State of New Jersey

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

Division of Water Policy and Supply

SPECIAL REPORT 10

PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER SUPPLY OF THE NEWARK, NEW JERSEY, AREA

1951

STATE OF NEW JERSEY

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

CHARLES R. ERDMAN, JR., COMMISSIONER

DIVISION OF WATER POLICY AND SUPPLY

HOWARD T. CRITCHLOW, DIRECTOR AND CHIEF ENGINEER

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By

Henry Herpers

and

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Prepared in cooperation with the
United States Department of the Interior
Geological Survey

LETTER OF TRANSMITTAL

Honorable Charles R. Erdman, Jr., Commissioner
Dept. of Conservation & Economic Development

Dear Sir:

I am transmitting herewith a report on the ground-water supplies of the Newark, New Jersey, area prepared by Henry Herpers of the State Geologic & Topographic Survey, and Henry C. Barksdale, District Engineer of the United States Geological Survey. This report has been prepared in cooperation with the United States Geological Survey as a part of the cooperative investigation of the ground water resources of the State.

The report describes the geology and ground-water conditions in the City of Newark and its vicinity. It defines the limits of a gravel-filled preglacial channel, the existence of which has only been inferred heretofore. It describes the critical lowering of the water levels in the eastern part of Newark, and the rather general intrusion of salt water into the water-bearing formations in that area. The report points out that the safe yield of the water-bearing formations in parts of the area may have been exceeded, and that further large developments in other parts of the area should be made with great caution, if at all.

I, therefore, recommend that this report be published as a Special Report of the Division of Water Policy & Supply, in order that the information contained therein may be made available to the people of the State.

Respectfully submitted,

H. T. CRITCHLOW
Director & Chief Engineer

Encl.

October 22, 1951

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

DIVISION OF WATER POLICY AND SUPPLY

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PRELIMINARY REPORT ON THE GEOLOGY AND GROUND-WATER SUPPLY OF THE NEWARK, NEW JERSEY, AREA

By Henry Herpers and Henry C. Barksdale

ABSTRACT

In the Newark area, ground water is used chiefly for industrial cooling, air-conditioning, general processing, and for sanitary purposes. A small amount is used in the manufacture of beverages. Total ground-water pumpage in Newark isestimated at not less than 20,000,000 gallons daily.

The Newark area is underlain by formations of Recent, Pleistocene and Triassic age, and the geology and hydrologic properties of these formations are discussed. Attention is called to the important influence of a buried valley in the rock floor beneath the Newark area on the yield of wells located within it. Data on the fluctuation of the water levels and the variation in pumpage are presented, and their significance discussed. The results of a pumping test made during the investigation were inconclusive. The beneficial results of artificially recharging the aquifers in one part of the area are described.

The intrusion of salt water into certain parts of the ground-water body is described and graphically portrayed by a map showing the chloride concentration of the ground water in various parts of the City. Insofar as available data permit, the chemical quality of the ground water is discussed and records are given of the ground-water temperatures in various parts of the City.

There has been marked lowering of the water table in the eastern part of the area, accompanied by salt water intrusion, indicating that the safe yield of the formations in this part of Newark has probably been exceeded. It is recommended that the study of the ground-water resources of this area be continued, and that artificial recharging of the aquifers be increased over as wide an area as possible.

INTRODUCTION

Purpose and scope of investigation

In the Newark area, the chief uses of ground water are for cooling by industries, for air-conditioning, and for general processing and sanitary purposes. Several beverage manufacturers use ground water as an ingredient in their products, and the water from a few wells is used for drinking. As one result of a recently completed survey of all known wells, it is estimated that not less than 20 million gallons of ground water is used in this area per day. In summer an estimated one to one and a half million gallons of ground water is used for air-conditioning alone.

Records kept by various well owners and by State and Federal agencies have shown a marked lowering of the water level in many Newark wells, as well as a diminution in the yield of some. They have also shown that the ground water in certain parts of the area has become brackish because of heavy pumpage and the infiltration of salt water from surface sources. These conditions are particularly severe in the eastern part of Newark, in what is known locally as the "Ironbound District." In order to give some conception of the seriousness of these conditions, it may be mentioned that in the year 1879 the water level in wells in eastern Newark ranged from a few feet above to 25 feet below the surface of the ground, and several 8-inch wells yielded as much as 500 gallons per minute when pumped by direct suction. Analyses of the water from these wells showed that it contained only 10 to 25 parts per million of chloride.[1]

1/Annual report of the State Geologist, p. 126 ff., 1879.

Analyses made by the City Chemist of Newark showed chloride contents ranging from 250 to 2,500 parts per million in water taken from wells in 1942, in this same area. Moreover, in 1947 the general water level ranged from 125 to 200 feet beneath the land surface, and pumping levels in wells ranged from 135 to 290 feet, depending upon the amount of water pumped and the season of the year. In view of these facts, it was decided to make an intensive study of the geology and ground water of the Newark area, and to publish a report on the findings, in order to summarize and make generally available our knowledge of the quantity and quality of ground-water resources of the area, and to facilitate the planning of ground-water pumpage in the future.

The area included in the present study and referred to herein as the Newark area is shown on figure 1. It lies principally in Essex County, but includes small parts of Hudson and Union Counties. It includes all of the city of Newark, except the extreme western part; the greater part of Harrison; and parts of Kearny, Irvington, East Orange, Bloomfield, and Elizabeth.

The Newark area lies wholly within the physiographic province known as the Piedmont Plain. The southeastern part of the area is a lowland with considerable tidal marsh, and the balance of the area is characterized chiefly by low ridges trending in a northeasterly direction. The average annual rainfall at Newark is approximately 47 inches, and the mean annual temperature is about 53°F.

Figure 1.-Map of northeastern New Jersey, showing location of the Newark area.

Acknowledgments

This report is the result of cooperative work by the Geologic and Topographic Survey and the Division of Water Policy and Supply, both of the New Jersey Department of Conservation and Economic Development, and by the United States Geological Survey. M. E. Johnson, State Geologist, H. T. Critchlow, Director of the Division of Water Policy and Supply, and A. N. Sayre, Geologist in Charge, Ground Water Branch, U. S. Geological Survey, have exercised general supervision over the work since its beginning. Mr. Johnson and Henry C. Barksdale, District Engineer of the Ground Water Branch, U. S. Geological Survey, have shared local responsibility for the progress and details of the work. The gathering of the data necessary for the preparation of this report has been largely in the hands of Henry Herpers of the Geologic and Topographic Survey and Jerome M. Ludlow of the U. S. Geological Survey. The greater part of this report was written by Mr. Herpers. The sections on the hydrology of the various formations were written by Mr. Barksdale.

Needing the help of the citizens and industries of Newark, and believing that they would gladly cooperate if they knew the facts, the Newark Chamber of Commerce was advised of the proposed survey and report, and a story giving the reasons for the work and indicating its importance was given the press early 1947. It is now the authors' pleasure to express their sincere appreciation of the help given the project by almost everyone approached. The work of gathering data was materially facilitated by the assistance of the following well contractors: Artesian Well and Equipment Co., C. W. Lauman & Co., Layne-New York Co., Parkhurst Well and Pump Co., Rinbrand Well Drilling Co., Samuel Stothoff Co., and William Stothoff Co. Especially valuable data on the operating characteristics of their wells, and other aid, were freely given by Mr. B. H. Bishop and other engineering personnel of P. Ballantine & Sons and by Mr. Wm. E. Helmstaedter, Mechanical Engineer, and others of the Celanese Corporation of America. Particular acknowledgment is made of the assistance

rendered by P. Ballantine & Sons in making their well field available for pumping tests and altering their plant routine to meet the requirements of the test. The Division of Water and the Department of Health of the City of Newark have assisted materially in locating wells and in furnishing records of analyses of well water.

OUTLINE OF GEOLOGY

The Newark area lies wholly within the section of New Jersey underlain by the Newark group of rocks of Triassic age. These rocks form a belt extending from the Hudson River across central New Jersey, Pennsylvania, and Maryland, and into Virginia. They consist of shale, sandstone, argillite, and conglomerate with included sheets, sills, and dikes of trap rock (basalt and diabase).

