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*

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GROUND WATER SUPPLIES of the PASSAIC RIVER VALLEY near Chatham, N. J.

BY

DAVID G. THOMPSON

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Board of Conservation and Development

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CONTENTS

ILLUSTRATIONS

ABSTRACT

In 1927 an average of about 10,000,000 gallons of water a day was pumped from several groups of wells situated in the Passaic River Valley near Chatham, to supply a number of suburban communities in northern New Jersey. About 53 per cent of the water was pumped by the Commonwealth Water Co. from a group of wells designated as the Canoe Brookfield, 37 per cent from two well fields of the East Orange Water Department known as the Dickinson and White Oak Ridge fields, and the remainder from smaller fields. Judging from past records of consumption by 1957 the total water requirements in the communities served from the well fields under consideration may be expected to be about 27,000,000 gallons a day. The greater part of this increase may be expected in the requirements of the Commonwealth Water Co. The purpose of this report is to consider to what extent future increases in consumption can be met by the development of additional supplies of ground water.

The principal supply of ground water is obtained from beds of sand and gravel, of Pleistocene age, which lie at a depth of approximately 100 to 135 feet and which are confined to pre-glacial channels cut in the bed rock. Elsewhere in the region the bed rock, which consists of red sandstone and shale and trap rock of Triassic age, is struck at depths as shallow as 60 to 75 feet, and the overlying material consists largely of clay which yields little or no water. In the well fields that have been studied the water-bearing formation is overlain by relatively impervious clay and there is little if any recharge directly from rain in the immediate vicinity. An unsolved problem is as to whether elsewhere there is sufficient recharge to meet the present and future draft.

Since about 1899, when the first well was drilled in the region, the static head has dropped 60 feet or more in the Canoe Brook field, about 25 feet in the White Oak Ridge field, and lesser amounts in the other fields. Careful measurements show that the hydrostatic head on the water in the sand and gravel fluctuates in accord with changes in the rate of pumping in near-by wells. Furthermore, changes in the rate of pumping in the Canoe Brook well field produce fluctuations in the head in the White Oak Ridge and Dickinson fields, and conversely changes in the rate of pumping in either of these two fields affects the water level in the Canoe Brook field. A large part of the decline in head is due to the fact that the water moves to the well fields in relatively constricted channels in the bed rock with consequent loss of head due to friction.

On the basis of detailed observations it is concluded that the maximum possible rate of pumping in the Canoe Brook field is limited to about 10 million gallons a day or less. This is because the drawdown that can be attained to produce given flows of water is definitely limited by the depth of the water-bearing formation. The rate of yield of the East Orange well fields presumably is also limited by the same factor. It may be possible to develop additional supplies of ground water in other buried channels in the bed rock. If this is done further observations should be made to determine whether the recharge of the formation is sufficient to meet any contemplated increases in draft.

The water pumped from the several well fields for public use is moderately mineralized, ranging from about 150 to 366 parts per million of total solids. However, samples from several test wells, particularly in the Dickinson field, are more highly mineralized, containing as much as 2,362 parts per million of total solids. The water of high mineralization appears to come from the bed rock and not from the overlying beds of sand and gravel.

GROUND WATER SUPPLIES OF PASSAIC RIVER VALLEY NEAR CHATHAM, NEW JERSEY

By David G. Thompson

INTRODUCTION

This report describes ground-water conditions in the Passaic River Valley near Chatham. It is confined principally to a consideration of public supplies and especially of the Canoe Brook well field of the Commonwealth Water Co. and the White Oak Ridge and Dickinson well fields of the East Orange Water Department, which lie from 1½ to 2½ miles north and northeast of Chatham. Some information is given in regard to the well fields of the Chatham and Madison Water Department, the Normandy Water Co., and other public and private well supplies. The area covered by the report is shown on Plate 1.

The investigation on which the report is based is one of several undertaken by the New Jersey Department of Conservation and Development in cooperation with the United States Geological Survey, to determine, as nearly as possible, the safe yield of the principal water-bearing formations in different parts of the State.[1]

These studies were made by the writer in consultation with and under the general direction of H. T. Critchlow, at the time chief of the division of waters of the New Jersey Department of Conservation

[1] Reports have already been prepared by the writer as follows: Ground-water supplies of the Atlantic City region (New Jersey Dept. Conservation and Development Bull. 30, 1928); Ground-water supplies in the vicinity of Asbury Park; Ground-water supplies of Camden and vicinity. Certain phases of the work have been discussed in the following papers: Memorandum on investigation of quantities of ground water available for public and industrial supplies in New Jersey, in Report of the Water Policy Commission to the Senate and General Assembly of the State of New Jersey, pp. 28A-40A, February, 1926; Ground-water problems on the barrier beaches of New Jersey: Geol. Soc. America Bull., vol. 37, pp. 436-474, 1926.

This report is as submitted for publication in 1929. Since it was prepared additional water supplies have been developed or changes in the method of recovery of water have been made at certain of the well fields described in this report. It has not been possible to incorporate in the report detailed information in regard to these changes. It is believed, however, that such changes do not affect the conclusions presented herein.

and Development, and O. E. Meinzer, geologist in charge of the division of ground water of the United States Geological Survey. In the investigation of the region described in the present report, Mr. Critchlow, John N. Brooks, then hydraulic engineer of the Department of Conservation and Development, and the late M. W. Twitchell, assistant State geologist, collaborated in the collection and discussion of much of the data relating to certain tests. The writer has been ably assisted at one time or another by E. W. Downs, formerly junior engineer of the United States Geological Survey, and H. C. Barksdale, then assistant hydraulic engineer of the Department of Conservation and Development.

Many of the data used in the report were furnished by the officials of public water systems in the region. The writer is glad to acknowledge the cooperation of Roswell M. Roper, engineer and general manager, and George Barnett, of the East Orange Water Department; W. I. McMane, vice-president of the Commonwealth Water Co.; F. R. Berry, engineer of the American Waterworks & Electric Co., of which the Commonwealth Water Co. is a subsidiary; the firm of Tribus & Massa, consulting engineers for the Borough of Madison; the Kelly Well Co., of Grand Island, Neb.; and all others who have given information or assistance in the course of the investigation.

WATER SUPPLIES OF THE REGION

Within the area shown on Plate 1 an average of about 10,000,000 gallons of water a day is pumped—all from wells—to furnish the public supply for several communities. A large part of this quantity —namely, that pumped by the East Orange Water Department and the Commonwealth Water Co.—is used outside of the area in which it is obtained. The sources of supply of the several systems are described briefly in the following pages.

Commonwealth Water Co.—The largest system is that of the Commonwealth Water Co., a subsidiary of the American Waterworks and Electric Co., which furnishes water to the towns of Summit, Millington, Stirling, Livingston and West Orange, the townships of Springfield (small part of), Millburn (the larger part of), New Providence and Maplewood, and the Borough of New Providence.

The company has two well fields, known as the Baltusrol and Canoe Brook fields. The Baltusrol field, about a mile south of Summit, contains 16 wells, 4 to 8 inches in diameter and 60 to 300 feet deep, which derive their water from deposits of Quaternary age and red sandstone of Triassic age. The capacity of the field in dry seasons is about 1,500,000 gallons a day. This field is not in the area covered by this report, and no further consideration is given to it.

The Canoe Brook well field lies along the stream of that name about 2 miles north of Summit and about 1½ miles northeast of Chatham. At one time or another about 50 wells have been drilled in this field, scattered over an area of about 150 acres, but since 1927 only about 15 of these have been in use.[1] The wells range in diameter from 6 to 26 inches and in depth from 50 to 315 feet. Most of the wells are not more than 10 inches in diameter and are equipped with slotted pipe for screens. These wells are pumped by air lift, and the water flows by gravity from the wells to a central pumping stream. Four of the wells are 24 to 25 inches in diameter at the top. Two of these are equipped with 16-inch Layne shutter screen, and the other two with 25-inch Kelly concrete screen. Three of these wells are pumped by low-duty pumps, which deliver water to the gravity collection pipe; the fourth pumps directly into the distribution main. In addition to the wells mentioned, about 20 test holes have been drilled in or near the well field, but these have not been cased. The location of many of the test holes and wells is shown on Plate 1.

The Canoe Brook wells have yielded at a rate as high as 8,000,000 gallons a day for short periods, and on many days the total pumpage has been 6,000,000 gallons.

Summit is supplied principally from the Baltusrol well field, and the other communities named, which are farther north, are supplied from the Canoe Brook well field, but both systems are interconnected. The distribution system is equipped with two balancing reservoirs, each of which has a capacity of about 1,000,000 gallons.

East Orange.—The water supply for East Orange is obtained from two well fields; a third field is used for reserve supply. The principal well field is near Canoe Brook where it is crossed by Parsonage Hill road, about 2½ miles northeast of Chatham. (See pl. 1.) This well field is sometimes known as the Canoe Brook field, but to distinguish it from the Canoe Brook field of the Commonwealth Water Co. it will be designated in this report as the White Oak Ridge field. This field contains 20 wells, 8 inches in diameter and 108 to 130 feet

[1] Since this report was written the Commonwealth Water Co. has completed a reservoir into which water is pumped from Canoe Brook when there is sufficient flow in the stream. As long as there is sufficient surface water available it is used to a large extent, thereby reducing the draft on the ground water reservoir. A 25-inch well was also completed in 1928, the draft from which is limited by regulation to 1.5 million gallons a day average for any month.

deep, most of which are scattered over an area of less than 25 acres.[1] The capacity of the field is between 2,500,000 and 3,000,000 gallons a day. The wells are pumped by suction.

The second field, known as the Dickinson field, is on the east side of the Passaic River about 1½ miles north of Chatham and 1¼ miles northwest of the White Oak Ridge pumping station. This field contains only three wells, of the Layne type, 24 inches in diameter at the top and 16 inches at the bottom and 130 feet deep. The wells are from 500 to 800 feet apart. One of these wells delivers 1,500,000 gallons a day, and the total yield of the three wells is about 2,500,000 gallons a day. The water is pumped by the low-duty pumps on the wells to the White Oak Ridge station, whence high-duty pumps boost it over South Mountain to the city.

The third well field of the East Orange Water Department, known as the Slough Brook field, is on the north side of the Parsonage Hill road about seven-eighths of a mile northwest of the White Oak Ridge pumping station. This field originally comprised about 20 wells, 8 inches in diameter and 200 to 250 feet deep, operated by air lift. In 1927, in order to obtain more efficient operating conditions, the small-diameter wells were replaced by several of large diameter which were to be equipped with deep-well turbine pumps. The yield of this field is between 750,000 and 1,000,000 gallons a day. The water is delivered to the White Oak Ridge pumping station and thence boosted over South Mountain. The wells in the Slough Brook field derive their water mostly from rock; those in the other two fields obtain water from sand and gravel.[2]

Chatham.—The water supply for Chatham is obtained from 6 wells situated in the western part of the town, about 800 feet north of Main Street (also called Morris Avenue). (See pl. 1.) The wells are 4 to 8 inches in diameter and 98 to 326 feet deep. Water is taken from the wells by direct suction and pumped into the distribution system, with a standpipe as an equalizer. The yield of the wells in recent years is not known except that one well drilled in 1924 yielded 260 gallons a minute.

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[1] Since this was written, three large diameter (30 in.) wells of the Kelly type have been put down by East Orange. The entire supply from the White Oak Ridge field is now (1932) obtained from these new wells and the old wells are not used. H. B. K.

[2] In 1931, permission was given East Orange to develop a new supply, northwest of the Dickinson field in the so-called Braidburn field in Florham Park, where three large wells had been developed. H. B. K.

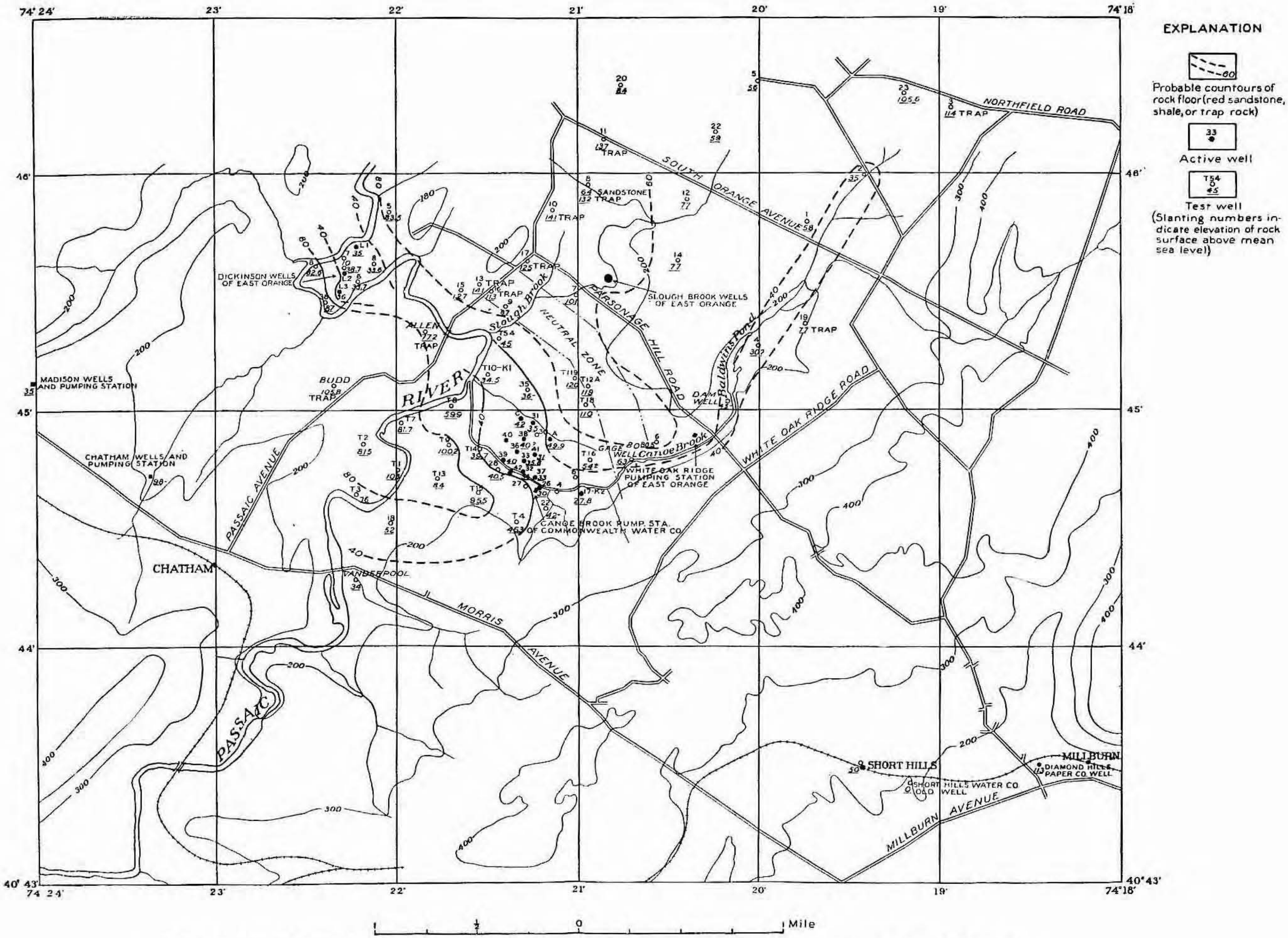

PLATE I.—Map of Passaic River Valley, near Chatham, showing the location of well fields and contours of surface of bedrock.

