wells, which range in depth from 15 to 35 feet. Dug wells which strike the first water bed at 15 feet sometimes fill to the top and are liable to pollution. The water from the second sand, at 30 to 35 feet, is preferred by those persons who have had wells driven to it, and is certainly less liable to pollution than that from 15 feet. In fact, in 1906, this 35-foot water was as good as need be, as no dug wells had been sunk deep enough to permit direct pollution of the water bed. The yields to pumps are remarkable. One 35-foot well, 2 inches in diameter, is stated to give 30 gallons per minute, while at the plant of the J. D. Gray Lumber Co., 2 wells furnish water enough for 250 horsepower. As a boiler water, though considered hard, it seems satisfactory, forming very little scale. Its quality is indicated by a field assay in table 7.

The expense for a 35-foot well at Waverly is slight. A 2-inch pipe can be driven for about $5, and the well equipped with a pitcher pump costs about $10.

Information collected regarding dug wells at various places in the county is summarized as follows:

Details of dug wells in Sussex County.

Location	Depth of well (Feet)	Water bed	Quality of water
Airland	20–60	Clay	Irony
Booker	10–30	Shallow, clay; deep, "black mud."	Soft
Comans Well	15–30	Clay	Fair, good
Hilda	10–50	Sand, marl	Soft and hard
Jarratt	12–30	Gravel	Soft
Lumberton	6–30	Shallow, sand; deep, clay or marl.	Soft and hard
Masons	7–35	....	Soft
Peanut	15–20	Loam	Soft
Westhope	8–40	Sand and clay	Soft

At Jarratt some wells dug for boiler supply are 16 feet square and 20 feet deep.

WARWICK COUNTY.

General description.—Warwick County, one of the smallest counties in the State, was one of the eight original shires of the colony of Virginia. It lies along the north bank of James River near the end of "the peninsula."

The topography is somewhat diversified though the relief is not great. The northern part of the county lies within the Sunderland terrace which has an elevation of 86 feet at Halstead's Point, in the extreme northern corner. The greater part of the county is included in lower terraces. The lowest plain includes Mulberry Island. The city of Newport News stands on two terraces.

Geology.—Columbia (Pleistocene) sands and loams mantle the surface. On the lower terraces are local lenses of clay that have been worked for brick on Mulberry Island and at Morrison. At Newport News dark bluish mud containing cypress stumps and bluish sand containing marine shells outcrop in the river bluff beneath gray pebbly sands.

Clayey sands and beds of shell marl mostly belonging to the Yorktown formation of the Chesapeake group (Miocene) are exposed in the creek valleys. The total thickness of the Chesapeake at Halsteads Point is about 450 feet, and at Newport News about 550 feet, its base lying 400 to 550 feet below sea level. The Pamunkey (Eocene), Upper Cretaceous, and Potomac (Lower Cretaceous) lie below the Chesapeake. The base of the Pamunkey is about 600 feet below tide at Halsteads Point, and 700 feet below at Newport News. Evidence as to the thickness of the Upper Cretaceous is contradictory. The base of the Potomac lies over 2,000 feet below tide at Newport News.

UNDERGROUND WATERS.

Distribution and quality.—The ground waters in the Columbia and Chesapeake beds show the usual variations in quality; here soft and clear, there hard and irony. Depths to the water table differ considerably, and where it rises to the surface after prolonged rains, as on flat stretches, the quality of the ground water is not considered so good as where the water table lies deeper.

An abundance of artesian water underlies the county but that so far developed is rather highly mineralized, the mineralization increasing toward the southeast. This increased mineralization is due in part to the water-bearing sands growing finer, and as a result yields to wells and heads of flows are least in the wells farthest down the river.

Springs.—There are no springs of especial importance in Warwick County, but a few are still used for household supply. The smaller springs seep from Columbia sands; the larger flow from shell beds in the Yorktown formation. The waters of the latter are apt to be hard. Some of the larger springs are so situated that they can be advantageously developed by rams.

Wells.—Dug wells are chiefly used. There are a few drilled wells along James River. Near Newport News there are numerous driven wells and a few at other places in the county.

LOCAL SUPPLIES.

The Newport News Water & Power Co. supplies the city of Newport News with water from a watershed it owns. Practically every one in Newport News uses this water, though on the outskirts of the city are shallow, driven and dug wells which obtain supplies, in some instances of suspicious purity, from Columbia sands. Attempts to get artesian water at Newport News have been mentioned. (See page 97.) The artesian wells in the county are all near James River. There are two on Mulberry Island, one at Mulberry Island post-office, the other at Curtis Point. Both of these wells probably get water from sands in the Chesapeake group at 360 to 380 feet below mean high tide. The owner of the well at the post-office has shipped more or less of the water to Newport News and Norfolk. It is soft, clear and refreshing, and has some local repute for medicinal properties. The accompanying analysis furnished by the owner, but recomputed to standard form, shows the large proportion of bicarbonate of soda characteristic of artesian wells in other parts of the Virginia Coastal Plain.

Analysis of water from well of P. H. Wright, Mulberry Island.

(W. H. Taylor, analyst.)

	Parts per 1,000,000
Silica (SiO_2)	13.0
Iron (Fe)	trace
Calcium (Ca)	4.2
Magnesium (Mg)	1.2
Sodium (Na)	354.0
Potassium (K)	15.0
Lithium (Li)	trace
Bicarbonate radicle (HCO_3)	454.0
Sulphate radicle (SO_4)	44.0
Chlorine (Cl)	273.0

The well at Curtis Point is of interest from its location and the quality of the water. In the latter respect it resembles the well at Mulberry Island post-office, but the water is more mineralized. A complete analysis appears in table 8.

At attempt to get a flow at Menchville on the mainland opposite Curtis Point proved unsuccessful, possibly because of the well being started on too high ground, as the head of the flow at Curtis Point is only about 20 feet above sea level. A well at Lee Hall 406 feet deep reaches a sand having about the same stratigraphic position as that yielding flows on Mulberry Island. The elevation of the well is 42 feet and the water rises within 12 feet of the surface.

Conditions reported from some of the places in Warwick County, where dug or driven wells are the sources of domestic supply, are summarized herewith:

Details of shallow wells in Warwick County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Denbigh	25–30	Clay and sand	Soft, hard
Halstead Point	30–50	Sand and marl	Hard and irony in deep wells
Lee Hall	18–25	Sand	Soft
Menchville	10–31	Sand	Soft
Mulberry Island	10–15	Sand	Soft, irony

Conclusions.—The wells already drilled indicate that from the Chesapeake sands under Warwick County, moderate heads, 20 to 30 feet, and fair flows at the northwest end of the county with diminishing yields and increasing mineralization southeastward, may be expected. Slightly higher heads and freer flows can probably be had from deeper sands in the Pamunkey, Upper Cretaceous, or Potomac, but heads over 35 feet above tide are not to be expected, nor is there any reason to expect much improvement in quality with depth. Water much better adapted to ordinary household use than the supplies obtained from some shallow wells at many places can be had west of Curtis Point. Farther east the outlook becomes increasingly dubious. Prospects in the immediate vicinity of Newport News have already been discussed. (See pages 97 to 116.)

WESTMORELAND COUNTY.

General description.—Westmoreland County lies south of Potomac River on the "northern neck." The topography is characterized by high terraces with undulating surfaces sharply cut by creek gorges and comparatively level lower terraces. Some of the creeks flowing to Rappahannock River head within a mile or two of the Potomac. Some of those flowing toward the Potomac empty into tidal inlets or rivers, such as Nomini River and Yeocomico River.

Elevations on the Sunderland terrace range from 160 feet in the vicinity of Bainesville to 110 feet back of Kinsale. Near Bainesville is a small area above the general level of the Sunderland, and there is another near Stratford. These areas may be remnants of the Lafayette terrace. Lower Columbia terraces are traceable along Potomac River. A striking feature of the topography of Westmoreland County are the famous Nomini Cliffs which extend for nearly 10 miles along the Potomac between Popes Creek and Currioman Bay. These cliffs in places are 200 feet high. Along Rappahannock River below Wilmont Landing are conspicuous cliffs, in places over 100 feet high.

Geology.—The loams, cobble beds, sands, and gravels of the Columbia formations outcrop in many road cuts and in the river cliffs. The lower formations of the Chesapeake group (Miocene) are exposed in many places. Over 200 feet of the Calvert are visible in the Nomini Cliffs and the diatomaceous clays of the formation are to be seen in the cliffs on Rappahannock River. The base of the Calvert is near tide level on the western edge of the county, while at the mouth of Yeocomico River at Lynch's Point it is 350 feet below. The greensands, clays, and shell beds of the Aquia and Nanjemoy formations of the Pamunkey (Eocene) have a total thickness of about 250 feet, and the base of the Pamunkey is 300 to 550 feet below river level. Little is definitely known of the thickness and extent of the Upper Cretaceous beds. The Potomac group may be 500 to 1,000 feet thick and the crystalline bed rock probably lies from 1,000 to 1,500 feet below tide.

UNDERGROUND WATERS.

Distribution and quality.—The Columbia formation and the top beds of the Chesapeake group carry ground water within the county limits. Near the edges of the highest terrace the water table is 30 to 60 feet below the surface and fluctuates slightly. On flat stretches of the same plain it may fluctuate 15 to 20 feet and rise to the surface after a wet season. The quality of the water varies from soft to irony or hard. Shallow water in the Chesapeake beds is at many places hard.

Sands in the Chesapeake, Pamunkey, and Potomac groups are known to contain artesian water. As the beds dip east the depths to the sands increase in going down the river. At the west end of the county the Chesapeake beds are little below tide level and do not give flows; east of Mount Holly most wells draw on them. The sands most widely developed are at the base of the Calvert formation. Higher sands supply wells at the east end of the county. The Nanjemoy sands have been reached by relatively few wells east of Colonial Beach. The heads of the flows vary but the waters most developed had heads of 15 to 30 feet above tide. All the waters sampled from wells reaching Chesapeake or Pamunkey sands were soft and alkaline.

Springs.—Small seeps and springs that feed the creeks flowing to Potomac River are found throughout the county. So numerous are they that as one man expressed it, a spring can be had on any hillside by a little work with a hoe. A few springs, such as those of R. O. Costenbader near Remus, and Wm. Taylor, opposite Kinsale, furnish drinking water or water for household supply; many are so situated that they can be developed to advantage by rams. From no spring is water marketed and none is a resort.

Wells.—On high ground dug wells curbed with wood are the chief source of domestic supply. Some of these wells are poorly located and very liable to pollution. On the high terraces wells are from 20 to 60 feet deep, on the lower terraces they are seldom over 40 feet and the average depth is under 20 feet. There are some bored and some driven wells, and along the river and the tidal courses of the creeks are many drilled wells of small diameter. The cost of these to the owner has averaged between 25 and 40 cents a foot.

LOCAL SUPPLIES.

No town in the Virginia Coastal Plain has benefited more from the development of artesian water than Colonial Beach. The first deep well was drilled in 1887. Before that all persons, and for some years afterward many persons, drank the water obtained by shallow wells 6 to 15 feet deep, and as a rule poorly protected. Typhoid fever obtained a foothold and was in some years epidemic. Since the substitution of artesian for dug wells typhoid has practically disappeared.

Nearly all the artesian wells reach a greensand in the Aquia formation of the Pamunkey, about 200 feet below river level. According to the driller, who sunk many of the wells in town, none of those reaching this sand is over 220 feet deep. The sand is immediately overlain by some 10 feet or so of red or chocolate-colored clay. The sections reported vary, but the following may be taken as an average:

Generalized section at Colonial Beach.

Material	Thickness *(Feet)*	Depth *(Feet)*
Soil and sandy loam	8	8
Yellow to buff clay	4	12
Gravel and sand	7	19
Blue marl, black sand, dark clay, shells	150	169
White clay	2	171
Red and chocolate-colored clay not over 10 feet thick on beach	10	181
Rather fine green or black sand, water bed	20	201

Some wells pass through "rock" 8 to 10 inches thick in the blue marl at 150 feet. Most of the wells are 1½ inches in diameter and were sunk by hand rigs. Prices for drilling have been $50 to $75, according to care in placing casing, etc.

The water from the 200-foot wells as it comes from the same horizon varies little in quality. It has a slight sulphur odor and is decidedly alkaline (see field assays, table 9). It is used for all purposes. As a boiler water it has a tendency to foam and pit tubes.

At the ice plant where a well to the 200- to 225-foot sands gave an insufficient supply, a well to a sand in the Potomac group found plenty of good water. The driller reported the following log:

Record of well at Ice Plant, Colonial Beach.

(Authority, Roland Rude, driller.)

Material	Thickness *(Feet)*	Depth *(Feet)*
Made land	6	6
Yellow clay	13	19
White clay	2	21
Green marl	39	60
Black earth with sand	140	200
Rocks in coarse brown sand, a little water	100	300
Black earth with large grains of heavy sand	50	350
White clay, with some very soft streaks	50	400
Red clay	15	415
White sand with plenty of water	7	422

The well is 1½ inches in diameter, the flow is 6 gallons per minute at an elevation of 5 feet.

Outside the thickly settled portion of the Beach there are still wells of good flow to the 200-foot sand. One of the best is that of the McGinnis estate at the south end of town, which when dug flowed about 3 gallons per minute at an elevation of 9 feet above high tide.

North of the Beach at Wilkerson's Wharf are two wells, 233 and 235 feet, respectively, flowing 3½ and 1⅗ gallons per minute at elevations of 4 and 7 feet above tide water. The wells are said to have struck the Beach flow at 214 feet but found it a mere drip. After going through 10 feet of white sand and "rock," the latter in layers 1 to 10 inches thick, and 20 feet of "red clay," the present flow was struck which rose 40 feet above sea level and gave 5 gallons per minute.

At L. C. Handy's, west of Wilkerson's, is a well that has a measured head of 22 feet, and flows into a tank about 20 feet above mean high tide. An attempt made to get a flow at an elevation of 30 feet above tide was unsuccessful though the well was sunk 471 feet, according to the driller.

In the vicinity of Erica the sands that yield waters to the wells near the head of Nomini River are apparently too fine to give flows, and several wells have gone to sands in the Pamunkey at reported depths of from 300 to 350 feet. One at the post-office, elevation about 20 feet, is said to be 336 feet deep and to have flowed in 1902 when drilled. In 1906 the water stood about 3 feet below surface.

A mile east of Maple Grove and some 3 miles west of Colonial Beach, a well was drilled in 1905, for Floyd Omohundro, on the Wicomico terrace at an elevation of 60 feet. This well found water in white sand, which rose to about 40 feet of surface. The well is cased for only about 40 feet, and, according to Mr. Omohundro, since it was drilled there has been a change in the quality and yield of the water in his dug well, 45 feet deep, about 20 feet distant, indicating that the artesian water finds its way into the dug well.

At or near Kinsale, on Yeocomico River and its inlets, a considerable number of flowing wells have been put down. Those at Kinsale are said to range in depth from 238 to 275 feet, most of them striking a water-bearing sand in the Calvert formation at 245 feet. The heads average about 17 feet above mean high tide, and the flows at an elevation of 6 feet are about 4 gallons per minute through a 1½-inch pipe. The water, which has a slight sulphur odor, is used at canning factories and also for drinking. In a boiler it works fairly well, not pitting the tubes, but having a tendency to foam. At the canning factories it is the custom to blow off some of the water in a boiler, one or two gages, several times a week. The general character of the water is indicated by the field assays in table 8.

North of Kinsale on Sandy Point Farm, the 5,000-acre estate of J. R. Dos Passos, of New York, there are no less than 15 flowing wells. Many of them are at tenants' houses and were intended to furnish pure water for domestic use, the supplies from shallow wells having, it was thought, caused malarial disorders. A marked improvement in the health of those using artesian water is claimed. The following log was furnished by the driller:

General record of wells near Sandy Point.

(Authority, F. H. Jones, driller.)

Material	Thickness (Feet)	Depth (Feet)
Loam	17	17
White sand	8	25
Blue clay (called fullers earth)	150	175
Marl and layers of shells	50	225
Thin layers of rock about 2 feet apart, with sand between	5	230
Black sand, water-bearing		230

This water has the general characteristics of the flows at Kinsale as shown by the field assay in table 8.

At Sandy Point farm on the river shore at Lynch Point, is a flowing well but 90 feet deep which may tap a sand in the St. Mary's formation of the Chesapeake. The head of the flow is about 3 feet above high tide. The water decidedly differs from the deeper flows; it contains more iron and lime, as shown by field assay (table 7), and is little used. In a way the well resembles in low head and quality of flow some of the wells in Accomac County.

Near Nomini River there are flowing wells at Mount Holly, Hinnom, Beal's Wharf, McGuire's Wharf, and Erica. Most of them draw on the Calvert sands of the Chesapeake group. The well at Mount Holly is 150 feet deep and flows, at an elevation of 9 feet above tide, about 5 (?) gallons per minute through a 1½-inch pipe. A field assay of the water is given in table 8. Some of the wells on Nomini River tap deeper sands, if reported depths are trustworthy, but the waters are much alike. Most of the wells have cost $40 each.

At Oak Grove, on the Wicomico terrace, several attempts to get artesian flows have failed, owing to the elevation of the surface, 60 feet. Some wells at Oak Grove, at 25 to 30 feet deep, are poorly situated and continually liable to pollution.

Two miles southeast of Oak Grove an attempt to get a flow at the residence of Andrew Flanner failed because of the elevation, though the well went down 664 feet. Mr. Flanner has a dug well 63 feet deep that gets water in Chesapeake sands.

Data collected regarding dug wells at a number of villages in Westmoreland County is summarized as follows:

Details of dug wells in Westmoreland County.

Location	Depth of wells (Feet)	Water bed	Quality of water
Bainesville	35–60	Sand and clay	Soft to hard
Erica	12–18	Sand and marl	....
Hague	35–40	Sand and gravel	Soft
Homers	20–45	Sand	Soft
Index	30–45	Sand and gravel	Soft
Kinsale	15–25	Sand and marl	Soft to hard
Leedstown	14–20	Sand	Soft
Machadoc	12–30	Sand	....
Maplegrove	30–60	Sand	Soft
Meter	15	Sand	Hard
Montross	30–50	Sand	Soft, hard
Oldhams	18–60	Clay	Soft
Potomac Mills	15–30	Sand and marl	Soft to hard
Rollins Fork	30–50	Sand	Soft
Remus	30–80	Sand	Good
Templeman Cross Roads	25–35	Sand	Soft
Tuckerhill	16–60	Sand	Good
White Point	18–20	Clay and sand	Soft
Zacata	15–40	Clay	Deep, hard; shallow, soft.

Conclusions.—The volume of flows obtainable by carefully cased wells from the artesian sands under Westmoreland County, the quality of the water, its superiority to the supplies obtained by many dug wells, and its freedom from disease germs, are reasons for more extensive development of these sands. Flows are not to be expected at points more than 35 feet above sea level, but higher heads than those found in the artesian sands nearest surface can be obtained by deeper drilling.

At Oak Grove, soft water free from disease germs can be had by pumps from wells to the Calvert sands at 250 feet, or the Potomac at 450 feet. The water from the latter will rise to about 25 feet of surface.

At Montross the water from the Pamunkey sands, to be reached at 400 feet, will rise to about 70 feet of the level of the Courthouse. In Kinsale, flows at the elevation of the higher ground in the village are impossible; wells to the Pamunkey sands at 500 feet may rise fully 30 feet above the river.

YORK COUNTY.

General description.—York County, one of the original shires of Virginia, lies along the south side of York River on "the peninsula," of which it covers the larger portion. The surface of the county is diversified by tributaries of York River, the more important creeks being Ware, Scimmins, King and Queen, which cut back into the several Columbia terraces. The greatest elevation of the Sunderland terrace, at the northwestern corner of the county, is about 110 feet.

Geology.—The Columbia formations form the soils over most of the county. No formations older than those of the Chesapeake group are visible. Along York River the St. Mary's and Yorktown formations outcrop, and at Yorktown, the type locality of the latter, and 3 miles up stream the bluffs are full of shells. Firm rock composed almost wholly of ground-up shells makes the base of the bluff at Yorktown. The bottom of the Chesapeake group lies 180 feet below tide water in the northwestern corner of the county, and 550 feet below in the vicinity of Messick. The Pamunkey (Eocene) greensands and clays which underlie the Chesapeake formations are about 100 to 200 feet thick. Their base is approximately 400 to 800 feet below sea level. Upper Cretaceous beds undoubtedly underlie the Pamunkey, but their thickness is undetermined. The base of the Potomac (Lower Cretaceous) group lies possibly 1,200 feet below tide water in the northwestern part of the county and 2,300 feet below in the southeastern. The total thickness of the group in the eastern part of the county is fully 1,300 feet.

UNDERGROUND WATERS.

Distribution and quality.—The Columbia formations all carry more or less ground water, the depth to the water table, the yield to wells, and the quality of the water differ with the location of the wells. Wells on high ground, away from a terrace seep or creek valley, obtain soft water from the Sunderland or Wicomico sands within 20 feet of surface; other wells may go 40 feet to water. On the sands of the lowest terrace, east of Yorktown, wells are only 8 to 15 feet deep. The water is mostly soft but in places is iron-bearing, and under marshy tracts along tidal inlets is brackish. Dug wells on this terrace sometimes fill to the top. Where, near terrace scarps or stream valleys, the sands of the higher terraces are thin or contain little water, dug wells go through them and obtain ground water from the Yorktown or St. Mary's formation. This water is at many places hard or irony.

Artesian waters underlie the whole county. The sands in the Calvert formation of the Chesapeake group, in the Nanjemoy formation of the Pamunkey, and in still lower formations, have been tapped by wells on the north bank of York River, but, according to reported depths of wells, only those in the Chesapeake group have been developed in York County.

The supplies obtained are of good volume, heads range up to 30 feet, and the quality is generally satisfactory, the mineralization being greatest in the wells farthest down stream. A slight sulphur odor and a high proportion of bicarbonate of soda are the prevailing characteristics.

Springs.—Seeps and small springs from Columbia sands feed creeks that flow to York River, but are of little economic importance. Most of the larger springs flow from shell beds in the Chesapeake group; a few are used for household supply, and some of these can be used to better advantage by rams.

Wells.—There are many driven wells, and a few drilled wells less than 100 feet deep, on the low expanses of the Talbot terrace in the southeast end of the county; there are a few deep drilled wells along York River; elsewhere dug wells are used to reach underground waters. The relatively small number of drilled wells is a result of the small amount of low ground on the south bank of the river, most buildings being on high ground.

LOCAL SUPPLIES.

At Yorktown there were in 1906 but 3 dug wells; one on the bluff is 60 feet deep, the two others at lower elevation are 40 and 14 feet deep, respectively. All three go into shell beds and yield hard water. Cisterns are the usual source of domestic supply. A drilled well on the beach, 750 feet deep, yields 1 gallon per minute through a 1-inch pipe. The water is considered good.

At Messick a drilled well 60 feet deep found a flow of slightly irony water in sands lying either at the base of the Columbia or the top of the Chesapeake group. Particulars of the wells drilled along York River and its tributary creeks above Yorktown are summarized in table 5. They draw on sands tapped by wells across the river in Gloucester County.

One of the more notable wells is that of A. G. Harwood. This well is 400 feet deep and the flow has a head of over 20 feet.

Conditions reported from a number of places in York County that rely on dug wells are summarized in the following table:

Details of dug wells in York County.

Location	Depth of well *(Feet)*	Water bed	Quality of water
Grafton	16	Sand and marl	Hard
Grove	20–60	Shallow, sand; deep, marl.	Hard
Messick	8–15	Sand	Soft to brackish
Oaktree	25–50	Sand and marl	Soft to hard

Conclusions.—The artesian water prospects in York County vary from good to poor. In the western part of the county good flows can be obtained from Chesapeake, Pamunkey, and Potomac sands down to 1,000 feet or more below sea level, and the resources are practically inexhaustible. Farther east, as indicated by deep drilling in Warwick County to the south, and in Gloucester County to the north, the Calvert sands probably grow fine or clayey; they yield little water, and this contains a decidedly high proportion of solids in solution.

