UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Water-Supply Paper 773

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

1936

NATHAN C. GROVER, Chief Hydraulic Engineer

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Water-Supply Paper 773—A

GEOLOGY AND GROUND-WATER RESOURCES

OF THE

ELIZABETH CITY AREA, NORTH CAROLINA

BY

S. W. LOHMAN

Prepared in cooperation with the
NORTH CAROLINA DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

Contributions to the hydrology of the United States, 1936
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N. C. Grover, Chief Hydraulic Engineer

GEOLOGY AND GROUND-WATER RESOURCES OF THE ELIZABETH CITY AREA, NORTH CAROLINA

By S. W. Lohman

Abstract

This report describes the geology and ground-water resources of parts of Camden and Pasquotank Counties, N. C., that lie within a radius of about 10 miles of Elizabeth City.

This area occupies a nearly level plain extending from sea level up to an altitude of about 17 feet, and a large part of the area lies between 5 and 10 feet above sea level. Part of the famous Dismal Swamp borders the area to the west, and there are several small swamps in the area. The surface is made up of Pleistocene terrace deposits and is underlain by sediments of Tertiary and Cretaceous age.

Elizabeth City derives its water supply from Knobbs Creek, a small branch of the Pasquotank River, which enters the river on the northwest edge of the city. The Pasquotank River is a broad arm of Albemarle Sound and is connected to the Atlantic Ocean through several small inlets. In years of normal precipitation the water in the Pasquotank River is only slightly saline and that of Knobbs Creek is fresh. In the years 1930 to 1933, however, there was a notable deficiency of rainfall, and hence of stream flow, in the vicinity of Elizabeth City, and at certain times each year the chloride content (or salinity) of Knobbs Creek water became noticeably high, reaching a maximum of about 5,000 parts per million in 1930.

The purpose of the investigation on which this report is based was to determine the possibility of developing a ground-water supply that would be adequate for the needs of the city, either as a permanent supply or as an auxiliary during certain periods when the present Knobbs Creek supply might become salty. The investigation was made by the United States Geological Survey in cooperation with the North Carolina Department of Conservation and Development.

Information was obtained as to the quantity and quality of water obtainable from all the deep wells and from many of the shallow wells in the area. In addition, one test well was drilled to a depth of 482 feet and several test holes and test wells were jetted down to depths of 20 to 65 feet. Numerous samples of ground water and a few samples of surface water were collected and analyzed in the laboratory of the United States Geological Survey. The physical properties of samples of sand obtained from test wells and test holes were determined in the laboratory, and these determinations were supplemented by several pumping tests in the field. Fossils were obtained from most of the test holes and test wells and were of value in determining the geologic age of the strata at different depths.

As the area lies at a low altitude, adjacent to a body of saline water, there is danger that some of the wells might be contaminated with saline water under certain conditions, and therefore the principles governing the relations between fresh and salt waters were given special consideration. This involved the construction of a water-table contour map of the area, which was made by determining the altitude above sea level of the water table in a number of shallow wells on different dates.

The results of this investigation indicate (1) that any water obtained from wells at depths of 200 to 300 feet or more would probably be too salty for ordinary use; (2) that a sand bed lying between the depths of 75 and 93 feet at the filtration plant would yield a sufficient quantity of potable water to supply the needs of the city, but that the water is of rather poor quality owing to its hardness and a chloride content of 200 to 300 parts per million; (3) that shallow sands covering a large area about 3 miles west of the city would probably supply the required quantity of water to a large number of shallow wells less than 30 feet deep and distributed over a large area, and that although this water may require treatment for the reduction of hardness and removal of iron, it has a very low chloride content that is not expected to increase appreciably with prolonged pumping.

INTRODUCTION

Location, area, and population

Elizabeth City is on the west bank of the Pasquotank River, in the northeast corner of North Carolina. (See fig. 1.) The Pasquotank River forms the boundary between Pasquotank County, to the southwest, and Camden County, to the northeast. The area covered by this investigation includes parts of Camden and Pasquotank Counties lying within a radius of about 10 miles of Elizabeth City. In 1930 Elizabeth City had a population of 10,037 and Pasquotank County had 19,143.

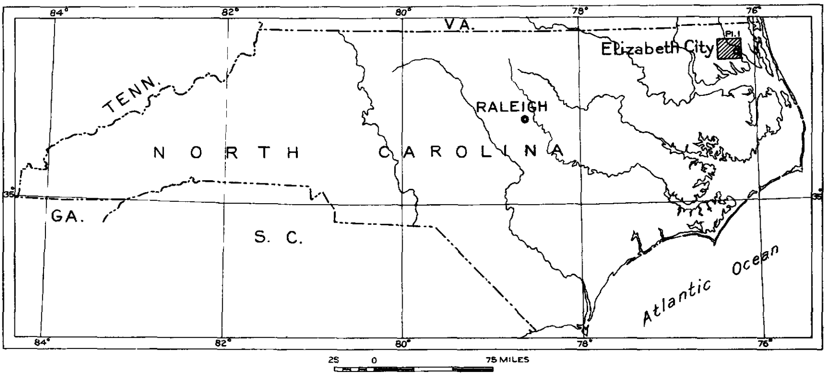


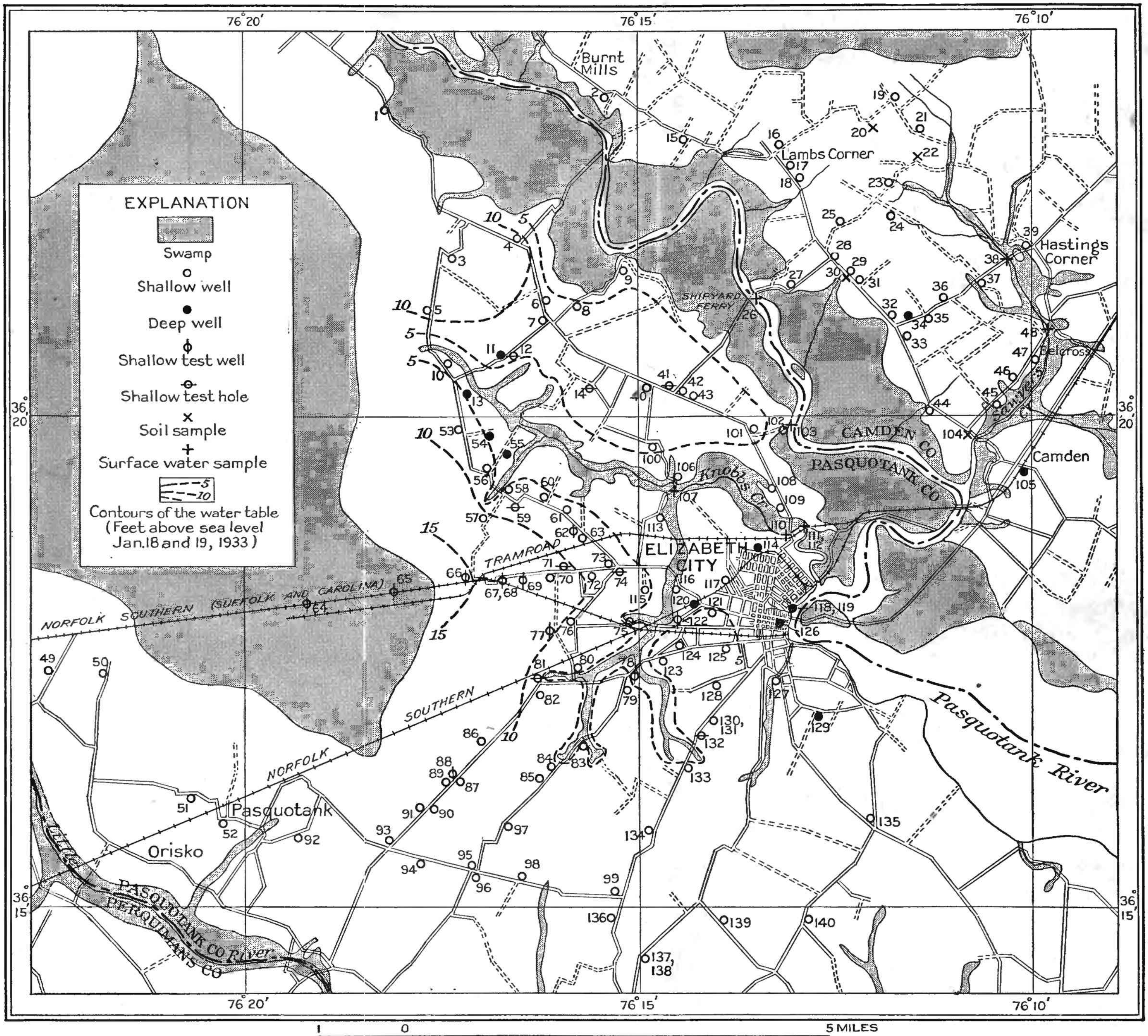
Figure 1. - Index map of North Carolina showing the location of Elizabeth City.

Purpose of the investigation

The purpose of the investigation on which this report is based was to determine the possibility of developing a ground-water supply that would be adequate for the needs of the city, either as a permanent supply or as an auxiliary during certain periods when the present Knobbs Creek supply might become salty. The investigation afforded an excellent opportunity to make a contribution to the important subject of the value of the shallow sands of the Coastal Plain as sources of water supply, by means of an intensive study of a specific locality.

Organization and field work

On September 6, 1932, Charles E. Ray, Jr., chief engineer, Division of Water Resources and Engineering, North Carolina Department of Conservation and Development, addressed a letter to N. C. Grover, chief hydraulic engineer, United States Geological Survey, outlining a serious situation with respect to the public water supply at



MAP OF THE ELIZABETH CITY AREA, N. C., SHOWING THE AREA COVERED BY SWAMP, THE LOCATION OF WELLS, TEST WELLS, TEST HOLES, AND SAMPLING POINTS, AND CONTOURS OF THE WATER TABLE.

Base and swamp boundaries from soil maps of U. S. Bureau of Chemistry and Soils.

Elizabeth City, and requested the cooperation of the Geological Survey in determining possible methods of remedying this situation. Subsequently, after conversations between Mr. Grover and Thorndike Saville, representing the North Carolina Department of Conservation and Development, D. G. Thompson, of the Geological Survey, made a preliminary investigation in September 1932. In a brief report Mr. Thompson pointed out that the available information did not indicate an easy solution to the problem of obtaining an adequate and permanent supply of good water, for the physical conditions are such that it would be difficult to protect Knobbs Creek from contamination by salt water, and the quantity of water available from the creek during a prolonged drought might not be sufficient for the public supply. The meager information in regard to deep wells indicated that all water below a depth of 300 feet, and possibly some at lesser depths, is too salty for use. Analyses of water from several wells indicated that the best water could probably be obtained from shallow wells situated far enough from the salty streams to avoid becoming contaminated during heavy pumping. However, the information did not indicate where such areas were to be found nor whether the supply obtainable from such wells would be adequate. It was therefore recommended that before any development of shallow wells was planned, tests should be made to determine whether and where good water-bearing materials are to be found and whether the supply would be sufficient to meet the needs of the city.

Subsequently an agreement was entered into between the United States Geological Survey and the North Carolina Department of Conservation and Development providing for a systematic investigation of the occurrence, quantity, and quality of the ground water in the Elizabeth City area. The writer was assigned to the investigation in November 1932 and spent about 2 months in the field. One week in June 1933 was spent in making a pumping test, and several brief trips to the area were made later. Test drilling and test pumping were conducted under the direction of J. C. Parker, superintendent of the Elizabeth City Public Utilities Commission. The first few weeks was spent in watching the results of test drilling, making pumping tests, collecting water and sand samples for analysis, and collecting data in the areas adjacent to Elizabeth City. The later part of December and nearly all of January were devoted to a study of the shallow water-bearing beds. A preliminary report describing the investigation was published in 1934.[1]

The physical properties of samples of water-bearing sands were determined by V. C. Fishel in the hydrologic laboratory of the United States Geological Survey. Samples of water were analyzed by E. W. Lohr and K. T. Williams in the water resources laboratory of the Geological Survey.

The investigation was made under the general direction of O. E. Meinzer, geologist in charge of the division of ground water.

Acknowledgments

The writer is indebted to the following persons for advice, data, and assistance in the field: J. C. Parker, superintendent of the Public Utilities Commission; R. W. Luther, Roger Taylor, and Mr. Smithson, of the filtration-plant staff; Charles E. Ray, Jr., H. J. Bryson, and J. P. Clawson, of the North Carolina Department of Conservation and Development; J. C. Overman, Mr. Swain, and Raymond Pritchard, of Elizabeth City; H. N. Butler, of Sanford; and F. W. White, of Belcross. The writer is also indebted to the following members of the United States Geological Survey: W. C. Mansfield, for determining 86 species of mollusks and the geologic ages represented; K. E. Lohman, for determining 101 species of diatoms and the geologic ages represented; L. G. Henbest, for determining species of Foraminifera and the geologic ages represented; R. W. Brown, for determining a species of swamp cypress and associated grasses; A. G. Fiedler, for advice on well-drilling methods; W. D. Collins, for advice concerning the chemical character of the water; and D. G. Thompson, for many helpful suggestions in the field work and in the preparation of the report.

PRESENT SOURCE OF SUPPLY

The present source of public water supply for Elizabeth City is Knobbs Creek, a branch of the Pasquotank River which enters the river on the northwest edge of the city. The Pasquotank River below Elizabeth City is a broad arm of Albemarle Sound and ranges in width from half a mile to more than 2 miles. The sound is separated from the open ocean by a long, narrow barrier beach and is connected to the ocean only

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1 Lohman, S. W., Investigation of ground water in the Elizabeth City area, North Carolina: Am. Water Works Assoc. Jour., vol. 26, no. 2, pp. 201-216, February, 1934.

A. TIDE DAM ON KNOBBS CREEK, LOOKING UPSTREAM.

B. SMALL SWAMP ABOUT 2 MILES SOUTHWEST OF ELIZABETH CITY.

through a few narrow inlets. Because of this condition there is said to be no appreciable lunar tide at Elizabeth City, but wind tides are known to be produced by strong winds from the east or southeast blowing water up the river and impeding its natural flow.

In 1926 the Public Utilities Commission constructed at Knobbs Creek where it is crossed by the main line of the Norfolk Southern Railroad a tide dam designed to prevent upstream tidal flow into that portion of the creek channel which is being used for a reservoir. It is said that there was an old tide dam in use on the creek before 1926. The new tide dam is constructed of concrete, with steel gates which extend 3 or 4 feet below the normal level of the creek and which open downstream when there is sufficient flow but automatically close if the high water in the river causes a backwater movement up the creek. (See pl. 2, A.) Knobbs Creek has a total drainage area of about 50 square miles of swampy land above the tide dam.

Because of the swampy nature of the drainage area the creek water contains much finely divided organic matter in colloidal suspension, which imparts a dark-brown hue that varies considerably with rainfall, tides, and temperature. To remove this color it has been found necessary to devise a special process of filtration employing two-stage coagulation, and the city has in operation a well-equipped and efficient filter plant, completed in 1927.

In each of the last three years there has been a notable deficiency of rainfall, and hence of stream flow, in the vicinity of Elizabeth City. (See p. 12 .) As shown in the following table, at certain times each year the chloride content of the water (which is an indication of its saltiness) became noticeably high.

Average, maximum, and minimum monthly chloride content of Knobbs Creek at intake of public supply, 1930-1933

[Parts per million. Data by R. W. Luther]

Date	Maximum	Average	Minimum
October 1930..	1,425	....	....
November......	2,522	....	325
December......	4,474	....	220
January 1931..	382	103	33
February......	190	84	23
March.........	66	45	20
April.........	48	20	11
May...........	40	23	19
June..........	172	50	15
July..........	390	144	19
August........	76	26	9
September.....	172	73	12
October.......	390	260	132
November......	498	450	360
December......	758	537	419
January 1932..	691	93	20
February......	23	20	18
March.........	23	19	10
April.........	24	20	18
May...........	26	20	16
June..........	328	133	22
July..........	397	325	148
August........	558	423	336
September.....	900	708	535
October.......	1,700	1,325	900
November......	1,800	860	143
December......	479	117	23
January 1933..	39	27	18
February......	22	17	16
March.........	25	23	19

Not only was the water of Knobbs Creek below the tide dam salty, but at the intake for the public supply, about 2,000 feet above the tide dam, the chloride was so high as to give the water a noticeably salty taste. According to R. W. Luther, superintendent of the filtration plant, the maximum chloride content, which was reached in 1930, was about 5,000 parts per million. In contrast, during the spring of 1932, when there was an abundant stream flow, the chloride dropped as low as 15 to 20 parts per million.

The relation between the average monthly chloride content of the Knobbs Creek water at the intake of the public supply and the accumulated rainfall deficiency at Elizabeth City is shown in figure 2. The accumulated rainfall deficiencies were obtained by adding the monthly departures from normal beginning with January 1930, but they were plotted beginning with January 1931, as chloride data are not available for 1930. At the end of 1930 the rainfall deficiency was 9.22 inches. The rainfall deficiency increased during January, February, and March 1931, but the precipitation was above normal during April and May, so that the chloride content of Knobbs Creek remained rather low. In June 1931 the precipitation was 2 inches below normal, and the chloride content rose somewhat. The rainfall was above normal during July and August, but the chloride content did not begin to decrease until after July, the lag being presumably due to the facts that the water that was high in chloride lingered along the bottom of the channel some time after the creek level rose, and that the luxuriant summer growth of vegetation withdrew large amounts of the water. From September to December 1932 the deficiency steadily mounted and was followed, as shown in figure 2, by a corresponding rise in the chloride content. During January 1932 the rainfall was only 1 inch above normal, yet the chloride content of Knobbs Creek fell rapidly. The close agreement of the two curves at this point seems to be explicable on the ground that the swamp

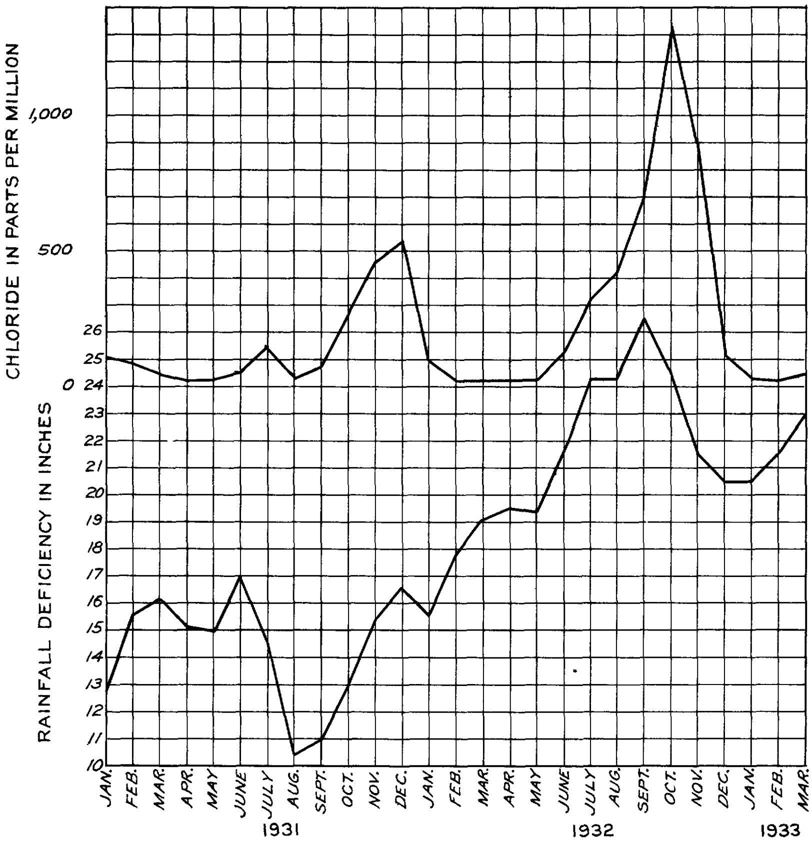

Figure 2. - Monthly average chloride content of water at intake of public supply on Knobbs Creek, and accumulated rainfall deficiency at Elizabeth City, January 1931 to January 1933. (Chloride data by R. W. Luther, rainfall data computed from Weather Bureau records.)

vegetation was largely dormant at this time, so that much of the rainfall was available as immediate run-off. Despite a moderate increase in the rainfall deficiency between January and May 1932, the chloride content remained rather low, but a rapid increase in the deficiency from May until September produced a rapid rise in the chloride content, which apparently continued for a month after the rainfall returned to normal, producing a lag similar to that encountered during June and July 1931. The rainfall was above normal between September 1932 and January 1933, with the result that the chloride content dropped rapidly.

