LONG ISLAND WATER RESOURCES DATA NO. 2

Groundwater (L.I.)

Population (LILCO-69)

Hydrology (L.I.)

Storm Water (USGS - '62)

WS-Nassau (G&H-63)

WS-Suffolk (Wiggin - '57)

Journal of the
HYDRAULICS DIVISION
Proceedings of the American Society of Civil Engineers

FRESH AND SALTY GROUND WATER IN LONG ISLAND, N. Y.

By Norbert J. Lusczynski,[1] M. ASCE, and Wolfgang V. Swarzenski[2]

SYNOPSIS

Test drilling in 1959 and 1960 at Atlantic Beach and Lido Beach provided the principal basis for the definition of the distribution and movement of fresh and salty ground water in sand, silt, and clay deposits beneath the barrier beaches of southwestern Long Island, N. Y. Basic concepts and techniques for the study of salt-water intrusion were developed during the investigation.

Multiple-observation wells were constructed for monitoring the intrusion of salty water. The lower part of the deep salty water body has nearly penetrated the entire thickness of clay deposits between Rockaway Park and Lido Beach; it is moving, though very slowly, toward the underlying fresh-water aquifer tapped by public-supply wells.

INTRODUCTION

The geologic environment and the approximate position of fresh-water and salt-water bodies beneath the barrier beach in southeastern Queens and south-

Note.—Discussion open until December 1, 1962. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. HY 4, July, 1962.

1 Hydr. Engr., Ground-Water Branch, U. S. Geol. Survey, Mineola, L. I., N. Y.
2 Geologist, Ground-Water Branch, U. S. Geol. Survey, Mineola, L. I., N. Y.

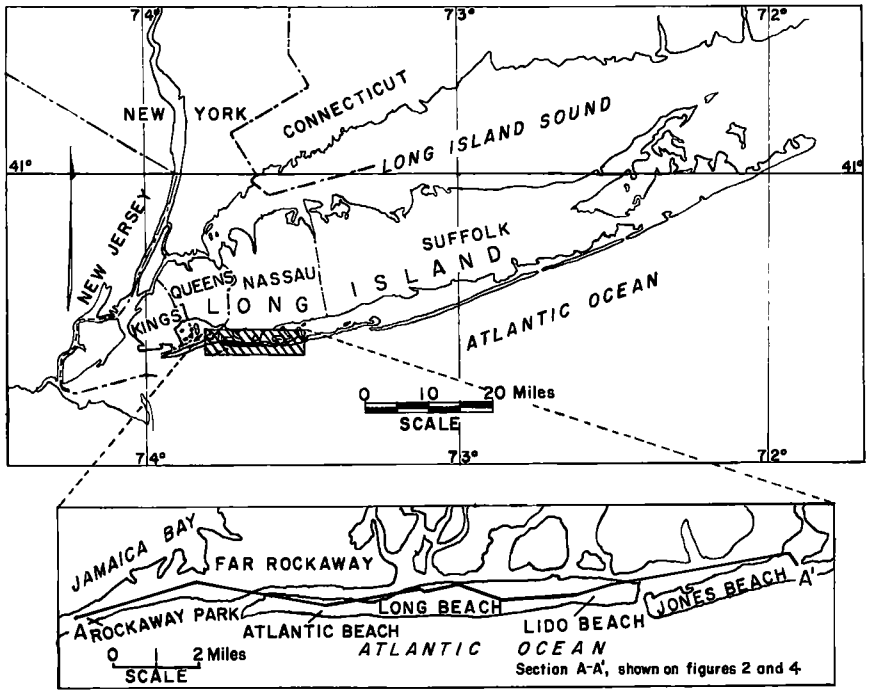


FIG. 1.—AREA OF INVESTIGATION

ern Nassau Counties were defined[3] by N. M. Perlmutter, J. J. Geraghty, and J. E. Upson on the basis of information available through 1956. In 1958, a more detailed investigation of salt-water encroachment in southern Nassau County, which included test drilling, was undertaken by the Geological Survey, United States Department of the Interior (USGS), in cooperation with the Nassau County Department of Public Works and the New York State Water Resources Commission. The principal purposes of the investigation were to determine the geologic environment and chloride concentrations of the fresh and salty ground water, and to determine the hydraulic relationships in and between continuous fresh water and salty water bodies. A report by the writers concerning the results of the test drilling in the Cedarhurst-Woodmere area has been published.[4]