In New Jersey, the sedimentary rocks of the Newark group have been divided on the basis of their lithology into three units. The lowest is chiefly red, buff, or gray arkosic sandstone and is called the Stockton formation; the middle unit, called the Lockatong formation, is composed largely of gray, purplish-gray, or dull-red argillite; and the uppermost unit, the Brunswick formation, consists chiefly of soft red shale and red sandstone. The Brunswick formation is the bedrock throughout the Newark area. In general, the strata have been tilted northwestward and locally they have been warped into gentle flexures with occasional faulting. The harder beds form ridges, most of which trend northeastward.

The northern part of the belt of Triassic rocks was glaciated in late geologic time, so that much of the surface is covered with a mantle of glacial drift, which in many places is thick enough to conceal the bedrock surface. Although the bedrock crops out in only a few places, it accounts for the relief in the western part of the Newark area. There the covering of glacial drift is thin. In the eastern section the bedrock is concealed by thick deposits of silt and clay with

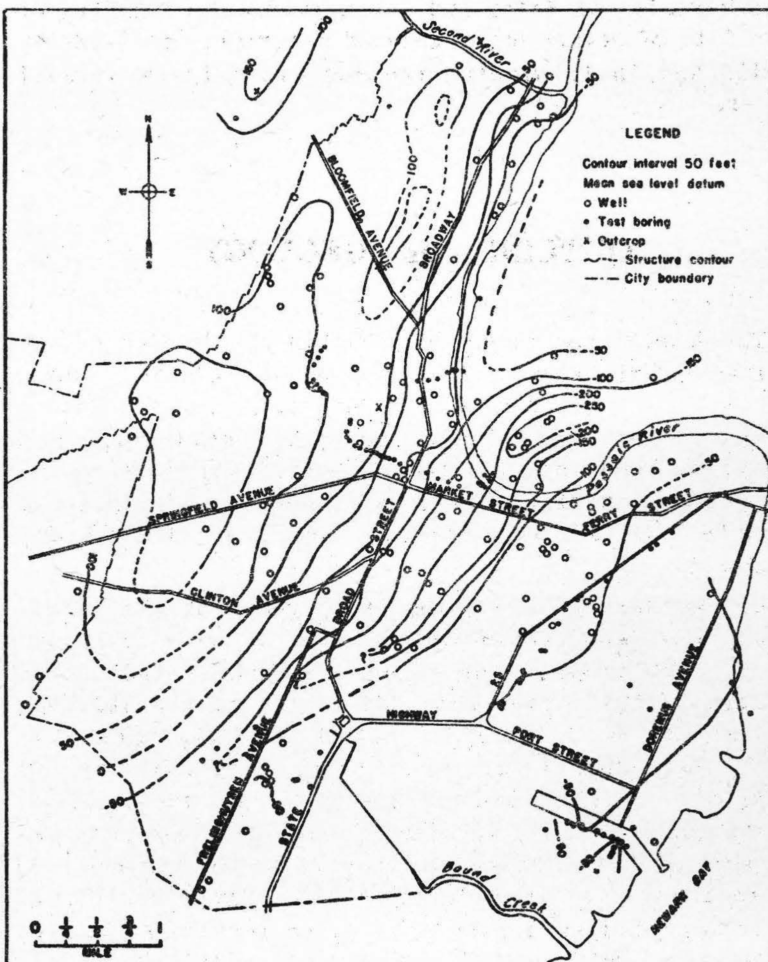

Figure 2.-Map showing elevation and configuration of bedrock beneath Newark, N. J., and vicinity.

thinner beds of sand and gravel, and, although topographically this region is a plain, borings have shown that the surface of the underlying bedrock does not conform with the ground surface. (See figure 2). The valleys of many of the streams in the glaciated area contain terraces of sand and gravel of glacial origin.

The geologic history of the area since the beginning of Triassic time is relatively simple. During Triassic time, sands and muds were deposited in an arid basin. Near the end of Triassic time the beds were faulted and tilted toward the northwest. Later erosion reduced the surface to a plain, over which the sea then advanced an indeterminate distance to the northwest. Sands and clays, such as those found in the coastal plain, were deposited in this sea. Still later, the sea withdrew and the forces of erosion removed the sediments of the coastal plain and then etched out the larger topographic features that we see today. During the Pleistocene epoch the details of the topography were altered by the ice. Hills were smoothed somewhat and much drift was deposited. The drift in some places filled valleys existing prior to glaciation and effected important changes in drainage. A general rise of sea level at the close of the Pleistocene epoch flooded low areas adjacent to the coast, forming Newark Bay at the junction of the Hackensack and Passaic Rivers. Since then the meadows have been formed by stream deposits, and very, very recently -- in terms of the geologic calendar -- much meadowland has been reclaimed by suitable drainage and by filling. A typical example of such "made" land is the area upon which Newark Airport has been built.

The succession of formations in the Newark area, arranged in normal sequence (i.e., youngest formation at top) is shown in the following table:

Table 1.--Stratigraphic table in the Newark area

Cenozoic era

Quaternary system

Recent series

Alluvium and meadow muck

Pleistocene series

Glacial till and stratified deposits of glacial origin

UNCONFORMITY

Mesozoic era

Triassic system

Newark group

Brunswick formation

UNCONFORMITY

Older rocks[2]

2/The deepest well drilled in Newark failed to pass through the red shale and sandstone at 2,538 feet. It cannot, therefore, be stated with certainty what sort of rock lies below the city at great depths. From the general geology of the Triassic rocks, presumably the Palisade diabase would be found at great depth, and more rocks of the Newark group below the diabase. Below the Triassic rocks lie crystalline rocks of very great age which extend to an undetermined depth.

HYDROLOGY AND GEOLOGY OF THE ROCK FORMATIONS

Recent deposits

Recent deposits are found mainly in the eastern part of the Newark area where they occur in the tidal marshes or meadow lands along Passaic River and bordering Newark Bay. They consist largely of unconsolidated mud and silt with inclusions of peat and other organic materials and occasional lenses of sand and gravel. They have been deposited on top of the Pleistocene sediments, or perhaps in places directly on the Triassic rocks, by the Passaic and Hackensack Rivers and by smaller streams flowing across the area and discharging into those rivers, or into Newark Bay. The Recent deposits range in thickness from a feather edge to 35 feet.

Hydrologically, the Recent deposits are of relatively little importance except as they may transmit water to the underlying rocks or exclude it from them. Their permeability is relatively low and they occur in the parts of the area that are exposed to salt water. Therefore their action as a barrier in retarding the percolation of salt water into the underlying rocks is perhaps their most important function. In this respect they perform imperfectly because there probably are breaks in the cover that they provide at critical points, such as the ship channels in the river and in the bay.

Pleistocene deposits

The Pleistocene deposits in the Newark area are all of glacial origin. They consist of till--an unconsolidated, unstratified, heterogeneous mixture of clay, boulders, and sand--and stratified glacial drift, which is composed of sand and gravel that have been more or less sorted and stratified by the action of glacial waters. The deposits of glacial origin overlie the bedrock throughout practically all the Newark area, the bedrock cropping out only in a few more or less isolated spots. The thickness of the Pleistocene deposits varies greatly. In the western part of the area they are only a few feet thick, forming a thin veneer over the underlying bedrock, but in the eastern part of the area they are so thick that they mask entirely the topography of the underlying rock. The map of the elevation and configuration of the bedrock beneath Newark, N. J., and vicinity (figure 2) shows that, in the area east of Broad Street, there is a large deep valley cut in the bedrock, which is entirely covered by glacial drift. At the surface this area presents the aspect of a plain. The depth to rock in the buried valley ranges from 125 feet to more than 190 feet in Newark, and to as much as 300 feet in Harrison. Farther east in the Newark area, bedrock lies at lesser depths. The buried valley extends northeastward across the city from its southwestern boundary, crossing Frelinghuysen Avenue near its northern end, and then extends east of and roughly parallel to Broad Street, finally crossing over into Harrison, where it bends eastward. It has not yet become possible to show the extension of the valley to the southwest or to the east because of the lack of sufficient reliable boring data, but its course and shape across the city of Newark is fairly accurately known. From its shape as shown on plate 1, it is apparent that the valley slopes toward the northeast, and this direction is therefore the probable direction of flow of the river that cut the valley prior to the Pleistocene epoch.