The presence of salty water in Knobbs Creek above the tide dam has been accounted for in several ways. According to L. L. Hedgepeth, former superintendent of the filtration plant, in a report to the Public Utilities Commission, "The tide dam is preventing upstream tidal flow but is not stopping bottom seepage into the upstream creek." He proved seepage under the dam by the following method:

> Hydrated lime was fastened to the grate bars, the bags slit from end to end, and then dropped into the creek immediately downstream from the gates. By this method we placed 100 pounds in front of each of the first five gates. Chemical analyses of the bottom water on the upstream side of these gates indicated a very definite increase in pH and alkalinity, which was not apparent on the surface nor in the upper strata of water.

Subsequent to these chemical tests, an endeavor was made to shut off any possible leakage beneath the dam by dumping a large quantity of clay into the creek on the downstream side of the dam. This appears to have been effective to a considerable extent, for after the clay was placed the water level in the creek above the dam dropped at a rate of about half an inch a day, and on September 20 it was about 1½ feet below the backwater from the Pasquotank River. Thus is appears that pumpage of 500,000 to 700,000 gallons of water daily from the creek, plus the evaporation and transpiration, exceeded the inflow by seepage of ground water.

After the stoppage of the greater part of the leakage by placing the blanket of clay, the chloride content of the creek above the dam did not decrease as might be expected. It is not entirely certain whether this was due to continued leakage past the dam or merely to residual salt water that had moved upstream before the dam was sealed. That the heavier salty water lies on the bottom of the creek and allows the fresher water to flow off at the surface was apparent during November and December 1932, when the rainfall was sufficient on numerous occasions to produce a considerable downstream flow through the tide gates, causing the surface of the creek to be relatively fresh, whereas the bottom strata of water remained brackish. About December 7, 1932, a baffle board extending to a depth of 4 feet below the surface was placed across the creek at the highway bridge just downstream from the intake, in an endeavor to keep the fresh water from flowing away. Samples of water were taken from different depths at points 20 and 150 feet upstream from the highway bridge, for several days, and tested for chloride, with the results shown in the following table:

Chloride content of Knobbs Creek water on successive dates in 1932, at two sampling stations, A and B, near the highway bridge

[By R. W. Luther and Roger Taylor. Parts per million]

Station A is 20 feet and station B 150 feet upstream from highway bridge.

	November 8	December 12		December 13		December 15		December 19	
	A	A	B	A	B	A	B	A	B
Depth (feet):									
Surface....	525-600	.....	.....	.....	.....	.....	.....	....	....
1.......	.....	.....	138	.....	.....	.....	.....	....	....
2.......	.....	.....	143	.....	.....	.....	348	....	29
3.......	600	114	.....	94	.....	337	.....	25	....
4.......	1,000	.....	198	.....	124	.....	351	....	26
5.......	1,500	400	400	193	188	830	.....	25	29
6.......	1,700	.....	.....	940	756	790	840	25	31
7.......	1,700	860	830	1,875	1,588	790	840	....	27
8.......	1,800	.....	.....	1,780	1,980	745	890	25	27
9.......	1,800	1,980	1,930	1,875	1,880	890	890	25	25
10.......	2,050	.....	.....	.....	.....	.....	.....	....	....
11.......	2,100	1,980	2,015	1,980	1,985	1,830	1,830	27	25
12.......	2,100	.....	.....	.....	.....	.....	.....	....	....
13.......	.....	.....	2,080	.....	1,985	.....	1,830	....	27
15.......	.....	.....	.....	.....	2,050	.....	1,930	....	27
16.......	.....	.....	2,080	.....	.....	.....	.....	....	....

This table shows that there was a noticeable decrease in the chloride content of the water down to a depth of 9 feet between November 8 and December 12, 1932, and as 2.75 inches of rain fell on November 7, the chloride content of the water at different depths was presumably even higher prior to November 8. The next heavy rain of 1.20 inches occurred on December 14, and it is interesting to note that while the chloride content of the water between the depths of 6 and 9 feet was reduced, that of the upper 6 feet was increased, possibly owing to a mixing of these two strata of water by currents that may have resulted from the baffle board. On December 17, 1.25 inches of rain fell and was effectual in clearing out the brackish water, as shown by the low content of chloride at all depths on December 19.

These results are not fully conclusive as to the effectiveness of the baffle board, but it is believed to have assisted in disposing of some of the underlying brackish water by producing deep-seated currents that brought some of the brackish water to the surface, whence it eventually passed through the tide gates. It seems logical to assume that if the tide gates had been placed near the bottom of the dam instead of at the top, the brackish water would have been forced through sooner, leaving fresher water above.

In discussing the possible sources of the salt water in Knobbs Creek above the dam, D. G. Thompson, of the United States Geological Survey, in a memorandum of October 7, 1932, made the following statement:

> If the high chloride reported at the intake a month after the clay sealing operation was completed is due to leakage, there remains undetermined the question of whether the leakage is beneath the dam, or at improperly seated gates, or whether it is moving upstream by underground percolation around the dam and across a narrow neck of land that lies in a loop of the creek, and possibly across a larger area of land between the creek and Pasquotank River.

In order to solve this problem Mr. Thompson suggested the sinking of several test holes across the necks of land and the collection of water samples from each test hole. This has not been done, to the writer's knowledge, but in January 1933 several test holes were put down across Knobbs Creek at the highway bridge under the direction of H. L. Rivers, working under W. M. Piatt, consulting engineer, of Durham, N. C., who was engaged in making a detailed survey of Knobbs Creek. The test holes were put down to determine whether the material underlying the creek at that locality was suitable as a foundation for a new and higher dam. In a test hole in a depression about 175 feet north of the creek, 11 feet of sand was encountered between the depths of 10 and 21 feet, part of which yielded water containing 210 parts per million of chloride, whereas no sand was encountered beneath the creek above a depth of about 50 feet. This occurrence at least suggests the possibility of leakage from the Pasquotank River through permeable sands lying north of Knobbs Creek and connecting with the creek at some point west of the highway bridge. To prove the existence of such leakage, however, would require the sinking of numerous test holes.

It is not the purpose of this report to suggest remedial measures for the Knobbs Creek supply. Remedial measures under consideration by the Public Utilities Commission and its consulting engineer include the possible construction of a new and perhaps higher dam farther upstream and may involve an enlargement of the reservoir basin by dredging.

SURFACE FEATURES

The surface of Pasquotank and Camden Counties in the vicinity of Elizabeth City is a low plain extending from sea level up to an altitude of about 17 feet within the area investigated. A large part of Elizabeth City and vicinity lies between 5 and 10 feet above sea level, and smaller areas between the drainageways lie between 10 and 17 feet.

Stephenson,[2] in 1912, included in the Pamlico terrace the whole area of the Coastal Plain in North Carolina below an altitude of 25 feet. In recent years, however, the Pamlico has been subdivided into the Princess Anne terrace, with shore line at 12 feet above sea level, and the Pamlico terrace (restricted), with shore line at about 25 feet. The Princess Anne terrace and formation were first described in Virginia by Wentworth,[3] and Cooke[4] has recognized them and extended the application of the name. The escarpment separating the Princess Anne terrace from the Pamlico terrace may be represented between wells 73 and 72 on figure 4, but as there are no topographic maps of the Elizabeth City area the escarpment was not traced by the writer, and the terrace deposits are here classed as Pamlico and Princess Anne undifferentiated.

Portions of the Dismal Swamp lie within the area, and Knobbs Creek and its tributaries drain a number of small connected swamps separated by higher, drained areas, as shown on plate 1. Several of these small swamps extend into Elizabeth City. The Dismal Swamp is an area of moderately elevated, nearly level land with such imperfect drainage that it generally remains inundated to a slight depth and gives rise to a luxuriant growth of vegetation. A view of one of the smaller swamps near Elizabeth City is shown in plate 2, B.

The area investigated is drained principally by the Pasquotank River, a broad estuary of Albemarle Sound--in large part by Knobbs Creek, which enters the river northeast of the city. A part of the territory west of Elizabeth City is drained by the Little River. Natural drainage is poor on the nearby farm lands in interstream areas, and an intricate system of ditches has been constructed to aid in draining the land.

CLIMATE

The climate of Elizabeth City and vicinity is characterized by long summers and comparatively short, mild winters. The average annual temperature, as shown by the following table, is 60.6° F.

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2 Stephenson, L. W., The Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey, vol. 3, p. 286, 1912.

3 Wentworth, C. K., Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey, Bull. 32, p. 81, 1930.

4 Cooke, C. W., Tentative correlation of American glacial chronology with the marine time scale: Washington Acad. Sci. Jour., vol. 22, no. 11, p. 311, 1932; Southern Maryland: 16th Internat. Geol. Cong. Guidebook 12, pp. 1-3, 1932.

Normal monthly and annual temperature at Elizabeth City

[Data from Weather Bureau records]

Month	Temperature (°F.)	Month	Temperature (°F.)
January.....	43.8	August......	77.7
February....	54.1	September...	72.5
March.......	51.0	October.....	63.4
April.......	58.9	November....	52.8
May.........	66.9	December....	43.9
June........	74.4		
July........	78.5	Year......	60.6

The distribution of the temperature and rainfall over the different months is favorable to a long growing season, and few summer days are so disagreeably hot as to interfere seriously with work out of doors. The autumns are generally warm and dry and are sufficiently long to allow the harvesting of the cotton and corn crops before the winter rains set in. The coldest weather generally occurs during January and February. The ground, however, seldom remains frozen for more than a few days at a time. The snowfall is light, usually not more than an inch at a time. Plowing is generally commenced in February.

Monthly and annual precipitation at Elizabeth City, 1920-1933

[From U. S. Weather Bureau records]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1920	2.20	7.95	4.01	3.55	1.08	3.98	8.64	6.45	2.10	1.25	4.40	6.82	52.43
1921	1.50	4.47	2.95	3.15	7.35	2.45	5.90	4.43	1.18	.45	1.87	3.45	39.15
1922	4.65	9.31	5.99	2.50	2.60	8.87	4.12	5.23	4.64	2.42	1.12	4.62	61.30
1923	3.62	4.90	4.54	3.12	1.80	1.10	5.30	4.45	3.45	2.80	1.98	2.75	39.81
1924	5.40	4.55	2.55	3.00	6.62	6.27	5.05	7.75	5.65	.55	2.50	3.92	53.81
1925	6.52	2.65	3.80	1.55	1.25	3.15	2.55	5.75	.35	3.55	3.38	4.27	38.77
1926	4.95	3.45	4.20	3.10	2.58	4.70	3.95	5.45	.10	1.80	3.65	5.05	42.98
1927	1.44	4.10	2.65	4.05	3.95	6.15	5.30	7.10	1.50	5.35	3.25	7.20	52.04
1928	1.50	4.55	1.80	5.65	3.25	8.00	6.70	1.40	13.35	1.30	2.15	5.10	54.75
1929	3.50	4.80	4.35	1.87	8.30	10.55	4.05	2.15	8.15	4.20	5.15	3.15	60.22
1930	5.23	1.45	1.90	1.65	3.85	5.70	6.00	1.85	1.80	2.15	3.35	3.60	38.53
1931	.50	1.30	3.20	4.25	4.20	3.35	8.25	8.60	3.55	.35	Tr.	2.88	40.43
1932	5.08	1.97	2.33	2.85	4.11	3.15	3.11	4.47	2.04	4.28	5.40	5.08	43.87
1933	4.04	3.12	2.36	2.06	2.42	1.45	7.39	8.78	6.27	.71	.62	1.37	40.59
Normal	4.04	4.15	3.76	3.23	3.97	5.35	5.87	4.47	4.14	2.27	2.41	4.09	47.75

As shown in this table, precipitation at Elizabeth City was more than 12 inches above normal during 1929, the year preceding the drought. During 1930 and 1931 the precipitation was 9 and 7 inches respectively below normal, with the result that widespread drought conditions prevailed, and Knobbs Creek became salty, as described on pages 5 to 9. During 1932 the precipitation was only 3.88 inches below normal, so that conditions were alleviated somewhat, but complete recovery from the drought had not yet been reached. In 1933 the precipitation was again 7 inches below normal, but the rains were not evenly distributed throughout the 12 months, and 55 percent of the annual precipitation of 40.59 inches occurred during July, August, and September. The heavy summer rains, coming at a time when they were badly needed, prevented a widespread drought.

GEOLOGY

Outline of stratigraphy and structure

The surface of Pasquotank and Camden Counties in the vicinity of Elizabeth City is underlain by fine sands and sandy loams of the undifferentiated (marine) Pamlico and Princess Anne formations, which are the lowermost terrace deposits along the Atlantic coast and are the youngest formations of the Columbia group, of Pleistocene age. The terrace deposits conceal marine beds of Pleistocene or Pliocene age or both, and at greater depths there are marine beds of Miocene age (Chesapeake group). At undetermined depths, probably about 700 or 800 feet below the surface, the Tertiary deposits are underlain by marine and nonmarine strata of Cretaceous age.[5] The beds all lie nearly horizontal but dip toward the coast at a very low angle.

The test wells put down in and near Elizabeth City during the investigation were of great value in determining the age of the sediments underlying the terrace deposits more closely than had hitherto been done, because so far as is known they are the only wells that have been drilled in this region from which fossils have been obtained and determined. The strata encountered in test drilling are described and their contained fossils are mentioned in the following pages.

Strata encountered in test drilling

Deep test well

The Public Utilities Commission of Elizabeth City undertook during the fall of 1932 to drill a 6-inch test well to a depth of at least 300 feet. The well was drilled back of the filtration plant by Dowdy & Butler, well-drilling contractors of Sanford, N. C. When completed the well was about 482 feet deep. Samples of drill cuttings were obtained every 5 feet during the drilling and were carefully

5 Clark, W. B., and others, The Coastal Plain of North Carolina: North Carolina Geol. Econ. Survey, vol. 3, pp. 453-454, 1912.

examined. The following log of this well shows the thickness and character of the material encountered and contains notes as to the occurrence and age of the fossils found:

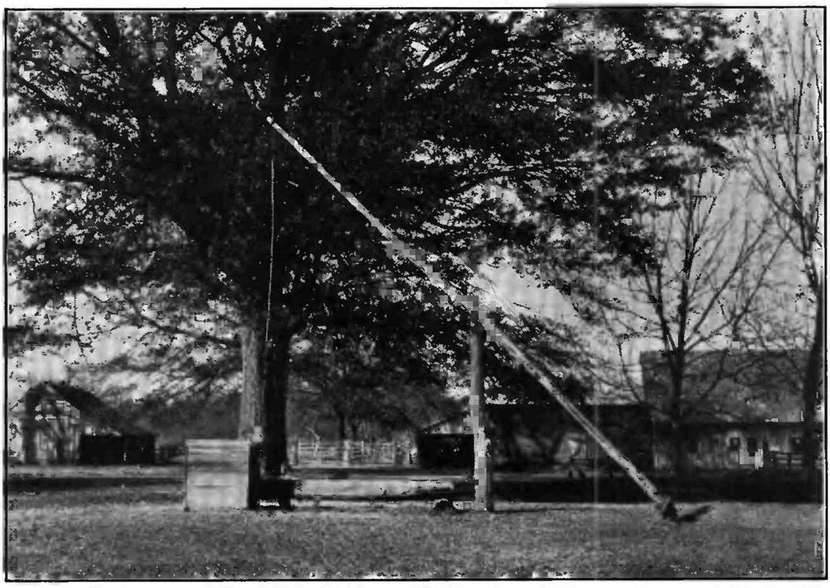
Log of deep test well back of filtration plant

[No. 114, pl. 1.]

Geologic age	Material	Thickness (feet)	Depth (feet)
Pleistocene (30± feet).	Sand, very fine, and silt..............	10	10
Pleistocene and upper Pliocene	Sand, very fine, and silt, with a few grains of fine gravel; few shells; Pleistocene and upper Pliocene diatoms at 30-35 and 45-50 feet..............	40	50
	Sand, very fine, and silt: no large particles............................	5	55
	Silt or clay, with some very fine sand.	5	60
	Clay; Pleistocene and upper Pliocene diatoms at 70-75 feet................	15	75
?			
Upper Miocene	Sand, medium-grained....................	5	80
	Sand, medium and coarse-grained, with fine gravel; few pebbles as much as 3/16 inch in diameter; water-bearing.	7	87
	Sand, fine-grained, with some medium-grained, some silt; few shells; contains upper Miocene mollusks and Foraminifera; water-bearing..........	6	93
	Shells, many broken, a few small pebbles, said to have been consolidated; contains upper Miocene mollusks and Foraminifera..........................	2	95
	Silt or clay, with very little sand and a few particles of fine gravel; few shell fragments in lower 25 feet.....	40	135
	Silt or clay; some sand grading from coarse to fine from top to bottom, a few shells in lower 5 feet; upper Miocene diatoms at 145-150 feet......	40	175
	Silt, very fine grained sand, some fine gravel, a few shell fragments; upper Miocene diatoms at 175-180 feet................................	10	185
	Silt or clay, very fine sand, few particles of coarse sand.............	15	200
	Clay; upper Miocene diatoms at 200-205 feet................................	10	210
	Clay, little sand, a few shells; upper Miocene diatoms at 250-255 feet......	90	300
	Clay, some fine sand, a few particles of fine gravel; a few shells.........	10	310
	Clay; upper Miocene diatoms at 310-315 and 330-335 feet.....................	75	385
?			
?	Clay, with a few grains of fine sand; no diatoms...........................	95	480
	Sandstone, hard, cemented with iron....	2±	482±
	Sand? (no sample), water-bearing. (See analysis of water.).............	?	?