The present paper is concerned with the results obtained along the barrier-beach area between Rockaway Park and Jones Beach in southwestern Long Island (Fig. 1). These are based on (1) information collected during the test drilling and electric logging of test wells at Atlantic Beach and Lido Beach,

3 "The relation between Fresh and Salty Ground Water in Southern Nassau and Southeastern Queens Counties, Long Island, N. Y." by N. M. Perlmutter, J. J. Geraghty and J. E. Upson, Economic Geology, Vol. 54, No. 3, 1959, pp. 416-435.

4 "Position of the Salt-Water Body in the Magothy (?) Formation in the Cedarhurst-Woodmere area of southwestern Nassau County, Long Island N. Y.," by N. J. Lusczynski and W. V. Swarzenski; Economic Geology, Vol. 55, No. 8, 1960, pp. 1739-1750.

ACKNOWLEDGEMENTS

The writers appreciate the support and cooperation of W. F. Welsch, former Senior Engineer, and H. L. Frauenthal, Assistant Hydraulic Engineer, Nassau County Department of Public Works, and A. H. Johnson, Associate Engineer, New York State Water Resources Commission. The Long Island Water Corportation and the Town of Hemstead permitted use of their properties for the drilling and maintenance of the multiple observation and sampling wells at Atlantic Beach and Lido Beach.

Publication of this paper was authorized by the Director, USGS in November, 1961.

and (2) water levels, chloride concentrations, and other miscellaneous information collected at existing wells between Rockaway Park and Jones Beach, in southwestern Long Island.

Fresh ground water in southern Nassau County under natural conditions has a chloride concentration of less than 20 ppm (parts per million); a chloride concentration in excess of 40 ppm indicates the mixing of fresh water with sea water. Therefore, fresh water is considered herein to be water that has a chloride content of less than 40 ppm whereas salty water has a chloride content of 40 ppm or more.

The 1929 mean sea level at Sandy Hook, N. J., is the datum to which all altitudes and depths are referred herein. Measurements below mean sea level are shown by a minus sign. The land surface in the area of investigation is less than 15 ft above mean sea level and the altitude of the water table ranges from mean sea level to approximately 3 ft above.

DRILLING PROJECTS IN 1959 AND 1960

Exploratory test holes were drilled by the standard rotary method during the summer of 1959 at Atlantic Beach and during the spring of 1960 at Lido Beach. On completion of the exploratory work, multiple observation wells (Table 1) were installed at each site.

At Atlantic Beach, an 8-in. test hole was drilled approximately 160 ft north of supply well N4405. Cores, 2 in. in diameter and as much as 18 in. long, were taken during the drilling, generally at intervals of 5 ft to 20 ft. The cored intervals totaled approximately 100 ft. When the final depth of 857 ft was reached, single-point electric logs were made. Subsequently, the hole was reamed to a size that was large enough to accommodate three individual casings for wells N6701, N6702, and N6703. Where casings of two sizes were used for a well (Table 1), they were connected by a reducer at approximately 40 ft below land surface. The uncased portion of the hole and most of the annular space were filled with material corresponding to or less permeable than that occurring naturally at the various depths. Gravel was placed in the annular space around each screen, extending 5 ft to 20 ft above and below the screen. Two casings for N6704 and N6705 were installed in a second hole drilled approximately 8 ft from the first hole. Also, two other wells (N6723 and N6724) were driven to shallow depths at sites nearly 40 ft from the first hole. These wells together with public-supply well N4405 compose a suite of eight individual wells, screened in different depth intervals at the Atlantic Beach test site (Table 1).

At Lido Beach, an 8-in test hole was drilled approximately 180 ft northeast of supply well N5227. Cores, 2 in. in diameter and as much as 18 in. long, were taken during the drilling, generally at intervals of 5 ft to 20 ft. The cored intervals totaled nearly 130 ft. When the final depth of 1,051 ft was reached, electric logs and gamma-ray logs were made. Subsequently, the hole was reamed to a size that was large enough to accommodate three individual casings for wells N6850, N6851, and N6852. The uncased portion of the test hole and most of the annular space were filled with clay, silt, sand, and fine gravel. Gravel was placed in the annular space around each screen, extending 5 ft above and below the screens. Also, approximately 20 ft of grout, consisting of a mixture of regular and special quick-setting cement and water,

TABLE 1.—OBSERVATION WELLS AT ATLANTIC BEACH AND LIDO BEACH, N. Y.