Madison.—The Borough of Madison is supplied with water from 9 wells in a tract of about 65 acres, near the eastern edge of town, about 1,000 feet northeast of Main Street. The wells are 5 to 8 inches in diameter and range in depth from 80 to 165 feet. They are pumped by direct suction. The pressure on the distribution system is equalized by a standpipe. In a test of the well field on October 21, 1925, the yield was about 1,180 gallons a minute (about 1,700,000 gallons a day).

Normandy Water Co.—The well field of the Normandy Water Co., which supplies Normandy Heights, is about 2½ miles northwest of Madison and an equal distance east of Morristown. The field comprises 27 wells which range in diameter from 4 to 8 inches and in depth from 80 to 90 feet. The wells overflow naturally into collecting basins, from which the water is pumped into the distribution system by a centrifugal pump. Two standpipes provide storage for about 500,000 gallons. In 1924 nine wells were in use and yielded about 576,000 gallons a day by natural flow. The capacity of the high-duty pump is about 850,000 gallons a day.

Other Wells.—There are a number of privately owned wells in the region covered by this report. Data in regard to some of them have been used in the study of certain problems, but no general compilation of the data has been made. Pertinent facts in regard to the well fields of certain public supplies a short distance outside of the area are considered briefly in the proper place.

CONSUMPTION

Annual Consumption.—Reliable statistics in regard to consumption of water from public supplies in the region are available only for the period since 1917.

In 1927 the average daily consumption in the area was a little more than 10,500,000 gallons. More than 50 per cent of the water was obtained from the Canoe Brook well field of the Commonwealth Water Co. About 9,700,000 gallons, or more than 90 per cent of the total, came from that field and the White Oak Ridge and Dickinson fields of the East Orange Water Department. These three fields lie within an area of less than 2 square miles.

AVERAGE DAILY CONSUMPTION OF GROUND WATER FOR PUBLIC SUPPLY FROM WELL FIELDS IN PASSAIC RIVER VALLEY NEAR CHATHAM, 1917-1927, IN THOUSAND GALLONS [a]

Year	*Commonwealth Water Co.* [b]	*East Orange Water Dept.*	*Madison Water Dept.*	*Chatham Water Dept.*	*Normandy Water Co.*	*Total*
1917	1,693	2,840	214	222	83	5,052
1918	1,796	2,984	199	284	61	5,324
1919	1,818	3,094	458	281	70	5,721
1920	2,075	3,257	449	287	70	6,138
1921	2,679	3,589	485	258	92	7,103
1922	3,062	3,471	454	333	95	7,415
1923	3,545	3,515	584	441	96	8,181
1924	3,923	3,557	514	392	84	8,470
1925	4,668	3,689	559	306	108	9,330
1926	5,122	3,894	513	272	131	9,932
1927	5,707	3,993	544	289	122	10,655
1928	6,397	4,226	573	314	148	11,658
1929	6,828	4,587	602	358	167	12,542
1930	5,787 [d]	4,654	609	354	292	11,696
1931	4,490	4,681	594	337	203 [c]	10,305
Ratio, 1927 to 1917, in per cent.	337	141	254	130	147	211

[a] From records filed with the Department of Conservation and Development.
[b] Canoe Brook well field only.
[c] Estimated. Plant was taken over by the Morristown Water Department, August 15, 1931, and separate records discontinued.
[d] A surface supply from Canoe Brook was placed in operation October, 1929, reducing the draft on the wells as indicated.

In the 10-year period 1918-1927 the total daily consumption from the region increased more than 100 per cent over the consumption in 1917. The greatest increase—237 per cent—was in the consumption from the Commonwealth Water Co.'s system. The next greatest increase—154 per cent—was in the consumption from the Madison system. The consumption from the systems of East Orange, Chatham, and the Normandy Water Co. increased less than 50 per cent.

The average annual rate of increase in consumption was about 560,000 gallons a day. The number of years in which the active increase was less than the average and in the number in which it was greater were equal. However, in the last half of the period the increase was less than the average in only one year. There was, therefore, a tendency for the consumption to increase somewhat more rapidly than the average for the entire period. The average increase for the five years, 1923-1927, was about 650,000 gallons daily. The greatest part of the total increase from year to year has been due to large increases in the consumption from the Commonwealth system, which averaged for the 10-year period about 410,000 gallons a day and for the last five years of that period more than 500,000 gallons a day. A detailed analysis of the probable future increase in consumption in the region is not within the scope of this paper, but certain facts may be pointed out.

Future Consumption.—If the consumption continues to increase at the same rate as the average for the 10 years 1918-1927, the total demand on the well fields under consideration will be about 16,000,000 gallons a day in 1937, about 22,000,000 in 1947, and 27,000,000 in 1957. On the other hand, if the rate is more nearly like the average for the years 1923-1927, the average will be about 17,000,000 gallons a day in 1937, about 24,000,000 in 1947, and about 30,000,000 in 1957. It is entirely possible that the consumption may increase at an even greater rate than in the five years 1923-1927.

If the demand on the Commonwealth Water Co.'s well field increases at the average rate for the five years 1923-1927, in 1937 it will be about 11,000,000 gallons a day, in 1947 about 16,000,000, and in 1957 about 22,000,000. On the same basis, in 1957 the demand on the East Orange system will be about 7,000,000 gallons a day, on the Madison system only a little more than 1,000,000, and on the Chatham and Normandy Water Co.'s systems considerably less than 1,000,000. From these figures it is obvious that the greatest problem in providing for future increases in consumption relates to the Commonwealth Water Co.'s system and the East Orange system.

Private Wells.—No data are available as to the consumption from privately owned wells in the region. There are no large industries here to use ground water, and the water from private wells is used largely for domestic purposes at dwellings not within the areas supplied by the different systems. It is believed that the consumption from private wells is not great, at most not over 100,000 gallons a day and probably much less.

Monthly Variations.—The fluctuations in average daily consumption from month to month are shown by the following table:

These figures show only a small range. The greatest range between maximum and minimum consumption was shown by the system of the Madison Water Department, although even here the maximum was only 26 per cent greater than the minimum. In the Commonwealth Water Co.'s system the maximum was only 16 per cent greater than the minimum. The summer of 1927 was cool, and the precipitation was above the normal, so that the summer consumption was perhaps relatively less than usual. However, in 1926, the difference between the maximum and minimum for the Commonwealth Water Co. was only 6 per cent greater than in 1927. As the months of highest and lowest consumption in any one year are not the same for all systems the difference between the maximum and minimum total daily consumption in the whole region is less than for the individual systems.

Daily Variations.—A point to be borne in mind when considering the well capacity that must be available in any well field is that the consumption is not divided equally throughout the day, but there are certain periods when the rate of pumping is much greater than in others. For example, during a test of the Commonwealth wells in June, 1927, during the daylight hours the rate of pumping was as high as 7,500,000 gallons a day, but at night it fell as low as 4,000,000 gallons a day. The total daily pumpage was about 6,000,000 gallons. The highest pumpage in any one day from the Canoe Brook well field of the Commonwealth Water Co. has been about 7,500,000 gallons, and the highest rate for a short period on such a day has doubtless been somewhat more than 8,000,000.

AVERAGE DAILY CONSUMPTION OF GROUND WATER FOR PUBLIC SUPPLY FROM WELL FIELDS IN PASSAIC RIVER VALLEY NEAR CHATHAM DURING 1927, BY MONTHS, IN THOUSAND GALLONS [a]

Month	*Commonwealth Water Co.* [b]	*East Orange Water Dept.*	*Madison Water Dept.*	*Chatham Water Dept.*	*Total*
January	5,234	4,022	500	279	10,035
February	5,244	4,035	481	261	10,021
March	5,230	4,064	498	286	10,078
April	5,426	4,047	539	293	10,305
May	5,506	3,950	561	282	10,299
June	5,932	4,137	605	287	10,961
July	5,973	3,909	582	291	10,755
August	5,875	3,668	516	296	10,355
September	6,062	3,833	589	310	10,794
October	6,032	4,070	560	318	10,980
November	5,991	4,036	535	303	10,868
December	5,950	4,016	571	270	10,807
Year	5,707	3,993	544	289	10,533

[a] From records filed with the Department of Conservation and Development.
[b] Canoe Brook field only.

GEOLOGIC CONDITIONS AFFECTING OCCURRENCE OF GROUND WATER [1]

TOPOGRAPHY

The region described in this report is a part of the geologic region known as the Piedmont Province. Its surface in general is that of a dissected plateau, with low hills. The rolling surface of fairly low relief is broken by several high ridges, locally called mountains, which trend in general northeast. The area which contains the well fields described in this report constitutes part of a plain that lies only a few feet above the Passaic River. This plain lies against one of the high ridges known as Second Watchung Mountain, or merely Second Mountain. (See pl. 1.) A short distance farther southeast lies First Mountain, separated from Second Mountain by a long, narrow trough. The altitude of the lowland part of the area is from about 175 to 225 feet, and the two ridges named attain 400 to 550 feet.

ROCK FORMATIONS

The bed rock of the region consists principally of red shale and sandstone of Triassic age. The high ridges are composed of basaltic lava, which is commonly called trap. The trap is much harder than the sandstone and shale and has therefore resisted weathering and erosion and forms the ridges. In the area under consideration, however, the bedrock crops out generally only in the ridges, being covered on the lowland by unconsolidated deposits of sand, gravel, and clay of varying thickness.

In the Pleistocene epoch the region was covered by the great continental glacier that moved down from the north. This glacier deposited a large part of the unconsolidated material that now covers the bed rock and produced other changes that must be considered in connection with the ground-water problems of the region.

PRE-GLACIAL TOPOGRAPHY AND EFFECT OF GLACIATION

The configuration of the surface and the drainage of the basin of the Passaic River before the coming of the glacier were very different

[1] The description of the geology of the region is based in part on data obtained in the field and in part on information obtained in the following reports of the New Jersey Geological Survey: Lewis, J. V., and Kümmel, H. B., The geology of New Jersey; Bull. 14, 1915; Salisbury, R. D., and others, the glacial geology of New Jersey: Final Rept., vol. 5, 1902: Salisbury, R. D., Surface geology, report of progress, in State Geologist Ann. Rept. for 1894, especially map of surface formations of the valley of the Passaic, 1895.

from those of today. In some places where the surface is now nearly level there were valleys cut many feet below the hills. The glacier pushed a great quantity of débris ahead of it, and much was carried directly in or on the ice. When the ice melted and retreated the débris was deposited on the bed rock. The deep valleys were filled, and the tops of some of the hills were scraped off, so that in general the surface was left more level than it was prior to the glaciation. A prominent feature left by the glacier was the great heterogenous mass of clay, sand, gravel, and boulders that was deposited at its front. This mass, which is known as a terminal moraine, has a very irregular surface, with numerous closed depressions that are not drained. Behind the terminal moraine the glacier also dropped much débris but the surface of this material is less irregular than the terminal moraine and it is known as ground moraine.

PRE-GLACIAL DRAINAGE

Salisbury and Kümmel have presented evidence that before the glacier moved southward and covered this region the principal drainage line did not follow the general direction of the present Passaic River but instead went southeastward through a deep gap in Second Mountain at Short Hills, and through First Mountain by a similar gap at Millburn.[1]

The Short Hills gap in Second Mountain is partially filled to an altitude of about 380 feet above sea level by unconsolidated material comprising part of the terminal moraine. Well records show that the unconsolidated material extends to a considerable depth. In the gap, near the Short Hills railroad station the bed rock was not struck at an altitude of 50 feet above sea level, and a quarter of a mile east of the station, at the well field of the Short Hills Water Co., the rock was struck at sea level.[2] The Millburn gap in First Mountain is still open, although partly filled with glacial deposits, and the break in the trap ridge is a conspicuous topographic feature. In contrast to these conditions, at Little Falls, where the Passaic River now passes through Second Mountain and the next lowest gap in that ridge, the bed rock in the gap is between 158 and 180 feet above sea level. The evidence indicates that the gap in the ridges at Short Hills was lower than the

[1] Salisbury, R. D., and Kümmel, H. B., Lake Passaic, an extinct glacial lake; New Jersey State Geologist Ann. Rept. for 1893, pp. 225-328, 1894. Salisbury, R. D., and others, The glacial geology of New Jersey; New Jersey State Geologist Final Rept., vol. 5, pp. 147-164, 1902. Lewis, J. V., and Kümmel, H. B., The geology of New Jersey: New Jersey Geol. Survey Bull. 14, pp. 116-120, 1915.