The entire set of drill cuttings were examined for diatoms by K. E. Lohman, of the United States Geological Survey, who determined 101 species from samples at the following depths:

A. JETTING OUTFIT IN OPERATION.



B. TYPICAL WELL SWEEP ON A DUG WELL IN THE ELIZABETH CITY AREA

Depth (feet)	U.S.G.S. diatom locality no.	Geologic age
30	1338	Pleistocene and upper Pliocene
45	1339	Do.
75	1340	Do.
145	1342	Upper Miocene
175	1343	Do.
200	1344	Do.
250	1345	Do.
310	1346	Do.
330	1347	Do.

Regarding the age of the diatoms, Mr. Lohman states as follows:

The age indicated by samples between 30 and 75 feet is Pleistocene and upper Pliocene, based on a comparison with diatoms found in excavations of the Dismal Swamp Canal in 1897-98. [6]

Samples at depths between 75 and 145 feet were barren of diatoms, but from 145 feet to 330 feet, inclusive, a good diatom assemblage was obtained, which is assigned to the upper Miocene. It is definitely post-Calvert (middle Miocene).

No diatoms were found below 330 feet.

The materials represented by samples obtained at depths between 145 feet and 330 feet were most probably deposited under strictly marine conditions, while those from 75 feet and upward were deposited in waters which changed from marine to brackish. Many of the forms found at depths of 30 feet and 45 feet are at present living in brackish estuaries.

The samples of sand between depths of 87 and 93 feet and the shell layer between 93 and 95 feet were examined for mollusks by W. C. Mansfield and for Foraminifera by L. G. Henbest, both of the United States Geological Survey, who are in agreement that the fauna at these depths strongly indicates an upper Miocene age, which agrees with the age determination from the flora given above. The material between the surface and a depth of about 30 feet was assigned to the Pleistocene, because definite Pleistocene mollusks were obtained down to that depth in several of the shallow test wells described below. The samples below a depth of 330 feet were barren of fossils, so that their exact age is not known, except that they are Tertiary and are upper Miocene or older.

Shallow test wells and test holes

During the later part of the investigation 9 shallow test wells and 8 shallow test holes were jetted down near Elizabeth City at the localities shown on plate 1. (See also pl. 3, A.) These tests were made to determine the extent, character, and ground-water possibilities

6 Woolman, Lewis, Fossil mollusks and diatoms from the Dismal Swamp, Virginia and North Carolina; Indication of the geological age of the deposit, with notes on the diatoms by C. S. Boyer: Acad. Nat. Sci. Philadelphia Proc., 1898, pp. 414-428.

of the shallow terrace deposits, and the work was done for the Public Utilities Commission by F. White, of Belcross, N. C., under the writer's supervision. The method of sinking the holes, the collection of sand and water samples, and the physical properties of the materials encountered are described on pages 31 to 39.

The logs of these tests are given in the following pages, with brief notes as to the ground-water conditions and the occurrence of fossils. The logs of some of the tests are also shown graphically on figure 4. The mollusks and Foraminifera obtained from some of the tests were studied by W. C. Mansfield and L. G. Henbest, respectively, of the United States Geological Survey, and the age of the deposits was determined by their studies.

In the area north of Elizabeth City between Knobbs Creek and the Pasquotank River the terrace deposits were fully penetrated by test holes 12, 14, and 41. In holes 12 and 14 a layer of clay was encountered at depths of 22 and 20 feet, respectively, below fine-grained sand containing silt and numerous small mollusks which were found to be of Pleistocene age. The fossil shells found in the clay in hole 14 were rather fragmentary and were not preserved for identification, but from data gathered west of Elizabeth City (described below) it is believed that the clay layer is of Pleistocene or Pliocene age. These holes were not extended below the clay stratum, because experience west of the city had shown that where present the clay layer was likely to be rather thick, and that no water-bearing beds of any importance would be encountered between the clay and depths of 60 to 75 feet. In hole 41, however, this clay was not struck until a depth of 42 feet had been reached, and no fossils were found in either the sand or the clay except for some rather poorly preserved wood fragments in the sand. It is not known just how much of the 42 feet of sand overlying the clay in hole 41 represents the Pamlico and Princess Anne formations, but in the area west of the city the definite Pleistocene fossils extended down only to a depth of 30 feet.

Logs of test holes 12, 14, and 41

	Thickness (feet)	Depth (feet)
Hole 12		
[4½ miles northwest of Elizabeth City]		
Sand, fine-to medium-grained, gray, with considerable silt	10	10
Sand, fine-grained, gray, with considerable silt	5	15
Sand, fine-grained, gray, with considerable silt; very fossiliferous (Pleistocene mollusks and Foraminifera)	5	20
Clay, bluish	(?)	(?)
Hole 14		
[3½ miles northwest of Elizabeth City]		
Sand, fine-to medium-grained, gray with reddish streaks, with considerable silt	12	12
Sand, fine-to medium-grained, gray, with considerable silt, very fossiliferous (Pleistocene mollusks and Foraminifera); fossils increase in abundance with depth	10	22
Clay, bluish, fossiliferous (mollusks)	(?)	(?)
Hole 41		
[3 miles northwest of Elizabeth City]		
Sand, fine-to medium-grained, yellowish white, clean	11	11
Sand, fine-to medium-grained, reddish yellow, color due to iron stains on some of the grains	4	15
Sand, medium-grained, similar to above but coarser	6	21
Sand, fine-to medium-grained, gray, with considerable silt; some wood fragments near bottom	21	42
Clay, dark	(?)	(?)

Twelve tests were made in the area west of Elizabeth City that lies between the Dismal Swamp and Knobbs Creek. As shown in the logs (given below), the Pamlico and Princess Anne formations in this area consist chiefly of fine-to medium-grained gray sand, which in some places contains fossils or silt or both. In eleven of these tests the thickness of this sand ranged from 26 to 30 feet and averaged 27¼ feet. In hole 122 the thickness of the sand is only 22 feet, and it is probable that the sand layer decreases in thickness still more toward the center of the city, for only very fine sand and silt were encountered near the surface in sinking the deep test well. The mollusks and Foraminifera obtained from these test holes are of Pleistocene age, which agrees with the age assigned to the Pamlico and Princess Anne formations.

Bluish clay was encountered below the terrace deposits in this area. Generally the tests were put down only to this clay or a short distance into it, because the knowledge obtained from the deep test well and from the logs of other wells 60 to 80 feet deep indicated that no other water-bearing sand was likely to be encountered below the uppermost sand until a depth of 60 to 75 feet was reached. Hole 68 penetrated 27 feet of this clay between the depths of 30 and 57 feet. Fossils were obtained in the clay in some of the wells, but they were generally fragmentary and not as abundant as those occurring in the sands. Evidence obtained from mollusks, Foraminifera, and diatoms in other test wells indicates that the clay underlying the terrace deposits is Pleistocene or Pliocene and was laid down in brackish water. In test well 88 this clay was encountered at a depth of 30 feet, and 10 feet of it was penetrated until at a depth of 40 feet the jetting bit struck a log or stump. The bit penetrated 18 inches of the wood with difficulty, and then the 1¼-inch pipe became stuck, so that the well could not be extsnded below that point. Fragments of the wood were submitted to Roland W. Brown, of the United States Geological Survey, who made the following statement concerning them:

> These peaty wood fragments are swamp cypress (*Taxodium distichum*). Associated with them are shreds of what appear to be eel grass (*Zostera marina*) or tape grass (*Vallisneria spiralis*), the eel grass growing in brackish or marine water and the tape grass growing in fresh water, sometimes close to brackish-water conditions, as in the Chesapeake Bay region, where it is an important article of food for wild ducks. It seems, therefore, that these remains were deposited with muds accumulating under or close to brackish-water conditions. I should say the age represented by these remains is Pleistocene.

Logs of test holes and test wells between Dismal Swamp and Knobbs Creek

	Thickness (feet)	Depth (feet)
Hole 59		
[1-3/4 miles west of Elizabeth City]		
Loam, sandy	4	4
Sand, fine- to medium-grained, gray, with several thin seams of clay aggregating 2 feet in thickness	6	10
Sand, fine- to medium-grained but coarser than above, gray.	15	25
Clay, bluish, fossiliferous	5+	30+
Well 62		
[2½ miles northwest of Elizabeth City]		
Soil, sandy; 6 inches of reddish iron-stained soil	1	1
Sand, fine-to medium-grained, gray; yields water freely at 10-12 feet	19	20
Sand, fine-to medium-grained, gray, with some clay; yields water freely	7½	27½
Clay, bluish, fossiliferous	2½+	30+
Well 66		
[3½ miles west of Elizabeth City]		
Soil, swampy	5	5
Sand, fine-to medium-grained, gray; yields water freely at 10-15 feet	15	20
Sand, fine-to medium-grained, fossiliferous (Pleistocene mollusks and Foraminifera)	7	27
Clay, bluish, fossiliferous	5+	32+

Logs of test holes and test wells between Dismal Swamp and Knobbs Creek - Continued

	Thickness (feet)	Depth (feet)
Well 68		
[3¼ miles west of Elizabeth City. Data taken from three tests within radius of 15 feet - (a) 2-inch jetted hole 30 feet deep for sand samples; (b) 1¼-inch driven well 17 feet deep with 2½-foot screen for water samples; (c) 1¼-inch jetted well 57 feet deep with 5-foot screen for sand and water samples]		
Soil, sandy clay	4	4
Sandy, fine-to medium-grained, clean, white; yielded little or no water	6	10
Sand, fine-to medium-grained, gray; yielded water with some difficulty; water cleared after 20 to 25 gallons had been pumped	5	15
Sand, fine-to medium-grained, gray; yielded water with some difficulty	5	20
Sand, fine-to medium-grained, gray, with some shells; yielded water freely; cleared fairly rapidly	5	25
Sand, fine-to medium-grained, gray, with some silt and shells; yielded water very freely; cleared rapidly	5	30
Clay, bluish	23	53
Clay, bluish, sandy	.1	53.1
Clay, bluish	3.9+	57+
Hole 71		
[2-3/4 miles west of Elizabeth City]		
Soil, clayey	5	5
Sand, fine-to medium-grained, gray, clean	10	15
Sand, fine-grained, gray, clean	5	20
Sand, fine-grained, gray, containing shell fragments and silt	7	27
Clay, sticky, blue, with few streaks of yellow clay and shell fragments	3+	30+
Hole 74		
[1-3/4 miles west of Elizabeth City]		
Soil, sandy; augered 6 inches in diameter	4	4
Sand, fine-to medium-grained, gray, with little silt	22	26
Clay, bluish, with few shells	4+	30+
Well 77		
[2½ miles west of Elizabeth City]		
Soil, clayey	5	5
Sand, fine-to medium-grained, gray; yielded water very freely at 10-15 feet	10	15
Sand, fine-grained, gray; yielded water freely but less than sand above	15	30
Clay, bluish	(?)	(?)
Well 78		
[1-3/4 miles west of Elizabeth City]		
Soil, sandy	4	4
Sand, medium-grained, gray, coarser than generally encountered; took up nearly all of the jetting water; yielded water very freely, but cleared with difficulty	14	18
Sand, fine-to medium-grained, gray; yielded moderate supply of water	9	27
Clay, bluish	3+	30+

Logs of test holes and test wells between Dismal Swamp and Knobbs Creek - Continued

	Thickness (feet)	Depth (feet)
Hole 81		
[2-3/4 miles southwest of Elizabeth City]		
Soil, sandy	1	1
Sand, fine-to medium-grained, reddish yellow, iron-stained	9	10
Sand, fine-to medium-grained, gray, coarser near bottom	14	24
Sand, fine-to medium-grained, gray, some silt, fossiliferous (whole and broken shells)	3	27
Clay, bluish, fossiliferous	3+	30+
Well 88		
[4 miles southwest of Elizabeth City]		
Soil	5	5
Sand, fine-to medium-grained; yielded water freely	10	15
Sand, fine-to medium-grained, gray, with some silt	6	21
Sand, fine-to medium-grained, gray, with shells (Pleistocene mollusks and Foraminifera); yielded water freely at 20-25 feet; cleared rapidly	9	30
Clay, with few shells	10	40
Cypress log (bit penetrated 18 inches of wood with difficulty but could not break through; swamp cypress and grasses of Pleistocene age)	1½+	41½+
Well 122		
[1 mile west of Elizabeth City]		
Soil, sandy	4	4
Sand, fine-to medium-grained, yellow; yielded water freely, cleared after 50 gallons pumped	13	17
Sand, finer than above, gray, a few streaks of silt or clay; yielded moderate supply of water	5	22
Clay, bluish	(?)	(?)
Hole 132		
[1½ miles south of Elizabeth City]		
Soil, clayey, rather tight	6	6
Sand, fine-to medium-grained, gray, with some coarse grains	14	20
Sand, fine-to medium-grained, gray, with some silt and shells	6	26
Clay, bluish, fossiliferous	4+	30+

Test wells 64 and 65 were put down in the Dismal Swamp along the seldom used right of way of the Norfolk Southern (Suffolk & Carolina) Railroad. These two wells are of great interest, for, as shown by the logs given below, they penetrated strata totally unlike those encountered in any of the other test wells. Instead of encountering impermeable clay at a depth of about 30 feet, as in other nearby test wells, they found permeable sands and shell beds from the surface down to a depth of at least 65 feet. The holes would have been sunk deeper but for the fact that no more pipe was immediately available. In test well 65, put down about 1 mile west of well 66, the material consisted chiefly of fine-to medium-grained sand, with a few layers of shells. The same is true of test well 64 except that a 2-foot bed of clay was encountered between depths of 30 and 32 feet--at the same horizon at which clay was encountered in many of the other test wells.

Studies of the mollusks and Foraminifera show that the sand down to a depth of about 30 feet is of Pleistocene age (Pamlico and Princess Anne formations) and that the beds below a depth of 50 feet are Tertiary. The beds at depths below 65 feet are of upper Miocene age, so that the materials between 30 and 50 feet appear to be of either Pleistocene or Pliocene age, and those between 50 and 65 feet appear to be of either Pliocene or upper Miocene age.

Logs of test wells 64 and 65

	Thickness (feet)	Depth (feet)
Well 64		
[5½ miles west of Elizabeth City]		
Mud, sandy, swampy	6	6
Sand, fine-to medium-grained, gray; yielded water freely	9	15
Sand, fine-to medium-grained, gray, with some clay	5	20
Sand, fine-to medium-grained, gray, and shells (Pleistocene mollusks and Foraminifera)	5	25
Sand, fine-to medium-grained, gray	5	30
Clay, sandy, impermeable	2	32
Sand, fine-to medium-grained, gray, with a few fine pebbles, and shells	3	35
Sand, fine-to medium-grained, gray, with a few fine pebbles	5	40
Sand, fine-to medium-grained, gray, with some mud	5	45
Sand, fine-to medium-grained, gray, with some shells	2	47
Shells, with some sand and silt (Pliocene or upper Miocene mollusks and Foraminifera)	8	55
Sand, fine-grained, gray, with some silt and a few shells, not highly permeable	10	65
Shells, with a little sand	(?)	(?)
Well 65		
[4½ miles west of Elizabeth City]		
Mud, sandy, swampy	7	7
Sand, fine-to medium-grained, gray, somewhat muddy near top; yielded water freely at 10-15 feet but cleared with difficulty	8	15
Sand, fine-to medium-grained, gray, somewhat coarser in places	5	20
Sand, fine-to medium-grained, gray, with a few muddy layers	3	23
Sand, fine-to medium-grained, gray, with numerous shells (Pleistocene mollusks and Foraminifera)	1	24
Sand, fine-to medium-grained, gray; yielded water freely	6	30
Sand, fine-to medium-grained, gray; a very few shells scattered throughout, especially in lower part	20	50
Sand, fine-to medium-grained, gray, clean; few shells; yielded water freely, cleared fairly rapidly	5	55
Shells, with mud, coarse sand, and small pebbles (upper Miocene mollusks and Foraminifera)	10+	65+

GROUND WATER

Outline of water-bearing beds

The fine-grained sands of the Pamlico and Princess Anne formations supply most of the water for domestic use in Camden and Pasquotank Counties. The water is recovered by means of shallow dug or driven wells, and many of the dug wells are equipped with well sweeps, as shown in plate 3, B. In addition to the shallow beds several deeper artesian zones are described by Stephenson and Johnson[7] as follows:

> In 1891 Mr. Henry E. Knox, Jr., bored ten wells in different parts of Elizabeth City, having an average depth of about 64 feet. Several of these, which were located on low ground, overflowed. Two water-bearing strata were penetrated at depths of about 58 and 78 feet, respectively, below the surface. The water from both strata is strongly sulphurous. (See records by Darton.[8])
>
> At the Ward brick yard a well was drilled to a depth of 326 feet, but after passing through the surface soil, nothing but blue clay was encountered to the bottom, and no water was found.
>
> In the western part of the county, near Parkville (P. O. Canaan), a 2-inch well was drilled in 1903 to a depth of 615 feet on the farm of Mr. T. G. Skinner. Water was found at depths of 14, 36, 60, and 260 feet. Below about 300 feet, however, only very salty water was encountered, which rose nearly to the surface.
>
> Owing to the high content of lime in the Tertiary beds which made up the materials for several hundred feet beneath the surface, water from these horizons will in most cases be hard. It will also be sulphurous and ferruginous in many cases. At depths exceeding 300 or 350 feet the water will be too salty for ordinary uses. Overflows are possible only on lowlands less than 10 feet above sea level.

Information was obtained concerning several artesian-water zones in and near Elizabeth City. The most productive of them is encountered in the city between depths of 75 and 93 feet, but north of the city some wells encounter one or more water-bearing sands between depths of 60 and 105 feet. A few water-bearing sands of apparently local extent have been reached at depths of less than 60 feet, and a few at depths greater than 105 feet. Salty water was obtained at a depth of about 482 feet in the deep test well at the filtration plant (no. 114, pl. 1), and it is reported that salty water was struck at a depth of about 1,207 feet in a test boring put down near the tide dam many years ago.

In the following pages the different water-bearing beds are described in order from bottom to top.

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7 Clark, W. B., Miller, B. L., Stephenson, L. W., Johnson, B. L., and Parker, H. N., The Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey, vol. 3, pp. 452-455, 1912.
8 U. S. Geol. Survey Bull. 138, p. 193, 1896.

Deep water-bearing beds

A deep test well was drilled for Elizabeth City about 1914 or 1916, near the tide dam, on the west bank of Knobbs Creek. Records of this well were said to have been kept, but they seem to have been lost during later years, and the following data were supplied from memory by R. E. Lewis, former superintendent of the water department. The well was drilled to a depth of 1,207 feet by a Mr. Sydnor and was 10 inches in diameter to a depth of 476 feet, where it was reduced to 8 inches, and at greater depth it was reduced to 6 inches. Potable water was encountered near the surface and presumably at a depth of about 75 or 80 feet. Salt water was said to have been encountered at depths of 476 and 1,207 feet, and the water from 476 feet flowed at the surface.

