REPORTS OF THE
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
STATE OF NEW JERSEY

In cooperation with the United States Geological Survey--
Division of Ground Water--O. E. MEINZER, *Geologist in Charge*

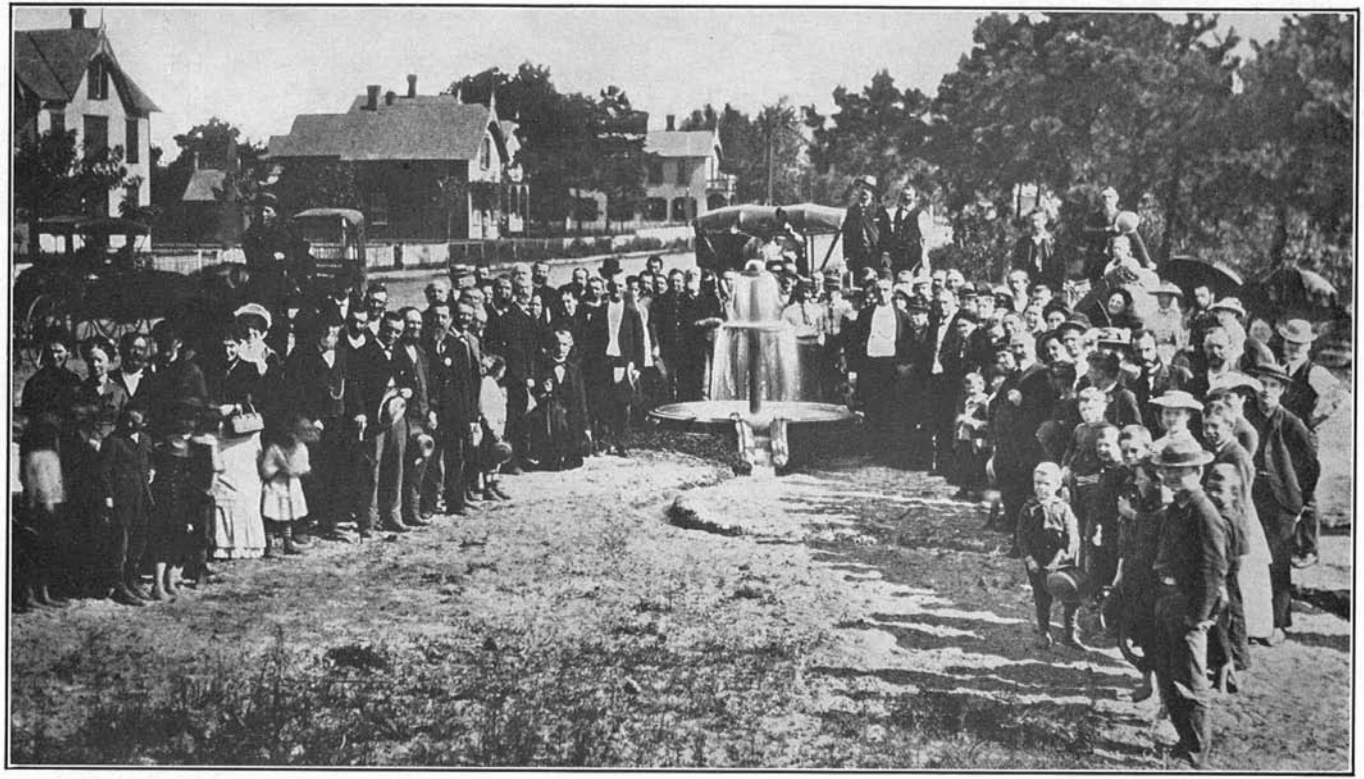
BULLETIN 35

GROUND WATER SUPPLIES *in the* VICINITY *of* ASBURY PARK

BY

DAVID G. THOMPSON

Published 1930



The completion of the first artesian well drilled in Ocean Grove. This is believed to be the first ever driven in the Asbury Park region.

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STATE HOUSE ANNEX, TRENTON, N. J.

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FOREWORD

This is one of several reports on the underground water resources of selected areas of New Jersey, made in cooperation with the United States Geological Survey, by the Division of Waters, H. T. Critchlow, Chief.

The report was prepared by David G. Thompson of the Federal Survey, but its publication has been somewhat delayed. In July, 1929, the work and personnel of the Division of Waters was transferred from the Department of Conservation and Development to the State Water Policy Commission, but since the investigations covered by this report were completed and the report written before this transfer, it is published as a report of the Department of Conservation and Development.

Other reports on the Camden area and the Canoe Brook area will be published shortly.

HENRY B. KÜMMEL,
State Geologist and Director.

March 1, 1930.

GROUND WATER SUPPLIES IN THE VICINITY OF ASBURY PARK

INTRODUCTION

Observations on ground water conditions in the vicinity of Asbury Park have been made by the writer since September, 1924. The study has involved principally the formation which supplies the wells of the Avon-by-the-Sea Water Department, but some information has been obtained in regard to other water-bearing formations in the region.

In collecting the field data the writer has enjoyed the cooperation of officials and employees of the water departments of Asbury Park, the Ocean Grove Association, Avon-by-the-Sea, and Belmar, of the Monmouth County Water Company, of Mr. Addison H. Riggs and the Casino Ice Company, owners of private wells, and of the Layne-New York Company which installed wells for the Borough of Avon and Monmouth County Water Company.

WATER SUPPLIES OF THE REGION

Asbury Park.—The Water Department of Asbury Park supplies part of the City of Asbury Park and the portion of Neptune Township which adjoins it. The water is obtained from eight wells situated in an area of only about 150 by 150 feet. Three of the wells are 600 feet deep, with casings from 4½ to 6 inches in diameter and screens 3½ to 4 inches in diameter. The other five wells are from 1,050 to 1,135 feet deep, with casings ranging in diameter from 6 to 10 inches and screens from 3½ to 8 inches. The wells are pumped by air lift. The water from the deeper wells contains so much iron that it must be filtered, and the use of the air lift aids in the process of aeration to precipitate the iron. For this purpose the water is pumped into an open concrete reservoir. It is distributed by direct pumpage into the mains, passing through pressure filters in the process. The system has no storage reservoirs or standpipe except the aerating reservoir, the capacity of which is 203,000 gallons. It is therefore necessary that the well capacity be sufficient to meet the peak loads. In April, 1926, the Board of Conservation and Development granted the City the right to divert an additional two million gallons from the deep horizon. The system has an emergency connection with the Monmouth County Water Company.

Monmouth County Water Company.—The Monmouth County Water Company, a subsidiary of the American Water Works and Electric Company, supplies part of Asbury Park, Ocean and Neptune Townships, and the boroughs of Bradley Beach, Neptune City, and Interlaken. It obtains water from two localities designated respectively as the Jumping Brook and Whitesville pumping station. The Jumping Brook station is located on the stream of that name, about three miles southwesterly from Asbury Park. A large part of the supply is surface water pumped from Jumping Brook. At this station there are also two 8-inch wells 1,000 feet deep. The minimum yield of the stream is estimated at 900,000 gallons a day and of the two wells at 1,600,000 gallons a day. At the Whitesville station, located on the western outskirts of Asbury Park, the water is obtained entirely from wells. At present the water is obtained from two Layne wells. One is 610 feet deep with 40 feet of 13-inch screen between the depths of 178 and 218 feet and 67 feet of 8-inch screen between the depths of 538 and 605 feet. The yield of this well is approximately 300 gallons a minute. The other well is 981 feet deep with 60 feet of 8-inch screen from 910 to 970 feet. This well yields about 900 gallons a minute. The two wells are pumped with Layne turbine pumps. At the Whitesville field there are also six old 600-foot wells and one 1,000-foot well which are no longer used. The water from the deep horizon, as at Asbury Park, has considerable iron and is aerated and filtered before being pumped into the mains. This treatment is not necessary for the water from the shallower well. Recently the Board of Conservation and Development granted the Monmouth County Water Company the right to obtain water from Swimming River through mains of the Tintern Manor Water Company, which is also a subsidiary of the American Water Works and Electric Company. Since some economy will result from using this source it is probable that the consumption from the wells of the Monmouth Water Company will be greatly reduced and they will be used principally in periods of peak consumption.

Ocean Grove.—The water supply for the Ocean Grove Camp Meeting Association is furnished by the Eastern New Jersey Power Company, which recently purchased the plant formerly operated by the Association. The water is all obtained in a well field the northeastern limits of which are only between 500 and 1,000 feet southwest of the Asbury Park well field. The well field contains 20 or more wells, but in 1924 only 16 were being used. The wells are scattered over an area about 500 feet wide and 1,000 feet long. Most of them are old, having been drilled in the early nineties. According to a report of the Camp Meeting Association for 1894 at that time there were 21 wells 450 feet deep and two wells 565 feet deep. In 1924 only 14 of these were in use, but the records of the Superintendent did not show whether these included the two deeper wells. These old wells are only four inches in diameter and the screens are perhaps even smaller. In 1894 a well was drilled to a depth of 1,134 feet, but for unknown reasons it was abandoned. In 1924 two wells, with 8-inch casing and 6-inch screen, were completed to a depth of about 650 feet. These yield about 125 to 150 gallons a minute each. The yield of the old wells in service is not known. By subtracting the yield of the new wells from the maximum pumpage in August, 1924, which probably represents nearly the capacity of the field it is estimated that the yield of all 14 old wells is only about 750 gallons a minute or about 45 gallons a minute for each well. All of the wells are pumped by air lift into reservoirs at the elevation of the surface. In the summer of 1925 a concrete reservoir with a capacity of 635,000 gallons was added. A standpipe is also used on the distribution system.

Avon-by-the-Sea.—Prior to January, 1925, the water supply for Avon-by-the-Sea was furnished by the Monmouth County Water Company through distribution mains owned by the Borough. Because of inadequate service in the summer of 1924 the Borough undertook the development of its own supplies. During the fall of the year two wells were drilled by the Layne-New York Company. The first was put into active service in January, 1925, and the second in April. The wells are situated near the Borough Hall and are about 200 feet apart. The No. 1 well is 506 feet deep and the No. 2 well is 503 feet deep. Both are 18 inches in diameter at the top with 80 feet of 8-inch screen at the bottom. Each well is pumped with a Layne deep-well turbine set at a depth of about 180 feet. The yield of the wells during a test on April 4, 1925, was about 325 gallons a minute for No. 1 and 275 gallons a minute for No. 2, when each well was operating alone. But when both were pumped simultaneously, the combined yield was 556 gallons a minute. During the summer of 1925 the yield of the wells decreased very greatly (p. 34), but later increased to about the original yield. The well pumps put the water directly into the distribution main, with an elevated tank to equalize pressure.