[2] Salisbury, R. D., and Kümmel, H. B., op. cit., pp. 304-305.

gap at Little Falls. Accordingly, in pre-glacial time, the drainage for the area directly west of the Short Hills gap must have gone through that gap. In fact, it is believed that the drainage of all the present Passaic River Basin above Little Falls went through the Short Hills gap.[1] The supposed course of the principal drainage lines is shown on Figure 1. Detailed data in regard to the position of the pre-glacial drainage channels just west of the Short Hills gap are given on pages 15-18.

[1] Borings at Mountain View where the Pompton River cuts through the third trap ridge show a drift-filled rock gorge, the bottom of which is 80 feet above tide. Hence the branch of the pre-glacial Passaic which cut that gorge could not have escaped through the Little Falls gap (158 feet) as was earlier assumed, before this deeper Mountain View gap was known. H. B. K.

FIGURE 1—Sketch map of Passaic River basin showing pre-glacial drainage. After Salisbury and others, op. cit. (1902), pl. 37.

As the glacier moved southward, or southwestward, it blocked the gap at Little Falls, and any drainage that may have gone through that gap was eventually diverted into the drainage system that went through the Short Hills gap. The glacier finally also blocked the Short Hills gap. West of Second Mountain the glacier moved only a short distance southwest of the area covered by this report. Its southern limit, marked by the terminal moraine, lies near the Delaware, Lackawanna & Western Railroad between Morristown and Summit and thence extends through the Short Hills gap to the southeast side of First Mountain. (See fig. 2.)

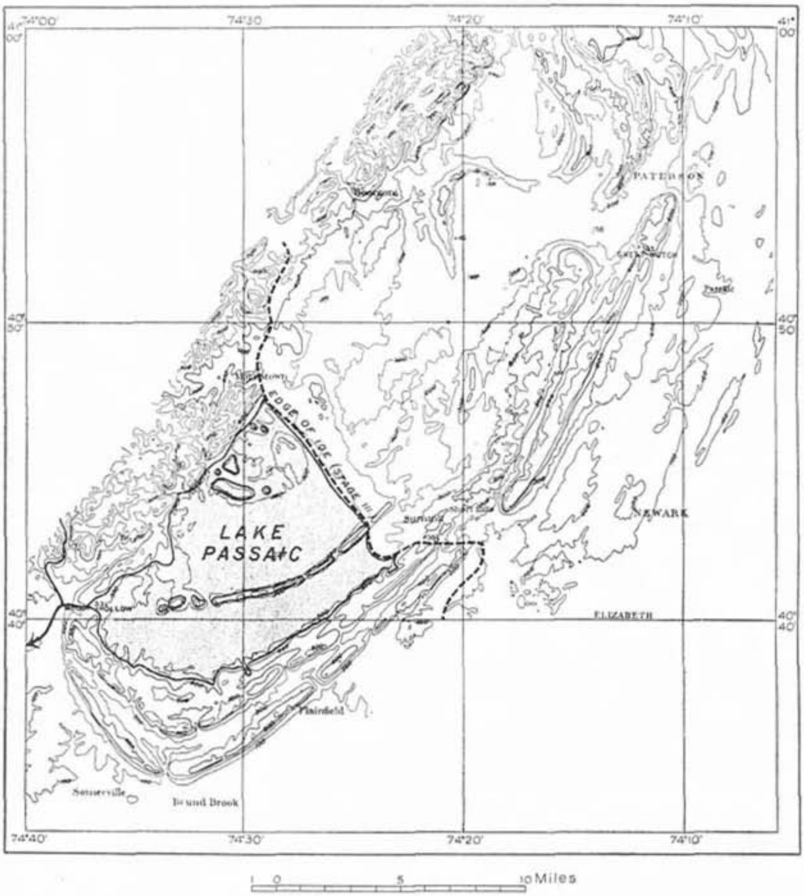

FIGURE 2.—Map of the Passaic River basin showing location of terminal moraine and area covered by Lake Passaic at time of maximum advance of glacier. After Salisbury and others, op. cit. (1902), pl. 40.

The terminal moraine is at present broken for about 2 miles, where it is cut by the Passaic River near Chatham.

When the ice was at its point of maximum advance and the Short Hills gap was blocked for a long time a lake was formed, which has been called Lake Passaic. When the ice melted and retreated the Short Hills gap was left blocked by the terminal moraine. Lake Passaic persisted until after the ice had retreated beyond Little Falls, where a low outlet was found and the drainage was established essentially as it is at present.

CHARACTER OF GLACIAL DEPOSITS

As a result of the events described above, the materials that overlie the bed rock—composed of sand, gravel, and clay—may be divided into several types, as follows:

(a) Locally there may be remnants of the pre-glacial soil and subsoil, not wholly removed by wear of the ice sheets. None of these have been identified. If present, they are likely to be buried beneath deposits left by the glacier. As suggested on page 16, certain beds of clay reported in well drilling may be of this type.

(b) Along the main pre-glacial drainage channels there may be sand or gravel beds deposited by pre-glacial or glacial floods which were overridden by the ice and buried beneath later deposits.

(c) In the part of the area covered by the ancient Lake Passaic lying south of the ice front, fine sand and clay accumulated to a considerable thickness, particularly in the area known as the Great Swamp. In the shallower portions of the area covered by the lake, deposits on the bed rock are thin. In the lower parts of the basin of Lake Passaic where the remnants of the lake persisted long after the ice had melted, there are beds of water-laid silt and clay.

(d) The terminal moraine and a large part of the region north of it is covered by till—that is unassorted or poorly sorted stony and sandy clay that was deposited as the ice melted. In places in the till are beds of sand and gravel deposited by streams formed by water from the melting ice.

The surface distribution of these types of material is very complex, but they have been accurately mapped by the State Geologist and his assistants. Their vertical distribution is also complex and ordinarily cannot be determined except by drilling. Lenses of sand and gravel of greater or lesser extent may underlie or be interbedded with till, and vice versa. Fortunately, many wells have been drilled on lands owned by the Commonwealth Water Co., and the city of East Orange.

and these wells, with a smaller number drilled elsewhere, afford valuable information.

BURIED ROCK VALLEYS REVEALED BY WELLS

The Canoe Brook well field of the Commonwealth Water Co., and the Dickinson field of the East Orange Water Department are on lowlands, more or less marshy, that constitute the flood plain of the Passaic River. The other two well fields of the East Orange Water Department and the well fields of the Chatham and Madison water departments are at altitudes only 20 to 40 feet higher. A study of data on the depth to bed rock in the area shows that the pre-glacial surface was much lower and had much greater relief. Plate 1 shows the altitude of the bed rock above sea level in about 70 wells and, by heavy contours, the shape of the pre-glacial surface in a large part of the area. In the preparation of the map, data were available for many wells in addition to those shown.

The wells are most numerous in the well field of the Commonwealth Water Co. and the shape of the bed-rock surface is accordingly best determined there. The significant feature is that beneath the present nearly level surface there is a well-defined valley cut in the bed rock about three-quarters of a mile wide which trends northwest. The bottom of it is 120 to 140 feet below the present surface and 50 to 80 feet below the rock divide on each side. In the Dickinson well field there is a similar valley which is of about the same width and depth and has the same general trend—in fact, it is apparently a continuation of the valley beneath the Canoe Brook well field. The data show that there is a depression in the general rock surface between the two fields, but unfortunately wells that would show whether the deep valley is continuous between the two fields have not been drilled at the critical locality, near the point where Passaic Avenue crosses the Passaic River, at the so-called lower Chatham Bridge. In several wells along the west side of Passaic Avenue trap was found rather near the surface. This apparently is a buried part of a trap ridge, known as Long Hill, that rises to a height of 465 feet south of Chatham. Outcrops of trap farther northeast, near Livingston, suggest that the buried ridge continues in that direction. The strike of the ridge is such that if it extended farther northeast it would lie about where trap was struck in the wells mentioned. Although data are lacking at the critical point, it appears very probable that the preglacial valley cuts through this trap ridge just about where the river now crosses Passaic Avenue.

If a straight line is drawn along the axis of the rock valley in the Dickinson and Canoe Brook well fields and continued southeastward, it passes almost directly through the points at Short Hills where, as shown on page 11, the bed rock lies very deep, and also through the wide open gap in First Mountain, near Millburn. This fact indicates beyond almost any reasonable doubt that the valley beneath the two well fields had its outlet through these two gaps in the trap ridges.

A branch of the main rock valley extends from a point near the pumping plant of the Canoe Brook well field northeastward approximately beneath Canoe Brook. The wells of the White Oak Ridge field are situated in this valley. North of that field the valley broadens somewhat. Data not shown on the map indicate that at the White Oak Ridge pumping station the western edge of the buried trap ridge that constitutes Second Mountain rises almost vertically to an altitude of 170 feet above sea level within 500 feet east of Canoe Brook.[1]

Data are not available to show the northeastward extent of the pre-glacial valley that underlies the present Canoe Brook. As a large stream at some earlier time cut through the trap at Little Falls, presumably some of the territory immediately south of that place drained northward. However, as the stream that drained through the Short Hills gap ran at a lower level than the one at Little Falls, its branch beneath the present Canoe Brook may have been powerful enough to work some distance toward Little Falls. It is entirely possible that this stream extended as far north as Canoe Brook does now.

The position of the pre-glacial surface in the northern part of the East Orange water reserve is uncertain. In well 4, near Baldwin Pond, about 2,500 feet northeast of the Parsonage Hill road, the first rock, described as red shale, is reported to have been struck at a depth of 223 feet, or 30 feet below sea level. (See fig. 4.) This is lower than the rock surface at any other point in the entire region, including the Short Hills gap, and it raises a question as to the possibility of the rock surface being really so low. Above the red shale was 82 feet of "sticky red clay," which is reported to have been struck at 52 feet above sea level. It is the opinion of the writer that this altitude more nearly represents the true pre-glacial surface and that the red clay is really a deeply weathered phase of red shale similar to that struck at a depth of 223 feet. Farther northeast, in wells 1, 2, and 23, red or blue clay was struck from 25 to 35 feet above the first material called rock. In view of the interpretation just given as to the position of

[1] Vermeule, C. C., East Orange wells at White Oak Ridge, Millburn Township, Essex County: State Geologist Ann. Rept. for 1904, fig. 18, 1905.

the pre-glacial surface in well 4, the question arises whether the top of these clays, especially the red clay, does not represent the old land surface, with a considerable thickness of weathered rock above the consolidated bed rock. If this is true the channel beneath Canoe Brook is not as extensive northeast of Baldwin Pond as is shown on Plate 1 by the 40-foot contour that indicates the bed-rock surface.

Southwest of the Canoe Brook pumping station there appears to be another branch valley, as indicated by the bed-rock surface at an altitude of only 34 feet above sea level in the Vanderpool well, on the south side of Morris Avenue near the point where it crosses the Passaic River at the so-called upper Chatham Bridge, and at an altitude of 52 feet in a test hole of the Commonwealth Water Co. about 1,800 feet northeast of the bridge. Unfortunately no well data are available that would make it possible to delimit the southeast side of this valley.

At Chatham bed rock was found as low as 35 feet above sea level—that is, at about the same altitude as the bottom of the rock valleys in the Canoe Brook and Dickinson fields. Apparently the Madison well field also lies in a channel. A question arises as to whether this channel is connected with any of the others described. As drawn on the basis of the available data the contours suggest that the southern branch valley just described may lead northwest beneath Chatham to the Madison field and beyond. If it does there must be a cut through the trap ridge similar to the buried one near the lower Chatham Bridge. On the other hand, the valley at Madison may extend northward on the west side of the buried trap ridge and connect with the valley that underlies the Dickinson well field.

On the map showing the conjectural pre-glacial drainage of the region (fig. 1) the main channel of the pre-glacial stream that went through the Short Hills gap is shown as going almost directly over the Chatham and Madison well fields. At the time of Salisbury's field studies on which the map was based no wells that might have shown how deep the rock lies at critical points had been drilled, so far as the writer can determine from published reports. The lines shown were to a large extent conjectural. The data now available (see pl. 1) bear out in a remarkable manner the general features of the conjectural map and add valuable information as to details of the course of the valleys. On Figure 1 a branch stream is shown as entering the main stream from the southwest, just east of Chatham—that is, essentially along the present course of the Passaic River above Chatham. Considering the present major features of this part of the region—namely, Second Mountain on the east and the trap ridge known as

Long Hill on the west—there is little doubt that such a stream did exist. The area drained by this ancient stream presumably was limited to the region between the two trap ridges, but it was probably larger than that of the stream that came from the northeast past the site of the White Oak Ridge pumping station.

DISTRIBUTION OF WATER-BEARING BEDS

General Statement.—It will be noted from Plate 1 that all the producing wells of the Commonwealth Water Co.'s Canoe Brook field, the White Oak Ridge and Dickinson fields of the East Orange Water Department, the Madison well fields, and probably also the Chatham well field lie in areas underlain by pre-glacial valleys. The facts available show that the water-bearing beds actually are confined to the pre-glacial channels and that outside of these channels relatively meager supplies can be obtained. This problem is of special significance in connection with the question of the possibility of developing additional supplies.