The deep test well at the filtration plant was drilled to a depth of about 482 feet when salty water was encountered under considerable artesian head. It was planned to test the well at this horizon by pumping with a centrifugal pump of large capacity, but as the pump needed repacking and would not hold suction, a small gasoline-driven sewer pump was substituted so that the test could proceed while the centrifugal pump was being repacked for use in testing the sand at 75 to 93 feet.

On November 30, 1932, at 9:05 a.m., the static water level in the well was 3.8 feet below the ground surface, but by the time the two pumps had been tried out the water level stood 6.3 feet below ground level at 2:50 p.m., just before the test began. The sewer pump had a 4-inch suction hose 31 feet long including a foot valve, and the hose was lowered into the 6-inch casing. Draw-downs were measured by means of a U-tube manometer filled with mercury and connected to an air pipe of known length that extended a known distance below the water surface. A tire valve and pump were connected to the system, and when a water-level measurement was desired the water was pumped out of the air pipe, and the resulting pressure in millimeters of mercury was converted to feet of water and subtracted from the length of the air pipe to give depth to water. The yield of the well was measured by timing the filling of a 48½-gallon steel barrel with a stop watch. Samples of water were taken at intervals for analysis. When pumping began the water was very muddy, owing to the fact that the 6-inch casing did not extend quite to the water-bearing stratum, leaving some open hole through clay. Thus no screen was used, and the water-bearing stratum was just tapped at its uppermost part. The results obtained are tabulated below.

Pumping test on well (no. 114) at depth of 482 feet

Time	Depth to water level below ground surface (feet)	Draw-down (feet)	Yield (gallons a minute)	Remarks
Nov. 30, 1932				
9:05 a.m.	-3.81	......	......	Static water level before any pumping.
2:50 p.m.	-6.31	......	......	Water level after two pumps tested and test ready to begin.
2:53	-19.91	16.10	......	Water very muddy.
2:56	-21.64	17.83	......	Do.
2:59	-21.15	17.34	......	Do.
3:04	-20.93	17.12	......	Do.
3:08	......	......	52	Do.
3:12	-11.98	8.17	......	Water began to clear up.
3:16	......	......	60.5	
3:19	-10.61	6.80	......	
3:23	-10.71	6.90	......	
3:30	......	......	......	Chloride 3,280 parts per million.
3:31	-11.51	7.70	......	
3:33	......	......	62	
3:40	-10.91	7.10	......	Water continued to clear up but still contained some mud.
3:45	-11.51	7.70	......	
3:58	-11.51	7.70	......	
4:05	-10.51	6.70	......	
4:19	-10.51	6.70	......	
4:20	......	......	......	Chloride 3,250 parts per million.
4:30	-9.61	5.80	......	
4:42	-10.51	6.70	......	
5:00	-10.51	6.70	......	
5:02	......	......	......	Pump stopped.
5:07	+.70	......	......	Water level above ground level.
5:10	+.76	......	......	Do.
5:30	+.76	......	......	Do.
Dec. 1, 1932				
8:00 a.m.	+1.00	......	......	Do.

The results shown above are of interest, even though the water obtained was unfit for ordinary use. While the water discharged was muddy, the draw-down ranged from 16 to nearly 18 feet, and with this pumping head the pump delivered only about 52 gallons a minute. After the water began to clear up, however, the water level rose steadily and the yield increased until the pump delivered 62 gallons a minute with a draw-down of only 6.7 feet; thus the specific capacity of the well was 9.25 gallons a minute per foot of draw-down. This decrease in draw-down and corresponding increase in yield may be explicable by one or both of the following reasons. The initial heavy draw-down may have been caused by some obstruction in the lower uncased part of the hole, such as an accumulation of drill cuttings just above the water-bearing stratum, which was removed after some minutes of pumping. It was probably due in part, however, to the fact that the heavily laden water had a higher specific gravity than the subsequent clear water. This is substantiated by the fact that although the water stood 3.8 feet below the ground level before pumping began, it rose to 0.7 foot above the ground level 5 minutes after the pump was stopped and stood 1 foot above ground level the next morning.

To judge from the specific capacity of the well, much more water could undoubtedly be obtained at this depth if the well were properly finished and a larger pump were used. An analysis (given below) showed a chloride content of 3,280 parts per million, however, and drilling was therefore stopped at 482 feet. The sample of water analyzed was collected at 3:30 p.m., during the pumping test, after the water had partly cleared up.

Partial analysis of water from well 114 at a depth of 482 feet

[By E. W. Lohr, U. S. Geological Survey. Parts per million]

Iron (Fe)	2.8
Calcium (Ca) (by turbidity)	60
Carbonate (CO_3)	0
Bicarbonate (HCO_3)	760
Sulphate (SO_4) (by turbidity)	280
Chloride (Cl)	3,280

Water-bearing beds of intermediate depth

Distribution and thickness. - In the vicinity of Elizabeth City there are several wells drawing water from depths of 60 to 110 feet. The locations of such wells on which data were obtained are shown on plate 1, and the data and analyses of water are shown on page 51.

The productive water-bearing bed below a depth of 30 feet was encountered between depths of 75 and 93 feet in the deep test well (no. 114). It is believed that this same bed of sand supplies wells 11, 105, 119, 126, and 129. Wells 13, 54, and 55 draw water from a deeper bed of sand which does not appear in the other wells, but wells 13 and 54 passed through a bed of sand at 64 and 60 feet, respectively, which, although only 5 to 7 feet thick, appears to be correlative with the sand at 75 to 93 feet in well 114. No adequate supply of water was encountered below a depth of 20 feet in well 120, nor below a depth of 40 feet in well 34, so that while the sand at 75 to 93 feet is more or less continuous over a large area, there are a few places where it is apparently thin or absent.

In general no important water-bearing sands are found between this clay bed (generally encountered at 20 to 30 feet) and a depth of 60 to 75 feet. Exceptions to this occur in well 89 and in two shallow test wells put down in the Dismal Swamp (nos. 64 and 65, fig. 4). The water in these shallow wells is not under artesian head, as it is in the wells treated in this section, and chemical analyses of the water show that it is not related to that from the artesian horizons. These wells are therefore discussed with the shallow water-bearing beds.

Physical properties. - The only data available on the physical properties of the water-bearing sand described above were obtained from four samples collected by the drillers of the deep test well at depths of 75, 80, 83, and 87 feet. Mechanical analyses and determinations of the coefficient of permeability of these four samples were made in the hydrologic laboratory of the United States Geological Survey by V. C. Fishel. A mechanical analysis of granular material consists in separating into groups the grains of different sizes and determining what percentage, by weight, each group constitutes. The permeability of a water-bearing material is its capacity for transmitting water under pressure. The coefficient of permeability, as determined in the laboratory, may be expressed as the number of gallons of water a day, at 60° F., that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.[9]

The mechanical analyses and coefficient of permeability of these four samples are shown on the following table.

Laboratory tests of water-bearing materials from deep test well at Elizabeth City

[By V. C. Fishel]

Depth (feet)	Mechanical analysis (percent by weight)							Coefficient of permeability
	Larger than 1.0 mm. (fine gravel)	1.0-0.50 mm. (coarse sand)	0.50-0.25 mm. (medium sand)	0.25-0.125 mm. (fine sand)	0.125-0.062 mm. (very fine sand)	0.062-0.005 mm. (silt)	Less than 0.005 mm. (clay)	
75-80	2.7	16.2	48.1	26.3	5.3	1.0	0.4	750
80-83	27.5	25.1	31.1	11.3	3.2	1.1	.5	675
83-87	31.3	22.7	29.3	10.6	4.6	.8	.4	675
87-93	7.5	4.2	22.6	55.4	6.4	2.2	1.4	350

9 Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, p. 148, 1927.

The table shows that all four samples contain but little very fine sand, silt, and clay and differ principally in their percentages of fine to coarse sand and fine gravel. The samples from depths of 80 and 83 feet contain almost equal amounts of fine gravel, coarse sand, and medium sand, with smaller amounts of fine sand, showing that they are not as well sorted as the samples from depths of 75 and 87 feet, but they have fairly large coefficients of permeability. The even higher coefficient of permeability of the sample from a depth of 75 feet may be due to the large amount of medium sand and the consequent better sorting. The sample from a depth of 87 feet has a still better degree of sorting, but most of it is fine sand, and its coefficient of permeability is therefore only about half as great as that of the other three samples.

The coefficients of permeability and the grain sizes indicate that moderately large quantities of water should be obtainable from the 18 feet of sand, particularly from the uppermost 12 feet. The actual yields obtainable are discussed below.

Head of water. - In most of the wells shown in the table the static water level is from 3 to 10 feet below the ground level, but at some of the wells it was not possible to obtain measurements. The static water level of the sand at 75 to 93 feet in the deep test well ranged from 4.8 to 5.2 feet below the ground. Well 55 is reported to flow during wet seasons, and it was reported that well 13 flowed at a depth of 64 feet, but the water in the lower sand that now supplies this well does not flow.

Thus the water from the beds of intermediate depth which are overlain by impervious beds is generally under considerable head, which, though not as great as that from the 482-foot sand, is sufficient in some places to raise the water up to the water table and in a few places to raise it above the ground surface. Wells of this kind in which the water stands higher than the water table (as observed in nearby shallow wells) may be properly termed "artesian wells", even though the water may not overflow at the ground surface.

Yield. - Some of the wells listed are of small diameter and are equipped only with hand pumps, but wells 105, 119, 126, and 129 are equipped with power pumps and yield considerable water. The two wells numbered 119 yield 75 to 80 gallons a minute each with a 10 or 12 foot draw-down. However, the most reliable data obtained as to the yield of the sand at 75 to 93 feet were obtained during a pumping test on the deep test well (no. 114) in December 1932. The results of this test, described below, do not show the maximum yield obtainable, however, because the test was made under very poor conditions; no well screen was used, and the 6-inch hole penetrated only the upper 6 feet of the 18-foot sand, as the lower 12 feet of sand caved in.

After the conclusion of the pumping test on the 482-foot sand an attempt was made to pull up the 6-inch casing so that the upper sand might be tested. The drillers removed part of the casing, but after repeated efforts they were forced to abandon the lower 300 feet of casing, which had become firmly lodged. A cement plug was set near the bottom of the well, and the hole was filled with clay up to the sand at 93 feet, to prevent the salty water below from contaminating the upper strata.

The well was then pumped for 2 days with an electrically driven centrifugal pump with a capacity of 1,000 gallons a minute, equipped with a regulating valve so that the output could be readily varied. The well was pumped at gradually increasing rates, and the draw-down was accurately measured every 1 or 2 minutes. With a draw-down of 20 feet the well yielded about 198 gallons a minute, or about 10 gallons a minute per foot of draw-down. To judge from the specific capacity thus shown, much more water could undoubtedly be obtained at this depth if the well were properly finished and a deep-well turbine pump were used.

Quality of water. - An analysis of the water from the sand at 75 to 93 feet when well 114 was first drilled showed only 180 parts per million of chloride (see analysis), whereas several samples collected during the preliminary pumping test contained about 300 parts per million. It was concluded that this increase in chloride content was produced by saline water from the 482-foot sand, which, having a greater artesian pressure, had escaped into the upper sand during a period of several days when the drillers were trying to recover a lost string of casing. It was also thought that the seal between the two beds might be inadequate. Accordingly, the well was bailed down to a depth of about 125 feet, a wooden plug was driven into the top of the lost string of casing, and this plug was followed by a cement and clay seal.

The pump was again started, and the well was pumped almost continuously for a week at a rate of about 158 gallons a minute, with a 15-foot draw-down. Samples of water were analyzed at intervals during the week and a 1-gallon sample was collected at the end of the week for a complete analysis. The results of these analyses are shown in the table on page 51.

The table of analyses shows comparable amounts of chloride in the waters of all the wells, including that of well 114 taken Nov. 12, before the well was completed. The chloride content of most of these waters ranges from 119 to 190 parts per million, and one analysis shows only 84 parts. However, the five analyses of water from well 114 taken from Dec. 12 to 21 show from 295 to 308 parts per million. Thus it appears that although the additional seal in this well may have been effective, considerable saline water had escaped into the sand at 75 to 93 feet, for a week's continuous pumping did not reduce the chloride content. It is believed that if a screen were installed so as to utilize the entire 18 feet of sand instead of only the upper 6 feet, the salt water might perhaps have been removed with prolonged pumping. However, a study of the analyses of the water from the test wells, together with those of other waters from the same general horizon, indicates that the water would not be entirely satisfactory for municipal use. The hardness is much greater than the average hardness of water used for municipal supplies throughout the United States. This deep test well was therefore abandoned, but it was recognized that if an adequate supply of shallow ground water was not found, there remained the alternative of developing an auxiliary supply from the sand at 75 to 93 feet.

Driller's log of Norfolk Southern Railroad well

[No. 120 in table and Pl. 1]

	Thickness (feet)	Depth (feet)
Loam	4	4
Sand, light; no water	7	11
Sand, light; good supply of surface water	9	20
Sand, light (?); small supply of water	45	65
Mud, black, and sand; no water	35	100
Mud, blue, and sand; few shells; no water	22	122
Sand, blue, and few shells; small supply of water	2	124
Mud, blue; no water	31	155
Mud, blue, and few shells; small supply of water	5	160
Mud, blue; no water	2	162

Drillers' log of North Carolina State Normal School wells

/No. 129 in table and Pl. 1/

	Thickness (feet)	Depth (feet)
Sand	10	10
Quicksand, white	12	22
Sand, blue, with marl and shells	6	28
Muck and shells; some water at 50 feet (salty?)	22	50
Marl and shells; good supply of salty (?) water at 60 feet	10	60
Sand and marl	5	65
Marl	10	75
Sand; strong supply of water	15	90

Note. - Drillers' terms "muck" and "marl" refer to fine silt or clay with small amount of sand and calcareous material.

Shallow water-bearing beds

Method of investigation

In determining whether it would be feasible to develop a public water supply from shallow wells it was necessary to give attention to two problems - first, whether the water-bearing materials are capable of yielding the required quantity and quality of water; second, whether salt-water contamination would result with continued pumping.

Information was obtained on numerous privately owned shallow wells at the localities shown on plate 1 and is given in tabular form. At several places in Elizabeth City fairly large quantities of water have been obtained by wells of small diameter, and this fact led to the belief that the desired quantity of water might be obtained from similar shallow wells. The available information did not, however, indicate where such wells should be located, and to determine this it was necessary to put down several test holes and test wells to ascertain the character, thickness, and water-bearing properties of the shallow beds, and to run levels to a number of wells to ascertain the altitude and shape of the water table. From this information an area was selected for the installation of a high-capacity test well (no. 69). Although it was not possible to select the locality for this well until after the completion of the other test work, it is deemed desirable to describe all these tests first, before discussing the results obtained.

This test work was confined to Pasquotank County, because it was thought by the Elizabeth City Public Utilities Commission that although favorable areas might exist in Camden County, any development there would involve the construction of a pipe line across the Pasquotank River, the cost of which might prove excessive.

Shallow test holes and test wells

Eight shallow test holes (nos. 12, 14, 41, 59, 71, 74, 81, and 132) and nine shallow test wells (nos. 62, 64, 65, 66, 68, 77, 78, 88, and 122) were put down at the locations shown on plate 1. The test holes were jetted down by using 5-foot sections of 2-inch pipe, inside of which was a ½-inch pipe with a jetting bit attached to the lower end. Water was supplied to the ½-inch pipe from a small gasoline-powered pump at the rate of 10 to 20 gallons a minute. The water and material were discharged through a T at the top of the 2-inch pipe. Samples of the material were obtained at different depths by collecting a bucketful of the liquid from the discharge pipe. After some time had elapsed for the finer particles to settle, the water was decanted off, and the wet sand, silt, or clay was poured into quart cans, which were oven-dried and shipped to the hydrologic laboratory of the United States Geological Survey, where the physical properties of some of the samples were determined.

The shallow test wells were put down to obtain water samples as well as samples of material, and the procedure was changed so that the wells could be pumped at any desired depth. This was accomplished with 1¼-inch pipe by substituting for the lowermost length of pipe a 5-foot length of 60-mesh well screen that was open at the lower end. When a water sample was desired, the lower end of the screen was temporarily closed with a cork stopper driven to the proper depth by tapping it with a suitable length of ½-inch pipe. A pitcher pump was then attached, and the well was pumped strongly by hand until the water cleared up sufficiently to yield a reasonably clear sample. It was also necessary to pump out considerable water in order to be certain of removing all the water injected into the water-bearing material by the jetting bit, so that the sample would contain only the natural ground water. Samples of material were collected from the test wells in the same manner as from the test holes. A view of the jetting outfit in operation is shown in plate 3, A.

Samples collected in this manner are not fully representative of the materials as they occur in nature, nor are they generally as good as samples obtained from cable-tool drilling, because the steady stream of water used in the process removes part of the finer material, leaving the sample somewhat coarser-grained than it should be. However, it was generally possible to determine, in a sand, for example, whether or not any considerable quantity of clay was mixed with the sand, by observing whether or not the water accompanying the sand was lightly or heavily charged with fine silt particles. Samples of clay, on the other hand, were found to be nearly exact duplications of their natural occurrence, because the clay is expelled from the discharge pipe in lumps. When beds of shells were encountered it was found that nearly all the smaller shells and many of the larger ones came up unbroken, so that good fossil collections were obtainable.

(See the logs of these tests and the geologic discussion concerning them. The ground-water data obtained from them are discussed in the remainder of this report.)

Gravel-wall test well

After the data obtained from the test wells and test holes and the leveling work had been carefully studied, it was deemed desirable to drill a large well to test the water-yielding capacity of the shallow beds, and a general locality was suggested.

The city took an option on some property, and a gravel-wall well was put down at the locality shown by test well 69 on plate 1. This well consists of a 9-inch casing about 30 feet long, slotted over the lower 25 feet and surrounded by 39½ tons of selected gravel with pebbles ranging in diameter from one-fourth to three-eighths of an inch. The gravel was introduced through four 6-inch casings sunk along a circle at a radius of 3 feet from the center of the well and also through a section of 24-inch casing that surrounded the 9-inch slotted casing down to a depth of 10 feet. The slots in the 9-inch casing are one-eighth of an inch wide - too narrow to allow the gravel to enter the casing. Sand and water were pumped out at the center, and the sand was gradually replaced by the gravel. After a week's preliminary pumping to clear the well of fine sand and silt, a thorough pumping test was made. (See pp. 40-42.)

The problem of contamination by salt water

It was reported that the chloride content of the water from some of the shallow wells in Elizabeth City generally increased when they were pumped heavily, and it was feared that if shallow wells were to be used for public supply in the city they might soon become salty.

However, a consideration of the principles governing the relations between fresh and salt water indicates that the danger of contamination would be much less in some localities than in others.