Well number (1)	Date completed (2)	Casing diameter, in inches[a] (3)	Screen settings in feet below sea level (4)	Screen diameter, in inches (5)	Geologic unit tapped by well[b] (6)
Atlantic Beach					
N 6724	August, 1959	4, $1\frac{1}{4}$	3.4, 5.4	$1\frac{1}{4}$	Re
N 6723	August, 1959	$1\frac{1}{4}$	51.8, 53.8	$1\frac{1}{4}$	uP
N 6705	August, 1959	4, $1\frac{1}{4}$	135.5, 145.5	$1\frac{1}{4}$	J
N 6704	August, 1959	4	273 , 283	4	M
N 6703	August, 1959	$1\frac{1}{4}$	457 , 467	$1\frac{1}{4}$	M
N 6702	August, 1959	4	656 , 666	4	M
N 6701	August, 1959	4, $1\frac{1}{4}$	811 , 821	$1\frac{1}{4}$	R
N 4405[c]	July, 1954	20, 8	995 , 1065	8	L
Lido Beach					
N 6920	May, 1960	4, 2, $1\frac{1}{4}$	33, 35	$1\frac{1}{4}$	Re
N 6853	May, 1960	6, 2	120, 125	4	M
N 6852	May, 1960	6, 2	251, 256	4	M
N 6851	May, 1960	4, 2	544, 549	4	M
N 6850	May, 1960	6, 2	891, 902	4	M
N 6849	May, 1960	6, 2	1020, 1030	4	R
N 5227[d]	June, 1956	12, 8	1190, 1250	8	L

[a] Casing of observation wells reduced from larger to smaller diameter at about 40 ft. from land surface.
[b] Re = Recent deposits; uP = upper Pleistocene deposits; J = Jameco gravel; M = Magothy (?) formation; R = clay member of Raritan formation; L = Lloyd sand member of Raritan formation.
[c] Supply well, Long Island Water Corp.
[d] Supply well, Point Lookout-Lido Beach Water Works, Town of Hemstead.

was placed above and below each gravel pack to prevent the movement of water along the annular space between the screens of the multiple wells. Two other wells (N6849 and N6853) were installed in a second hole drilled approximately 11 ft from the first hole. Also, well N6920 was driven to a shallow depth about 30 ft from the first hole. These wells and public-supply well N5227 make up a suite of seven individual observation wells, screened at different depths, at the Lido Beach test site (Table 1).

Each of the multiple wells at Atlantic Beach and Lido Beach was developed to yield from one gallon to several gallons per minute with 20 ft to 25 ft of drawdown, in order that water samples could be taken periodically. Also, each well was equipped with a continuous water-level recorder.

GEOLOGICAL ENVIRONMENT

The geology of southern Nassau and southeastern Queens Counties has been described[5] in detail by Perlmutter and J. J. Geraghty on the basis of informa-

[5] "Geology and Ground-Water Conditions in Southern Nassau and Southeastern Queens Counties, Long Island, N. Y., with special reference to sea-water encroachment," by N. M. Perlmutter and J. J. Geraghty, U. S. Geol. Survey Open-file report, Dept. of the Interior, Washington, D. C.

Neither the maximum nor the average rate of movement of salty water across the clay zone can be determined with accuracy, principally because of the uncertainty regarding the permeability and continuity of the lowermost solid clay zone in the clay member of the Raritan formation. However, any downward advance will be indicated in the future by the increase in the chloride content of the water in the observation wells screened near the bottom of the clay member at Atlantic Beach and Lido Beach. At present, there are no such monitoring wells in the clay member in the Long Beach area.

CONCLUSIONS

The position and chloride concentrations of the fresh water and salty water bodies between Rockaway Park and Jones Beach in southwestern Long Island, N. Y. have been described. Vertical components of the hydraulic gradients within and between fresh water and salty water bodies are defined.