Belmar.—The water supply for Belmar is obtained from nine wells scattered over an area that is approximately 500 by 500 feet. The wells are all about 650 feet deep. Five of them are six inches in diameter to a depth of about 150 feet and 4½-inch casing below that, with strainers of the same diameter. Three of the wells are eight inches in diameter at the top with 4½-inch strainer. A new well, completed in 1924, is 16 inches in diameter to a depth of 132 feet, 12 inches from 132 feet to the top of the water-bearing sand at a depth of about 590 feet, and the strainer is eight inches in diameter. The length of strainer in each well is about 60 feet. All of the wells are pumped by air lift except the new well which is pumped by an American Well Works turbine pump. The water is pumped to a small concrete reservoir and thence into the mains, with a standpipe for storage.

Other municipalities.—North of Asbury Park the water supply for Allenhurst is obtained from wells. The well field was not visited during the present investigation and no data are available in regard to it except that there are five wells, each about 550 feet deep. Until the fall of 1925 the water supply of Deal Beach was obtained from wells. At that time the system was purchased by the Tintern Manor Water Company and water from Swimming River is now furnished.

The water supply for the numerous shore resorts south of Belmar for many miles is obtained from wells. No study has been made of any of these supplies during the present investigation.

Private wells.—In past years a number of private wells have been drilled in the Asbury Park region. Many of these have been abandoned and the writer has been able to find very few now in use. The Casino Ice Company, on the south bank of Shark River in Belmar, has two wells. They are reported to be about 500 feet deep, with 8-inch casings and 6-inch screens. The wells are said to yield a total of about 400 gallons a minute. In summer they are pumped practically 24 hours a day, but from October 1 to May 1 they are pumped for only a few hours at intervals of a week or two. At the gas plant well in Belmar there are seven shallow wells about 25 or 30 feet deep. These are pumped at the rate of only about 500 gallons an hour or less than 10 gallons a minute. At the boathouse of Addison H. Riggs, on an island in Shark River, there is a well that has not been used for several years. It is said to be about 490 feet deep. Inquiry from water works officials failed to reveal any other private wells in the region, but others may be found by a more careful search.

WATER HORIZONS

In the Asbury Park region three important water-bearing formations are recognized. These are, in order from top to bottom, the Mount Laurel-Wenonah, the Englishtown, and the Raritan. Some water is also obtained in sand beds lying above the Mount Laurel-

Wenonah formation, but little water is taken from them and no further consideration is given to them. The water-bearing sands are separated by beds of a more clayey nature which do not yield water freely.

The Mount Laurel-Wenonah formation is drawn upon by the wells of the Avon Water Department and the Casino Ice Company in Belmar, and by some of the wells of the Ocean Grove Water Department. The depth to the top of the Mount Laurel-Wenonah in the Avon wells is about 420 feet and the bottom about 500 feet. The Ocean Grove wells utilizing this horizon are 450 feet deep.

The Englishtown formation supplies the wells of the Allenhurst and Belmar Water departments, and some of those in the Whitesville, Asbury Park and Ocean Grove well fields. Dr. M. W. Twitchell states that in the Asbury Park region the top of the Englishtown sand lies about 75 feet below the base of the Mount Laurel-Wenonah formation. In general the depth to it in the Asbury Park region is about 600 feet.

The Raritan formation, which comprises a series of water-bearing sands, is the principal source of supply in the Asbury Park well field and the Whitesville field of the Monmouth County Water Company and also supplies the Jumping Brook wells of that company. In the Asbury Park field the beds utilized lie between a depth of about 1,000 to 1,135 feet, but in the Whitesville field the depth is somewhat less. It is possible that water-bearing sands lie below 1,135 feet, but a well drilled at Asbury Park revealed none between 1,135 feet and its bottom at 1,321 feet.[1]

The strata in the Asbury Park region rise toward the surface in a northwesterly direction and outcrop some miles distant. The nearest outcrop of the Mount Laurel-Wenonah formation is about three miles northwest of Freehold or about 16 miles from Asbury Park. The Englishtown formation outcrops near the town of that name about 21 miles northwest of Asbury Park. The nearest outcrop of the Raritan formation is near Jamesburg, about 26 miles from Asbury Park.

The depth of the different water-bearing horizons in the Asbury Park region varies somewhat from place to place, due in part to differences in elevation and in part to the location at points relatively up or down the dip of the formation. In general the depth to a given formation is less at points in the northern and northwestern parts of the region than at points farther south or southeast. Thus the depth of wells which draw on the Englishtown formation is about 550 feet at Allenhurst, 600 feet at Asbury Park and Whitesville, and 650 feet

[1] Annual report of State Geologist for 1895, pp. 72-74.

at Belmar. However, when drilling new wells, in order to be sure that a selected horizon is reached it is desirable that a careful study of the sand samples and well log be made by a competent geologist. The importance of making such a careful study was emphasized recently. In drilling a well operations were stopped in a sand which on casual inspection appeared to be from a formation that had yielded a good supply of water about two miles distant. Subsequent study of the well log and a few samples showed that instead of being in that formation the well actually was drawing on a formation whose water-bearing capacity is not as good as that of the first-mentioned sand.

The three water-bearing horizons presumably extend some distance out beneath the ocean. Whether they outcrop under water or whether the salt water has no access to them is uncertain. Considering the depth to the formations along the coast and assuming that the dip of the beds beneath the ocean is the same as on land, the charts of the U. S. Coast and Geodetic Survey show that if the horizons mentioned do outcrop it must be roughly at least 100 miles off shore; for it is only at such a distance that the ocean bottom lies at a depth great enough to intersect the formations. However, each of the three formations is beveled off below sea level in New York harbor and sea water can enter them in that region.

CONSUMPTION

In the present report it is not necessary to give detailed consideration to the consumption of water in the Asbury Park region. The following table gives the average daily consumption for the years 1917 and 1925; also the average daily consumption in August of the two years, that being in general the month of maximum consumption.

AVERAGE DAILY CONSUMPTION OF WATER IN ASBURY PARK REGION IN 1917 AND 1925, IN THOUSANDS OF GALLONS

	Average for Year				Average for Month of August			
	1917	1925	Increase in 8 Years		1917	1925	Increase in 8 Years	
	Gallons	Gallons	Gallons	Per cent	Gallons	Gallons	Gallons	Per cent
Asbury Park Water Dept.	812	1,211	399	44	1,474	2,321	847	57
Monmouth County Water Co.	883[a]	1,453[b]	570	68[d]	1,640	2,348	708	43[f]
Ocean Grove Camp Meeting Association	379	418	39	10	1,149	1,112	—37[g]	—3[g]
Avon-by-the-Sea Water Department	[c]	121	121	[d]	[c]	240	240	[f]
Belmar Water Dept.	288	439	151	52	681	955	274	40
Allenhurst Water Dept.	117	175[e]	58[e]	50[e]	242	386[e]	144[e]	60[e]
Total	2,479	3,817	1,338	56	5,186	7,362	2,176	41

[a] 302,753 gallons of surface water and 580,526 gallons of ground water.
[b] 1,070,000 gallons of surface water and 383,000 gallons of ground water.
[c] Supplied by Monmouth County Water Company in 1917.
[d] The increase in consumption in Avon-by-the-Sea cannot be determined separately. The total increase in territory originally supplied by the Monmouth County Water Company, including Avon-by-the-Sea was 691,000 gallons or 78 per cent.
[e] Record incomplete. Consumption given is for 1924 and increase is computed on basis of 1924 figures.
[f] Increase in territory originally served by Monmouth County Water Comany was 948,000 gallons or 58 per cent.
[g] Decrease.

As shown by the table the present average daily consumption for the entire year is not quite 4 million gallons a day. The increase since 1917 has equaled a little more than half of the consumption in that year. This increase from year to year has been somewhat irregular with decreases in certain years, but there has been no great boom period with a rapid increase nor is there now any indication of such in the near future. The greatest increase in consumption has been in the territory originally supplied by the Monmouth County Water Company, part of which in 1925 was supplied by the Avon Water Department.

Judging from past years, it may be expected that the consumption in the Asbury Park region will not show any marked acceleration in the rate of increase from year to year, at least for some time to come. The average increase in the territory in the eight years following 1917 was about 175,000 gallons a year (p. 15). If this rate were maintained, in 1935 the average daily consumption in the territory extending from Allenhurst to Belmar would be a little more than 5,500,000 gallons, and in 1950 it would be about 8,250,000 gallons. The tendency of water consumption as a whole during the past has been for the per capita consumption to increase gradually and it is probable that there will be some further increase in the future. Therefore the estimate just given is perhaps too low. If the average increase each year is double that of the past eight years the total consumption in the region in 1950 will be about 12,500,000 gallons a day.

As is usual in the resort cities along the coast of New Jersey the summer consumption is much greater than that in winter. In February, 1925, the average daily consumption in the region, excluding Allenhurst for which figures are not available, was 2,284,000 gallons a day, and in August of the same year it was 6,976,000 gallons a day, an increase of 305 per cent. The greatest increase, 484 per cent, occurred in Ocean Grove, but in Avon it was almost as great. The smallest increase, 227 per cent, was in the territory served by the Monmouth County Water Company, and the next smallest in Asbury Park. The greatest increases occurred in sections that are practically entirely residential, in which the seasonal fluctuation is probably greatest, and the smallest increases were in the sections that contain a larger proportion of the population which handle the year-round needs of the resorts. The table shows that the increase in consumption in August from 1917 to 1925 was not as great as the increase for the entire year, except in the territory supplied by the Asbury Park and Allenhurst Water Departments. However, this may be due only to conditions prevailing during the years considered and a more careful analysis of the statistics for all years may disprove it as a general fact. In 1925 the average daily consumption in August was about 190 per cent of the average for the entire year. On this basis the consumption in August, 1950, would be about 15.5 million gallons if the average increase from year to year is only 175,000 gallons a day or nearly twenty-four million gallons if it is double that rate as estimated above. Considering the figures given here, the present indications are that the demand for water in the future will be much less in the Asbury Park region than in other important areas in South Jersey which are now largely dependent upon ground water, such as the Camden and Atlantic City regions.