The danger of contamination depends upon the relations which exist between fresh and salt waters near seacoasts, the principles governing which were first applied in Europe by Badon Ghyben[10] and Herzberg[11] and later utilized in the United States by Brown.[12] The fundamental facts to be understood in regard to these relations are as follows: (1) Where bodies of fresh and salt water are in contact the salt water, being heavier than the fresh, will lie below the fresh water - in other words, the fresh water floats, so to speak, on the salt water. (2) The depth to the contact between the fresh and salt water is a function of the altitude of the water table above sea level and of the density of the salt water. This may be expressed by the simple formula

$$h = \frac{t}{g-1}$$

in which h is the depth of the fresh water below sea level, t is the height of the fresh water above sea level, and g is the density of the salt water. The density of ocean water is about 1.025. From these relations, if the fresh-water head is 2.5 feet above sea level the fresh water will extend 100 feet below sea level. In other words, for each foot of fresh water above sea level the fresh water extends about 40 feet below sea level.

The boundary between the fresh and salt water in the Elizabeth City area between the Pasquotank and Little Rivers would probably be something like that shown in figure 3, provided the river waters were appreciably saline and the water-bearing materials were more or less homogeneous and permeable without impervious layers or barriers. Actually the materials are probably not everywhere homogeneous, and impervious layers are known to underlie a considerable part of this area. However, if the water-bearing material is more or less permeable in all directions toward the rivers and downward to the beds containing

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10 Badon Ghyben, W., Nota in verband met de voorgenomen put boring nabij Amsterdam: K. Inst. Ing. Tijdschr., 1888-89, p. 21, The Hague, 1889.

11 Herzberg, Baurat, Die Wasserversorgung einiger Nordseebader: Jour. Gasbeleuchtung und Wasserversorgung, Jahrg. 44, Munich, 1901.

12 Brown, J. S., A study of coastal ground water, with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 537, pp. 16-17, 1925.

salty water that are known to lie beneath the area at a greater or less depth, then if the water table is lowered to sea level or below there is danger of contamination by either horizontal or vertical (upward) movement. If, however, the water table near the pumped wells can be maintained a foot or two above sea level, according to the principles enunciated it should be possible to pump water from wells 20 to 30 feet deep without danger of contamination. Furthermore, if the shallow water-bearing beds are underlain by an impervious bed that would prohibit upward movement of salt water from underlying beds (which is the condition over a considerable part of the area), it would probably be possible to draw down the water level in pumped wells a few feet below sea level if between the wells and any surface sources of salt water the water table were maintained at an altitude high enough above sea level to provide a barrier of fresh water around the wells.

In accordance with the principles governing the relation between salt and fresh water, it is evident that the fairly high chloride content in some of the shallow wells in Elizabeth City is to be explained by their closeness to the salty Pasquotank River. The water table is not much above the river, and a comparatively small lowering of the water table by pumping has permitted the salt water to move into the water-bearing formations.

Because of these relations an essential consideration, if shallow wells are not to be contaminated, is to locate them where the water table is highest above sea level, provided, of course, that the water-bearing material is everywhere equally permeable. To determine the most favorable localities, it is necessary to construct a contour map of the water table. First, however, the character of the water-bearing materials will be considered.

Distribution and thickness

The information obtained as to the character, distribution, and thickness of shallow water-bearing beds in the Elizabeth City area was obtained largely from the shallow test holes and test wells. The strata encountered in shallow test drilling and the logs of the test wells and test holes are given from the geologic standpoint, and this information will now be considered from a hydrologic standpoint.

The logs of test holes 12, 14, and 41 show that in the area between Knobbs Creek and the Pasquotank River the character and thickness of the shallow water-bearing sands are variable over rather short distances. In holes 12 and 14 the sand is only 20 to 22 feet thick and is underlain by clay. In hole 41 there is 42 feet of sand above the clay layer.

The logs of twelve test holes and test wells and descriptions of the material encountered in the area between Knobbs Creek and the Dismal Swamp west of the city are given on pages 18 to 20. Conditions in this

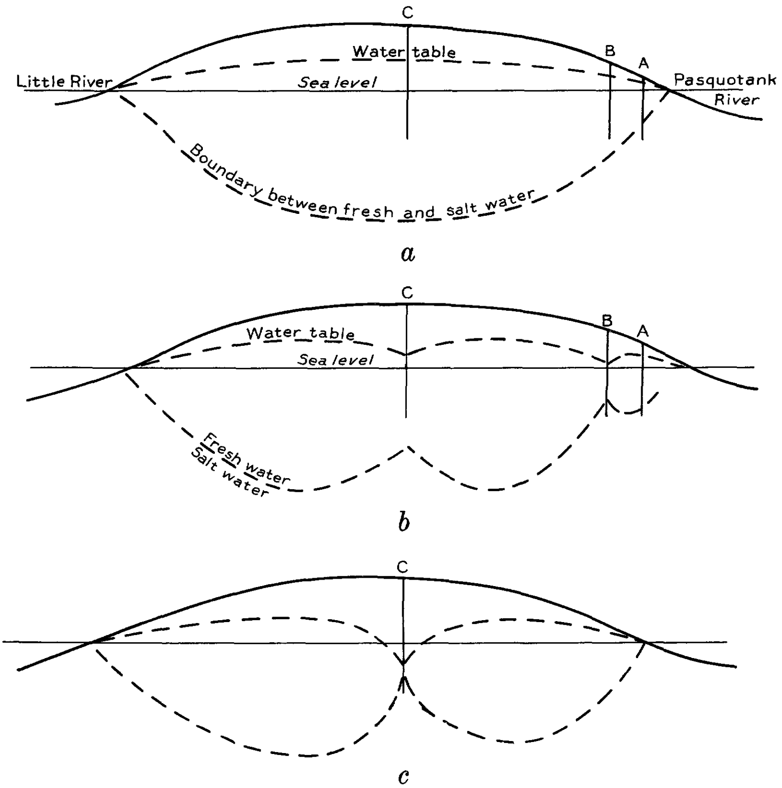

Figure 3. - Diagrams showing probable relations between fresh and salt water in the Elizabeth City area, if it is assumed that the water-bearing materials are homogeneous and permeable both laterally toward the Pasquotank and Little Rivers and downward to considerable depth. (Not drawn to scale.)

Diagram a shows theoretical relations between fresh and salt water before pumping. A shallow well, A, near either river may encounter salt water even without pumping.

Diagram b shows that when well B is pumped, only a moderate lowering of the head may result in drawing in salt water, whereas in well C an equal lowering of head may not result in drawing in salt water.

Diagram c shows that too great a lowering of the head in well C may also result in drawing in salt water.

area are rather uniform, as shown by the fact that in eleven of the tests, covering several square miles, the sand ranged in thickness from 26 to 30 feet and averaged $27\frac{1}{2}$ feet, and in well 122, which is close to the city, the sand was 22 feet thick. In all these test wells and holes clay underlies the shallow beds of sand.

Test wells 64 and 65 were put down in the Dismal Swamp, and the logs show that the water-bearing sands are at least 65 feet thick in this locality. The bed of clay encountered in the other tests was not found in well 65, and only a 2-foot bed of clay was penetrated in well 64, between the depths of 30 and 32 feet. Thus this part of the Dismal Swamp is underlain by the thickest water-bearing beds encountered in any of the test wells.

The logs of some of the test holes and test wells west of Elizabeth City are shown graphically in figure 4.

Physical properties

Laboratory tests

The information given below concerning the physical properties of the shallow water-bearing beds was obtained from field observations and laboratory tests of samples of material collected from several test holes and wells and of a few samples of surface material. The samples collected from the test wells and holes were washed to the surface by the jetting method and therefore cannot be regarded as truly representative of the materials as they occur undisturbed in nature, because some of the finer particles were washed away.

No laboratory tests were made of samples collected from test holes in the area between Knobbs Creek and the Pasquotank River, but a field examination of samples from test holes 12 and 14 shows that most of the material is fine-grained sand with considerable silt and that it contains an abundance of shells in the lower part. In test hole 41 the upper 21 feet of sand appears to contain very little silt, but the lower 21 feet contains considerable silt. Thus the fine sand over much of the area north of hole 41 appears to have low permeability, and the area of permeable sand such as that in hole 41 does not appear to be widespread.

The logs of test wells and test holes put down west of Knobbs Creek have been given, and the physical properties of some of the samples obtained from these tests are shown in the following tables:

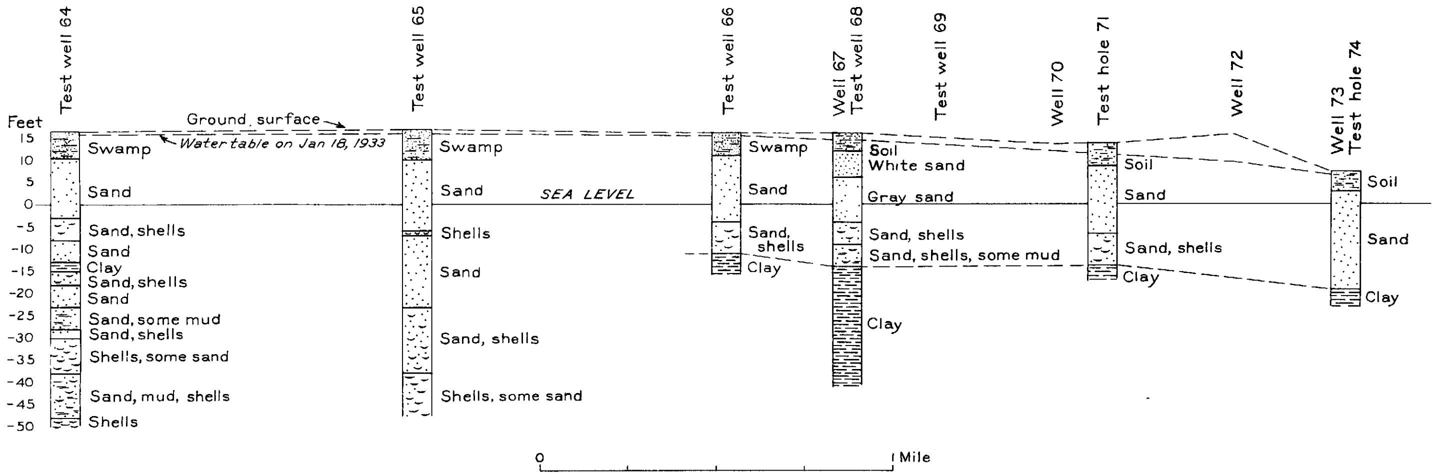

Figure 4. - Cross sections of test wells and test holes along a line connecting no. 64 and no. 74 west of Elizabeth City, showing the character of the material, the altitude of the ground surface, and the altitude of the water table on January 18, 1933.

Physical properties of samples of sand from shallow test wells and test holes in the Elizabeth City area, west of Knobbs Creek

[By V. C. Fishel, U. S. Geological Survey]

No. on Pl. 1	Depth below ground surface (feet)	Coefficient of permeability [1]	Porosity (percent)
65........	15	700	.....
65........	20	550	.....
68........	15	625	.....
68........	25	500	.....
71........	20	575	42
77........	20	475	40
78........	15	725	36
122........	20	475	42

1 See page 26 for definition.

Mechanical analyses of samples from test well 68 and test hole 71

Type of material	Size of grain (millimeters)	Percentage by weight	
		Test well 68 (depth 15 feet)	Test hole 71 (depth 20 feet)
Fine gravel....	1-2	0.0	0.1
Coarse sand....	0.5-1	.3	1.4
Medium sand....	0.25-0.5	24.0	14.0
Fine sand......	0.125-0.25	67.3	74.9
Very fine sand.	0.062-0.125	7.1	10.5
Silt and clay..	Less than 0.062	.2	1.0

The first table above shows that the coefficient of permeability of the samples of sand is about the same as that of the samples collected from the deep test well, but a comparison of the mechanical analyses shows that the shallow sands consist chiefly of fine sand, with lesser amounts of medium and very fine sand and almost no coarse sand or fine gravel, whereas the upper sands from the deep test well contain considerable medium and coarse sand and fine gravel. Moreover, as explained above, the shallow sands are probably less permeable than the laboratory tests indicate, owing to the loss of some of the finer materials in jetting the samples to the surface.

The samples from test wells 78 and 65 at a depth of 15 feet show coefficients of permeability of 700 and 725, respectively, but over most of the area between Knobbs Creek and the Dismal Swamp, west of Elizabeth City, the sand is less permeable.

As shown in the logs, layers of shells and layers containing considerable silt occur in some areas, and the silt and perhaps to some extent the shells reduce the permeability of the sand.

Five samples of material from Camden County were tested in the laboratory - three samples from road cuts, one from a sand pit, and one from a dug well, as shown in the following tables:

Physical properties of samples of material from Camden County

[By V. C. Fishel, U. S. Geological Survey]

All locations except no. 46 are designated on plate 1 by a cross (X).

No.	Source	Depth below surface (feet)	Porosity (percent)	Coefficient of permeability
20	Sand pit	3	36.8	1,450
22	Road cut	1½	48.0	320
30	Road cut opposite well 29	2 or 3	46.7	320
46	Bottom of well 46	10	43.3	235
104	Road cut	5	49.2	75

Mechanical analysis (percent by weight)

No.	Larger than 1.0 mm. (fine gravel)	1.0-0.50 mm. (coarse sand)	0.50-0.25 mm. (medium sand)	0.25-0.125 mm. (fine sand)	0.125-0.062 mm. (very fine sand)	0.062-0.005 mm. (silt)	Less than 0.005 mm. (clay)
20	11.1	37.4	37.0	11.0	1.0	0.8	1.4
22	.4	3.4	18.4	44.2	13.3	13.0	6.5
30	.1	1.4	7.2	59.7	14.7	10.5	6.3
46	.2	3.7	34.1	32.6	10.5	15.7	3.2
104	.0	.3	2.4	6.6	22.2	65.7	2.8

Sample 20 was taken from a sand pit which is reported to supply the State Highway Department. Its coefficient of permeability (1,450) is the highest obtained during the investigation, and the mechanical analysis shows that nearly 75 percent of this material is medium and coarse sand. If this material were of sufficient thickness and areal extent, it should yield water copiously, but no data are available as to its thickness, and its areal extent is thought to be rather small. It is penetrated by well 19, but no similar material could be found elsewhere in the vicinity. The other samples show rather low coefficients of permeability, particularly no. 104, which consists largely of silt.

The table shows very clearly that a higher porosity does not necessarily indicate a high permeability, for sample 20, with a porosity of 36.8 percent, has a much higher permeability than sample 104, which has a porosity of 49.2 percent.

Pumping test on test well 69

The gravel-wall test well (no. 69) put down at the locality shown on plate 1 not only furnished valuable information as to the maximum yield obtainable from a single well in the shallow water-bearing beds, but also afforded a means for determining the coefficient of permeability of the water-bearing material as it occurs undisturbed beneath the surface.

A method was developed in Germany by G. Thiem for determining the coefficient of permeability of any water-bearing material from measurements of yield on a pumped well and measurements of the draw-downs in two or more observation wells nearby. Thiem's method was thoroughly tested near Grand Island, Nebr., by L. K. Wenzel,[13] of the United States Geological Survey, in a cooperative investigation with the Nebraska Geological Survey.

The coefficient of permeability is computed from the following formula, which is Thiem's formula modified by Wenzel for convenient use in the United States:

$$P = \frac{527.7q \log \frac{a'}{a}}{\frac{h + h'}{2} (S - S')}$$

in which P is the coefficient of permeability as defined on page 26; q is the yield of the pumped well, in gallons a minute; a and a' are the respective distances of any two observation wells from the pumped well, in feet; h and h' are the thicknesses of saturated water-bearing material at the same two observation wells, in feet; and S and S' are the respective draw-downs at the same two observation wells, in feet. The above formula applies to water-table conditions and may be modified for use under artesian conditions.

As shown in figure 5, six $1\frac{1}{4}$-inch driven wells equipped with ordinary screened well points were put down along a straight east-west line at distances of 50, 100, and 200 feet from the pumped well (three to the east and three to the west), and one well was put down 10 feet west of the pumped well. In addition a well was dug 1,000 feet east of the pumped well and equipped with a 7-day automatic water-stage recorder, in order to observe whether the

13 Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield: U. S. Geol. Survey Water-Supply Paper 679-A.

effect of pumping could be detected for a distance of 1,000 feet (see pl. 4 and description of well 69b). The altitude of the top of each observation well with reference to the pumped well was then determined instrumentally.

After the static water level in each well had been accurately measured, the pump was started, and the yield of the pumped well and the depth to water in each well were measured hourly. It was intended to pump the well day and night for a week or more, but trouble with the pump necessitated brief stops at intervals.

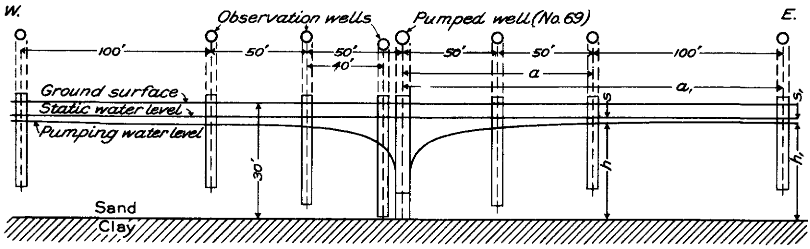

Figure 5. - Arrangement of wells and ground-water conditions during a pumping test on well 69, in the Elizabeth City area.

Figure 5 shows the slope of the water table at the well (known as the cone of depression) after 31 hours of continuous pumping at an average rate of 40½ gallons a minute with a static water level of 3½ feet below ground level. The draw-down in the pumped well was 19½ feet, giving a specific capacity of only a little more than 2 gallons a minute per foot of drawdown, which was considerably below the expected yield.

The average coefficient of permeability obtained by using the draw-downs in the observation wells spaced at 100 and 200 feet from the pumped well is about 320, but the average in wells spaced at 50 and 100 feet is only about 180. The difference between the coefficients obtained from the pumping test and those obtained from the laboratory tests is probably in part due to the removal of silt and very fine sand from the laboratory samples during the process of jetting the wells, which would result in making the coefficients obtained in the laboratory too high. However, the yield of the pumped well as compared with the yields obtained from other shallow wells indicates that the sand is less permeable in the immediate vicinity of the pumped well than it is in most other places.

The difference between the permeabilities computed from the wells at 50 and 100 feet and those computed from the wells at 100 and 200 feet is due in part to the fact that equilibrium had not been established in the 100-200-foot zone by the end of the period of 31 hours of pumping, and therefore water was still being removed from storage in that zone. However, that there is an actual difference in permeability is indicated by the fact that the observation wells 100 and 200 feet from the pumped well yielded more water when pumped than the observation wells at 10 and 50 feet. In this pumping test most of the water appears to have been taken out of storage by unwatering the sand above the cone of depression (see fig. 5), and relatively little water appears to have reached the locality by lateral movement of ground water. According to Wenzel,[14] in a sand of rather low permeability and fairly high specific yield, a long period of pumping may be required before approximate equilibrium is reached.