Sizable reserves of fresh water are in the Lloyd sand member, especially in the eastern part of the project area where the aquifer is approximately 500 ft thick. In the overlying aquifers, significant quantities of fresh water are found only in the Magothy (?) formation, eastward from Lido Beach.

Salty water with chloride concentrations as high as from 10,000 ppm to 16,000 ppm was found in permeable [Magothy (?) formation, Jameco gravel, and upper Pleistocene] but also in the clay deposits (20-ft clay, Gardiners clay, and the clay member of the Raritan formation) underlying the barrier beaches in southwestern Long Island. The chloride content of the salty water in the clay member decreases with depth between Rockaway Park and Lido Beach. At Atlantic Beach, it decreases from approximately 16,000 ppm in the upper part to 110 ppm at the observation well screened in the lower part of the clay member. At Lido Beach, it decreases from as much as 173 ppm in the upper part to 62 ppm at the observation well screened in the lower part of the clay member.

Isochlors in the Atlantic Beach-Lido Beach area delineate large bodies of salty water with chloride concentrations of less than 10,000 ppm, the desalinization of which may be economically feasible in the future.

Under present conditions, salty water in the clay member is moving downward very slowly at and near the supply wells screened in the Lloyd sand member; the rate of movement cannot be determined accurately. However, at Atlantic Beach and Lido Beach, further downward advance of salty water will be revealed by the increase in chloride content at the observation wells screened near the bottom of the clay member.

In the Long Beach area, the chloride content of salty water in the basal Magothy (.) and in the clay member is not known precisely. The chloride content of water in the upper part of the Lloyd sand member of the Raritan formation is also uncertain. The chloride content of water in these formations should be determined near well N41 at the center of Long Beach through the use of multiple observation wells.

Rockaway Park and Long Beach, and an upward movement in the area between Lido Beach and Jones Beach. On this date, the gradient across the lowermost clay zone in the clay member was approximately 0.09 ft per ft downward at Atlantic Beach, 0.09 ft per ft upward at Lido Beach, and probably 0.2 ft per ft downward in the center of Long Beach. These are for approximately average conditions.

During the summer, withdrawals from the Lloyd sand member are increased by nearly 4×10^6 gal per day at Long Beach and by nearly 1×10^6 gal per day at Lido Beach. Withdrawals at Atlantic Beach, made only during the summer, are about 0.5×10^6 gal per day. This seasonal increase in withdrawals produces a general lowering of water levels, and thus a lowering of environmental heads in the Lloyd sand member along section A-A' (Fig. 4). Throughout the area, the water levels during the summer are lower than on October 28, 1960, by nearly 5 ft in the Atlantic Beach-Lido Beach area. This is suggested by the water-level record in 1953-1954 at well N40 near well N41 in Long Beach. Locally at each of the pumped wells, the water levels are lower than those of October 28, 1960, by approximately 10 ft at Atlantic Beach and Lido Beach, and by about 15 ft at Long Beach. This local lowering of water levels is estimated on the basis of pumping rates and preliminary values for the coefficients of transmissibility and of storage determined for the Lloyd sand member from an aquifer test at Lido Beach, in May, 1960. For the test, well N46 was pumped and the drawdown was observed in well N5227, located 410 ft from the pumped well.

Thus, during the summer, the gradients across the clay member are downward everywhere in section A-A', except in the Jones Beach area. Locally at the pumped wells, the gradient across the lowermost clay zone in the clay member may be at least 0.4 ft per ft at Atlantic Beach and 0.2 ft per ft at Lido Beach, and perhaps as much as 0.8 ft per ft at Long Beach.

Although no permeability tests have been made, the permeability of the lowermost clay in the clay member may be estimated to be between 0.01 gal per day per sq ft and 0.001 gal per day per sq ft. The basis for the estimate is the value of 0.007 gal per day per sq ft furnished by a private laboratory for the permeability, probably in a vertical direction, of a core sample in the 20-ft clay from a test boring immediately north of Long Beach in the central portion of section A-A'. The rate of downward movement of the salty water in the clay zone, computed by the Darcy formula[12] from an assumed permeability of 0.01 gal per day per sq ft, an assumed porosity of 1/3, and an estimated gradient of 0.8 ft per ft, is nearly 0.1 ft per month. This rate may apply to the immediate vicinity of supply wells in the center of Long Beach during the summer months. At Atlantic Beach and Lido Beach, the rate of downward movement may be nearly 0.05 and 0.03 ft per month, respectively. If the permeability of the clay zone is much less than 0.01 gal per day per sq ft, the downward movement will be correspondingly slower. However, in areas where the solid clay may be missing near the pumped wells or where it may be more permeable than 0.01 gal per day per sq ft, the rate of downward movement may exceed 0.1 ft per month.