At Yorktown the same sand that is tapped at Gloucester Point yielded little water and the flows from the sands reached by the 750-foot well on the beach were disappointingly small. Stronger flows may perhaps be had by going deeper, but the water will not be any better. Heads will not be over 30 feet above tide and to raise the water to the top of the bluff pumping will be necessary.

On the low ground that begins 4 miles below Yorktown the same conditions probably prevail as in the east end of Gloucester County. Fair water, that will rise 2 or 3 feet above tide, may be found in the Yorktown formation by wells 80 to 100 feet deep; but little or no water will be found in the lower half of the Chesapeake, or in the Pamunkey. Deeper drilling will find flows in Upper Cretaceous or Potomac beds, but the water will be highly mineralized and at the wells farthest east decidedly saline. There is no reason to believe that better water will be found below 1,000 feet than above that depth. It probably will not pay to try to develop the sands in the Potomac group anywhere in the low ground below the scarp that runs across the peninsula from Newport News to 4 miles east of Yorktown.

TABULATED WELL DATA.

The following table (5) summarizes the information collected by correspondence and field work in regard to a large number of wells in the Tidewater region of Virginia. The list is very far from being complete, no attempt having been made to procure information regarding every well or even a majority of the wells at places where much drilling has been done, such as Colonial Beach, West Point, and Franklin. The depths, heads, and yields printed are in general correct, but some, because they were given from memory by owners, well drillers and others, are little better than guesses. Where figures reported by different persons varied, the more probable figures were taken. The authority for the items relating to each well is shown by the letters in the fifth column of the table, O standing for owner, D for driller, and M for miscellaneous—some third party—in many instances the local postmaster.

In tables 7, 8, 9, 10, and 11 are assembled available analyses and field assays of water from some of the wells listed in table 5. Information regarding the mineral constituents of the water from some of the springs mentioned is segregated in table 6.

Attention is called to the fact that some of the assays and analyses are more reliable than others, but the writer has not attempted to designate those that he considers the most carefully made. As regards the field assays, which are distinguished by (F) after the name of the analyst in the last column of each of the tables, they were made with the apparatus devised by the U. S. Geological Survey.[a] The determinations practicable with this apparatus differ widely in accuracy. The writer's experience is that the determination of chlorine can be made with most precision, and that the accuracy of the determinations of iron, calcium, sulphates, or total hardness may be seriously impaired by substances in solution interfering with the reaction that should normally take place.

[a]Leighton, M. O., Field Assay of Water, U. S. Geol. Survey, W. S. Paper 151, 1905, pp. 27-75.

Results of all analyses and field assays are stated in parts per million and in ionic form. Thus, a water containing dilute solutions of bicarbonate of lime, bicarbonate of soda, sulphate of soda, sulphate of potash, and chloride of soda (common salt) has its composition indicated by so many parts per million of calcium (Ca), sodium (Na), potassium (K), bicarbonates (HCO_3), sulphates (SO_4), and chlorides (Cl).

TABLES OF ANALYSES OF WELL AND SPRING WATERS

TABLE 5—*Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide.	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
ACCOMAC						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Accomac	near	Benj. T. Melson	I. B. Clark	O	1904	24	50	2	50	15,35	50
Accomac	2 mi. E.	L. L. Tiffany	....	M	1899	2	100	2	100	....	....
Belinda	½ mi. E.	M. E. Hall	I. B. Clark	O	1902	2	68	1½	....	....	....
Belinda	½ mi. E.	M. E. Hall	J. W. T. Robertson	O	1899	6	84	2	....	....	....
Belinda	Near	Hall & Rose	I. B. Clark	O	1902	2	68	1¼	....	....	....
Belinda	½ mi. S.	J. D. Bull	....	..	....	....	80	....	40	....	....
Bellehaven	....	C. S. Witham & Bros	....	M	....	....	86	1½	....	....	....
Bellehaven	....	D. R. Mister	....	O	....	5	120	1½	120	....	....
Bellehaven	....	C. F. Chase	....	M	1901	2	60	1½	....	6-16	....
Bloxom	....	Guilford Church	W. McK. Taylor	M	....	....	105	1½	....	....	....
Boggs	near	H. Battail	I. B. Clark	O	1906	10	150	1½	150	....	130
Boggs	near	F. C. Taylor	I. B. Clark	O	1904	8	150	1½	150	75	60
Cashville	....	E. M. Boggs	J. W. T. Robertson	O	1902	8	101	1½	101	....	100
Cashville	....	H. R. Boggs	J. W. T. Robertson	O	1902	6	97	1½	97	....	97
Cashville	....	H. R. Boggs & Bro	J. W. T. Robertson	O	1904	6	90	1½	....	....	....
Cashville	....	Broadway Baptist Church	J. W. T. Robertson	M	1904	12	110	1½	110	....	110
Cashville	....	S. Crockett	Bailey East	D	....	2	112	1½	112	....	....
Cashville	....	W. S. Finney	J. W. T. Robertson	O	1902	7	100	1½	100	....	100
Cashville	....	T. W. Scott	J. W. T. Robertson	O	1902	2	97	1½	97	....	....
Cashville	....	T. W. Scott	J. W. T. Robertson	O	1904	2	87	1½	87	....	....
Cashville	....	T. W. Scott	J. W. T. Robertson	O	1906	2	90	1½	90	....	....
Chesconnessex	....	Bailey East	Bailey East	O	1905	1½	137	1½	137	40,75,100	....
Chesconnessex	....	J. L. Savage	I. B. Clark	D	1903	5	103	1½	....	....	....
Chesconnessex	....	F. Jenkins	J. W. T. Robertson	M	1901	1	90	1½	90	....	....
Chincoteague Is.	....	United States	....	..	1885?	3	135	2	....	....	....
Chincoteague Is.	....	James Williams	James Williams	..	1890	5	70	1½	....	....	....
Craddockville	....	Thos. J. Custis	I. B. Clark	O	1902	2½	62	1½	60	12,22	60
Craddockville	....	G. B. Mason	J. W. T. Robertson	O	1902	6	60	2	60	....	20
Craddockville	....	L. J. Melson	J. W. T. Robertson	O	1900	4	140	1½	140	....	....
Craddockville	....	L. J. Melson	I. B. Clark	D	1904	7½	175	1½	173	....	140
Davis Wharf	....	S. J. Bull	J. W. T. Robertson	..	1902	....	105	2½	....	....	105
Finney	near	Susan A. Finney	....	M	1899	2	90	1½	90	....	....
Finney	....	W. F. Rogers	J. W. T. Robertson	O	1901	1½	83	1½	83	....	83
Finney	....	Mears	I. B. Clark	D	1906	1½	80	1½	....	....	83
Finney	....	S. F. Rogers	....	..	....	....	....	....	....	....	....
Fox Island	....	Wm. Ellinger	J. W. T. Robertson	O	1903	0	76	1½	....	....	....
Franklin City	near	Wm. B. Powell	F. T. Mumford	..	1904	60	73	1½	70	36,38	....
Gratons	¼mi.N.E.	W. A. Bloxom	F. T. Mumford	O	1904	11	151	1½	151	80	....
Gratons	....	J. W. Weasells	F. T. Mumford	O	1904	10	160	1½	160	85	....
Gratons	near	E. D. Groton	F. T. Mumford	..	1904	10	100	1½	100	75	....
Harborton	near	J. W. Adams	J. W. Adams	D	1905	8	149	1½	....	....	138
Harborton	near	W. H. B. Custis	J. W. Adams	D	1900	8	144	1½	....	....	55
Harborton	near	Allen & Sennen	....	M	1882	6	148	1½	....	....	....
Harborton	near	S. K. Martin	I. B. Clark	D	1903	10½	137	1½	137	35, 128	94
Harborton	near	Martin & Mason Co	J. W. T. Robertson	O	1903	2	140	1½	140	35, 128	100
Harborton	....	Geo. Moore	J. W. Adams	D	1906	8	174	1½	....	....	60
Harborton	....	W. K. Reed	J. W. Adams	D	1905	8	139	1½	139	....	55
Harborton	....	J. W. Walker	J. W. Adams	D	1905	8	145	1½	145	....	55
Hallwood	....	Wesley Bloxom	J. W. Adams	D	1904	5	150	....	....	....	....
Hallwood	....	Wm. T. Bloxom	J. W. T. Robertson	D	1906	7	103	....	....	....	....
Hallwood	near	James A. Hall	I. B. Clark	..	1903	10	186	1½	20	110, 150	....
Hallwood	near	New York, Philadelphia & Norfolk R. R.	....	..	....	10	35-60	....	....	....	....
Hallwood	....	James W. Tailor	....	..	1902	10	140	1½	....	....	....
Hopkins	....	John Barnes	J. W. T. Robertson	..	....	....	125	1½	125	....	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
Gray sand	Columbia	+17		5	58	Soft	Domestic and stock
	Columbia (?)	+10	1¼		59		Drinking and stock
Sand and shells	Columbia	+10		2		Hard, brackish, irony	Washing oysters
	Columbia (?)	+2					Abandoned
Sand and shells	Columbia	0				Hard, brackish, irony	Washing oysters
	Columbia	flows				Soft	Domestic
	Columbia						Domestic
	Chesapeake (?)	+5					Domestic and canning factory
Sand	Columbia	+4					Drinking
	Chesapeake (?)						Drinking
	Chesapeake (?)	+8				Soft	Domestic
Sand	Chesapeake (?)	+8	5			Soft	Domestic
	Chesapeake (?)	+5		8	60	Slightly sulphur and iron-bearing	Domestic
	Chesapeake (?)	+4		8		Slightly sulphur and iron-bearing	Domestic and stock
	Columbia (?)						Stock
	Chesapeake (?)			10	59	Slightly sulphur and iron-bearing	Domestic
	Chesapeake (?)	+1					
	Chesapeake (?)	+4		8	60	Slightly sulphur and iron-bearing	Domestic
Sand	Chesapeake (?)	+2	¼–1				Domestic
	Columbia (?)	+3	2				Domestic
	Columbia (?)						Domestic
	Chesapeake	0				Irony	Domestic and stock
	Chesapeake						Domestic
	Chesapeake	+2	1				Domestic
	Chesapeake (?)						No flow, abandoned
	Columbia						No flow, abandoned
Gravel	Columbia	+5	3				Domestic and stock
	Columbia	+1½	3				Domestic and stock
Shelly rock	Chesapeake (?)	+6	1			Soft	Domestic and stock
	Chesapeake (?)	+8?					
Sand	Chesapeake (?)						
			6		59	Slightly sulphur-bearing	Domestic and stock
	Columbia (?)	+3	4		60	Slightly sulphur-bearing	Domestic and stock
Gravel	Columbia (?)	+2	4				Domestic and stock
Gravel	Columbia (?)						
Sand and gravel	Columbia (?)	0		5		Hard, salt and iron-bearing	Washing oysters
	Columbia						Domestic
Sand and shells	Chesapeake (?)			15		Soft	Domestic and stock
Rock at 85	Columbia (?)	+5				Soft	Domestic and stock
Sand and shells	Columbia (?)	+6		15		Soft	Domestic and stock
Sand	Chesapeake (?)	+8					Domestic
Sand	Chesapeake (?)	+8					Domestic
	Chesapeake (?)	+8	4–5		62		Boiler
Gravel	Chesapeake (?)	+12	1			Slightly sulphur-bearing	Domestic and stock
Gravel	Chesapeake (?)	+8	5			Slightly sulphur-bearing	
	Chesapeake (?)	+8½					Domestic
	Chesapeake (?)	+8½					Domestic
	Chesapeake (?)						Domestic
Shells	Chesapeake (?)	+1		15			Domestic and stock
Shells	Chesapeake (?)	+3½		15			Household
Gravel	Chesapeake (?)					Irony	Not used
	Columbia						Locomotives
	Chesapeake (?)					Irony	Not used
Rock at 63 ft	Chesapeake (?)	flows				Soft	Domestic and stock

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
ACCOMAC—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Hopkins		Oliver Barnes	J. W. T. Robertson	O	1897	.....	108	2	.....	.....	70
Hopkins		J. S. Gordy	J. W. T. Robertson	O	1902	.....	119½	2	119½	60	116
Hopkins	½mi.S.E.	A. J. Lewis and W. J. Russell	J. W. T. Robertson	O	1904	4	64	1½	64	15	48
Hopkins		Frank Lewis	J. W. T. Robertson	D	1903	2½	175	1½	170	115–170	120
Hopkins		H. A. Lewis	W. McK. Taylor	O	1901	1	95	1½	95	.....	75
Justisville	near	J. R. Ewell	W. McK. Taylor	M	.....	.....	130	1½	.....	.....	....
Justisville		J. T. Willett	W. McK. Taylor	O	1906	.....	68	1½	65	.....	65
Leemont	2 mi. S.E.	J. H. Hopkins	J. W. T. Robertson	O	1897	5	100	1½	100	.....	....
Leemont		H. A. Lewis	W. McK. Taylor	O	1899	8	122	2	122	.....	....
Locustville		G. L. Dougherty	I. B. Clark	D	1905	6	104	1½	104	.....	....
Locustville		B. T. Gunter	J. W. T. Robertson	O	1899	6	140	2	122	.....	122
Mappsville		J. W. Tailor	I. B. Clark	D	1904	40	70	1½	70	16, 32	....
Marsh Market	near	Jas. A. Hall (Two wells)	I. B. Clark	D	1904	.....	55–72	1½	.....	.....	....
Marsh Market	near	Jas. A. Hall (Two wells)	J. W. T. Robertson	O	1906	5	92	2	.....	.....	....
Mearsville	2mi.N.W.	J. R. Hart	W. McK. Taylor	M	1901	3	85	2	85	25, 40	....
Mearsville		S. Rue	J. W. T. Robertson	D	1906	6	150	2	.....	.....	....
Mearsville		W. J. Somers	I. B. Clark	D	1904	6½	117	1½	117	80	100
Mandua		Richard Cutter	J. W. Adams	D	1906	4	82	1½	.....	.....	80
Mandua		H. Guy	J. W. T. Robertson	D	1905	2	80	2	.....	.....	60
Mandua		John B. Henderson	.....	O	1902	8	153	1½	153	.....	140
Mandua		Dr. A. T. L. Kusian	J. W. T. Robertson	O	1902	2	74	2	70	8	70
Mandua		John O. Stevens	J. W. Adams	D	1906	.....	140	1½	140	92	100
New Church	near	J. E. Johnson	I. B. Clark	O	1905	24	125	2	125	35,40,82	125
Onancock	near	Town	C. S. York & F. A. Merrill	D	1895	8	16–50	2½	50	.....	....
Onancock	near	Town	B. T. Parker	M	1890	10	350	....	.....	.....	....
Onancock	near	Town	J. H. K. Shanahan	M	1894	10	486	....	140	140	....
Onancock	near	H. L. Crockett	J. W. T. Robertson	O	1899	2½	109	1½	104	94	....
Onancock	near	W. B. Pitts	J. W. T. Robertson	O	1900	4	130	2	.....	.....	....
Onancock	near	M. L. Hurst	J. W. T. Robertson	O	1900	3	36	1½	35	9	20
Onley	near	Joseph Bull	J. W. T. Robertson	O	1905	15	51	....	.....	.....	....
Onley	near	J. W. Rodgers	I. B. Clark	D	1905	10	53	1½	53	10, 25	....
Parksley	3 mi. W.	W. McK. Taylor	W. McK. Taylor	O	1904	6½	135	1½	135	10,30,60	135
Pungoteague		S. W. Ames	I. B. Clark	O	1903	18	210	1½	204	20,30,55	208
Pungoteague	1 mi. N.	T. J. Custis	J. W. T. Robertson	O	1902	.....	140	1½	140	.....	140
Pungoteague		S. D. Taylor	J. W. T. Robertson	O	1904	20	110	1½	63	.....	63
Pungoteague		G. B. Mason	J. W. T. Robertson	O	1899	.....	60	2	60	10	....
Pungoteague		J. S. Waterfield	J. W. T. Robertson	O	1902	4½	158	1½	158	150	158
Pungoteague		J. S. Waterfield	J. W. T. Robertson	..	1902	.....	140	1½	.....	.....	....
Quinby	¾ mi. W.	Machipongo Bridge Co.	J. W. T. Robertson	O	1904	5	87	1½	87	16, 32	....
Sanford	near	Frank McKay	J. W. T. Robertson	O	1898	5	76	2	.....	.....	....
Sanford		J. J. Furniss	.....	..	.....	.....	82	2½	.....	.....	....
Saxis	near	J. T. Weaver	I. B. Clark	O	1904	4	112	1½	110	73	112
Sanford		Baltimore, Chesapeake & Alantic Steamboat Company	I. B. Clark	D	1903	4	95	1½	.....	.....	....
Tangier Island		J. J. Daly	J. W. T. Robertson	D	1905	3	250	2	141	8	169

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
	Chesapeake (?)						Domestic and stock
Sand and rock at 90 ft.	Chesapeake (?)	flows	2				Domestic and stock
Gravel	Columbia	+1½		25		Soft	Domestic and stock
	Chesapeake (?)	+4	2				Domestic and stock
	Columbia	+2	½			Sulphur	Domestic and stock
	Chesapeake (?)					Soft	
	Chesapeake (?)			5			Domestic and stock
Rock at 90 ft. gravel	Chesapeake (?)	+5	2½			Soft, slightly sulphur and iron-bearing	Domestic and stock
Sand	Chesapeake (?)	+6½				Slight sulphur	Domestic
	Chesapeake (?)	+7	1½				Domestic
Sand	Chesapeake (?)	+3½		12			Domestic
Sand	Columbia	+5					Domestic and stock
	Columbia	+5					Domestic and stock
	Columbia	+4		5			Boiler
Rock at 40 ft. Sand	Columbia	+1½		8		Soft, irony	Household and stock
	Columbia (?)						
Sand	Columbia	+8	1½				Household and stock
	Columbia	+8	1½				Domestic and stock
	Columbia	+2½					
	Chesapeake (?)	+7		5	58		Domestic and stock
Rock	Columbia	+4	1¾		59	Soft, slightly iron-bearing	Drinking and stock
	Columbia (?)						Domestic and stock
	Columbia (?)	+15		5			Domestic
Sand	Columbia					Hard	Town supply
	Chesepeake						No flow, abandoned
	Chesapeake			5		Sulphur-bearing	No water below 140 feet, abandoned
Sand	Columbia	+3	1				
Sand	Columbia		4			Soft	Domestic and stock
	Columbia	+5	2				Domestic and stock
	Columbia						
	Columbia	+8		5			Domestic
Sand	Columbia	+7				Soft	Domestic and stock
	Chesapeake (?)	+8			59	Soft	Domestic and stock
	Columbia (?)						Domestic and stock
	Columbia	+10		6	60		Domestic and stock
	Columbia	flows	3				Domestic and stock
Sand and gravel	Chesapeake (?)		18(?)				Domestic and stock
	Columbia (?)						Domestic and stock
Sand	Columbia	+7	1½	25		Irony	Domestic
Sand and shells	Columbia	±0					Domestic and stock
	Columbia			5			Domestic and stock
Sand and gravel	Columbia	±0		5		Hard	Domestic and stock
	Columbia	±0					
Fine sand	Chesapeake (?)	±0		5		Salty	No flow, abandoned

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
ALEXANDRIA						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Addison		Standard Brick Co.		..	1895	.....	140	....	....	....	....
Addison		New Washington Pressed Brick Co.		O	1898	.....	131	....	....	....	....
Alexandria		Southern Railway		..	....	.....	370±	....	....	....	....
Alexandria		C. M. Adams		O	1898	200	68	48	64	....	....
Alexandria		Alexandria Fertilizer and Chemical Co.	R. L. Thomas	O	1906	10	445	8–6	225	350	....
Alexandria		Belle Pre Bottle Co.		O	1907	40	185	6	175	....	....
Alexandria		People's Ice Co.		O	1894	82	401	8–6	....	....	....
Alexandria		Robert Portner Brewing Co.	W. C. Miller	O	1888	38	430	8	410	61	370
Alexandria		Robert Portner Brewing Co.		O	1902	35	370				
				O	1903	38	392	8	370	61	....
Alexandria		Washington, Alexandria & Mount Vernon Ry.	Washington Well Drilling Co.	M	1904	8	135	6	60	....	....
....		G. N. Saegmuller	W. C. Miller	D	....	.....	555	....	80	....	....
Ballston		Livingston Heights Syndicate		..	....	.....	160	6	160	100	....
Ballston		Admiral Weaver		O	.....	300	60	24	50	....	....
Fostoria		A. M. Lathrop	W. C. Miller	D	.....	172	....	....	....	....	....
Weddebourne		R. W. Walter		O	.....	480	130	6	126	30	....
CAROLINE											
Etta		C. M. Harris	C. M. Gouldman	..	1905	16	175	1½	173	....	12
Mossneck		A. B. Lewis	Geo. Heflin	D	.....	30	169	2	167	100	167
Port Royal		J. D. Farish	C. M. Gouldman	O	1905	35	243	2	....	....	....
Port Royal		C. M. Gouldman	C. M. Gouldman	M	1905	23	200	1½	200	175	40
Port Royal		Mrs. Eliza T. Pratt		M	.....	25	200?	2	200?	....	....
Port Royal		Town of Port Royal	Hammer & Hall	M	1905	4	235	1½	235	....	....
CHARLES CITY											
Roxbury	near	T. L. Walker	Sydnor Pump & Well Co.	O	1902	40	280	2–1	280	70	80
Shirley	near	H. S. Saunders	H. E. Shimp	D	1908	.....	355	2	....	....	....
Sturgeon Point		J. J. Truax	Sherman Jones	O	1895	50	60	72	40	....	....
Westover	1¼mi.E.	Wm. M. Ramsay	Sydnor Pump & Well Co.	O	1901	15	139	10	134	139	....
Willcox Wharf		E. A. Saunders, Jr., and Son (6 wells)		O	1907	2–24	168–184	2	168–184	....	....
DINWIDDIE											
Petersburg	¼mi.E.	J. B. Worth Co.	A. P. Jerguson	D	1892	5	600	8	....	....	....
ELIZABETH CITY											
Fort Monroe	near	Chamberlain Hotel	Thos. B. Harper	O	.....	4	945	4	....	....	....
Fort Monroe	near	United States		M	.....	3	907	....	....	....	....
Fort Monroe	near	United States		M	1896	3	2,254	15–6	....	many	2250
North End Point			R. H. Milligan	D	1896	4	1,035	3	....	....	....
North End Point			J. S. Darling	M	1887	2	1,172	6(?)	....	....	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
Sand	Patuxent	+5		75		Soft	Boiler
	Patuxent					Soft	Boiler
							Abandoned
Sand and gravel		130				Soft	Domestic and stock
Sand and gravel	Patuxent	–5		60		Acid and iron-bearing	
	Patuxent			65			Glass works
	Patuxent	+3		300		Soft	Ice manufacture, table water
Sand	Patuxent			90	62	Soft	Brewing, boilers and drinking
	Patuxent			80 200			Brewing, boilers and drinking
		+23	3		61		Drinking
Granite				2			
				2			
Granite				15		Excellent	
Granite				13			
		+27	¼		63		Household and stock
Black clay	Patuxent (?)		¼				
	Pamunkey (?)						Domestic
Dark sand	Pamunkey (?)	+24				Soft	Domestic and stock
	Pamunkey (?)					Soft	Domestic
	Pamunkey (?)	+10	10		61	Soft	Domestic and stock
Gravel	Potomac			10	61	Soft, slightly sulphur	Boiler, domestic and stock
							No flow; not used
Clay	Chesapeake	+10				Soft	Domestic and stock
Fine black sand	Pamunkey	+5		70		Soft	Domestic and stock
	Pamunkey	+32	6–80				Domestic and stock
Granite				100		Soft	Boiler, ice manufacture
	Upper Cretaceous	+14	10			Saline, ferruginous	Flushing
						Saline	Never used
Sand	Several					Saline	Never used
							Never used; no flow
							Never used: no flow

