STATE OF NEW JERSEY

# DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

## DIVISION OF WATER POLICY AND SUPPLY

# SPECIAL REPORT 17

## SALT-WATER ENCROACHMENT INTO AQUIFERS OF THE RARITAN FORMATION IN THE SAYREVILLE AREA, MIDDLESEX COUNTY, NEW JERSEY

## WITH A SECTION ON A PROPOSED TIDAL DAM ON THE SOUTH RIVER

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

1962

# Salt-Water Encroachment Into Aquifers of the Raritan Formation in the Sayreville Area, Middlesex County, New Jersey

**with a section on**

**A proposed Tidal Dam on the South River**

***By***

**Charles A. Appel**

**Prepared by the U. S. Geological Survey in cooperation with the State of New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply**

**1962**

STATE OF NEW JERSEY

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

H. MAT ADAMS, *Commissioner*

DIVISION OF WATER POLICY AND SUPPLY

GEORGE R. SHANKLIN, *Chief Engineer and Acting Director*

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*Hon. H. Mat Adams, Commissioner*
*Department of Conservation and*
*Economic Development*
*205 West State Street*
*Trenton, New Jersey*

DEAR SIR:

I am transmitting a report on "Salt-water encroachment into aquifers of the Raritan Formation in the Sayreville area, Middlesex County, New Jersey," which has been prepared by Charles A. Appel, Engineer, U. S. Geological Survey, under a cooperative agreement with the Survey for conducting the Statewide Ground-Water Investigation Program authorized by the Water Supply Act of 1958.

The report presents information on an investigation begun in 1957 under the accelerated ground-water program authorized by the Legislature, for the re-examination of the danger of salt-water contamination to the fresh-water aquifers in a highly developed industrialized portion of Middlesex County located south of the lower Raritan River and Raritan Bay and extending up the valleys of Lawrence Brook and South River. Results of other studies regarding this problem area were published as Special Reports Nos. 7 and 8 and issued in 1937 and 1943, respectively. The report defines the extent of salt-water encroachment into the Farrington and Old Bridge Sand Members of the Raritan Formation and discuss the rate of movement of the sale-water front in the Farrington Sand Member since the previous investigation in 1943, and the probable causes for this continued advance and possible remedial measures to restrict further movement of salt water therein.

The report also includes a preliminary investigation of the merits of a tidal dam, proposed for construction by the Division and local interest on South River. The dam would protect the fresh-water aquifer in the Old Bridge Sand Member of the Raritan Formation and augment the natural yield therefrom by artificial recharge from South River. Geologic and hydrologic data are presented to assist in the evaluation of the feasibility and desirability of constructing this tidal dam and recharge pond and in estimating the resulting benefits in terms of increased water supply.

The information presented is of vital interest and importance for the safe development and protection of adequate local water resources essential for the continued growth and prosperity of this metropolitan section of New Jersey. I therefore recommend that this report be published as a Special Report of the Division of Water Policy and Supply.

Respectfully submitted,

GEORGE R. SHANKLIN
*Chief Engineer and Acting Director*

April 4, 1962

**SALT-WATER ENCROACHMENT INTO AQUIFERS OF THE RARITAN FORMATION IN THE SAYREVILLE AREA, MIDDLESEX COUNTY, NEW JERSEY**

**WITH A SECTION ON A PROPOSED TIDAL DAM ON THE SOUTH RIVER**

*By* CHARLES A. APPEL

## ABSTRACT

The principal sources of ground water in the Sayreville area are the Old Bridge Sand and Farrington Sand Members of the Raritan Formation of Late Cretaceous age. These aquifers yielded about 32.3 mgd (million gallons per day) for public and industrial water supplies in 1958; about 24.5 mgd was withdrawn from the Old Bridge Sand Member.

Although the Old Bridge Sand Member is exposed to salt water in the Raritan Bay near South Amboy and in the South River near Old Bridge, there is no widespread salt-water encroachment problem in this aquifer. However, the intensity and distribution of pumping has been limited by the threat of such encroachment.

Widespread salt-water encroachment in the Farrington Sand Member has caused numerous wells to be abandoned; the greatest advance of salt water has been in the area south of Parlin. If not restricted, the encroachment of salt water threatens to render a considerable part of this aquifer unfit for use in most of the area south of Parlin.

The potential benefits of a proposed tidal dam on the South River are discussed. This dam would provide water for infiltration into the Old Bridge Sand Member and water for industrial and public supplies.

# INTRODUCTION

The Sayreville area, consisting of about 120 square miles, is that part of Middlesex County which is south of the Raritan River and east of Lawrence Brook, as shown on figure 1. It lies entirely within the Atlantic Coastal Plain physiographic province. Its proximity to the metropolitan New York region has made it an ideal area for industrial development.

Ground water constitutes the main source of water supply in the Sayreville area. The principal sources of ground water are the Old Bridge and Farrington Sand Members of the Raritan Formation of Late Cretaceous age. However, the availability of water of suitable quality from these aquifers in a considerable part of the area is being threatened by salt-water encroachment, which may be a critical factor in the further industrial development of the area.

## PREVIOUS WORK

Barksdale (1937) carried on a study of hydrologic conditions to determine the safe yield of the Farrington Sand Member. The results of that study pointed out that the safe yield of the sand was limited by salt-water intrusion from the estuaries of the Raritan River and Washington Canal rather than by the capacity of the sand to intercept, store, or transmit water.

A later study (Barksdale and others, 1943) showed that the Farrington Sand Member, was overdeveloped as indicated by salt-water encroachment in several localities. Considerable concern was directed to the area between the Washington Canal, the South River, and the well fields at Parlin, where the salt-water front had advanced about 2 miles inland. The report also pointed out that the Old Bridge Sand Member had been developed to about its safe yield.

## PURPOSE OF THE INVESTIGATION

Recognizing the need for additional regulations to control ground-water diversions in areas where overdevelopment is prevalent or appears imminent, a private ground-water diversion law was enacted in 1947 to supplement regulatory control which had been exercised by the State of New Jersey over ground-water diversions for public potable use since 1910 (Title 58, Chapter 1, Revised Statutes). This law, known as Chapter 375, P. L. 1947, authorizes the New Jersey State Department of Conservation and Economic Development through the Water Policy and Supply Council of the Division of Water Policy and Supply to regulate the diversion of

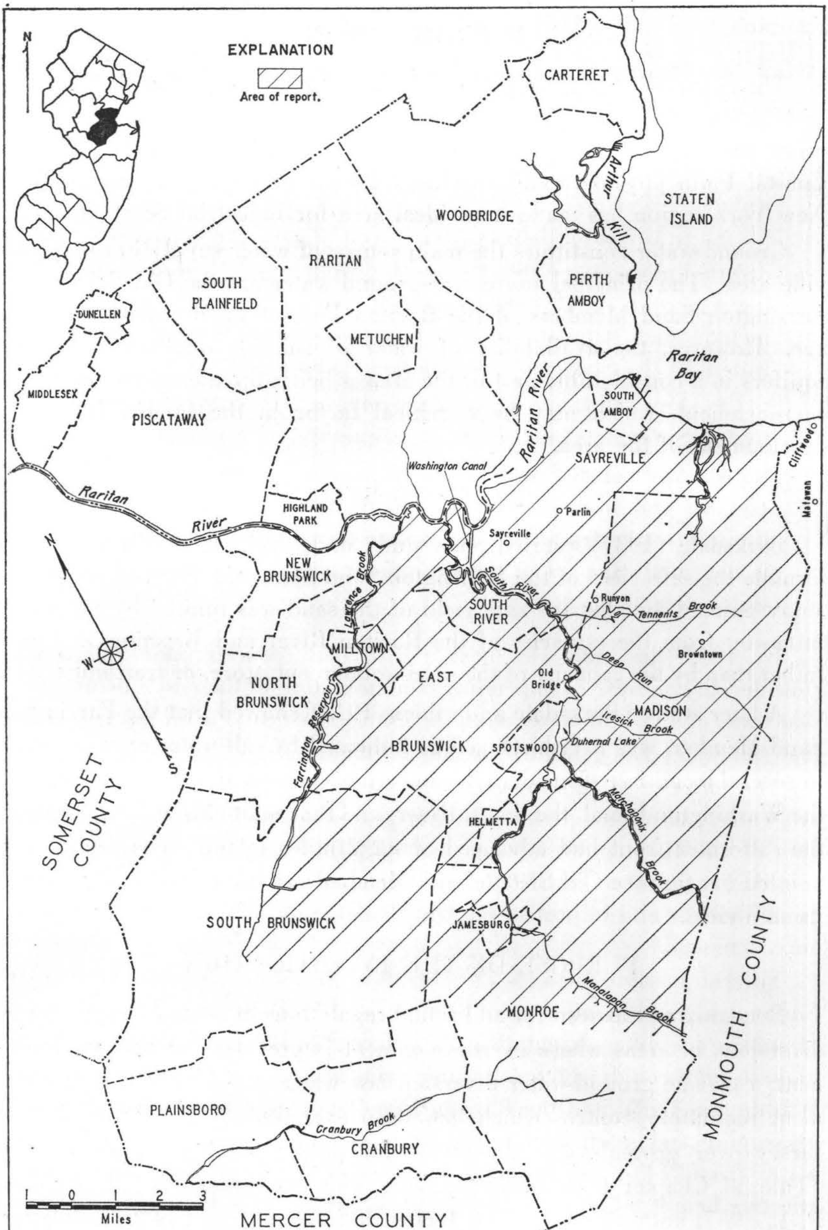



**Figure 1.—Map of New Jersey showing the Sayreville area in Middlesex County.**

subsurface and percolating waters of the State for private domestic, industrial and other uses. The law provides the following:

1. The Water Policy and Supply Council shall delineate from time to time such areas of the State where diversion of subsurface and percolating waters exceeds or threatens to exceed, or otherwise threatens or impairs, the natural replenishment of such waters.

2. In areas so delineated no such waters shall hereafter be diverted in excess of 100,000 gpd for any purpose without obtaining a permit. Such permit may be refused or, if granted, may include such stipulations as may be necessary to conserve such waters of the State and prevent their exhaustion.

3. Any refusal to grant a permit shall be subject to review by the Supreme Court, both as to question of law and fact.

4. Any person, corporation or agency diverting in excess of 100,000 gpd from such sources shall have the privilege of continuing to take from the same source the quantity of water which is the rated capacity of the equipment at that time used for such water diversion.

By 1949, the industries near Parlin had reduced their withdrawals considerably because of impending contamination of their well fields. Since that time, analyses of water samples from wells near Parlin have indicated that salt water has continued to move inland.

The purpose of this investigation was (1) to determine the extent of salt-water encroachment into the Farrington and Old Bridge Sand Members of the Raritan Formation, and (2) to determine the most feasible remedial measure to restrict the movement of salt water in the Farrington Sand Member and to protect the Old Bridge Sand Member from salt-water encroachment.

Several possible methods of controlling salt-water encroachment in the Farrington Sand Member have been proposed. These are (1) construction of subsurface dikes or cutoff walls adjacent to the sand-filled gaps in the diabase sill through which salt water gains access to the aquifer, (2) lining Washington Canal and the Raritan River with impermeable material, (3) developing and maintaining a water-level trough seaward from the salt-water front, (4) developing and maintaining a fresh-water head at an effective height adjacent to the places where there is hydraulic continuity between the aquifer and the sources of contamination or inland from the salt-water front, and (5) construction of a tidal dam to prevent salt water from advancing upstream to the places where there is hydraulic continuity between the aquifer and the stream channels.

As part of this investigation, the Division of Water Policy and Supply recommended a preliminary study of a proposed tidal dam on the South River downstream from the Old Bridge Sand Member. In addition to eliminating the salt-water problem in the Old Bridge Sand Member, it would also provide a replacement source of water to the area affected by a salt-water problem in the Farrington Sand Member. The potential diversion from such a dam is considered in this report.

This investigation was carried on under the general supervision of Philip E. LaMoreaux, then chief of the Ground Water Branch of the U. S. Geological Survey; Henry C. Barksdale, Branch Area Chief, Atlantic Coast Area; and George R. Shanklin, Chief Engineer and Acting Director of the Division of Water Policy and Supply. Allen Sinnott, district geologist, was in immediate charge of the study.

The author gratefully acknowledges the cooperation and information supplied by many public and industrial water-supply officials and private individuals. Special acknowledgment is made of basic data collected by the Duhernal Water Companies which have been of immeasurable value in this investigation.

## Key to Well or Well Field Numbers

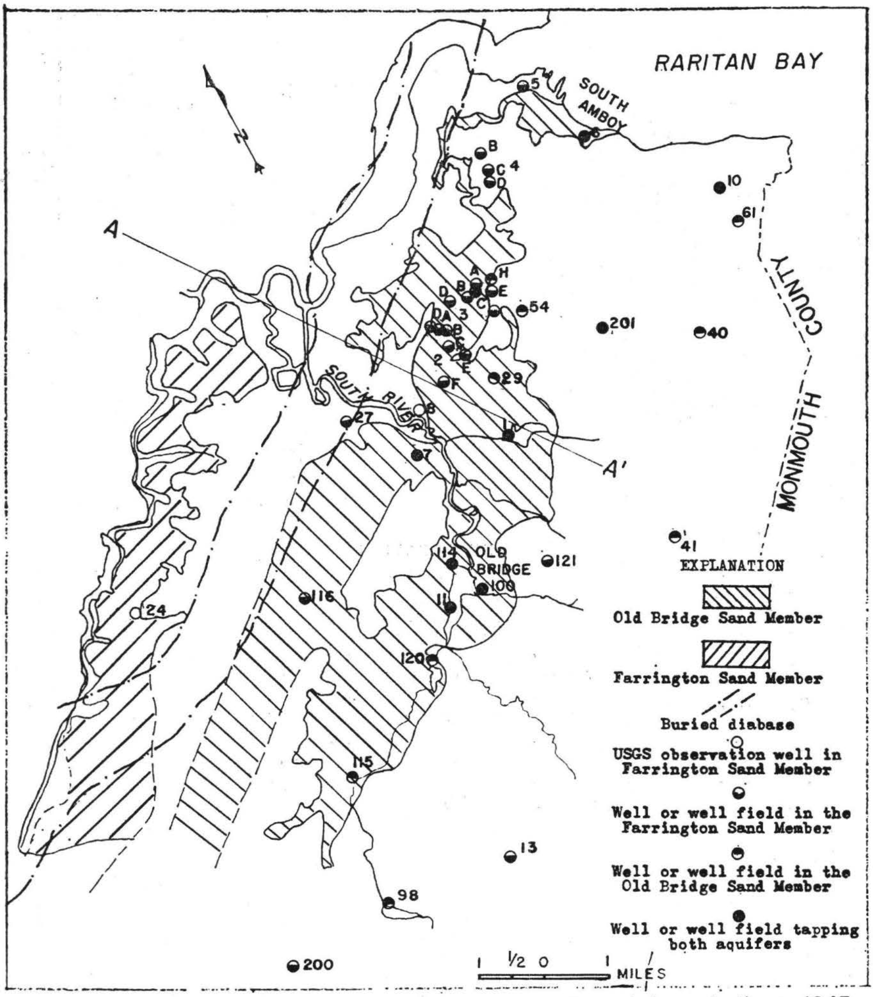
[Numbers not consecutive; they have been assigned, in part, to agree with earlier reports on material in USGS files]

1. Perth Amboy Water Department
2. Hercules Powder Co.
3. E. I. du Pont de Nemours & Co.
4. National Lead Co.
5. Jersey Central Power & Light Co.
6. South Amboy Water Department
7. South River Water Department
8. Sayreville observation well 4
10. Laurence Harbor Water Co.
11. Peter J. Schweitzer Co.
13. State Home for Boys
24. Fischer observation well
27. Thomas & Chadwick Co.
29. Sayreville Water Department
40. Westbury Water Co.
41. Browntown Water Co.
54. John Monteath Lumber Co.
61. Oschwald Brick Co.
98. Jamesburg Water Co.
100. Duhernal Water System
114. Anheuser-Busch Co.
115. Geo. Helme Co.
116. East Brunswick Water Department
120. Spotswood Water Department
121. Madison Water Co.
200. Forsgate Farms
201. Midtown Water Co.