12 "Methods for Determining Permeability of Water-Bearing Materials, with Special Reference to Discharging Well Methods, with a Section on Direct Laboratory Methods, and Bibliography on Permeability and Laminar Flow," by L. K. Wenzel and V. C. Fishel, U. S. Geol. Survey Water-Supply Paper 887, Dept. of the Interior, Washington, D. C., 1942, pp. 3, 71-72.

on available through 1956. The geologic formations occurring beneath the south-shore beaches of Long Island, including the present area of investigation, are examined in a report[6] by Perlmutter and H. C. Crandell. Therefore, only a resume of the geologic environment, incorporating the results of the test drilling at Atlantic Beach (1959) and Lido Beach (1960), is presented herein.

In the area of the barrier beaches (Fig. 1) from Rockaway Park to Jones Beach, crystalline bed rock occurs at depths ranging from 975 ft to approximately 1,650 ft below mean sea level. The "basement," which is composed of rocks that are believed to be of Precambrian (?) age, slopes to the southeast and is overlain by the following unconsolidated deposits in ascending order: The Lloyd sand member and the clay member of the Raritan formation of Late Cretaceous age; the Magothy (?) formation, also of Late Cretaceous age; the Jameco gravel and Gardiners clay of Pleistocene age; and upper Pleistocene and Recent deposits. The inferred distribution of these geologic units along the barrier beaches (section A-A; Fig. 1) is shown in Fig. 2. Information on the occurrence of the different units in most of the area is scanty, being restricted to a few drillers' logs. However, test holes at Atlantic Beach (N6701, 1959) and Lido Beach (N6850, 1960) show the lithology and the stratigraphy of the deposits down to and including the clay member of the Raritan formation at these sites. The areal extent and lithology of the unconsolidated deposits, which are approximately 1,000 ft to 1,650 ft thick, are important factors in the distribution of shallow and deep salty water bodies in the area.

The Lloyd sand member of the Raritan formation consists of fine to coarse quartzose sand and gravel, at many places in a clayey matrix, and some strata of sandy and solid clay. The Lloyd sand member, occurring directly above bedrock, is approximately 275 ft thick at the western end of section A-A' (Fig. 2). However, its thickness increases to about 400 ft to 450 ft in the Long Beach area and probably reaches approximately 500 ft near Jones Beach. Electric logs and drillers' logs indicate that, in general, the uppermost 100 ft to 150 ft of the Lloyd sand member consists of fine-textured material, whereas coarser and more porous deposits are found below. As shown in Fig. 2, the top of the Lloyd sand member occurs at a depth of 700 ft below sea level in Rockaway Park, sloping to nearly 1,175 ft near Jones Beach. Being confined above by the clay member of the Raritan formation, the Lloyd sand member is a true artesian aquifer. Because the overlying beds principally contain salty water, it is the only source of large quantities of fresh water in the western and central parts of the barrier-beach area.

Beneath the barrier beaches (Fig. 2), the clay member of the Raritan formation ranges in thickness from 130 ft to 180 ft, and consists of clay, sandy clay, silt, and sand; disseminated lignite, pyrite, and iron-oxide concretions are common throughout. The cores of test wells at Atlantic Beach and Lido Beach and also in the Woodmere area[4] have shown the clay member, in general, to consist of thin, probably lenticular, beds of clay at the top, underlain by 50 ft to 100 ft of silt and very fine to fine clayey micaceous sand. The latter is, in all respects, similar to the finer portions of the Magothy (?) formation and is estimated to be at least one hundred times, and perhaps several hundred times, more permeable than the clays. A bed of clay at the base

6 "Geology and Ground Water Supplies of the South Shore Beaches of Long Island, N. Y." by N. M. Perlmutter and H. C. Crandell, N. Y. Academy of Science Annals, Vol. 80, 1959, pp. 1060-1076.