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
ESSEX											
						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Bowlers Wharf..	near	Claybrook & Neale Packing Co.	L. Rude	O	1898	5	165	1½	165	....	16
Bowlers Wharf..	near	Garrett & Hunt	Garrett & Hunt	O	1903	5	167	2	167	130	151
Bowlers Wharf..	near	Garrett & Hunt	H. L. Skimp	O	1896	5	185	....	.....	130	....
Bowlers Wharf..	near	Garrett & Hunt	....	M	......	8	182	1½	.....	....	....
Bowlers Wharf..	near	C. P. Garrett	J. H. Taylor	O	1902	10	185	1½	185	170	....
Bowlers Wharf..	½mi. S.	I. W. Hunt	I. W. Hunt	O	1898	19	182	1½	.....	....	....
Blowers Wharf..	1 mi. N.	Frank Hutchinson	J. H. Taylor	O	1903	4	172	1½	170	....	160
Blowers Wharf..	1 mi. N.	R. C. Kaighn	J. H. Taylor	O	1902	4	168	1½	165	....	163
Bowlers Wharf..	near	R. G. Neal	W. S. Johnson	O	1888	9	130	1½	.....	....	....
Bowlers Wharf..	½mi. S.	A. D. Pitts	J. H. Taylor	M	1905	.....	240	1½	.....	....	192
Bowlers Wharf..	near	Wm. J. Rice	W. S. Johnson	O	1888	7	260	1½	.....	....	....
Butylo	2mi.N.W.	I. W. Hunt	I. W. Hunt	O	1898	5	221	1½	.....	....	80
Caret	....	J. P. Taliaferro	Hammell & Hale	M	1903	30	300	1½	290	....	....
Center Cross	2mi. S. E.	C. F. Kriete	Lyle & Rude	O	1891	80?	350	1½	.....	....	300
Center Cross	2mi. S. E.	C. F. Kriete	W. S. Johnson	O	1895	4	190	1½	.....	....	180
Center Cross	2mi. S. E.	C. F. Kriete	L. Rude	O	1903	6	195	1½	.....	....	190
Champlain	....	Joseph Baker	....	..	1903	33	75	1	.....	....	....
Chance	....	J. H. C. Beverly	L. Rude	O	1898	40	380	2	380	250	....
Chance	....	J. H. C. Beverly	L. Rude	M	......	20	260	....	.....	....	....
Chance	....	Mrs. M. S. Sale	L. Rude	..	1897	30	180	2	180	none	....
Dunnsville	....	J. E. Kriete	Geo. Beazeley	O	1888	7	300	1½	.....	....	188
Dunnsville	....	J. E. Kriete	Chas. Ramsam	O	1903	100	60	36	.....	....	....
Loretto	....	H. L. Baylor	L. Rude	M	1888	−7	160	....	.....	....	....
Loretto	....	W. C. Dickinson	L. Rude	O	1900	38	198	1½	198	....	....
Tappahannock ..	near	G. N. Anderson	....	M	......	18	274	1½	.....	....	....
Tappahannock ..	near	T. E. Blakey	O. D. Hale	O	1906	19	272	1½	.....	....	65
Tappahannock ..	near	Wm. V. A. Andrews	Hammell & Hale	M	1902	20	270	1½	.....	....	....
....	....	John Bradley	H. E. Shimp	M	1902	10	278	1½	.....	....	....
Tappahannock ..	¼mi. E.	B. B. Brochenborough	Geo. Beazeley	O	1901	18	272	3–2	272	....	272
Tappahannock ..	1mi.N.W.	B. B. Brochenborough	Hammell & Hale	O	1905	27	273	1½	270	....	....
Tappahannock ..	1mi.N.W.	B. B. Brochenborough	Hammell & Hale	O	......	15	270	....	.....	....	....
Tappahannock ..	near	R. T. Cauthorn	W. J. Reamey	O	1895	18	275	1½	.....	....	275
Tappahannock ..	near	G. F. Croxton	Hammell & Hale	O	1904	20	268	1½–¾	.....	....	268
Tappahannock ..	near	G. W. Daingerfield	O. D. Hale	O	1906	21	275	1½	2	....	65
Tappahannock ..	¼mi. E.	Donaldson & Schultz	Hammell & Hale	M	1900	4	256	1½	256	125	60
Tappahannock ..	near	J. W. Faulconer	Hammell & Hale	O	1903	15	275	¾	275	150	275
Tappahannock ..	....	J. H. Henley	Hammell & Hale	O	1898	16	275	1½	275	....	275
Tappahannock ..	near	T. C. McDaniel	....	O	1903	17	282	1½	278	....	278
Tappahannock ..	near	L. E. Munford Banking Co.	Hammell & Hale	O	1904	18	275	1½	275	150	....
Tappahannock ..	2mi. W.	D. Passagaluppi	H. E. Shimp	O	1903	8	275	1½	.....	....	....
Tappahannock ..	....	W. B. Robinson	Hammell & Hale	O	1904	.....	277	2	277	60–275	....
Tappahannock ..	near	G. R. Scott	....	..	......	18	275	1½	.....	....	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
Sand	Calvert	+12	49		61½	Soft	Canning factory
Sand	Calvert	+15	30		63	Soft	Drinking and washing oysters
	Calvert	+15				Soft	Not used
	Calvert		5			Soft	
	Calvert	+15	17				Household
	Calvert	+19	2				
	Calvert	+10	7½		61½		Household and stock
	Calvert	+10	3				Household and stock
	Calvert		⅓				Household and stock
	Pamunkey	+14	6		61¼		Household
	Pamunkey	+12	7		61		Household
	Calvert	+15	20				Household
	Pamunkey	+31	⅙			Soft	Drinking
		+30					Not used, no flow
	Calvert	+12	6		61	Soft	Stock
	Calvert	+30	32		62	Soft	Canning factory
	Calvert					Soft	
White sand	Potomac	+43	2			Soft	Domestic
	Pamunkey						
White sand	Pamunkey	+35	2½			Soft, iron and sulphur	Domestic
Sand	Pamunkey		16			Soft	Stock
	Calvert (?)						
	Pamunkey		22				
	Pamunkey		5				Household
Sand	Pamunkey		½		60		Household
Sand	Pamunkey	+30	3		61	Soft	Domestic and public
Sand	Pamunkey		3			Soft	Household
Sand	Pamunkey						Household and stock
	Pamunkey	+31	2	2	62	Soft	Domestic
	Pamunkey	+35	2⅙			Soft	Domestic
	Pamunkey					Soft	Stock
	Pamunkey	+31	2		61½	Soft	Domestic
Sand	Pamunkey	+29	1½			Soft	Domestic and stock
Sand	Pamunkey	+25	1¾		61		
Sand	Pamunkey	+20	12–5½		62½		Pickle house
Sand	Pamunkey	+18	2			Soft	Household and stock
Sand	Pamunkey	+16	1			Soft	Hotel
Sand	Pamunkey	+20	1¾		61	Soft	Household
Sand	Pamunkey	20					Domestic and stock
Sand	Pamunkey						Domestic and stock
Fine sand	Pamunkey	+20	1–3			Soft	Domestic and stock
Sand	Pamunkey						Canning factory and domestic

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
ESSEX—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Tappahannock ..	near	H. Southworth	Hammell & Hale.....	O	1903	19	275	1½	.....	....	....
Tappahannock ..	near	R. C. Phillips & Co.....	Geo. Beazeley	O	1892	15	275	1½	.....	....	100
Tappahannock ..	near	Mrs. C. N. Temple......	Hammell & Hale.....	O	1904	.....	177	3	.....	70, 112 156	....
Tappahannock ..	near	E. N. Ware.............	H. E. Shimp.........	O	1898	18	280	1½	.....	....	....
Tappahannock ..	near	T. R. B. Wright........	Hammell & Hale.....	O	1904	18	277	1½	.....	....	....
Ware's Wharf...	1mi.N.W.	R. W. Eubank..........	Wm. S. Johnson.....	O	1888	2	190	1½	190	....	....
Ware's Wharf...	near	H. H. Ware.............	L. Rude	O	1899	5	180	1½	170	....	....
Ware's Wharf...	near	R. L. Ware Estate......	Wm. S. Johnson.....	O	1890	+3	205	1½	185	140	....
Ware's Wharf...	¾mi.N.W	R. L. Ware, Jr..........	L. Rude	O	1899	12	180	1½	170	100	....
Ware's Wharf...	near	W. L. Ware.............	Geo. C. Taylor.......	M	1895	14	170	1½	165	....	80
FAIRFAX											
Accotink	....	C. Lukens...............	——Bushong	M	1887	50	75	5	69	50	18
Accotink	....	J. P. H. Mason.........	....	O	1866	180	91	56	88	45	....
Clifton Station	....	W. H. Edwards	....	O	1895	.....	.....	.....	100	....	....
Gunston	....	....	L. W. Shepard.......	D	......	.....	560	....	264	....	....
Falls Church	....	Henry Birge	——Baker	M	1897	.....	80	6	.....	....	....
Fort Hunt	....	....	J. C. Miller.........	O	1891	30	165	6	.....	....	....
Fort Hunt	....	United States	J. C. Miller..........	D	1899	40	212	8	202	....	....
Mount Vernon...	....	Mount Vernon Co.	J. H. K. Shannahan	O	......	4	525	6	340	525	....
Riverside	....	Riverside Brick Co......	....	O	......	.....	125	6	.....	....	....
Woodbridge	....	....	Sydnor Pump & Well Co.	D	......	.....	600	6	150	....	....
GLOUCESTER											
Achilles	near	B. A. Rowe.............	....	O	1903	6	50	2	.....	....	....
Achilles	near	B. A. Rowe.............	H. E. Shimp.........	O	1903	6	615	2	450	600	268
Achilles	near	Union Church	H. E. Shimp.........	D	1905	5	450	2	400	....	400
Allmondsville ...	near	W. W. Allmond.........	J. V. Bray...........	O	1888	6	270	1½	270	150	....
Allmondsville ...	near	W. W. Allmond.........	H. E. Shimp.........	D	1907	20	400(?)	2–1	400	200	400
Bridges	3 mi. W.	G. E. Brown............	....	..	......	.....	.....	.....	585?	....	....
Bridges	3 mi.S.W.	James Brown	H. E. Shimp.........	D	1904	5	610	2–1	60 535	....	....
Bridges	2 mi. S.	Chas. Catlett	H. E. Shimp.........	O	1903	3	65	1½	.....	....	....
Bridges	2 mi. S.	Chas. Catlett	H. E. Shimp.........	O	1903	3	128	1½	.....	....	....
Bridges	2 mi. S.	Chas. Catlett	H. E. Shimp.........	O	1903	3	440	2–1	.....	....	....
Bridges	3 mi.S.W.	L. M. Kemp.............	H. E. Shimp.........	D	1905	0	510	1½	500	300	....
Bridges	....	Joshua Minor	....	..	1904	.....	550	.....	.....	....	....
Bridges	2 mi.S.W.	Dr. Oliver	H. E. Shimp.........	D	1904	.....	365	2	.....	....	....
Cappahosic	⅛ mi. E.	Sidney Monsell..........	H. E. Shimp.........	O	1904	33	416	4–1½	416	375	289
Claybank	at	L. M. Newcomb.........	H. E. Shimp & S. H. Fetterholf......	O	1905	6	367	1½	365	none	....
Freeport	near	E. C. Farinholt.........	H. E. Shimp.........	O	1901	2	330	1½	330	....	16 330
Freeport	near	R. H. Farinholt........	H. E. Shimp.........	O	1901	10	338	1½	330	....	280
Glass	....	L. Hall	H. E. Shimp.........	D	1904	.....	615	2–1	.....	....	....
Gloucester	near	W. E. Carr	Geo. Hughes.........	O	1885	70	350±	1½	350?	....	....
Gloucester	near	W. E. Carr	....	O	1895	70	180	1½	59	....	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
Sand	Pamunkey		1¾		61½		Domestic
Sand	Pamunkey	+29	1¼			Soft	
Sand	Pamunkey	+10	1½			Soft	Household and stock
	Pamunkey						Domestic
	Pamunkey		3		62		Domestic
Porous rock	Calvert	+5			61	Soft	Domestic and stock
	Calvert	+14	5½		61½	Soft	Domestic
Black sand	Calvert	+14	2–1		61	Soft	Domestic and stock
	Calvert	+14			61½	Soft	Domestic
Rock	Calvert	+16	½		61½		Domestic
Gravel		+40		16	56(?)	Hard	Stock and drinking
Blue clay		+92				Soft	Domestic and stock
Soft slate		–0				Soft	Domestic and stock
							Domestic
White sand	Patuxent			10			Domestic, stock
		+23		53		Soft	Supplies fort
Sand	Patuxent	+1		30			Drinking
	Columbia	±0		10		Soft	Boiler
Sand	Upper Cretaceous	+16	1¼		61½	Slightly saline, sulphur	Domestic
Rock	Pamunkey (?)	+10	¼		60	Slightly saline, sulphur	Drinking
Black sand	Calvert	+15	3		63	Soft, sulphur	Drinking
Rock	Pamunkey		2½			Soft	
							Washing oysters, medicinal
							Little water below 60 ft. Not used
	St. Marys	+1½				Soft	Drinking
	St. Marys						
	Calvert					Soft, sulphur	Little used
	Pamunkey	+32					
	Pamunkey				65(?)		
	Calvert (?)	+39					
Fine, dark green rock	Pamunkey	+42	5		65	Soft	Domestic, stock, boiler
	Calvert	+30	1½				Household and stock
	Calvert	+16	2		63		Household and stock
	Calvert		½		63		Household and stock
	Upper Cretaceous						
Black sand		+40					No flow, abandoned
		+40?					No flow, abandoned

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
GLOUCESTER—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Gloucester Point	near	Chesapeake S. S. Co., Gloucester County	H. E. Shimp	D	1903	6	694	2½ –1	690	none	180 694
New Upton	....	R. J. Bristow	H. E. Shimp	O	1901	8	415	¾	415	8–42 235	....
Pinetta	....	....	....	..	....	....	215	1½	....	....	....
Pinetta	....	E. H. Scanlan	....	..	1903	....	350	....	350	....	....
Selden	S. W.	Joseph Bryant	Sydnor Pump & Well Co.	O	1905	6	1,020	8	....	....	....
Selden	....	Joseph Bryant	....	..	1900	7	110	6	....	....	....
Selden	....	Joseph Bryant	D. E. Miller and H. E. Shimp	D	1905	7	981	6–2	850	....	981
Selden	S. W.	Alfred W. Withers	Sydnor Pump & Well Co.	O	1901	6	716	6–4	716	....	....
Sassafras	3 mi. S.	B. T. Weaver	H. E. Shimp	O	1904	4	336	1½	330	....	....
Severn	near	J. M. Shackelford	W. D. Diggs	O	1902	5	610	2	585	610 13 33 160	575
Signpine	3mi. S.W.	R. C. Coleman	....	O	1886	3½	211	1½	211 180	196	....
Signpine	2 mi. N.	E. H. Scanlan	H. E. Shimp	O	1903	25	350	2	....	....	....
Signpine	3½ mi. E.	Peter Van Name	——Thompson	O	....	5	180	2	....	....	....
Wareneck	2 mi. E.	W. A. Jones	....	M	....	8	300	1¼	....	....	....
GREENESVILLE											
Emporia	....	Town	Sydnor Pump & Well Co.	M	1906	....	600	8	470	62 370	28
HANOVER											
Ashland	¼ N.	Randolph-Macon College	....	O	....	....	140	2	....	....	....
Ashland	⅛ N.	Randolph-Macon College	....	O	....	....	100	4	....	....	....
Ashland	....	G. W. M. Taylor (Henry Clay Inn)	Sydnor Pump & Well Co.	M	1906	....	365	8	....	....	....
Ashland	....	Ashland G. S. & W. Co.	....	..	....	....	374	10	....	....	....
Doswell	near	Richmond, Fredericksburg & Potomac R. R.	....	..	....	....	250 327	6	....	....	....
HENRICO											
Catman	....	Curles Neck Farm	F. M. Gould	..	1900	30	926	8	....	32 150	311
ISLE OF WIGHT											
Benns Church	....	Heath	....	..	....	....	250	....	....	....	....
Ivor	....	Shaw Lumber Co	....	O	1907	60	190	6	185	....	....
Shoal Bay	3 mi. E.	J. A. Morgart	J. P. Ginder	O	1900	32	383	2	383	none	383
Shoal Bay	3 mi. E.	J. P. Tower	W. Wilson	M	1907	32	380	1½	....	....	200
Shoal Bay	½ mi. N.	W. D. Turner	....	M	1906	18	226	2½	220	none	200
Smithfield	....	Smithfield Mineral Water Co.	....	O	....	....	300	....	....	....	....
Zuni	near S.	J. M. Darden	J. T. Moore	O	1895	25	150+	2	....	....	....
Zuni	near	Town of Zuni	J. T. Moore	D	1895	....	162	2	....	....	....
Zuni	5 mi. E.	Mt. Carmel Christian Ch.	J. T. Moore	D	....	35(?)	190	2	....	....	....

Table 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
"White rock"	Upper cretaceous	+20	2		64+	Soft, sulphur	Drinking, household, etc.
Below rock	Calvert	+16	¼			Soft	Domestic and stock
	Calvert (?)	+4					
	Pamunkey						
							No flow, abandoned
	St. Marys	+8½		10		Hard	Drinking
	UpperCretaceous	+5	½			Saline, sulphur	
Sand	UpperCretaceous	+32	52		70	Saline, sulphur, irony	Washing, bathing
Dark green sand	Pamunkey	+20	1½	40		Soft	Domestic and stock
Rock	Pamunkey (?)	+16	⅕		65	Soft	Drinking
Rock at 196 ft. Sand	Calvert	+8	1			Soft, sulphur	Household and stock
Porous rock	Pamunkey	+30	1⅓			Soft	Domestic
	Calvert	+15	½			Soft, sulphur	Household
	Calvert						Stock
Granite		+20		100		Irony	Abandoned
Sandstone	Newark						Abandoned
Sandstone	Newark						Not used
	Newark						Hotel supply
				45 85			Public supply
	Newark	+30?					Drilled for locomotive supply; abandoned
Granite		+4		100	62	Soft	Domestic and stock
	St. Marys						
	St. Marys (?)						Domestic and boiler
Black and white sand	Calvert	+36	1/10		58	Soft, alkaline	Hotel, medicinal
Black and white sand	Calvert						
Black and white sand	St. Marys	+30	1/10			Alkaline	Drinking, medicinal
	St. Marys	flows				Soft, alkaline	Drinking, medicinal
	St. Marys	32(?)	2			Soft	Drinking
	St. Marys		1			Soft	Domestic and stock
	St. Marys		1½				Drinking

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
JAMES CITY						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Croaker	3½ mi. E.	W. H. Davis	Coleman Whitaker	O	1897	0	200	3½	200	185	200
Diascond	2 mi. S.	——Brick Co.	H. E. Shimp	M	1908		250?				
Lee Hall	4 mi. S. W.	Duke & Smith	H. E. Shimp	O	1903	23	429	2			
Lee Hall	4 mi. S. W.	Duke & Smith	H. E. Shimp & S. H. Fetterholf	O	1906	18	395	2	375	330	375
Lee Hall	near	H. M. Clement	S. H. Fetterholf	D	1906	40				300	
Lee Hall	2 mi. W.	Charles Bailey	H. E. Shimp	M	1908	10	200	2	200		
Jamestown	at	Asso. Preservation of Va. Antiquities	SydnorPump&WellCo.	O	1905	12	270	6	270		270
Jamestown	1½ mi. NE.	C. F. Ayers	Frank Carman	O	1906	15	300	3	295	171–271 15 45 190 260	298
Jamestown	1½ mi. N.	Chas. Babcock	Frank Carman	D	1906	12	320	3	310	280	298
Jamestown	⅛ mi. E.	Miss L. J. Barney		O	1894	10	290	3			
Jamestown	1 mi. N.	G. L. Burleson	Frank Carman	O	1906	15	310	3	309		309
Jamestown	1½ mi. NE.	E. Gilley	Frank Carman	O	1905	18	298	3	298		
Jamestown	2 mi. E.	Miss Rose D. Johnson		..	1901	6	250?	7			
Jamestown		Southern Land Co.	——McCormick	O	1906	20	270	1½			
Lightfoot	1 mi. S. W.	Powhatan Hunting Club.	S. H. Fetterholf	D	1903	8	140	2			
Williamsburg	¼ m. N. W.	Eastern State Hospital	G. Vaiden	M	1888	80	876	3–1			
Williamsburg	¼ m. N. W.	Eastern State Hospital	Frank Gould	M	1902	84	280	8			
Williamsburg	¼ m. N. W.	Marshall Estate	Frank Gould	M	1899	84	285	6			
Williamsburg	¼ mi. E.	Mrs. Israel Smith	G. Vaiden	M		88	299(?)	6			
Williamsburg	½ m. N. W.	William and Mary College	Frank Gould	M	1898	84	290	6	290	sever'l	280
Williamsburg	⅛ mi. N. E.	G. Vaiden	Frank Gould	O	1888	70(?)	276	6			
Williamsburg	¼ mi. W.	Williamsburg Knitting Mill	Frank Gould	M	1889	75	286	6	286		286
Norge	near	Chesapeake & Ohio Ry.	Sydnor Pump & Well Co.	O	1909	110	419	8			415
KING AND QUEEN											
Gressith	2 mi. W.	W. F. Anderson	W. Johnston	O	1885	11	206	2	206	150	180
King and Queen	near	County	Frank E. Pearce	M	1889	20	216	2	216		216
King and Queen	2 mi. S. W.	S. Bird	Frank E. Pearce	M		18	200(?)				
Little Plymouth	2 mi. S. W.	R. H. Spencer		O	1886	20	168	1½			
Mantapike	½ mi. S.	Mantapike Canning Co.	Jos. Ryland	D	1903	6	150	2	150		36
Plainview	5 mi. N.	Garrett Post	Wm. Johnson	O	1888		210	2	210	215	
Shackelford	3¼ mi. SW	W. H. Bland	J. V. Bray	O	1890		175	2	175	160	175
Shackelford	3¼ mi. SW	R. M. Hart	Frank Pearce	O	1895	8	172	1½	172	160	172
Truhart	1½ mi. SE.	Miss E. B. Savage	J. V. Bray	D			175	2	175		
Walkerton		Dr. B. B. Bagby	W. H. Walker	O	1889	25	275				
Walkerton		Ivan Clark	H. E. Shimp	O	1906	21	240	1½	225		225
Walkerton		P. P. Dillard	Frank Eaton	O	1889	32	265 250?	1½			20
Walkerton		H. B. Gray	Joseph Ryland	O	1889	35	355	1½			7
Walkerton	2 mi. N.	A. B. Gwathmey	H. E. Shimp	O	1906	8	190	1½			