## SUMMARY OF STRATIGRAPHY AND WATER-BEARING PROPERTIES

A discussion of the geologic and hydrologic characteristics of the strata in the Sayreville area, including those units that directly affect the hydrology of the Raritan Formation, are given in detail in an earlier report (Barksdale and others, 1943). Only a general discussion of these characteristics is given here.

The materials that crop out in the area are either Quaternary deposits or units of the Raritan Formation of Late Cretaceous age. The intake areas of the important aquifers in the Raritan Formation are shown on figure 2.




Modified from Barksdale and others, 1943

**Figure 2—Map of the Sayreville area showing the intake areas of the Old Bridge and Farrington Sand Members of the Raritan Formation and locations of the major public and industrial water-supply systems that tap these aquifers.**

The Raritan Formation is underlain by rocks of Triassic and early Paleozoic age. The structural relationship of the geologic units in this area is shown on figure 3.

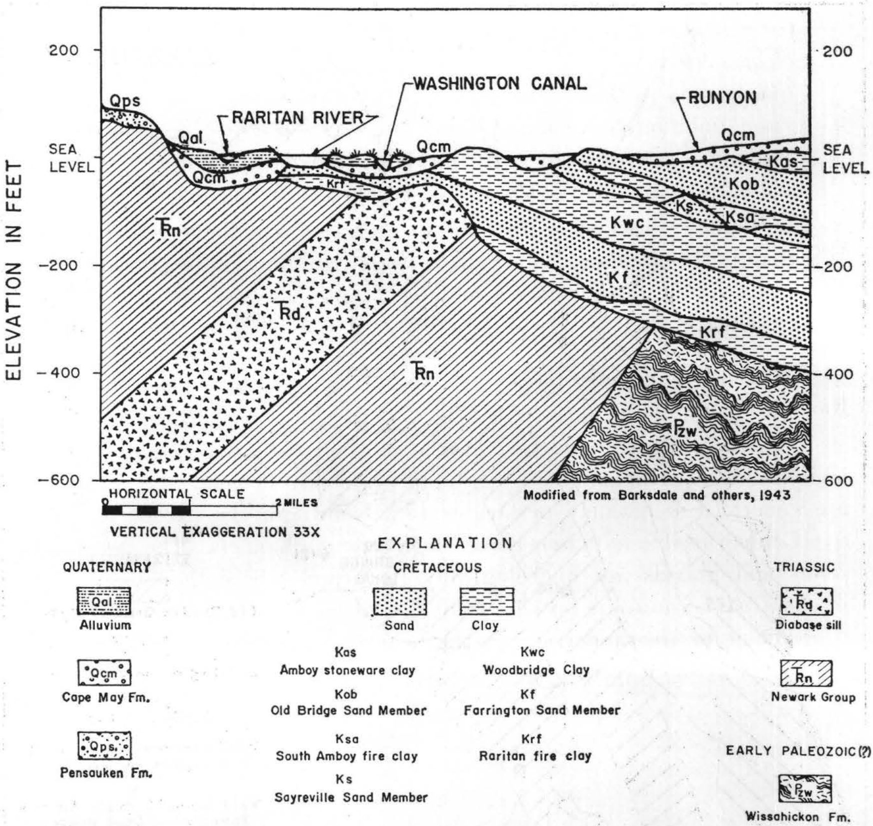



**Figure 3.—Generalized geologic cross section along line A—A[1].**

In most of Middlesex County it is possible to divide the Raritan Formation into fairly distinct geologic units; however, attempts to trace recognized units in the outcrop areas, both downdip and along the strike, have been only moderately successful.

The Raritan Formation has been described by Barksdale and others (1943, p. 66) as follows:

> The Raritan Formation is composed of alternating and irregular beds of clay, sand, and gravel. The sands are predominantly white or light colored, but gray and yellow beds are not uncommon, particularly in the region west of Jamesburg, and sometimes

> they are colored pink or orange by small percentages of iron oxides. The clay beds range in color from white through cream and light gray to dark gray and brick red. In composition they range from dark, sandy and lignitic beds, usually containing many nodules of pyrite or marcasite, to white-burning, highly refractory clays of great value. Many of the sandy beds are relatively clean or free of clay, but all gradations occur from nearly pure quartz sand to beds containing a high percentage of clay, muscovite, limonite, feldspar, or other minerals. Lignite is a fairly common constituent of both the sands and dark impure clays.
>
> Most of the Raritan Formation is believed to have been formed in shallow brackish water and in estuaries and lagoons rather than in the open sea. This belief is based not only on the variable character of the formation and the lignite but also upon fossil evidence. . . .

The general geologic and hydrologic characteristics of the units in the Raritan Formation are given—youngest at the top—in table 1.

Deposits of Quaternary age overlie most of the area. These deposits which consist principally of the Cape May and Pensauken Formations are generally moderately permeable sands and gravels, except for relatively impermeable alluvium along some stream channels. The permeable sands and gravels are hydrologically important where they overlie the intake areas of aquifers because they absorb water from precipitation and transmit it to the underlying water-bearing material. Locally, shallow wells obtain water from these deposits.

**Table 1.—General geologic and hydrologic characteristics of the units of the Raritan Formation (Late Cretaceous age) in the Sayreville area**

| *Unit* | *Description* | *Physical properties of the aquifers* | | *Remarks* |
|---|---|---|---|---|
| | | *Average porosity percent by volume* | *Permeability gpd/ft² [a]* | |
| Amboy stoneware clay | Light-gray to nearly black clay; abundant carbonaceous materials; locally has mottled-red appearance; occurs in some places as gray to black sandy clay; lignitic. Thickness 0 to 30 feet. | | | An aquiclude[b] |
| Old Bridge Sand Member | White to light-yellow, fine- to medium-grained, occasionally coarse-grained, slightly micaceous sand; locally contains thin, irregular clay beds. Thickness 80 to 110 feet. Dips southeast 40 to 45 feet per mile. | 40 | 1,000 to 1,500 | Most productive aquifer in the Raritan Formation. Effective intake area is about 33 square miles. |
| South Amboy fire clay | Varicolored light-gray, white, or brick-red clay; locally sandy. Thickness 0 to 35 feet. | | | An aquiclude[b] |
| Sayreville Sand Member | Layers of fine white micaceous sand, fine- to coarse-grained white sand, with or without clay beds, and arkosic sand beds. Usually thin and lacks continuity. Thickness 0 to 40 feet. | 44 | 30 to 500 | Owing to thinness and lack of continuity, this sand member is unimportant as an aquifer. So far as known, no wells in this area draw water entirely from this aquifer. |
| Woodbridge clay | Dark-gray clay to gray sandy clay and clayey sands. The basal part is varicolored white, light-gray, and brick-red compact clay. Scattered in the upper portion are nodules of impure siderite, lignite, and pyrite. Thickness 50 to 100 feet. | | | An aquiclude[b] |

| | | | | |
|---|---|---|---|---|
| Farrington Sand Member | Light-gray or light-yellow, fine- to medium-grained sand grading into a coarse, arkosic sand sprinkled with small pebbles and gravel in the lower part. This sand is commonly divided by clay layers into two or more parts. Thickness 35 to 135 feet. Dips southeast 55 feet per mile. | 34 | 1,200 to 1,500 | Second in importance as a productive aquifer to the Old Bridge Sand Member. Intake area is 10.2 square miles. Not deposited on high parts of diabase ridge. |
| Raritan fire clay | Varicolored blue, brown, gray, or red clay. Basic part has brick-red color. Thickness 0 to 90 feet. | | | An aquiclude[b] |

[a] Coefficient of permeability is the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at the prevailing temperature.

[b] A formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring.

# SALT-WATER ENCROACHMENT

## OLD BRIDGE SAND MEMBER OF RARITAN FORMATION

The Old Bridge Sand Member is exposed to salt water in the Raritan Bay near South Amboy and in the South River near Old Bridge (fig. 2). The chemical composition of water in the Raritan Bay is similar to that of sea water. Thus, water with a chloride concentration of as much as 19,000 ppm (parts per million) may enter the aquifer at that point. The South Amboy Water Department has wells that tap this aquifer relatively close to the bay. Apparently, however, the cone of depression created by pumping these wells has not extended to the bay, for analyses of water samples collected semiannually from the wells have not shown any appreciable increase in chloride content.

### *Extent of Encroachment*

The chloride content of water in the South River generally ranges from a few parts per million directly below Duhernal Dam to as much as several thousand parts per million about 2½ miles downstream from Old Bridge. The analysis of water from a well about 400 feet from Deep Run near Runyon (a tributary of the South River) has shown a chloride content as high as 35 ppm in 1959. Samples collected from this well in 1942 contained about the same amount. This concentration is appreciably higher than the normal chloride content of water in this aquifer. The analysis of water from a recently drilled well about half a mile from Tennent Brook—another tributary of the South River—has shown an increase in chloride content from 18 to 112 ppm in 1 year. However, this high concentration is not attributed to salt-water encroachment.

At present, the chloride concentration of water from the Old Bridge Sand Member indicates that salt-water encroachment has not reached serious proportions. However, the regular collection of water samples from wells in this vicinity should be continued, to monitor changes of chloride content.

Table 2 shows the public supply and industrial withdrawals from the Old Bridge Sand Member for the period 1943-58. Most of the pumpage from this aquifer is withdrawn where it is under water-table conditions. In addition, most of the withdrawals from this aquifer are associated with artificial recharge developments. Thus, the cone of influence of each well for a considerable period of time is confined to a relatively small area.

## FARRINGTON SAND MEMBER OF RARITAN FORMATION

Prior to large-scale pumping from the Farrington Sand Member, the fresh-water head near Runyon was about 35 to 40 feet above mean sea level. Data necessary to map the piezometric surface accurately are unavailable. However, the earliest records of static water levels in wells in this area indicate that the piezometric surface sloped toward the sources of contamination. This may indicate that salt water was not entering the aquifer.

**Table 2.—Estimates of pumpage, in thousands of gallons per day, from the Old Bridge Sand Member of the Raritan Formation for public and industrial supplies in the Sayreville area, 1943-58**

| Year | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 |
|---|---|---|---|---|---|---|---|---|
| Industrial | 14,160 | 12,852 | 12,282 | 11,987 | 10,640 | 11,729 | 13,397 | 14,078 |
| Public Supply | 8,486 | 8,273 | 8,450 | 8,862 | 8,462 | 8,676 | 7,942 | 7,521 |
| Total | 22,646 | 21,125 | 20,732 | 20,849 | 19,102 | 20,405 | 21,339 | 21,599 |

| Year | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 |
|---|---|---|---|---|---|---|---|---|
| Industrial | 15,333 | 14,650 | 15,628 | 16,813 | 15,233 | 14,607 | 14,398 | 14,832 |
| Public Supply | 8,312 | 8,792 | 10,079 | 10,182 | 7,919 | 8,509 | 9,010 | 9,636 |
| Total | 23,645 | 23,442 | 25,707 | 26,995 | 23,152 | 23,116 | 23,408 | 24,468 |

### *Extent of Encroachment*

As early as 1930, analysis of water from a well near Washington Canal indicated that salt water had entered the aquifer, although at that time it was thought that the upper part of the well casing had deteriorated and that salt water entered the aquifer from the overlying Quaternary sands. In 1937, it was pointed out that if the Farrington Sand Member was exposed to salt water along the Washington Canal and the Raritan River the safe yield of the aquifer would be limited by salt-water encroachment (Barksdale, 1937). Test wells were drilled along the Raritan River and the Washington Canal and water samples were collected from these wells to determine the chloride concentration. The results of these analyses and studies of areal water-level measurements indicated that the fresh-water head had been lowered in certain areas adjacent to the Raritan River and

Washington Canal allowing salt water to move into the aquifer (Barksdale and others, 1943).

The areas in which salt water can enter the Farrington Sand Member are influenced locally by its hydrologic boundaries. The continuity of the Farrington Sand Member is interrupted in many places by a buried diabase sill "* * * that rises from the ground level of the bedrock floor on which the Raritan Formation was deposited * * *" (Barksdale, 1937, p. 6). Between South River and South Amboy, the ridge stood high enough that the Farrington Sand Member was not deposited on top of it except in some gaps or low places (fig. 3). It is through these gaps or low places that the aquifer is hydraulically connected with salt water in the Raritan River, in the Washington Canal, and in the South River. Test borings along the Raritan River show that in many places the diabase sill lies directly beneath the Woodbridge clay, and hence the clay separates the Farrington Sand Member from the river. At these places, salt water cannot enter the aquifer. In 1929, the Washington Canal was deepened. Removal of silty and clayey material from the canal bottom exposed permeable sand to the salt water.

The three principal places where salt water has entered the Farrington Sand Member are (1) near the confluence of the South River and the Washington Canal, (2) about a mile downstream from the confluence of the Washington Canal and the Raritan River, and (3) near the mouth of the Raritan River. The concentration of salt water at each of these places is different and changes continually. Analyses of samples collected during an earlier investigation (Barksdale and others, 1943, p. 120) showed the following concentrations:

> At the northern end of the Washington Canal where it joins the Raritan River, the chloride content of the samples taken has varied from 44 parts to 12,000 parts per million, and most of the samples contained more than 7,000 parts per million. At the Washington Street Bridge between South River and Sayreville, the bottom samples from the South River were found to contain from 17 parts to 10,725 parts per million of chlorides, and most of them contained more than 5,000 parts per million.

Samples collected near the mouth of the Raritan River contained as much as 19,000 ppm of chloride. Hence, the salinity of the Raritan River near South Amboy is as high as sea water, whereas the salinity of the water in Washington Canal is about 25 to 35 percent of sea water. These samples were collected once a month at the bottom of the stream at high tide. The chloride concentration in these streams probably vary continually because of variation of daily tide and fresh-water runoff.