The character of the Pleistocene deposits varies throughout the Newark area. In general, these deposits consist chiefly of till in that part of the area lying west of Broad Street, whereas the cuttings taken from many test borings and wells in the eastern part of the area show that the Pleistocene deposits there consist largely of stratified materials with interbedded lenses of till. (See logs 1 to 4 in appendix.)

The Pleistocene deposits in the bottom of the buried valley are worthy of special attention. In the southwestern part of the Newark area they consist for the most part of fine sand and clayey sand, but in the northeastern part the bottom of the valley contains deposits of coarse sand and gravel which in many places contain much water. (See logs 1 and 2 in appendix.) In fact, some of the best wells in the Newark area pump from these deposits.

Other coarse deposits of glacial origin are found in the valley of the Passaic River north of the point where the river makes its great eastward bend.

The Pleistocene deposits are one of the two major aquifers in the area. Their hydrologic function is twofold. In the first place, under favorable circumstances they yield water in substantial quantities directly to wells. In the second place, they absorb and store water from precipitation and from surface sources and transmit it to the underlying rocks.

Where the deposits contain beds of sand and gravel that are thick enough and extensive enough, they yield large quantities of water to wells finished in them. Insofar as is known, these conditions are limited almost entirely to the buried valley, where several wells yielding from 175 to more than 600 gallons per minute have been developed. For example, a well drilled for the Driver Harris Co. in Harrison near the locality where the buried valley crosses the Passaic River yielded 600 g.p.m. with a draw down of approximately 60 feet.

Detailed and extended records of water levels in and of pumpage from wells in this aquifer are not available. It is therefore impossible to say at this time whether water is being withdrawn from this aquifer at a rate less than, equal to, or greater than the rate at which recharge is available. The fact that two or three million gallons of water have been withdrawn daily for a number of years from the sand and gravel in the buried valley suggests that a large quantity of recharge occurs. On the other hand, the fact that the static water levels in some wells tapping this aquifer are now substantially below sea level suggests caution before further developments are made.

A more definite and immediate threat to the safe yield of the gravels of Pleistocene age is the apparent intrusion of salt water from surface sources. Wells near the point where the buried valley crosses the Passaic River are yielding water that contains 200 to 500 parts per million of chloride and is already unsuitable for some uses. Inasmuch as there is hydraulic continuity between the gravels and the underlying rocks, the problem of salt-water intrusion will be discussed in more detail in a section of this report that deals primarily with the water supply from the rocks.

The second function of the Pleistocene deposits, that of absorbing, storing, and transmitting water to the underlying rocks, is, in the aggregate, more important than their yielding water directly to wells. As already indicated, they overlie the rocks to varying thicknesses throughout most of the area. In general, there appears to be some correlation between the thickness and nature of the Pleistocene deposits and the yield of wells tapping the underlying rocks. This is to be expected because the storage capacity of the rocks is relatively low and sustained large yields can be obtained from them only if some adequate source of recharge is available. Where the overlying deposits are thick and moderately porous and permeable, they supply the necessary recharge. On the other hand, where they are thin or relatively impermeable, they may fail to supply recharge to the rocks or may even retard the movement of water into them.

Newark group

Brunswick formation

Geology

As mentioned previously in the outline of the geology of the Newark area, the sedimentary rocks of the Newark group of Triassic age in New Jersey have been divided upon the basis of their lithology into three units--the lower, or Stockton formation, the middle, or Lockatong formation, and the upper, or Brunswick formation. It should now be pointed out that whereas these lithologic distinctions can be made in central New Jersey, they are not apparent in the northern part of the belt of Triassic rocks. The Lockatong formation does not continue farther northeastward than Franklin Park, Middlesex County, and the distinction between the Stockton and Brunswick formations is no longer obvious, as it is farther southwestward, because the whole Newark group becomes, in general, coarser-grained. In the northern part of the State, particularly in Bergen County, these sediments become predominantly sandy and even conglomeratic. In the Newark area, the tendency of the rocks to increase in coarseness toward the northeast is shown by the fact that wells drilled in the southern part, near the Elizabeth line, have penetrated rock that is chiefly soft red shale, whereas in north Newark, especially near the Belleville line, the rocks are principally sandstone with interbedded shale. In fact, during the latter part of the last century several sandstone quarries were operated in north Newark, especially along Bloomfield Avenue and in the southern part of Branch Brook Park. The change from soft shale to hard sandstone is reflected in the change in topography from a rather flat, low-lying plain with few rock hills in southern Newark to hills with rather pronounced relief in the northern part of the city. In the Newark area, therefore, the bedrock is all designated as Brunswick formation. A representative section showing the variations in the rock under Newark is shown in log 3. (See appendix 1.)

The bedrock originated as sand, silt, and mud which were derived from the erosion of older rocks northwest and southeast of the great basin in which the sediments were laid down during the Triassic period. Three times during the period of deposition great sheets of basaltic lava were poured out on the surface and were then buried by sediments later in the Triassic. The remnants of the flows now form the Watchung Mountains, but it is impossible to state whether or not the flows ever extended as far east as the Newark area, for there are no igneous rocks of this type in that area, so far as is known. Toward the end of the Triassic period, the sediments were intruded by similar magma which apparently did not have enough force to push through to the surface but spread out beneath the surface in a great sill some 900 feet or more thick, usually following the bedding planes of the sediments but frequently cutting across them. Because of erosion, the sill is exposed today in the Palisades in eastern Hudson and Bergen Counties and also in certain mountains in central New Jersey. At the close of Triassic time, the entire Newark group of rocks were tilted toward the northwest, which is their attitude today and in the process they were faulted and greatly fractured.

The total thickness of the rocks of Triassic age in the Newark area is unknown but is estimated at about 6,000 to 7,000 feet.

The deepest well drilled in Newark reached a depth of 2,538 feet and failed to pass through the normal red shales and sandstones. It is therefore impossible to state with accuracy what lies below that depth, but presumably a well drilled to great depth in Newark would eventually strike the Palisade diabase, and below that would strike more sedimentary rocks of Triassic age before entering the crystalline basement rocks upon which the Triassic sediments were deposited.

Hydrology

GENERAL.--

The Brunswick formation yields water primarily and almost exclusively from the cracks in the rocks of which it is composed. The primary pore spaces in the rocks are generally so small that water moves through them very slowly, if at all, under the hydraulic gradients that are established by pumping. Were it not for the fact that the formation has been extensively cracked and fractured, and has thus acquired a kind of secondary permeability, it would yield very little water.

There is in the Brunswick formation a kind of modified water-table condition wherein the water is generally free to move in any direction and seek the level determined by the factors affecting recharge and discharge. The various systems of cracks intersect so that water can move more or less freely in all directions. However, the cracks are not of uniform size and capacity in all directions, and water is likely to move more freely in some directions than in others. For the area as a whole, there may be no one direction that is generally more favorable to flow than others. It probably differs from place to place.

The capacity of the formation to store and transmit water decreases with depth. As greater depths are reached, the weight of the overlying materials increases and tends to close the cracks. Thus less and less space is available to store water and the resistance to its movement is increased. It is probable that the cracks that are horizontal, or nearly so, are first affected and most affected in this way. The horizontal cracks tend to distribute water uniformly in all directions, so that the tendency of the water to flow in the direction of the prevailing vertical cracks is probably accentuated with depth. The cracks along the bedding planes, which appear to be very numerous near the surface and are more nearly horizontal than vertical, probably are less and less important with depth.

There is, therefore, little foundation for the common belief that water is transmitted for long distances underground through the Brunswick formation, particularly along the bedding planes of the rocks. It is unlikely that the bedding planes, or rather the horizontal cracks along them, provide the path of least resistance to the flow of water. Actually, water probably flows through the formation most readily in vertical or nearly vertical cracks. Except along major faults, individual vertical cracks are not likely to extend very far without interruption, and are not likely to transmit water for distances greater than 2 or 3 miles. Furthermore, as the vertical cracks necessarily intersect the rock surface locally, they will receive recharge or discharge water locally depending upon the hydraulic gradient.