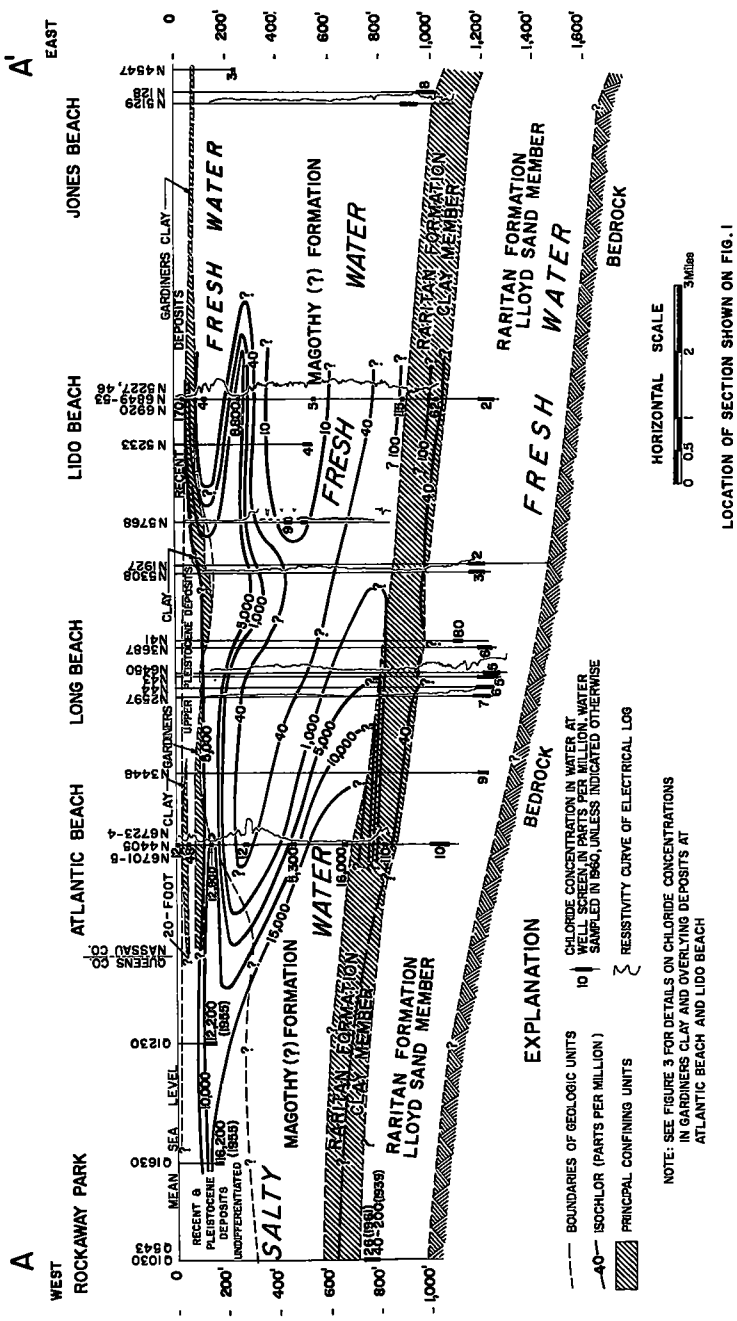


FIG. 2.—GEOLOGIC SECTION AND APPROXIMATE GROUND-WATER ISOCHLORS

immediately above and below the Gardiners clay varied from approximately 0.01 ft per ft upward to about 0.01 ft per ft downward, with the downward trend predominating.

The environmental head at the well screened in the Lloyd sand member at Lido Beach was nearly 4.2 ft higher than that at the bottom of the Magothy (?) formation on October 28, 1960. Most of this difference occurred within the 154-ft thickness of the clay member, and about 2.7 ft in the 30-ft clay zone at the bottom of the clay member. Therefore, the upward gradient averaged approximately 0.03 ft per ft across the clay member and about 0.09 ft per ft across the clay zone.