**Table 3.—Estimates of average pumping, in thousands of gallons per day, from the Farrington Sand Member of the Raritan Formation for public and industrial supplies in the Sayreville area, 1943-58**

[Use of water: Ind., Industrial; P. S., Public Supply]

| Municipality | Use of Water | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| East Brunswick Township | Ind. | 53 | 154 | 159 | 112 | 379 | 210 | 14 | 12 | 16 | 17 | ---- | 9 | 59 | 119 | 301 | 114 |
| | P. S. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | 298 | 380 | 460 | 575 | 640 | 901 | 947 |
| Madison Township | Ind. | ---- | ---- | 730 | 2,382 | 3,743 | 3,509 | 2,087 | 2,960 | 2,718 | 2,974 | 3,098 | 1,980 | 2,719 | 2,179 | 2,257 | 811 |
| | P. S. | 679 | 1,402 | 964 | 804 | 1,574 | 1,875 | 2,178 | 1,799 | 1,807 | 1,485 | 1,969 | 2,636 | 2,871 | 2,668 | 2,646 | 2,464 |
| Monroe Township | Ind. | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | P. S. | 123 | 136 | 127 | 141 | 198 | 213 | 191 | 168 | 186 | 184 | 162 | 159 | 207 | 154 | 148 | 164 |
| Sayreville Borough | Ind. | 3,304 | 2,748 | 2,731 | 2,765 | 2,815 | 1,619 | 306 | 286 | 133 | 143 | 170 | 170 | 180 | 188 | 167 | 115 |
| | P. S.* | ---- | ---- | ---- | ---- | 252 | 565 | 455 | 414 | 512 | 534 | 508 | 441 | 407 | 368 | 408 | 400 |
| City of South Amboy | Ind. | 224 | 224 | 224 | 224 | 224 | 224 | 224 | 224 | 224 | 224 | 285 | 309 | 309 | 309 | 309 | 309 |
| | P. S. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| South River Borough | Ind. | 255 | 255 | 255 | 255 | 255 | 255 | 255 | 255 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | P. S. | 246 | 249 | 242 | 285 | 298 | 301 | 315 | 314 | 314 | 330 | 361 | 505 | 531 | 465 | 489 | 435 |
| Spotswood Borough | Ind. | 165 | 38 | 44 | 650 | 1,470 | 1,700 | 1,168 | 1,013 | 1,018 | 1,314 | 1,796 | 1,904 | 1,801 | 1,536 | 2,082 | 1,971 |
| | P. S. | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Total industrial | | 4.031 | 3,449 | 4,173 | 6,418 | 8,916 | 7,547 | 4,084 | 4,780 | 4,169 | 4,732 | 5,409 | 4,432 | 5,128 | 4,391 | 5,176 | 3,380 |
| Total public supply | | 1,048 | 1,787 | 1,333 | 1,230 | 2,322 | 2,954 | 3,139 | 2,695 | 2,819 | 2,831 | 3,380 | 4,201 | 4,591 | 4,295 | 4,592 | 4,410 |
| Grand Total | | 5,079 | 5,236 | 5,506 | 7,648 | 11,238 | 10,501 | 7,223 | 7,475 | 6,988 | 7,563 | 8,789 | 8,633 | 9,719 | 8,686 | 9,768 | 7,790 |

* Wells belong to City of South Amboy.

The distribution and rate of pumpage in this area has changed considerably from 1943 to 1958. This change has been influenced primarily by the contamination of the Farrington Sand Member by salt water.

Industrial pumpage, except for the period 1946-48, did not vary greatly, whereas the public-supply pumpage increased fourfold from 1943 to 1958, as shown in table 3. In 1958, the total pumpage in Sayreville Borough was only about 0.5 mgd, a decrease of about 2.8 mgd since 1943. This decrease was due to the reduction in withdrawals by the Duhernal Companies (du Pont and Hercules Powder Co. near Parlin and National Lead Co. near South Amboy). New developments and more consumption of existing supplies have increased the pumpage in parts of the Sayreville area. The most significant increases were in Madison Township, Spotswood Borough, and East Brunswick Township.

The total pumpage from the Farrington Sand Member and the withdrawals from wells of the Duhernal Companies and from wells of the Perth Amboy Water Department are shown on figure 4. It should be pointed out that after 1948 practically all the pumping by the Duhernal companies was shifted from wells in Sayreville Borough to wells near Old Bridge. The Fischer observation well (well 24, fig. 2) is in the intake area of the aquifer about 5.3 miles southwest of the Sayreville well (well 8, fig. 2). The water-level fluctuations in the Fischer well generally reflect seasonal trends and do not appear to respond to changes in pumping in the Sayreville area. The Sayreville observation well taps the aquifer where water is under artesian pressure. Water-level fluctuations in this well correspond to changes in total pumpage and, particularly, reflect changes in pumping from the wells of the Perth Amboy Water Department.

Progressive increase in the chloride concentration above the normal chloride content in an aquifer is a significant indication of salt-water encroachment. Chloride is the dominant constituent of sea water, whereas in most ground water it is a minor constituent. The normal chloride content of native fresh water in the Farrington Sand Member in areas distant from sources of contamination is generally less than 5 ppm. A chloride concentration of 10 ppm is assumed to indicate movement of salt water in the aquifer. This concentration in itself does not render the water unfit for use. However, available data are inadequate to delineate what part of the area seaward from the 10-ppm isochlor does not contain water having a chloride content greater than 250 ppm (limit recommended by U. S. Public Health Standards for potable water). The tolerance for chloride in water for most industrial uses, except as a coolant, is less than 250 ppm (California State Water Pollution Control Board, 1957). Several industries in this area have indicated that their use of water limits the maximum acceptable chloride concentration to about 50 ppm.

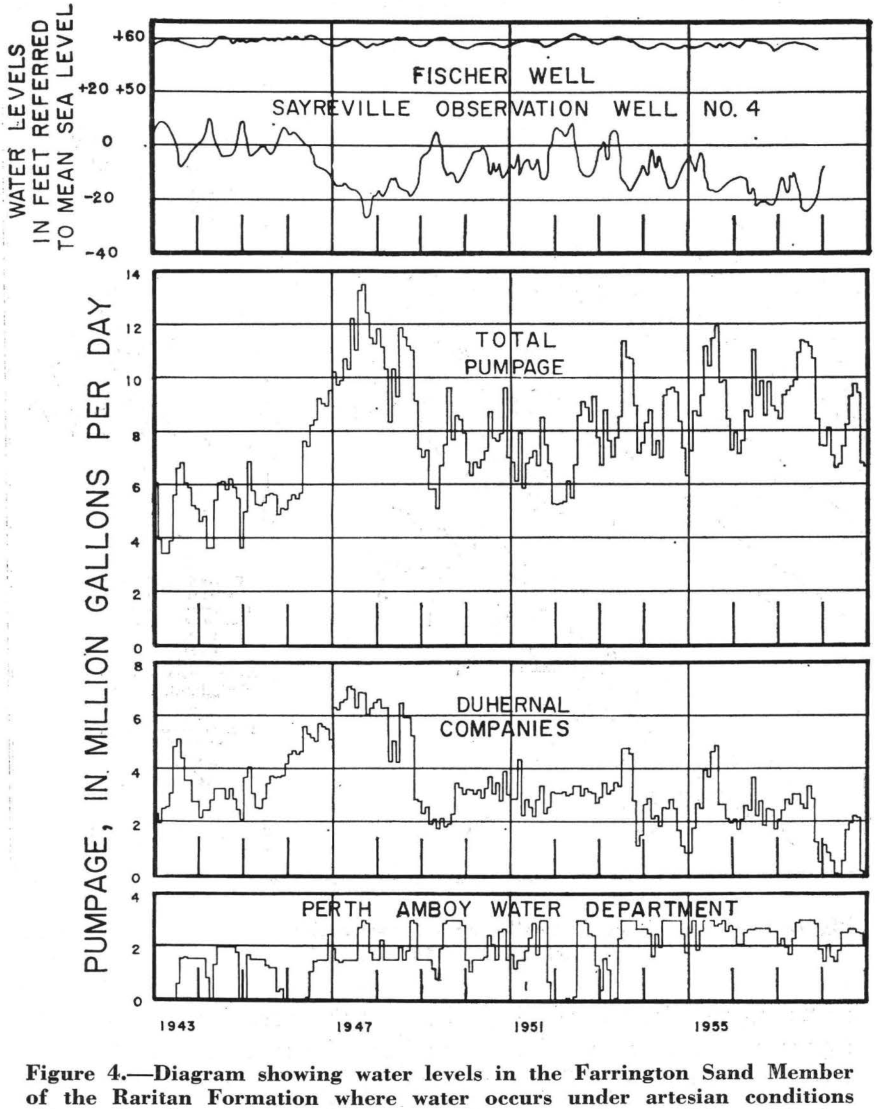



**Figure 4.—Diagram showing water levels in the Farrington Sand Member of the Raritan Formation where water occurs under artesian conditions (Sayreville observation well 4) and under water-table conditions (Fischer well) and pumpage, 1943-58.**

The pattern of the contaminated areas in 1958 was similar to the contaminated area delineated in 1943 (fig. 5). Many of the wells used by Barksdale and others (1943) are no longer available and are not shown

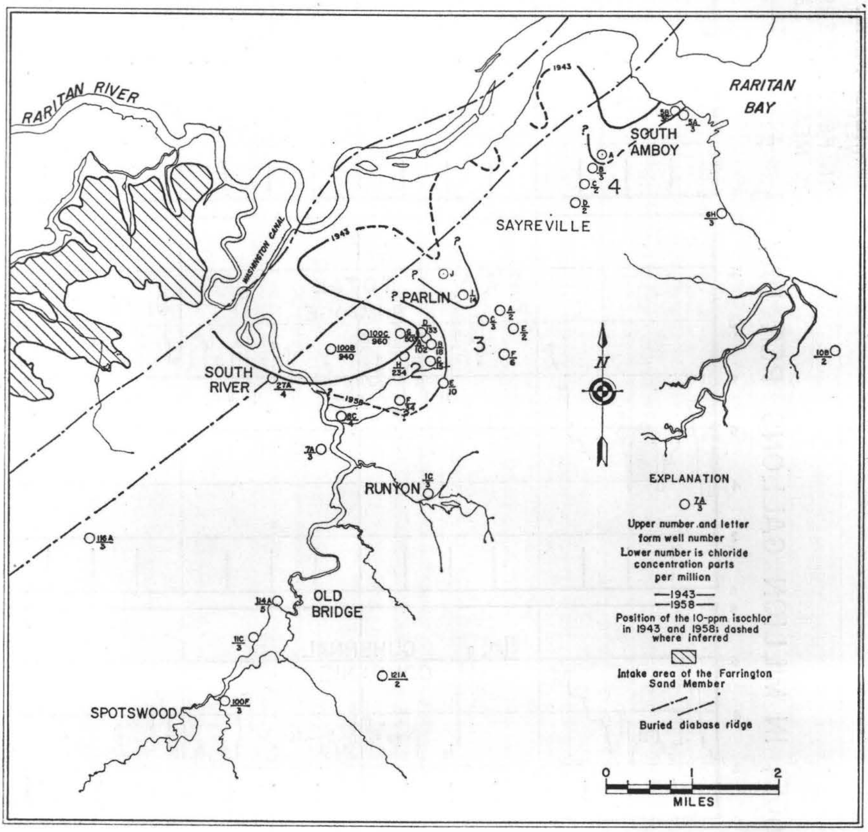



**Figure 5.—Map of the Sayreville area showing the position of the 10-ppm isochlor in 1943 and 1958.**

on this figure. Several wells located behind the front have been sampled regularly since 1943, and chemical analyses of these samples have shown a considerable increase in the chloride content. Water from well 100C contained 154 ppm of chloride in 1943 and 960 ppm of chloride in September 1958. In 1943, water from well 2G contained 19 ppm of chloride, whereas in 1958 it contained 503 ppm. Water samples from several other wells northwest of the front have been collected periodically and analyzed for their chloride content by the Duhernal companies and the Survey. These wells are shown in figure 6. An example of how

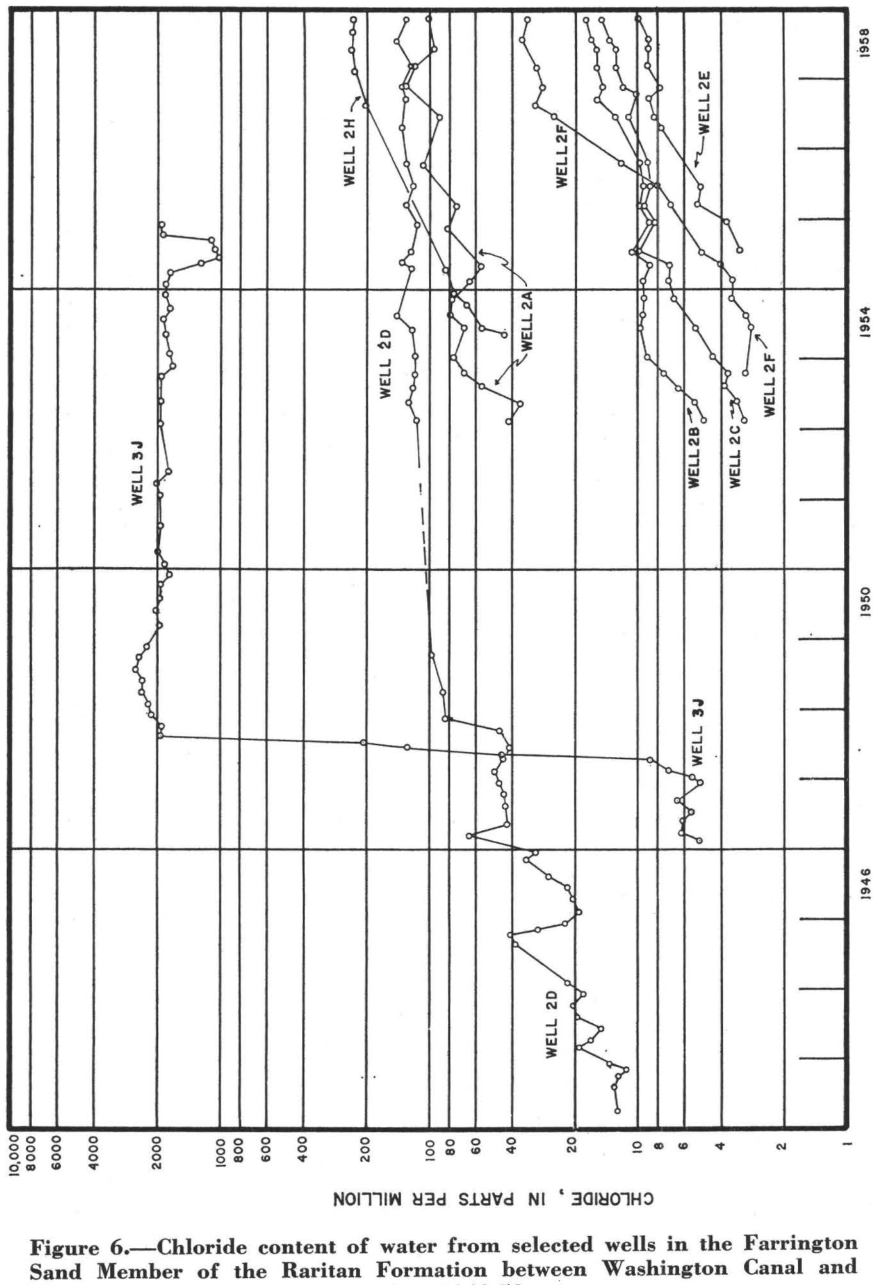



**Figure 6.—Chloride content of water from selected wells in the Farrington Sand Member of the Raritan Formation between Washington Canal and Parlin, 1943-58.**

**Table 4.—Chloride content in parts per million, of water from wells tapping the Farrington Sand Member of the Raritan Formation in the Sayreville area**