In the Asbury Park region there are three important water-bearing horizons, namely, the Mount Laurel-Wenonah, the Englishtown, and the Raritan formations (p. 12). In considering the effect of pumping on these formations (see pages 22 to 44) it is desirable to know the relative changes in consumption from each formation from winter to summer. Therefore the following table is inserted showing the average daily consumption in the region according to sources for the months of February and August, 1925, and for the entire year. These figures represent approximately the pumpage in the months of minimum and maximum consumption respectively, although the least and greatest consumption did not always occur in these months.

ESTIMATED DAILY AVERAGE CONSUMPTION OF WATER IN ASBURY PARK REGION FOR FEBRUARY, AUGUST AND THE ENTIRE YEAR 1925, ACCORDING TO SOURCE, IN THOUSANDS OF GALLONS

	February	August	Year
SURFACE WATER			
Monmouth County Water Company	786	1,364	1,070
Total surface water	786	1,364	1,070
GROUND WATER			
Shallow horizons above Mount Laurel-Wenonah formation			
Monmouth County Water Company	0	200	49[b]
Gas Company, Belmar	12	12	12
Total, shallow formations	12	212	61
Mount Laurel-Wenonah formation			
Ocean Grove Water Department	170	834	313
Avon Water Department	50[a]	240	121[a]
Casino Ice Company (private wells)	15	575	290
Total, Mount Laurel-Wenonah formation	235	1,649	724

Englishtown formation			
Monmouth County Water Company..	0	200	49[b]
Asbury Park Water Department ...	79	321	121
Ocean Grove Water Department.....	60	279	105
Belmar Water Department	228	955	439
Allenhurst Water Department......	91[c]	386[c]	175[c]
Total, Englishtown formation	458	2,140	889
Raritan formation			
Monmouth County Water Company..	236	508	284
Asbury Park Water Department...	675	2,000	1,090
Total, Raritan formation	911	2,508	1,374
Total ground water	1,525	6,123	2,873
Total all sources	2,311	7,487	3,943

[a] Operation of plant begun February 6, 1925. Average for February is for 23 days and average for year is for 329 days.

[b] Consumption practically entirely in summer months.

[c] Record for 1925 incomplete. Figures given are for 1924 which are probably not greatly different from 1925 consumption.

The above data are at best only a rough estimate. In only three cases is the consumption of public systems as reported to the Department of Conservation and Development obtained wholly from a single source. These are the surface water consumption of the Monmouth County Water Company and the consumption of the Avon and Belmar Water Departments. The private supplies of the Casino Ice Company and the Gas Company in Belmar are from single sources but the water is not measured nor is any definite record kept of the pumpage. The supply for the other systems is obtained from two or more formations in such a way that it cannot be reported separately. The figures given are based on statements of the owners as to yield of wells during tests, hours of pumping each well, or whatever other data furnished some clue as to the relative amount was obtained from each source.

The significant facts shown by the table are: The pumpage is least from the Mount Laurel-Wenonah formation at all times of the year and greatest from the Raritan formation. Except in the summer months the difference between the pumpage from the Mount Laurel-Wenonah and the Englishtown formations is not great, and if more accurate data were available the difference might be found to be even less than reported. The pumpage from other formations is almost negligible. There may be some private wells not listed which draw on any one of the formations, but if so the consumption from them is probably not great. There is a very great increase in the pumpage from wells between February and August. Excluding the unimportant shallow horizons the increase is greatest for the Mount Laurel-

Wenonah formation, being 700 per cent, and least for the Raritan, being 275 per cent. For the Englishtown formation it is 467 per cent.

The Monmouth County Water Company is now serving surface water from Swimming River, and its wells will probably be used to a much less extent. The effect of this will be to cut down considerably the consumption from the Raritan formation at all times of the year and to a less extent the consumption from the Englishtown formation in the warmer months.

It is important to note that the data given in the table do not cover the entire consumption from the formations named, but only in a relatively narrow zone extending from Allenhurst to Belmar. Water is pumped from the Englishtown formation and perhaps from the Mount Laurel-Wenonah at points further south along the coast, and at points inland. The Raritan formation is not drawn on elsewhere along the coast except possibly at Lavalette, but it is utilized inland, notably at the Runyon water works of the Perth Amboy Water Department.

QUALITY OF WATER

The quality of water obtained from the Mount Laurel-Wenonah, Englishtown, and Raritan formations is shown by the following table of analyses in which the samples from each separate formation are grouped together.

ANALYSES OF GROUND WATERS IN THE ASBURY PARK REGION

(ANALYZED BY C. S. HOWARD, U. S. GEOLOGICAL SURVEY. PARTS PER MILLION.)

	Mount Wenonah	Laurel- formation	Englishtown formation		Raritan formation		Miscellaneous	
	1	2	3	4	5	6	7	8
Silica (SiO_2)	10	11	9.5	9.1	9.4	5.5	16	6.0
Iron (Fe)	.10	.10	1.7	.69	7.9	8.1	.75	.05
Calcium (Ca)	32	32	26	25	11	....	32	11
Magnesium (Mg)	6.6	7.2	5.4	5.7	1.2	....	3.2	3.9
Sodium and potassium (Na-K)	6.9	9.4	8.3	7.3	6.2	6.2	8.6	5.0
Bicarbonate radicle (HCO_3)	98	100	85	99	32	37	104	41
Sulphate radicle (SO_4)	34	32	25	12	14	15	17	17
Chloride radicle (Cl)	3.0	4.0	2.0	3.0	4.0	4.0	3.3	2.0
Nitrate radicle (NO_3)	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Total dissolved solids at 180° C.	139	138	124	109	60	66	134	72
Total hardness as $CaCO_3$ (calculated)	107	110	87	86	32	44	93	44
Date of collection	Nov. 13 1924	Nov. 12 1924	Nov. 13 1924	Nov. 13 1924	Aug. 4 1925	Nov. 13 1924	Aug. 4 1925	Nov. 13 1924

1.—Several 480-foot wells, Ocean Grove Water Department.
2.—503-foot well, Avon-by-the-Sea Water Department.
3.—600-foot well, Asbury Park Water Department.
4.—650-foot well, Belmar Water Department.
5.—981-foot well, Whitesville field of Monmouth County Water Department.
6.—1,135-foot well, Asbury Park Water Department.
7.—600-foot well, Whitesville field of Monmouth County Water Company. This well draws from two horizons, the Englishtown between the depths of 538 and 605 feet, and as yet unidentified horizon between the depths of 178 and 218 feet.
8.—Filtered water served by Asbury Park Water Department, a mixture of water from the Englishtown and Raritan formations.

In commenting on the analyses, W. D. Collins, Chemist in charge of the quality of water division of the U. S. Geological Survey, states: "It is interesting to note how nearly identical are the samples from Ocean Grove [No. 1] and Avon-by-the-Sea [No. 2]. The analyses are almost as much alike as would be expected of two samples taken from the same bottle. The analysis of the Belmar well [No. 4] is very much like that of the water from the same level at Asbury Park [No. 3], although the Asbury Park water has a little more sulphate and more iron than the sample from Belmar." The similarity in the character of the two samples from the Raritan formation is also noteworthy, for the difference between any of the constituents in either sample is not great.

It will be noted that both the total solids and total hardness are greatest in the samples from the uppermost of the three formations and least in the deepest. On the basis of these constituents alone the Raritan water would be most satisfactory. However, the hardness of the water from the Mount Laurel-Wenonah is not great enough to cause any disagreeable results from its use. The water from the Raritan formation is so high in iron that it must be aerated and filtered and this increases somewhat the cost of production. Sample No. 8 shows the reduction in iron in the water served in Asbury Park after filtration. The filtered water is a mixture from the Englishtown and Raritan formations and the quantities of most of the constituents in the filtered sample are intermediate between those of the samples from the two horizons, but the iron is less than in either. When analyzed, the sample from the Belmar well (No. 4) contained some iron which was precipitated after collection. It seems probable that the iron would be precipitated in the basin in which it is collected before being pumped into the distribution system, but actually it was so slight as not to be noticeable.

The differences in the quality of the water from the three horizons are not great enough to furnish any strong basis for choice in developing public supplies, except perhaps the cost involved in filtering the water from the Raritan formation. More important than quality of the water are the factors of difference in initial cost of drilling to different depths, and differences in the relative water-bearing capacities of the formations which are discussed on subsequent pages.

WATER-BEARING CAPACITY OF FORMATIONS

GENERAL STATEMENT

Some data have been obtained which indicate the relative water-bearing capacity of the Mount Laurel-Wenonah, Englishtown, and Raritan formations in the Asbury Park region, and their value as sources of water supply. These observations relate principally to the effect of pumping during short tests and of seasonal changes in pumping. The conditions for obtaining good data have been most favorable for the wells that draw from the Mount Laurel-Wenonah formation and the discussion relating to that formation is more detailed than for the other horizons.

MOUNT LAUREL-WENONAH FORMATION

Pumping Tests of Avon Wells

Description of the Tests.—The effect of pumping has been determined to a certain extent by observations during pumping tests of the wells at Avon and by measurements of those and other wells in the regions at intervals of about a month for more than a year.

A preliminary test of the Avon No. 1 well on August 25, 1924, was not witnessed by the writer, but a report of the driller shows that in eight hours' pumping the discharge decreased gradually from about 380 gallons a minute at the end of the first hour to 325 gallons a minute at the end of the test.