Pumping was continued for more than a month without material changes in the water levels, but rainfall on numerous days during the month apparently replenished much of the water pumped from storage, so that possibly equilibrium conditions were not reached at all.

The water table

Altitude and shape

In order to determine the altitude and shape of the water table it is necessary to construct a contour map of it. For this purpose reference points were established at a number of shallow wells, and measurements of the depth to water level below the reference points were made from time to time. The altitude of the reference points was determined instrumentally by J. P. Clawson and W. J. Overman from several United States Coast and Geodetic Survey bench marks, and is given in the table of well records. The depth to water level below the reference point in each well on different dates is given in the table of water levels.

From measurements of the depth to water level in these wells on January 18 and 19, 1933, when the water-table was at a high stage, the water-table contour map shown in plate 1 was constructed. This map shows that in the area between Knobbs Creek and the Pasquotank River on the dates mentioned the water table stood not much higher than 5 feet above sea level in most places and stood 10 feet or more above sea level only in the small area above the headwaters of Knobbs Creek. Similar

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14 Wenzel, L. K., Personal communication.

conditions were found to the south and for a short distance west of Elizabeth City, but in the area beginning about 3 miles west of the city the water table on these dates was a little more than 15 feet above sea level, and observations indicate that the water table stood at about this altitude over the entire southern part of the Dismal Swamp west of the city, and the altitude doubtless increases to the northwest. As shown in figure 4, the hydraulic gradient or slope of the water table is greater between the 5 and 10 foot contours than between the 10 and 15 foot contours, indicating that the water moves faster between the former than between the latter.

It was shown that, other things being equal, the danger of contamination by salt water is less in areas where the water table stands at a high altitude, and in this respect the area about 3 miles west of Elizabeth City appears to be much more favorable than other nearby areas.

The contour map in plate 1 shows the water table at a high stage, and there remain to be considered the fluctuations of the water table and its altitude at low stages.

Fluctuations

Some information as to the fluctuations of the water table was obtained from occasional observations in numerous privately owned shallow wells and a few shallow wells installed by the Public Utility Commission. (See tables of well records and water levels.) It was planned to have employees of the Public Utility Commission make periodic measurements at a few of the wells, but unfortunately this plan was not carried out successfully.

The maximum fluctuations recorded in wells west of Elizabeth City ranged from 3 to 7 feet between October 8, 1932, when the water table was apparently at a low stage, and December 15, 1932, when the water table reached a very high stage. The water level in wells that were observed before and after a rain of several days' duration commonly rose from 1 to 2 feet, indicating that the rainfall was not appreciably hindered from reaching the water table and that recharge was fairly rapid.

During the preparations for the pumping test of well 69 in July 1933, an observation well (69b) was dug 1,000 feet east of the pumped well and equipped with a 7-day automatic water-stage recorder. This well was installed for the dual purpose of (1) ascertaining whether or not the effect of pumping well 69 could be detected for a distance of 1,000 feet, and (2) determining accurately the fluctuations of the water table and their relation to precipitation over a considerable period. The maintenance of the recorder was placed in the hands of city employees, but unfortunately, through a change of personnel, the recorder was not attended to regularly, so that there are several gaps in the record.

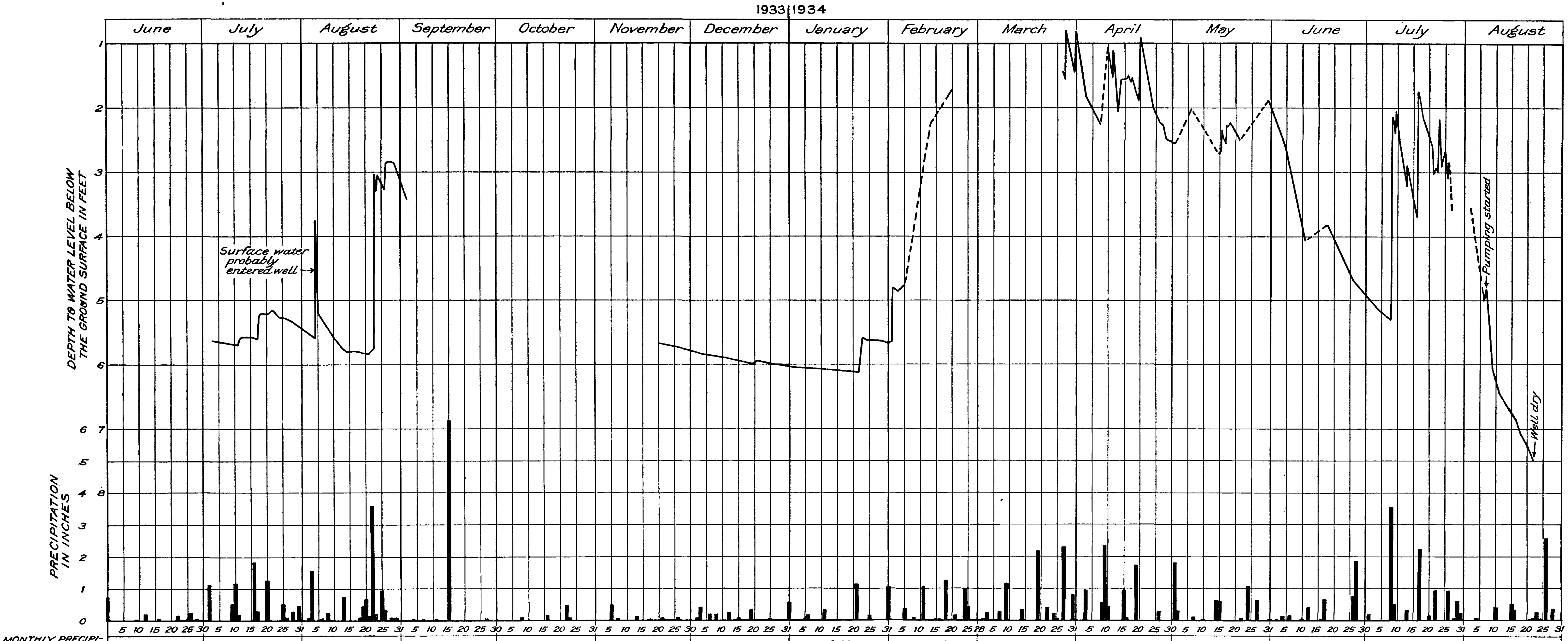
The fragmentary record of the fluctuations of the water table in well 69b is shown graphically on plate 4, together with the daily and monthly precipitation at Elizabeth City, for the period from July 1933 to August 1934. Despite the gaps, this record is of considerable interest in showing the rapid rise of the water table in response to precipitation.

As shown on plate 4, the precipitation was considerably below normal in June 1933, the month just before the beginning of the record, so that the water table was at a rather low stage. Moderate rains in July caused several rises in the water table. The apparent sharp rise of the water table ending on August 4, 1933, as a result of heavy rain on August 3, appears to have resulted from surface water having entered the top of the well, although precautions were taken to prevent this in the construction of the well.

Heavy precipitation accompanying a tropical storm in the later part of August produced a sharp rise in the water table of about 2.7 feet, and subsequent rains of less intensity served to keep the water table at a high stage for the remainder of the month.

It is unfortunate that the record is not available for September, October, and most of November 1933, because it would have been interesting to observe the effect of the heavy rain of 6.25 inches that accompanied the tropical storm of September 15.

Subnormal precipitation in October, November, and December 1933 caused a gradual decline of the water table to a point about 6.1 feet below the ground surface on January 22, 1934. After the growing season the period of winter recharge did not begin until the later part of January 1934. The water table rose rapidly during February and appears to have reached its highest stage in March, although the record is missing for part of February and March. The maximum recorded fluctuation of the water table due to natural causes occurred between January 22 and March 28, 1934, when the water table rose a total of 5.3 feet. The precipitation was more than 4 inches above normal in March and April 1934, with the result that the water table stood from 1 to 2 feet below the ground surface during those months. Despite above-normal rains in May, the spring vegetation was beginning to make



	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August
MONTHLY PRECIPITATION IN INCHES	1.45	7.39	8.78	6.27	0.71	0.62	1.37	2.32	5.33	7.92	7.28	5.39	4.02	9.71	4.62
DEPARTURE FROM NORMAL IN INCHES	-3.90	+1.52	+4.31	+2.13	-1.56	-1.79	-2.72	-1.72	+1.18	+4.16	+4.05	+1.42	-1.33	+3.84	+0.15

GRAPH SHOWING FLUCTUATIONS OF THE WATER TABLE IN WELL 69b AND DAILY PRECIPITATION AT ELIZABETH CITY, JULY 1933 TO AUGUST 1934.

demands on the soil moisture, and the water table declined somewhat. In June not only were there greater losses by evaporation and transpiration, but the precipitation dropped below normal, and accordingly the water table declined rapidly and continued to decline until July 8. The summer decline was arrested sharply by heavy rains beginning on July 8, producing a sudden rise of the water table of more than 3 feet. The summer decline continued during the early part of August, but on August 7 the water table in the vicinity of well 69b was artificially lowered by heavy withdrawal of water, so that the useful life of the observation well ended on this date.

It has been indicated above that there is a close correlation between the height of the water table in the different wells and the amount of precipitation, when allowances have been made for other factors such as the losses due to evaporation and transpiration during the growing season. In particular, the record of well 69b, which is within the area of the proposed shallow-well development for the city, shows that in this area the precipitation is not hindered appreciably from reaching the water table. The sharp rises in the water table, such as those shown in plate 4, generally occur almost immediately or within 24 hours after a good rain, the time depending upon the intensity and duration of the rain and the depth to the water table. Several factors contribute to this rapid recharge - (1) the sandy, porous character of the soil, which readily absorbs the rainfall; (2) the rather uniform fine sand that occurs both above and below the water table and allows rapid percolation to the water table; and (3) the fact that the water table in the vicinity of this well stands close to the surface of the ground throughout most of the year and seldom falls more than 6 feet below the surface.

Quantity of water

Yield of wells

Information as to the yield of shallow wells in the Elizabeth City area was obtained from a few industrial wells and several test wells put down during the investigation.

The Elizabeth City Hosiery Co. has 10 shallow driven wells (no. 117) that are reported to have an aggregate yield of 80 gallons a minute, or an average of 8 gallons a minute, but it is not known whether this rate could be maintained for a considerable period, as the wells are pumped for only a few hours each day. The 4 shallow driven wells of the Wright Purity Ice & Fuel Co. (no. 127) are reported to have an aggregate yield of about 18 gallons a minute, or an average of only about 4½ gallons a minute. No data are available as to the yield of the 8 driven wells of the Crystal Ice & Coal Co. (no. 118).

In order to collect water samples from the shallow test wells that were jetted down with water, it was necessary to pump out considerable water in order to make sure that all the water introduced into the wells in the jetting process was removed, so that the samples contained only ground water. This pumping was also necessary in order to clear the water of fine sand and silt.

In test wells 64, 65, and 66 the water-bearing sand at all points below a depth of 10 feet yielded water freely to a pitcher pump which was pumped at a rate of about 10 gallons a minute. In testing well 68 it was found that the sand between depths of 15 and 17 feet yielded only about 5 gallons a minute, but the sand from 20 to 30 feet yielded water freely. The sands in test well 77 yielded water freely from a depth of 10 feet to the bottom, but the sand between depths of 10 and 15 feet appeared to be more permeable than the average and might have yielded 15 gallons or more a minute if a larger pump had been used. In jetting down test well 78, the sand between depths of 4 and 18 feet yielded water very freely, and, as shown in the table, a sample of sand from this well at a depth of 15 feet had the highest coefficient of permeability of all the samples obtained west of Elizabeth City. Water from this sand was pumped at the rate of 12 gallons a minute, and a larger pump would doubtless have yielded more. In trying to get through this sand, the jetting water was entirely absorbed by the sand, so that the pipe soon became clogged with sand. By removing the jetting pipe and attaching a pitcher pump, the sand was removed and the well was "pumped down" with ease. Test well 122 was pumped at the rate of 10 gallons a minute at depths below 10 feet.

In the area west of Elizabeth City, therefore, most of the test wells yielded at least 10 gallons a minute at different depths for short periods, a few wells yielded only about 5 gallons a minute at certain depths, and a few wells, notably test well 78, yielded more than 10 gallons a minute at different depths for short periods. These yields indicate that, despite the fine texture and small thickness of the sand, the quantity of water desired by the city might be obtained from a number of wells distributed over a considerable area.

The gravel-wall test well (no. 69) yielded only 40½ gallons a minute with a 19½-foot draw-down. Thus the low permeability and small thickness of the sand definitely limit the amount of water that can be withdrawn from one well, even from a well that is constructed for great efficiency.

Water in storage

The shallow water-bearing sand in most of the area between Knobbs Creek and that part of the Dismal Swamp lying west of Elizabeth City ranges in thickness from 26 to 30 feet but becomes deeper within the swamp. In order to estimate the amount of water in storage in a given area it is necessary to know the thickness of saturated sand over the area and to make a safe assumption as to the effective porosity or specific yield of the sand. The average thickness of saturated sand over an area of several square miles ranged from 20 feet in dry seasons to 25 or 28 feet in wet seasons, and the porosity of several samples of sand ranged from 36 to 42 percent. However, the effective porosity, or specific yield, is less than the actual porosity, as it represents only the volume of water that drains out because of the force of gravity. If the average effective porosity is 30 percent, an average of more than 1,000,000,000 gallons of free ground water is stored under each square mile of the area.

Recharge from precipitation and lateral movement of ground water

The average annual precipitation in the area is about 48 inches. A study of the intake conditions and of the rise in the water levels in observation wells in response to rainfall, as shown in plate 4, indicates that there is considerable recharge of the ground-water supply from rainfall. An average annual recharge of only 12 inches would amount to an average daily recharge of about 570,000 gallons to the square mile. However, on the assumptions that the sand throughout the area has a coefficient of permeability of 300, that the average natural hydraulic gradient is 3 feet to the mile, and that the average thickness of saturated sand is 20 feet, the amount of ground water flowing through a cross section of the sand 1 mile in width at right angles to the direction of movement is only about 18,000 gallons a day. Because only a small amount of ground water can enter a given area by lateral movement, it is obvious that most of the recharge must come from local precipitation. Moreover, the rate of withdrawal of water from one well is limited by the relatively low permeability of the sand and the small draw-down that is possible. Thus if a large supply of water is to be withdrawn from the shallow sands, it must be obtained by using a considerable number of wells distributed over a large area.

Quality of water

The analyses of waters from shallow wells are shown in the table. Most of these waters came from privately owned wells or from shallow test wells in Pasquotank County, in the vicinity of Elizabeth City, but some came from privately owned wells in Camden County.

By comparing the analyses of waters from shallow wells with those from wells of intermediate depth, it will be seen that they differ chiefly in chloride content. Except in well 118, which is very close to the salty Pasquotank River, the chloride content in most of the shallow wells ranges from less than 10 to less than 50 parts per million, and only a few samples contained from 50 to 90 parts. In contrast, the chloride content of the deeper wells is about 200 parts or more. The analyses of water samples from test wells 69 and 69a show only 15 parts per million of chloride. Thus in the area where the public water supply may be obtained, the chloride content is negligible.

The waters from some of the shallow wells contain excessive amounts of iron and are rather hard, owing to their content of calcium bicarbonate. Analyses of waters from test wells 64 and 65, in the Dismal Swamp, show that the waters contain excessive amounts of iron and are very hard, and that the hardness increases with depth. The logs of these test wells show that they penetrate several shell beds and that shells are especially numerous near the bottoms of the wells. Apparently the hardness of the water in these wells results from the calcium bicarbonate that has been dissolved out of the shell beds. Although test wells 64 and 65 penetrated the thickest shallow water-bearing beds standing considerably above sea level, this area was unsuited to ground-water development, owing to the hardness of the water.

As shown by the analyses of waters from test well 69, the hardness of the water and the iron content increased considerably during the pumping test, perhaps owing to some movement of ground water from the west, where the hard iron-bearing waters occur. However, the results of the pumping test indicated very slight movement of ground water, so that there may be lenses of shells in the vicinity of test well 69. Well 69a, put down by the city after the pumping test, yielded water that contains even more iron and is harder than the water from well 69.

The iron can be removed and the hardness reduced in the city filtration plant, and it is believed, according to the principles outlined, that the chloride content of the water will not increase materially.

Analyses of a few samples of water collected from streams are tabulated, and the location of the sampling points is shown on plate 1. These samples were not taken at times when the chloride content of the streams was noticeably high, but they show the increase in chloride content with depth, as in Sawyers Creek at sampling point 48, and show noticeable differences in chloride content between wet and dry periods, such as the decrease in chloride content of Knobbs Creek from September 20 to December 1, 1932, at sampling point 110. Some additional chloride data for Knobbs Creek are given on page 6.

Selection of site for shallow-well field

The selection of the site for the shallow-well field in which test well 69 was put down was dependent upon several factors - areal distribution, thickness, and water-bearing properties of the sands; altitude, shape, and fluctuations of the water table with special reference to the problem of contamination by salt water; and the quantity and quality of water available.

The region lying between Knobbs Creek and the Pasquotank River was found to be unsuited for extensive shallow ground-water development, because of the discontinuous nature of the shallow beds, their proximity to the Pasquotank River and Knobbs Creek, and the low altitude of the water table - with the resultant danger of contamination by salt water.

West of Knobbs Creek the thickest beds of sand and the highest water levels were encountered in test wells 64 and 65, in the Dismal Swamp, but analyses of samples from these wells showed that the ground water in this area is very hard, owing to numerous beds of marine shells, and contains a large amount of iron, although the chloride content of all the shallow wells west of the city is low.

In the area between Elizabeth City and that part of the Dismal Swamp which lies about 3 miles west of the city, the shallow sand is 20 to 30 feet thick and is continuous over many square miles. Near the city the altitude of the water table is so low that contamination by salt water was feared if a large quantity of water were pumped. The area selected as being most favorable is that which borders the Dismal Swamp on the east, where a large area is underlain by 25 to 30 feet of fine sand resting on a thick bed of clay. Although the sand here is not as thick as it is within the swamp, it is rather uniform and continuous over several square miles, the water table stands nearly as high as in the swamp, and the water is softer and contains less iron.

CONCLUSIONS AND RECOMMENDATIONS

The results of this investigation show that in the Elizabeth City area there are two sources of ground water that could be developed for supplying the city.

A pumping test on the sand bed lying between depths of 75 and 93 feet indicated that two or more properly constructed wells in this sand should yield the amount of water required for the public supply of Elizabeth City. The high chloride content of the water is the most objectionable feature of this source, but an auxiliary supply could be obtained from this sand for use during periods when the Knobbs Creek supply is unfit for use.