Figure 3 shows the logs of several wells along a line from southwest to northeast across the Canoe Brook well field and along the western border of the White Oak Ridge well field. Figure 4 shows similar well logs along a line from northwest to southeast through the Dickinson and Canoe Brook well fields.

Figure 3 shows that the bed-rock surface rises from the Vanderpool well and forms a ridge southwest of the Canoe Brook well field. The field itself, as previously stated, is underlain by a deep, rather narrow valley. Northeast of the field is another buried rock divide, which lies south of the Parsonage Hill road, and beyond it the bed rock slopes to lower levels beneath the headwater portion of the Canoe Brook drainage basin. The line of the section as chosen does not show how the ancient valley lies beneath the present Canoe Brook, but if other wells had been chosen such a channel would be seen to connect the Canoe Brook and White Oak Ridge well fields.

Canoe Brook Well Field.—The logs of wells in the Canoe Brook field show that the material overlying the bed-rock surface consists of an alternation of beds of sand, gravel, and clay and in places a mixture of all three or a mixture of any two of them. In some wells boulders are common. The wells have been drilled by several different drillers, and different methods have been used. A study of the logs show that the use of terms has not been uniform, and the interpretation of the logs is uncertain.

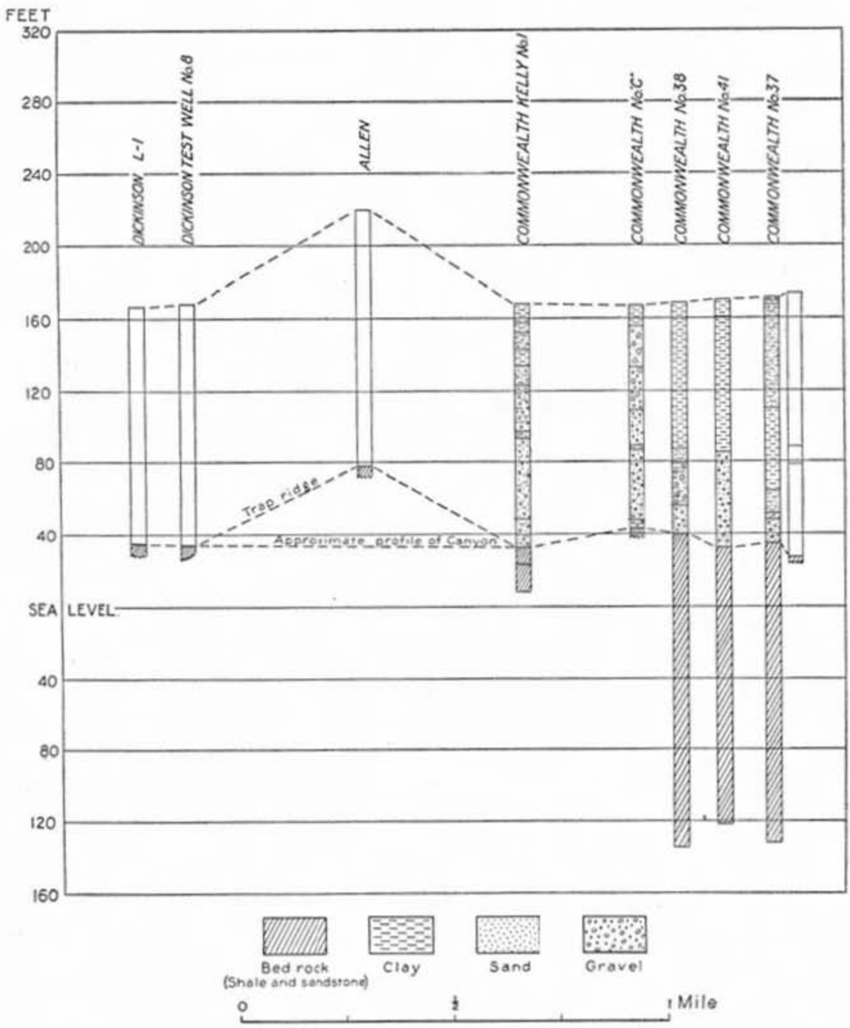

FIGURE 3.—Logs of wells along a line through Canoe Brook and White Oak Ridge well fields.

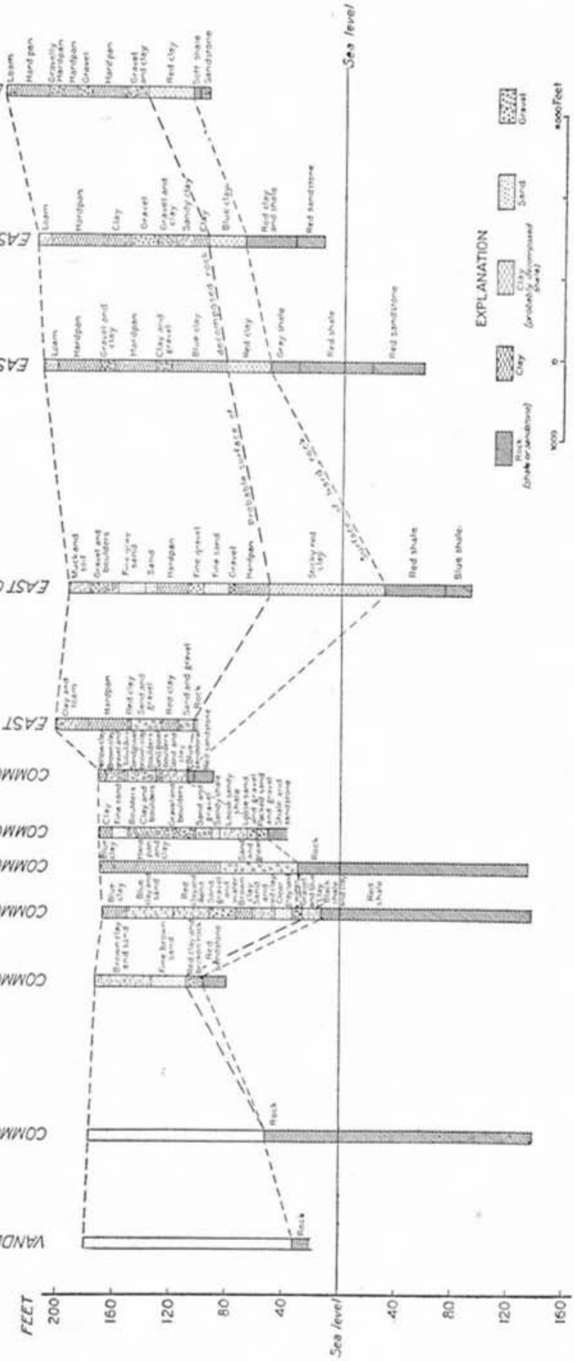

FIGURE 4.—Logs of wells along a line through the Dickinson and Canoe Brook well fields.

In the Canoe Brook field water is apparently obtained from three principal horizons. In some wells in this field water-bearing sand is struck at a depth of 70 to 80 feet and extends for 10 to 20 feet, but in several wells no water-bearing material was reported at this depth. The principal water-bearing bed appears to consist of sand and gravel, which generally lie just above the bed-rock surface. The bed is struck at a depth of about 100 to 120 feet and is from 10 to 35 feet or more in thickness. It is reported in all wells in the producing field except two or three, notably wells 27 and 40. In wells 35 and 41 sand or gravel appears to extend continuously from the upper water-bearing bed, at a depth of 80 or 85 feet, to the lower one. There is some question, however, as to the reliability of the drillers' logs in reporting sand and gravel. In many of the logs clay is reported as occurring with sand or gravel. Such a report was made in the log of a test well, but subsequently, when a large-diameter well (Kelly No. 1) was constructed at the same locality by means of a clam-shell bucket it was found that in places where gravel was reported the material was dominantly clay, with pebbles scattered through it. This material is undoubtedly a glacial deposit, either the unassorted till or clay deposited in Lake Passaic with pebbles that were carried out into the lake on floating ice. It is probable that much of the material reported as sand, gravel, and clay, clay and gravel, etc., does not have a very great water-bearing capacity.

A number of the producing wells in the Canoe Brook field have been drilled to a depth of more than 300 feet, of which 100 feet or more is in rock, in order to obtain the proper submergence for the air-lift pipes. In some of the wells some water is obtained from the rock. No definite information is available as to the relative yield of the bed rock and the sand and gravel beds, but it is believed that the greater part of the supply is obtained from the unconsolidated beds above the bed rock. The principal evidence supporting this idea is the fact that four of the wells of largest yield do not penetrate the rock.

If the water is obtained largely from the sand and gravel, and especially from the lower beds, below 100 feet, the most significant fact shown by the well logs is that the water-bearing beds are confined to the pre-glacial valleys indicated by the contours of the bed-rock surface. The areas in which additional ground water supplies can be obtained are therefore limited. It is possible, and indeed probable, that additional areas can be developed, but considerable test drilling will be necessary to find the buried pre-glacial valleys.

East Orange Well Fields.—Conditions in the White Oak Ridge well field of the East Orange Water Department are in general the same as in the Canoe Brook field of the Commonwealth Water Co. in that sand and gravel occur at two horizons above the bed rock.[1]

The beds at the upper horizon, however, lie somewhat nearer the surface than in the Canoe Brook field—at a depth of only 20 to 60 feet. The lower sand and gravel, which in a large part of the field lie directly on the bed rock, from the principal source of water. No wells in this field penetrate the bed rock. Although the wells in use are within only a few hundred feet of the pumping station, it has been determined that the lower sand and gravel extend for about 4,000 feet northwest of the station. Beyond that point they pinch out, and for about 1,000 feet a thick body of clay lies directly on the rock. At a point about 5,500 feet northwest of the White Oak Ridge station along the Parsonage Hill road the first sand bed, which elsewhere in the well field is underlain by clay with more sand and gravel below, extends continuously from a level within 15 or 20 feet of the surface to the bed rock at a depth of about 75 feet. On the other hand, in a well about 800 feet farther west (No. 7, pl. 1), 500 feet south of the Parsonage Hill road and 200 feet east of Slough Brook, no sand or gravel was reported to a depth of 101 feet. On Plate 1 the contour lines indicating the shape of the bed-rock surface show widening of the valley beneath the present Canoe Brook in the area north and northwest of the White Oak Ridge well field. As indicated on page 16, there is some question as to the interpretation of well logs in this area, and the pre-glacial surface may not lie as low as is indicated on the map. The logs of several wells in this area (wells 5, 7, 12, and 14, pl. 1) show no sand or gravel. Although sand and gravel may be present in parts of the area where no drilling has been done, it appears that the real extent of such deposits is rather slight. No logs of wells in the Dickinson well field are available, but it is known that the principal supply of water occurs in sand and gravel directly above the bed rock.

Chatham, Madison, and Normandy well fields.—The available information in regard to conditions in the vicinity of Chatham and Madison is confined to logs of wells in the two municipal well fields. At Chatham the log of only one well is available. This shows the material to be nearly all clay, or clay mixed with sand and gravel, and therefore probably not good water-bearing material, to a depth

[1] Vermeule, C. C., op. cit., pp. 255-263, fig. 18.

of 42 feet. From that depth to the bottom of the well, at a depth of 90 feet, the material is wholly sand or gravel except for 1 foot of clay at a depth of 75 feet.

At Madison the logs of nine wells are available. These show considerable variation in a distance of about 1,100 feet. In well 9, at the northwest end of the well field, sand or gravel extends almost continuously from a depth of about 28 feet to the bottom, at 147 feet, although in two places some clay is mixed with these materials. On the other hand, in well 1, in the southeastern part of the field, in the total depth of 148 feet, sand or gravel was found only at the depths of 15 to 17 feet, 26 to 27 feet, 102 to 103 feet, and 109 to 148 feet. Wells intermediate between the two mentioned show more or less of a gradation from the dominantly sandy material to the dominantly clayey material.

The Madison well field is only a few hundred feet north of the north base of the terminal moraine. The Chatham wells are situated somewhat similarly with respect to the terminal moraine, although the characteristic topography of the moraine appears to be absent, presumably because the Passaic River has eroded its valley through the moraine. The well fields of the Normandy Water Co., about 2½ miles northwest of Madison, also occupies a similar position near the base of the terminal moraine, on the side from which the ice came. No information was obtained in regard to the materials penetrated by these wells, but the fact that they have a fairly large yield by natural flow suggests that good water-bearing beds are present. In view of the conventional description of a terminal moraine as consisting of a heterogeneous mixture of materials, the presence of so much water-bearing material associated with the glacial drift on the iceward side of the moraine is somewhat unusual. In contrast, it is rather common to find good water-bearing beds on the so-called outer edge of the moraine, for the water from the melting ice flows down the front of the moraine and carries with it some of the sand, gravel, and clay. As it deposits this load it sorts the material into coarse and fine and forms what is known as an outwash plain. Such a plain exists on the southwest side of the terminal moraine near Chatham and Madison, sloping southwestward to the so-called Great Swamp. It seems likely that conditions are favorable for the development of ground-water supplies beneath this outwash plain.

SOURCE OF WATER

A question of real concern relates to the source of the water that is pumped from the well fields under consideration. The logs of all wells studied show a greater or less thickness of clay above the water-bearing beds. The water must gain access to the beds outside of the well fields. If the water-bearing beds are everywhere or nearly everywhere overlain by similar clay beds, which are relatively impervious, the recharge of the formation may be small as compared to the draft on it, and some of the water that is pumped may be coming from storage, which will gradually be reduced.