More detailed observations were made during a 10-hour test on well No. 2 on November 12, 1924. At the end of the first hour the discharge was approximately 320 gallons a minute. At the end of five hours it had decreased to about 310 gallons and at the end of eight hours it had decreased to about 300 gallons a minute. The discharge apparently continued to decrease during the entire test, but in the last few hours the rate of decrease was so slow that an actual change could be noticed only in observations two or three hours apart. The drawdown or number of feet the water was lowered in well No. 2 during pumping was estimated to be about 100 feet. The water level in No. 1 well dropped during the entire period that No. 2 was pumped. This is shown graphically in Fig. 1. The rate of lowering was very rapid at first, being about five feet during the second hour; but it became less and less, and in the last hour the water dropped about four-tenths of a foot. The drop in the No. 1 well during the period of observation

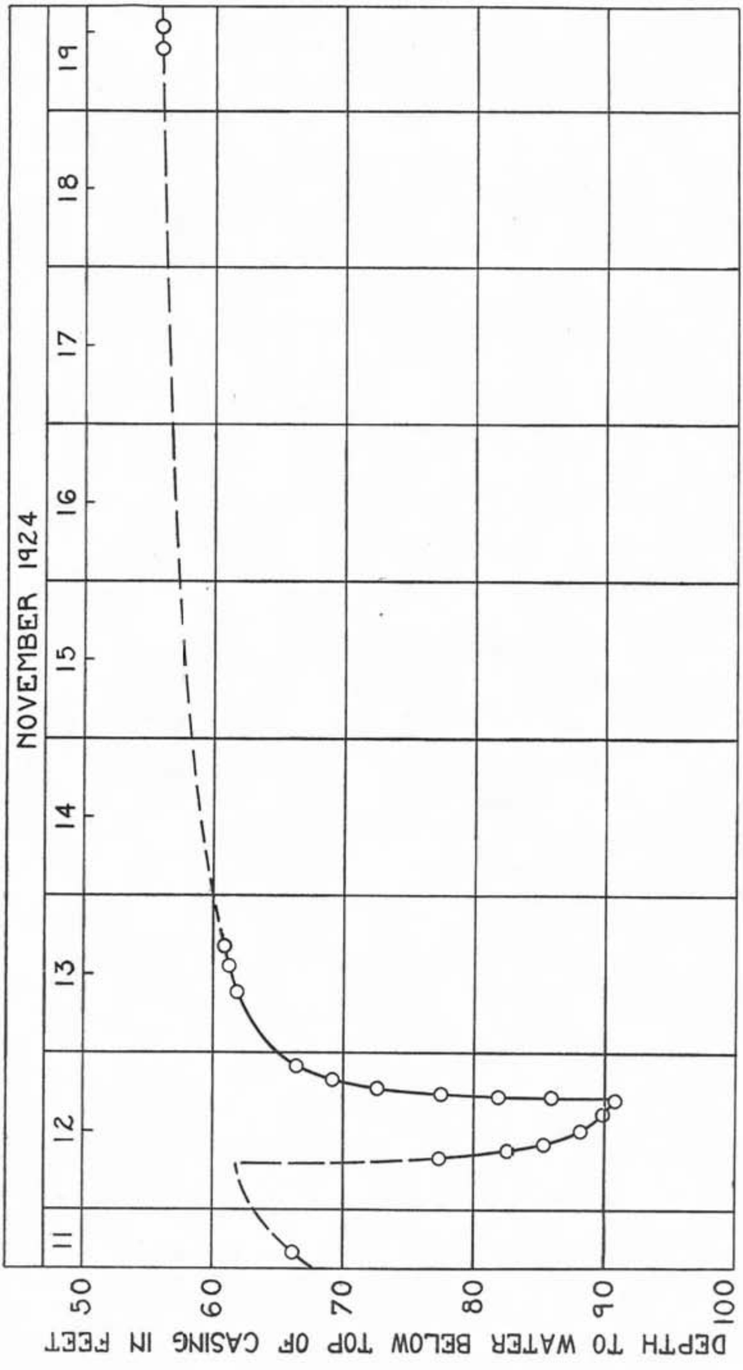


Figure 1—Graph Showing Movement of Water Level in Avon Well No. 1 During the Test of Well No. 2, November 12, 1924.

was 23.6 feet and judging from the level to which the water rose the day after the test, the total drop was at least 30 feet. From the graph it is evident that the water level would have continued to drop for at least several hours more if pumping had continued, although the subsequent drop would have been only a few feet.

During the final test of the two Avon wells on April 2, 1925, each well was pumped alone for two and a half hours and both were run together for three and a half hours, but these periods were probably not long enough for completely stable conditions to be reached. Also it was not possible to make as accurate measurements of water level as in the preliminary test.

The average yield of well No. 1, when pumped alone for two and one-half hours, was 325 gallons a minute, and the drawdown near the end of the period was about 108 feet. The average yield of well No. 2, when pumped alone for a like period, was 275 gallons a minute, and the drawdown was about 113 feet. The tests of the wells running separately was made, following the three-hour period in which the two wells had been run together and this doubtless caused a slight decrease in the yield of each well from what it would have been if only one well at a time had been run since the head had been unduly lowered. The combined yield of the two wells running together for three and one-half hours was 556 gallons a minute or 44 gallons less than the sum of the yield of the wells when each was running alone, a decrease of 7 per cent. The drawdown in well No. 1 when both wells were running was about 115 feet. The drawdown in well No. 2 at this time was not determined, but there is reason to believe that it was at least 120 feet. Thus when both wells were running the specific capacity (p. 25) was cut to 2.4 gallons per minute per foot of drawdown.

During the test on April 2 frequent measurements were made on the water level in the Riggs well and one of the Casino Ice Company wells to determine whether the pumping of the Avon wells affect these wells. At the end of the test the water in the Riggs well was 1.25 feet lower and in the Casino well 0.42 of a foot lower than before pumping began. Because of a possible slight but unproved tide effect in the wells it cannot be definitely stated that this lowering of the water level was caused entirely by the Avon wells. However, by reducing the elevation of the water level to a common datum by means of spirit levels there was found to be a very definite gradient of the static head of the water from the Casino well toward the Riggs and Avon wells. It is therefore concluded that the pumping of the

Avon wells affected both the Riggs well, half a mile away, and the Casino well 800 feet farther. This is an unusually great distance for the effect of one or two pumping wells to be felt in other wells, especially in view of the small yield of the wells.

Conclusions.—The significant facts revealed by the tests just described are: (1) the comparatively small yield of the wells, and the fact that it apparently declines for some time after pumping is begun; (2) the very great drawdown created by the comparatively low rate of pumpage; (3) the great lowering of the water in well No. 1 when No. 2 was pumped; and (4) the great distance to which the effect of pumping was transmitted from the wells. These facts suggest that the Mount Laurel-Wenonah formation in the vicinity of Avon is a relatively poor water-yielder. This is also shown by the following comparison with wells in other localities.

The value of a well as a water yielder is shown to some extent by its specific capacity or yield per unit of drawdown. This is determined by dividing the tested yield by the drawdown during the test. For the No. 2 well the specific capacity during the test of November 2 was only a little more than three gallons per foot of drawdown. The specific capacity of wells in other formations for which data are available is given in the following table. These wells were all drilled by the Layne-New York Company which put down the Avon wells, and accordingly should be as nearly comparable from the constructional standpoint as is possible. Differences in the specific capacity, therefore, may be ascribed largely to the differences in the water-yielding capacities of the formations or differences in the length and diameter of the screen. The diameter of the screen is the same in all the wells except those of the Camden Water Department and the Merchantville Water Company, but the lengths of the screen are different in some wells. To put the results on a more comparable basis a column is added showing the yield per square foot of screen in the well and specific capacity per square foot of screen (yield divided by drawdown divided by square feet of screen).

COMPARISON OF YIELD OF CERTAIN WELLS IN FORMATIONS OF NEW JERSEY COASTAL PLAIN

Locality and well designation	Formation	Length of screen	Diameter of screen	Yield	Drawdown.	Specific Capacity	Yield per sq. foot of screen	Specific Capacity per sq. ft. of screen
		feet	inches	g. p. m.	feet	Gals. per foot	g. p. m.	g. p. m.
Avon No. 2	Mount Laurel-Wenonah	80	8	300	100[a]	3	1.9	.019
Whitesville, 981 foot well	Raritan	66	8	950	76	12.5	6.9	.09
Merchantville Water Co. near Fish House	Raritan	32.5	26	1,050	47	22	4.8	.10
Camden, Puchack field, Well No. 1	Raritan	32	26	1,320	38	35	6.1	.16
Camden, Puchack field, Well No. 4	Raritan	50	26	1,675	25	67	4.9	
Margate City	Kirkwood	61	8	700	37	19	5.7	.15
Atlantic City, Abbott's Dairy	Kirkwood	60	8	630	40	16	5.0	.13

[a] Estimated by driller.

The table shows that the Avon wells have the lowest yield of any of those listed, the other wells affording from four to eight times as much water. No unusual difficulty was encountered in the construction of the Avon wells and there is no reason to ascribe their low yield to any other cause than the physical character of the Mount Laurel-Wenonah formation which results in low permeability. This is what is to be expected from the texture of the formation where it outcrops on the surface. It is there a fine, mealy sand, with very minute pore-spaces.

Brief consideration may be given to certain conditions observed during the tests on the Avon wells, namely, the decline in head in well No. 1 when well No. 2 was pumped which continued during the entire test, and the decline in the yield of the wells as pumping continued.

The first condition has been found in tests of other wells drawing from other formations and appears to be characteristic of water-bearing formations. The head in the pumping well and also in the surrounding water-bearing formation, as indicated by the water level in adjacent wells, drops rapidly as soon as pumping is begun. Although the maximum discharge of the pump is reached within a few minutes after starting, the head continues to drop for some time—that is, there is a lag in the establishing of a stable condition. The lowering of head continues at a slower and slower rate until there is no further decline. Water is entering the well through the screen as rapidly as it is being withdrawn. The typical curve representing the movement of the water level with respect to time when a well is pumped drops almost vertically, then curves gradually until it is practically horizontal. When pumping is stopped the curve rises steeply and then curves gradually until it is horizontal—that is, it is essentially the reverse of the pumping curve. The curves shown in Fig. 1 are typical except that the pumping period was so short that the stable condition was far from being reached. The time required to reach the stable condition differs with different water-bearing formations. In some it is reached in a few minutes or at most a few hours. In others it may not be reached for several days although the decline in head after a day or two may be almost imperceptible. In general, the stable condition is reached most quickly in formations that are good water-bearing materials and most slowly in poor water-bearing materials. The exact cause of the lag of the head reaching a stable condition is not known but it seems to be dependent upon the physical characteristics of the water-bearing materials which govern their permeability and porosity.

The second condition results in part from the first condition and in part from the type of pump used. As the water level drops lower and lower the pump must raise the water a greater and greater distance and for a given quantity of water a greater amount of power is required. However, when a well is equipped with the type of motor and pump used in the Avon wells the power available cannot be increased. The result is that since more power is required to lift a unit quantity of water the total quantity that can be pumped is automatically decreased gradually as long as the water level recedes in the well. If, instead of the type of pump used in the Avon wells, any other type of pump is used by which more power may be applied as the head drops the discharge may be kept up, for the ability of the well to yield water has not been impaired merely by the lowering of the head.