The required quantity of water could be obtained from shallow water-bearing beds, as in the area near test well 69. The water from this source would require treatment for removal of iron and reduction of hardness, but it has a very low chloride content, which would probably not increase appreciably with prolonged pumping. Only a small quantity of water can be withdrawn from any one well, because of the relatively low permeability of the sand and the small draw-down that is possible. Moreover, only a relatively small quantity of water can be withdrawn perennially from any one locality, even if any number of wells are sunk in that locality, because the rate of lateral percolation into any locality will unavoidably be slow. To obtain a large perennial supply it will be necessary to distribute the wells over a large area, because the supply must be derived chiefly from precipitation on the area rather than from lateral percolation into the area.

Records of wells of intermediate depth in the Elizabeth City area

(Location of wells is shown in plate 1)

No.	Depth (feet)	Diameter (inches)	Water-bearing bed: Depth to top (feet)	Water-bearing bed: Thickness (feet)	Water-bearing bed: Character of material	Depth to which well is cased (feet)	Depth to water level (feet)	Method of lift a/	Use of water b/
11	65±	1¼	60	18±	Sand	60±	Few	H	D
13	104	1¼	104	(?)	Sand and shells	99	do.	H	D
34	90	1¼	30±	10±	Fine sand	---	(?)	N	N
54	106	1¼	98	8	Coarse sand and shells	101	Few	H	D
55	110	1¼	100	10	Sand	105	do.	H	S
105	85	2	73	12	Fine sand	---	10±	P	D,B
114	93	6	75	18	Medium and coarse sand and shells	75	5	P	N
119	81	2	66	15	do.	76	3-4	P	C
120	162	6	11	9	Fine sand	---	---	N	N
126	88	2	(?)	(?)	Sand	83	Few	P	H,I
129	90	8	75	15	do.	75	10±	P	D,B

a/ H, Suction pump, hand operated; N, none; P, suction pump, power operated.
b/ B, Boiler feed; C, cooling; D, domestic; H, hotel; I, making ice; N, none; S, stock.

Owner, type and finish of well, and remarks

11 Wilson Temple. Jetted well with 5-foot screen. Adequate yield. See analysis.
13 Bruce Davis. Jetted well with 5-foot screen. Adequate yield. Water in sand between 64 and 71 feet overflowed at surface. See analysis.
34 H. C. Ferebee. Jetted well. No water below 40± feet. Water in fine sand between 30± and 40± feet would not clear up. See analysis.
54 Cecil Pritchard. Jetted well with 5-foot screen. Adequate yield. Also water between 60 and 65 feet but no water above 60 feet. See analysis.
55 Hershey Sawyer. Driven well with 5-foot screen. Adequate yield. Flows during winter. No sand or water above 100 feet. See analysis.
105 Camden High School. 5-foot well screen. Adequate yield. Jetted well.
114 Elizabeth City. Drilled well, open. See analyses and log. Yield 198 gallons a minute, draw-down 20 feet.
119 Crystal Ice & Coal Co. 5-foot well screen. Two wells, same depth and yield. See analysis. Yield 75-80 gallons a minute, draw-down 10-12 feet. Jetted well.
120 Norfolk Southern Railroad Co. Drilled well, open. See log. Small yield, no adequate supply of water below 100 feet.
126 Virginia Dare Hotel. Jetted well with 5-foot screen. Adequate yield. See analysis.
129 North Carolina State Normal School. Drilled well. Two wells, same depth and diameter, each yields 60 gallons a minute. See analysis and log.

Analyses of water from wells of intermediate depth in the Elizabeth City area

[Parts per million. Numbers at heads of columns correspond to those in preceding table and on pl. 1]

	11	13	54	55	105	119	126	129
Iron (Fe)	4.3	--	--	35	0.65	13	1.2	2.2
Calcium (Ca) (by turbidity)	140	--	--	100	70	26	70	50
Sodium and potassium (Na+K) (calculated)	82	--	--	--	--	159	0	179
Bicarbonate (HCO_3)	576	--	--	552	318	326	428	410
Sulphate (SO_4) (by turbidity)	2	--	--	3	1	1	1	2
Chloride (Cl)	120	119	138	84	108	181	190	136
Total dissolved solids (calculated)	675	--	--	--	--	561	--	562
Total hardness as $CaCO_3$	465	--	--	--	--	177	315	140
Date of collection (1932)	Dec. 7	Nov. 21	Nov. 21	Nov. 26	Dec. 1	Sept. 20	Dec. 14	Sept. 19

	114	114	114	114	114	114
Silica (SiO_2)	--	--	--	--	--	53
Iron (Fe)	0.44	3.4	4.1	1.4	0.4	.23
Calcium (Ca)	--	--	--	--	--	66
Magnesium (Mg)	--	--	--	--	--	47
Sodium (Na)	--	--	--	--	--	197
Potassium (K)	--	--	--	--	--	22
Bicarbonate (HCO_3)	276	464	468	464	470	469
Sulphate (SO_4)	--	--	--	--	a/1	3.3
Chloride (Cl)	180	298	302	295	302	308
Nitrate (NO_3)	--	--	--	--	.0	.10
Total dissolved solids	--	--	--	--	932	925
Total hardness as $CaCO_3$	285	352	345	354	330	b/358
Date of collection (1932)	Nov. 12	Dec. 12	Dec. 12	Dec. 12	Dec. 14	Dec. 19
Time of collection	--	2:21p.m.	3:33p.m.	4:18p.m.	9:35a.m.	12:15p.m.

a/ By turbidity. b/ Calculated.

Analysts: 11, 55, 105, 114, 126, E. W. Lohr, U. S. Geological Survey; 119, 129, K. T. Williams, U. S. Geological Survey; 13, 54, R. W. Luther, city chemist, Elizabeth City, N. C.

Records of shallow wells and test holes in the vicinity of Elizabeth City, N. C.

(Location of wells is shown in plate 1)

No.	Type a/	Depth (feet)	Diameter (inches)	Character of water-bearing material	Finish b/	Method of lift c/	Use of water d/	Altitude of reference point (feet): Above sea level	Altitude of reference point (feet): Above ground level
1	Dn	12	1¼	Fine sand and silt	D	H	D	-----	0
2	Dn	--	1¼	--------	D	H	D	-----	---
3	Dg	9	36± sq.	Blue clay with little fine sand	O	B	S	e/15.65	3.2
4	Dg	10±	24± sq.	--------	O	W	D	e/15.79	3.3
5	Dn	11½	1¼	--------	D	N	N	e/11.40	.6
6	Dg	12.1	30 sq.	--------	O	W	D,S	e/15.99	2.1
7	Dn	17	1¼	Fine sand	D	H	D	-----	---
8	Dg	9.7	24	--------	O	W	D	e/12.24	.2
9	Dn	11.7	1¼	--------	D	N	N	e/10.96	.7
10	Dg	12½	30± sq.	Fine sand and silt	O	B	D	e/14.36	3.0
12	J	20	2	do.	O	N	N	-----	---
14	J	22	2	Fine to medium sand and silt	O	N	N	-----	---
15	Dn	--	1¼	--------	D	H	D	-----	---
16	Dg	8.8	---	--------	O	W	S	-----	2.0
17	Dg	7.7	---	--------	O	W	D	-----	2.2
18	Dn	--	1¼	--------	D	H	D,S	-----	---
19	Dg	12½	24±	Coarse sand	O	B	D,S	-----	3.4
21	Dn	--	1¼	Fine sand	D	H	D,S	-----	---
23	Dg	5.9	---	--------	O	N	N	-----	3.1
24	Dn	--	1¼	--------	D	H	D	-----	---
25	Dg	10.4	24	--------	O	-	D	-----	1.0
27	Dg	11½	---	Sandy loam	O	W	D,S	-----	3.3
28	Dg	5½	---	White sand	O	W(?)	D,S	-----	2.3
29	Dg	8.8	36 sq.	Fine sand	O	(?)	D,S	-----	3.2
31	Dn	--	1¼	--------	D	H	D	-----	---
32	Dg	10.6	---	Fine sand	O	B	S	-----	3.4
33	Dg	9.4	---	Reported coarse sand	O	-	S	-----	2.1
35	Dg	11	---	Sand	O	W	S	-----	2.5
36	Dn	12	---	do.	D	H	D	-----	---
37	Dg	8.2	---	Fine sand	O	B	D,S	-----	1.8
39	Dn	--	1¼	Sand	D	H	D	-----	---
40	Dg	7.6	24 sq.	Fine sand	O	B	D,S	e/12.48	2.4
41	J	42	2	Fine to medium sand	O	N	N	-----	---
42	Dg	8 or 10±	24	Fine sand	O	W	D	e/12.64	2.7
43	Dg	8	24	--------	O	W	D,S	e/13.60	2.6
44	Dg	9.1	---	Fine sand	O	W	D,S	-----	1.3
45	Dg	8.3	24 sq.	--------	O	W	D,S	-----	2.7
46	Dg	9.9	24	Fine and medium sand	O	W	D,S	-----	.0
47	Dg	7.3	36 sq.	do.	O	W	D,S	-----	2.9
49	Dg	10-12	24	--------	O	B	S	-----	3.2
50	Dg	10-12	---	--------	O	W	D,S	-----	2.7
51	Dg	8-10	---	--------	O	W	D,S	-----	2.9
52	Dg	10-12	---	Fine sand	O	W	D,S	-----	3.0
53	Dg	10	---	Silt and clay	O	B	D,S	e/15.40	3.2
56	Dn	14.7	1¼	--------	D	H	D,S	e/14.60	2.5
57	Dn	13	1¼	--------	D	H	D,S	f/14.65	1.9
58	Dg	8.6	24	Sand	O	W	D,S	e,f/13.01	1.9
59	J	30	2	Fine sand	O	N	N	-----	---
60	Dg	7½	24 sq.	Silt and sand	O	W	D,S	f/13.40	4.0
61	Dn	11.8	1¼	Fine sand	D	H	S	f/12.30	2.4
62	J	30	1¼	do.	S	H	T	-----	---
63	Dg	3.7	24	--------	O	W	S	f/16.01	2.8
64	J	65	1¼	Fine sand	S	H	T	f/17.12	.9
65	J	65	1¼	do.	S	H	T	f/17.37	.4
66	J	32	1¼	do.	S	H	T	f/17.05	.9
67	Dn	10	1¼	do.	D	N	N	f/16.12	.3
68	J	57	1¼	do.	S	H	T	-----	---
69	Dd	30	9	do.	G	P	T	-----	---
70	Dn	13	1¼	do.	D	H	D	f/15.85	2.4
71	J	30	2	do.	O	N	N	-----	---
72	Dg	13.3	---	--------	O	W	D,S	f/19.01	2.7
73	Dn	18	1¼	do.	D	H	D	f/ 9.59	2.2
74	J	30	2	do.	O	N	N	-----	---
75	Dg	8	24	--------	O	B	D	f/ 8.07	1.9
76	Dg	10.6	---	--------	O	B	D	f/13.80	2.8
77	J	30	1¼	Fine sand	S	H	T	-----	---
78	J	30	1¼	Fine and medium sand	S	H	T	-----	---
79	Dg	8½	---	--------	O	W	D,S	f/13.01	2.5
80	Dg	11	24	--------	O	B	D,S	f/11.81	2.8
81	J	30	2	Fine sand	O	N	N	-----	---
82	Dn	12.8	1¼	--------	D	H	S	f/13.36	2.2
83	Dg	10-12	24	--------	O	B	D	f/11.80	3.0
84	Dn	15	1¼	--------	D	H	D,S	-----	---
85	Dg	--	---	--------	O	W	D,S	f/13.71	3.1
86	Dg	10	---	--------	O	W	D,S	f/17.26	2.7
87	Dg	10	24	--------	O	N	N	f/15.04	2.4
88	J	41½	1¼	Fine sand	S	H	T	-----	---
89	J	45	1¼	do.	S	P	T	-----	---
90	Dn	--	1¼	--------	D	P	D	-----	---
91	Dn	16	1¼	--------	D	H	D	f/16.19	2.3
92	Dg	--	---	--------	O	W	S	-----	2.2
93	Dg	10-12	---	--------	O	W	S	f/15.96	2.3
94	Dn	--	1¼	--------	D	H	-	f/16.67	5.0
95	Dg	13.7	24	--------	O	W	D,S	f/15.68	3.5
96	Dn	14	1¼	--------	D	H	D,S	-----	---
97	Dn	16	1¼	--------	D	H	D,S	f/15.46	2.7
98	Dn	12½	1¼	--------	D	H	D,S	f/14.89	2.5

See footnotes at end of table.

Records of shallow wells and test holes in the vicinity of Elizabeth City, N. C. - Continued

No.	Type a/	Depth (feet)	Diameter (inches)	Character of water-bearing material	Finish b/	Method of lift c/	Use of water d/	Altitude of reference point (feet) Above sea level	Above ground level
99	Dn	--	1¼	--------	D	H	D,S	f/16.82	5.0
100	Dn	15.6	1¼	--------	D	H	D,S	e/ 9.08	2.7
101	Dg	9½	24	Fine sand and loam	O	W	D,S	e/12.33	2.0
102	Dn	--	1¼	do.	D	N	N	e/ 2.58	.6
106	Dn	15-20	1¼	--------	D	H	D	-----	---
108	Dn	--	1¼	--------	D	H	D	-----	---
109	Dg	7½	24	--------	O	W	S	e/ 7.79	1.7
113	Dg	10½	24	--------	O	W	D,S	e/ 6.78	1.0
115	Dn	10½	1¼	--------	D	H	D,S	f/ 9.26	.7
116	Dn	10½	1¼	--------	D	H	D,S	f/ 5.72	2.2
117	Dn	15±	1¼	--------	D	P	D,I	-----	---
118	Dn	13±	1¼	--------	D	P	I	-----	---
121	Dg	9.7	24	--------	O	W	D	f/10.94	2.0
122	J	22	1¼	Fine sand	S	H	T	-----	---
123	Dn	10	1¼	--------	D	H	D	f/11.28	2.2
124	Dg	8-10	---	--------	O	W	D	f/18.98	3.0
125	Dn	12½	1¼	--------	D	H	D	f/ 8.20	2.2
127	Dn	two 18, two 20	1¼	Sand	D	P	D,I	-----	---
128	Dg	10	24	--------	O	B	D,S	f/15.76	3.5
130	Dg	7.4	24	--------	O	B	D	f/12.37	2.1
131	Dn	12	1¼	Fine sand	D	H	D	-----	---
132	J	30	2	do.	O	N	N	-----	---
133	Dg	10-12	24	--------	O	B	D,S	f/10.68	1.5
134	Dg	10-12	24	--------	O	B	S	f/13.61	2.5
135	Dn	14-15	1¼	--------	D	H	D	-----	---
136	Dn	12-15	1¼	--------	D	H	D	-----	---
137	Dn	10½	1¼	Fine sand	D	H	D	-----	---
138	Dg	6.7	24	do.	O	B	S	-----	4.0
139	Dg	7½	---	--------	O	-	D	-----	---
140	Dg	7½	36 sq.	Fine sand	O	B	D	-----	2.9

a/ Dd, drilled; Dg, dug; Dn, driven; J, jetted.
b/ D, screened drive point; G, slotted casing, gravel packed; O, open; S, 5-foot well screen.
c/ B, bucket and rope; H, pitcher pump, hand operated; N, none; P, suction pump, power operated; W, well sweep, see pl. 3, B.
d/ D, domestic; I, industrial; N, none; S, stock; T, test purposes.
e/ Altitude determined instrumentally by J. C. Overman.
f/ Altitude determined instrumentally by J. P. Clawson.

Owner and remarks

1 R. L. Hinton. See analysis.
2 Issac Meggs. See analysis.
3 Paul Bros.
4 M. E. Russel estate (Dan Russel, tenant).
5 Elizabeth City (Sycamore well). Put down by Public Utilities Commission for observation. Near large sycamore tree.
6 Dennis Overman, Jr.
7 Berea Baptist Church. See analysis.
8 Bob Sawyer (R. M. Voliva, tenant).
9 Elizabeth City (Possum Quarter well). Put down by Public Utilities Commission for observation. On south side of Possum Quarter road on rise above the river.
10 M. P. Jennings (J. L. Stafford, tenant).
12 Temporary test hole. See log.
14 Do. do.
15 Owner unknown. See analysis.
16 Ike Williams.
17 George Williams.
18 D. Gilbert. See analysis.
19 L. T. Turner. Coarse sand underlies small areas in this vicinity. See physical properties of sand sample 20.
21 Owner unknown. See analysis.
23 Lem Turner. Unused well.
24 Trafton (tenant).
25 Mrs. M. Wiggam.
27 G. I. Sawyer.
28 John Sawyer. White sand at bottom, dark silt and clay above. See analysis.
29 Do. See physical properties of soil sample 30, taken in road cut opposite well.
31 A. H. Wallace.
32 H. C. Ferebee. There is also a driven well 20 feet deep ending in sand.
33 L. J. Jeralds. Top, silt and clay; middle, fine sand; bottom, coarse sand. A driven well nearby penetrated 4 feet of the coarse sand.
35 Upton Produce Co. On narrow ridge 3 to 4 feet above the surrounding land. Ridge is reported to consist of sand down to a depth of at least 18 feet, but adjoining land contains considerable silt or clay. Sand ridge may be an old sandbar.
36 Harry Ferbe. Reported all sand. See analysis.
37 B. F. Alston. Reported all fine sand. Sand flows into well.
39 R. L. Whaley. Reported all sand. See analysis.
40 Mrs. D. S. Davis. Water reported to have bad taste, due presumably to inflow of surface water from barnyard. See analysis.
41 Temporary test hole. See log.
42 E. V. Hinton (?).
43 G. D. Pritchard.
44 W. O. DeFord. Blue silt at surface, white sand at bottom. See analysis.
45 Forehan (Frank Sawyer, tenant).
46 S. E. Overby. Sand underlain by clay. See physical properties of sand sample 46.
47 R. L. Bray. Reported sand from top to bottom. See analysis.
49 Auley Farm.
50 Layden (Chambers, tenant).
51 John Butts.
52 Noah Bright (C. C. Bright, tenant). Reported upper 4 feet hard clay, rest fine sand.