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
Gravel	Calvert	+20	20		60(?)	Alkaline	Domestic and medicinal
							Drinking
	Pamunkey	+30	10		63½		Domestic and stock
	Pamunkey	+30	2		65		Boiler
		+25				Soft	
	Calvert (?)	+41	40–29		65		Drinking, domestic and stock
Gravel	Calvert (?)	+30	78		64	Fine	Household and stock
Gravel	Calvert (?)	+40	¼		63(?)		Household and stock
	Calvert (?)	+20?	2½		63		Household and stock
	Calvert (?)	+41	70		64		Household and stock
	Calvert (?)	+40?	6				
	Calvert (?)		5				Household and stock
	Calvert (?)		¼		60		Stock
	Calvert (?)		2				Drinking
White quicksand		+38					No flow, abandoned
Sand	Calvert	+40		50	62(?)	Soft	Hospital purposes
	Calvert			100	62(?)		Hospital purposes
	Calvert					Hard, irony	Domestic
	Calvert	+34		60			Drinking, etc.
	Calvert	+27		150			Ice manufacturing
	Calvert	+38		1,000(?)			Boiler and washing
Coarse greensand	Pamunkey (?)	+40		200+		Soft, alkaline	For locomotives, not used
Rock	Calvert	+28	8			Alkaline	Domestic and stock
Black sand	Pamunkey	+18	1	15	60¾	Soft, slightly sulphur	Public, no longer flows
	Pamunkey	+16		10	61		No longer flows
Shells	Calvert			3		Good	Domestic and stock
	Calvert (?)	+20	7½		62	Soft	Canning factory
Under rock	Calvert (?)	+6	15			Soft, sulphur	Domestic
Shell rock	Calvert	+20	5		62½	Soft	Domestic and stock
	Calvert	+20	12		62	Soft	Domestic
	Calvert						
Sand under rock	Pamunkey	+30	$\frac{1}{10}$		58	Soft, sulphur	Domestic
Rock at 180	Pamunkey	+35	1⅔		62		Household and stock
Sand	Pamunkey		½		63		Household
	Potomac			2	60		Drinking and stock
Greensand with shells	Pamunkey	+35	20		63		Household

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
						Ft.	Ft.	In.	Ft.	Ft.	Ft.
KING AND QUEEN —Cont.											
Walkerton	near	W. T. Haynes	Frank Eaton	O	1889	.....	260	1½	....	......	260
Walkerton	near	Hefron & Haynes Steamboat Co.	Frank Eaton	M	1888	5	185	1½	....	......	18
Walkerton	near	Mattapony Piehle Co.	J. V. Bray	O	1904	8	330 350	1½	....	......	330
Walkerton	near	Mattapony Piehle Co.	J. V. Bray	O	1902	6	260	1½	....	......	....
Walkerton	near	John A. Mitchell	John A. Mitchell	O	1891	32	372	1½	250	......	....
Walkerton	near	Mrs. C. T. Roberts	Joseph Ryland	M	1895	32	250	1½	....	......	....
Walkerton	1 mi. E.	John N. Ryland	Joseph Ryland	O	1906	50	275	1½	275	......	45 270
Walkerton	near	Miss Lucy Stacy	Joseph Ryland	M	1896	33	260?	1½	....	......	16
Walkerton	near	R. M. Trice	Frank Eaton	M	1889	.....	260?	1½	....	......	....
Walkerton	near	Mrs. Mary Turner	Frank Eaton	M	1889	32	260	1½	....	......	20
Walkerton	near	H. H. Walker	H. E. Shimp	O	1905	37	240	1½	....	......	....
Walkerton	near	Mrs. Melville Walker	....	M	1889	35	270?	1½	....	......	45
Walkerton	near	Walkerton Pickle Co.	W. H. Walker	M	1904	.....	350	1½	....	......	....
KING GEORGE											
Dido	at	C. E. Davis, 2 wells	Chas. Pfeil	O	1898	8	175	1½	....	150 90 15	....
Dogue	2 mi. E.	J. S. Dickinson	L. Rude	O	1897	40	260	2	....	......	....
Mathias Point	....	W. Mayo	L. Rude	D	1907	12	175	....	....	......	....
Mathias Point	at	P. H. Pemberton	C. W. Walcott	O	1902	8	236	1¼	236	none	16 236
Pluck	near N.	Lyttleton Johnson	Chas. H. Jones	M	1895	6	190	2	190	none	....
Pluck	near	Johnson Bros.	....	M	.....	8	300	2½	....	......	....
Pluck	¼ mi. N.	H. N. Stuart	....	..	1893	8	50	1¼	42	......	....
Port Conway	2 mi. N.E.	J. H. Law	....	M	1905	28	305	....	....	......	....
Port Conway	1 mi. E.	R. V. Turner	Hammell & Hale	O	1905	20	250	1½	....	......	....
Port Conway	near	R. V. Turner	Hammell & Hale	O	1903	3	232	1½	224	15	219
Rollins Fork	2 mi. S.	Vulcan Fire Brick Co., (2 wells)	....	M	1900	11	275?	1½	....	......	....
Sealston	2 mi. E.	John Curtis	Geo. Heflin	D	1904	30	250	2	....	......	....
KING WILLIAM											
Aylett	near	J. C. Fox	Jos. Ryland	D	1905	25	189	2	.....	none	20
Aylett	near	J. B. Moore	H. E. Shimp	O	1906	25	190	1½	180	......	30 190
Cohoke	near N.	Cohoke Club	J. A. Smith	..	1886	18	215	2	215	......	....
Cohoke	....	Dr. Edwards	H. E. Shimp	D	1906	35	232	2–1	230	......	230
Cohoke	1 mi. S. E.	J. W. Johnson	H. E. Shimp	D	1906	20	250	....	240	......	20 240
Elsing Green	near W.	Roger Gregory	H. E. Shimp	D	1906	20	205	2	200	......	190
Elsing Green	....	Roger Gregory	H. E. Shimp	D	1906	20	300	2	....	......	220
King William	near	King William County	F. E. Pearce	..	1898	.....	350	....	....	......	....
King William	1½ mi. N.	John Cook	....	M	1889	4	260	1½	....	......	....
Lester Manor	3 mi. W.	J. T. Dantey	H. E. Shimp	D	1906	20	245	3–2	240	......	240
Lester Manor	3 mi. W.	Frank Robbins	H. E. Shimp	D	1906	40	400(?)	3–1	275	......	70

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
	Pamunkey						Household
	Pamunkey		1¼		61		Drinking
Gray sand	Potomac	+30? +15	5		63½	Soft, alkaline, sulphur	Salting pickles
	Pamunkey	+30?	4		63		Salting pickles
Sand	Potomac	+43?			64		Household
	Pamunkey	+25					
	Pamunkey	+33					
	Pamunkey	+33					Household
	Pamunkey		¼				Household
	Pamunkey	+32	⅙		60		Household
	Pamunkey	+35			60		Hotel
	Pamunkey	+35?					
	Potomac	+15				Soft, sulphur, alkaline	Pickle factory
	Pamunkey	+18	2½	6		Soft	Domestic, packing fish
	Potomac	+36				Hard	Domestic, stock
	Pamunkey						
Sand	Potomac	+10	2				Stock, domestic and irrigation
	Pamunkey	+8 flows	several			Soft	Domestic, stock and oystermen
Sand	Potomac	+3				Sulphur	Domestic, stock, too irony
	Pamunkey	+2		3		Very irony	Stock
	Pamunkey (?)	+29	2	3½	60		Household
	Pamunkey				61		House and stock
	Pamunkey	+23	13.5		61	Soft, slightly sulphur	Canning factory, domestic and stock
	Pamunkey		2		63		Drinking, boiler
"Quicksand"	Potomac	+31	1½			Soft, sulphur	Domestic
Gray sand	Pamunkey	+28	½		60½		Household and stock
Dark green sand	Pamunkey		1¾		60½		Household and stock
Dark sand	Pamunkey	+31				Soft, iron	Domestic, stock
"Soft rock" greensand	Pamunkey	+35?	$\frac{1}{10}$	1		Soft	Household and stock
Greensand	Pamunkey	+32				Soft	
Greensand	Pamunkey	+30	5			Soft	Drinking and stock
	Pamunkey	+30	7		62		Drinking and stock
							No flow, not used
	Pamunkey		3⅛		61		Household and stock, formerly boiler
"Shelly rock" greensand	Pamunkey	+31	4		60?	Soft	Domestic and stock
Greensand		+36	5		60?		Household and stock

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
KING WILLIAM —Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Lester Manor	3 mi. W.	J. A. Robins	H. E. Shimp	D	1907	20	200	3	200		190
Lester Manor		T. L. Robins				36	260	3–2	250	19	240
Manquin	2mi. S. W.	Miss Cora Skidmore	Frank E. Pearce	M	1888	32	270	2½	270	none	270
Manquin	1 mi. S.	C. B. Chapman	Sydnor Pump & Well Co.	M	1896	30	237	6			237
Palls	1½mi. SW	J. H. Montague			1888	32	399	1½	398		
West Point		City	Frank E. Pearce	M		8–15	165	1½	165	120	
West Point		City	Challenge Wind Mill & Feed Co. (2 wells)	M	1904	10	335	3	337	120 165	
West Point	½ mi. N.	Mrs. S. E. Carr		M	1886	8	165	1½			
West Point	1mi. N.	Denmead Bros.	J. V. Bray	O	1892	5	105	1½	105		105
West Point	1mi. N.	Denmead Bros.	Frank E. Pearce	O	1895	2	158	1½	158	105	20 158
West Point	¼ mi. E.	B. W. Edwards	Frank E. Pearce	M	1888	2	158	1½			
West Point	¼mi. N. E.	Dr. W. T. Gatewood	J. Frank Smith	O	1886	14	180	2			
West Point	1 mi. N. E.	Dr. W. T. Gatewood	J. Frank Smith	O	1902	14	315	1½			
West Point	1 mi. N. W.	Guthrie & Kidd	J. V. Bray	M	1906	1–3	169	1½	169		
West Point		B. W. Hefron		O		7	165				
West Point		B. W. Hefron		O	1903	7	325				
West Point		B. W. Hefron				7	120	1½			
West Point	1 mi. S. E.	J. W. Marshall	J. Frank Smith	M	1904	5	165	1½			
West Point	¼ mi. E.	J. W. Marshall	J. Frank Smith	O	1902	14	332	2			
West Point	¼ mi. S.	T. O'Conner				8	165	1½			160
West Point	near S.	J. W. Owens	J. V. Bray	O	1899	20	165	1½	160	15	165
West Point	⅞ mi. S. E.	M. M. Puller	J. Frank Smith	O	1902	8	325				
West Point	1 mi. S.	Geo. W. Richardson		O		6	160	1½	160	120	
West Point	1 mi. S.	Geo. W. Richardson	H. E. Shimp	O	1905	6	366?	4–1¼	366?	120	360?
West Point	¾ mi. S. E.	Geo. W. Richardson	Sydnor Pump & Well Co.	O	1904	10	325	1½			
West Point	½ mi. N.	J. W. Sheldon	J. V. Bray	O	1901	15	175	1½			
West Point	¾ mi. S.	[a]Southern R. R. Co. (big well)		M	1881	5	120?	6	120		
West Point	¾ mi. S.	Southern R. R. Co. (6 wells)	Frank E. Pearce	M	1888	5	160	2	160		20 160
West Point	1 mi. S. E.	Southern R. R. Co.	E. Wilkinson	D	1900	5	165	1½	165	120	
West Point	1 mi. S. E.	Southern R. R. Co.	E. Wilkinson	D	1899	5	165	1½	165	120	
West Point	2 mi. S. E.	United States	E. Wilkinson	D	1893		165	2			160
West Point	½ mi. S W	West Point Ice Co. (2 wells)	Frank E. Pearce	M	1888	6	185	2	185?		185?
West Point	¼ mi. S.	Wm. Wheeler	J. Frank Smith	D	1902	8	326	1½	315	112 150	306
West Point	¼ mi. S. E.	E. Wilkinson	J. V. Bray	O	1887	10	165	1½	120		

[a]Southern R. R. had about 15 wells.
[b]Initial head 29 feet.
[c]Flow at first 20 gallons per minute.
[d]Combined yield of wells.

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
Greensand	Pamunkey		5½			Soft	
	Pamunkey		1½			Soft	
Sand	Potomac (?)	+39	2		61		Household and stock
Gray micaceous sand	Potomac (?)	+39	6½				Household, boiler supply, stock
	Potomac (?)	33	⅜		61		Household and stock
	Calvert	+8		2–6		Soft	Public
Sand	Pamunkey	+20	37		66	Soft	City water works
	Calvert		2				Domestic
	Calvert	+9?	½		62	Soft sulphur	Boiler
	Calvert	+10	20?		63	Soft	Drinking
	Calvert						Boiler
	Calvert	+11		12	62		Household
	Pamunkey				67½		Household
	Calvert	+13					Boiler at brick yard
	Calvert					Soft	Household
	Pamunkey					Soft	Household
	Calvert				65	Soft sulphur	Drinking
	Calvert	+14	10?		63		Washing oysters
	Pamunkey	+20			64½		Household
	Calvert		¾–2⅛		62		Stable
Sand	Calvert	[b]+18			61¾		Drinking
	Pamunkey		9½		67		Household
	Calvert		7		63	Soft	Washing oysters
Black sand	Pamunkey	+30?	70(?)		66	Soft	Washing oysters
	Pamunkey				65		Household
	Calvert		5		61¾		Household
	Calvert					Soft, sulphur	Drilled for locomotive, little used
	Calvert		4½			Soft	Drinking or steamboats and wharf
Gravel	Calvert				63½	Soft	Drinking at Beach Park
	Calvert		[c]7½		65?	Soft	Park at Terminal Hotel, drinking, etc.
	Calvert	+20	50?			Soft	Drilled for dredge, used now occasionally by boats
	Calvert		[d]21	42	61¼	Soft	Ice mfg., drinking
Sand and gravel	Pamunkey	+18	20			Soft	Domestic and stock
Sand	Calvert	+ 7		8	62		

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
						Ft.	Ft.	In.	Ft.	Ft.	Ft.
LANCASTER											
Bertrand	near S.	T. J. Rateliffe & Co.	T. J. Rateliffe	O	1889	9	272	1¼	268	220	90
Bertrand		J. C. Ewell (2 wells)	L. T. Custer	O	1902	12	275	2			80
Irvington	1 mi. N.W.	Carter Creek Fish Guano Co.	R. H. Milligan	O	1899	6	580	3–2	580	550 450 350	580
Irvington	1 mi. N.W.	Carter Creek Fish Guano Co.					330	1½	330		
Irvington	¾ mi. SW	Est. of I. H. Francis	R. H. Milligan	D	1905	5	537	3			
Irvington	¾ mi. SW	Est. of I. H. Francis				6	330?	1½			
Irvington	near	W. A. Dameron & Bros.	L. Rude	O	1891	3½	330	1½	330		
Irvington	near	Messick & Gunby	H. A. Crittenden	O	1903	4½	450?	1½			
Kilmarnock	near		R. H. Milligan	D	1903		637	2			
Lancaster		Wm. Chilton					250	1½			100
Lancaster	near	County	L. Rude	M		77	450				
Merry Point	near	Crallé, Jones & Co.	J. C. Ewell	M	1902		325	2½	325		100
Millenbeck	near S. E.	Millenbeck Oyster Co.	L. F. Carter	M	1892	10	315	1½		none	
		W. Warren	H. E. Shimp	D	1904		325	1			
Monaskon		B. L. Farinholt		O	1889	6	300	1½			
Monaskon		B. L. Farinholt				6	255				
Ocran		J. F. Bellows				6	507	3			
Ocran		Bellows & Squires	R. H. Milligan	O	1907	10	660	3	660		660
Weems		B. G. Doggett and Chas. Chance	L. Rude	M	1896	3½	330	1½	330		
Weems		B. G. Doggett and Chas. Chance	L. Rude		1894		260	1½			
Weems		W. Messick	H. E. Shimp	D	1904		485	2–1			
Westland		B. L. Farinholt		M	1896		443				
Whealton	1½ mi. W.	O. D. Hale	Hammell & Hale		1904	10	244	1½	233		
Whealton	near	Lewis, Lankford-Tull Co.	Hammell & Hale	D	1902	8	256	1½	251	none	214
Whealton	near	J. W. Whealton			1894	6	262	1½			
Whealton		Whealton Packing Co. (3 wells)	Hammell & Hale		1894–1903	4	265	1½		70	
Whitestone	near				1890		300+				
MATHEWS											
Fitchetts		Fitchetts	J. W. T. Robertson		1904		100±	2			
Mathews	near	County	H. E. Shimp	M	1905	2	817	2–1		125	
Mathews	near		Hammell & Hale	M		8	390				
Mathews	3 mi. S.	R. T. Sears	Wm. S. Johnson	M	1891	8	300±				
Mathews	near		G. E. Steer	M	1891	8	360±				
Port Haywood	1½ mi. E.	Sterling Diggs	H. E. Shimp	O	1904	10	112±	3–2			
Port Haywood	1½ mi. N.	Perry Lumber Co.	H. E. Shimp	D	1907	10	107	3–2	100		100
Traders	1 mi. N.	John M. Campbell		D	1907	15	110	3–2	100		

[a] Flow at first 45 gallons per minute.

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
Sand	Calvert	+18	1½			Sulphur	Domestic, stock, washing oysters
Clay	Calvert	+18	2			Soft	Domestic, stock, washing oysters
Sand	Pamunkey (?)	+35	30		69	Soft	Boiler, domestic and stock
	Calvert					Soft sulphur	Not used
	Pamunkey (?)		[a]33⅓		69		Drilled for hotel supply, household
	Calvert		1¼		65	Soft, sulphur	Household
	Calvert	+4	½		64	Soft, sulphur	Drinking
		+6?	2		64	Soft	Drinking, washing oysters, canning
	Upper Cretaceous		140				
	Calvert						
		+15					
	Calvert	+32					No flow, abandoned
	Calvert	+4?	½			Sulphur	Domestic, stock, boiler
	Calvert	±0				Sulphur	Drinking, cooking
	Calvert						
	Calvert	+12	50–12			Soft, sulphur	Domestic and boats
	Calvert						
	Pamunkey (?)		7				
Sand	Upper Cretaceous						Fish factory
	Calvert	+6	2⅛		64	Soft, sulphur	Drinking
	Calvert						
	Calvert						
							No flow, abandoned
Porous sand rock	Calvert	+18	15			Soft	Domestic and stock
Shell rock	Calvert		16		61(?)	Soft	Canning factory, domestic and stock
	Calvert						Domestic and stock
	Calvert	+15	20			Soft, sulphur	Canning factory, domestic and stock
							No flow, abandoned
	St. Marys (?)						Canning factory
		+6½	1		59	Soft, sulphur	Drinking
							Never used, no flow
							Never used, no flow
							Never used, no flow
Fine sand	St. Marys (?)	+5		very small		Sulphur	Abandoned
	St. Marys	+7		30	58	Soft	Boiler, drinking and stock
	St. Marys				57½		Domestic and stock

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
						Ft.	Ft.	In.	Ft.	Ft.	Ft.
MIDDLESEX											
Bushy							300+				
Butylo	1½mi.SE	B. L. Farinholt		M	1895	0	280	1½			
Bayport	¼mi.S.E.	Bland Bros.	Hammell & Hale	D	1902	7	248	1½	242	none	218
Bayport	near	R. H. Bland & Co., 3 wells	Hammell & Hale	O	1894–1906	6	260–300	1½			
Bayport	near	B. L. Farinholt	L. Rude	M	1891	6	300	1½			
Dew	near	L. Nelson	L. Rude	O	1894	4	297	1½			50
Sandy Bottom	1 mi. E.	D. A. Taylor	J. W. T. Robertson	O	1901	7	78	2	75	35	74
Urbanna		G. S. Chowning	H. E. Shimp	O	1900	5	250	1½			
Urbanna		G. W. Hurley	R. H. Milligan	D	1904		478	3			300
Urbanna		G. W. Harley, (2 wells)	H. E. Shimp	D	1901	4	275–290	1½			
Urbanna		G. W. Harley, (2 wells)	L. Rude			2	227	1	227		70
Urbanna	¼ mi. E.	Hoskiss & Donaldson	G. P. Beazeley	O	1896	6	272	2	272		
Urbanna		Urbanna Mfg. Co		M	1902	2	275?	1½			
Urbanna		G. V. Wagemen	G. V. Wagemen		1905	6	232	1½			
NANSEMOND											
Chuckatuck	1 mi. E.	Dr. Livins Langford	Tom Johnson	O	1906		188	2			
Chuckatuck				M	1908	25	300		300		
Everets	1½ mi. E.	Josiah Gray	E. E. Wagner	D	1904	36	100	1¼	50		
Everets		G. A. Greene	E. E. Wagner	D	1904		90	1¼			
Everets		H. Saunders	E. E. Wagner	D	1904	5	50	1¼			
Everets		T. J. Saunders	C. M. Johnson	O	1896	5	54	1¼	50		
Everets		E. E. Wagner	E. E. Wagner	D	1900	8	100	1¼	100	50, 80	80
Reids Ferry		Nansemond River Brick & Tile Co.		O	1902	15	150	2			
Suffolk	1 mi. E.	A. B. Cramer	A. B. Cramer		1905	55	253				
Suffolk	½mi.N.E.	Gay M'f'g Co	Sydnor Pump & Well Co.		1896	55	300				
Suffolk			Leach		1885		250				
Suffolk		Norfolk & Portsmouth Traction Co.	Sydnor Pump & Well Co.		1901	58	803?	6	650?		
Urbanna		L. B. Wageman		M		5	250	1½			
Urbanna	near		R. H. Milligan	D	1906	10	590	3		300	300
Waterview		Powell & Son	Geo. Heflin		1906		350	2			
NEW KENT											
Boulevard		Wm. Weber	Sydnor Pump & Well Co.	O	1902	22	260	4½	265	224	52
Lanexa		Robert Turner	H. E. Shimp	M	1908	28(?)	110	2	110		
Lily Point		Richmond Shooting and Hunting Club	H. E. Shimp	D			225	1½			220
Plum Point	near	Frederick Knoll	J. V. Bray	O	1897	9	150	1½	150		35
Plum Point	⅛mi.S.E.	J. L. Richardson	Frank E. Pearce	O	1891	12	168	1½	168	120	165
Providence Forge	⅛ mi. E.	R. E. Richardson	P. H. Sweet	M	1896	25(?)	215	1			100?

[a] Initial flow 25 gallons per minute.
[b] Flowed at first.