*[Results of analyses by U. S. Geological Survey, except as noted]*

| Well no. and owner | Owner's well no. | Chloride content on indicated date of collection | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | June 1957 | Sept. 1957 | Oct. or Nov.[b] 1957 | Feb. or Mar.[c] 1958 | July 1958 | Sept. or Nov.[d] 1958 | April or May[e] 1959 |
| 1A Perth Amboy Water Dept. | Layne 1 | ---- | 2.2 | ---- | 2.6 | 2.8 | 2.9 | 2.9 |
| 1C Do. | Layne 2 | ---- | 2.9 | ---- | 2.8 | 2.5 | 3.2 | ---- |
| 2A[a] Hercules Powder Co. | 1 | 97 | 139 | [b]130 | [c]117 | 97 | [d]102 | 92 |
| 2B[a] Do. | 2 | 13 | 16 | [b] 15 | [c] 16 | 17 | [d] 18 | 22 |
| 2C[a] Do. | 3 | 11 | 10 | [b] 12 | [c] 13 | 14 | [d] 15 | 21 |
| 2D[a] Do. | 4 | 139 | 131 | [b]131 | [c]120 | 143 | [d]133 | 134 |
| 2E[a] Do. | 5 | 8 | 9 | [b] 8 | [c] 9 | 9 | [d] 10 | 9 |
| 2F[a] Do. | 6 | 25 | 31 | [b] 29 | [c] 31 | 36 | [d] 34 | 30 |
| 2G Do. | 39F | ---- | 430 | ---- | [a]427 | ---- | [a]503 | ---- |
| 2H Do. | 59F | ---- | 201 | ---- | [a]226 | ---- | [a]234 | [a]264 |
| 3A E. I. duPont de Nemours & Co. | 1 | ---- | ---- | ---- | ---- | 2.1 | 2.2 | [e] 2.8 |
| 3C Do. | 3 | ---- | ---- | ---- | 2.4 | 2.4 | 2.6 | [e] 2.6 |
| 3E Do. | 5 | ---- | ---- | ---- | ---- | 2.0 | 2.2 | [e] 1.9 |
| 3F Do. | 6 | ---- | ---- | ---- | ---- | 8.9 | 6.2 | [e] 2.0 |
| 3I Do. | 58F | ---- | ---- | ---- | ---- | 14.0 | ---- | ---- |
| 4B National Lead Co. | 2 | ---- | ---- | 2.3 | 2.9 | 2.9 | 2.8 | 3.3 |
| 4C Do. | 3 | ---- | ---- | 2.4 | 2.1 | 2.1 | 2.1 | 2.5 |
| 4D Do. | 4 | ---- | ---- | 2.9 | 2.5 | 2.5 | 2.4 | 3.1 |
| 5A Jersey Central Power & Light Co. | 5 | ---- | 27 | ---- | 28 | 9.5 | 2.8 | 2.6 |
| 5B Do. | 4 | ---- | 52 | ---- | 44 | 39 | 36 | 42 |
| 6H South Amboy Water Dept. | 8 | ---- | ---- | ---- | 2.0 | 2.1 | 3.1 | 2.5 |
| 7A South River Water Dept. | 1 | ---- | 2.8 | ---- | 3.4 | 3.0 | 3.1 | 3.4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7B | Do. | 2 | ---- | 2.7 | ---- | 2.8 | 2.6 | 2.6 | ---- |
| 8C | Borough of Sayreville | Old test well 3 | ---- | ---- | ---- | 4.0 | 3.9 | ---- | [e] 4.3 |
| 8D | Do. | do. 4 | ---- | ---- | ---- | 3.5 | ---- | ---- | ---- |
| 10B | Laurence Harbor Water Co. | 2 | ---- | 2.7 | ---- | 2.1 | 2.2 | 2.1 | 2.3 |
| 11C | Peter J. Schweitzer Co. | 1 | ---- | ---- | 2.5 | 3.8 | ---- | 3.2 | ---- |
| 11D | Do. | 8 | ---- | ---- | 5.6 | 4.8 | 4.9 | ---- | ---- |
| 13A | State Home for Boys | 2 | ---- | 1.6 | ---- | 1.8 | ---- | ---- | 2.0 |
| 13B | Do. | 3 | ---- | 1.6 | ---- | ---- | 1.9 | 2.4 | ---- |
| 27A | Thomas & Chadwick Co. | 1 | ---- | ---- | ---- | 4.3 | 4.0 | 4.3 | 4.4 |
| 100B | Duhernal Water System | 32F | ---- | 832 | [a]929 | 1,020 | 940 | 940 | 1,180 |
| 100C | Do. | 33F | ---- | 938 | ---- | 960 | 980 | 960 | 950 |
| 100F | Do. | AF | ---- | ---- | ---- | ---- | 2.5 | ---- | ---- |
| 114A | Anheuser-Busch Co. | 1 | ---- | 6.4 | ---- | 4.9 | ---- | 4.9 | ---- |
| 116A | East Brunswick Water Dept. | 1 | ---- | 3.5 | ---- | 3.4 | ---- | 3.4 | ---- |
| 116B | Do. | 2 | ---- | 2.9 | ---- | 2.9 | 2.9 | ---- | ---- |
| 121A | Madison Water Co. | 1 | ---- | ---- | 1.9 | 2.6 | 2.4 | 2.0 | 2.8 |

[a] Analyzed by Hercules Powder Co.
[b] Sample collected in November 1957.
[c] Sample collected in early March 1958.
[d] Sample collected in early November 1958.
[e] Sample collected in early May 1959.

rapidly changes in the chloride content can occur is shown by the graph for well 3J. At the end of 1947, the chloride content of water in this well was 5 ppm. Then it began rising rapidly, and in August 1948 it was about 2,000 ppm. Table 4 gives the chloride content of water samples from selected wells in the Farrington Sand Member in the Sayreville area.

Although the pattern of the contaminated areas in 1958 was similar to that of 1943, the apparent direction of movement of the salt-water front changed in the area south of Parlin. In 1958 the apparent direction of movement was southward toward the wells at Runyon, whereas in 1943 its movement was eastward toward the wells at Parlin. The change in direction of movement was caused by changes in the areal distribution of pumping from 1943 to 1958 (see table 3). It is estimated that in this period the 10-ppm isochlor advanced at an average rate of about 240 feet per year. At this rate of movement, the salt-water front would reach the Runyon well field in about 20 years (fig. 5). However, as the front moved closer to an area of pumping, the rate of movement would increase because of the steeper hydraulic gradient.

Another procedure in the appraisal of the extent of salt-water encroachment is to estimate the rate of movement by use of an average permeability and effective porosity of the aquifer and compute the ground-water velocities that would result from average hydraulic gradients for selected periods. The velocity changes in direct proportion to changes in the hydraulic gradient. The velocity of water through a sand may be estimated from the equation:

$$v = \frac{P\ I}{7.48\ p}$$

where v is the average velocity of the ground water in feet per day, P is the field coefficient of permeability of the aquifer in gallons per day per square foot, p is the porosity of the materials in the aquifer, and I is the hydraulic gradient.

The aquifer is assumed to have an average permeability of 1,200 gpd/ft$^2$ and a porosity of 34 percent (Barksdale and others, 1943). The gradient between the salt-water front and the wells at Runyon depends primarily on the rate of pumping at Runyon. Periods were chosen for analysis when the rate of pumping at Runyon and from other parts of the aquifer were practically consistent for at least a month.

The water level in the Sayreville observation well 4 (at the same location as 8C in fig. 5) is considered to be indicative of the head near the front. This well is about 1.3 miles from an observation well at Runyon. The average water level for October 1951 at the Sayreville observation well was about 12 feet below mean sea level and at the Runyon observation well, about 35 feet below mean sea level. The average pumpage during this month was about 7.5 mgd, of which 3 mgd were withdrawn at Runyon and about 3.3 mgd from wells near Old Bridge, to the southwest. Under these pumping conditions, the monthly average gradient was about 18 feet per mile toward Runyon. This gradient would produce a rate of movement of about 590 feet per year toward Runyon.

Pumping at Runyon, except for a few days, was discontinued from early November 1951 to late March 1952. The average pumpage from the Farrington Sand Member for that period was about 5 mgd, of which 4 mgd was taken from wells near Old Bridge. The water level in the Sayreville well and the Runyon well appeared to have stabilized by early January 1952 at about 8 feet and 9.5 feet above mean sea level, respectively. The average water level in well 100B, about 2 miles northwest of the Runyon well and about 0.7 miles north of the Sayreville well, was about 6.9 feet above mean sea level at that time. The relative positions of these water levels indicate that the gradient was to the northwest. Water levels in other wells near the canal also were above mean sea level; hence, it appears that salt water was not entering the aquifer at the time pumping was discontinued at Runyon. Pumping resumed at Runyon in the summer of 1952, at which time a gradient of about 18 feet per mile toward Runyon was reestablished.

From 1952 to late summer of 1957, the water level in the Sayreville well declined. In August 1957, the hydraulic gradient between the Sayreville well and the Runyon well was about 25 feet per mile. Under this condition, the rate of ground-water movement was computed to be about 820 feet per year. At this rate, the 10-ppm isochlor would reach Runyon in about 6 years.

Water levels in wells near Parlin indicate that the gradient of the piezometric surface in that part of the aquifer containing salt water is steepened toward the wells at Runyon when they are heavily pumped. Although the wells of the South River Water Department are closest to the front, it is believed that salt water has been moving chiefly toward the heavier pumped wells near Runyon. The estimates of the time required for the 10-ppm isochlor to reach the well field at Runyon do not mean that the water pumped from wells at that time would contain 10 ppm of chloride. For the purpose of illustration, assume a uniform hydraulic gradient to the Runyon well field from all directions and a uniform transmissibility. It is estimated that the contaminated water would enter the Runyon well field from a sector of about 45°, so that the salt water would be withdrawn with the native fresh water in a proportion of 1 part salt water to 7 parts fresh water. The water now obtained from the Runyon well field contains about 3 ppm of chloride. Thus, the contaminated water would have to contain about 380 ppm of chloride for the mixed water pumped at Runyon to contain 50 ppm of chloride. Samples of water from well 100B, about 2 miles northwest of Runyon, contained 1,180 ppm of chloride in April 1959. If the rate of movement toward Runyon from that part of the sand was 800 feet per year, it would be about 13 years before the water pumped at Runyon would contain 140 ppm of chloride. If the contaminated water contained 7,000 ppm of chloride (about the concentration of most of the samples collected from Washington Canal), the resulting mixture would contain about 880 ppm.

Because the position of the 10-ppm isochlor near the du Pont well field was inferred in 1943, an average rate of movement cannot be estimated (fig. 5). The chloride content of water from well 3J increased from about 5 ppm in January 1948 to about 2,000 ppm in August 1948. Well 3I yielded water containing about 19 ppm and 14 ppm of chloride in the fall of 1948 and summer of 1958, respectively. However, it appears that the salt water did not advance significantly from 1948 to 1958. The salt water in that part of the aquifer probably is within the cone of depression created by the heavy pumping at Runyon; if so, the salt water would move slowly to the south.

Near South Amboy, the position of the 10-ppm isochlor in 1958 was about 0.4 mile farther inland toward the well field of the National Lead Co. (fig. 5). However, it is believed that little salt-water encroachment has taken place in that well field since a major decrease in pumping in 1948. The chloride content of water from well 4A increased from 10 ppm in 1946 to 47 ppm in 1951. This well has not been sampled recently. However, well 4B, immediately inland from well 4A, has continued to yield water containing less than 10 ppm of chloride.

In February 1958, wells 5A and 5B at the Jersey Central Power & Light Co. in South Amboy yielded water containing 28 and 44 ppm of chloride, respectively. The chloride content of water from well 5A decreased from 28 ppm in February 1958 to 9.5 ppm in July 1958, to 2.6 ppm in April 1959. This decrease may have been the result of less pumping from that well. Apparently, the contact between the salt water and the native fresh water is in the vicinity of that well field. Increased pumping from wells south of this area may extend the salt-water front inland.

### *Possible Methods of Control*

Salt-water encroachment is not prevalent in the Old Bridge Sand Member of the Raritan Formation; however, the danger of it has limited the development of this aquifer. A proposed tidal dam on the South River downstream from the intake area of the Old Bridge Sand Member would eliminate the potential salt-water encroachment into the aquifer near Old Bridge. A discussion of the potential benefits of such a dam is presented in the section "Tidal Dam on the South River." Near South Amboy, if future chemical analyses show a significant increase in chloride concentration, protective measures would be required such as those discussed for the Farrington Sand Member in the following paragraphs.

By 1949, industries nearest the sources of contamination substantially reduced their withdrawals of water from the Farrington Sand Member because of impending contamination. The reduced pumpage permitted the head in the sand to rise enough to restrain further salt-water encroachment. However, increased withdrawals in other parts of the aquifer have created a landward gradient which has drawn the salt water farther inland. The area of greatest concern is between Washington Canal and the Perth Amboy Water Department well field near Runyon. If heavy pumping continues, wells at Runyon will be pumping water with a high-chloride content, the concentration depending on the ratio of salt water to fresh water.

As salt-water encroachment becomes more widespread, additional wells may be abandoned because the salinity of the water will become too high for use. The point probably will be reached, however, where the remaining areas of withdrawal will be far enough away from the sources of contamination that the head in the aquifer will be greater than the head at these sources. But this probably would not take place until the aquifer in a considerable part of the area was rendered unfit for use. Even though such a condition would not occur for many years, it probably would hamper further development of this area.

Several possible methods of controlling salt-water encroachment in the Farrington Sand Member have been proposed. These are (1) constructing subsurface dikes or cutoff walls adjacent to the sand-filled gaps in the diabase sill through which salt water gains access to the aquifer, (2) lining Washington Canal and the Raritan River with impermeable material, (3) developing and maintaining a water-level trough seaward from the salt-water front, (4) developing and maintaining a fresh-water head at an effective height adjacent to the places where there is hydraulic continuity between the aquifer and the sources of contamination, or inland from the salt-water front, and (5) constructing a tidal dam to prevent salt water from advancing upstream to the places where there is hydraulic continuity between the aquifer and the stream channels.

Subsurface dikes or cutoff walls at the three principal places where there is hydraulic continuity between the aquifer and the sources of contamination would prevent salt water from entering the aquifer. These structures could be constructed either by excavating a trench adjacent to the source of contamination that completely penetrates the aquifer and lining it with impermeable material or injecting a compound such as emulsified asphalt into closely spaced wells adjacent to the source of contamination. However, three trenches totaling as much as 3 miles in length and in places more than 50 feet in depth would be necessary. The injection method would require hundreds of wells to seal off the aquifer effectively. The initial costs of equipment and material probably would be high, but cost of maintenance would be low.

A lining of impermeable material, such as clay, along the riverbeds through which the salt water gains access to the aquifer would form an impermeable blanket to protect the aquifer from further contamination. A considerable volume of material would be required to line the river channels involved.

Salt water could be prevented from migrating inland by pumping from a line of wells seaward from the salt-water front, to create a water-level trough deep enough to maintain a seaward gradient along the front. These wells would have to be spaced close enough to intercept all inland-moving salt water. Such an arrangement would result in the removal of some fresh water from the inland side of the trough. The pumped saline water would be corrosive to equipment and, also, would create a disposal problem. In addition, the withdrawal of fresh water probably would further reduce development of the aquifer.