SUMMARY

To summarize briefly the geologic conditions affecting the occurrence of ground water in the region under consideration, the best water-bearing beds are confined to the relatively small areas where there are well-developed valleys in the pre-glacial surface. Furthermore, these beds as a whole lie just above the old surface, and in most of the region no good water-bearing material is found within 50 to 75 feet of the surface. The principal ancient channels are one that underlies the Canoe Brook and Dickinson well fields, one that underlies the Madison well field, and one that is presumed to exist beneath the Passaic River, south of Chatham. The ancient valley that underlies the present valley of Canoe Brook does not appear to be very extensive. As shown below, the Canoe Brook well field is developed about to its capacity, and it is therefore believed that further developments should be sought in other parts of the channels mentioned.

QUANTITY OF WATER AVAILABLE

METHOD OF STUDY

The quantity of water that can be pumped from a particular area depends upon several factors, including the extent of the intake area of the water-bearing formation—that is, the area where it crops out and receives percolation from rainfall—the extent of the formation in so far as it serves as a reservoir for storing water, and the permeability of the formation. In the area under discussion it has not been possible to determine any of these factors by direct observation. It is not even known where the water-bearing formation crops out, and drilling to show the extent of the formation has been confined to a comparatively small area. It is not known, for example, whether the water-bearing beds encountered in the wells at Madison and Chatham are the same as those tapped in the Canoe Brook well field of the Commonwealth Water Co. and the White Oak Ridge and Dickinson fields of the East Orange Water Department. However, certain observed facts, discussed in part below and reasonable inferences derived therefrom lend support to the belief that the intake area is sufficiently large or there is enough water in storage to supply the present consumption and perhaps even an increased consumption for some years to come. Assuming this to be true, until evidence to the contrary is found, there still remains to be considered the influence of the permeability of the water-bearing formation in determining its ultimate safe yield.

The method following in the present study has been to observe the effects of pumping at certain rates and from the observations to estimate the effect of pumping at stated increased rates. This method has the advantage that the effect produced by pumping at a certain rate is the combined result of the influence of the different factors that control the yield of the formation. It has the disadvantage that because of the complicated interaction of the factors involved it may be difficult to evaluate correctly the influence of each factor. It also had the disadvantage that generally the operating conditions can not be controlled as much as may be desired to determine the effect of any one factor. For example, in tests which are described below it was not possible to stop pumping from the Canoe Brook well field longer than a few hours, although a shut-down of a day or more was desirable. Also the rate of pumping had to be changed to meet the demand, although it should desirably have been kept constant. Nevertheless, the tests have yielded results that are of much value.

Certain special tests were made covering periods of several hours to several days. During these tests measurements of the depth to water were made at frequent intervals in several wells of the Commonwealth Water Company and the East Orange Water Department, and the rate of pumping in each field was determined. In addition, continuous records of the water level in two wells in the Canoe Brook field and one in the White Oak Ridge field were obtained by means of automatic water-stage recorders. The results of the investigation may best be described in the chronologic order in which the tests were made.

TEST OF OCTOBER 2-7, 1925

From October 2 to 7, 1925, a test was made to determine whether pumping from the wells in the Canoe Brook field of the Commonwealth Water Co. affected wells in either the Dickinson field or the White Oak Ridge field of the East Orange Water Department, and vice versa. During this test, at different times, the rate of pumping in each of the three fields in turn was reduced to a minimum and then increased to the maximum limit in order to produce as widely different effects as possible. Hourly observations were made of the pumpage from each field and, during the day time, of the depth to water in about 20 wells. The fluctuations of the water level in two wells (No. 30 in the Canoe Brook field and the so-called "neutral zone" well about midway between that field and the White Oak Ridge field) was obtained by automatic water-stage recorders. The profile of the piezometric surface at certain critical times is shown in Figure 5. The chronologic record of the fluctuation in rate of pumping in the three fields and of the water level in certain of the observation wells is shown graphically in Figure 6. In this diagram the record of pumpage and of the water level in two wells equipped with water-stage recorders is shown for several days prior to the test, to give a basis for comparison of conditions during the test with average conditions.

In Figure 5 the profiles of the piezometric surface are not shown in their correct position for their entire length because it was not possible to determine the water level at certain points. For example, in the Canoe Brook field there are several pumping wells between wells 30 and 4, and the piezometric surface at any time was very irregular, with cones of depression around each pumping well. Well 41, the only one in which the pumping level could be determined, had a yield about as great as any other well in the field, and the head was presumably as low as at any other point. The position of the piezometric surface at the point marked "White Oak Ridge well group" represents the altitude of the water level in the pumping wells as determined by a vacuum gage on the suction line. Actually there must have been a cone of depression around each well. As the shapes of these numerous individual cones could not be determined the profiles have been constructed by drawing straight lines between the points of observation.

The results of the tests show that the water level in the observation wells situated near pumping wells fluctuates closely in accord with

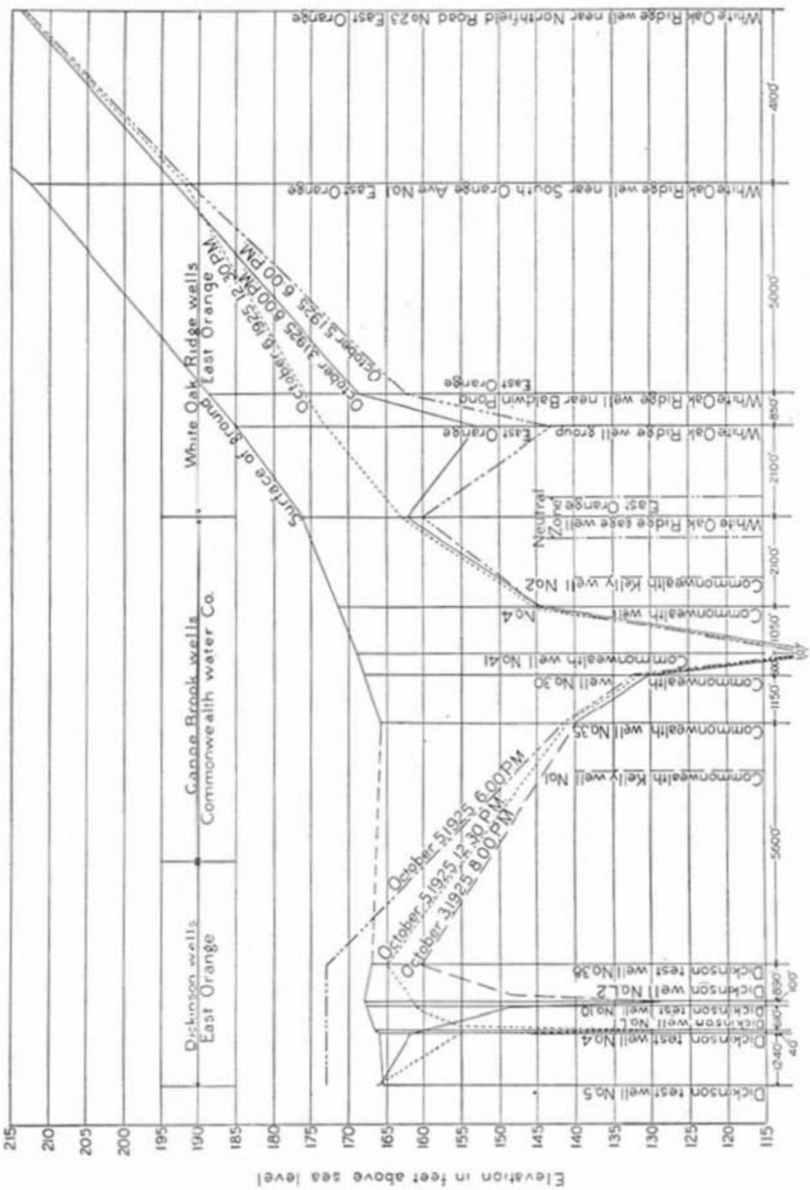

FIGURE 5.—Profiles of piezometric surface between Dickinson, Canoe Brook and White Oak Ridge well fields at certain times on October 3, 5, and 6, 1925.

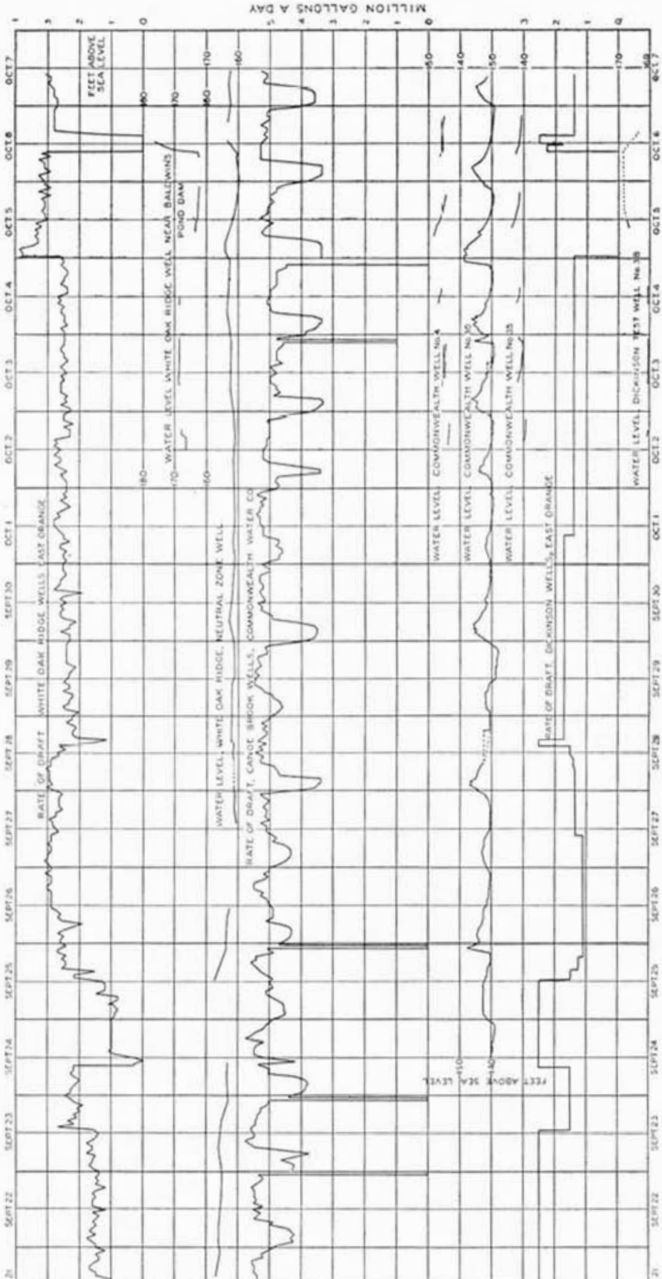

FIGURE 6.—Graphs showing fluctuations in rate of pumping and of the water level in observation wells in Dickinson, Canoe Brook, and White Oak Ridge well fields, September 21 to October 7, 1925.

fluctuation of the pumpage from the near-by wells.[1] Another fact that is not very evident on the graph because of the small vertical scale but that is shown on charts from the automatic recorders is that there is some lag in the movement of the water level before it becomes fully adjusted to a given pumping condition. The charts from the recorder on well 30 in the Canoe Brook field show that the water level practically never reached a stable condition. When the rate of pumping was increased the water level continued to drop until the rate was reduced. Then it rose until there was another change in the rate.

Figure 6 shows some striking examples of the relationship between rates of pumping and head in the different fields. Attention is called to the following; detailed study of the diagram will show others.

Prior to the period of the controlled test, about noon on September 25 there was a marked increase in the rate of pumping at the White Oak Ridge wells, which continued with some variation until about 3 a. m., September 26. The water level in the gage well in the neutral zone dropped between 5 and 6 feet, in spite of the fact that there was a diminished draft in the Canoe Brook field with a total shutdown from 10 to 11 p. m., on September 25. Again, an abrupt decrease in pumping at White Oak Ridge for a short time on the afternoon of September 28 was accomplished by an abrupt rise in the gage well, pumping from the Canoe Brook wells being about uniform. Since the gage well in the neutral zone is nearer to the wells that were being pumped in the White Oak Ridge than those in the Canoe Brook field it is not surprising that these changes in the water level occurred.

On the other hand, the connection between the pumping in Canoe Brook wells and the height of water in the gage well in the neutral zone is distinctly shown on September 30, 1 to 4 a. m., on October 3, 2 to 4 a. m., and October 3-4, 10 p. m. to 6 a. m., when there were marked decreases in the pumping rate at the Canoe Brook wells, and slight although distinct rises in the head at the gage well. About midnight of October 4-5, there was sudden increase in the pumpage at the White Oak Ridge wells, and about the same time a shutdown complete or partial for 8 hours at the Canoe Brook field. The head rose about 2 feet in the gage well in the neutral zone. In this instance the shutdown in the Canoe Brook field had a greater effect on the head in the gage well than did the pumping at White Oak Ridge.

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[1] In studying Figure 6 the reader should note that rates of draft in the well fields is plotted upward from a base of zero. Therefore, on the graph when there is a given change in pumpage the normal change in movement of the line representing water level is in the opposite direction.

From Figure 6 there is no clear indication that pumping from either the Canoe Brook or the Dickinson field affects the water level in the other field. However, the profiles in Figure 5 indicate that such is the case. On October 5, when there was no pumping from the Dickinson field, the piezometric surface between the two fields was much higher than on October 3 and 6, when wells 2 and 1, respectively, in the Dickinson field were operating, in spite of the fact that on October 5 the piezometric surface between the Canoe Brook field and the White Oak Ridge field was lower than on the other two occasions. The profiles also show how changes in the pumping rate in the White Oak Ridge field affect the head in the nearest part of the Canoe Brook field. By analogy it may be reasoned that if the pumping in either of the East Orange well fields affects the head in the Canoe Brook field, pumping in that field will affect the head in the other two fields. The effect resulting from any particular change in pumping condition during the period of the test was not great, since it was not possible to maintain any great difference in the rate of pumping for a long time. If greater differences could have been obtained, the effects would have been correspondingly greater.