Certain characteristics of individual wells in the area may be better understood in the light of the foregoing general description of the rocks from which they draw their water. The yield of a well tapping the Brunswick formation depends primarily upon the number and size of the cracks that it encounters below the water table, or more specifically upon their capacity to transmit water. Thus, two adjacent wells may pass through almost identical layers of rock, and one may yield a substantial quantity of water whereas the other may yield very little, depending upon the character of the cracks encountered in each. It is therefore impossible to predict the yield of a proposed well except in general terms based upon the average yield of other wells in the vicinity. Furthermore, all predictions of yield of wells in the Brunswick formation should be qualified by a statement that the final proof must be the actual yield of the finished well, because the number and capacity of the cracks encountered cannot be determined in advance. what, no water witches in Newar

There is usually little or nothing to be gained by deepening an unsuccessful well below the average depth of the productive wells in the area, because the cracks become smaller and probably less numerous with increased depth. It is almost always wiser to move to another site, even if only a short distance away, and to drill another well, rather than to double the depth of a poor well in the hope of improving its yield. It is obviously impossible to determine the nature and pattern of the deeply buried cracks at any site from observations at the surface. There are, of course, rare exceptions to this general rule, but it holds well enough to make its observance sound economic policy. For example, it has already been mentioned that one well in Newark was drilled to a depth of more then 2,500 feet. That well, though very expensive, was unproductive.

As a general rule, in the Brunswick formation most of the productive cracks occur within the first 200 or 300 feet of the rock. In some parts of the Newark area, however, most of the productive wells penetrate the rock 400 or even 500 feet. Sufficient data are not available to indicate whether the rock there is unusually productive at great depths or whether many of these wells are unnecessarily deep, because most of them were not tested before they had been drilled to their full depth. It is possible that the bottom parts of many of these holes are not very productive.

An interesting though probably extreme example of a well that was unproductive at depth is one about 800 feet deep that was observed in the course of the studies preceding this report. When the regional water level declined, the yield of this well dropped sharply. With the thought that some of the productive cracks might have been clogged either in the drilling or subsequently, the owner employed a driller to clean out and redevelop the well. A thorough job was done and it is unlikely that there remained any cracks that were sealed with mud or otherwise clogged. Nevertheless, the yield of the well did not improve substantially. It was therefore abandoned and made available as an observation well. During the spring and early summer of 1947 the water level in the well declined normally to a level of 101 feet below mean sea level, where it stopped abruptly. While the water levels in other observation wells in the vicinity continued to decline to about 230 feet below mean sea level and the pumping levels in some adjacent wells were still lower, the water level in this well remained at 161 feet. In the late fall and winter, after the regional water level had recovered to 161 feet, this well again became responsive to variation in pumpage and fluctuated normally. The same performance was repeated in the summer of 1948 and again took place in 1949. Apparently the only explanation for the peculiar behavior of the water level is that no cracks were encountered below 161 feet and that therefore the well is water-tight at greater depths. This is, no doubt, an unusual case, but it does serve to emphasize the dependence of the yield of rock wells upon cracks, as well as the relative unimportance of horizontal cracks at depth and the decreased chance of hitting good cracks at increased depth.

The character of the Brunswick formation as an aquifer also explains another peculiarity of the wells that tap it. Ordinarily, in a relatively uniform aquifer, the interference between two or more wells is dependent mainly upon the distance between them. In the Brunswick formation, as in similar aquifers, a pumping well often affects the water level in a second well substantially more than that in a third well at the same distance but in a different direction. The explanation of this peculiarity, of course, lies in the fact that the different systems of cracks differ in their capacity to transmit water.

The Brunswick formation does not yield water as freely as some of the other important water-bearing formations in the State, especially those that yield water from the pore spaces in well-sorted medium-to coarse-grained sand and gravel. This is due primarily to the fact that its capacity to store and transmit water is smaller. The deficiency is most marked in regard to its capacity to store water. The specific yield (the storage capacity expressed as a percentage of the volume of the aquifer) of a coarse, well-sorted sand is frequently as much as 25 percent. The specific yield of the upper 300 feet of the Brunswick formation, based upon the volume of cracks, is probably more nearly in the order of 1 or 2 percent. Therefore, it is easy to understand the hy-

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drologic importance of sources of ready recharge such as bodies of surface water or of relatively permeable sand and gravel in areas where large quantities of ground water are withdrawn from the formation. The capacity of individual cracks to transmit water is probably larger than that of a comparable volume of pore spaces in a sand. It is not surprising, therefore, to find that the capacity of the Brunswick formation to transmit water is about one-fourth of that of some of our important sand aquifers in spite of the relatively limited volume of cracks.

Pumping Tests – In January 1949, through the cooperation of the officials of P. Ballantine & Sons, two pumping tests were run on wells tapping the Brunswick formation. For several days all the company's wells were operated to suit the requirements of the test. At each of their two plants two wells were run continuously until conditions approaching equilibrium were established. This involved wasting water at some times of the day in order to have an adequate supply available at others, but it seemed to be the only practical way of reaching an approximate state of equilibrium. After about 24 hours, the effects of changing the rates of pumping at the plant appeared to have been eliminated, and, with one exception which will be discussed later, the effects of pumping at other plants in the area seemed to be of little importance.

The wells pumped during the two tests are shown on figure 3. They were selected to provide the best possible spread of observation wells in as many directions as possible. The first test was made by pumping well 1 at plant 1. This well is centrally located, and water levels were observed in seven other wells at various distances and directions from it. In the second test, well 9 at plant 2 was pumped and water levels were observed in the same group of observation wells. In this test, however, the pumping well was in one corner of the well field so that the distances to the observation wells were greater and their directions were less varied.

During the pumping tests, water-stage recorders were maintained on well 5 at plant 1 and on wells 8 and 10 at plant 2. The water levels in well 7 at plant 1 were measured by air pressure, using an 8-inch pressure gage on which it was possible to note changes of water level of one- or two-tenths of a foot. The water levels in the other wells were measured by air pressure, using ordinary pressure gages that would probably not indicate changes of water level of less than one foot. There were only four wells, therefore, in which water levels could be observed accurately; of these wells 5 and 7 at plant 1 appear to have been drawn down below the most productive cracks encountered in them. The best observations were therefore obtained in wells 8 and 10 at plant 2. Two of the wells observed, wells 4 and 8 at plant 1, were operated continuously during both tests to supply water for manufacturing purposes.

During the first test a prompt and distinct effect was observed in well 8, plant 2, when well 1, plant 1, was started and again when it was shut down. This seemed to indicate that these two wells tapped the same system of cracks. No distinct effect was observed in any of the other wells during this first test, even though it was continued for several hours. Well 7 at plant 1 is almost in a straight line with well 8, plant 2, and well 1, plant 1. It is in the opposite direction from well 1 and only about half as far away, yet no effect was observed in it. No definite effects of pumping or shut-down were observed in any of the other wells.

During the second test, when well 9, plant 2, was pumped a prompt and distinct effect was observed in well 10, plant 2, both at the beginning and at the end of pumping. None of the other wells being observed showed any distinct effect. It is interesting to note, however, that the recorder on well 10 showed a small but definite effect whenever well 27 at the plant of the Celanese Corporation of America was started or stopped. This well is approximately southwest of well 10 and about 2,400 feet from it, a distance substantially greater than that between any of the wells at the Ballantine plants.