Environmental heads in the Long Beach area at wells N3448, N44, and N5308 in the Lloyd sand member were computed from fresh-water heads observed on October 28, 1960. On this date only wells N43, N2597, and N6450 were pumped in the Long Beach area. The rate of withdrawal totaled approximately 3×10^6 gal per day. The average density of the salty water along the vertical at each of these well sites was estimated from the isochlors in Fig. 2. Environmental heads at the bottom of the Magothy (?) formation at the sites of these wells were interpolated from heads at Atlantic Beach and Lido Beach. The differences in environmental head above and below the clay member indicate downward gradients of approximately 0.02 ft per ft at the site of well N3448 and about 0.04 ft per ft at the site of well N44. At well N5308 in eastern Long Beach, the gradient was practically zero. Based on indications at Atlantic Beach, the gradient across the lowermost clay zone may be several times that across the entire clay member in central Long Beach; it may be as much as 0.2 ft per ft at well N44 and at other pumped wells in central Long Beach.

An environmental head of 15 ft in the Lloyd sand member at Jones Beach is estimated from the piezometric-surface contour map[11] of the Lloyd sand member in western Long Island. The environmental head at the bottom of the Magothy (?) formation at well N128 was 8.1 ft on October 28, 1960; thus, an upward gradient across the clay member at the site of well N128 is indicated. The upward gradient continues from the bottom to the top of the Magothy (?) formation, as is evidenced by the head decrease of 1.1 ft in approximately 750 ft between wells N128 and N4547.

The environmental head in the Lloyd sand member at well Q543 in Rockaway Park is from -2 ft to -3 ft. This is determined by Eq. 2 from the water level observed in October, 1960, assuming that the average density of the salty water in the Magothy (?) formation and overlying deposits is approximately 1.020 gm per ml (equivalent to 15,000 ppm chloride). The environmental head in the basal Magothy (?) at Rockaway Park at well Q543 is estimated to be between sea level and 2 ft above, from water levels observed in 1955, at wells Q1230 and Q1630 to the east (Fig. 4). On this basis, the gradient across the clay member is downward at Rockaway Park.

MOVEMENT OF SALTY WATER IN THE CLAY MEMBER OF THE RARITAN FORMATION

As shown previously, the vertical gradients across the clay member on October 28, 1960, indicate a downward movement of water in the area between

11 "Ground Water from Lloyd Sand Member of the Raritan Formation in Long Island, N. Y.," by N. J. Lusczynski and C. M. Roberts, U. S. Geol. Survey open-file Report, Dept. of the Interior, Washington, D. C., 1952.

of the Raritan formation in the Atlantic Beach-Lido area, and the vertical gradients in fresh water and salty water bodies in the deposits overlying the clay member in Section A-A'. For the sake of brevity and convenience, the vertical component of the hydraulic gradient will be referred to as vertical gradient, or simply gradient.

It has been shown[9] that the hydraulic gradient between two points along a vertical in ground water of variable density is the difference in environmental heads at the points, divided by the distance between them.

Environmental heads in the Rockaway Park-Jones Beach area are shown in Fig. 4 for October 28, 1960. They were computed by Eqs. 1 and 2 from the average of high and low water levels observed on that date; water levels in the project are affected by oceanic tides.

The densities used in the equations are those for the prevailing ground-water temperatures. They were based on determinations of the density of the fresh water and salty water by the USGS from water samples taken at the wells screened in fresh and salty water. The density of the salty water was also established in the field from the water levels in the well before and after the introduction of fresh water into a well screened in salty water. For the field tests, sufficient fresh water was poured into the well to displace the salty water down to the bottom of the well. The average density of the water between sea level and the point in question was computed from the average chloride content of the water as determined from the chloride-distribution curves (Fig. 3) on the basis of the known relation between chloride content and total solids of salty water in Atlantic Beach and Lido Beach.

According to water-level data collected principally in 1959 and 1960, the environmental heads shown in Fig. 4 for October 28, 1960, are within a foot of the yearly average environmental head at each point of observation. The computed environmental heads at the multiple wells at Atlantic Beach indicate upward gradients above -280 ft in the upper part of the Magothy (?) formation (Fig. 4). Specifically, an upward gradient is indicated across the shallow salty-water body and also across the intermediate salty-water body is indicated (Figs. 3 and 4). Below -280 ft, the gradients are downward; they persist from this depth throughout the entire thickness of the deep salty-water body in the Magothy (?) formation and Raritan clay into the fresh-water body in the Lloyd sand member. The decrease in environmental head between the bottom of the Magothy (?) formation and the screen zone in the Lloyd sand member is 4.1 ft. Most of this difference is in the 178 ft of the clay member, and about 2.6 ft is in the 29-ft clay zone at the bottom of the clay member. Thus the average downward component of the gradient is approximately 0.02 ft per ft across the entire clay member, and about 0.09 ft per ft across the lowermost clay zone in the clay member.