Test of January 26, 1926

Observations were made on the effect of pumping a new well in the Canoe Brook field on January 26, 1926. The well, known as Kelly No. 1, drilled near the site of well T 10, in the northern part of the well field, is 135 feet deep. The lower 75 feet of the well is equipped with concrete screen, the inner diameter of which is 25 inches and the outer diameter 32 inches. Sand is reported throughout the section in which the screen is set. However, clay is also reported at several depths, with a total thickness of 30 feet, and the materials at such depths probably do not yield much water. During the test, which continued from 10.55 a. m. to 5.30 p. m., observations on the depth to water and yield of the well were made every 15 minutes. The movement of the water level in well 35, about 1,100 feet to the southeast, was observed by means of a water-stage recorder, and frequent measurements were made of the depth to water in several other wells. The data for Kelly well 1 and well 35 are shown graphically in Figure 7.

In the graphs only a few of the many readings on yield and water level during the test are shown. The points are so chosen, however, as to show the general trend of conditions. At certain times the rate

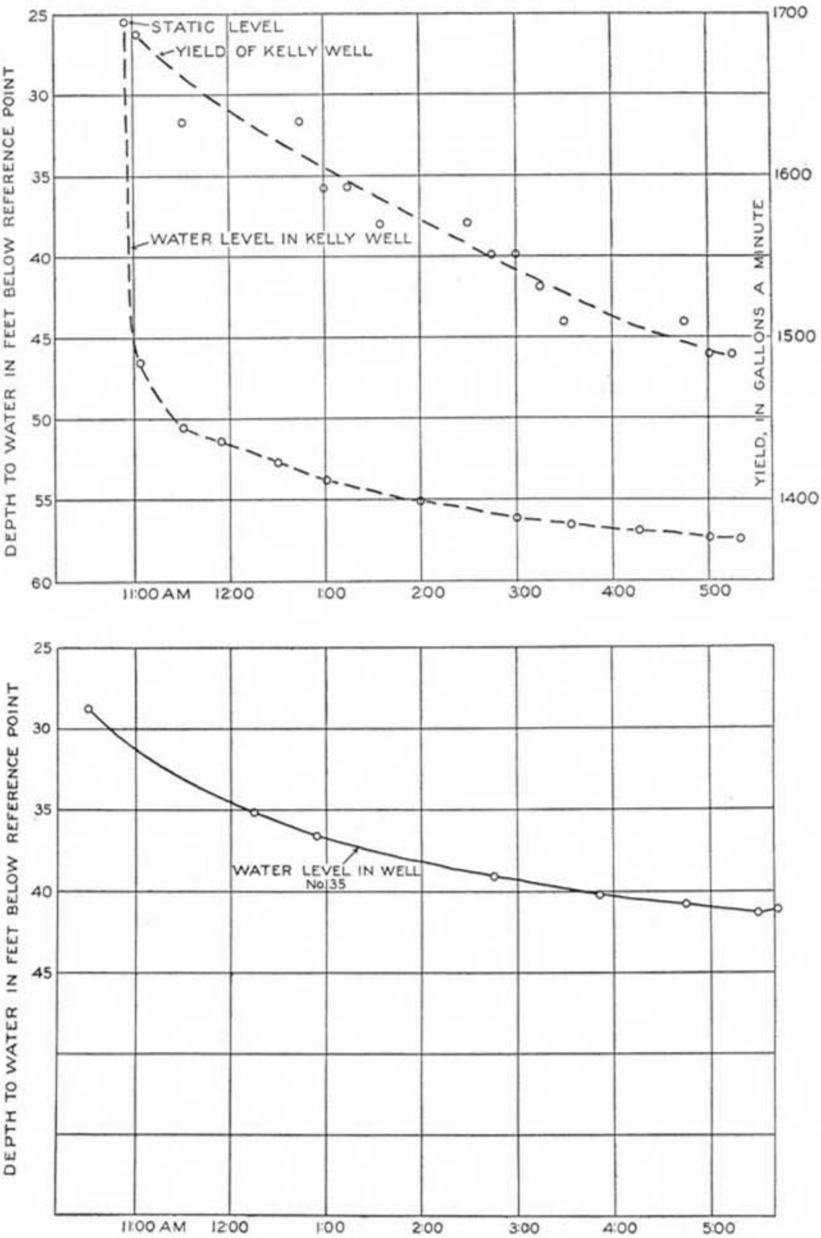

FIGURE 7.—Graphs showing yield of Kelly well 1 and movement of water level in Kelly well 1 and well 35, Canoe Brook field, January 26, 1926.

of discharge apparently remained constant for an hour or more, although probably there was actually a small decrease—so small that it could not be measured on the scale used in measuring the discharge over a weir. For such times the graph shows only the first and last readings at a given rate.

During the first half hour of the test the yield of the well exceeded 1,650 gallons a minute. However, it decreased gradually throughout the test, and when pumping stopped the yield was only about 1,490 gallons a minute. The graph indicates that if pumping had continued the yield would have continued to decrease for at least several hours and perhaps for many hours. The decline in yield was accompanied by a gradual but continual lowering of the water level. As a matter of fact, the decline in yield was probably due largely to the loss of head in the well and surrounding water-bearing beds. It is worthy of note, however, that after the first hour the yield apparently declined at a greater rate than the water level in the pumped well.

During the test the water level in well 35 dropped nearly 10 feet. After the first hour the rate of drop was as rapid in well 35 as in the pumped well, if not more rapid. Part of the drop was presumably due to an increase in the pumpage from other wells in the field, as records on the well for several days before and after the test showed a drop of 1½ to 2½ feet during the day and a rise of about as much at night. Prior to the beginning of the test there had already occurred a drop in level of about 1½ feet because of the increase in pumpage during the morning hours. However, to judge from the records of other days, the 6½ hours of pumping from the Kelly well caused a loss of head of at least 10 feet in well 35.

Numerous measurements on several other wells in different parts of the Canoe Brook field indicate that during the pumping test the head in them was lowered from 1 to 3 feet or more, the amount depending upon the location of the well with respect to the Kelly well. In well 4, at the extreme northeast corner of the field, the loss in head appeared to be at least 1 foot.

Perhaps the most significant fact revealed by the test of the Kelly well is that at the rate of pumping in effect, a period of six hours is not sufficient to determine the true yield of the well. The curve showing the yield of the well (fig. 7) shows no inclination to become horizontal, and experience in other regions shows that the yield may decrease for at least several hours and by an amount that may be as much as 100 gallons a minute. By analogous reasoning it is concluded that the yield of the well field under any particular conditions for a period of a few hours can not be considered to be the yield that can be maintained during continuous pumping for several days at a time. That this statement can safely be applied to the entire Canoe Brook field is suggested by records from water-stage recorders on wells 30 and 35, which show that as long as a high rate of pumping was maintained the water level continued to drop.

In general, the observations in the Canoe Brook field indicate that the head on the water fluctuates in accordance with changes in pumpage, but that there is a lag in the movement of the head, so that it does not reach a stable condition for a certain rate of pumpage until some time after the rate has been established.

Test of June 20-29, 1927

From June 20 to 29, 1927, a prolonged series of observations of certain wells in the Canoe Brook and White Oak Ridge fields was made. The test was made primarily for the purpose of determining the effect of pumping from a new well, known as Kelly well 2, in the northeastern part of the Canoe Brook field. (See pl. 1.) The well is 133 feet deep, and the lower 75 feet is equipped with a concrete screen, the inside diameter of which is 25 inches and the outside diameter 32 inches. This well is equipped with a high-duty pump which pumps directly into the distribution main of the Commonwealth Water Co. against a high pressure. The discharge of the well is recorded by a Venturi meter.

During the test continuous records were obtained of the pumpage from the two well fields of the East Orange Water Department and the Canoe Brook field of the Commonwealth Water Co. Water-stage recorders gave continuous records on well 30 in the Canoe Brook field and on a well in the so-called neutral zone between the two well fields. (See pl. 1 for location of wells.) The general trend of the water level in the pumped wells in the White Oak Ridge field was determined by hourly readings of the vacuum on the suction line from these wells. The depth to water in Kelly well 2 was measured frequently during the day, but it was not possible to do so at night. The essential data obtained during the test are shown graphically in Figure 8. In this diagram the graph indicating the movement of the water level in well 30 is shown merely as a series of straight lines connecting the highest and lowest points each day. The true line is not straight, for the water level changes faster at some times than at others, and also for short periods it moves in the opposite direction to the general trend.

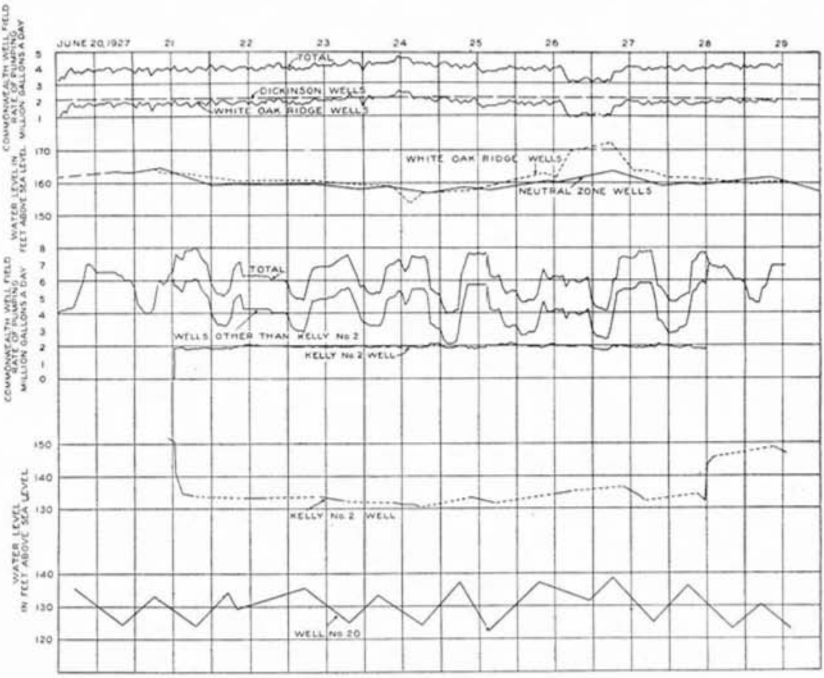

FIGURE 8.—Graphs showing rate of pumping and fluctuation of water level in certain wells in the White Oak Ridge and Canoe Brook fields, June 20-29, 1927.

The Kelly well 2 was operated continuously from about noon on June 21 to noon on June 28, but observations were made for about 36 hours before and after that time to afford a basis for comparing the conditions produced by pumping the well with those when it was not in operation. As shown by the graphs, the pumpage from the two fields fluctuated constantly, in response to the demand, and it is practically impossible to find two periods when conditions were the same. Furthermore, when the Kelly well was pumped, the draft on the other wells in the Canoe Brook field was reduced by an amount equal to the rate of pumping from it. As a result the center of draft or lowest point of the piezometric surface in the well field was shifted toward the Kelly well. For these reasons close comparisons can not be made, and only general differences in conditions are of value in considering the effect of pumping the Kelly well No. 2.

The yield of the Kelly well fluctuated more or less throughout the test, with a range from about 1,700,000 to 2,100,000 gallons a day

(1,180 to 1,460 gallons a minute). When Kelly well 1 was tested on January 26, 1926, its yield declined for some hours after it started to pump (see p. 32), but no such decline in yield was found in Kelly well 2. This is to be accounted for, at least in part, by the conditions under which the pump operates. When pumping directly into the distribution main, as it did during the test, one of the factors that influences the yield of Kelly well 2 is the pressure against which the pump is operating. If the pressure increases, the yield of the well decreases, and vice versa. As the pressure fluctuates from time to time it is not possible to consider fluctuations in the yield of the well as due wholly to conditions at the well itself. There is reason to believe, however, that the yield would have decreased if the pressure had remained constant. This is suggested by the fact that the water level in the Kelly well dropped for at least five hours after pumping began. It may have dropped even further, but observations were not made during the night. It remained at about the same level on the second day of pumping (June 22) as at the end of the first day, although the total pumpage from the Canoe Brook field was much less than on the first day. On the third and fourth days, when the total pumpage increased, the water level in the Kelly well dropped again, and it reached the low point of the test in the late afternoon of June 24. Thereafter it rose and reached its highest level when the well was pumped during the night of June 26-27. The rise in water level undoubtedly occurred because the total pumpage from the Canoe Brook field was less on June 26, which was Sunday, than on any other day during the test. A reduction in pumpage from the White Oak Ridge well field may also have been partly responsible for the rise in water level in the Kelly well.

The graphs of water-level movement in the neutral-zone well and the White Oak Ridge wells show a trend similar to that of the movement in the Kelly well. The graph for the White Oak Ridge wells, however, shows certain irregularities that are traceable to notable changes in pumpage from those wells. The most marked irregularity occurred on the afternoon and night of June 26, when, as already pointed out, there was a great reduction in pumpage from both well fields. Another noticeable irregularity occurred about noon on June 24, when the water level dropped several feet in response to a sudden increase in pumpage.