It is believed to be significant that all the wells that were observed to affect one another during the

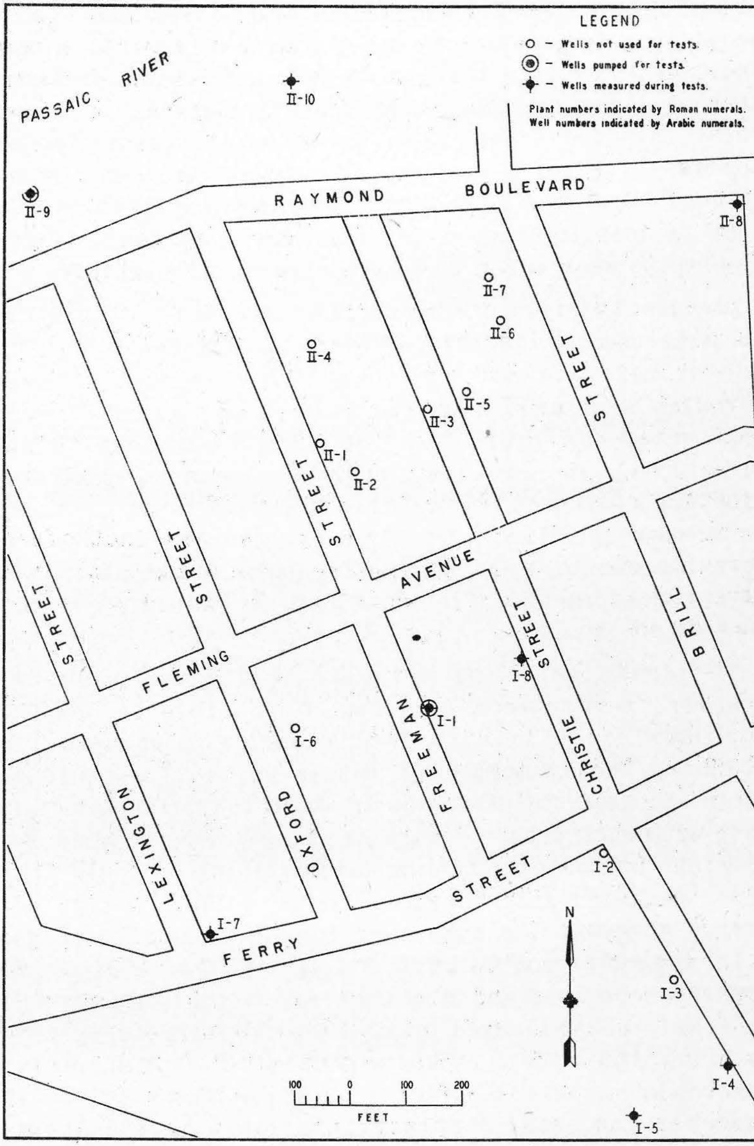

Figure 3.-Map of a part of Newark, N. J., showing the location of wells at the plants of P. Ballantine & Sons and indicating the wells used for pumping tests in January 1949.

two tests at the Ballantine plants lay along lines trending in a general northeasterly direction. This seems to indicate that in the vicinity of the Ballantine and Celanese plants there is a dominant system of cracks in that direction. No doubt there are cracks in transverse directions, but their capacity to transmit water appears to be much smaller. Consequently, water moves through the cracks that trend northeast much more easily than it does in other directions and the primary interference between wells is to the northeast or southwest.

One result of this distribution of cracks is that the formulae used to compute coefficients of transmissibility and storage are not applicable to this area. These formulae are based upon the assumption, among others, that water can move freely through the aquifer in all directions. In some other localities where the distribution and character of the cracks are more nearly equal in transverse directions, it is believed that these formulae can be applied significantly to wells in the Brunswick formation. In this part of Newark, however, they do not apply.

The tests were not without significant results, however, merely because it was impossible to compute the usual coefficients from them. For example, in planning the locations of future wells, it should be useful to know the direction in which they will interfere most with each other or with existing wells. Similarly, it might be possible to plan an operating schedule that would minimize interference between wells and thus decrease somewhat the pumping lift. Artificial recharge will be most effective if it is distributed in a direction transverse to the major cracks, thus supplying more of them without depending upon the poorer cracks to distribute the water. The movement of contaminating materials such as salt water from the river or bay is probably most easily accomplished in a northeasterly or southwesterly direction after it reaches the rock. The structure of the rock does not, of course, affect appreciably the movement of such contaminants through the materials above the rock.

Long-term fluctuations of water levels and pumpage - In the investigation that preceded this report, it was found that relatively few well owners had kept accurate and continuous records of pumpage and that still fewer had more than an occasional record of the water levels in their wells. Fortunately, important exceptions to this general rule were some of the larger users of ground water. In only one part of the area, however - the so-called "Ironbound District" in eastern Newark - was it possible to obtain sufficient data to justify a long-time estimate of pumpage rates and to compare it with similar records of water levels. In this area the two largest users of ground water are P. Ballantine & Sons and the Celanese Corporation of America. These companies are keeping excellent records of pumpage and water levels and have done so for some time.

When the records that these two companies furnished were combined with other data available in the area, it was possible to prepare a diagram (figure 4) that shows some significiant trends of water levels and pumpage.

Probably the most striking features of figure 4 are the long-term trends toward greater pumpage and lower water levels. These two trends go together, of course, and from the studies made thus far it is not possible to say whether the lowering of water levels indicates a pumping rate in excess of natural recharge or merely the lowering necessary to induce flow into the area at the increasing rates. The apparent reversal of the downward trend of water levels in 1948 and 1949 is due to unusually good natural recharge coupled with artificial recharge that will be discussed later.

Almost equally striking are the seasonal fluctuations of water level and pumpage, which are related to each other and are due primarily to seasonal demands for water. Much of the water taken from the ground in the area is used for cooling and the demand is naturally greater in the summer. Furthermore, there is a seasonal demand, which is greatest in summer, for the products of some of the users of ground waters. This tends to accentuate the seasonal use of water. There is, of course, a greater recharge from precipitation during the winter when the demands of vegetation are at a minimum, but this probably accounts for only a few feet of the total fluctuation of water levels.

There is a notable similarity between the fluctuations of water level in the different wells shown in the diagram. This indicates that there is an over-all

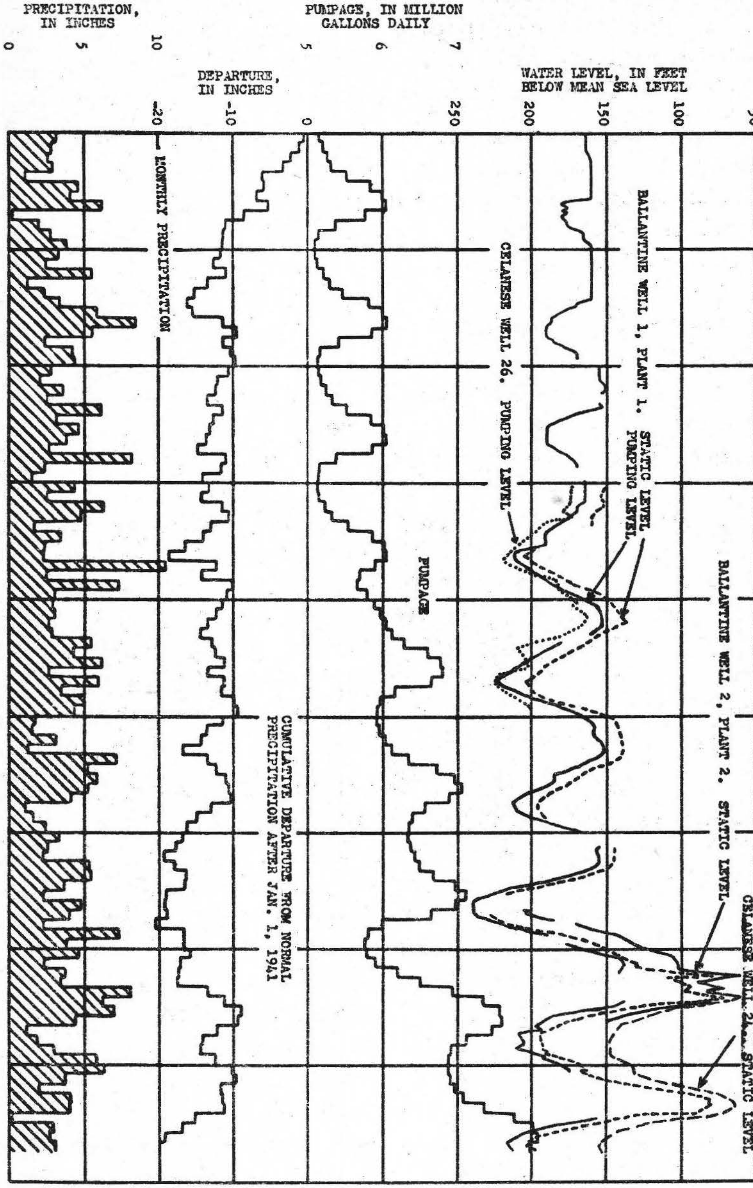

Figure 4.-Diagram showing fluctuations of pumpage and water levels in the eastern part of Newark, the monthly precipitation, and the cumulative departure from normal precipitation, 1941 to 1949.

connection between the various wells in the area and that the regional pumpage is of primary significance in determining the major fluctuations of water level. Minor differences are due, ofcourse, to local conditions.