Owner and remarks - Continued

53 J. G. Miller. No sand reported.
56 Roy MacPherson. See analysis.
57 S. Jennings (Arthur Brooks, tenant).
58 J. B. Jennings. Upper 4 to 5 feet reported to be clay, rest sand.
59 Temporary test hole. See log.
60 C. L. Harris. See analysis.
61 H. F. Sample.
62 Temporary test well. See log and analysis.
63 S. W. Morgan.
64 Temporary test well. Milepost 45 on Suffolk & Carolina Railroad. See log and analysis.
65 Do. do 44 do. do.
66 Do. Along Suffolk & Carolina Railroad. See log and analysis.
67 Elizabeth City (Suffolk & Carolina Railroad well). Put down by Public Utilities Commission for observation. Within 50 feet of test well 68.
68 Temporary test well. Summarizes data obtained from two jetted and one driven well described in log. See physical properties of sand samples, and analysis.
69 Elizabeth City. See description of well and pumping test, and analysis; also see analysis of water from well 69a, near well 69. See water levels in well 69B, 1,000 feet east of well 69.
70 Paul Ives.
71 Temporary test hole. See log, and physical properties of sand sample.
72 J. C. Overman. See analysis.
73 S. B. Carter.
74 Temporary test hole. See log.
75 Lowry.
76 G. R. Harold.
77 Temporary test well. See log and analysis.
78 Do. See log.
79 Grandy Bright.
80 Mrs. J. R. Bright.
81 Temporary test hole. See log.
82 Warner Reddick.
83 C. D. Harris.
84 Joe Tuttle. See analysis.
85 E. P. Cartwright.
86 Owner unknown. See analysis.
87 Miles Bright (Mrs. Gray, tenant).
88 Temporary test well. See log.
89 Foreman Stock Farm. Reported to yield about 5 gallons a minute. See analysis.
90 J. J. Watson. See analysis.
91 Foreman (Ricks, tenant).
92 Presley Harris.
93 Frank Alberson.
94 Vacant house.
95 P. C. Harris.
96 Mark Worden. See analysis.
97 Henry Franklin.
98 C. Overton.
99 C. L. Robinson (G. L. Baker, tenant).
100 Joe Winslow.
101 H. C. Ferrell. See analysis.
102 Elizabeth City (lower brick house well). Put down by Public Utilities Commission for observation well. Near brick house landing, within 100 feet of the river. See analysis.
106 Fred Markham. See analysis.
108 N. H. Caroon. do.
109 N. H. Caroon (Davis, tenant).
113 C. B. Pritchard.
115 Martin Pritchard.
116 T. Cooper (Sam Barnes, tenant).
117 Elizabeth City Hosiery Co. Two groups of wells, group of 6 spaced 15 to 20 feet apart, group of 4 spaced 10 to 12 feet apart; combined yield reported 80 gallons a minute. Use 15,000± gallons a day, softened and also supply Avalon and Pasquotank Hosiery Co. See analysis.
118 Crystal Ice & Coal Co. Water sample a composite from 6 of 8 similar wells. See analysis.
121 C. S. Armstrong.
122 Temporary test well. See log, physical properties of sand sample, and analysis.
123 T. Commander.
124 Charles Harris.
125 Joe Winslow.
127 Wright Purity Ice & Fuel Co. Combined yield of 4 similar wells reported to be about 18 gallons a minute. Log, clay 10 feet, sand and clay 2 feet, sand 8 feet. Makes clear ice.
128 Ike Meekins.
130 Paul F. White.
131 Do. About 20 feet from well 130. See analysis.
132 Temporary test hole. See log.
133 M. B. Sample.
134 C. B. Harold.
135 Grocery store. See analysis.
136 Owner unknown. do.
137 Nathan S. Leary (G. Chapel, tenant). See analysis.
138 Do. do. Reported all fine sand except for 4 feet of clay below top soil. See analysis.
139 Dr. Peters. See analysis.
140 J. L. Brock. Sand with some silt down to 12-15 feet. See analysis.

Depth to water levels below reference points in shallow wells in the vicinity of Elizabeth City, N. C.

Well No.	Date	Water level (feet)
1	----	2-3±
3	Sept.28, 1932	10.1
	Oct. 8	9.93
	26	9.9
	Nov. 26	5.86
	28	6.05
	Dec. 15	4.64
	Jan. 19, 1933	4.68
	Apr. 6	5.40
4	Sept.28, 1932	10.75
	Nov. 25	8.24
	28	8.34
	Dec. 15	5.06
	Jan. 19, 1933	4.75
	Apr. 6	6.20
5	Oct. 8, 1932	6.36
	Nov. 26	2.55
	28	2.51
	Dec. 15	1.00
	Jan. 19, 1933	1.01
	Apr. 6	1.50
6	Nov. 28, 1932	10.50
	Dec. 15	10.16
	Jan. 19, 1933	9.02
	Apr. 6	8.48
8	Nov. 28, 1932	7.87
	Dec. 15	7.87
	Jan. 19, 1933	6.88
9	Nov. 25, 1932	8.05
	28	8.03
	Dec. 15	7.88
	Jan. 19, 1933	7.08
10	Nov. 28, 1932	12.50
	Dec. 15	11.47
	Jan. 19, 1933	9.46
	Apr. 6	7.36
16	Dec. 1, 1932	5.87
	16	4.42
17	Dec. 1, 1932	7.47
	16	4.29
19	Dec. 12, 1932	8.28
	16	6.89
23	Dec. 2, 1932	6.74
	16	5.38
25	Dec. 2, 1932	5.37
	16	3.10
27	Sept.19, 1932	12.3±
	Dec. 1	12.37
	16	11.68
28	Dec. 1, 1932	5.32
	16	4.04
29	Dec. 1, 1932	8.95
	15	7.65
32	Sept.19, 1932	8
	Dec. 1	9.32
	15	8.77
33	Dec. 1, 1932	9.20
35	Dec. 2, 1932	8.11
	16	7.03
37	Dec. 2, 1932	6.51
	16	4.90
40	Nov. 25, 1932	4.84
	28	4.69
	Dec. 15	3.53
	Jan. 19, 1933	3.92
42	Nov. 26, 1932	5.31
	28	4.98
	Dec. 15	4.14
	Jan. 19, 1933	4.56
	Apr. 6	5.67
43	Nov. 25, 1932	7.38
	28	6.57
	Dec. 15	5.10
	Jan. 19, 1933	4.46
44	Dec. 1, 1932	8.35
	16	6.90
45	Dec. 2, 1932	4.73
	16	3.55
46	Dec. 2, 1932	3.36
	16	1.85
47	Dec. 2, 1932	5.17
49	Oct. 8, 1932	12.2
	26	10.7
	Dec. 8	8.40
	15	6.57
	Jan. 19, 1933	7.26
50	Sept.27, 1932	12.3
	Oct. 8	12.15
	26	12.0
	Dec. 8	8.39
	15	4.78
50	Jan. 19, 1933	6.21
	Apr. 7	7.32
51	Sept.27, 1932	9.7
	Oct. 8	9.7
	26	9.7
	Dec. 8	8.47
	15	6.42
	Jan. 19, 1933	5.06
52	Sept.27, 1932	12.7
	Oct. 8	12.0
	26	11.5
	Dec. 8	11.15
	15	9.87
	Jan. 19, 1933	9.88
	Apr. 8	9.88
53	Sept.28, 1932	12.3
	Oct. 8	12.6
	26	12.2
	Nov. 26	11.15
	28	11.10
	Dec. 15	9.67
	Jan. 19, 1933	6.32
	Apr. 6	7.19
56	Nov. 28, 1932	9.07
	Dec. 15	7.53
	Jan. 19, 1933	5.42
57	Jan. 6, 1933	3.32
	18	2.78
58	Nov. 28, 1932	7.74
	Dec. 15	6.12
	Jan. 11, 1933	4.31
	18	3.98
	Apr. 6	5.16
60	Nov. 28, 1932	7.39
	Dec. 15	5.90
	Jan. 11, 1933	6.52
	18	6.29
	Apr. 6	7.32
61	Jan. 6, 1933	5.51
	18	4.78
63	Jan. 11, 1933	6.40
	18	5.64
64	Jan. 18, 1933	1.42
65	Jan. 18, 1933	1.44
66	Jan. 18, 1933	1.61
67	Oct. 8, 1932	8±
	Nov. 26	3.95
	28	3.80
	Dec. 15	1.68
	22	1.84
	Jan. 5, 1933	2.13
	11	1.96
	18	1.78
	Apr. 6	2.55
a/69b		
70	Jan. 6, 1933	4.47
	18	3.77
72	Nov. 28, 1932	12.17
	Dec. 15	10.84
	Jan. 11, 1933	10.14
	18	9.36
	Apr. 6	10.46
	June 11, 1934	10.62
	18	11.27
	26	11.85
	July 4	12.1
	10	11.50
	18	11.04
	Aug. 2	10.94
	14	12.1
	23	12.46
	30	11.53
	Sept. 5	11.40
	13	9.06
73	Jan. 6, 1933	3.61
	18	3.30
75	Jan. 6, 1933	4.39
	18	3.95
	Apr. 6	4.87
76	Jan. 6, 1933	4.51
	18	3.93
	Apr. 7	5.02
79	Nov. 26, 1932	6.64
	Dec. 15	4.0
	Jan. 11, 1933	4.90
	19	4.78
	Apr. 7	6.17
80	Jan. 6, 1933	6.29
	11	6.57
	18	6.27
82	Jan. 6, 1933	4.23
82	Jan. 19, 1933	3.70
83	Jan. 6, 1933	6.66
	11	6.68
	19	5.95
	Apr. 7	7.33
85	Jan. 6, 1933	6.35
	11	5.90
	19	5.45
	Apr. 7	6.65
86	Nov. 26, 1932	9.68
	Dec. 15	5.86
	Jan. 11, 1933	6.63
	19	6.48
87	Jan. 6, 1933	4.87
	11	4.60
	19	4.45
	Apr. 7	5.86
91	Jan. 6, 1933	6.05
	19	4.41
92	Sept. 8, 1932	10.88
	26	11.0
	Dec. 8	9.58
	15	9.19
	Jan. 19, 1933	7.00
93	Jan. 6, 1933	4.49
	11	4.21
	19	4.09
94	Jan. 11, 1933	6.50
	19	6.10
95	Jan. 11, 1933	6.62
	Apr. 7	6.43
97	Jan. 11, 1933	6.55
	19	5.48
98	Jan. 11, 1933	7.98
	19	7.26
99	Jan. 11, 1933	6.48
	19	6.40
100	Nov. 28, 1932	4.77
	Dec. 15	3.66
	Jan. 19, 1933	3.76
101	Nov. 25, 1932	8.39
	28	8.40
	Dec. 15	7.05
	Jan. 19, 1933	4.81
	Apr. 6	6.77
102	Nov. 25, 1932	1.61
	28	2.01
	Dec. 15	.62
	Jan. 19, 1933	1.45
109	Nov. 28, 1932	4.60
	Dec. 15	2.51
	Jan. 19, 1933	4.06
	Apr. 6	4.70
113	Dec. 15, 1932	5.73
	Jan. 19, 1933	4.08
	Apr. 6	5.33
115	Jan. 6, 1933	3.05
	18	2.25
116	Jan. 6, 1933	3.83
	18	3.52
121	Jan. 6, 1933	5.87
	18	5.23
123	Jan. 7, 1933	3.68
	18	3.23
124	Jan. 11, 1933	9.71
	18	9.08
	Apr. 8	10.10
125	Jan. 1, 1933	3.21
	18	2.83
128	Jan. 6, 1933	6.31
	19	5.96
130	Nov. 28, 1932	4.34
	Dec. 15	2.99
	Jan. 6, 1933	4.03
	19	3.49
	Apr. 8	5.53
133	Jan. 6, 1933	3.51
	11	3.34
	19	2.58
134	Jan. 11, 1933	4.32
	19	4.31
138	Oct. 8, 1932	9.8
	26	9.88
	Dec. 7	6.94
	Jan. 19, 1933	5.58
	Apr. 8	6.95
140	Sept.27, 1932	9.2
	19	9.4
	Oct. 26	8.5
	Dec. 7	6.61
	Jan. 19, 1933	5.03

a/ See pl. 4.

Analyses of waters from shallow wells in the Elizabeth City area

[Parts per million. Numbers of analyses correspond to numbers of wells on plate 1 and in the preceding table of well data]

No.	Depth for special samples (feet) a/	Date of collection	Total dissolved solids (calculated)	Iron (Fe)	Calcium (Ca) (by turbidity)	Sodium and potassium (Na+K) (calculated)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Total hardness as $CaCO_3$
		1932								
1	--	Nov. 25	--	0.42	1	--	10	2	9.0	--
2	--	Dec. 1	--	3.4	--	--	--	--	7.0	--
7	--	Nov. 26	--	6.0	70	--	222	4	36	--
15	--	Dec. 2	--	.26	1	--	29	3	16	--
18	--	Dec. 1	--	.14	7	--	5.0	1	21	--
21	--	Dec. 2	--	.26	1.5	--	12	13	17	--
24	--	Dec. 2	--	3.9	--	--	--	--	16	--
28	--	Dec. 1	--	.26	--	--	--	--	29	--
31	--	Dec. 1	--	2.2	5	--	12	6	11	--
33	--	Dec. 1	--	.05	--	--	--	--	57	--
36	--	Dec. 2	--	--	--	--	--	--	75	--
39	--	Dec. 2	--	.27	18	--	47	10	23	--
40	--	Nov. 25	--	.20	5	--	10	16	18	--
44	--	Dec. 1	--	.05	1	--	14	2	9.0	--
47	--	Dec. 2	--	.47	6	--	17	14	36	--
56	--	Nov. 28	--	5.7	10	--	46	14	69	--
60	--	Nov. 28	--	1.9	10	--	70	18	40	--
		1933								
62	12	Jan. 10	--	7.2	30	--	14	80	59	144
62	25	Jan. 10	--	.40	18	--	74	10	32	66
64	15	Jan. 16	--	22	130	--	462	2	18	398
64	25	Jan. 16	--	48	130	--	468	2	17	412
65	15	Jan. 12	--	14	--	--	--	--	--	--
65	30	Jan. 12	--	28	80	--	308	2	11	292
65	55	Jan. 16	--	20	120	--	424	2	10	352
66	15	Jan. 10	--	2.4	18	--	84	2	42	75
66	25	Jan. 10	--	.24	80	--	370	2	14	292
68	10	Jan. 5	--	1.1	7	--	27	6	4.0	20
68	17	Jan. 5	--	.60	9	--	37	8	12	30
68	25	Jan. 17	--	9.9	28	--	110	6	12	88
68	30	Jan. 17	--	7.6	75	--	298	2	12	218
69	--	July 5	--	6.4	16	--	100	50	14	80
69	--	July 6	--	5.2	35	15	181	2	15	140
69	--	July 7	--	6.8	45	11	196	2	15	159
69	--	July 31	--	8.4	45	13	204	5	15	165
69	--	Aug. 5	--	9.3	40	13	188	5	15	153
b/69a	--	Aug. 15	--	12	60	19	286	1	14	213
c/69a	--	Aug. 15	--	15	65	20	314	1	15	237
		1932								
72	--	Nov. 28	--	.04	9	--	17	6	31	--
		1933								
77	15	Jan. 10	--	1.9	4	--	36	3	8.0	14
77	30	Jan. 10	--	.60	8	--	63	3	9.0	38
78	15	Jan. 9	--	3.3	8	--	30	24	39	39
78	25	Jan. 9	--	1.7	6	--	32	5	13	14
		1932								
79	--	Nov. 26	--	1.3	18	--	1	50	75	--
84	--	Dec. 8	--	11	--	--	--	--	28	--
86	--	Nov. 26	--	.22	18	--	14	20	54	--
		1933								
88	15	Jan. 17	--	28	50	--	253	4	8.0	240
88	25	Jan. 17	--	10	80	--	343	3	7.0	262
		1932								
89	--	Sept.19	263	10	55	22	293	1	11	208
89	--	Nov. 26	--	7.5	55	--	296	4	10	--
90	--	Nov. 26	--	8.7	16	--	124	4	41	--
96	--	Dec. 8	--	5.8	--	--	--	--	91	--
101	--	Nov. 25	--	.01	18	--	10	5	84	--
102	--	Sept.20	119	.10	16	13	11	45	29	69
106	--	Nov. 26	--	3.6	24	--	58	28	40	--
108	--	Nov. 25	--	.25	9	--	24	8	13	--
117	--	Dec. 21	--	4.1	9	--	30	60	85	54
118	--	Sept.20	526	.15	48	147	84	90	206	134
		1933								
122	15	Jan. 9	--	.04	2	--	10	1	7.0	14
122	22	Jan. 9	--	.04	4	--	23	2	8.0	20
		1932								
131	--	Nov. 29	--	10	--	--	--	--	23	--
134	--	Dec. 7	--	3.0	--	--	--	--	7.0	--
135	--	Dec. 7	--	3.4	--	--	--	--	38	--
136	--	Sept.19	87	8.0	10	17	74	2	14	45
137	--	Sept.19	142	2.8	6	13	42	32	39	94
138	--	Dec. 7	--	1.0	--	--	--	--	8.0	--
139	193	Sept.19	193	.73	14	51	11	50	71	50

All analyses by E. W. Lohr except nos. 89, 102, 118, 136, 137, and 139, which were made by K. T. Williams.

a/ Depth to the bottom of the 5-foot screen when jetting was stopped for a time to permit collection of samples.

b/ 2-inch well, 30 feet deep. 285 feet southwest of well 69. Sample collected as soon as water cleared.

c/ Sample collected after 100 gallons had been pumped after collection of first sample.

Analyses of surface water

Analyses of waters from streams in the Elizabeth City area

[Parts per million]

No.	Date of collection (1932)	Color	Total dissolved solids (calculated)	Iron (Fe)	Calcium (Ca) (by turbidity)	Sodium and potassium (Na+K) (calculated)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Total hardness as $CaCO_3$
26	Dec. 1	---	---	---	---	---	---	---	635	---
38	Dec. 2	---	---	---	---	---	---	---	19	---
48	do.	---	---	---	---	---	---	---	100	---
48	do.	---	---	---	---	---	---	---	580	---
48	do.	---	---	---	---	---	---	---	1,005	---
103	Sept.20	205	947	0.58	20	286	11	70	525	201
107	do.	150	528	.82	10	150	18	25	299	136
107	Dec. 1	---	---	---	---	---	---	---	22	---
107	do.	---	---	---	---	---	---	---	76	---
110	Sept.20	140	1,158	.71	25	366	30	80	638	212
110	Dec. 1	---	---	1.5	---	---	---	---	126	---
110	do.	---	---	2.3	---	---	---	---	232	---
111	Sept.20	100	1,559	1.5	30	506	30	100	871	256
112	do.	100	1,598	1.6	30	556	28	110	888	180

Source of sample, depth below surface at which it was taken, and analyst

No.	Source
26	Pasquotank River at shipyard ferry, at surface. Analyst, E. W. Lohr.
38	Sawyers Creek, 0.3 mile southeast of Hastings Corner, 0.5 foot below surface. Analyst, E. W. Lohr.
48	Sawyers Creek at bridge 0.6 mile west of Belcross, at surface. Analyst, E. W. Lohr.
48	do. 0.5 foot below surface. Analyst, E. W. Lohr.
48	do. 4.5 feet below surface (at bottom). Analyst, E. W. Lohr.
103	Pasquotank River at brickhouse landing, near surface. Analyst, K. T. Williams.
107	Knobbs Creek at Creek Road bridge, near surface. Analyst, K. T. Williams.
107	do. do. Analyst, E. W. Lohr.
107	do. 5.0 feet below surface. Analyst, E. W. Lohr.
110	Knobbs Creek at intake of public supply, at surface. Analyst, K. T. Williams.
110	do. do. Analyst, E. W. Lohr.
110	do. 5.0 feet below surface. Analyst, E. W. Lohr.
111	Knobbs Creek about 75 feet above tide dam, near surface. Analyst, K. T. Williams.
112	Knobbs Creek just below dam, near surface. Analyst, K. T. Williams.