A study of the graph leads to the conclusion that the long period of pumping from the Kelly well lowered the head on the water in the White Oak Ridge well field and, according to the principles of hydraulics, must have caused a decline in the yield of the wells for a given "input" of power. This is shown in part by a decline of several feet in the water level in both the White Oak Ridge wells and the neutral-zone well for 12 hours or more after pumping of the Kelly well started on June 21, although during that period there was no increase in the average rate of pumping from the White Oak Ridge wells. Furthermore, at that time the water level in the neutral-zone well reached a point about 3 feet lower than on the preceding day, although the rate of pumping was the same. Subsequently, on July 23, 24, and 25, the water level in these two wells dropped even lower, although there was little if any increase in the rate of pumping from the White Oak Ridge wells except for a period of a few hours on June 24. When the Kelly well was shut down on June 28 the water level in the neutral-zone well rose for nearly 24 hours, although during that time the pumpage from the White Oak Ridge wells was slightly more than on the preceding day.

Although there is evidence that the Kelly well affected the head on the water in the White Oak Ridge field, it is difficult, for reasons above stated, to evaluate the effect. Conditions in the early part of the test suggest that it may have lowered the head as much as 5 feet, although this is not certain. In this connection it must be remembered that when the Kelly well was being operated, the rate of pumping from the rest of the field was much below its rated capacity. If the other wells were pumped to capacity at the same time, the loss of head in the White Oak Ridge field would have been even greater.

In considering the capacity of the Canoe Brook field it must be borne in mind that when the Kelly well is being pumped, the yield of the other wells for a given input of power is doubtless somewhat less than when it is not pumped. Furthermore, the test of June 20-29 was made in the early part of the summer, before there had been any great loss of head due to seasonal variations in the recharge of water-bearing beds. The recharge is generally least in the later part of the summer, and it is possible that in the dry season of the year the yield of the wells will be less and the effect on the White Oak Ridge wells will be greater.

The test showed that the Kelly well 2 has a large specific capacity—that is, its yield is large in proportion to the drawdown or loss in head. During the test the yield was never less than 1,650,000 gallons a day (about 1,145 gallons a minute), and the maximum drawdown as compared to the static water level just before pumping began was about 20 feet. The yield was therefore fully 57 gallons a minute for each foot of drawdown. Among the wells in New Jersey for which the writer has definite data there is only one that has a higher specific capacity. This is a well in the Puchack Creek field of the Camden Water Department, which in a test on May 10, 1924, had a specific capacity of 68 gallons a minute.[1]

The specific capacity of Kelly well 1 in the Canoe Brook field at its lowest yield in the test of January, 1926, was 46 gallons a minute.

ORIGINAL AND PRESENT HYDROSTATIC HEAD

The profiles of the piezometric surface in Figure 5 shows a great decline in the hydrostatic head from the two East Orange well fields to the Canoe Brook field. It has been shown on page — that there is good reason for believing that a buried channel in the pre-glacial rock surface leads from the vicinity of the Canoe Brook field southeastward through the Short Hills gap. Presumably ground water moves along this channel, and it would be natural to expect a hydraulic gradient from points high in the drainage area to lower points. The question arises, whether the lower head in the Canoe Brook field results from this condition or from some other cause, especially from pumping.

Canoe Brook field.—Fortunately, rather definite information is available to answer this question. According to records furnished by E. W. McMane, of the Commonwealth Water Co., the first well (No. 1) in the Canoe Brook field was drilled in 1899 to a depth of 132 feet. At this depth it taps the principal water-bearing beds in the field. When the well was completed a hose was attached to the top of the casing, and the water rose in it to a level 30 feet above the surface. As the ground at this point is about 173 feet above sea level, the original static level must therefore have been slightly more than 200 feet above sea level. As shown in Figure 5 the head in October, 1925, in wells in this field that were not pumped (Nos. 4 and 35) was from about 130 to 140 feet above sea level. In the 25 years between 1899 and 1925 the head therefore dropped 60 feet or more. There is no doubt that this great loss in head has been due to pumping from the water-bearing formation. For several years after the first wells were drilled they seem to have overflowed naturally into a "suction well" from which the distribution pumps drew. Gradually the

1 Thompson, D. G., Ground-water supplies of Camden and vicinity. (On the press.)

water level was lowered as pumping increased, until it fell below the limit of suction lift. The time when this occurred is not definitely known, but it was probably about 1910, as in that year an air compressor was installed on the pumping plant.

White Oak Ridge Field.—No data are available as to the static head in the White Oak Ridge field when the first well was drilled in the Canoe Brook field, in 1899. Vermeule states that when the White Oak Ridge field was developed in 1903 "the static pressure on the group of wells near the pumping station was about 8 pounds per square inch (equal to a head of 18.5 feet) at the surface of the ground,"[1] which was about 185 feet above sea level. The static level at that time was therefore slightly more than 200 feet above sea level, and in 1899, before there was any pumping in the Canoe Brook field, it may have been considerably higher. In 1925, when the White Oak Ridge wells were not pumped, the water rose in them to an altitude of about 176 feet above sea level, or at least 25 feet below the original head. However, as shown by the graph of the water level in the observation well near Baldwin Pond on October 6 (fig. 5), if the wells had been shut off for a long period the water undoubtedly would have risen several feet higher.

Dickinson Field.—When the first wells were drilled in the Dickinson field, in 1923, the head was about 176 feet above sea level. This is considerably below the head in the Canoe Brook field in 1899, and presumably at that time the head was higher in the Dickinson field than in 1923. However, if there was an outlet for the ground water farther down the Passaic Valley, the head in the Dickinson field may not have been quite as high as in the Canoe Brook field. No data are available to show whether this is true.

Madison and Chatham fields.—In 1898 the head in a well drilled at the Madison waterworks was 199 feet above sea level, and that in a well at Chatham was about 2 feet lower. These heads are so nearly the same as that in well 1 in the Canoe Brook field that they suggest that the water-bearing beds in the two localities are connected. On October 21, 1925, the head on wells in the Madison field, after all wells had been shut down for about four hours, was 192 feet above sea level. The data are not sufficient to show whether the head would have risen further if the wells had been shut off longer. Also there is no information to show the cause of the apparent loss in head below

[1] Vermeule, C. C., State Geologist Ann. Rept. for 1904, p. 259, 1905.

the original level—whether it was from pumping in the Madison field, the Chatham field, or the more distant well fields.

Interpretation of Differences.—There can be little doubt that a large part of the decline in head in the Canoe Brook and White Oak Ridge well fields is due merely to the fact that the water-bearing beds are confined to relatively narrow elongated channels simulating conduits. In order to reach the pumping wells the water must flow through a comparatively small cross section, with a greater velocity than if the beds spread out in all directions, and consequently there is a considerable loss of head due to friction. On the other hand, some of the decline in head may be due to a draft in excess of recharge, with consequent withdrawals from storage. In order to determine whether this is true it would be necessary to have observations on fluctuations of the head in parts of the storage area that are not affected directly by pumping wells. Unfortunately, no such observations are available. Of some value, however, are the data in regard to water level, on October 3 to 6, 1925, in wells Nos. 1 and 23 of the East Orange Water Department, located respectively near South Orange Avenue and near Northfield Road. (See Figure 5.) Although the head in these wells before there was any pumping in the region is not known, in 1925 it was within a few feet of the original head in the Canoe Brook field. The observations on the wells in the Madison well field similarly show only a rather small difference between the original head and the head after the wells had been shut down for several hours in 1925. The value of the data in regard to this field is lessened, however, by the fact that it is not certain that the water-bearing beds are connected with those in the other fields.

A further significant fact is that even in the Canoe Brook field, where the head has declined the most, the water-bearing formation is everywhere saturated and the water under artesian pressure except perhaps within a few feet of pumping wells. When these are shut off the water rises above the top of the water-bearing formation. Therefore, it may be considered that there has been no draining of the formation in the well fields. If there has been any actual withdrawal from storage it has been at some distance from the fields and there is presumably a considerable volume of water still in storage.

SEASONAL FLUCTUATION OF HEAD

Water-stage recorders have been maintained on wells 30 and 35 and on the well in the so-called neutral zone between the Canoe Brook well field of the Commonwealth Water Co. and the White Oak Ridge well field since late in September, 1925. Unfortunately, however, the records from all three wells are lacking for many long periods, as a result of circumstances that could not be controlled. The recorder installation on well 30 was damaged by a caving of the ground around the well, and it could not be reset for a long time. Well 35 could not be reached for long periods when it was surrounded by overflow water from the Passaic River. The recorder on the well in the neutral zone has never worked properly, largely because of the small diameter of the well and the nearness of the water level to the surface, which hinders the free movement of the float and counterweight past each other.

The record of the lowest water level reached each day in wells 30 and 35, with the daily pumpage from the Canoe Brook field, is shown graphically in Figure 9. The record from the well in the neutral zone is so incomplete that it is not reproduced. The pumpage shows considerable variation from day to day, which is due to several conditions. As compared to the fluctuation in consumption between different seasons of the year at certain other localities in New Jersey, notably the shore resorts, the fluctuation here is not great.[1] More striking than any seasonal increase in consumption is a gradual increase from year to year.

In accord with the graph of consumption, the graph showing the movement of the water level in the observation wells shows no marked seasonal fluctuations but more or less fluctuations from day to day. A comparison of the pumpage and water-level graphs shows in general a fairly close correspondence in that when there is a sharp increase in the consumption there is a fall in the water level in the wells. The graphs thus furnish additional evidence showing that the head of the water fluctuates with the rate of pumping.

[1] See especially Thompson, D. G., Groundwater supplies of the Atlantic City region: New Jersey Dept. Conservation and Development Bull. 30, figs. 13 and 14, 1928; and Ground-water supplies of the Asbury Park region: New Jersey Dept. Conservation and Development Bull. 35, figs. 2 and 4, 1930.

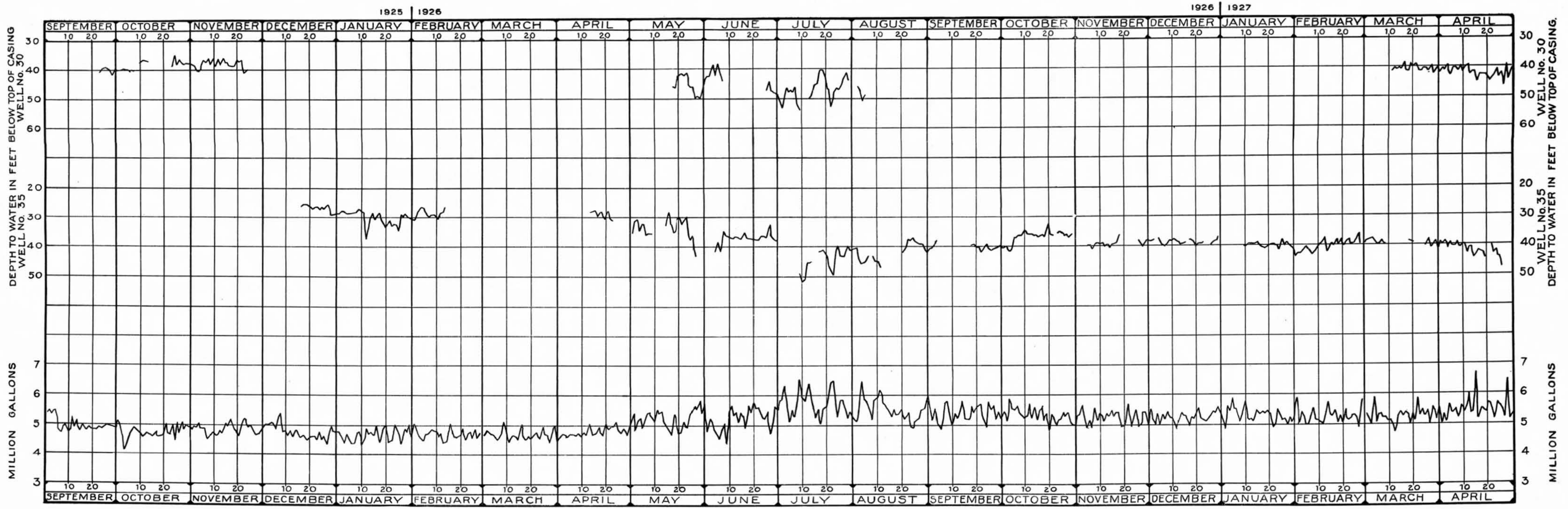

FIGURE 9.—Graphs showing movement of water level in wells Nos. 30 and 35, and daily pumpage from Canoe Brook well field of Commonwealth Water Co., September, 1925—April, 1927.

EFFECT OF FUTURE INCREASES IN PUMPAGE

The data are not sufficient to determine the mathematical relation between the rate of pumping and the head. It may be assumed, however, that under the principles of hydraulics governing the flow of ground water as studied in other localities the head fluctuates approximately directly as the rate of flow. On this assumption the effect of future increases in pumpage may be considered.

During the pumping test of October, 1925, when the pumpage from the Canoe Brook field was at a rate of about 5,000,000 gallons a day, the water level in well 41, which was being pumped, was about 90 feet below the original static level in the well field. (See pp. 26-30 and Fig. 6.) The loss of head was thus about 18 feet per million gallons of pumpage from the entire field. As shown by Figure 3, the top of the water-bearing formation in well 41 is at an altitude of 85 feet above sea level or 115 feet below the original static level. On the basis of the figures just given, if the rate of pumping in the well field were increased to more than about 6,500,000 gallons a day—assuming the draft to be distributed among all the wells in the same proportions as existed in 1925—the top of the formation in well 41 would be drained. Thereafter the direct ratio would not be expected to hold, but for further increases in the rate of pumping the decline in head would be disproportionately great.