The wide range of seasonal fluctuations of water levels and the great depths to which they have been drawn are noteworthy. During recent years a change of one million gallons daily in the rate of pumping in this area has resulted in water-level fluctuations in the order of 60 to 75 feet. Furthermore, with a total pumpage of about seven million gallons daily the water levels have been lowered to 200 feet or more below mean sea level. In view of the fact that an early well in this vicinity flowed at an altitude of perhaps 10 feet above sea level, the current water levels represent actual drawdowns of more than 210 feet. The rate of lowering per million gallons pumped seems to be increasing and, indeed, this would be expected because of the decreasing capacity of the cracks with increasing depth. The figures strongly suggest that the rate of pumping in this vicinity cannot safely be increased very much more without serious consequences, unless the increase is accompanied by some measure of conservation such as artificial recharge.

The precipitation at Newark varies considerably from month to month, as indicated at the bottom of the diagram. The trend of the accumulated departure from normal precipitation is perhaps more useful in the study of ground-water trends because it indicates periods when increasing or decreasing amounts of water are available for underground storage or withdrawal. After the very dry period of 1941, the accumulated departure shows an essentially horizontal trend. This indicates that the long-term downward trend of water levels is not due to changes in precipitation. Some of the shorter trends may, however, have had some influence on the water levels. For example, the less severe drawdown in the summer of 1946 than in 1945 is probably due to the above-normal precipitation during the summer of 1946, as indicated by the rising trend of the departure line. Similarly, the sharp decline in the summer of 1947 is probably related to the declining trend of precipitation during that summer. It is obvious from a study of the diagram, however, that the fluctuations of pumpage rather than those of precipitation are the principal causes of the water-level fluctuations.

Artificial recharge.-- The graphs of water levels in figure 3 show a sharp and abrupt rise in March 1948 and again in February 1949, both without any corresponding decrease in pumpage. These apparent anomalies are caused by artificial recharging through wells, conducted experimentally by P. Ballantine & Sons with the cooperation of the Newark Water Department. On occasions during the winter when the temperature of the city water was as low as or lower than that of the ground water and when the city's reservoirs were overflowing, conditions were ideal for recharging. Water that would otherwise have gone to waste was stored underground and conserved for future use. Recharge was accomplished through several wells. In 1948 about 168 million gallons was stored in the ground in this way and in 1949 about 236 million gallons.

It had been hoped that the results of the pumping tests discussed earlier in this report would furnish accurate data for evaluating the effects of recharging. Unfortunately, it developed that conditions in this vicinity were unsuited to analysis in this way. However, the evaluation of the artificial recharge is not wholly dependent upon pumping tests.

As a result of the recharging, the water levels in the area as a whole were higher at the beginning of the season of heavy demand than they would otherwise have been. The greatest benefit occurred in the immediate area of the recharging, that is, in the Ballantine well field, but there were substantial gains at considerable distances. For example, during the recharging in 1949 a recorder was maintained on a well of the Celanese Corporation of America approximately half a mile from the center of recharging and water levels there rose sharply and promptly when the recharging was begun.

The water used for recharging probably did not drift very far away from the area in which it was introduced into the aquifer. Previous pumping had established a deep depression in the water table there and the effect of the recharging was to fill the depression partly. The improved water levels observed elsewhere occurred before water could possibly have moved through the aquifer from the point of recharge to the point of observation. They represented a backing up of water that had previously been flowing into the Ballantine well field and that became available for withdrawal elsewhere when recharging began. The effect outside the Ballantine well field was exactly the same as if the rate of pumping at Ballantine's had been decreased by the amount that was recharged. And indeed the demand upon natural recharge was decreased by exactly that much. Much of the recharge water probably circulated directly to other wells in the Ballantine well field during the recharging. The remainder was almost certainly drawn into them soon after recharging ceased. Whatever benefits were derived from the higher quality and lower temperature of the recharge water were probably restricted entirely to the Ballantine well field. The gain in head and therefore in water stored in the ground extended to other nearby parts of the area.

Observations made during the recharging experiments indicated that the water levels in parts of the Ballantine well field may have risen above the top of the rock. This is not surprising in view of the limited capacity of the cracks in the rock. As soon as the water levels rose into the overlying glacial material the storage capacity was much greater. At no time did the head rise far enough to cause any loss of recharge water out of the system of aquifers. The highest water levels during the recharging were still more than 50 feet below mean sea level.

Chemical quality of the ground water

The chemical quality of the ground water from rock wells in the Newark area is shown by the analyses in table 1, on page 49. Analyses A and B are of water taken from wells in the western part of the area farthest removed from the Passaic River and Newark Bay. The water is hard, principally because of its calcium and magnesium content. It is too hard for boiler use, but is suitable for most other uses, particularly for cooling. Several tanneries using ground water in their operations report that the quality of the water has a "favorable" effect on their processes. One producer of carbonated water reported that the ground water imparted a pleasing taste to his product. Where not contaminated by bacterial or other harmful impurities, the water is potable.

The general quality of water pumped from wells in the areas nearer the river and bay is shown in analyses C and D. This water is generally reported to be far more corrosive than the ground water in the areas farther from the river and bay, and where the chloride content is high the necessity of frequent replacement of ordinary bronze impellers on pumps has been reported. One user has apparently solved this problem by the use of impellers and pump bowls constructed of a high-nickel-content alloy. The highly mineralized water, of course, is generally not potable.

The high sulfate content of waters from some rock wells may be a function of the depth of the well. This may be explained by the fact that gypsum (calcium sulfate) has been observed in the cuttings taken from very deep wells. (See log of well 3, in appendix.) Gypsum has also been observed by the senior author in the cuttings from another deep well in Newark, and Meredith E. Johnson, New Jersey State Geologist, has observed gypsum in cuttings taken at 580 feet from a well drilled in the Brunswick formation near Westfield, New Jersey. In the cuttings from the bottom of the Celanese Corporation well, the gypsum occurred as large plates (1 1/2 by 1/2 by 1/8 inches) which had every appearance of having been the fillings of cracks. Presumably, therefore, gypsum, originally deposited in the cracks in the rock, has remained in the deeper cracks because it was not exposed to the circulation of meteoric waters.

Occasionally, wells drilled into the rocks of the Brunswick formation have yielded water of high mineral content upon completion. In such wells, it has sometimes been possible to lower the mineral content of the water by pumping the well heavily for a prolonged period. High mineral concentrations of this sort are probably caused by the ground water having been more or less stationary long enough to dissolve the mineral matter from the rock. Heavy pumping permits circulation of ground water and may induce a flow of water of lower mineral content toward the well. So far as is known, no instances of this sort have been reported in the Newark area.