Along the Washington Canal and the Raritan River, a fresh-water head of about 3 feet above mean sea level probably would be sufficient to prevent infiltration of salt water into the aquifer. The fresh-water head adjacent to the places where the aquifer is exposed to the sources of contamination would be raised most effectively by (1) artificial recharge through wells adjacent to and paralleling the entryways of contamination, (2) rearrangement of pumpage, or (3) reduction or elimination of pumping for as great a distance inland as necessary. Recharge through wells would form a fresh-water ridge to halt infiltration of salt water into the aquifer. This ridge would be a series of peaks at each recharge well with low points between. The rate of recharge and the well spacing would be determined by the minimum fresh-water head necessary to repel the flow of salt water beyond the low points. Some of the recharge water would flow toward the sources of contamination. Studies of the recharge operations at Manhattan Beach, Calif., show that about 5 percent of the recharge water flowed seaward and therefore could not be reclaimed (Laverty and van der Goot, 1955). This method would require a supplemental water source. Some recharge operations have used reclaimed sewage water with success. Chlorine is added to the waste water to prevent bacterial slimes from clogging the recharge wells and aquifer and to avert sanitary problems.

These recharge wells could also be placed inland from the part of the aquifer containing water of high salinity. Because salt water has a greater specific gravity than fresh water, the head of fresh water must be greater than the head in the part of the aquifer containing salt water to stabilize the salt-water front. The head differential required between the fresh and the salt water depends on their relative specific gravities. The specific gravity of salt water has been found to depend on the chloride concentration (Parker and others, 1955, p. 598, 599). Sea water contains about 19,500 ppm of chloride and has an average specific gravity of about 1.025. The specific gravity of water with a chloride concentration of 1,130 ppm at 25°C referred to distilled water at 25°C as unity was found to be about 1.00179. The chloride concentration of the contaminated water from well 100B, was 1,180 ppm in April 1959. This well is near Parlin about a mile northwest of the salt-water front. The difference in specific gravities between the contaminated water and the fresh water is so small as to be considered negligible. Therefore, the fresh-water head need be only minutely greater than the head in the contaminated part of the aquifer to prevent migration of contaminated water inland.

The fresh-water head could be raised to establish a gradient toward the front by relocating withdrawals from the Farrington Sand Member farther from the salt water and closer to the intake area. However it is doubtful that such a program would be economically justifiable.

It was shown in an earlier discussion that the elimination of pumping at Runyon permitted a hydraulic gradient toward the salt-water front near Parlin to be established. Pumpage from the aquifer at that time was about 4 mgd near Old Bridge. One program might be to discontinue pumping from wells at successive distances inland from the salt-water front in areas that would have another source of supply adequate to replace this loss. Water levels and chloride concentrations in wells near the front would be measured to ascertain when the landward gradients were reversed. Thereafter, no additional pumping would be permitted that would reestablish landward gradients near the contaminated part of the aquifer.

It is possible, by means of the Theis nonequilibrium formula (Theis, 1935), to compute the theoretical recovery that would occur at various distances in response to a reduction in pumping. Although this formula was developed to relate the drawdown in the piezometric surface to the rate and duration of pumping at various distances in an aquifer of infinite areal extent, it also can be used to determine recovery in response to a reduction in pumping if it can be assumed that the aquifer has been in hydraulic equilibrium. A coefficient of transmissibility of 100,000 gpd per foot and a coefficient of storage of about 0.0001 appear to be about average for the hydraulic characteristics of the Farrington Sand Member in this area. Figure 7 shows the theoretical recoveries at various distances

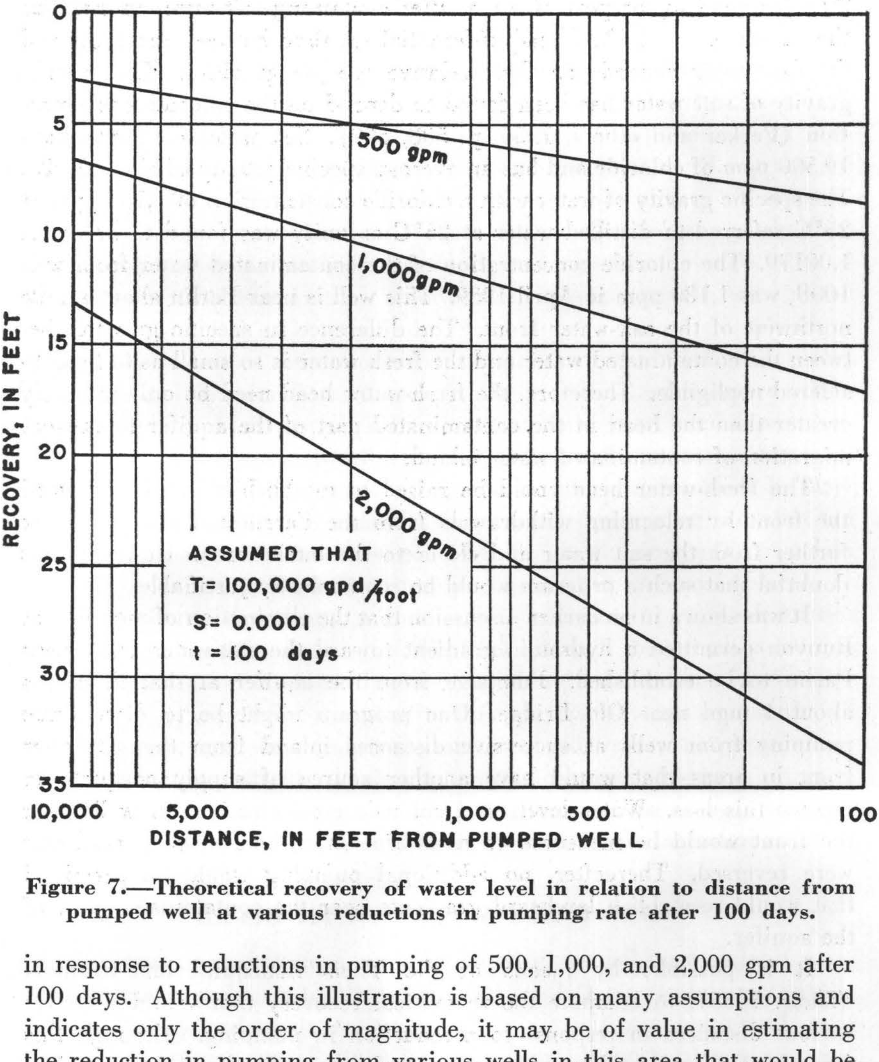



**Figure 7.—Theoretical recovery of water level in relation to distance from pumped well at various reductions in pumping rate after 100 days.**

in response to reductions in pumping of 500, 1,000, and 2,000 gpm after 100 days. Although this illustration is based on many assumptions and indicates only the order of magnitude, it may be of value in estimating the reduction in pumping from various wells in this area that would be necessary to permit the fresh-water head near the salt-water front to rise to an effective height.

The construction of a tidal dam across the mouth of the Raritan River would prevent salt water from advancing upstream to the places where there is hydraulic continuity between both the Farrington and the Old Bridge Sand Members and the stream channels. In addition, a fresh-water lake would be formed which would provide water for infiltration into the Farrington and Old Bridge Sand Members and the development of surface-water supplies. A dam at this site would involve considerable costs for property rights and construction. Also, owing to navigation on the Raritan River, it would be necessary to construct locks. As stated earlier, the salt-water problem in the Farrington Sand Member is most critical near Washington Canal. It would be desirable to locate a tidal dam no farther upstream than the confluence of Washington Canal and the Raritan River to remedy the problem directly in that critical area.

It is not within the scope of this study to determine which of these methods to control salt-water movement in the Farrington Sand Member is most economically feasible. However, it is essential to compare the benefits and limitations of these methods. In each method, the salt water in the aquifer probably would have to be removed by pumping from wells between the front and the sources of contamination to restore the quality of the water in the aquifer. Both the subsurface barrier and the lining of the river-channel route of contamination with impermeable material would, by isolating the aquifer, permit its full utilization for development. The yield of the aquifer would no longer be limited by salt-water intrusion, but only by the aquifer's capacity to transmit water and by its available recharge. The pumping trough does not resolve the fundamental problem of overdevelopment. Substantial quantities of fresh water are wasted to restrict the size of the area of contamination, and thereby the yield of the aquifer is decreased. Raising the fresh-water head adjacent to either the sources of contamination or the salt-water front by decreases in draft, or by rearrangement, restricts the full utilization of the aquifer. If supplemental water were available for recharge through wells immediately inland from the sources of contamination, practically all the aquifer could be utilized. Consideration might be given to the use of reclaimed sewage water as recharge water.

## TIDAL DAM ON THE SOUTH RIVER

A tidal dam on the South River has been proposed in an earlier study (Barksdale and others, 1943). However, at that time waste materials that were discharged into the South River created an undesirable condition. Since the construction of the Middlesex County Trunk Sewer in 1958, the condition of the South River has improved.

A tidal dam is a structure that prevents the surface and underground upstream flow of tidal salt water. To function effectively, a tidal dam requires the following two main characteristics (1) a spillway elevation higher than spring high tide, and (2) construction on relatively impermeable materials. A spillway about 7 feet above mean sea level would be adequate to prevent the upstream flow of salt water during spring tides. Extremely high tides, such as those associated with severe storms, might rise above a spillway at this elevation. However, these would occur rarely and would be of short duration. The pollution could be kept to a minimum by constructing the crest of the dam a few feet above the spillway. The Old Bridge intake area is underlain by a tight clay of low permeability. Hence, even if the elevation of fresh water behind the dam were to be below the high-tide level downstream, only a minimum of salt water would flow either around or under the dam.

If the tidal dam on the South River were located as shown on figure 8, it would provide a reservoir surface area, when full of about 400 acres and a storage capacity of about 600 million gallons (about 930 second-foot-days). This site would be relatively near the downstream edge of the contact of the Old Bridge Sand Member of the Raritan Formation and the South Amboy fire clay. The reservoir would have a total drainage area of about 121 square miles, of which 104 square miles are upstream from other storage facilities. If the spillway elevation were about 7 feet above mean sea level, the reservoir would have a maximum depth of about 26 feet and an average depth of about 4.5 feet.

The fresh-water lake would provide water for infiltration into the Old Bridge Sand Member and water for industrial and public supplies.

### *Infiltration Into the Old Bridge Sand Member*

The farthest upstream location of a dam on the South River that would prohibit salt-water access to the Old Bridge Sand Member as shown on figure 9 was based on placing the dam downstream from the intake area of the Old Bridge Sand Member as shown on figure 2. However, for several thousand feet upstream from this site, the sand probably is protected from serious salt-water encroachment by the alluvial muds and clays that blanket the channel of the South River. The most favorable site probably would be determined after a comparison of construction costs at different sites.

A tidal dam on the South River located downstream from the Old Bridge Sand Member would make available to the aquifer large quantities of fresh water that presently are lost to the sea. Well fields near this fresh-water reservoir could develop additional water supplies by induced infiltration. A location upstream of that shown on figures 8 and 9 would reduce the volume of storage available.

The factors that determine the rates at which water can be induced from a surface source into an aquifer are (1) the permeability of the aquifer, (2) the permeability of the materials on the bottom of the surface-water body, and (3) the hydraulic gradient established between the surface-water body and the adjacent aquifer.

Numerous logs of wells that penerate the Old Bridge Sand Member in this area show that it contains clay lenses. Therefore, the aquifer is not uniform in thickness and extent. The results of several aquifer tests indicate an average coefficient of permeability of about 1,200 gpd per square foot.

Figure 8 shows the location of borings* made to determine the nature and extent of the materials that would underlie a reservoir on the South River. A study of some of the deeper test borings suggests that the Old Bridge Sand Member thins to the northwest.

Figure 9 shows the thickness of relatively impermeable muds or clays. The greatest thickness of surficial muds or clays generally was found either in or very near the South River or its tributaries; as much as 11.2 feet of mud was penetrated in test boring 112. Permeability tests were made on several samples from the bed of the South River, collected by the Porter tube method. (See table 5.) Except for samples from boring 93, they showed low permeabilities. The samples from borings 92, 95, and 98 were most characteristic of the muds penetrated in the South River.

**Table 5.—Coefficients of permeability for samples of material taken in the river bed of the South River**

| *Boring no.* | *Depth of sample (in feet below river bottom)* | *Coefficient of permeability (gallons per day per square foot)* |
|---|---|---|
| 92 | 0.5 - 1.0 | 4.2 |
| 93 | 0 - 0.5 | 140 |
| 93 | 4.0 - 4.5 | 44 |
| 93 | 4.5 - 5.0 | 424 |
| 95 | 0.5 - 1.0 | .03 |
| 96 | 1.5 - 2.0 | .3 |
| 96 | 2.0 - 2.5 | .04 |
| 98 | 8.5 - 9.0 | .3 |
| 99 | 5.0 - 5.5 | .09 |
| 100 | 7.0 - 7.5 | .7 |

Part of the bed of the South River channel that traverses the intake area of the Old Bridge Sand Member is covered with organic materials. These materials may be an accumulation of wastes that were discharged into the South River prior to the contruction of the South River Branch of the Middlesex County Trunk Sewer in 1958. At some sites in the present river channel, these organic materials were found to be several feet thick. They are composed of gel-like or colloidal particles mixed with alluvial muds which form relatively impermeable deposits. A large part of the land surface that would be inundated by the construction of a dam having a spillway elevation of 7 feet above mean sea level contains dense tidal-marsh growths which influence deposition of fine-grained materials allowing only small quantities of water to infiltrate into the aquifer. Although

* Logs showing the materials penetrated are given in the Appendix.

a certain degree of hydraulic continuity has been indicated by above-normal chloride concentrations in several wells near Deep Run and the South River, it is believed by the writer that the removal of the muds and clays underlying the reservoir site would increase its effectiveness as a means of recharging the Old Bridge Sand Member. This probably could be best accomplished by dredging, scouring, or infiltration ditches. Certain parts of the reservoir site would require little if any land preparation. Shallow hand-augered samples obtained from the bed of the South River immediately downstream from Duhernal Dam generally consisted of permeable sands and gravels.

For any given distance between the reservoir and a pumped well, the optimum hydraulic gradient is that which permits the greatest infiltration. It is undesirable to dewater a large part of the aquifer because the saturated thickness and transmitting capacity of the aquifer are hereby reduced. The proportion of the pumped water represented by induced recharge from the reservoir increases as the pumped wells are located closer to this source of recharge. In addition, less drawdown is created inland. However, pumped wells should be spaced at distances from the reservoir which permit the greatest infiltration of water of suitable quality to the aquifer.

It is difficult to estimate accurately the maximum rate of recharge that could be anticipated from a reservoir on the South River. The extent of removal of the relatively impermeable materials that underlie a considerable part of the reservoir site under discussion and the hydraulic gradients that would be established are not known. However, results of studies at nearby Tennent Pond and Duhernal Lake may suggest the order of magnitude of recharge. The maximum rate of recharge from Tennent Pond was estimated to be about 0.09 mgd per acre (Barksdale and others, 1943). If the rate of recharge from the 400-acre proposed reservoir should be comparable to the maximum rate at Tennent Pond, the total recharge may be about 36 mgd. Results of studies at Duhernal Lake in October 1943 indicated a rate of recharge of about 0.03 mgd per acre (Barksdale and DeBuchananne, 1946). On this basis the recharge would be about 12 mgd from the proposed reservoir.