During the same test the lowest water levels in wells 30 and 35, which were not being pumped, were about 70 and 60 feet, respectively, below the original static level, and the loss in head per million gallons was 14 and 12 feet, respectively. Observations were not made on well 41 during subsequent tests, but the records for wells 30 and 35 may afford an opportunity to check the above estimates. During the tests of June 20-29, 1927, when the pumpage from the Canoe Brook field reached a rate of about 7,500,000 gallons a day, the water level in well 30 dropped to a point about 75 feet below the original static level, and the loss of head per million gallons was only 10 feet instead of 14 feet. The head in well 35 dropped to a point about 77 feet below the original static level, and the loss of head was a little more than 10 feet per million gallons. The loss of head in the two wells was not as great as during the test of October, 1926, and it was not in the same proportion. In fact, the yield of the field was greater than the limit of 6,500,000 gallons just given, and the decline in head per million gallons was less than in October, 1925. This was presumably because in the later test the increase in draft was not divided between the wells in use in 1925 but occurred in the new Kelly wells, on the outer borders of the field. The difference between expected and actual conditions may possibly be due in part to the fact that the two tests were made at different seasons of the year, when the conditions of recharge of the water-bearing beds may be different. Therefore, the conditions cannot be accurately compared.

If only the lowest decline in head observed in either of wells 30 and 35 is used as a basis for further computation, namely, 10 feet per million gallons, it is found that the top of the water-bearing formation in non-pumping wells would be unwatered if the rate of pumping were increased to 10,000,000 or 12,000,000 gallons a day, assuming the draft to be distributed proportionally along the wells operating as it was during the test of June, 1927. If it were distributed as during the test of October, 1925, draining would occur at a slightly lower rate of pumping. However, these figures are for wells that are not pumping. Since the water level in pumping wells would be at least 20 or 30 feet lower draining of the formation would begin at much lower quantities than those just stated and more nearly as in the estimate based on observations on well 41. It therefore is questionable as to whether a rate of pumping of as much as 10,000,000 gallons a day in the Canoe Brook field could be reached without excessive draining of the formation. It should be remembered that this limit is imposed by the permeability of the formation in the well field regardless of conditions of recharge and storage elsewhere in the underground drainage area.

Even though the figures just given may be subject to some error there is no doubt that there will be a considerable loss in the head if the pumpage increases very much and that the maximum rate of pumping that can be attained is limited by the thickness and depth of the water-bearing formation. Also, an increase in rate of pumping in the Canoe Brook field may be expected to cause some loss of head in the near-by White Oak Ridge and Dickinson well fields. The data obtained during the test indicate that the decline in head in the White Oak Ridge field will be only a very few feet for every million gallons of additional pumpage in the Canoe Brook field, and probably the decline in head in the Dickinson field will be even less. Presumably, increases in pumpage in the Dickinson or White Oak Ridge field will cause a loss of head in the Canoe Brook field approximately equal to the loss produced in the respective fields by pumpage in the Canoe Brook field. As in the Canoe Brook field, the extent to which the draft from the East Orange fields may be increased is presumably limited by the thickness and depth of the water-bearing formation.

The loss of head in any of the well fields will result in a decrease in the yield of the wells for a given input of power, and the cost of pumping will increase. In order to maintain efficient pumping conditions, it may be necessary to lower the air pipe in wells pumped by compressed air or the pump bowls of turbine pumps. One or the other of these methods of pumping is used in the Canoe Brook and Dickinson well fields, and adjustments to a lowering of the head may be made with comparative ease. In the White Oak Ridge field, however, where the wells are pumped by suction, the head cannot be lowered much more than a few feet without breaking the suction. If this occurs the well field can be used only by installing an air-lift system, lift pumps, or deep-well turbine pumps.

It may be pointed out that in any of the well fields of the region the pumpage cannot be increased indefinitely, for the increase in quantity that can be pumped is limited by the depth of the bottom of the water-bearing stratum. If the water comes principally from the alluvium the head can not be lowered below an altitude of 25 to 35 feet above sea level or about 70 feet below the pumping level in well 41 during the tests in October, 1927. As a matter of fact the yield of the wells would doubtless decrease before that point was reached.

As pointed out on page 39, it is not certain whether the water-bearing deposits in the Chatham and Madison fields are connected with the deposits in the other fields. However, even if they are connected, it is believed that increases in pumpage in the other fields will cause very little if any additional loss in these fields, because they are so far from the other well fields and their loss in head below the original static level has been so small.

POSSIBILITY OF FUTURE DEVELOPMENTS

It has been shown on page 42 that the yield of the Canoe Brook field of the Commonwealth Water Co. is limited by the depth to which the head may be lowered. The same condition is undoubtedly true of the White Oak Ridge and Dickinson fields of the East Orange Water Department; but as the consumption from those two fields is much less than that from the Canoe Brook field, according to the present rates of increase in consumption the capacity of those fields will not be reached nearly as soon as that of the Canoe Brook field. The question arises whether additional supplies may be developed in other localities.

The channels in the bed rock that underlie the Commonwealth and East Orange fields doubtless extend for some distance beyond those fields. The great expanse of relatively flat land along the Passaic River northwest and north of the Dickinson field especially suggests favorable conditions for obtaining additional supplies. If the bed-rock channel there spreads out into a wide valley—and this is entirely possible—doubtless a very large quantity of water is stored in the unconsolidated alluvium that fills the channel. On the other hand, if the channel is as narrow as it is in the Dickinson and Canoe Brook well fields the quantity stored is very much less, and the opportunity of developing a large supply depends largely on the recharge at some distant locality and the permeability of the alluvium filling the channel. If the channel is relatively narrow the hydraulic conditions are much like those governing the rate of flow in a pipe line. Water will be flowing throughout the length of the channel to feed the well fields already situated along it—that is, the Dickinson and Canoe Brook fields. As the hydraulic head or water level at any point is affected by the rate of flow, the development of additional fields along the channel will cause a loss of head everywhere, including the fields now in operation. Obviously, it would not be wise to undertake any large additional developments where it is definitely known that the rock channel is narrow and pumping from fields now in existence has produced a loss of head that approaches the limit of safety. It is believed that such conditions exist in the bed-rock channel that underlies the present Canoe Brook in and north of the White Oak Ridge field; and although some additional supply may perhaps be obtained from that channel, it is doubtful whether any large quantity may be expected. On the other hand, it is uncertain whether the channel beneath the Passaic River north and northwest of the Dickinson field spreads out or is narrow. It may be worth prospecting there.[1]

Reference has been made to the possible existence of a more or less distinct buried rock channel beneath the lowland along the Passaic River south of Chatham and perhaps of a branch to the northwest toward Chatham and Madison. The position of the surface contours indicates that this channel probably joins the main channel through the Short Hills Gap, at a point southeast of the Canoe Brook field. It seems likely that the effects of pumping in the Canoe Brook, Dickinson, and White Oak Ridge well fields are not communicated to the southwestern channel. At least, the loss of head resulting from pumping in those fields has probably been much less in the southwestern channel than in the channel beneath the three pumping fields. There-

[1] Since this was written the Braidburn field of East Orange has been developed with marked success. H. B. K.

fore, the locality southeast of Chatham seems to be a favorable place for prospecting for additional supplies.

In considering the possibility of developing additional supplies there must be borne in mind the fact that has already been emphasized that the recharge may not be sufficient to permit any great increase in draft. In order to determine whether this is true, data should be obtained to determine the extent of the water-bearing beds. Observations also should be made on fluctuations of the water level in wells as far as possible from the pumping wells to see if there is a progressive decline in the static head that is greater than should be expected from given increases in the rate of pumping.

To determine the course of the buried rock channels for further developments will require the drilling of numerous test wells at considerable expense. Possibly the same result could be obtained more economically by some of the newly developed geophysical methods of prospecting, especially those in which variations in the electrical resistivity of the different kinds of material are used. These methods have been used with a good degree of success to determine the boundary between bed rock and overlying unconsolidated sand, gravel, and clay at dam sites and elsewhere.[1] The conditions in the Passaic River Valley seem to be well adapted for determining the course of the buried rock channels by these methods.

[1] See Geophysical prospecting, a symposium of papers and discussion presented at meetings of the Am. Inst. Min. and Met. Eng., especially Crosby, I. B., and Leonardon, E. G., Electrical prospecting applied to foundation problems, pp. 199-210, 1929; also Gish, O. H., and Rooney, W. J., Measurement of resistivity of large masses of undisturbed earth: Terrestrial Magnetism and Atmospheric Electricity, vol. 30, pp. 161-188, 1925.

QUALITY OF WATER

Analyses of five samples of water from wells in the Passaic River Valley near Chatham are given in the following table:

ANALYSES OF WATER FROM WELLS IN THE PASSAIC RIVER VALLEY NEAR CHATHAM (ANALYZED BY C. S. HOWARD. COLLECTED OCT. 6 AND 7, 1925. PARTS PER MILLION)

	1	2	3	4	5
Silica (SiO_2)	22	25	18	24	20
Iron (Fe)	.31	.08	.09	.15	.08
Calcium (Ca)	37	33	32	50	34
Magnesium (Mg)	4.5	5.7	5.1	18	9.6
Sodium and potassium (Na+K) (calculated)	15	6.1	11	36	5.3
Carbonate radicle (CO_3)	0	0	0	0	0
Bicarbonate radicle (HCO_3)	121	107	110	110	118
Sulphate radicle (SO_4)	36	19	25	171	19
Chloride radicle (Cl)	6.4	7.0	5.0	5.6	8.6
Nitrate radicle (NO_3)	.30	1.0	.65	.29	1.8
Total dissolved solids	179	155	148	366	168
Total hardness as $CaCO_3$ (calculated)	111	106	101	199	124

1. Well 41, Canoe Brook field of Commonwealth Water Co. Depth 303 feet; clay and sand, 0—85 feet: sand and gravel, 85—139 feet; Triassic sandstone, 139—303 feet.
2. Composite sample from 20 wells, White Oak Ridge field of East Orange Water Department. Depths 100 to 125 feet; clay and sand in upper part, gravel in lower part.
3. Layne well 1, Dickinson field of East Orange Water Department. Depth 135 feet; mostly clay, 0—100 feet; sand 100—135 feet.
4. Layne well 3, Dickinson field of East Orange Water Department. Depth 135 feet; mostly clay, 0—105 feet; sand, 105—135 feet.
5. Mixed sample from several wells, well field of Borough of Madison.

The analyses show that the mineral content of all the waters is moderate. The predominating constituent is calcium carbonate except in sample 4, in which it is calcium sulphate. All the waters may be considered good for domestic use, although they are somewhat hard, especially No. 4. They are only fair for boiler use, because some scale will be formed.

The most highly mineralized sample is No. 4, which contains 366 parts per million of total dissolved solids and 199 parts per million of hardness. This sample is from Layne well 3 in the Dickinson field of the East Orange Water Department (well L-3 on pl. 1). Prior to the installation of the three pump wells in this field several test wells were drilled, and partial analyses of the water from them were made. The water from some of these wells was much more highly mineralized than those for which analyses are given above, and the quality changed considerably within a short distance. For example, in test well 6, only 600 feet northeast of Layne well 3, a sample collected November 23, 1922, contained 2,362 parts per million of total solids and 985 parts per million of hardness. In another sample from the same well collected February 19, 1923, the total solids were 2,541 and the hardness was 1,154 parts per million. In well 3B, about 600 feet southwest of Layne well 3, the total solids were 2,196 and the total hardness 710 parts per million. In well 1B, about 800 feet northwest of Layne well 2, the total solids in two samples were 1,596 and 1,620, and the total hardness in each was 763 parts per million. In two samples from test well 5, about 1,100 feet northeast of Layne well 1, the total solids were 928 and 960 and the total hardness 440 and 466 parts per million. In several other test wells the concentration was much less, and the waters are obviously of about the same composition as those shown in the table on page 46. In seeking an explanation for the high concentration of the water from certain wells it was found that all these wells were drilled 40 feet or more into the bed rock, whereas those in which the mineral content of the water was moderate penetrated the rock only a very few feet. It therefore appears that the high mineral content is due to some constituents of the bed rock. This inference is further supported by the fact that the water from the wells of the Slough Brook field of the East Orange Water Department, in which the supply is all obtained from bed rock, is said to be of poor quality. It is therefore obviously not desirable to drill for water far into the rock. However, the quality of the water in the rock may perhaps improve, after the wells have been pumped for some time. This is suggested by the fact that the water from well 41 (sample 1 in the table on p. 46) in the Canoe Brook field of the Commonwealth Water Co. is of good quality, although the well penetrates the bed rock for more than 160 feet.

CONCLUSIONS

1. The supplies of ground water that have so far been developed in the Passaic River Valley near Chatham occur in beds of sand and gravel overlain by clay that lie in ancient channels cut in the bed rock.

2. It is believed that not more than about 10,000,000 gallons of water a day can be pumped from wells in the Canoe Brook field, and the maximum possible rate of pumping may be even less. This is because of the limited thickness and depth of the water-bearing formation which does not permit the drawdown required to obtain larger quantities of water.

3. Any considerable increase in the rate of pumping in the Canoe Brook field will probably cause some decline in head in the neighboring White Oak Ridge and Dickinson well fields. Conversely, any considerable increase in rate of pumping in either of the East Orange well fields may be expected to cause some decline in head in the Canoe Brook field.

4. Water-bearing beds may exist in other buried channels in the bed rock than those that have already been discovered and additional supplies of water can perhaps be developed. However, if additional supplies are developed careful observations should be made of fluctuations of the water level to determine whether or not the recharge is sufficient to meet a large additional draft on the formation.

INDEX

E

F

G

H

K

L

M