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
	Chesapeake					Soft	Not used
	Calvert	+16	20			Sulphur	General
Shell rock	Calvert		16			Soft	Domestic, stock, canning factory, packing
	Calvert	+20				Hard (?)	Drinking and cooking
	Calvert	+18	20		64		Washing oysters, drinking
Rock	Calvert		½			Soft, alkaline	Drinking
Gravel	Columbia(?)	+2				Hard, irony	Domestic except laundry
	Calvert		3				Drinking, etc., at boat yard
	Pamunkey	+25?	75		68		Making ice
	Calvert				66½		Making ice
	Calvert	+15	3	105			Making ice
Under rock	Calvert	+12	[a]3			Soft, sulphur	Boiler, pickling cucumbers
	Calvert					Soft, sulphur	Household
	Calvert	+10	5		65½		
	St. Marys						No flow, abandoned
		+30				Soft	
	St. Marys	+17					Household
	St. Marys						Household
	St. Marys						Household
Sand	St. Marys	+9	⅓		58		Household and stock
White sand	St. Marys	+15	2½			Soft	Household
							No flow, abandoned
							No flow, abandoned
							No flow, abandoned
							No flow, abandoned
Sand	UpperCretaceous	+32		11			Ice making
	Calvert				63		Canning factory
	UpperCretaceous	+34		105	67		Not completed
	Calvert						
Soft	Pamunkey	+32					
Sand	Pamunkey						
White sand with black	Pamunkey	+40?	3				
Shell rock	Chesapeake				58?	Lime?	Domestic and stock
Sand	Chesapeake	+12				Soft	Domestic and stock
	Pamunkey	+15[b]			60½		Store, household

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
						Ft.	Ft.	In.	Ft.	Ft.	Ft.
NEW KENT—Cont.											
Providence Forge	⅛ mi. NW	E. B. Townsend	Sydnor Pump & Well C.	M	1902	20	216	4½	216	....	215
Providence Forge	....	James Christian	H. E. Shimp	M	1908	25(?)	215	2	215	....	....
Providence Forge	....	Southern Pine Lumber Co.	....	M	1907	25	220	2	.....	....	....
Whitehouse	near S. E.	Southern Railway	P. H. Sweet	D	1893	5(?)	200	1½	200	....	....
Walkers	near	——McCann	H. E. Shimp	M	1909	25	200	2	200	....	....
NORFOLK											
Buell	....	E. H. Barney Co.	....	..	......	.....	....	....	.....	....	....
Buell	1 ½mi. N.	Pocomoke Guano Co.	Walter Goodman	O	1906	6	86	2½	86	12	82
Buell	N.	Roanoke R. R. & Lumber Co.	....	..	......	.....	53 562	1½ 5	53	....	....
Buell	....	Norfolk Crosoline Co.	....	..	......	.....	50–75	2	60	....	....
Greatbridge	⅛ mi. N.	J. E. Hall	J. E. Hall	O	1902	5	75	3	70	....	....
Buell	....	....	....	..	......	.....	562	....	.....	....	....
Lambert Point	....	Norfolk & Western R. R.	A. L. Miller	O	......	13	616	12–3 6	110	603	....
Pinners Point	....	Va.-Carolina Chem. Co.	J. H. K. Shannahan	..	1903	.....	40	4	40	....	....
Piney Beach	¾mi.N.E.	Jamestown Exposition Co.	Norfolk Mfg. & Supply Co.	O	1906	10	50	2½	10	none	....
Norfolk	....	City	....	M	......	10	140	6	.....	....	....
Portsmouth	....	Portsmouth Retail Lumber Corporation	....	..	1907	13	48	1½	.....	....	....
Rixton	....	Geo. S. Bunting	Geo. S. Bunting	O	1890	10	575	2–1	.....	....	260
NORTHAMPTON											
Cape Charles	1¼mi.SE	New York, Phila. & Norfolk R. R. (24 wells)	T. M. Ward	O	1900	8	40, 90	3	.....	8	10, 20, 30, 40, 90
Cape Charles	....	Wharton Fisheries Co.	R. H. Milligan	D	1899	3	249	3	.....	....	....
Cape Charles	....	Scott Estate Town and 17 wells	Eclipse Windmill Co.	M	1886	12	400	....	.....	....	....
Cape Charles	....	Heckle & Kellogg	....	M	......	10	16–40	....	.....	....	....
Capeville	3 mi. E.	J. H. Roberts	J. W. T. Robertson	O	1902	1	189	1½	125	....	....
Cheriton	....	Huff Bros.	Huff Bros.	O	......	.....	63	2	16	....	....
Mockham Island	....	....	J. W. T. Robertson	..	......	.....	189	....	.....	....	....
Nassawadox	....	W. A. Jones (2 wells)	....	O	1906	3	75	1½	.....	....	....
Nassawadox	2½ mi. NE	Thomas Upshur	W. M. E. Tilghman	D	1904	5	127	1¼	.....	....	....
Oyster	near	W. T. Travis	J. W. T. Robertson	D	1901	3	185	1½	171	....	....
Oyster	....	W. T. Travis	J. W. T. Robertson	D	1901	3	205	1½	175	....	....
Oyster	....	W. T. Travis (3 wells)	J. W. T. Robertson	M	1901	.....	175–200	1½	.....	....	....
Bone Island	8 mi. E.	Ashton Starke	....	O	1906	6	169	1½	169	....	....
Willis Wharf	....	W. Ballard	J. T. Walkley	D	1905	15	98	1½	98	46 18	....

[a]Initial flow 65 gallons.

Table 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
Sand	Pamunkey	+27?			61		Domestic
Sand	Pamunkey	+20					Domestic
Sand	Pamunkey	+25					Drinking and boiler
Blue sand	Pamunkey	+13	1⅔			Soft	Domestic
Sand	Pamunkey	+15					Domestic
Gravel, sand and shell	Columbia	±0				Hard	Boiler and domestic
Sand	Columbia (?)						Drinking
		+10				Irony	Not used
Gravel		+1½?			70		Domestic and stock
	Columbia (?)	+8				Hard	Domestic, stock and boiler
	Calvert (?)	+5				Alkaline, saline	
Fine micaceous sand		+28	[a]51		72	Saline	Drinking, washing
Gravel	Columbia		30			Salty	
Sand and gravel	Columbia	±0				Alkaline	Drinking, boiler
	Yorktown (?)	+4				Irony	Abandoned
Gravel	Columbia						
							No flow, abandoned
Sand	Columbia	+0		100			Locomotives, machine shops
Gravel and sand	St. Marys (?)	+1	10	80		Brackish	Boiler
							No flow, abandoned
							Town supply, making ice
Shells	Chesapeake (?)	−½				Good	Domestic and stock
	Columbia						Domestic
		±0					
	Columbia	+4					Domestic and stock
	Columbia (?)	+6	1½				Domestic and stock
	Chesapeake		2			Soft, slightly sulphur-bearing	Domestic
	Chesapeake		2				Domestic
	Chesapeake						Boats, domestic and drinking
Sand	Chesapeake	−6	¾			Soft, slightly sulphuretted	Drinking, etc.
Shells	Columbia					Hard	Domestic

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
NORTHUMBERLAND						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Bond Point	near	A. M. Byers	Chas. H. Jones	M	1903	5	200(?)	....	....	....	....
Bond Point			L. Rude	..	....	....	265	1½	265	....	....
Coan	near	T. H. Fallin	L. Rude	O	1888	53?	265	1½	260	....	....
Coan	near	T. H Fallin (2 wells)	Chas. H. Jones	O	1896	1½	270	1½	260	240	....
Coan		T. H. Fallin	T. H. Fallin	O	1898	0	310	1½	300	240	90
Coan	3 mi. N.	T. H. Fallin		O	....	3	290	....	....	....	....
Coan		T. H. Fallin		O	....	4	318	....	....	....	....
Cowart	near S. E.	S. Cowart	Hammell & Hale	O	1903	5	310	1½	310	280	150 310
Cowart		J. L. Dobyns		M	....	....	288	2	....	....	....
Cowart		L. Hedley		..	....	....	....	....	....	....	....
Fairport	near S. E.	McGill & McNeal Co	R. H. Milligan	O	1903	3	690	2	690	....	....
Fairport			J. H. K. Shannahan	M	1898	6	662	...	650	....	..
Fairport		Morris-Fisher Co.		..	....	....	393	1½	....	....	....
Fleeton	⅛ mi. SW	Fleets Point Devel. Co.	R. H. Milligan	O	1904	8	746	2	746	240 400 692 710 721	....
Fleeton		Fleets Point Devel. Co.	R. H. Milligan	D	....	....	690	2	....	....	....
Heathsville	1 mi. N.	W. C. Snow	S. E. Booth	O	1896	6	265	2	265	none	....
Hyacinth	2 mi. S.W.	Roland Park	Chas. H. Jones	..	1904	5	270(?)	1½	....	....	....
Hopeside		S. A. Whittaker	S. A. Whittaker	..	1904	8	365	4	365	....	20
Lewisetta		Gavner Bros.		M	....	....	325– 700	....	....	....	....
Lewisetta		C. R. Lewis & Co	J. H. K. Shannahan	..	1894	....	317	5–2	....	....	....
Lodge	½ mi. S.	Benj. Chambers (3 wells)	L. Rude	..	....	....	255	1½	240	none	100
Mila	near	Hinton-Toulson Oil & Guano Co.	R. H. Milligan	O	1904	10	635	3	635	none	600
Mundy Point				M	....	....	270(?)	2	....	....	....
Mundy Point	near E.	W. J. Courtney	N. M. Shannahan	O	1899	6	268	6	....	....	....
Reedville	near S.W.	Edwards & Reed Co	R. H. Milligan	O	1902	5	685	2	682	350	....
Reedville		Haynie & Snow Co	R. H. Milligan	D	....	....	683	2	....	....	....
Reedville		Jas. C. Fisher	R. H. Milligan	M	1904	....	698	2	698	400	....
Reedville		McGill-McNeal Co	R. H. Milligan	D	1903	3	680	3	680	....	....
Reedville	near	McNeal-Edwards Co	R. H. Milligan	O	1902	5	682	2	682	....	....
Reedville	near	Albert Morris	R. H. Milligan	D	1904	8	724	2	690	none	690
Reedville		Morris & Fisher Co		..	....	....	405	....	....	....	....
PRINCESS ANNE											
Virginia Beach		Princess Anne Hotel		..	1890	8	73	2	....	....	....
Virginia Beach		Princess Anne Hotel		..	1889	8	600	....	....	....	....
Waterway		Norfolk City Water Wks.	C. L. Parker	..	1898	11	1,750	12– 4½	1,480	783, 1,227, 1,750	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
	Calvert		1½				
	Calvert	flows					
	Calvert	+12	¾		63		Drinking
	Calvert	+10	1½				Canning factory and domestic
	Calvert		7½				Canning factory and domestic
	Calvert		1				Domestic
	Calvert		1				Domestic
Rock	Calvert	+8	3			Soft, slightly sulphur	Drinking
	Calvert	+6	2				Domestic
Sand	UpperCretaceous	+35	45			Soft	Boiler at fish factory
Sand	UpperCretaceous	+30	75				
	Calvert (?)		2			Soft	
Sand	UpperCretaceous	+35	40			Soft, alkaline	Boats, domestic and stock
	UpperCretaceous		10			Soft, alkaline	Boats, domestic and stock
Sand	Calvert (?)		3			Soft, sulphur	Drinking
	Calvert		1¼		62½		Not used
Gravel and sand	Calvert						
Gravel			3–18				
	Calvert		17				
Porous rock	Calvert	+14			62	Slight sulphur	Boilers, domestic
Rock at 500							
Black sand	UpperCretaceous	+40	45			Soft, alkaline	Fish factory boiler
	Calvert		1, ⅓			Soft	Household and stock
	Calvert	+12				Soft, alkaline	Washing oysters
Sand	UpperCretaceous		33	30		Soft	Fish factory, boiler and drinking
	UpperCretaceous		45				
	UpperCretaceous		18				
Sand	UpperCretaceous	+38	50			Soft	Fish factory boiler
Sand and gravel	UpperCretaceous	+25	35			Soft, alkaline	Fish factory boiler and drinking
Sand	UpperCretaceous	+38	40	200		Soft	Washing, drinking
	UpperCretaceous						
	Columbia					Irony	Washing, etc., no longer used
							No flow, abandoned
Sand	Upper Cret's (?)	+25?	75		76	Saline, sulphur	Part of public supply

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
PRINCESS ANNE —Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Waterway		City of Norfolk		..	1894		730	6–3	730	12, 300	
PRINCE GEORGE											
Blairs	2 mi. W.	David Dunlap	A. L. Davis	M	1903	65	307	4		60	
City Point	⅛mi.NW	Misses Epps	Sydnor Pump & Well Co.	O	1905	55	111	6	103	85	103
City Point	⅛mi.NW	Misses Epps		O		55	53	8			
PRINCE WILLIAM											
Agnewville	near E.	Rufus Davis	Henry Daniels				65	6	45		
Myron		Washington Fertilizer Co.	W. C. Miller	D	1901		257	4	238	127 167	256
RICHMOND											
Downings		W. B. Hale	Hammell & Hale	..	1901	8	241	1½	232		81
Ivondale	near E.	Mrs. J. H. Lemoine		O	1889	50	254	2½			
Naylors		A. A. Taliaferro	H. E. Shimp	D	1904		320	1			
Naylors	near S.	Waddington & Holme	L. Rude	O	1894		320	1½	225	160 250	
Naylors	near S.	Waddington & Holme	L. Rude	O	1893	5	386	1½	386	160 250 290	386
Sharps	¾ mi. NW	P. Y. Barber	L. Rude	O	1899	15	240	1½	240		
Sharps		A. J. Davis					325			200	
Sharps		F. Downing					325			200	
Sharps	1 mi. N.E.	J. M. McCarty	L. Rude	O	1894	10	240	2	240		
Sharps	¼ mi. NW	D. W. C. Sharp (2 wells)	L. Rude	O	1890	4	212	1½	212	90	
Sharps		E. Sharp	L. Rude	O		3	230	1½			188
Sharps	¼ mi. NW	G. L. Smith & Bro. (2 wells)	L. Rude	O	1903	+3	245	2	245		
Sharps	¼ mi. NW	J. B. Smith	L. Rude	..	1888	15	255	1½	250		
Sharps	¼ mi. NW		L. Rude	D	1907	4	440	1½	230 365		
Warsaw	3 mi. E.	E. W. Garland	L. Rude	O	1899	11½	188	2	187	65	185
Warsaw		E. W. Garland	E. W. Garland	..	1893	10	68	36	68		
Warsaw	3mi. S.	W. A. Jones (2 wells)	W. S. Johnson	M	1890	22	200	1½	200		
Warsaw	3mi. S.	M. D. Kalbach	—Hale	O	1906	8	181	1½	177		176
Warsaw	3mi. S.	G. M. Sydnor (2 wells)	—Hale	..	1906	3	180	1½	177		50– 177
Warsaw	2 mi. E.	Totuskey Canning Co.	H. E. Shimp	M	1899	5	177	1½			50
Warsaw		Frank Garland	Hammell & Hale	..	1902		165				
Wellfords	2 mi. S.E.	W. G. Brockenbrough	L. Rude	O	1904		366	¾	366	180	300
Wellfords		H. T. Douglas, Jr.	Hammell & Hale	O	1894	20	227	2	227	60, 190	
Wellfords	near N.	Frank Garland	Hammell & Hale	O	1902	4	161	1½	165		114
SOUTHAMPTON											
Arringdale	near	Camp Manufacturing Co. (4 wells)	J. T. Moore and others	D	1891	30	75	1½	75		30
Boykins		W. D. Barden		M			90	2			

TABLE 5 (*Continued*)—*Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
....	....	......	35	....	......	....	Not used
....	....	+30	....	....	......	....	No flow, not used
Sand	Patuxent	+15	....	25	......	....	Household
....	Pamunkey	......	....	....	......	....	Abandoned
Gravel	....	......	....	....	......	Hard	Domestic
Coarse sand and gravel	Patuxent	55	....	320	......	Soft	Boiler, domestic
Rock at 200 gravel sand rock	Calvert	+18	18	....	......	Soft	Domestic
Sand	Calvert	+6	....	....	......	Hard, iron and sulphur	Household
....	Pamunkey	......	....	....	......	....	....
Black sand	Pamunkey	+30	2	....	......	....	Domestic and canning factory
....	Pamunkey	+25	3	....	63	....	Domestic and stock
Sand	Calvert	+12	....	....	......	Soft	Household and stock
....	Pamunkey	+20	....	....	......	....	....
....	Pamunkey	+20	....	....	......	....	....
Gravel	Calvert	+26	530	....	63	Soft	General
Sand	Calvert	+16	....	....	......	Soft	Washing oysters
Rock	Calvert	+9	....	....	......	Soft	Canning factory
Gravel	Calvert	......	4	....	......	Soft	Washing oysters, drinking
Gravel	Calvert	+14	....	....	......	Soft	Household
Fine gray sand	Pamunkey (?)	......	....	....	......	Soft	....
Sand	Calvert	+36	16	....	62½	Soft, sulphur	Drinking
....	Calvert	+30	16	....	......	....	....
....	Calvert	......	¼	....	60	....	Domestic
Sand	Calvert	+20	2	....	61	....	Boiler at saw mill
Black sand	Calvert	+20	12	....	62	....	Drinking and canning factory
....	Calvert	+20	5	....	62	....	Canning factory
Rocky clay	Calvert	......	....	....	......	....	....
Clay	Pamunkey	+20	5	....	62?	Soft, sulphur	Household and stock
Rock	Calvert	+40	3½	....	......	Sulphur, iron	Household
Shell rock	Calvert	+22	24	....	......	Soft	Tomato canning factory, drinking
....	St. Marys	+40?	6	....	......	Hard	Domestic and stock
....	St. Marys	......	+10	....	......	Slightly alkaline	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
SOUTHAMPTON—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Boykins		J. W. Drury		M			105	2			
Boykins		E. H. Grizzard		M			87	1½			
Boykins		M. J. Knight					98	2			
Boykins		R. M. Knight		M			110	2			
Boykins		Henry de Laathe		M			90	2			
Boykins		F. M. Powell	P. P. Ellis	M			100	2			
Boykins	near	W. A. Powell	P. P. Ellis	O	1903		85	2	85	none	85
Boykins		Town of Boykins		M			85	2			
Boykins		W. W. White	J. T. Moore	M			130	2			
Branchville	near	P. G. Ellis	R. G. Ellis	O	1901		250	2	250	15–150	
Branchville	near	P. P. Ellis	P. P. Ellis	O					235		
Branchville	2 mi. S.E.	B. H. Beale	P. P. Ellis	D		15(?)	130	1	130		
Branchville	near	Grizzard Bros. & Co	P. P. Ellis	M					150		
Branchville	near	T. J. Harrell	George Wilkins	M		35	207	2	90 140 160		
Branchville	near	T. E. Peat	P. P. Ellis	D		20	130	1½	130		
Capron		Trent & Vinson		O		50(?)	400	2			
Capron		Trent & Vinson		O		50(?)	225	2			
Courtland		R. F. Whitfield	J. T. Moore	D	1910	28	165	2			
Courtland		Bain & Co	J. T. Moore	M			140	2			
Courtland	near	Town	J. T. Moore	D			125	2	125		
Courtland		Williams & Ketcham	J. T. Moore	D			160	2			
Courtland		W. Shands					170	2			
Courtland	near	W. J. Sebrell		D			160				
Courtland	2 mi. S.	W. A. Howell	J. T. Moore	D	1909	15(?)	207	2			
Delaware	near	Seaboard Air Line	George Wilkins	M			175	2			
Franklin	½ mi. N.	Camp Manufacturing Co. (17 wells)		M		10	130	1½	130		
Franklin		J. L. Camp		O		70	190	2			
Franklin		R. H. B. Cobb									
Franklin		P. F. Darden					177	2			
Franklin		W. H. L. Goodman		O		22	154	2			
Franklin		Goodman & Barrett		O		22	142	2			
Franklin		O. W. Hayes		O		18	150	2			
Hugo	near	Farmers' Mfg. Co	P. P. Ellis	D	1908		125	2	125	none	
Sands		T. H. Barrett	P. P. Ellis	D			222		222		
Sebrell	near	Tidewater Railway Co	Sydnor Pump & Well Co.	O	1907	58	344	10			344
Storeys	near	J. T. Moore	J. T. Moore	O		55(?)					
Sedley	near	Philip Rogers	J. T. Moore	O		60	200	2½			
SPOTTSYLVANIA											
Fredericksburg	½ mi. NW	E. D. Cole	—Alexander	O	1902	50	152	2	150		150
SURRY											
Bacons Castle	near	W. A. Warren	A. L. Spandour		1896	84	460	4			80
Bacons Castle	4 mi. E.		A. L. Spandour		1894	22	400+	1½			
Dendron		Surry Lumber Co			1888	125	386 315	6			
Homewood	2 mi. S.E.	W. F. Gray	Whitmore	M	1889	5	219	1½			
Homewood	½ mi. SW	W. F. Gray	Whitmore	M	1888	5	250	1½			
Homewood	1 mi. NW	W. F. Gray	Whitmore	M	1888	5	240	1½			

Table 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
	St. Marys						
	St. Marys						
	St. Marys						
	St. Marys						
	St. Marys						
	St. Marys						
White sand	St. Marys		3			Soft	
	St. Marys						
	St. Marys						
Rock at 100 ft.							
Gravel	UpperCretaceous		3			Soft, sulphur	Drinking, fish pond
	UpperCretaceous						
White sand		32(?)	20			Soft	Domestic and stock
Sand	Chesapeake	+35	5			Soft	Domestic
White sand		+35?	20			Soft	Domestic and stock
		30(?)		8			
		30(?)		8			Household and stock
	Chesapeake (?)	37	7			Soft	Domestic
	Chesapeake (?)						
	Chesapeake (?)						
	Chesapeake (?)						
	Chesapeake (?)		small				
	Chesapeake (?)		24				
	Chesapeake (?)	32(?)					
	Chesapeake (?)						Domestic
White sand	Chesapeake (?)	+22					Drinking and stock
White sand	Chesapeake (?)	+26					Household
White sand							
White sand	Chesapeake (?)						
White sand	Chesapeake (?)	+23	2				
White sand	Chesapeake (?)	+23	2				
White sand	Chesapeake (?)	+22	5				Household
White micaceous sand	Upper Cret's (?)	45	2			Soft	Domestic
	Upper Cret's (?)	+45					No flow
Sand and gravel	Potomac	+43			106	Soft	Locomotives
	Chesapeake (?)						No flow, abandoned
	Patuxent	+30					Medicinal and household
							No flow, never used.
		+30	10		63½	Soft	Drinking, making brick
							No flow, abandoned
Soft rock	Calvert	+35	2½		62½	Soft, sulphur	Household and stock, formerly boiler
	Calvert				64½		Domestic and stock
	Calvert						

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
SURRY—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Homewood	near	W. F. Gray	A. L. Spandour	M	1887	6	330(?)	1½			
Homewood	at	W. F. Gray	A. L. Spandour	M	1887	6	330(?)	1½			
WARWICK											
Leehall	near	J. Clements	S. H. Fellterholf	D	1906	43	460	2			
Menchville				M		25	300				
Mulberry Is.	S.	Phillip Lederhor	H. E. Shimp	O	1904	5	384	2-1			
Mulberry Is.	at	P. H. Wright	H. E. Shimp	O	1900	10	370	1	370	200 275	
Newport News		Old Dominion Land Co.		O		30	582				
Newport News		Old Dom. Brewing Co.	H. E. Shimp	D	1907		500	2			
Tidewells	near N.	C. E. Daiger	Chas. H. Jones	O	1896	8	225	2			180
Tuckerhill	3 mi. E.	J. R. Dor Passor (15 wells)	Chas. H. Jones	O	1898– 1906	5–15	235– 250	1½	225– 235		40
Tuckerhill	3 mi. S.E.	J. R. Dor Passor	Chas. H. Jones	O	1903	1	90	1½	70		70
Tuckerhill	3 mi. S.E.	Chas. H. Jones	Chas. H. Jones	O			245	1½			120
Tuckerhill	3 mi. N.W.	Jas. S. Sydnor	Chas. H. Jones	O	1894	14	248	2	240	228	64
White Point	at	D. W. Allen	Jones & Allen	O	1896		240	1½	240		80
White Point	½ mi. S.	D. W. Allen	Chas. H. Jones	O	1898		240	1½	240		80
White Point	½ mi. N.E.	G. L. Wilson	Chas. H. Jones	O	1901	10	216	2	210	12, 20	28
Wilkerson	⅛ mi. N.	Gouldman Bros.					240	1½			
Wilkerson	1 mi. W.	L. C. Hardy	Chas. Pfeil	O	1904	20	248	1½			
Wilkerson	1 mi. W.	L. C. Hardy	E. Gouldman	O		30	470				
Wilkerson	near	W. S. Wilkerson	Chas. Pfeil	O	1903	4	235	1½			
Wilkerson	near	W. S. Wilkerson	Chas. Pfeil	O	1906	7	235	1½			
Zacata	3 mi. W.	W. E. Goodridge	Chas. H. Jones	O	1904	12½	160	2– 1¼	158		45
Zacata	3 ½ mi. E.	Westmoreland Oyster Packing Co.	Chas. H. Jones	O	1900	3½	158	2– 1¼	152		40
WESTMORELAND											
Bealer	near	Beale & Biddle	Chas. Jones	O	1899	2	175	1½	172		
Chiltons		Hardwick & Sanford	Chas. Jones	O	1903	10	155	1½	155		
Coles Point		E. C. Barnes					220	1½			
Coles Point	¼ mi. S.E.	John Bronson	Chas. Jones	O	1896	5	216	1½	205		85
Coles Point		S. W. Godman					207				
Coles Point	¼ mi. E.	Wm. Mayo	L. Rude	D	1907	15	360	1½	350	220	350
Colonial Beach	near N.W.	Theodore Barnes		..	1902	10	240	1	240		
Colonial Beach	½ mi. S W	Mrs. Bell		O	1890	9	200				
Colonial Beach	⅛ mi. N.E.	M. A. & E. S. Bentley		O	1894	10	200	1¼	200		
Colonial Beach	½ mi. S W	D. C. & L. J. Connelly	Chas. Pfeil	..	1904	10	214	1½			
Colonial Beach	¼ mi. N.	Colonial Beach Hotel (5 wells)		M	1904	12	212	1½	212		
Colonial Beach	½ mi. N.	Mrs. C. A. Eckstein	Chas. Pfeil	O	1898	6	196	1¼	196		
Colonial Beach	1 mi. S.	J. C. Felch	Chas. Pfeil	M	1905	10	224	1½			
Colonial Beach	⅛ mi. S W	E. Gouldman	E. Gouldman	O	1904	15	245	2	225		60
Colonial Beach		John Hammond	Chas. Pfeil	O	1903	6	200⅓	2	200⅓		80 200
Colonial Beach	near W	T. B. Harrison		O	1896	12	200	1			