Table 2.--Analyses of water from rock wells in the Newark area
(Results in parts per million)

Well	A	B	C	D	E	F
Color	0	0	0	0		
Total hardness as $CaCO_3$	300	282	380	2,870		
Dissolved solids	431	378	749	4,780		
Specific conductance, micromhos at 25^0 C.	669	614	1,220	6,960		
pH	7.2	7.6	7.5	7.3		
Silica (SiO_2)	22	20	18	31	34	
Iron (Fe)	.17	.13	1.1	.15		
Calcium (Ca)	105	67	111	865	340	426
Magnesium (Mg)	9.3	28	25	173	60	51
Sodium (Na)	19	16	87	447	18	48
Potassium (K)	1.8	2.7	2.8	7.0		
Carbonate (CO_3)	0	0	0	0		
Bicarbonate (HCO_3)	202	213	150	210	76	19
Sulfate (SO_4)	88	66	91	911	993	1,380
Chloride (Cl)	25	28	230	1,900	6.2	26
Fluoride (F)	.1	.1	.1	.0		
Nitrate (NO_3)	45	29	31	6.2		

Table 2.--Analyses of water from rock wells in the Newark area (continued)

A) From 310-foot well, Frick Bros. Creamery, Irvington, N. J.

Analysis by U.S.G.S., January 1948.

B) From 300-foot well, Hooton Chocolate Co., Newark, N. J.

Analysis by U.S.G.S., January 1948.

C) From 558-foot well, Kresge Dept. Store, Newark, N. J.

Analysis by U.S.G.S., January 1948.

D) From 805-foot well, P. Ballantine & Sons, well 1, plant 1, Newark, N. J. Analysis by the U.S.G.S., January 1948.

E*) From 250-foot well, Celluloid Works, Newark, N. J. Analysis by P. Ballantine & Sons, 1879. (See Ann. Rept. New Jersey State Geologist for 1879, p. 127.)

F*) From 615-foot well, Lister Bros., Newark, N. J. Analysis by P. Ballantine & Sons, 1879. (See Ann. Rept. New Jersey State Geologist for 1879, p. 127.)

* Recalculated to p.p.m. by H. Herpers.

Reliable and detailed analyses of waters from wells pumping from the sand and gravel in the buried valley are not available at the present writing.

Salt-water intrusion

The infiltration of salt water into the body of fresh ground water is referred to as salt-water intrusion. In the Newark area it is believed to be caused principally by heavy pumping in areas adjacent to Newark Bay and the Passaic River. (1) Heavy pumping lowers the general ground-water levels, creating a difference in head between the ground-water body and the nearby bay and river, inducing a flow of salt water into the water-bearing formations. Another factor that probably contributes to salt-water intrusion is (2) the dredging of ship channels in the Passaic River and Newark Bay. As mentioned previously in the discussion of the hydrology of the Recent deposits, those deposits (the silt & clay) act as an imperfect barrier to the infiltration of salt water into the underlying materials. It is not improbable, therefore, that the deepening of ship channels in the river and bay has contributed to the breaking of the imperfect seal formed by the Recent (and, in some places, Pleistocene) deposits. In the areas of salt-water intrusion, the water in both the unconsolidated materials and the rocks is affected.

The attached map (figure 5) shows the distribution of the chloride content of the ground water in the area. Most of the data upon which the map was based were provided by the Newark City Chemist, through the courtesy of Dr. Charles V. Craster, Health Officer of the City of Newark. As almost all the analyses were made in 1942, when the City of Newark made a survey of certain qualities of the waters from wells in the city, the map presents a picture of the chloride content of the ground water at that time. Recent check analyses made in the investigation preceding this report, confirm generally the distribution of chloride shown. The curved lines represent points of equal chloride concentration.

Several areas of ground water with high chloride concentrations are shown, and all are in areas of relatively heavy pumpage. The first of these is along the Passaic River near the northern boundary of Newark, where there are several industries that use well water in processing.

The pumpage here is not as heavy as in the other areas, and great amounts of river water have not been drawn into the ground-water body. Mention might here be made of the single well near the bank of the Passaic River, just south of the area, marked A on figure 5, the water from which contained 1,710 parts of chloride per million. This well pumps from a gravel bed about 45 feet below the surface which is probably in direct hydraulic connection with the river.

The second area of high chloride concentration is near the intersection of Harrison Avenue and McCarter Highway. Here, fairly heavy pumpage has induced an inflow of water from the river.

The third area, near the intersection of Raymond Boulevard and Broad Street, contains several wells that pump large amounts of water, principally for air-conditioning.

The fourth and largest area with high concentrations of chloride in well waters is in the eastern part of the Newark area and is bounded roughly by Harrison Avenue on the north; by Fourth Street, extended to Port Street on the west; by Port Street on the south; and by the Passaic River and Newark Bay on the east. The area contains many industries that require large amounts of ground water for cooling and processing. Heavy pumping, continued over a period of many years, has caused the depression of the upper surface of the ground-water body, which has, in turn, led to river-water intrusion on a large scale. That the present character of the water in this area is materially different from its original character can be seen by comparison of analyses D, E, and F (See table 2 on p. 38) Analysis D was made of water taken from a well of P. Ballantine & Sons in January 1948, whereas analyses E and F, made in 1879, are of water taken from wells not far from the Ballantine plant. Analyses E and F show that the ground water in this section originally had a chloride content comparable to that of water taken from wells in areas away from the river and bay.

About 4,000 feet northeast of the intersection of State Highway 25 and Port Street a great concentration of chloride was found in three wells belonging to a single company. Some of the differences in chloride content in this area may be due to differences in depth. The highest concentration (2,700 p.p.m.) was encountered in a well 535 feet deep, whereas lower concentrations were found in nearby shallower wells. At the time the deep well was drilled, it was thought that the highly saline water might be caused by a pocket of stationary ground water, which had acquired its high salt content from the formation because of a lack of normal ground-water movement in the vicinity. On the basis of this assumption, the well was pumped steadily at a high rate of discharge for a few weeks with the idea of pumping out the pocket of highly mineralized water and inducing a flow of fresh water into the well. The results were inconclusive and the well was finally abandoned because of the unsatisfactory quality of the water.

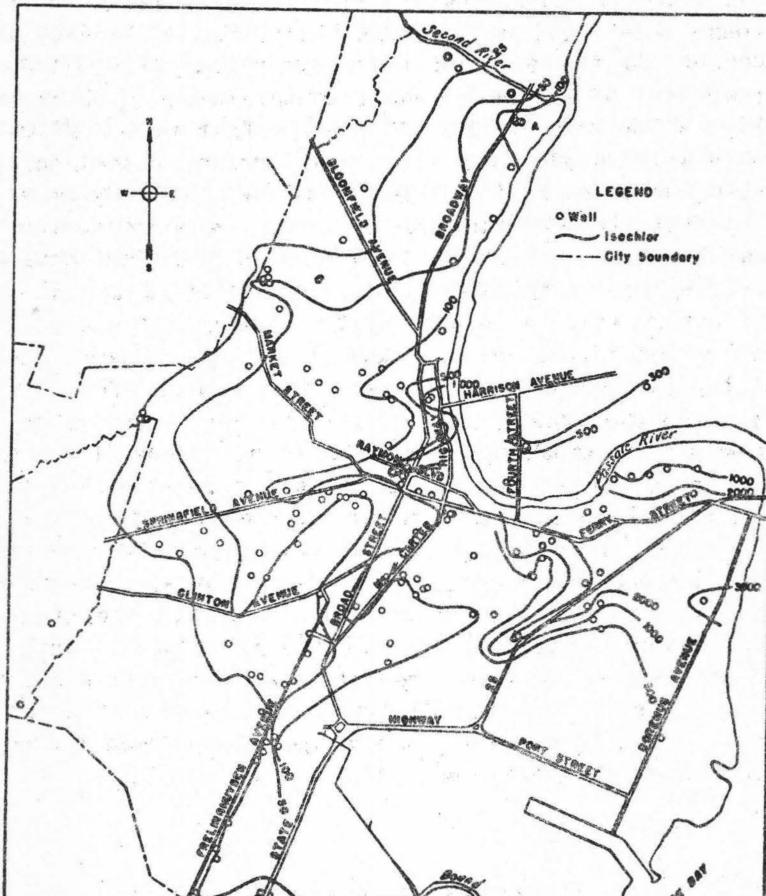

Figure 5.-Map showing chloride content of the ground water beneath Newark, N. J., and vicinity.