Effect of Seasonal Changes in Pumpage

Fluctuations of Head.—In addition to the tests on the Avon wells described above measurements were made on the Avon, Riggs, Casino, and Ocean Grove wells at intervals of about once a month between September, 1924, and December, 1925. The measurements of the Avon No. 1 well, the Riggs well, and the Casino well are shown on the accompanying graph, Fig. 2, which also shows the daily pumpage from the Avon wells. No measurements could be made on the Riggs and Casino wells during the summer months, in the first case because the water level dropped below an obstruction in the well and in the second case because the well was in continuous operation.

Two series of measurements are given for the Avon No. 1 well, indicated respectively by + and ×. The upper series (+) shows the water level in the No. 1 well when the No. 2 well was not pumping and the lower series (×) shows the water level when the No. 2 well was pumping.

It will be noted that after April 28 in several instances for the Avon well there are measurements of the non-pumping level on successive days. In such cases the first of the two measurements was made in the late afternoon only two or three hours after one or the other of the wells had been pumped and the water in the well was still rising fairly rapidly from the low level during pumping. The second measurement was generally made during the morning of the succeeding day before either well was pumped and the water level had risen to a greater height. During July and August and September one or the other of the Avon wells was pumped for 18 to 20 hours each day and

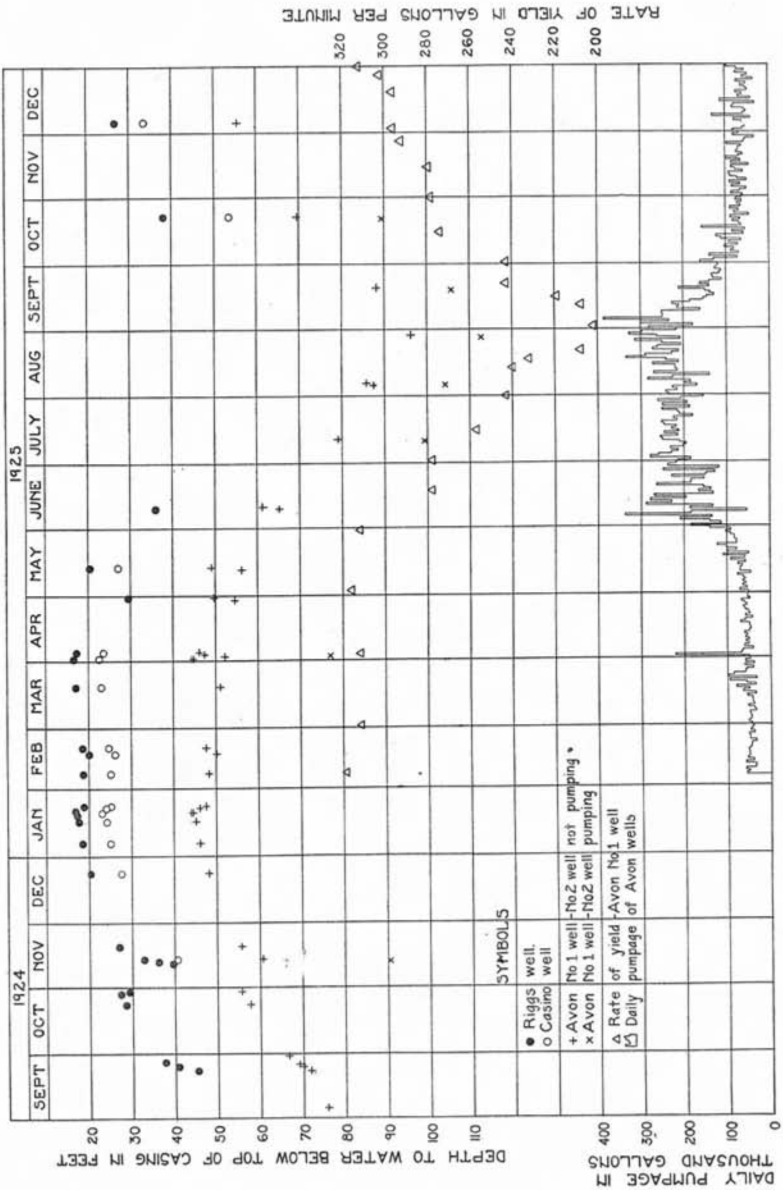


Figure 2—*Graph Showing Fluctuation of the Water Level in Avon Well No. 1, Riggs and Casino Wells, the Yield of Avon Well No. 1, and the Daily Pumpage of the Avon Well.*

the period of complete rest occurred only in the very early morning hours. The higher of the two measurements shown on successive days was made between 8 and 9 o'clock in the morning before pumping for the day was started. The lower measurement shows the depth to water between 4 and 6 o'clock in the afternoon with No. 2 well pumping. The difference between the pumping and non-pumping level is much less in summer than in the rest of the year. This is because in summer the wells are pumped for many hours and the period of recovery is so much shorter that the water level cannot rise to a position comparable to that in the other months.

The graph shows that the static level in the No. 1 well was more than 70 feet below the top of the casing during most of September, 1924, and thereafter it rose during the fall months to a level of about 45 feet in January, 1925. This level, with a variation of a few feet, depending upon the conditions at the time of measurement, was maintained until about the middle of April. Thereafter the water level dropped rather rapidly and on August 28 it was 96 feet below the reference point when both wells were idle, a drop of more than 50 feet since the high point of April 1. On August 28 it was about 113 feet below the reference point when No. 2 was pumping. After the period of heavy pumping ended the water level rose again, as in the fall of 1924.

Since measurements are lacking for August, 1924, it is not possible to compare accurately the static head at its low point in 1924 and 1925. However, on September 19, 1925, after the water had begun to rise it was more than 10 feet lower than at the time of measurement two weeks earlier in 1924 and therefore at its low point was presumably considerably lower than in 1924. On February 12, 1926, the depth to water in the Avon No. 1 well was 48.64 feet or at about the same level as at the corresponding time in 1925.

The measurements of water level in the Riggs and Casino wells, so far as they are available, show fluctuations in harmony with those in the Avon well, although the change from one time to another is not always the same in all three wells. Measurements in observation wells at the Ocean Grove Water Works show similar seasonal fluctuations, the observed range from April 1 to August 28, 1925, being more than 50 feet.

The great fluctuation in the static head in the wells between winter and summer is undoubtedly due principally if not wholly to fluctuations in the pumpage. As shown by the preliminary test on the Avon No. 2 well the water level dropped generally during the entire period of the test and evidently would have continued to drop for some time if pumping had continued. Under ordinary conditions in winter the Avon wells are pumped for only two or three hours and during the rest of the day the water has an opportunity to recover to the level at which it stood before pumping. But as pumpage increases in summer, during pumping the head on the formation drops to a lower level, the recovery period is shorter and in some wells, as the Casino Ice Company wells, this period is eliminated entirely. Since the pumpage from each field increases in summer and, as shown above, the areas of influence of the Avon and Casino wells overlap, the decrease in head in the Avon wells is due not only to pumpage from them, but also from the Casino wells. The area of influence of the Ocean Grove wells may also overlap that of the Avon wells. In brief, the condition is that the static level varies in accordance with the pumpage. Sufficient data are not available to permit of a positive statement but it is probable that the great lowering of the head found in the wells under observation is not confined to their immediate locality but extends several miles from the wells.

It has been shown on page 24 that when there is a change in the rate of pumping from a well the static head does not immediately become adjusted to the new condition but there is a considerable lag before a stable condition is reached. There is undoubtedly such a lag when the pumpage from the Mount Laurel-Wenonah formation increases greatly in summer. Figure 2 shows that the pumpage at Avon, and doubtless also from the other wells drawing on the same horizon, was highest during the latter part of August and the first few days of September. Probably the lag following the increase to the maximum pumpage had not completely run its course and if pumping at that rate had been continued the head would have dropped somewhat farther. As it was, after the first week in September the pumpage decreased so rapidly that not only was the downward movement stopped but the head began to rise. Support for the belief that the lowest level that would result from the high pumping rate had not been reached is afforded by the water-level measurements on well No. 1 shown on Fig. 2. These show that the head had declined at an almost uniform rate during the summer months, whereas if the stable condition were being approached it would be expected that the decline in head would become less and less—in other words, that the curve would become nearly horizontal.

The summer of 1925 was dry, with rainfall below the normal, and it has been suggested that the great lowering of the static head during the summer of 1925 was due to the deficiency in rainfall. It is the opinion of the writer that the greater part of the drop in head is not due to this condition, however, but to the seasonal increase in pumpage as described above. The most convincing argument in support of this opinion is a comparison with conditions in the fall of 1924. As shown by the graph, when the first well at Avon was completed in September, 1924, the static head was about 75 feet below the surface and thereafter during the fall it rose. In other words, it was low at the end of the summer season, although not as low as in 1925 when the Avon wells were pumping, and it rose as the pumpage decreased. It happened that the months of October and November, 1924, were unusually dry and yet during that period the static head rose except during the first 10 days of November when the Avon No. 2 well was being pumped considerably by the drillers. If the drop in head in 1925 were due to a deficiency in rainfall a drop in head should also have occurred in October and November, 1924. In further support of the writer's opinion it may be said that according to hydraulic principles the most natural thing to be expected is a drop in head as the movement of water to a well increases and a rise in head as it decreases. The increase in draft occurred principally in the Avon field which was not in use in 1924. It cannot be definitely proven that none of the drop in head in the summer of 1925 was due to deficient rainfall, but if some of it was due to this cause it is the writer's belief that it was only a relatively small part of the total drop in head.

Fluctuations of Yield of Wells at Avon.—As the static head on the Mount Laurel-Wenonah formation fell during the summer of 1925, the yield of both wells of the Avon Water Department decreased considerably as shown by the charts from the Venturi meter on the discharge line from the wells. All of the charts have not been examined critically but the following data are sufficient to show the trend of the conditions.

It is not feasible to present as complete an analysis of the charts as might be desired, for some of them are obviously inaccurate, since the meter clock did not always keep correct time. After some study the method was adopted of reading from the charts the rate of yield at the end of two hours' pumping. A longer period could not be used for in winter the pumps are run only 2 or 3 hours. In the summer months, however, after a run of several hours the rate of yield is generally somewhat less than that at the end of two hours' run. On many days the rate of yield declined gradually during the entire pumping period of 18 to 24 hours, as shown by a typical chart in Fig. 3.