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds: Material	Principal water beds: Group or formation	Head of water above mean high tide	Yield per minute: Flow	Yield per minute: Pump	Temperature	Quality	Uses
		Ft.	Gal.	Gal.	°F.		
			4		63½		
	Calvert	+35	3				
		+30					Domestic and stock
							Never used, no flow
	Calvert (?)	+22	2		67	Alkaline	Drinking, stock, boats
Rock	Calvert (?)	+29	¾		63½	Alkaline	Domestic stock and medicinal
		+20					Never used, no flow
							Abandoned
Sand	Calvert	flows	1			Soft	House and stock
	Calvert		½–1		62–63		Household and stock
Gravel	St. Marys		3			Ferruginous	
	Calvert						Household and stock
Rock and sand	Calvert		2			Soft	Household and stock
Sand	Calvert		1⅛		63		
Sand	Calvert				61		
	Calvert		1			Soft	Canning factory
	Pamunkey						
	Pamunkey	+22					Domestic and stock
							No flow, not used
	Pamunkey		3½		62		Drinking and public
	Pamunkey		1⅗		61		Hotel
Sand	Pamunkey					Soft	Domestic and stock
Sand	Pamunkey		2			Soft	Domestic and stock
	Calvert		8				General
	Calvert					Soft	Tomato cannery and domestic
	Calvert	+12	3				
	Calvert		1½			Sulphur	Domestic and stock
	Calvert	flows					
Rock cays 210–230, sand	Pamunkey	+30	6			Soft	House and stock
	Pamunkey				61		Household
	Pamunkey		⅞		61		Household
	Pamunkey		¼				Hotel
	Pamunkey	flows	2			Soft	Household
	Pamunkey		5	15			All
	Pamunkey		½		61		Household
	Pamunkey		⅕		61		Household
Thin rock at 220, chocolate col'd clay	Pamunkey	+19	3			Soft	Household
Sand	Pamunkey		4–1½		62¾		Ice manufacture
	Pamunkey		½		64½		Household

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
WESTMORELAND —Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Colonial Beach..	2 mi. SW	L. W. Jett	L. W. Jett	O	1901	15	230	1½	222	75	222
Colonial Beach..	W.	Dr. A. E. Johnson		..	1899	10	225				
Colonial Beach..	W.	D. Knowlton	C. Jones	O	1902	20	250				
Colonial Beach..	½ mi. N.	M. E. Loeffler	E. Gouldman	O	1906	20	244	1¼	200		
Colonial Beach..	¼ mi. SW	Mutual Ice Co	R. Rude	D	1909	5	422	1½	415	220	
Colonial Beach..	S. W.	Maguinnis Estate	——Graves	M	1898	9	214	1½			
Colonial Beach..	2 mi. SW	O. L. Massey		M	1900		225	1½			
Colonial Beach..	near N.	A. Mensch	Chas. Pfeil	D		6	204	1¼	204		
Colonial Beach..	near	——Pierson	Chas. Pfeil	D	1897	8	208	1½			
Colonial Beach..	near N.	Reh & Ninde		O	1900	10	225	1	225		
Colonial Beach..	½ mi. W.	John Sebastian	E. Gouldman	D			80	1½			
Colonial Beach..	½mi.NW	J. R. Sutton	Chas. Pfeil	O	1905	18	230	1½	230		
Colonial Beach..	1 mi. S.	J. M. Taylor	——Roane	O	1896	4	210	2			50
Colonial Beach..	N.	J. W. Thompson		O	1904	20	242	1¼	242		
Colonial Beach..	W.	Town	——Roane	M		11	225				
Colonial Beach..	1 mi. S.	Town		M	1902	8½	247	1½			
Colonial Beach..	near S.W.	F. W. Walcott	Johnson	O	1888	10	276(?)	1½	230	none	80
Colonial Beach..	S. W.	C. W. Welles	Chas. Pfeil	O	1904	8	214	1½	214	70	86
Colonial Beach..	½mi.SW	C. W. Welles	Chas. Pfeil	O	1909	8	214	1½	214		
Erica	1 ½ mi. E.	N. T. Ames	Chas. Jones	O	1902	7	187	1½	187		100
Erica	1½mi.SW	Paul Detrick		M	1900	13	327	1½			
Erica	near S.W.	E. T. Barnett	Chas. H. Jones	O	1903	15	335	3			
Hague	3 ½ mi. N.	G. F. Brown (3 wells)	L. Rude	O	1894	8	247	2			247
Hinnom		J. B. Hall	Chas. H. Jones	O	1897	2	144	1½	144		44
Hinnom	near	Hardwick & Sanford	Chas. H. Jones	O	1903	8	154	1½	144		
Kinsale	½mi.N.E.	G. P. Bailey	G. P. Bailey	O	1894	8	238	1½	235		235
Kinsale		G. P. Bailey	Chas. H. Jones	..	1901	6	238	1½	235		40
Kinsale		G. P. Bailey	Chas. H. Jones	..	1903	6	238	1½	235		40
Kinsale	¼mi.N.E.	Dameron & Courtney	L. Rude	O	1893	4	275	1½			159
Kinsale	½mi.N.E.	S. B. Hardwick		O	1892	6	245	1½			100
Kinsale	⅜mi.N.E.	V. B. Hardwick		O	1902	8	245	1½			40 220
Kinsale	1 mi. N.	Chas. Taylor	Chas. H. Jones	O	1903	7	260	1½	260	199	140
Maple Grove..	1 mi. E.	Floyd Omohundro	E. Gouldman	O	1905	60	300	1½			40
Meter		B. H. Bronson		..			240				
Meter	⅓ mi. W.	H. L. Shepard	Chas. H. Jones	O	1896	6	227	1			
Mount Holly....	½ mi. E.	S. J. Hopkins	Chas. H. Jones	O	1897	4	135	2	135		25
Mount Holly....	near	Nominie Packing Co	Chas. H. Jones	O	1903	9	153	1½	153	144	50
Oak Grove	2mi.S.W.	Andrew Flanmer	Shaw & Roane	O	1897		664	1½	300		110
Oak Grove		Andrew Flanmer		O			63	48			

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
Sand	Pamunkey	+35			61		Household and public
	Pamunkey		½		60½		Household
	Pamunkey		⅙		62		Household
	Pamunkey	15	¼				Hotel
White sand	Potomac		6				Making ice
	Pamunkey	+15	1¼		64½	Soft, sulphur	Household
	Pamunkey					Soft, sulphur	Household
Rock	Pamunkey		2			Soft, sulphur	Hotel
	Pamunkey					Soft, sulphur	Flow stopped
	Pamunkey		½		61	Soft, sulphur	Hotel and store
	Pamunkey					Soft, sulphur	
	Pamunkey					Soft, sulphur	Flow stopped, not used
	Pamunkey	+12	1			Soft, sulphur	Household
	Pamunkey		½		63	Soft, sulphur	Household
	Pamunkey		⅕		63	Soft, sulphur	Public
	Pamunkey		⅓		61	Soft, sulphur	Public
Black sand	Pamunkey	+18 +10	4			Soft, irony	Domestic and hotel
Red clay	Pamunkey	+14	¾		62	Soft, sulphur	Household
Clay	Pamunkey	+6	1			Soft	Household
Gravel	Pamunkey	+9	¾			Soft, sulphur	Household and stock
	Pamunkey		2¼		65	Soft	Household and stock
Sand	Pamunkey	+12				Irony	Household and stock
Rock at 200 feet	Pamunkey					Soft, sulphur	Household and stock
White sand	Chesapeake		1½		63¾		
	Chesapeake	+20	18			Soft	Canning factory
Rock	Chesapeake	+18	4				Steamboat and canning
	Chesapeake	+16	4		64		Canning factory and steamboat dock
	Chesapeake		4				
Sand	Chesapeake	+18	7			Soft	Canning factory and drinking
	Chesapeake	+18	4				Canning factory and drinking
Sand	Chesapeake	+15	8				Canning factory and drinking
Sand	Chesapeake		5		61	"Slightly hard"	Household and stock
White sand		+20					Not used, no flow
		flows				Soft, slightly sulphur	Domestic
Rock at 125 feet	Chesapeake	flows	⅓		63	Soft, sulphur	Household and stock
Rock	Chesapeake	+18	2		63		
							No flow, never completed
	Chesapeake						Household

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

County and Postoffice	Direction and distance from postoffice	Owner	Driller	Authority	Date (approximately)	Elevation above mean high tide	Depth	Diameter	Depth to principal water bed	Depth to other water beds	Length of casing
WESTMORELAND—Cont.						Ft.	Ft.	In.	Ft.	Ft.	Ft.
Oak Grove	2 mi. W.	W. D. Wirt.............	Chas. Pfeil	O	1894	23	190	2	190	....	40
Potomac Mills..	4 mi. N. E.	James Muse.............	F. K. Walcott.......	M	1900	22	280	3	280	....	....
YORK											
Grove	5 mi. S. W.	A. G. Harwood..........	H. E. Shimp.........	M	1903	30	429	2	429	none	60
Lackey	1 mi. N. E.	Mrs. K. Kirkwood........	H. E. Shimp.........	M	1903	.....	450	1	450	300	....
Magruder	2 mi. N. E.	....	....	M	1890	2	226	1½	.....	....	....
Messick	2 mi. N. W.	S. J. Marynham.........	J. W. T. Robertson	..	1904	.....	90	....	.....	....	....
Oaktree	3 mi. E.	Edward Maynard	S. H. Felterholf......	D	1905	11	367	2	.....	....	....
Yorktown	3 mi. N. W	G. B. Donnelly...........	H. E. Shimp and S. H. Felterholf	D	1903	2	429	2	.....	70	....
Yorktown	5 mi. N. W	——Squires	S. H. Felterholf......	D	1906	6	358	2	.....	....	....
Yorktown	....	Am. Cem. & Eng. Co...	H. A. McTavish.....	M	1909	3	750	3	750	....	....
Williamsburg ...	4 mi. N.	....	S. H. Felterholf.....	..	1906	.....	408	2	.....	....	....

TABLE 5 *(Continued)—Data of wells in Coastal Plain Province of Virginia.*

Principal water beds		Head of water above mean high tide	Yield per minute		Temperature	Quality	Uses
Material	Group or formation		Flow	Pump			
		Ft.	Gal.	Gal.	°F.		
....	Pamunkey	flows	⅕	....	......	Soft	Domestic and stock
Rock at 80 ft. gravel	Pamunkey	flows	½	....	......	Soft	Domestic and stock
Gravel...........	Pamunkey	+20	....	....	......	Alkaline	Domestic, boiler
Gravel...........	Pamunkey	......	4½	....	......	Soft, alkaline	Domestic and stock
....	Chesapeake	+20	20	....	......	....	....
....	....	......	....	....	......	Sulphur	Domestic
....	Pamunkey	+25	1½	....	......	....	Household
Green rock	Pamunkey	+38	4	....	......	....	Household and stock
....	....	+28	3	....	......	....	Household and stock
....	....	+10	1	....	......	"Good"	....
....	....	+25	10–1	....	......	....	Drinking, &c.

TABLE 6—*Analyses and field assays (F) of water from springs.*

County and locality	Name of Spring	Owner	Source	Turbidity	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)
ALEXANDRIA									
Ballston	Powhatan		Granite	....	38.0	....	12.	....	.2
Glencarlyn	Erup Mineral	H. H. Young	Gravel	....	47.8	9.0	....	....	.1
CHARLES CITY									
Oldfield		A. M. Wheeler	Sand	....	73.17	....	17.4	....	.5
Oldfield		A. M. Wheeler	Sand	....	61.08	....	19.65	....	.87
CHESTERFIELD									
Bon Air	Beaufont	Beaufont Lithia Spring Water Co.	Granite	....	63.	....	16.	....	.25
Buckhead Springs	Buckhead Chloride Lithia	T. S. Wheelwright	Sand	....	43.	....	7.4	....	.1
Manchester	Bellfont Lithia		Granite	....	45.	....	14.	....	1.
Manchester	Fonticello Lithia	W. G. Taylor	Granite	....	46.	....	14.	....	1.6
Manchester	Lion Lithia	Virginia Lithia Springs Co.	Sand	....	28.1	....	10.	....	.11
Temples	Campfield Lithia	Campfield Lithia Water Co.	....	....	28.	....	5.3	....	.3
Swansboro	Holly Lithia	Holly Springs Co.	Sand and gravel	....	35.6	....	10.7	....	.29
Swansboro	Holly Lithia	Holly Springs Co.	Sand and gravel	....	35.4	....	11.2	....	.35
Wiseville	Rocky Run Lithia	David Adkins	....	....	....	....	....	....	1.1
ESSEX									
Meade	Sulphur	Chas. Tombs	Sand and iron crusts	.0	....	....	....	....	1.5
Meade	Sulphur	Chas. Tombs	Sand	.0	....	....	....	....	tr.
GLOUCESTER									
James Store		County	Marl	.0	....	....	....	....	.0
HANOVER									
Hanover Station		R. F. & P. Ry.	Sand	.0	....	....	....	....	....
Ellerson		B. A. Taliaferro	Sand	....	19.	....	6.2	....	.08
HENRICO									
Barton Heights		Town	Marl and sand	.0	106.	42.	....	....	.03
East Richmond	Como Lithia	I. J. Hawkes	Sand and gravel	....	34.	tr.	5.4	....	.1
Elko		R. W. Swift	Sand	.0	....	....	....	....	tr.
Richmond		County	Sand	.0	....	....	....	....	....
Richmond		Home Brewing Co.	Gravel	....	124.	16.	....	....	tr.

[a]Ammonium (NH_4), .069.
[b]Ammonium (NH_4), .016.
[c]Ammonium (NH_4), .013.
[d]Barium (Ba), .02.
[e]Barium (Ba), .008.
[f]Barium (Ba), trace.

TABLE 6 *(Continued)—Analyses and field assays (F) of water from springs.*

Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Lithium (Li)	Arsenate radicle (AsO_4)	Phosphate radicle (PO_4)	Sulphate radicle (SO_4)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Nitrate radicle (NO_3)	Iodine (I)	Bromine (Br)	Chlorine (Cl)	Total hardness as $CaCO_2$	Date	Analyst
......	0.	1.6	1.	....	3.7	1.2	0.[a]	0.	0.	1.2	......	12.	1.55	tr.	0	3.8	......	1905	J. K. Haywood
......	......	2.9	1.8	....	5.7	1.5	tr.	......	......	3.3	......	9.1	....	....	....	6.3	......	1905	J. K. Haywood
......	......	4.5	1.5	....	10.45	3.18	[b]	......	......	2.57	......	11.82	8.85	....	....	10.61	......	1908	....
......	......	2.25	.8	....	9.2	3.	[c]	......	......	2.10	......	10.8	3.32	....	....	7.40	......	1908	....
8.4	tr.	1.4	1.	....	4.	2.1	.07	tr.	0.04	1.3	......	15.	....	.06	tr.	5.2	......	....	Henry Froehling
.53	......	1.4	2.5	[d]	3.6	2.3	.001	ft.tr.	.009	.72	......	3.1	8.8	....	....	11.	......	1904	Froehling & Robertson
......	......	1.9	.4	....	3.8	2.9	.03	......	......	10.	......	5.3	....	....	....	5.8	......	....	W. H. Taylor
.07	tr.	2.	.61	....	3.5	1.5	.08	tr.	.04	2.5	......	13.	....	....	....	5.4	......	....	Henry Froehling
.78	.022	1.0	.4	....	2.98	1.2	.011	.039	.035	4.1	......	3.9	....	.11	tr.	3.6	......	....	Froehling & Robertson
.11	tr.	.8	.9	[f]	3.2	1.9	.05	tr.	.03	2.4	......	8.	0.0	tr.	tr.	5.2	......	....	N. B. Tucker
.76	......	1.86	.47	....	2.8	1.4	.09	tr.	tr.	2.47	......	10.7	....	tr.	....	2.8	......	1894	C. H. Chalkey
.8	......	1.35	.35	[e]	4.6	1.	.033	......	.03	4.3	......	4.8	2.7	tr.	....	4.4	......	1907	Froehling and Robertson
......	......	40.	.46	....	1.1	1.6	.07	......	......	6.3	1.2	......	....	....	....	......	......	....	....
......	......	little	......	....	......	....	......	......	......	tr.	0	24.	....	....	4.	......	44.	1906	S. Sanford (F)
......	......	0.(?)	......	....	......	....	......	......	......	>30	0	10.	....	....	4.	......	28.	1906	S. Sanford (F)
......	......	much	......	....	......	....	......	......	......	>30	0.	180.	....	....	....	8.8	75.	1906	S. Sanford (F)
......	......	......	......	....	......	....	......	......	......	0.	......	15.	....	....	....	9.	17.	1906	S. Sanford (F)
.11	.02	.7	.3	....	2.2	.8	.01	tr.	.03	2.3	......	2.7	....	tr.	....	3.1	......	....	Henry Froehling
......	......	......	......	....	......	....	......	......	......	......	......	......	.44	....	....	16.5	32.5	1905	E. C. Levy
.53	......	.86	1.1	....	4.7	2.1	.07	tr.	......	.41	......	7.9	....	.39	tr.	10	......	1892	Henry Froehling
......	......	mod.	......	....	......	....	......	......	......	tr.	......	58.	....	....	....	3.	58.	1906	S. Sanford (F)
......	......	0	......	....	......	....	......	......	......	0	......	12.	....	....	....	5.5	48.	1906	S. Sanford (F)
......	......	8.6	6.	....	......	....	......	......	......	6.5	......	......	tr.	....	....	37.	46.	1907	First Scientific Station for the Art of Brewing

TABLE 6 *(Continued)—Analyses and field assays (F) of water from springs.*

County and locality	Name of Spring	Owner	Source	Turbidity	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)
JAMES CITY									
Williamsburg		Mrs. R. M. Smith	Marl	.0					.0
KING GEORGE									
Hickory Fork			Sand						tr.
KING WILLIAM									
Enfield		G. W. Scott	Sand	.0					.4
NEW KENT									
Whitehouse	Belmont Lithia	R. E. Richardson	Marl		221.		33.		4.7
NORFOLK									
	White Oak Mineral				146.		5.4		tr.
	Landale Mineral Spring		Sand		87.		5.3		.06
PRINCE GEORGE									
Blair		David Dunlop		.0					tr.
Warwick Church		Warwick Church	Sand	.0					tr.
PRINCESS ANNE									
Waterway	Diamond		Sand						
SPOTTSYLVANIA									
Fredericksburg		Aqueduct Co.	Sand and gravel						
Fredericksburg	Gunnery	City	Sand and gravel	.0					tr.
Fredericksburg	Mint	City	Sand and gravel	tr.					
Fredericksburg	Silk Mill			.0	157.				.08
SURRY									
Claremont		E. S. Collins	Marl	.0	207.	60.	39.		.04
Claremont	Trepho Lithia	E. E. Harry	Sand	.0					1.5
Claremont	Trepho Lithia	E. E. Harry	Sand		573.		34.		2.9
SUSSEX									
Waverly	Cappahaunk		Marl	.0					3.
Waverly	Cappahaunk		Marl		293.		23.		.7
WESTMORELAND									
Kinsale		Chas. Taylor	Sand	.0					

*Also contains Barium (Ba), .15; Strontium (Sr), .10; Zinc (Zn), faint trace.