Temperature of the ground water

The average temperature of the ground water in the Newark area is approximately 55° F. The temperature of ground water, except as explained below, is largely a function of the depth of the aquifer from which it is drawn, and of the mean annual temperature of the air, which at Newark is 52.3° F. Water from very shallow wells will usually vary in temperature over the year. Water from somewhat deeper wells, however, has a temperature that, for all practical purposes, is equal to the mean annual temperature. The effect of the mean annual temperature on the temperature of ground water does not extend to great depths. It is known from numerous deep wells, mines, and test borings that the temperature of the earth's crust increases with depth. The rate at which the ground temperature increases with depth, known as the geothermal gradient, varies, depending upon many conditions, but generally an increase of 50 to 150 feet in depth will raise the temperature 1° F. Of course, in regions of active volcanism this rate of increase does not apply. In the Newark area the normal geothermal gradient is not known as all temperature measurements have been made at the point of discharge of the pumps. Each measurement, therefore, represents merely the temperature of the water issuing from the well, which is probably an average of the temperatures of water at all producing levels.

CONCLUSIONS

The studies that preceded this report were not detailed or prolonged enough to arrive at definite answers to important questions that arise with regard to the safe yield of the aquifers in the Newark area. Only very tentative conclusions can be made at this time. Observations and studies should be continued over a period of years in order that the safe yield may be defined.

Continuing observations should be made of the pumping rates in every well in the area and of the water levels in an adequate number of observation wells so that the rate and direction of flow in the aquifers and the amount of recharge to them may be defined. Periodic analyses of the water from representative wells throughout the area should be made in order to detect changes in its quality and especially to define the intrusion of salt water. Geologic information should be sought to extend our knowledge of the buried channel that passes through the area and of the materials that fill it. Whenever wells or other deep excavations are made, particular attention should be given to the nature of the material overlying the rock in order to establish its geologic and hydrologic characteristics more fully, and ultimately to define the best areas of recharge.

In many parts of the area conclusive data are not available, but it seems probable that there are localities where additional quantities of ground water may be obtained. It also seems probable that in some heavily pumped parts of the area the safe yield is being approached or has already been exceeded. For example, in the area around the plants of P. Ballantine & Sons and the Celanese Corporation of America, the water levels have been lowered to such an extent that it seems unlikely that any substantial additional quantity of water can be withdrawn from the ground safely or economically. The quality of the ground water in this area is already unfit for some uses.

The experiments with artificial recharge at the Ballantine plant during the last two years offer promise of great improvement in the ground-water conditions in some parts of the area if water is available for continuing such recharge. This is certainly sound conservation practice and should be expanded as much as possible. Whenever recharging is undertaken in the future, careful observations should be made of water levels and of the quality and quantity of water recharged and withdrawn, in order to evaluate the effects more closely and to trace the movement of the water.

APPENDIX I - SELECTED WELL LOGS

1. Log of well 2, drilled for Driver Harris Co., Harrison, N. J., by C. W. Lauman & Co.
Log furnished by C. W. Lauman & Co.

Depth	Thickness	Description	Correlation
0' - 21'6"	21'6"	Fill	Fill
21'6" - 30'10"	9'4"	Sand and gravel	Glacial drift
30'10" - 39'0"	8'2"	Coarse sand and gravel	"
39'0" - 41'10"	2'10"	Streaks of hard red clay and gravel	"
41'10" - 58'2"	16'4"	Red clay, fine sand and gravel	"
58'2" - 62'2"	4'0"	Clay and gravel	"
62'2" - 71'9"	9'7"	Hard red clay and broken rock	"
71'9" - 82'0"	10'3"	Red clay and fine sand	"
82'0" - 112'11"	30'11"	Red clay and rock	"
112'11" - 135'0"	22'1"	Red clay	"
135'0" - 141'0"	6'0"	Hard packed sand	"
141'0" - 155'0"	14'0"	Red clay	"
155'0" - 166'0"	11'0"	Clay, sand, and gravel	"
166'0" - 173'3"	7'3"	Hardpan	"
173'3" - 176'3"	3'0"	Clay, fine sand, and gravel	"
176'3" - 187'3"	11'0"	Cemented sand and gravel	"
187'3" - 192'3"	5'0"	Fine brown sand and clay	"
192'3" - 212'10"	20'7"	Red clay	"
212'10" - 222'6"	9'8"	Sand, gravel, and red clay	"
222'6" - 225'6"	3'0"	Coarse sand and gravel	"
225'6" - 231'6"	6'0"	Clay and gravel	"
231'6" - 234'6"	3'0"	Coarse sand and small gravel	"
234'6" - 240'0"	5'6"	Clay and sand	"
240'0" - 243'0"	3'0"	Coarse brown sand, gravel, and some clay	"
243'0" - 253'0"	10'0"	Medium coarse red sand and grit	"
253'0" - 270'0"	17'0"	Red clay and gravel	"
270'0" - 291'0"	21'0"	Hard clay, sand, and large gravel	"
291'0" - 292'0"	1'0"	Medium coarse sand and large gravel	"
292'0" - 337'0"	45'0"	Red Shale	Triassic

2. Log of well 2 drilled for John Nieder, 247 Emmet Street, Newark, N. J., by Layne-New York Co. Log furnished by Mr. W. A. North of Layne-New York Co.

Depth	Thickness	Description	Correlation
0' - 3'	3'	Concrete	Recent
3' - 5'	2'	Cinders	Fill
5' - 15'	10'	Yellow clay	Recent ?
15' - 27'	12'	Fine red sand	Glacial drift
27' - 55'	28'	Red quicksand	"
55' - 80'	25'	Tough red clay	"
80' - 125'	45'	Soft red clay	"
125' - 190'	65'	Red sandy clay	"
190' - 210'	20'	Soft red clay	"
210' - 215'	5'	Hardpan	"
215' - 225'	10'	Sand and clay	"
225' - 408'	183'	Red rock	Triassic

APPENDIX I - SELECTED WELL LOGS (CONT.)

3. Log of well 27 drilled for Celanese Corporation of America by Layne-New York Co. Compiled by H. Herpers from samples furnished by Wm. E. Helmstaedter, Mechanical Engineer, Celanese Corporation of America.

Depth	Thickness	Description	Correlation
2' - 27'	25'	Fine-grained red-brown sand	Glacial drift
27' - 32'	5'	Coarse gravel composed of red shale (to 1/2 in.)	"
32' - 71'	39'	Fine-grained red sandy clay	"
71' - 354'	283'	Red shale	Triassic
354' - 365'	11'	Red shale (softer than last)	"
365' - 377'	12'	Soft red shale (similar to last)	"
377' - 419'	42'	Fine-grained red sandstone	"
419' - 537'	118'	Red shale	"
537' - 580'	43'	Red shale (softer than last)	"
580' - 650'	70'	Very soft red shale	"
650' - 695'	45'	Soft red shale with some gypsum grains	"
695' - 725'	30'	Red shale. A few gypsum grains	"
725' - 730'	5'	Fine-grained red sandstone	"
730' - 787'	57'	Red shale with some gypsum grains	"
787' - 796'	9'	Fine-grained red shaly sandstone with gypsum grains	"
796' - 840'	44'	Red shale	"
840' - 856'	16'	Red sandy shale with large (1-1/2 in. x 1 in. x 1/8 in.) plates of gypsum, which appear to have been deposited in fractures in rock	"

4. Log of test boring No. 19, made at crossing of Route 25 addition and Lehigh Valley R. R. yards by Giles Drilling Co. for State Highway Department. Compiled by H. Herpers from inspection of samples.

Depth	Description	Correlation
0' - 3'	Cinders	Fill
4' - 5'	Cinders and meadow muck	Fill and Recent
10' - 11'	Cinders, gray clay, and meadow muck	"
16' - 17'	Gray, slightly sandy clay	Recent
20' - 21'	Red and gray clay and medium sand	Recent (reworked glacial drift)
30' - 31'	Fine red silty sand	Glacial drift
40' - 41'	Red clay	"
50' - 51'	Red sandy clay	"
60' - 61'	Red sandy clay and red shale (top of rock)	Triassic
61' - 71'	Red shale (core)	"

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