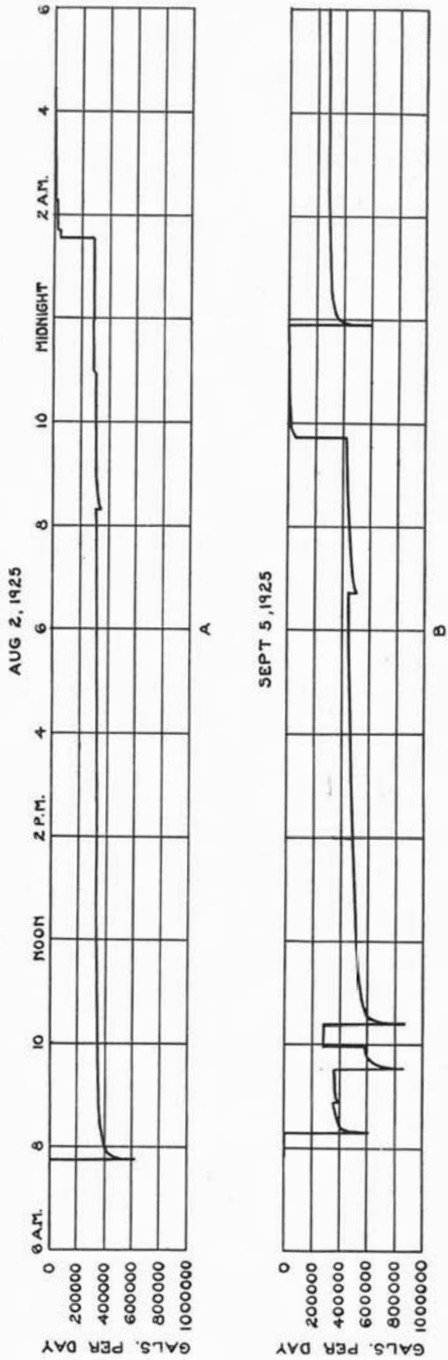


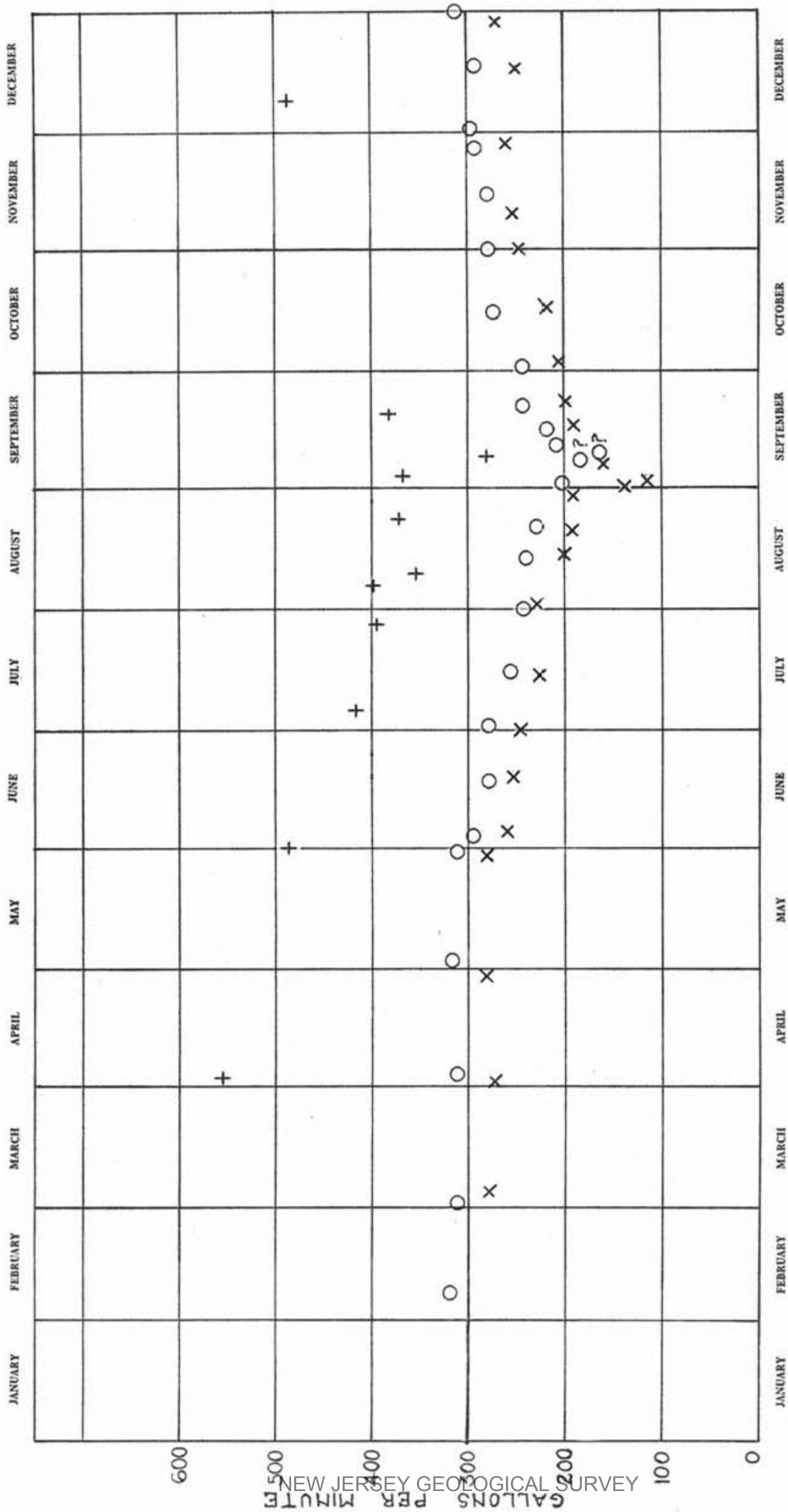
Figure 3—Typical Venturi Chart, Showing Decrease in the Yield of the Well During the Pumping Period.

This condition is due in part to two things. The sudden drop in yield immediately after pumping begins is partly due to the rapid decrease in head in the well in the first few minutes of operation, becoming less as pumping continues. As shown in the pumping tests it is probable that the head declines for at least several hours after pumping is begun. The pumps operate at practically a constant speed and therefore do only a constant amount of work. Accordingly as the distance to the surface increases the quantity of water pumped must decrease. The decline in yield is also due in part to the fact that the pressure in the standpipe, against which the pumps work generally is low when the pump is started and increases as pumping continues. Hence the pump is working against an increasing pressure. Consequently, the quantity that the pump can raise diminishes for this reason also. The two factors noted combine to produce the same effect, namely, a rather rapid decline in yield at first, which continues at a slower and slower rate as pumping continues.

The rate of yield of well No. 1 on certain days is shown on Fig. 2 and the same data together with the rate of yield of well No. 2 pumping alone, and wells No. 1 and No. 2 pumping together are shown in Fig. 4. The days for which data are shown have been chosen so far as possible to show both the general trend and variations from it. Although the method used for determining the yield of the wells at different times is rather unsatisfactory the graphs show certain significant facts.

The most important fact shown is the great decrease in the yield from the end of May to September 9, and thereafter just as marked an increase in the yield during the fall and early winter. The decrease in yield was very rapid during the last half of August and first week of September, when the daily pumpage was the greatest. The increase was even more rapid after the first week in September, following a rapid decline in the daily pumpage. By the end of January, 1926, the yield of the wells was back to practically what it was a year previous.

The average rate of yield of well No. 1 from February to May, inclusive, was about 315 gallons a minute. On September 7 this had dropped to 184 gallons a minute. Neglecting this low rate of yield the decrease from May 30 to September 7 was 110 gallons a minute or 35 per cent of the original yield. The rate of yield of well No. 2 declined from about 281 gallons a minute on May 29 to 139 gallons on August 31, a drop of 50 per cent. The Venturi chart for September 2 shows a rate of yield even lower—only 115 gallons a minute, but



+ Wells No. 1 and No. 2 pumping together. O Well No. 1 pumping alone. × Well No. 2 pumping alone

Figure 4—Graph Showing the Seasonal Fluctuation in the Yield of Avon Wells No. 1 and No. 2.

certain peculiar features on it raise a question as to its accuracy. The rate of yield of wells No. 1 and 2 pumping together declined from a maximum of 555 gallons per minute on April 2 to 368 gallons per minute on September 3, or a drop of 34 per cent.

A comparison of the decrease in rate of yield with the lowering of the water-level in the wells (or head in the formation) leads to the conclusion that the decrease is without doubt due to the drop in the water level, which in turn, as has been shown above, is due to the increased pumpage in the summer months. Since during the winter of 1925-1926 the yield of the wells increased to about their original yield it is obvious that the marked decrease during the summer was not due either to any decrease in the efficiency of the pumping equipment or sanding up of the wells.

Tests on Sand Samples

Two samples of sand from the Avon well No. 2 were tested in the Laboratory of the U. S. Geological Survey. The tests included mechanical analyses and determination of the porosity and coefficient of permeability. The results of the tests are given in the following table, which shows that the coefficient of permeability is 566 and 887 respectively, and the porosity is 34 and 30 per cent.

MECHANICAL ANALYSES, COEFFICIENT OF PERMEABILITY, AND POROSITY OF SAMPLES OF THE MOUNT LAUREL-WENONAH SAND, AVON NO. 2 WELL

Laboratory No.	Mechanical composition (per cent)								Coefficient of permeability	Porosity per cent	Remarks
	Greater than 2 mm.	2.0-1.0 mm.	1.0-0.5 mm.	.5-.25 mm.	.25-.10 mm.	.10-.05 mm.	Silt .05-.005 mm.	Clay, less than .005 mm.			
303	......	2.60	52.35	35.58	5.58	.50	1.60	1.70	566	34	Depth 421 to 461, characteristic of upper part of formation.
305	......	4.98	26.93	39.97	9.65	1.07	16.63	.76	.887	30	Depth 461 to 501, characteristic of lower part of formation.

The results of the tests are mainly of value in comparing the water-bearing qualities of the Mount Laurel-Wenonah sand with those of some of the other principal water-bearing formations in the State. For this purpose the coefficient of permeability is useful. Tests have been made on about 25 samples from the so-called 800-foot sand of the Kirkwood formation which supplies a large quantity of ground water in the Atlantic City region. The results of these tests and the meaning and use of the coefficient of permeability are discussed in a report on that region. The lowest coefficient in 17 samples from the Atlantic City region was 688, the highest was 10,464, and the next highest, 4,362. The average for the 17 samples was approximately 3,000. The coefficient of nearly two-thirds of the samples was more than 2,000, whereas that of the sand of the Avon well is only 556 and 887. In brief, these results indicate that the 800-foot sand in the Atlantic City region will yield approximately at least three to five times as much water under a given head as will the Mount Laurel-Wenonah sand at Avon. In this way the tests on the sand samples support the other evidence presented above which indicates that the Mount Laurel-Wenonah is a relatively poor water-bearing formation.