TABLE 6 *(Continued)—Analyses and field assays (F) of water from springs.*

Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Lithium (Li)	Arsenate radicle (AsO_4)	Phosphate radicle (PO_4)	Sulphate radicle (SO_4)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Nitrate radicle (NO_3)	Iodine (I)	Bromine (Br)	Chlorine (Cl)	Total hardness as $CaCO_2$	Date	Analyst
....	....	much	....	....	....	....	....	....	....	>30	....	160.	....	....	....	9.5	140.	1906	S. Sanford (F)
....	....	little	....	....	....	....	....	....	....	tr.	....	30.	....	....	....	10.	....	1906	S. Sanford (F)
....	....	little	....	....	....	....	....	....	....	tr.	0.	18.	....	....	....	7.6	31.	1906	S. Sanford (F)
.053	.16	34.	1.8	....	5.5	3.4	.01	....	.26	3.5	....	132.	tr.	....	....	2.7	....	....	W. H. Taylor
....	....	21.	2.8	....	14.	3.6	....	....	....	29.	....	55.	....	....	....	15.	....	....	W. H. Taylor
.18	tr.	5.8	2.5	....	14.	1.3	.01	tr.	....	28	....	9.2	5.5	.009	tr.	13.	....	....	S. Sanford (F)
....	....	little	....	....	....	....	....	....	....	>30	....	42.	....	....	....	3.1	55.	1906	S. Sanford (F)
....	....	little	....	....	....	....	....	....	....	>30	....	42.	....	....	....	4.5	33.	1906	S. Sanford (F)
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	little	....	....	....	....	....	....	....	....	....	17	....	....	....	9.	10.	1906	S. Sanford (F)
....	....	little	....	....	....	....	....	....	....	>30	0	50	....	....	....	27	....	1906	S. Sanford (F)
....	....	....	....	....	....	....	....	....	....	....	0	23	....	....	....	35.	18	1906	S. Sanford (F)
....	....	6.4	....	....	....	....	....	....	....	....	....	29.	....	....	....	....	24.	1905	E. C. Levy
....	....	35.	7.6	....	23.	....	....	....	....	17.	10.	155.	.9	....	....	6.6	....	1906	E. B. Dole
....	....	some	....	....	....	....	....	....	....	>30	0.	180.	....	....	....	6.	140	1906	S. Sanford (F)
1.95	....	2.9	3.2	....	11.	2.1	.03	....	....	3.8	....	395.	....	....	....	3.5	....	1907	J. B. Weems
....	....	much	....	....	....	....	....	....	....	>30	....	305	....	....	....	7.5	220	1906	S. Sanford (F)
9.9	tr.	93.	1.5[a]	....	5.4	2.9	.19	.034	.12	1.6	143.	....	....	tr.	tr.	11.	....	....	Froehling & Robinson
....	....	0.(?)	....	....	....	....	....	....	....	>30	....	32.	....	....	....	14.	13.	1906	S. Sanford (F)

TABLE 7—*Analyses and field assays (F) of well water from Columbia formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)
ACCOMAC							
Accomac	County	dug	26				
Accomac	G. L. Doughty	driven	34				
Accomac	B. T. Melson	drilled	50				
Belinda	M. E. Hall	drilled	68				
Chincoteague	D. J. Whealton	driven	14				
Fox Island	W. Ellinger	driven	32				
Fox Island	W. Ellinger	driven	32				
Franklin City	James Chapman	driven	70				
Franklin City	N. Y. P. & N. R. R.	driven	80	250.			
Greenbackville	J. T. Sharpley	driven	40				
Greenbackville	Elihu Tull	driven	34				
Hallwood	N. Y. P. & N. R. R.					14.	
Nandua	J. R. Henderson	drilled					
Nandua	A. T. L. Kusian	drilled	75				
New Church							
New Church							
Onancock	Town	driven					
Onancock	Town	dug and driven					
Onancock	M. L. Hurst	driven	36				
Pungoteague	S. T. Taylor	driven	62				
Tasley	N. Y. P. & N. R. R.	dug	12	71			
Tasley	N. Y. P. & N. R. R.	driven		112.		6.8	
Wachapreague	W. E. Brittingham	driven	12				
CAROLINE							
Bowling Green	Gill	dug	35				
Bowling Green	Town	dug					
Bowling Green	R. P. Vincent	dug					
Bowling Green	Dr. A. Webb	dug					
Delos		dug	20				
Messaponax		dug	22				
Port Royal	Arkins	dug	25				
CHARLES CITY							
Charles City	Mrs. Major	dug	40				
Shirley	H. I. Saunders	driven	30				
CHESTERFIELD							
Manchester	Chesterfield Laundry						
ELIZABETH CITY							
Hampton	Hampton Institute						
Hampton	Hampton Institute			524.			
Hampton	Hampton Mfg. Co.	dug					
Hampton	Hampton Roads Ry. & Elect. Co.	dug					
Hampton	City	dug	22				
ESSEX							
Center Cross		dug	22				
Tappahannock	Jas. Jackson	driven	13				
GLOUCESTER							
Achilles							
Bridges	Thos. Bridges	driven	12				

TABLE 7 *(Continued)—Analyses and field assays (F) of well water from Columbia formations.*

Iron (Fe)	Manganese (Mn)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
tr.	....	....	....	......	......	....	....	0.	25.	tr.	......	15.	15.	1906	S. Sanford (F)
tr.	....	....	mod.	......	......	....	....	0.	130.	tr.	......	......	91.	1906	S. Sanford (F)
1.5(?)	....	....	0.(?)	......	......	....	....	0.	11.	tr.	......	5.5	25.	1906	S. Sanford (F)
....	....	....	much	......	......	....	....	0.	180.	much	......	630.	440.	1906	S. Sanford (F)
2.	....	....	much	......	......	....	....	0.	240.	47.	......	210.	180.	1906	S. Sanford (F)
10.	....	....	....	......	......	....	....	......	340.	......	......	320.	18.	1907	S. Sanford (F)
3.5	....	....	much	......	......	....	....	0.	330.	>30.	......	740.	300.	1907	S. Sanford (F)
.8(?)	....	....	little	......	......	....	....	0.	230.	tr.	......	60.	85.	1906	S. Sanford (F)
little	....	....	....	......	......	....	....	......	....	......	......	14.6	......	1893	
tr.	....	....	little	......	......	....	....	0.	34.	tr.	......	9.	20.	1906	S. Sanford (F)
1.5	....	....	much	......	......	....	....	0.	45.	tr.	......	20.	......	1906	S. Sanford (F)
1.2	....	.9	6.	63.	......	....	....	......	17.	10.	......	tr.	......	....	Baldwin Locomotive Works
.5	....	....	little	......	......	....	....	......	42.	>30.	......	6.5	43.	1906	S. Sanford (F)
1.	....	....	much	......	......	....	....	......	180.	0.	......	30.	110.	1906	S. Sanford (F)
0.	....	....	113.	......	......	....	....	0.	83.	tr.	......	49.	102.	1906	H. N. Parker (F)
0.	....	....	much	......	......	....	....	......	100.	>30.	......	47.	55.	1906	S. Sanford (F)
1.	....	....	much	......	......	....	....	......	110.	>30.	......	9.5	58.	1906	S. Sanford (F)
2.(?)	....	....	little	......	......	....	....	......	62.	tr.	......	8.	50.	1906	S. Sanford (F)
0.	....	....	some	little	......	....	....	0.	....	some	......	16.	......	1899	C. B. Dudley
1.2	....	.9	8.6	66.	......	....	....	......	17.	10.	......	1.7	......	....	Baldwin Locomotive Works
tr.	....	....	mod.	......	......	....	....	......	180.	15.	......	110.	200.	1906	S. Sanford (F)
....	....	....	little	......	......	....	....	......	17.	tr.	......	73.	......	1906	S. Sanford (F)
tr.	....	....	mod.	......	......	....	....	0.	11.	0.	......	39.	60.	1906	S. Sanford (F)
.5	....	....	much	......	......	....	....	0.	37.	little	......	28.	90.	1906	S. Sanford (F)
1.8	....	....	mod.	......	......	....	....	......	37.	tr.	......	80.	60.	1906	S. Sanford (F)
1.5	....	....	....	......	......	....	....	......	....	......	......	......	50.	....	S. Sanford (F)
....	....	....	little	......	......	....	....	0.	19.	......	......	14.	52.	1906	S. Sanford (F)
....	....	....	much	......	......	....	....	......	....	>30.	......	120(?)	115.	1906	S. Sanford (F)
0.	....	....	little	......	......	....	....	0.	15.	0.	......	24.	38.	1906	S. Sanford (F)
tr.	....	....	little	......	......	....	....	0.	20.	0.	......	8.	35.	1906	S. Sanford (F)
....	....	....	....	......	......	....	....	......	....	......	......	......	......	1906	H. Bentley Smith Co.
....	....	....	188.	16.5	......	....	....	......	....	32.	......	113.	38.	....	W. S. Sweetser
0.	....	....	some	tr.	......	....	....	some	....	some	24.	85.	......	1902	C. B. Dudley
....	....	....	....	......	......	....	....	......	....	......	......	......	......	1904	H. Bentley Smith Co.
....	....	....	....	......	......	....	....	......	....	......	......	......	......	1904	H. Bentley Smith Co.
tr.	....	....	much	......	......	....	....	......	160.	tr.	......	87.	180.	1906	S. Sanford (F)
.5	....	....	....	......	......	....	....	......	23.	tr.	......	15.	21.	1906	S. Sanford (F)
1.5	....	....	mod.	......	......	....	....	......	300.	62.	......	54.	76.	1906	S. Sanford (F)
tr.	....	....	0.	......	......	....	....	......	12.	0.	......	11.	18.	1906	S. Sanford (F)

TABLE 7 (*Continued*)—*Analyses and field assays (F) of well water from Columbia formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)
GREENVILLE							
Emporia	Emporia Mfg. Co.	bored and driven	22				
HANOVER							
Ellerson	R. L. Acree	dug	42				
Hanover C. H.	County	dug	25				
HENRICO							
Ginter Park	S. H. Hawes	dug	32	62.	.17	8.0	
Richmond	Lewis Ginter L. & I. Co.	dug	27				
Richmond	Roseneegk Brewing Co.	dug	10	110.	40.	19.	
ISLE OF WIGHT							
Moonlight	Dr. Wells	dug	10				
JAMES CITY							
Williamsburg[a]	H. Johnson	dug	35				
KING GEORGE							
King George	County	dug	30				
Passapatanzy		dug	20				
KING AND QUEEN							
Cumnor	C. C. Vaughan	dug	30				
MATHEWS							
Mathew C. H.		dug	10				
MIDDLESEX							
Churchview		dug	22				
NORFOLK							
Berkley	Portsmouth, Berkeley & Suffolk Water Co.						
Berkley	Portsmouth, Berkeley & Suffolk Water Co.	driven	20-35				
Buell[a]	Pocomoke Guano Co.	driven	86	600.	301.		
Port Norfolk	Air Line Mfg. Co.	driven		170.	53.	7.7	
Port Norfolk	Air Line Mfg. Co.	driven	38				
Port Norfolk	Portsmouth & Norfolk Tract. Co.	driven	16-50	210.	72.	14.	7.
Port Norfolk	Seaboard Air Line R. R.	driven	60	280.	15.	40.	2.9
Port Norfolk	Seaboard Air Line R. R.	driven	old wells	275.[b]	7.7	44.	.34
Port Norfolk	Seaboard Air Line R. R.	driven	60	218.	8.	42.	3.
Port Norfolk	Seaboard Air Line R. R.	driven	new wells	[b]	10.	43.	tr.
Portsmouth	United States	driven	35	236.	85.	9.9	5.8
Norfolk	Imperial Co.			1,294.	24.	34.	
NORTHAMPTON							
Cape Charles	Heckle & Kellogg	driven		195.			
Cape Charles	N. Y. P. & N. R. R.	drilled	90			20.	
Cape Charles	N. Y. P. & N. R. R.	driven	18	251.		17.	
Cape Charles	N. Y. P. & N. R. R.	driven	12	226.			
Cape Charles	N. Y. P. & N. R. R.	drilled	90			21.	5.1
Cape Charles	N. Y. P. & N. R. R.	drilled	97	218.			

[a] Water may come from Chesapeake (Miocene) sand.
[b] Sample taken after prolonged pumping.

TABLE 7 *(Continued)—Analyses and field assays (F) of well water from Columbia formations.*

Iron (Fe)	Manganese (Mn)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
....	....	....	....	....	....	....	....	....	....	....	....	....	....	1904	H. Bentley Smith Co.
0.5	....	....	little	....	....	....	....	0.	16.	0.	....	6.	21.	1906	S. Sanford (F)
tr.	....	....	little	....	....	....	....	0.	22.	tr.	....	31.	41.	1906	S. Sanford (F)
1.7	....	....	5.4	4.6	.9	tr.	....	1.4	....	tr.	31.	7.	....	1906	Froehling & Robertson
tr.	....	....	0.(?)	....	....	....	....	0.	12.	>30.	....	8.	18.	1906	S. Sanford (F)
....	....	....	5.4	.56	13.	....	....	....	....	....	....	31.	....	1904	H. Bentley Smith Co.
2.(?)	....	....	little	....	....	....	....	....	14.	tr.	....	11.	....	1906	S. Sanford (F)
0.	....	....	much	....	....	....	....	....	180.	tr.	....	46.	....	1906	S. Sanford (F)
....	....	....	little	....	....	....	....	0.	32.	0.	....	....	....	1906	S. Sanford (F)
tr.	....	....	little	....	....	....	....	0.	7.3	....	....	14.	8.	1906	S. Sanford (F)
tr.	....	....	little	....	....	....	....	0.	23.	little	....	25.	32.	1906	S. Sanford (F)
tr.	....	....	mod.	....	....	....	....	....	40.	mod.	....	50.	75.	1906	S. Sanford (F)
tr.	....	....	little	....	....	....	....	0.	24.	0.	....	30.	23.	1906	S. Sanford (F)
.10	....	....	....	....	....	....	....	12.	....	20.	....	17.	35.	....	....
tr.	....	....	....	....	....	....	....	....	25.	tr.	....	15.	35.	1906	S. Sanford (F)
....	....	....	74.	31.	50.	....	....	292.	....	....	....	78.	....	....	Sparrows Point Boiler Compound Co.
....	....	....	27.	4.3	7.	....	....	28.	....	18.	....	24.	....	1905	H. Bentley Smith Co.
2.5(?)	....	....	little	....	....	....	....	....	64.	little	....	28.	56.	1906	S. Sanford (F)
....	....	....	21.	7.2	....	....	....	54.	....	49.	....	....	....	1906	Sparrows Point Boiler Compound Co.
....	....	....	35.	6.3	45.	....	....	78..	....	7.5	tr.	50.	....	1906	Froehling & Robertson
....	....	....	32.	6.	49.	....	....	83.	....	4.8	tr.	48.	....	1906	
....	....	....	38.	6.9	18.	....	....	73.	....	2.3	tr.	26.	....	1906	Froehling & Robertson
....	....	....	34.	8.3	18.	....	....	73.	....	3.2	tr.	25.	....	1906	
....	....	....	36.	3.4	....	....	....	31.	....	32.	....	....	....	1906	Sparrows Point Boiler Compound Co.
1.3	....	....	11,410.	42.	310.	....	....	187.	....	8.1	tr.	574.	....	1906	Froehling & Robertson
....	....	....	....	....	....	....	....	....	....	0.	....	48.	....	1905	York Mfg. Co.
1.2	....	.9	50.	67.	....	....	....	....	350.	3.4	....	1.7	....	....	....
3.6	....	27.	31.	55.	....	....	....	....	124.	14.	....	3.4	....	....	Baldwin Locomotive Works
....	....	....	much	some	....	....	....	....	....	much	.70	35.	....	1899	C. B. Dudley
....	....	....	6.5	2.2	....	....	....	....	....	5.3	....	20.	31.	....	Baldwin Locomotive Works
....	....	....	much	little	....	....	....	much	....	little	....	21.	....	1899	C. B. Dudley

TABLE 7 *(Continued)—Analyses and field assays (F) of well water from Columbia formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)
NORTHAMPTON—Cont.							
Eastville	N. Y. P. & N. R. R.					8.5	
Eastville	N. Y. P. & N. R. R.		10	190.			
Eastville	County	driven	40				
Exmore	N. Y. P. & N. R. R.		12	144.			62.
Exmore	N. Y. P. & N. R. R.	driven	18			22.	4.8
Exmore	N. Y. P. & N. R. R.	driven	12(?)	87.3		8.5	
Exmore	N. Y. P. & N. R. R.	driven	30			33.	8.2
NORTHUMBERLAND							
Heatsville	J. E. Nelms	dug	45				
PRINCESS ANNE							
Waterway	Norfolk County Waterworks	driven	30	115.	51.		
Virginia Beach	Walker	driven	17				
Waterway	Norfolk County Waterworks	driven					
PRINCE GEORGE							
Claremont							
Garysville	H. C. Browning	dug	25				
SURRY							
Bacon's Castle	M. Bell	dug	28				
Dendron	E. Jones	driven	25				
Homewood	W. F. Maddera	dug	30				
SUSSEX							
Wakefield	Baine Peanut Co.	dug	12	389.	180.	10.	
Wakefield	E. W. Brittle	driven	20				
Wakefield	S. Parr	dug	16				
Waverly	Waverly Peanut Co.	dug	16	65.	4.4	10.	
Waverly	J. D. Gray	driven	35				
WESTMORELAND							
Kinsale	Hotel	dug					
Leedstown	Jas. Baxter	dug	20				
Oak Grove	A. Flanmer	dug	63				
Potomac Mills	John Barrack	dug	27				

TABLE 7 *(Continued)—Analyses and field assays (F) of well water from Columbia formations.*

Iron (Fe)	Manganese (Mn)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
1.2	....	.9	17.	54.	......	....	....	......	77.	8.5	......	1.7	......	....	Baldwin Locomotive Works
little	....	....	some	much	......	....	....	......	....	much	......	35.	......	1899	C. B. Dudley
0.	....	....	little	......	......	....	....	......	13.	55.	......	40.	67.	1906	S. Sanford (F)
much	....	....	some	much	......	....	....	......	....	much	......	43.	......	1899	C. B. Dudley
....	....	....	3.1	1.7	......	....	....	......	....	3.8	......	14.	25.	....	....
1.2	....	.9	6.	52.	......	....	....	......	....	17.	......	1.7	......	....	Baldwin Locomotive Works
....	....	....	4.8	3.	......	....	....	......	....	7.8	......	13.	34.	....	Baldwin Locomotive Works
....	....	....	....	......	......	....	....	0.	30.	......	......	30.	70.	1906	S. Sanford (F)
....	....	....	....	......	......	....	....	......	....	......	.75	8.	128.	1907	Booth, Garrett & Blair
tr.	....	....	little	......	......	....	....	......	26.	>30.	......	74.	50.	1906	S. Sanford (F)
tr.	....	....	little	......	......	....	....	......	8.	>30.	......	17.	42.	1906	S. Sanford (F)
0.	....	....	much	......	......	....	....	0.	110.?	0.	......	11.	97.	1906	S. Sanford (F)
4.5(?)	....	....	....	......	......	....	....	......	100.	>30.	......	11.	55.	1906	S. Sanford (F)
tr.	....	....	mod.	......	......	....	....	0.	23.	0.	......	95(?)	70.	1906	S. Sanford (F)
....	....	....	0.(?)	......	......	....	....	......	12.	0.	......	5.	41.	1906	S. Sanford (F)
.5	....	....	little	......	......	....	....	......	23.	0.	......	10.	38.	1906	S. Sanford (F)
....	....	....	21.	......	......	....	....	24.	....	11.	......	93.	......	1904	H. Bentley Smith Co.
....	....	....	little	......	......	....	....	......	81.	0.	......	22.	55.	1906	S. Sanford (F)
tr.	....	....	0.(?)	......	......	....	....	......	14.	0.	......	22.	48.	1906	S. Sanford (F)
....	....	....	10.	2.2	6.1	....	....	10.	....	2.1	......	20.	......	1904	H. Bentley Smith Co.
tr.	....	....	little	......	......	....	....	0.	16.	0.	......	12.	11.	1906	S. Sanford (F)
....	....	....	....	......	......	....	....	0.	35.	......	......	35.	37.	1906	S. Sanford (F)
tr.	....	....	much	......	......	....	....	0.	62.	>30.	......	20.	......	1906	S. Sanford (F)
tr.	....	....	much	......	......	....	....	0.	21.	much	......	31.	42.	1906	S. Sanford (F)
tr.	....	....	little	......	......	....	....	......	31.	......	......	26.	13.	....	S. Sanford (F)

Table 8—*Analyses and field assays (F) of well water from Chesapeake formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)
Accomac								
Accomac[a]	B. T. Gunter	drilled	122.					2.
Accomac[a]	L. L. Tiffany	drilled	100.					tr.
Cashville[a]	Susan A. Tiffany	drilled	100.					tr.
Franklin City[a]		drilled	80.	250.				little
Harborton[a]	Allen & Lennau	drilled	140.					tr.
Pungoteague	S. W. Ames	drilled	210.	250.		45.		.1
Charles City								
Malvern Hill[b]	G. M. Gill	bored	70.					1.
Wilcox Wharf[b]	T. W. Hubbard	dug	43.	333.	3.1	34.		.75
Essex								
Bowler's Wharf	Donaldson & Schultz	drilled						
Bowler's Wharf	Claybrooke & McNeal Packing Co.	drilled	165.					tr.
Center Cross	C. F. Kriete	drilled	190.					tr.
Tappahannock	B. B. Brockenbrough	drilled	272.					tr.
Tappahannock	R. T. Cauthorn	drilled	275.	494.	48.			
Ware's Wharf	W. L. Ware	drilled	170.					tr.
Gloucester								
Allmondsville	W. W. Allmond	drilled	270.					0.
Freeport	E. C. Farinholt	drilled	330.					.8
Freeport	R. H. Farinholt	drilled	338.					
Gloucester C. H.	Town	dug	30.					tr.
Henrico								
Elko	E. J. Furman	driven	35.					1.
Isle of Wight								
Day's Point	J. A. Morgart	drilled	383.	434.		12.		.19
Shoalbay	Dr. Wm. D. Turner	drilled	226.	786.	15.	18.		.81
Smithfield	Smithfield Mineral Water Co.	drilled	300.	566.	.94	10.5		.22
Zuni	Town	drilled	161.					tr.
Zuni		drilled				16.2		.28
James City								
Croaker	Wilbur H. Davis	drilled	200.	521.		21.		
Jamestown	C. F. Ayers	drilled	300.					tr.
Jamestown	Association for the Preservation of Virginia Antiquities	drilled	267.					tr.
Williamsburg	Marshall Estate	drilled	285.	523.		21.		tr.
Williamsburg	Galba Vaiden	drilled	276.	662.	40.			
Williamsburg	Mrs. R. M. Smith	drilled		185.		1.1		
Williamsburg	Mrs. R. M. Smith	drilled						3.0
Williamsburg	Eastern State Hospital	drilled	286.	553.		28.		tr.
King George								
King George	Edward Hunter	dug	45.					tr.
King William								
West Point	Denmead Bros.	drilled	105.					tr.
West Point	Southern Railway	drilled	165.	927.		25.		.11
King and Queen								
Chain Ferry	Wm. Blake	drilled	165.					tr.
Lancaster								
Irvington	W. A. Dameron & Bro.	drilled	330.					tr.

[a]May be in Columbia beds.
[b]Source of main supply uncertain.
[c]Also ammonium radicle (NH_4), .39; borate radicle (B_2O_7), trace.
[d]Biborate radicle (B_4O_7), 3.5
[e]Ammonium radicle (NH_4), 9.7; borate radicle (B_2O_7), trace.