Another analysis, using inflow and outflow records (accounting for evaporation losses) at Duhernal Dam for the water year 1958, indicates an average recharge of about 7 mgd, or about 0.04 mgd per acre. Applying this rate of recharge from the proposed reservoir would suggest about 16 mgd. These examples are intended to be illustrative rather than exhaustive. Also, it has been assumed that storage in the reservoir was adequate to maintain the rate of recharge. The recharge rate from this reservoir could be higher if dredging were extensive and exposed more permeable materials than those at either Duhernal Lake or Tennent Pond. As stated earlier, the Old Bridge Sand Member thins to the northwest, thereby decreasing both its storage capacity and its capacity to transmit water. Hence, it is possible that near the northern part of the reservoir the Old Bridge Sand Member might be considered too thin for development of large-scale infiltration supplies. Under severe drought conditions (as in 1957) inflow into the proposed reservoir and the estimated reservoir storage capacity would have been adequate to maintain a sustained yield of about 14 mgd (discussed in detail in a following section entitled "Reservoir Storage").

To determine the quantities of water that could be induced from a surface pond by a hypothetical system of wells, the author has assumed certain geologic and hydraulic characteristics that generally prevail in the Old Bridge Sand Member in the area under given conditions. The area considered in this discussion will be that part of the proposed reservoir downstream from Duhernal Dam. The assumptions made for this computation are (1) the reservoir is considered as a line source of recharge, (2) the aquifer is freely connected with the reservoir, (3) the aquifer adjacent to the reservoir has an average thickness of 60 feet, (4) the aquifer has an average coefficient of permeability of 1,200 gpd per square foot, (5) the reservoir surface elevation is constant and is about 6 feet above mean sea level, and (6) the reservoir water enters the aquifer horizontally along a section parallel to the reservoir.

This well system would consist of 21 wells, each 2 feet in diameter, along a line adjacent to the reservoir and 500 feet from it. It is also assumed that these wells will be spaced 500 feet apart along the 10,000-foot length downstream from Duhernal Dam, that the maximum allowable drawdown in any discharge well will not exceed 40 feet, and that each well will be pumped at the same rate. The total discharge from these wells would be about 19 mgd. This computation was made by using a formula developed by Rorabaugh (1956, p. 123). The calculated discharge may be increased by any of the following: (1) placing the discharge wells closer to the recharge source, (2) increasing the individual well diameters, (3) using more wells placed closer to each other, thereby increasing the number of wells. This computation is not adjusted for well losses which would reduce the total discharge for any given drawdown. Also, Rorabaugh's (1948) formula is developed for water at a temperature of 60°F, and this computation would have to be corrected if the temperature of the water in a given ground-water development differed appreciably from 60°F. A decrease of 1° in temperature will cause a decrease in flow rate of about 1.5 percent. Of the assumptions made in this computation, the most critical condition is that the aquifer must have hydraulic con-

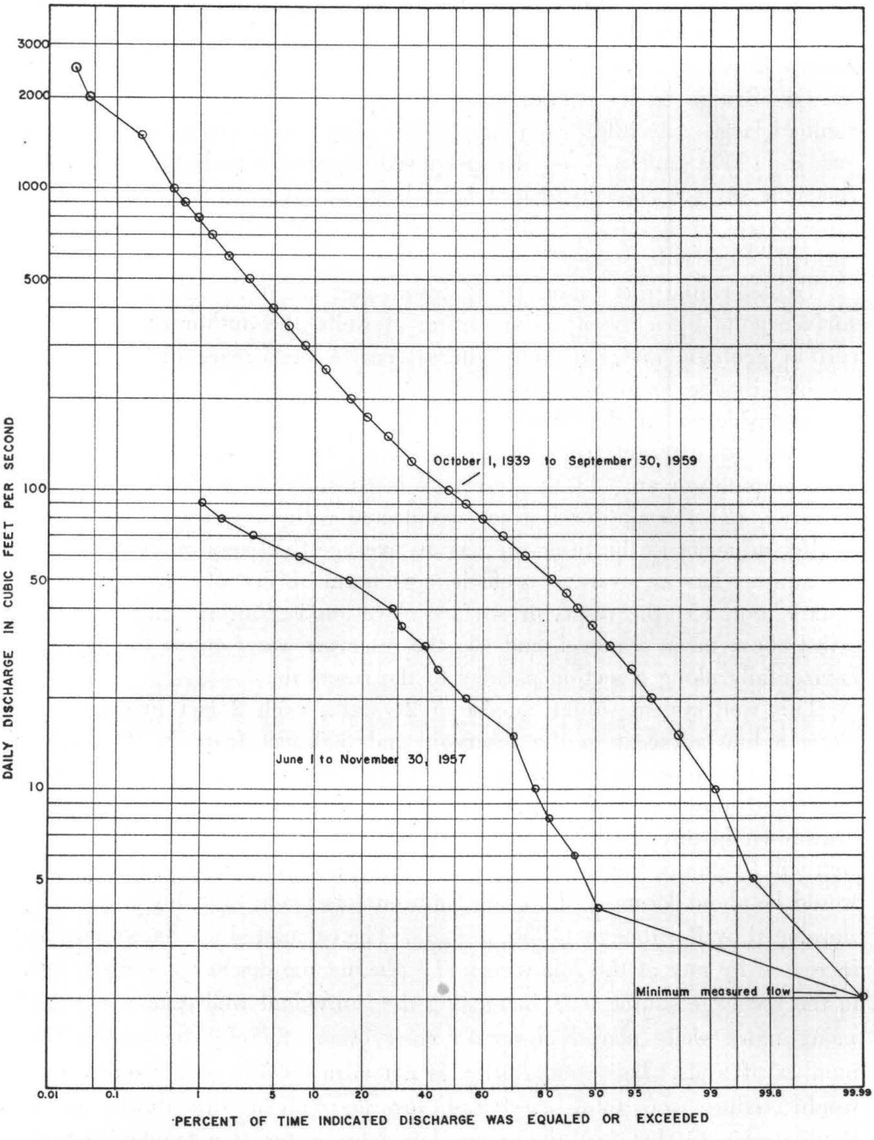



**Figure 10.—Flow-duration curve for South River at Old Bridge (at Duhernal Dam) October 1, 1939, to September 30, 1959, and the lowest 6-month record, June 1 to November 30, 1957.**

nection with the reservoir. At present, this condition does not exist. However, with adequate dredging it might be created, and, hence, such a computation would not be unreasonable for the well-distribution system.

### *Reservoir Storage*

The dependable sustained yield from a surface reservoir is determined by the storage capacity of the reservoir, the duration and magnitude of the lowest anticipated inflow, and the evaporation and other losses.

The major part of inflow into the reservoir on the South River would be outflow from Duhernal Lake. The intermediate contributing area of about 17 square miles between Duhernal Dam and the proposed dam would contribute an additional inflow equal to about 15 percent of that from Duhernal Lake.

Figure 10 shows a duration curve of daily outflow from Duhernal Lake for the period October 1, 1939, to September 30, 1959,* and a duration curve for the 6-month period of lowest record. A flow-duration curve is a cumulative frequency curve that shows the percentage of time during which specified discharges were equaled or exceeded in a given period, irrespective of chronological sequence. For example, in the period 1939-59 the daily outflow from Duhernal Lake was at least 30 cfs (cubic feet per second)† during 92 percent of the time. It is important to keep in mind that the duration curve based on the 20-year record is an average curve for this period and does not represent the distribution of yearly flow. It is for this reason that a duration curve for the 6-month period of lowest record, June 1 to November 30, 1957, is shown also. For that period the daily discharge from Duhernal Lake was at least 3.8 cfs during 92 percent of the time, which is considerably less than that indicated by the long-term record. If the pattern of regulated outflow is of the same magnitude in the future, the 20-year duration curve may be used to estimate the percentage of time that a particular discharge will be equaled or exceeded.

Figure 11 shows a hydrograph and a mass curve for the outflow from Duhernal Lake for the lowest 6-month record, June 1 to November 30, 1957. The mass curve is a plot of cumulative daily outflow from Duhernal Lake against time, whereas the hydrograph is simply a plot of daily outflow. If the reservoir had been full and had had a storage capacity of about 900 cfs-days (580 mg) on June 30, 1957, a withdrawal of 21.6 cfs (about 14 mgd) could have been sustained throughout the period, and the reservoir would have been filled again by November 14, 1957.

Records of evaporation at the Runyon Weather Station for the period 1923-56 show an average annual evaporation loss from a pond or lake

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* Curve prepared from records of South River at Old Bridge (Duhernal Dam).

† 1 cubic foot per second (cfs) is equal to 646,317 gpd.

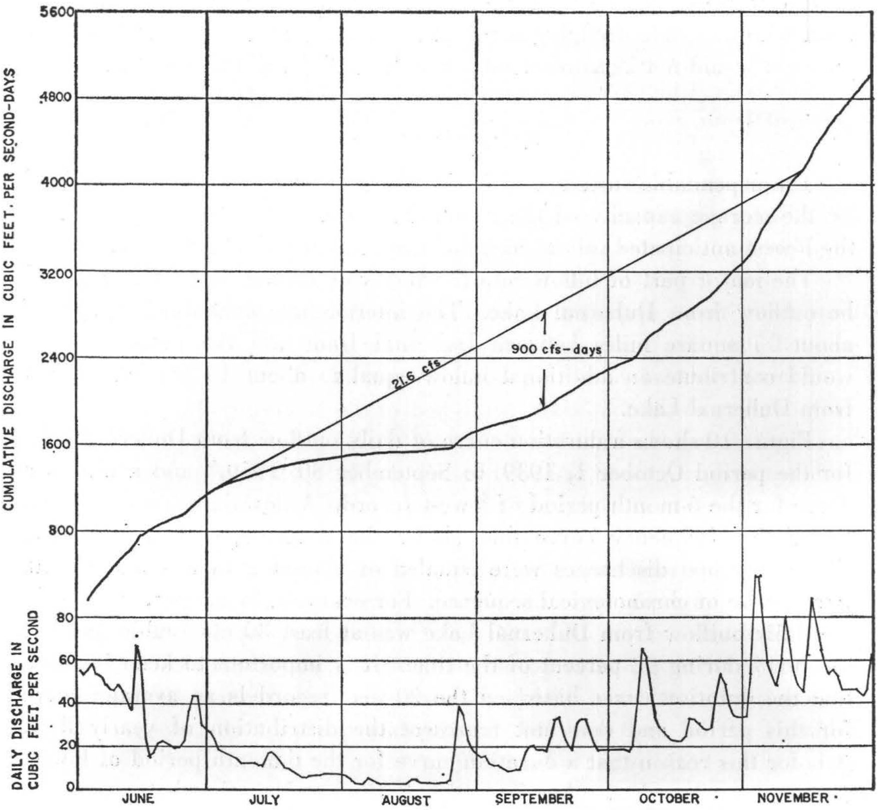


**Figure 11.—Hydrograph and mass curve of discharge from Duhernal Lake, June 1 to November 30, 1957.**

of about 19.5 inches for May through October. Assuming a certain reservoir area-storage relationship, the writer calculated that an allowance for evaporation losses would have required an additional 160 cfs-days (about 100 mg) of reservoir storage above that shown on figure 10 to maintain a yield of 14 mgd. However, these losses would have been made up by inflow from the intermediate contributing area between Duhernal Dam and the proposed dam, which was not accounted for in plotting the mass curve. If June 1 to November 30, 1957, could be considered representative of the most severe conditions that might be anticipated in the future, the estimated reservoir storage of about 600 million gallons probably would be adequate to maintain a dependable yield of about 14 mgd. During periods of average inflow, a yield of several times this could be maintained.

### *Reservoir Silting*

The area is moderately covered with vegetation which helps to protect the soil from rapid erosion. Except for relatively impermeable alluvial deposits along the tributary streams, the soils are relatively permeable and absorb precipitation readily.

A large part of the sediment load carried by streams in this drainage area probably settles out in the reservoirs at Duhernal Lake and behind the Tennent Brook dam at Runyon. During periods of high flow, the outflow from these upstream reservoirs probably would contain some suspended materials that would settle out in the reservoir on the South River.

Silting reduces both the storage capacity of the reservoir and the permeability of the materials in the bed of the reservoir. In some areas it has been found desirable to construct sluice gates that can be lowered sufficiently during flood periods to allow the finer silt loads to pass through.

The reservoir at Duhernal Dam was constructed about 20 years ago. Studies carried on several years ago by engineers of the Duhernal companies indicate that the silting in that reservoir has lowered only slightly the infiltration capacity of the bottom materials overlying the Old Bridge Sand Member. Silting of a reservoir behind the proposed tidal dam on the South River probably would not create a major problem. However, after a period of time, silting of reservoirs does reduce the infiltration capacity of the reservoir bed, and to date the most effective method of removal has been by periodic dredging.

### *Chemical Quality of Surface Water*

Water samples were collected from the South River a short distance below Duhernal Dam and analyzed by the New Jersey State Department of Health (table 6). The sampling was part of a study made to determine the condition of the Raritan River and its tributaries after the construction of the trunk sewer.

Temperature is an important consideration for public and industrial water uses. Water with a temperature of more than 60°F is usually considered undesirable for drinking (California State Water Pollution Control Board, 1957). All the temperatures reported in table 6 were above 60°F. However, these were of samples collected in the summer. Temperature data collected by the Duhernal Water System at stations near the confluence of Matchaponix Brook and Duhernal Lake indicate average annual temperatures of 49.6°F and 56.7°F for 1957 and 1958, respectively. In 1958, the minimum average monthly temperature and maximum average monthly temperature were 36.0°F and 72.7°F, respectively.

**Table 6.—Water analyses of samples from South River, below Duhernal Dam**

*[Analyses by New Jersey State Department of Health. All data, except pH and color, in parts per million]*

| *Date of collection* | *Temperature °F* | *pH* | *Color* | *Chloride* | *Turbidity* | *BOD*[1] | *Dissolved oxygen* | *Percent saturation*[2] |
|---|---|---|---|---|---|---|---|---|
| June 10, 1958 | 68 | 4.6 | 10 | 7 | 0 | 1.0 | 8.9 | 97 |
| June 17, 1958 | 68 | 5.0 | 20 | 8 | 5.5 | 2.0 | 10.3 | 112 |
| June 24, 1958 | 70 | 5.4 | 10 | 7 | 0 | 1.0 | 9.96 | 110 |
| July 1, 1958 | 75 | 5.3 | 40 | 9 | ---- | 3.5 | 8.82 | 103 |
| July 15, 1958 | 73 | 4.6 | 30 | 10 | ---- | .2 | 9.34 | 108 |
| July 22, 1958 | 73 | 6.8 | 40 | 3 | ---- | 3.0 | 8.30 | 96 |
| August 5, 1958 | 73 | ---- | 30 | 10 | ---- | .4 | 8.0 | 92 |
| August 19, 1958 | 77 | 6.6 | 50 | 8 | ---- | 4.0 | 10.8 | 129 |
| August 26, 1958 | 77 | 6.8 | 80 | 8 | ---- | .9 | 8.35 | 100 |
| January 14, 1959 | ---- | 4.8 | 15 | 8 | 10.0 | 1.0 | 12.3 | ---- |
| March 9, 1959 | ---- | 4.3 | 40 | 8 | 15.5 | 2.0 | 11.57 | ---- |
| February 10, 1960 | ---- | 4.6 | 10 | 11 | 14 | 1.8 | ---- | ---- |

1 Biochemical oxygen demand.

2 Computed by dividing parts per million dissolved oxygen in sample by parts per million oxygen necessary to produce saturation at that temperature.

According to the climatic conditions that usually prevail in this area, the average temperature of the water in shallow lakes or similarly impounded water bodies will tend to be close to that of the average air temperature. At depths greater than 10 feet below the water surface of a shallow lake, this relationship no longer exists (Hutchinson, 1957). The average depth of the reservoir in the South River will be less than 10 feet; the temperature of the water impounded will be below 60°F for about 7 or 8 months a year.