Effect of Future Increases in Pumpage

From the data afforded by the observations in the Avon area and from similar observations in other regions it is concluded that if the pumpage from the Mount Laurel-Wenonah formation is increased—whether from the well fields now in use or in new localities in the region—the static head will drop still lower. On the other hand, if the pumpage remains about the same as in 1925 it is probable that the head will not go much lower than in the summer of that year. However, since there is probably some lag in adjustment of the head to a given rate of pumping it is likely that if the maximum rate obtained during the summer of 1925 is maintained for a longer period the head may drop somewhat below the low point of that period before a stable condition is reached.

It is not possible with the available data to make any accurate estimate as to the lowering of head that would result from a given increase in pumping, but the following may give some indication as to what may be expected. From April to September, 1925, the static head in the Avon No. 1 well was lowered about 50 feet. The increase in pumpage in the same period is estimated to be about 1.4 million gallons a day. This is a lowering of about one foot for every 28,000 gallons increase in the daily pumpage. However, as indicated on page 30, it is probable that if pumping at the same rate had continued for a longer period the head might have dropped even lower.

That the drop might have been considerable before a stable condition would have been reached is suggested by a comparison with the lowering of head prior to 1925. Information as to the original head is found in the record of a well drilled in 1884 on the property of Eben C. Jayne at the corner of Ocean and Sixth Avenues, Ocean Beach (now Belmar).[1] The well was 485 feet deep and cased to a depth of 471 feet. The report states that when finished the water rose "vertically 34 feet above the ground, and about 50 feet above low-water mark of the ocean." About the same year, in a well drilled to a depth of about 420 feet at Ocean Grove, the head was 28 feet above the surface.[2] The surface elevation is estimated to be about 15 feet above sea level and the head therefore was about 43 feet above sea level. It seems certain that these wells were drawing from the Mount Laurel-Wenonah formation,—the Ocean Grove well from the upper part of the horizon and the Jayne well from the lower part. In the winter of 1924-25 the water level in the Avon wells at its highest point was about 45 feet below the surface or about 15 feet below mean low tide. Since 1884 the head had declined about 65 feet. This is to be attributed largely if not wholly to pumping in the region. So far as the records of the Department of Conservation and Development indicate there is practically no pumpage from the Mount Laurel-Wenonah formation other than at the localities mentioned on page 13. The estimated pumpage from the formation in the winter of 1924-25 was about 235,000 gallons a day. On this basis the decline in head had been about one foot for each 4,000 gallons per day; that is, the quantity of water obtained per foot drop in head was only about one-seventh that obtained when the water was lowered 50 feet during the summer of 1925. If the conditions are comparable the data must indicate that if pumping had been maintained at the high rate of August, namely, 1,650,000 gallons a day, the head would have dropped very much farther. If the decrease in head were directly proportional to the increase in pumpage on the basis of the most conservative figures, a further increase in draft of one million gallons above the rate of August, 1925, would lower the static head some 35 feet below the low point of 1925 or about 130 feet below the surface. On the other hand, if the lower yield per foot decrease of head over a long

[1] Annual report of the State Geologist for 1884, p. 214.
[2] Annual report of the State Geologist for 1885, p. 129.

period is more nearly correct an increase in pumpage of one million gallons would cause the head to drop about 650 feet below the surface. It cannot be said definitely that the decline in head is directly proportional to the increase in pumpage. Nevertheless, the periodic measurements since September, 1924, suffice to show that the effect of any large increase in pumpage is to cause a considerable lowering of the head in the Mount Laurel-Wenonah formation.

As in the consideration above of the yield of the Avon wells a comparison of the seasonal fluctuation of the head on the Mount Laurel-Wenonah sand with that of the head on other water-bearing sands shows that it is not as good a water-bearing formation as the others. The seasonal fluctuation in a well to the Raritan formation at the Whitesville station of the Monmouth County Water Company was only about 15 feet from August 27, 1925, to January 9, 1926, although at the time of the measurement on August 27 a well not over 250 feet distant was pumping about 900 gallons a minute from the formation, whereas it was idle on January 9. As shown by the table on page 18, the difference in pumpage in winter and summer from the Raritan formation in the region, is fully as great as from the Mount Laurel-Wenonah sand, but the effect on the static or non-pumping head is considerably less. Less definite observations on wells to the Englishtown sand indicate that the seasonal fluctuation of the head on it is probably less than on the Mount Laurel-Wenonah sand, although perhaps not much less, whereas the pumpage is probably greater. The seasonal fluctuation of the head on the Kirkwood sand at Atlantic City during 1925 was only 20 to 25 feet for a seasonal change in pumpage estimated to be nearly five million gallons a day or about 200,000 gallons a day for each foot of decline in head. The seasonal fluctuation in the head on the Raritan formation at Camden appears to be at most only about 10 feet for a change in pumpage of 3.5 million gallons a day, or 350,000 gallons a day for each foot decline in head. As compared to the fluctuation in all these formations, that in the Mount Laurel-Wenonah sand is rather great.

The most direct ultimate effect of a great lowering of the head if the pumpage is increased will be an increase in the cost of pumping. This may result not merely from the increased power consumption necessary to raise the water from a greater depth but also from expenditures necessary for changing the pump installations to suit the new conditions. The Avon pump bowls are set at a depth of about 180 feet. Observations show that the pumping level in the summer of 1925 was at least 160 feet below the surface. The pumping level probably is not lowered relatively as much as the non-pumping level for a given increase in pumpage. Nevertheless, a considerable increase in pumpage may cause the pumping level to fall below the pump bowls and it would be necessary to lower them. The bowls are 15 inches in diameter, and are set in 18-inch casing which reaches to a depth of 210 feet. Below that the casing is only 12 inches in diameter. If it were necessary to lower the bowls to a greater depth than 210 feet it would be necessary to install a pump with smaller bowls.

Another possible result of a lowering of the head with increased pumpage may be the drawing in of salt water from beneath the ocean. This problem is considered on pages 44 to 47.

The increase in consumption from the Mount Laurel-Wenonah formation in recent years has been rather small and it is not anticipated that the head will be lowered to such an extent that any important pump changes will be needed in the near future or that salt water contamination is especially imminent. Nevertheless, in view of possible unexpected increases in consumption, it is important to watch the fluctuations of the static head to determine more accurately, if possible, what changes may be expected in the future.

ENGLISHTOWN FORMATION

Details.—Comparatively few data are available in regard to the permeability of the Englishtown formation. No reliable pumping data have been obtained. Uncertain data in regard to a well at the Belmar Water Works seem to indicate a drawdown of about 55 feet when pumping 200 gallons a minute. The static level is reported to have been 90 feet. A vacuum gage connected with the pump bowls at a depth of 114 feet by a long tube showed a vacuum of 28½ inches, presumably indicating that the water level was 31 feet below the bowls or 145 feet from the surface. On the basis of this data the specific yield was about three and a half gallons per minute per foot of drawdown or somewhat more than that of the Avon well No. 2. (See page 26.) However, there is said to be less screen in the Belmar well and the specific capacity per foot of screen is about .030 or somewhat greater than in Avon well No. 2. Since the well was put in service the yield has declined and there is some reason to believe that the first test may not have been severe enough to indicate the true water-bearing capacity of the formation which may be lower than the test data seem to indicate.

No test data are available for the wells that draw from the Englishtown formation in the Ocean Grove field. On August 27, 1925, the pumping level in one well was 154 feet below the top of the casing. Since the wells were in operation almost 24 hours a day a non-pumping level could not be determined. The pumping level on that day was 116 feet below the highest non-pumping level observed during the present investigation, namely, 37.94 feet on April 1, 1925. As compared to this the difference between the non-pumping level in the Avon No. 2 well on April 1 and the non-pumping level on August 27 was 122 feet. The actual yield of the Avon well on August 27 was less than 200 gallons a minute. The reported yield of the Ocean Grove well is about 300 gallons a minute. Actually it was probably less although perhaps not as low as the yield of the Avon well.

In an observation well in the Englishtown formation at the Whitesville station of the Monmouth County Water Company the range in water level from its low point on August 27, 1925, to April 10, 1926, was 38.29 feet. On the former date a well not over 300 feet distant was pumping from the same horizon. As compared to this, the range in water level on the Mount Laurel-Wenonah formation in the Avon No. 1 well between the same dates was 50 feet. In this connection it should be borne in mind that, as shown in the table on page 18, the increase in pumpage from winter to summer was probably a little greater from the Englishtown than that from the Mount Laurel-Wenonah, and yet the effect was not as great. The Whitesville well draws water from two horizons, so it does not afford a very precise basis for comparison.

No data have been found to show what the original static head was in the Englishtown horizon in the area between Asbury Park and Belmar. In 1896, at Mantoloking, 10 miles south of Belmar, the water level in a well to what is believed to be the Englishtown rose nine feet higher than in a well drilled to what is probably the Mount Laurel-Wenonah formation.[1] If the same relation existed in the Asbury Park region the original head on the Englishtown was probably at least 60 feet above sea level. In the winter of 1924-1925 the head on the Englishtown at Ocean Grove at its highest point was approximately 25 feet below sea level, or about 85 feet below the estimated original head. The total lowering of head at that time was somewhat greater than for the Mount Laurel-Wenonah formation, but the draft from the Englishtown formation in the Asbury Park region was nearly double. In addition there was some consumption from the Englishtown at several places south of Belmar.

[1] Annual report of State Geologist for 1896, p. 152.

Summary.—Although the data are inadequate for close comparisons, such as they are, they seem to indicate that the Englishtown formation in the Asbury Park region yields water somewhat more freely than the Mount Laurel-Wenonah. Compared to the Kirkwood and Raritan formations, pages 38 and 43, it is a much poorer water-bearer than the other two sands. Although the Englishtown does seem to be a better water producer than the Mount Laurel-Wenonah, the decline in head that has already occurred in it indicates that a further considerable decline may be expected if there is any great increase in pumpage.