TABLE 8 *(Continued)—Analyses and field assays (F) of well water from Chesapeake formations.*

Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Phosphate radicle (PO_4)	Nitrate radicle (NO_3)	Bromine (Br)	Iodine (I)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
....	....	much	......	....	....	....	......	140.	tr.	....	....	....	......	12.	91.	1906	S. Sanford (F)
....	....	much	......	....	....	....	0.	124.	0.	....	....	....	......	11.	87.	1906	S. Sanford (F)
....	....	much	......	....	....	....	0.	170.	0.	....	....	....	......	11.	65.	1906	S. Sanford (F)
....	....	much	some	....	....	....	much	....	little	....	.8	....	......	14.6	....	1893	C. B. Dudley
....	....	some	......	....	....	....	0.	90.	......	....	....	....	......	38.	56.	....	S. Sanford (F)
....	....	25.	11.	32.	14.	....	0.	218.	1.6	....	3.6	....	......	12.	....	1906	R. B. Dole
....	....	tr.	......	....	....	....	......	115.	0.	....	....	....	......	27.	35.	1906	S. Sanford (F)
.5	....	2.5	.5	122.	....	....	tr.	313.	7.7	....	.1	....	......	4.3	....	1906	R. B. Dole
....	....	......	......	....	....	....	0.	200.	>25.	....	....	....	......	8.6	56.	1906	S. Sanford (F)
....	....	mod.	......	....	....	....	0.	150.	tr.	....	....	....	......	4.2	50.	1906	S. Sanford (F)
....	....	mod.	......	....	....	....	0.	205.	......	....	....	....	......	......	65.	1906	S. Sanford (F)
....	....	0.	......	....	....	....	12.	410.	>30.	....	....	....	......	5.8	7.3	1906	S. Sanford (F)
....	....	......	......	....	....	....	......	....	35.	....	0.	....	......	2.	25.	....	S. Sanford (F)
....	....	little	......	....	....	....	tr.	230.	>30.	....	....	....	......	3.	19.	1906	S. Sanford (F)
....	....	little	......	....	....	....	22.	402.	10.	....	....	....	......	106.	....	1906	R. B. Dole (F)
....	....	tr.	......	....	....	....	12.	680.	tr.	....	....	....	......	25.	3.2	1906	S. Sanford (F)
....	....	tr.	......	....	....	....	12.	670.	tr.	....	....	....	......	30.	8.	1906	S. Sanford (F)
....	....	much	......	....	....	....	0.	75.	>30.	....	....	....	......	147.	100.	1906	S. Sanford (F)
....	....	much	......	....	....	....	0.	190.	little	....	....	....	......	4.2	110.	1906	S. Sanford (F)
.53	.008	2.6	1.1	169.	6.2	.008	204.	....	11.	.85	....	.36	.0004	25.	....	1903	Froehling & Robertson
.64	tr.	3.9	1.4	193.	11.	tr.[c]	......	518.	1.6	.17	.75	.73	.77	17.	....	1907	Froehling & Robertson
1.2	tr.	7.	2.6	188.	6.1	....	175.	133.	9.	.13[d]	tr.	.012	.012	27.	....	1907	Froehling & Robertson
....	....	little	......	....	....	....	30.	370.	tr.	....	....	....	......	5.	14.	1907	S. Sanford (F)
....	....	2.76	4.1	140.	....	....	185.	....	12.5	....	....	....	......	4.	....	1909	N. S. Hill
....	....	2.9	tr.	130.	11.	tr.	......	350.	5.8	....	.2	....	......	2.7	10.	....	....
....	....	......	......	....	....	....	6.1	310.	......	....	....	....	......	135.	3.8	1906	S. Sanford (F)
....	....	......	......	....	....	....	14.	280.	tr.	....	....	....	......	57.	3.8	1906	S. Sanford (F)
....	....	7.2	2.7	185.	16.	....	179.	....	10.	....	....	....	......	103.	....	....	W. H. Taylor
....	....	12.	3.7	131.	....	....	198.	....	21.	....	....	....	......	149.	....	....	Keystone Chemical Co.
....	....	53.	2.2	107.	....	....	......	....	......	....	....	....	......	14.	....	....	Henry Froehling
....	....	much	......	....	....	....	......	360.	mod.	....	....	....	......	15.	480.	....	S. Sanford (F)
....	....	8.	4.3	191.	17.	....	188.	....	10.	....	....	....	......	107.	....	....	W. H. Taylor
....	....	mod.	......	....	....	....	0.	36.	>30.	....	....	....	......	170.	58.	1906	S. Sanford (F)
....	....	0.	......	....	....	....	0.	260.	>30.	....	....	....	......	3.	21.	1906	S. Sanford (F)
.86	....	4.8	47.	213.	14.	[e]	......	306.	307.	.6	tr.	.18	.04	6.7	....	....	Henry Froehling
....	....	tr.	......	....	....	....	......	230.	tr.	....	....	....	......	6.	14.	1906	(F.)
....	....	little	......	....	....	....	0.	480.	>30.	....	....	....	......	18.	10.	1906	S. Sanford (F)

TABLE 8 *(Continued)—Analyses and field assays (F) of well water from Chesapeake formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)
MIDDLESEX								
Urbanna	G. V. Wagenen	drilled	232.					
Dew	D. M. Nelson	drilled	297.					
NANSEMOND								
Everetts	T. J. Saunders	drilled	54.					tr.
NORFOLK								
Norfolk	Pocomoke Guano Co.	drilled	86.	600.				
NORTHAMPTON								
Bone Island		drilled	169.					1.5
Oyster	W. F. Travis	drilled	185.				tr.	
Sandy Island	Wharton Fisheries Co	drilled	249.					tr.
Sandy Island	Wharton Fisheries Co	drilled	249.	918.				little
NORTHUMBERLAND								
Coans	Thomas Fallin	drilled	260.					1.5
Hardings	Wharton Fisheries Co.	drilled	......	462.				.13
Lodge	Wharton Fisheries Co.	drilled	255.	220.				tr.
RICHMOND								
Warsaw	E. H. Garland	drilled	188.					1.
Warsaw	G. M. Sydnor	drilled	180.					
SOUTHAMPTON								
Boykins	Baptist Church	drilled	127.					tr.
Boykins	E. H. Grizzard	drilled	85.					tr.
Boykins	W. A. Powell	drilled	110.					tr.
Boykins	Town	drilled	90.					tr.
Courtland	R. T. Whitfield	drilled	165.	277.	20.	25.	....	.9
	Railroad	drilled	......	244.	23.	27.	....	.16
SURRY								
Homewood	W. F. Gray	drilled	250.					tr.
Homewood	W. F. Gray	drilled	315.	785.		37.	....	.1
WESTMORELAND								
Beales Wharf	Beales & Biddle	drilled	175.					
Kinsale	G. P. Bailey	drilled	238.					tr.
Kinsale	Dameron & Courtney	drilled	275.					
Lynch's Point	J. R. Dos Passos	drilled	90.					5.
Mount Holly	S. J. Hopkins	drilled	135.					
Sandy Point	J. R. DosPassos	drilled	250.					
WARWICK								
Curtis Point	Philip Lederhos	drilled	363.	910.		18.	....	.12
Mulberry Island	P. H. Wright	drilled	373.	1,158.		13.	....	tr.
Mulberry Island	P. H. Wright	drilled	373.					tr.

[a]Ammonium radicle (NH_4) 9.7; borate radicle (B_2O_7) trace.
[b]Sodium and potassium.

TABLE 8 *(Continued)—Analyses and field assays (F) of well water from Chesapeake formations.*

Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Phosphate radicle (PO_4)	Nitrate radicle (NO_3)	Bromine (Br)	Iodine (I)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
		little					16.	450.	tr.					9.5	5.6	1906	S. Sanford (F)
		little					15.	360.	>30.					12.	8.	1906	S. Sanford (F)
								220.	tr.					6.	81.	1906	S. Sanford (F)
		74.	31.	50.			292.							78.		1905	Sparrows Point Boiler Compound Co.
		much					0.	240.	>30.					610.	140.	1907	S. Sanford (F)
		mod.					5.	200.	0.					19.	70.	1906	S. Sanford (F)
		some					0.	210.	>30.					420.	95.	1906	S. Sanford (F)
		some	some				some		little					427.		1901	C. B. Dudley
		some					0.	260.	0.					6.7	40.	1906	S. Sanford (F)
		7.2	1.8				24.	396.	.3					6.6		1907	R. B. Dole
									0.		0.			4.	42.		G. W. Lehmann
		mod.					0.	250.	>30.					5.	32.	1906	S. Sanford (F)
		little					0.	210.	0.					4.	34.	1906	S. Sanford (F)
		some					0.	170.	>30.					6.	62.	1907	S. Sanford (F)
		little					0.	170.	>30.					5.2	42.	1907	S. Sanford (F)
		little						150.	tr.					7.	21.(?)	1907	S. Sanford (F)
		little						150.	tr.					5.3	50.	1907	S. Sanford (F)
											0.			19.	16.	1909	N. S. Hill
											0.			18.	25.	1909	N. S. Hill
		0.					15.	425.	>30.					35.	7.3	1906	S. Sanford (F)
		6.8	2.2	295[b]			23.	468.	26.		.3			152.			R. B. Dole
		little					0.	185.	>30.					6.	12.	1906	S. Sanford (F)
		little					0.	210.	>30.					5.3	23.	1900	S. Sanford (F)
		little					0.	220.	>30.					5.3		1906	S. Sanford (F)
		some					0.	320.	much					7.	50.	1900	S. Sanford (F)
		some					0.	180.	>23.					5.	18.	1906	S. Sanford (F)
		little						250.	>30.					5.7	13.	1906	S. Sanford (F)
		7.2	1.2	350[b]			22.	448.	32.		tr.			244.		1902	R. B. Dole
		4.2	1.2	354.	15.	tr.		454.	44.					273.		1905	W. H. Taylor
							6.	400.	39.					250.	11.	1906	S. Sanford (F)

TABLE 9—*Analyses and field assays of well water from Pamunkey formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)
CAROLINE								
Port Royal	Town	drilled	235	......	......	......	......	......
CHARLES CITY								
Roxbury	Thos. Walker	drilled	250	......	......	......	......	tr.
Westover	W. S. Ramsay	drilled	135	......	......	......	......	tr.
ESSEX								
Tappahannock	F. S. McDaniel	drilled	280	......	......	......	......	tr.
Tappahannock	R. T. Cauthorn	drilled	......	494.	48.	......	......	......
Tappahannock	Donaldson & Schultz	drilled	256	......	......	......	......	......
GLOUCESTER								
Sassafras	B. F. Weaver	drilled	336	......	......	......	......	2.
Achilles	Union Church	drilled	500	......	......	......	......	5.5
JAMES CITY								
Lee Hall	Duke & Smith	drilled	429	......	......	......	......	tr.
Lee Hall	Duke & Smith	drilled	395	......	......	......	......	tr.
Norge	Chesapeake & Ohio Ry.	drilled	419	718.	9.9	40.	6.	......
KING GEORGE								
Mathias Point	C. H. Pemberton	drilled	286	......	......	......	......	tr.
Port Conway	R. V. Turner	drilled	232	......	......	......	......	tr.
Port Conway	J. H. Low	drilled	305	......	......	......	......	......
Port Conway	R. V. Turner	drilled	250	......	......	......	......	......
Port Conway	Dr. Jones	drilled	305	......	......	......	......	.3
Wilsmont Landing	Vulcan Fire Brick Co.	drilled	300(?)	......	......	......	......	......
KING WILLIAM								
Aylett	J. B. Moore	drilled	190	303.	......	17.	......	.2
Elsing Green	Roger Gregory	drilled	300	......	......	......	......	tr.
West Point	West Point Waterworks	drilled	335	......	......	......	......	......
KING AND QUEEN								
King and Queen	County	drilled	216	......	......	......	......	1.
Walkerton	Ivan Clark	drilled	235	......	......	......	......	tr.
LANCASTER								
Irvington	Carters Creek Fish Guano Co.	drilled	580	......	......	......	......	tr.
NEW KENT								
Boulevard	Wm. Webber	drilled	260	60.	......	23.	......	.08
Providence Forge	E. R. Richardson	drilled	215	......	......	......	......	tr.
Providence Forge	E. B. Towsend	drilled	250	......	......	......	......	tr.
NORTHUMBERLAND								
Harding	S. A. Whitaker	drilled	......	462.	......	......	.13	......
RICHMOND								
Naylors Wharf	E. A. Waddington	drilled	320	......	......	......	......	......
WESTMORELAND								
Colonial Beach	M. A. & E. S. Bentley	drilled	200	......	......	......	......	tr.
Colonial Beach	L. W. Jett	......	230	......	......	......	......	......
Colonial Beach	Ice Works	drilled	235	......	......	......	......	......
Erica	E. T. Barrett	drilled	335	......	......	......	......	tr.
Erica	Wm. Detrick	drilled	327	......	......	......	......	tr.
Wilkerson	W. S. Wilkerson	drilled	233	......	......	......	......	tr.
STAFFORD								
Brooke	Richmond, Fredericksburg and Potomac R. R. Co.	dug	20	......	......	......	......	tr.

TABLE 9 *(Continued)—Analyses and field assays of well water from Pamunkey formations.*

Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Strontium (Sr)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
......	......	little	....	......	......	......	......	0.	180.	>30.	....	6.	5.	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	0.	195.	>30.	....	2.5	14.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	405.	>30.	....	54.?	31.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	8.4	470.	>30.	....	7.5	11.	1906	S. Sanford (F)
......	......	......	....	......	......	......	......	......	......	34.	....	2.	25.	1904	G. H. Lehmann
......	......	......	....	......	......	......	......	0.	210.	>30.	....	8.6	56.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	>10.	645.	54.	....	220.	18.	1906	S. Sanford (F)
......	......	mod.	....	......	......	......	......	0.	800.	135.	....	1,500.	67.	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	0.	440.	>30.	....	190.	7.3	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	0.	470.	>30.	....	280.	12.	1906	S. Sanford (F)
......	......	11.	....	3.1	252.	......	......	180.	......	39.	....	176.	....	1910	Froehling & Robertson
......	......	0.(?)	....	......	......	......	......	0.	250.	>30.	....	12.5	7.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	140.	>30.	....	5.	1.	1906	S. Sanford (F)
......	......	......	....	......	......	......	......	0.	190.	>30.	....	......	....	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	240.	>30.	....	>10.	....	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	190.	>30.	....	5.	2.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	270.	>30.	....	5.	....	1906	S. Sanford (F)
......	......	3.2	....	.4	105.	8.8	......	22.	245.	18.	0.	1.0	....	1906	R. B. Dole
......	......	little	....	......	......	......	......	0.	360.	>30.	....	>10.	14.	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	0.	480.	>30.	....	17.5	2.	1906	S. Sanford (F)
......	......	......	....	......	......	......	......	0.	220.	>30.	....	7.5	41.	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	13.	280.	>30.	....	3.	7.3	1906	S. Sanford (F)
......	......	0.(?)	....	......	......	......	......	20.	500.	>30.	....	13.	1.	1906	S. Sanford (F)
.6	......	2.1	....	.4	9.2	......	......	0.	29.	1.6	4.4	6.5	....	1906	R. B. Dole
......	......	little	....	......	......	......	......	0.	200.	>30.	....	4.	24.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	10.?	300.	>30.	....	3.8	10.	1906	S. Sanford (F)
......	......	7.2	....	1.8	......	......	......	24.	396.	.3	....	5.5	....	1907	R. B. Dole
......	......	tr.	....	......	......	......	......	15.	390.	......	....	7.6	....	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	8.	330.	>30.	....	11.	12.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	15.	270.	>30.	....	10.	16.	1906	S. Sanford (F)
......	......	5.	....	3.6	127.	......	......	0.	354.	20.	....	......	....	1906	M. G. Roberts
......	......	little	....	......	......	......	......	0.	340.	>30.	....	>10.	13.	1906	S. Sanford (F)
......	......	......	....	......	......	......	......	20.	395.	>30.	....	5.	11.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	18.	380.	>30.	....	9.	11.	1906	S. Sanford (F)
......	......	little	....	......	......	......	......	0.	25.	>30.	....	9.	5.6	1906	S. Sanford (F)

TABLE 10—*Analyses and field assays (F) of well water from Upper Cretaceous formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)
ELIZABETH CITY						
Fort Monroe	Hotel Chamberlain	drilled	945.	9,131.	47.	20.
Fort Monroe	Hotel Chamberlain	drilled	945.	9,248.	......	14.
Fort Monroe	Hotel Chamberlain	drilled	945.	8,846.	......	......
Fort Monroe	Hotel Chamberlain	drilled	945.	....	......	......
GLOUCESTER						
Achilles	B. A. Rowe	drilled	600.	....	......	......
Gloucester Point	County and Chesapeake Steamship Co.	drilled	694.	....	......	......
Roanes	A. W. Withers	drilled	716½	3,417.	......	20.
Severn	J. M. Shakelford	drilled	610.	5,008.	......	39.
KING WILLIAM						
Manquin	E. B. Chapman	drilled	237.	232.	......	33.
Manquin	Miss Cora Skidmore	drilled	270.	....	......	tr.
LANCASTER						
Ocran	....	drilled	660.	616.	......	56.
MIDDLESEX						
Urbanna	J. W. Hurley	drilled	650.	....	......	......
NANSEMOND						
Suffolk	Norfolk & Portsmouth Traction Co.	drilled	803.(?)	596.	20.	......
NORFOLK						
Lamberts Point	N. & W. R. R.	drilled	616.	1,093.	......	10.
Lamberts Point	N. & W. R. R.	drilled	616.	....	......	16.
Lamberts Point	N. & W. R. R.	drilled	616.	....	......	11.
Lamberts Point	N. & W. R. R.	drilled	616.	....	......	......
Lamberts Point	N. & W. R. R.	drilled	616.	1,067.	......	8.56
Lamberts Point	N. & W. R. R.	drilled	616.	86.	......	2.4
Lamberts Point	N. & W. R. R.	drilled	616.	1,128.	......	6.
NORTHUMBERLAND						
Fairport	....	....	690?	214.	80.	......

[a]Sodium and potassium.

TABLE 10—*(Continued)—Analyses and field assays (F) of well water from Upper Cretaceous formations.*

Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
16.	......	....	....	88.	71.	3,339.	....	....	328.	....	251.	tr.	4,929.	......	1906	Penniman & Brown
......	16.	23.	....	97.	44.	3.268.	87.	tr.	....	433.	265.	......	4,978.	......	1906	W. H. Taylor
......	......	....	....	......	......	....	....	....	....	....	......	......	....	133.	1896	Booth, Garrett & Blair
......	6.	....	....	mod.	......	....	....	....	5.	740.	180.	......	4,530.	70.	1906	S. Sanford (F)
......	2.5	....	....	much	......	....	....	....	5.(?)	840.	160.	......	1,400.	57.	1906	S. Sanford (F)
......	1.	....	....	little	......	....	....	....	6.	730.	38.	......	410.	21.	1906	S. Sanford (F)
......	1.	....	....	23.	14.	1,188.[a]	....	....	21.	544.	155.	tr.	1,630.	......	1906	R. B. Dole
......	4.9	....	....	46.	26.	1,826.[a]	....	....	0.	628.	216.	.7	2,500.	......	1906	R. B. Dole
......	1.	....	....	1.4	.2	74.	5.	....	6.7	188.	13.	0.	1.1	......	1906	R. B. Dole
......	tr.	....	....	little	......	....	....	....	0.	210.	>30.	......	>10.	2.	1906	S. Sanford (F)
......	tr.	....	....	little	little	much	s'm	e...	much	....	some	......	some	......	1907	G. H. Seyms
......	tr.	....	....	0.	......	....	....	....	14.	315.	>30.	......	9.	0.	1906	S. Sanford (F)
......	tr.	....	....	2.9	1.7	<214.	....	....	<280.	....	9.8	0.	23.	13.	1904	First Scientific Station for the Art of Brewing
0.91	......	....	....	5.	1.7	415.	21.	....	245.	....	43.	......	351.	......	1891	Shepard Laboratory
2.3	......	....	....	5.2	2.4	459.	....	....	....	601.	43.	......	291.	......	1906	N. & W. Railway
2.6	......	....	....	4.8	2.7	434.	....	....	....	617.	43.	......	293.	......	1907	Dearborn Laboratories
......	.5	....	....	little	......	....	....	....	9.	560.	41.	......	290.	......	1906	S. Sanford (F)
......	1.37	....	....	3.9	2.2	340.	11.	....	370.	....	45.	......	300.	......	....	N. & W. Railway
1.2	......	....	....	6.3	4.7	16.5	....	....	10.	....	20.	......	23.	......	1909	N. & W. Railway
1.9	......	....	....	5.1	3.3	437.	....	....	312.	....	45.	......	290.	......	1909	N. & W. Railway
......	......	....	....	......	......	....	....	....	....	....	0.	0.	6.	67.	....	G. H. Lehmann

TABLE 11—*Analyses and field assays (F) of well water from Potomac formations.*

Locality	Owner	Type of well	Depth (feet)	Total solids	Organic and volatile matter	Silica (SiO_2)
ALEXANDRIA						
Alexandria	New Washington Brick Co.			86.	......	33.
Alexandria	Belle Pre Bottle Co.	drilled	155.	110.	......	38.
Alexandria	Mutual Ice Co.	drilled	401.	176.	......	21.
Alexandria	Robert Portner Brewing Co.	drilled	431.	170.	14.	......
Alexandria	Robert Portner Brewing Co.	drilled	400?	205.	......	27.
Alexandria	Robert Portner Brewing Co.	drilled	431.	......	......	......
FAIRFAX						
Fort Hunt	United States	drilled	215.	342.	......	......
GLOUCESTER						
Roanes	Joseph Bryan		850.(?)	......	......	......
KING GEORGE						
Sealston	John Curtis	drilled	250.	......	......	......
KING WILLIAM						
Palls	J. H. Montague	drilled	399.	......	......	......
MATHEWS						
Mathews C. H.	County	drilled	817.	......	......	......
PRINCE GEORGE						
City Point	Misses Eppes	drilled	111.	179.	......	23.
PRINCESS ANNE						
Waterway	Norfolk City Waterworks	drilled	1,100.(?)	......	......	......
SOUTHAMPTON						
Sebrell	Tidewater Railway	drilled	344.	295.	9.9	78.
SPOTTSYLVANIA						
Fredericksburg	E. D. Cole	drilled	120.	43.	4.3	12.

[a]Sodium and potassium.
[b]Oxide and carbonate of iron 6.8

TABLE 11 *(Continued)—Analyses and field assays (F) of well water from Potomac formations.*

Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total hardness as $CaCO_3$	Date	Analyst
....	1.4	....	....	4.1	2.6	10.	....	....	0.	30.	11.	0.	6.9	....	1910	Chase Palmer
....	4.6	....	....	6.5	3.9	12.	....	....	0.	51.	6.4	1.	13.	....	1910	Chase Palmer
....	....	....	....	tr.	1.4	49.	....	....	....	39.	36.	....	32.	....	1899	J. D. Hird
4.	....	....	....	7.1	.0	....	....	....	....	....	17.	0.	19.5	200.	1903	First Scientific Station for the Art of Brewing
....	1.	....	....	8.6	19.	32.	....	....	tr.	105.	3.	tr.	47.	....	1910	Chase Palmer
..	tr.	....	....	....	....	....	....	....	....	130.	>30.	....	44.	....	....	S. Sanford (F)
....	....	....	....	....	....	....	....	....	....	....	....	....	5.4	....	....	W. Mew
....	2.5	....	....	mod.	....	....	....	....	11.	660.	100.	....	1,090.	33.	1906	S. Sanford (F)
....	....	....	....	mod.	....	....	....	....	0.	120.	tr.	....	....	....	1906	S. Sanford (F)
....	tr.	....	....	tr.	....	....	....	....	0.	175.	>30.	....	5.	7.5	....	S. Sanford (F)
....	3.	....	....	much	....	....	....	....	0.	673.	tr.	....	167.	....	1906	R. B. Dole (F)
....	.4	....	....	52.	3.2	16.[a]	....	....	0.	155.	5.3	6.	16.	....	1906	R. B. Dole (F)
....	tr.	....	....	little	....	....	....	....	5.	610.	110.	....	1,030.	7.5	1906	S. Sanford (F)
2.1	....	....	....	.79	.26	82.	....	....	84.	....	25.	....	10.6	....	1901	....
([b])	....	....	....	.5	2.9	3.3	...	....	10.	....	3.5	....	....	....	....	J. N. Barney

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PREPARED IN COÖPERATION WITH
U. S. GEOLOGICAL SURVEY
VIRGINIA GEOLOGICAL SURVEY
UNIVERSITY OF VIRGINIA
THOMAS LEONARD WATSON, Director
MAP OF THE
COASTAL PLAIN
OF
VIRGINIA
Showing flowing wells and limits of flow, at an elevation of twenty feet, from different artesian sands, and probable variation in chlorine content of artesian water 200 to 700 feet below sea level in southeastern part of the Virginia Coastal Plain.
BY
SAMUEL SANFORD
1912
LEGEND
Western boundary of Coastal Plain
Western limit of area in which deep wells give scanty flows, or highly mineralized water
Western limit of flows from Chesapeake sands
Western limit of flows from Pamunkey sands
Western limit of flows from Potomac sands
Dotted lines, isochlors, figures, parts per million of chlorine
Flowing wells from Columbia (?) sands
Flowing wells from Chesapeake sands
Flowing wells from Pamunkey sands
Flowing wells from Potomac or Upper Cretaceous sands
Superimposed circles indicate more than one group of artesian sands
Scale 1/500000
0 10 20 30 40 Miles
0 10 20 30 40 50 Kilometers
MARYLAND
WEST VIRGINIA
D. C.
WASHINGTON
CHESAPEAKE BAY
ATLANTIC OCEAN
POTOMAC RIVER
POCOMOKE SOUND
LOUDOUN
CLARKE
FAUQUIER
FAIRFAX
PRINCE WILLIAM
CULPEPER
STAFFORD
KING GEORGE
ORANGE
SPOTTSYLVANIA
WESTMORELAND
CAROLINE
LOUISA
HANOVER
RICHMOND
NORTHUMBERLAND
ESSEX
LANCASTER
KING AND QUEEN
KING WILLIAM
MIDDLESEX
GOOCHLAND
HENRICO
POWHATAN
NEW KENT
GLOUCESTER
MATHEWS
AMELIA
CHESTERFIELD
CHARLES CITY
JAMES CITY
YORK
PRINCE GEORGE
SURRY
ELIZABETH CITY
WARWICK
NOTTOWAY
DINWIDDIE
SUSSEX
ISLE OF WIGHT
PRINCESS ANNE
NORFOLK
BRUNSWICK
GREENSVILLE
SOUTHAMPTON
NANSEMOND
ACCOMAC
NORTHAMPTON
RICHMOND
PETERSBURG
NORFOLK
PORTSMOUTH
HAMPTON
CAPE HENRY
CAPE CHARLES
POCOMOKE CITY