The pH values on the South River for the period of sampling were always lower than 7. The average annual pH of water at the confluence of Matchaponix Brook with Duhernal Lake, as reported by the Duhernal Water System, was 5.0 and 4.7 for 1957 and 1958, respectively. The pH is lower than 7 in acidic solutions and higher than 7 in basic solutions. It is a general practice that the pH of potable water supplies be either neutral or slightly basic.

The concentrations of the other constituents shown in table 6 would classify the water as a good supply, requiring only the usual treatment, such as filtration and disinfection, for general use (California State Water Pollution Control Board, 1957). It is possible to treat any water to render it chemically acceptable for a particular use. The demand and the kind of treatment required would determine the economic feasibility of its use as a major water supply.

## SUMMARY

There are two principal aquifers in the Sayreville area—the Old Bridge Sand and the Farrington Sand Members of the Raritan Formation. Danger of salt-water encroachment in the Old Bridge Sand Member has limited the intensity and distribution of pumping from that aquifer. A tidal dam on the South River downstream from the Old Bridge Sand Member would reduce the danger of salt-water encroachment and would provide fresh water for infiltration into the aquifer. A considerable part of the present river channel is underlain by mud and clay, the removal of which would increase the effectiveness of this reservoir in the recharging of the Old Bridge Sand Member. Also, this reservoir would provide fresh water for surface-water supplies. It has been estimated from the lowest 6-month record of discharge from Duhernal Dam that a reservoir storage of 900 cfs-days would have been adequate to maintain a yield of about 14 mgd.

Widespread salt-water encroachment has caused several wells to be abandoned in the Farrington Sand Member. In the area south of Parlin, it is estimated, the 10-ppm isochlor advanced from 1943 to 1958 at an average rate of about 240 feet per year. Unless controlled, salt-water encroachment threatens to render a considerable additional part of the aquifer unfit for use. Several measures for control are being considered, the feasibility of which probably will be determined by economics. The collection of water samples from selected wells in the Farrington Sand Member will be continued, and these samples will be analyzed for chloride content to monitor the extent of encroachment.

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# APPENDIX

## LOGS OF SELECTED TEST HOLES AND WELLS IN THE VICINITY OF THE SOUTH RIVER

[a] Depth in feet below mean low water; [b] Data obtained from the Duhernal Water System; [c] Data obtained from the Middlesex County Sewerage Authority; [d] Borings made by Corps of Engineers, descriptions adapted from M. E. Johnson, former State Geologist; [e] Data obtained from the Perth Amboy Water Department.

| *Boring No.* | *Description* | *Thickness (feet)* | *Depth (feet)* |
|---|---|---|---|
| 1 | Sand, coarse; occasional clay balls | 5 | 5 |
| 2 | Mud and dark-gray clay | 7 | 7 |
| 3 | Mud and clay | 2 | 2 |
| 4 | Water | 3 | 3 |
| | Mud and clay | 1 | 4 |
| 5 | Mud | 1.5 | 1.5 |
| | Sand, medium; a few pebbles | 2.5 | 4 |
| | Sand, medium to coarse | 1 | 5 |
| 6 | Mud and clay | 3 | 3 |
| | Sand, medium, and gravel | 1 | 4 |
| | Sand, fine to medium | 3 | 7 |
| 7 | Topsoil | .5 | .5 |
| | Sand, medium to coarse | 3 | 3.5 |
| 8 | Water | 4.5 | 4.5 |
| | Sand, medium to coarse | 1 | 5.5 |
| 9 | Sand and mud | .5 | .5 |
| | Sand and gravel | 5.5 | 6 |
| 10 | Water | 2 | 2 |
| | Sand, medium to coarse, and gravel | 1 | 3 |
| 11 | Mud and clay | 5.5 | 5.5 |
| 12 | Mud and clay | 8 | 8 |
| 13 | Mud | 4 | 4 |
| | Sand, medium to coarse | 2 | 6 |
| 14 | Mud and clay | 2.5 | 2.5 |
| | Sand, medium to coarse | 1 | 3.5 |
| 15 | Mud | 4 | 4 |
| 16 | Sand, coarse, and gravel | .5 | .5 |
| 17 | Mud | 1 | 1 |
| | Sand, medium to coarse; some pebbles | 1.5 | 2.5 |
| 18 | Mud | 5.5 | 5.5 |
| | Sand, medium to coarse | 1 | 6.5 |
| 19 | Mud | 6 | 6 |
| | Sand, medium to coarse, and gravel | 1 | 7 |

| Boring No. | Description | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| 20 | Sand, medium | .5 | .5 |
| | Clay | 2 | 2.5 |
| | Sand, medium to coarse, and gravel | 3.5 | 6 |
| 21 | Mud and clay | 6 | 6 |
| | Sand and gravel | 1 | 7 |
| 22 | Mud and clay | 7 | 7 |
| | Sand, medium to coarse | 1 | 8 |
| 23 | Water | 1 | 1 |
| | Mud and clay | 3 | 4 |
| 24 | Mud | 1 | 1 |
| | Sand, medium to coarse, and gravel | 1.5 | 2.5 |
| | Sand, medium | 1.5 | 4 |
| 25 | Sand, medium to coarse, and gravel | 3 | 3 |
| | Sand, medium | 1 | 4 |
| 26 | Mud and clay | 1 | 1 |
| | Sand, medium | 1.5 | 2.5 |
| 27 | Clayey topsoil | 1 | 1 |
| | Sand, fine to medium | 3 | 4 |
| 28 | Mud and clay | 1.5 | 1.5 |
| | Sand, medium to coarse, and gravel | 1.5 | 3 |
| 29 | Mud | 1.5 | 1.5 |
| | Sand, fine to medium | 4 | 5.5 |
| 30 | Topsoil | 1 | 1 |
| | Clay | 6 | 7 |
| 31 | Sand, medium | 4 | 4 |
| 32 | Mud | 4.5 | 4.5 |
| 33 | Mud | 6.5 | 6.5 |
| 34 | Mud | 1 | 1 |
| | Sand, medium | 2 | 3 |
| 35 | Sand, medium, and some gravel | 4 | 4 |
| 36 | Mud | 2.5 | 2.5 |
| | Sand, medium | 1.5 | 4 |
| 37 | Mud | 3 | 3 |
| | Clay, sandy | 2 | 5 |
| 38 | Sand, fine to medium | 2.5 | 2.5 |
| | Sand, clayey | 1.5 | 4 |
| 39 | Sand, fine, and clay | 4.5 | 4.5 |
| 40 | Sand, medium | .1 | .1 |
| | Clay, tight | 1.4 | 1.5 |

| Boring No. | Description | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| 41 | Mud and clay | .5 | .5 |
| | Clay, sandy, gray | .5 | 1 |
| | Clay, brown | 2 | 3 |
| 42 | Water | 2 | 2 |
| | Mud and clay | 2.5 | 4.5 |
| 43 | Sand, medium | 4 | 4 |
| 44 | Clay | 2 | 2 |
| 45 | Sand, medium to coarse, and gravel | 3 | 3 |
| | Clay, tight | .5 | 3.5 |
| 46 | Water | .5 | .5 |
| | Sand, medium | .3 | .8 |
| | Clay | .7 | 1.5 |
| 47 | Water | 3 | 3 |
| | Mud and clay | 1 | 4 |
| 48 | Sand, coarse, and gravel | 1.5 | 1.5 |
| 49 | Mud and clay | 1.5 | 1.5 |
| | Sand, coarse, and gravel | .5 | 2 |
| 50 | Water | 2.5 | 2.5 |
| | Mud | 1 | 3.5 |
| 51 | Water | 3 | 3 |
| | Sand and mud | 1 | 4 |
| 52 | Water | .5 | .5 |
| | Sand and gravel | .25 | .75 |
| | Clay | .5 | 1.25 |
| 53 | Clay | .5 | .5 |
| | Sand, fine to medium | .3 | .8 |
| | Clay | 1.2 | 2 |
| 54 | Water | 1 | 1 |
| | Sand | .5 | 1.5 |
| | Clay | .5 | 2 |
| 55 | Sand and gravel | 1 | 1 |
| 56 | Water | 4 | 4 |
| | Mud and clay | 2 | 6 |
| 57 | Water | 1 | 1 |
| | Sand, coarse, and gravel | .5 | 1.5 |
| 58 | Sand and gravel | 1 | 1 |
| 59 | Mud and clay | 1.5 | 1.5 |
| 60 | Water | 3 | 3 |
| | Clay | .5 | 3.5 |
| 61 | Clay | 1.5 | 1.5 |

| *Boring No.* | *Description* | *Thickness (feet)* | *Depth (feet)* |
|---|---|---|---|
| 62 | Mud and clay | 3 | 3 |
| 63 | Water | 1.5 | 1.5 |
| | Sandy clay and mud | 2 | 3.5 |
| 64 | Mud and clay | 2 | 2 |
| 65 | Sand, fine | .1 | .1 |
| | Mud and clay | 1.4 | 1.5 |
| 66 | Sand, fine, and mud | 1.5 | 1.5 |
| 67 | Mud and clay | 5 | 5 |
| 68 | Sand and mud | .5 | .5 |
| | Sand, coarse, and gravel | 1 | 1.5 |
| 69 | Mud and clay | 3.5 | 3.5 |
| 70 | Sand, fine to medium | .5 | .5 |
| | Sand, coarse, and gravel | .5 | 1 |
| 71 | Sand, medium | .7 | .7 |
| | Sandy clay | .8 | 1.5 |
| 72 | Sand, clayey | 1.5 | 1.5 |
| 73 | Water | 7 | 7 |
| | Sand, fine | .5 | 7.5 |
| 74 | Water | 4 | 4 |
| | Sand, fine | 1 | 5 |
| 75 | Water | .5 | .5 |
| | Sand, fine | 1 | 1.5 |
| 76 | Water | 8 | 8 |
| | Sand, fine to medium, and gravel | 1 | 9 |
| 77 | Water | 1.5 | 1.5 |
| | Mud | 4 | 5.5 |
| 78 | Sand, fine | .5 | .5 |
| | Clay | .5 | 1 |
| 79 | Sand, and some gravel | 20 | 20 |
| | Pebbles | 1 | 21 |
| | Clay, gray | 3 | 24 |
| 80 | Sand, and some gravel | 21 | 21 |
| | Gravel | 1 | 22 |
| | Clay, gray | 3 | 25 |
| 81 | Sand and clayey sand | 23 | 23 |
| | Clay, gray | 4 | 27 |
| 82 | Sand and some gravel | 35 | 35 |
| | Clay, gray | 2 | 37 |

| Boring No. | Description | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| 83 | Sand and some gravel | 38 | 38 |
| | Clay, gray | 17 | 55 |
| 84 | Sand and some gravel | 48 | 48 |
| | Clay, gray | 4 | 52 |
| 85 | Sand with clay streaks | 42 | 42 |
| | Clay, gray | 8 | 50 |
| 86 | Sand and some gravel with clay streak | 45 | 45 |
| | Clay, gray | 10 | 55 |
| 87 | Sand | 81 | 81 |
| | Clay, gray | 3 | 84 |
| 88 | Sand and some gravel | 66 | 66 |
| | Clay, blue-gray | 7 | 73 |
| 89 | Water | 11.5 | 11.5[a] |
| | Sand, medium, and clay | 5 | 16.5 |
| 90 | Water | 8 | 8[a] |
| | Sand, fine to medium | 4 | 12 |
| | Clay with wood | 1 | 13 |
| 91 | Water | 4.5 | 4.5[a] |
| | Sand, fine to medium, with wood | 4 | 8.5 |
| | Sand, medium | 1.5 | 10 |
| | Clay, dark-gray | At bottom | |
| 92 | Water | 20.5 | 20.5[a] |
| | Mud and clay | 3 | 23.5 |
| | Sand, medium | At bottom | |
| 93 | Water | 15 | 15[a] |
| | Sand, medium to coarse | 5 | 20 |
| | Clay, light-gray | At bottom | |
| 94 | Water | 14 | 14[a] |
| | Clay, gray, and mud | 5 | 19 |
| | Clay, sparkling gray | 1 | 20 |
| 95 | Water | 16 | 16[a] |
| | Mud | 5 | 21 |
| | Clay, dark-gray | .5 | 21.5 |
| 96 | Water | 18.5 | 18.5[a] |
| | Mud | 1.5 | 20 |
| | Clay, gray, micaceous | 1 | 21 |
| 97 | Water | 4 | 4[a] |
| | Mud | 11.5 | 15.5 |
| 98 | Water | 11 | 11[a] |
| | Mud | 9 | 20 |
| | Clay, gray, micaceous | 1 | 21 |

| Boring No. | Description | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| 99 | Water | 11 | 11[a] |
| | Mud | 1 | 12 |
| | Sand and gray clay | 4.5 | 16.5 |
| | Clay, gray | .5 | 17 |
| 100 | Water | 5 | 5[a] |
| | Mud | 6.5 | 11.5 |
| | Clay, gray | 1.5 | 13 |
| 101 | Water | 1.5 | 1.5[a] |
| | Mud | 8 | 9.5 |
| | Clay, gray, micaceous | .5 | 10 |
| | Sand, coarse, and a pebble | .2 | 10.2 |
| | Clay, white, sparkling | .8 | 11 |
| 102 | Water | 3.5 | 3.5[a] |
| | Sand, fine to medium, micaceous | 3.5 | 7 |
| 103 | Water | 14 | 14[a] |
| | Mud | 3 | 17 |
| | Clay, yellow | 2 | 19 |
| | Clay, white, micaceous | At bottom | |
| 104[b] | Sand, brown | 15 | 15 |
| | Sand, brown, and gravel | 5 | 20 |
| | Sand, white | 7 | 27 |
| | Clay, white | 3 | 30 |
| | Sand, white | 1 | 31 |
| | Sand, white, and red rock | 1 | 32 |
| | Sand, white, and brown rock | 4 | 36 |
| | Sand, white | 6.5 | 42.5 |
| | Sand, coarse | 1.5 | 44 |
| | Sand, brown, coarse | 3 | 47 |
| | Sand, gray | 3 | 50 |
| | Sand, white, coarse | 8 | 58 |
| | Sand, gray, medium | 5 | 63 |
| | Sand, brown | 2 | 65 |
| 105[b] | Clay, red | 4 | 4 |
| | Sand, brown, and coarse gravel | 11 | 15 |
| | Sand, coarse and gravel | 3 | 18 |
| | Sand and coarse gravel | 4 | 22 |
| | Sand and gravel | 3 | 25 |
| | Sand, brown | 1 | 26 |
| | Sand, red | 1 | 27 |
| | Sand, brown | 1 | 28 |
| | Sand, gray | 2 | 30 |
| | Sand, brown, coarse | 6 | 36 |
| | Sand, light-brown | 18 | 54 |
| | Clay, yellow | 3 | 57 |
| | Clay, blue | 2 | 59 |
| 106[c] | Sand, brown, fine and medium, and gravel | 8 | 8 |
| | Sand, brown and white, medium | 3.3 | 11.3 |
| | Sand, white, fine | 6.7 | 18 |