THE RARITAN FORMATION

Data in regard to the water-bearing capacity of the Raritan formation are even more meager than those relating to the Englishtown. The Raritan is used at only three localities in the region—the Asbury Park well field, and the Whitesville and Jumping Brook Stations of the Monmouth County Water Company. The Asbury Park wells are so arranged that measurements cannot be obtained easily. Observations have been made only on wells at the Whitesville field.

The specific capacity of an 8-inch Layne well at the Whitesville station was 12.5 gallons per foot of drawdown or fully four times as great as that of the Avon well No. 1 drawing from the Mount Laurel-Wenonah formation (p. 26). The ratio between the specific capacity per foot of screen for the two wells was also about the same. In the Asbury Park well field two wells with 6-inch screen yield 650 to 750 gallons a minute each from the Raritan and a well with 8-inch screen yields about 1,000 gallons a minute. The drawdown in these wells is believed to be about 55 feet, but no measurements have been made for some time. On this basis, however, the minimum specific capacity will be 11 or 12 gallons per foot of drawdown. There is little doubt that the wells in the Raritan yield much more water than those in either the Mount Laurel-Wenonah or Englishtown formations.

A few monthly measurements on a well at the Whitesville station show that the seasonal fluctuation in head on the Raritan is slight as compared to the fluctuation on the other two formations. At its lowest observed point on August 27, 1925, the water stood only 15.88 feet below the top of the casing although a well not over 250 feet distant was pumping about 900 gallons a minute. During the spring of 1926 the water stood practically at the top of the casing. The maximum seasonal fluctuation was about 16 feet as compared to 38 feet in a well to the Englishtown at Whitesville and more than 60 feet in a well to the Mount Laurel-Wenonah at Avon under comparable conditions.

The original head on the Raritan sand in a 1,321-foot well at Asbury Park was about 12 feet above the surface or about 22 feet above sea level.[1] The head on the formation at Whitesville during the winter of 1925-1926 is estimated to have been at least 15 feet above sea level or less than 10 feet below its original level. At its lowest in August, 1925, the head was near sea level. The maximum decline in head on the Raritan formation, therefore, has been much less than the decline in head on either the Mount Laurel-Wenonah or the Englishtown formations, although the draft from it in both summer and winter is greater than from either of the other sands (p. 18).

In brief, all indications show that the Raritan sand is the best water-bearing formation in the Asbury Park region. The data available are hardly sufficient to permit careful comparisons with the Raritan elsewhere in the State or with the Kirkwood. On the basis of the specific capacities per square foot of screen (p. 26), the Raritan at Asbury Park compares favorably with the same formation at Camden and with the 800-foot sand at Atlantic City. However, because of the greater distance from the outcrop it is probable that a large draft on the Raritan at Asbury Park would cause a greater lowering of the head than the great draft at Camden has produced.

The head on the Raritan may be expected to decline as the pumpage increases, but the decline for a given increase will be much less than for either the Mount Laurel-Wenonah or Englishtown formations. All indications are that at least several million gallons additional can be drawn from the Raritan before the head has dropped so low as to require important changes in pumping equipment or cause a possible invasion of salt water (p. 46).

POSSIBILITY OF CONTAMINATION OF WELLS BY SALT WATER

General Statement.—In many localities near the ocean where the head on water-bearing formations has been lowered by pumping, salt water has been drawn in. In view of the situation of the wells in the Asbury Park region near the ocean and especially of the great lowering of the head on the Mount Laurel-Wenonah and Englishtown formations it is pertinent to consider this danger. Unfortunately, no definite information is available and it is necessary to resort to conjecture.

[1] Annual report of State Geologist for 1895, p. 74.

Conditions in the Mount Laurel-Wenonah and Englishtown.—At its lowest point during the summer of 1925 the non-pumping head on the Mount Laurel-Wenonah formation was about 65 feet below sea level in the Avon wells and about 10 feet lower in the Ocean Grove observation wells. The head on the Englishtown was probably about 40 feet below sea level. No data are available to show over how large an area this great lowering of the head extended. Judging from conditions in the Atlantic City region, where more information was obtained, it is probable that the head on the Mount Laurel-Wenonah formation in the Asbury Park region is below sea level for several miles inland and doubtless for a nearly equal distance out beneath the ocean. The area in which the head on the Englishtown formation is below sea level perhaps is not quite as extensive seaward, but undoubtedly reaches out for some distance offshore.

Both of these formations were originally deposited beneath the ocean and must have at one time contained salt water. Without discussing the method by which fresh water came to be in the formations it may be stated that the danger of future contamination depends upon whether salt water is anywhere present in the formations offshore and if so how near it is to the pumping wells. If it is within the area in which the head has been lowered there will be a tendency for the salt water to move toward the wells. If the salt water is only near the border of the area of influence of the wells the rate of movement landward will be slow and it may take many years for the salt water to reach them. However, the rate of movement will increase as the salt water approaches the wells. Furthermore, it will increase if the consumption increases. If the salt water is now just beyond the area of influence of the wells, an increase in consumption, with consequent further lowering of head, will start the salt-water movement toward the land.

No information is available to show whether salt water actually is anywhere present in either the Mount Laurel-Wenonah or Englishtown formations. The analyses on page 20 show that the chloride content, which is the best indication of the presence of salt water, is exceedingly low. If the formations outcrop beneath the ocean it must be either at a distance of about 100 miles offshore, or in Sandy Hook Bay about 15 miles north of Asbury Park. Even though the nearest of these points of access is probably beyond the limit of the area in which the head on the formations has been lowered, it is entirely possible that salt water may be present in the formation much nearer to the wells in the Asbury Park region. Some of the factors bearing on the problem of possible invasion of fresh-water horizons by salt water have been considered in a report on the so-called 800-foot sand in the Atlantic City region. The evidence given in that report led to the conclusion that salt water may eventually be drawn into the Atlantic City wells. In comparing the conditions in the two regions the only factor of value is the elevation of the original static head. In the Atlantic City region the head on the 800-foot horizon was about 20 feet above sea level. For the Asbury Park region the original head on the Mount Laurel-Wenonah formation was about 50 feet above sea level and on the Englishtown possibly even higher. The greater head on these formations is to be attributed to a greater elevation of water in the intake area of the formations up the dip from the pumping wells. In this condition there is a suggestion that there may be less danger from salt water contamination of the Mount Laurel-Wenonah and Englishtown formations than of such contamination of the 800-foot sand at Atlantic City. On the other hand, since a given increase in pumpage causes a greater lowering of head on the Mount Laurel-Wenonah and Englishtown formations than on the 800-foot sand, the apparent factor of safety due to the difference in original head may eventually be more than offset by a considerable increase in pumpage from the Mount Laurel-Wenonah. There are no other data that furnish any basis for consideration as to the possibility of salt water contamination of these horizons.

Conditions in the Raritan Formation.—In considering the possibility of contamination of the Raritan formation the most important fact is that even in the summer of 1925 the head on the formation apparently was at most only a few feet below sea level. If the head was below sea level offshore such depression probably did not extend very far out. Although it is impossible to say whether salt water is present in the formation offshore and if so how far out, other conditions being equal there is much less danger of salt water contamination of the Raritan in the Asbury Park region than of the Mount Laurel-Wenonah or Englishtown formations.

Conclusions.—In view of the possibility of contamination it is desirable that occasional analyses of water from each formation be made and a watch kept for conditions that may give information on this problem.

In the Atlantic City region some wells have been contaminated by salt water entering the casing through holes in the upper horizons which are salty. The upper horizons in the Asbury Park region do not bear salt water except perhaps right at the ocean's edge. Therefore, local contamination of wells in the Asbury Park region does not seem likely.

GENERAL SUMMARY AND CONCLUSIONS

In the Asbury Park region there are three principal water-bearing horizons, namely, in descending order, the Mount Laurel-Wenonah, the Englishtown, and the Raritan. The largest quantity of water is obtained from the Raritan and the smallest from the Mount Laurel-Wenonah. The quality of water from all three formations is good except that the water from the Raritan formation contains much iron and must be aerated and filtered. The choice of formation to be used in developing a water supply should be based on other factors which relate to the water-bearing capacities of the three sands.

The yield of the wells that draw from the Raritan formation is relatively large while that of wells from the other two formations is comparatively small and the drawdown is great. The summer increase in pumpage causes a very considerable decline of the head on these two formations, and the head has been lowered many feet below its original position. Any further large increase in pumping will cause the head to decline much farther with consequent increase in pumping cost and the possible drawing in of salt water from beneath the ocean. On the other hand, pumping from the Raritan formation has caused but little lowering of the head.

In view of the already considerable pumping lift in wells drawing from the Mount Laurel-Wenonah and Englishtown formations, it is desirable that further decline be limited. It is therefore recommended that so far as possible additional supplies be developed from the Raritan formation. This will require a greater initial cost for drilling to a greater depth and installing filters, but since the pumping lift will not be so great, at least for some time to come, this plan of development may be more economical in the long run.

If the increase in water consumption in the Asbury Park region continues at the same rate as during the period from 1917 to 1925 it is estimated that in 1950 the consumption will be a little more than 8,000,000 gallons a day. On the other hand, if the average increase each year is double that of the past eight years the consumption in 1950 will be about 12,500,000 gallons a day. Although the data are inadequate to permit specific predictions it seems probable that even the larger quantity of water can be obtained from wells without over-drawing the supply or lowering the head inordinately. However, the draft may increase at a greater rate than indicated, especially by the development of ground water supplies in nearby communities south of the Asbury Park region. Therefore, it will be a wise precaution to continue observations on the three horizons in order that a more definite basis may be available for a determination of the effect of future increases in pumpage.

RECOMMENDATIONS FOR FUTURE WORK

If more definite data is to be obtained bearing on the ultimate safe yield of the water-bearing formations in the Asbury Park region the observations now being made should be continued and additional observations should be made as follows:

1. The study should be extended to include all wells drawing from any of the three principal horizons which may affect the head in the Asbury Park region. This would include mainly public supply wells southward along the coast for some miles, but might also include private wells.

2. If possible, periodic observations should be made to determine the seasonal fluctuations of head on the Englishtown and Raritan formations. Adequate opportunities for such observations are now lacking but wells may subsequently become available for measurement.

3. Pumping tests with observations on several wells should be made on wells drawing from the Englishtown and Raritan formations to obtain data as to their yields for comparative purposes. Tests on the Englishtown can perhaps be made in the Belmar well field and on the Raritan in the Asbury Park.

4. Sand samples should be obtained from new wells for laboratory tests.

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