| *Boring No.* | *Description* | *Thickness (feet)* | *Depth (feet)* |
|---|---|---|---|
| 107[c] | Topsoil | 1.1 | 1.1 |
| | Sand, brown, gravel | 7.5 | 8.6 |
| | Sand, brown, coarse, and gravel | 9.4 | 30.7 |
| 108[c] | Topsoil | 1.5 | 1.5 |
| | Sand, brown, and gravel | 8 | 9.5 |
| | Sand, dark-brown, and gravel | 2.8 | 12.3 |
| | Sand, dark-brown | 4.7 | 17 |
| 109[c] | Topsoil | 1.2 | 1.2 |
| | Sand, brown | 5.1 | 6.3 |
| | Sand, brown, gravel | 5.2 | 11.5 |
| | Sand, brown, coarse | 3.5 | 15 |
| 110[c] | Sand, brown and black, fine, and gravel | 2.3 | 2.3 |
| | Sand, brown, medium to coarse, and gravel | 10.5 | 12.8 |
| | Sand, brown and white, fine | 13.2 | 26 |
| 111[c] | Water | 6 | 6 |
| | Black silt, some bog roots | 4 | 10 |
| | Sand, brown, gravel | 5.5 | 15.5 |
| | Sand, brown and white, medium; trace of clay | 9.5 | 25 |
| | Sand, medium to coarse, and silt | 6 | 31 |
| | Sand, white, medium | 4 | 35 |
| 112[c] | Mud, meadow bog | 11.2 | 11.2 |
| | Sand, brown | 5.6 | 16.8 |
| | Sand, brown, gravel | 6.2 | 23 |
| 113[c] | Topsoil | 1.5 | 1.5 |
| | Sand, brown | 4.8 | 6.3 |
| | Sand, brown, some gravel | 5.9 | 12.2 |
| | Sand, brown, coarse gravel | 6.8 | 19 |
| 114[c] | Topsoil | 2.3 | 2.3 |
| | Sand, brown, fine | 4.5 | 6.8 |
| | Sand, brown, coarse | 5.6 | 12.4 |
| | Sand, brown, gravel | 5.6 | 18 |
| 115[c] | Water and topsoil | 2.7 | 2.7 |
| | Sand, brown, fine | 3.5 | 6.2 |
| | Sand, brown, gravel | 5.2 | 11.4 |
| | Sand, gray and brown | 4.6 | 16 |
| 116[c] | Meadow mud | 2.8 | 2.8 |
| | Sand, brown | 3.8 | 6.6 |
| | Sand, brown, gravel | 8.1 | 14.7 |
| | Sand, gray and brown | 2.3 | 17 |
| 117[c] | Meadow mud | 3.8 | 3.8 |
| | Sand, brown, fine | 5.4 | 9.2 |
| | Sand, brown, gravel | 4.5 | 13.7 |
| | Sand, brown and gray | 4.3 | 18 |
| 118[c] | Mud, meadow bog | 7.1 | 7.1 |
| | Sand, brown | 4.6 | 11.7 |
| | Sand, brown, gravel | 4.7 | 16.4 |
| | Sand, gray and brown | 1.6 | 18 |

| *Boring No.* | *Description* | *Thickness (feet)* | *Depth (feet)* |
|---|---|---|---|
| 119[c] | Cinders, sand and gravel | 3.6 | 3.6 |
| | Sand, brown, gravel | 13.4 | 17 |
| 120[c] | Topsoil | 1.6 | 1.6 |
| | Sand, brown, fine, trace of gravel | 6.5 | 8.1 |
| | Sand, brown, gravel | 8.9 | 17 |
| 121[c] | Mud, meadow bog | 4.1 | 4.1 |
| | Sand, brown | 2.8 | 6.9 |
| | Sand, brown, gravel | 9.1 | 16 |
| 122[c] | Mud, meadow bog | 3.1 | 3.1 |
| | Sand, brown, gravel | 12.9 | 16 |
| 123[c] | Topsoil | 1.5 | 1.5 |
| | Sand, brown, fine | 6.8 | 8.3 |
| | Sand, brown, gravel | 10.7 | 19 |
| 124[d] | Sand, brown, medium-grained, and small gravel | 12 | 12 |
| | Sand, white and light-tan, fine- to medium-grained, micaceous | 29 | 41 |
| | Sand, light-tan, medium-grained | 18.5 | 59.5 |
| | Clay, gray, dry, compact | 2.5 | 62 |
| 125[d] | Sand, brown, medium-grained | 8 | 8 |
| | Sand, medium- to coarse-grained, and small gravel | 10 | 18 |
| | Sand, white and brown, coarse | 23 | 41 |
| | Sand, white, fine- to coarse-grained | 12 | 53 |
| | Sand, slightly clayey, medium-grained | 4.6 | 57.6 |
| 126[d] | Sand, rusty-brown, fine- to medium-grained | 2.5 | 2.5 |
| | Sand, brown, clayey, fine- to coarse-grained, and gravel | 12.5 | 15 |
| | Sand, light-gray, fine- to medium-grained | 31 | 46 |
| | Sand, white, very fine-grained, clayey, highly sericitic, and compact gray clay | 13.5 | 59.5 |
| 127[d] | Sand, brown, clayey, medium- to coarse-grained, and gravel | 18 | 18 |
| | Sand, tan, fine- to medium-grained | 13 | 31 |
| | Clay, light-yellow, compact | 13 | 44 |
| | Clay, gray, sericitic | 5.5 | 49.5 |
| | Consolidated limy ledge or stratum containing iron carbonate and a little lignite | 5 | 54.5 |
| | Sand, light-gray, clayey, lignitic and micaceous | 6.8 | 61.3 |
| 128[d] | Sand, light-brown and gray, fine- to medium-grained, and some iron-stained pebbles | 5 | 5 |
| | Mud, gray, soft, containing plant roots | 13 | 18 |
| | Sand, mixed with gray clay, and gravel | 9 | 27 |
| | Sand, gray, clayey, very micaceous, a few thin clay laminae, some coarse sand, and 1 quartz pebble | 11 | 38 |
| | Clay, gray, micaceous, sandy | 7 | 45 |
| | Clay, dark-gray, micaceous, containing ferruginous limestone concretions | 15 | 60 |

| Boring No. | Description | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| 129[d] | Sand, fine- to medium-grained, clayey | 6 | 6 |
| | Clay, brownish-gray, soft, some plant roots | 11 | 17 |
| | Sand, gray, clayey, fine- to medium-grained, some coarse grains | 11.6 | 28.6 |
| | Clay, gray, sandy, compact, sericitic | 6.1 | 34.7 |
| | Clay, gray, sandy, lignitic, containing concretions of sand, clay, pyrite and lime | 12.9 | 47.6 |
| | Clay, gray, sandy, lignitic, and fine-grained sericitic sand | 10 | 57.6 |
| 130[d] | Clay, brown, and plant roots | 2 | 2 |
| | Clay, dark-gray, peaty | 7 | 9 |
| | Sand, gray, clayey, fine-grained | 6 | 15 |
| | Clay, gray, sericitic and sandy | 10 | 25 |
| | Clay, gray | 11 | 36 |
| | Clay, gray, sandy, lignitic, containing limestone concretions | 14 | 50 |
| | Clay, olive-gray | 2 | 52 |
| | Clay, gray, with sandy micaceous streaks | 4 | 56 |
| 131[e] | Topsoil, sandy | 5 | 5 |
| | Gravel, coarse, sand, and some fine sand | 19 | 24 |
| | Sand streaks, gray, boulders, clay | 9 | 33 |
| | Clay, blue | 2 | 35 |
| | Sand and streaks of blue clay | 11 | 46 |
| | Sand, gray, coarse | 22 | 68 |
| | Clay, white, tough | 12 | 80 |
| 132 | Water | .5 | .5 |
| | Sand, coarse, and gravel | 1.5 | 2 |

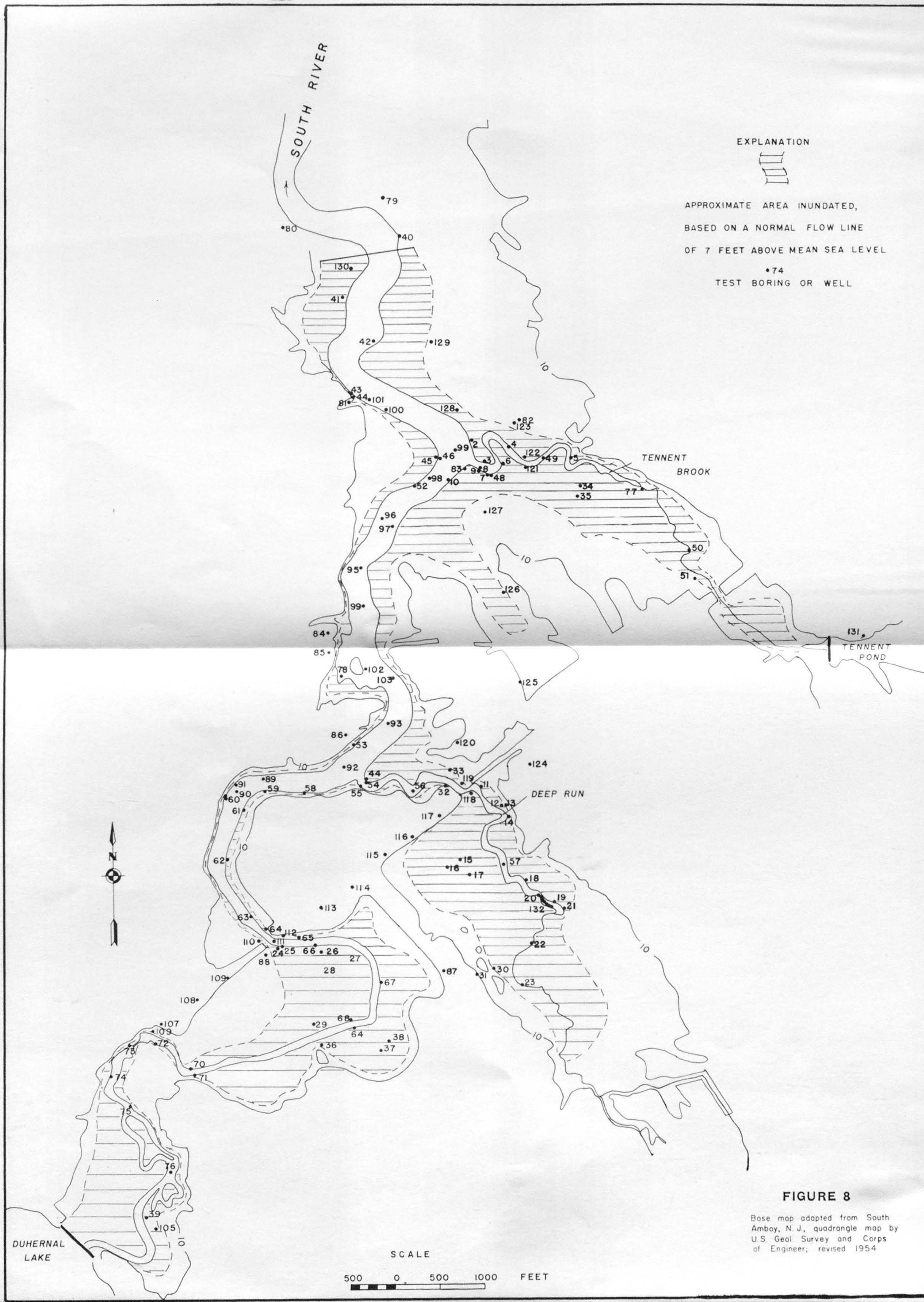


**FIGURE 8**

Base map adapted from South Amboy, N.J., quadrangle map by U.S. Geol. Survey and Corps of Engineer; revised 1954

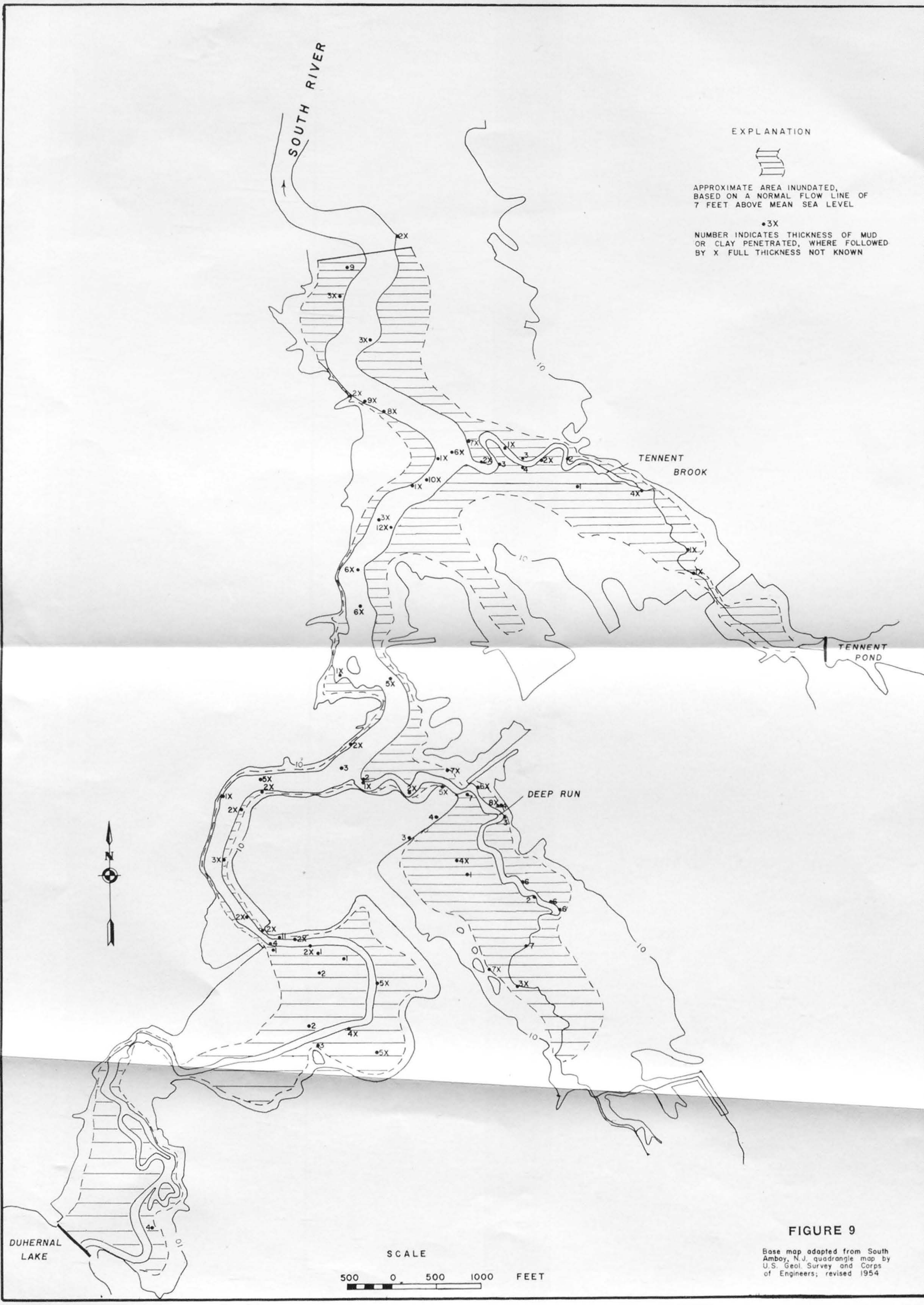


FIGURE 9

Base map adapted from South Amboy, N.J. quadrangle map by U.S. Geol. Survey and Corps of Engineers; revised 1954