The environmental heads for October 28, 1960, at the multiple wells at Lido Beach, indicate upward gradients from the Lloyd sand member of the Gardiners clay across the deep and intermediate salty-water bodies. The gradient across the portion of the deep salty-water body in the Magothy (?) formation is practically zero. The gradient across the principal part of the shallow salty-water body in the Gardiners clay at Lido Beach (Fig. 3) could not be computed as water levels were not observed on October 28, 1960, at the shallowest well. However, from June to August, 1960, the gradients between the wells screened

of the member is found in nearly all wells along the section from Rockaway Park to Lido Beach. This clay stratum, 20 ft to 40 ft thick, appears to have greater lateral continuity than the overlying deposits and may constitute the chief aquiclude between the Lloyd sand member and the deposits above.

At Atlantic Beach, the cores of well N6701 and the electric logs of wells N6701 and N4404 have shown the absence of extensive clay zones within the clay member, except for 29 ft of clay at the base. Salty water, containing 16,000 ppm of chlorides, occurs in the upper part of the clay member at the site of these wells. The distribution of chloride at Atlantic Beach is examined subsequently and is shown in Fig. 3. The clay member appears to be relatively permeable from Atlantic Beach eastward as far as well N3448 (Long Beach). Farther east, at Long Beach and Lido Beach, available data indicate the presence of fairly thick strata of solid clay within the clay member.

The Magothy (?) formation, which overlies the Raritan formation, contains as much as 1,000 ft of unconsolidated clay, silt, sand, and gravel of terrestrial origin. The top of the formation is as high as -80 ft at Jones Beach, Lido Beach, and Long Beach. Toward the west, the top of the Magothy (?) is found at -149 ft in Atlantic Beach and at -304 ft in Rockaway Park (Fig. 2). The Magothy (?) surface was undoubtedly greatly dissected by erosion in Pleistocene, and perhaps Tertiary time, particularly in the Rockaway Park area and to the north and east.

Within the project area, the bulk of the Magothy (?) formation consists of clayey and silty very fine to medium gray sand, and thin clay layers. Lignite and pyrite zones are common throughout the formation. Coarse sand and gravel occur in the lower half of the Magothy (?) deposits at Atlantic Beach (Fig. 3), whereas at Lido Beach, more permeable zones are found in the upper part of the formation and also from -685 ft to -827 ft, terminating 81 ft above the bottom of the formation. As in the other parts of Nassau County, individual strata of the Magothy (?) formation appear to be mostly lenticular and of limited lateral extent. A comparison of the logs of N6850 and N6701 indicates that the Magothy (?) at Lido Beach is generally less permeable and contains a larger quantity of silt and clayey very fine sand than the Magothy (?) at Atlantic Beach. At Rockaway Park, and particularly in the Long Beach and Lido Beach areas, the lowermost 100 ft of the Magothy (?) formation contains material of low permeability; it includes strata of red and white clay and white clayey silt, exemplified by log N6850. This material, also recognized in drillers' logs in the Long Beach area, forms a distinct unit in the basal Magothy (?) that may be as impermeable as the clay member of the Raritan formation. Thus, in some places, the effective thickness of the impermeable beds lying between the Lloyd sand member and the Magothy (?) formation may be increased 50% and more.

The deposits of Recent and Pleistocene age range in thickness from 20 ft or 30 ft to about 300 ft. Whereas the Recent deposits consisting of dune and beach sand, muck, silt, sand, and gravel, are found everywhere in the area, the deposits of Pleistocene age occur discontinuously, and their distribution is known only imperfectly. An early Pleistocene outwash deposit, the Jameco gravel, consists of coarse sand and gravel of heterogeneous composition, in places interbedded with fine sand and lignite, probably reworked from Cretaceous deposits. At Atlantic Beach, the Jameco gravel occurs between -113 ft and -149 ft. The formation probably extends west of Atlantic Beach, although it cannot be distinguished from overlying younger outwash deposits, on the

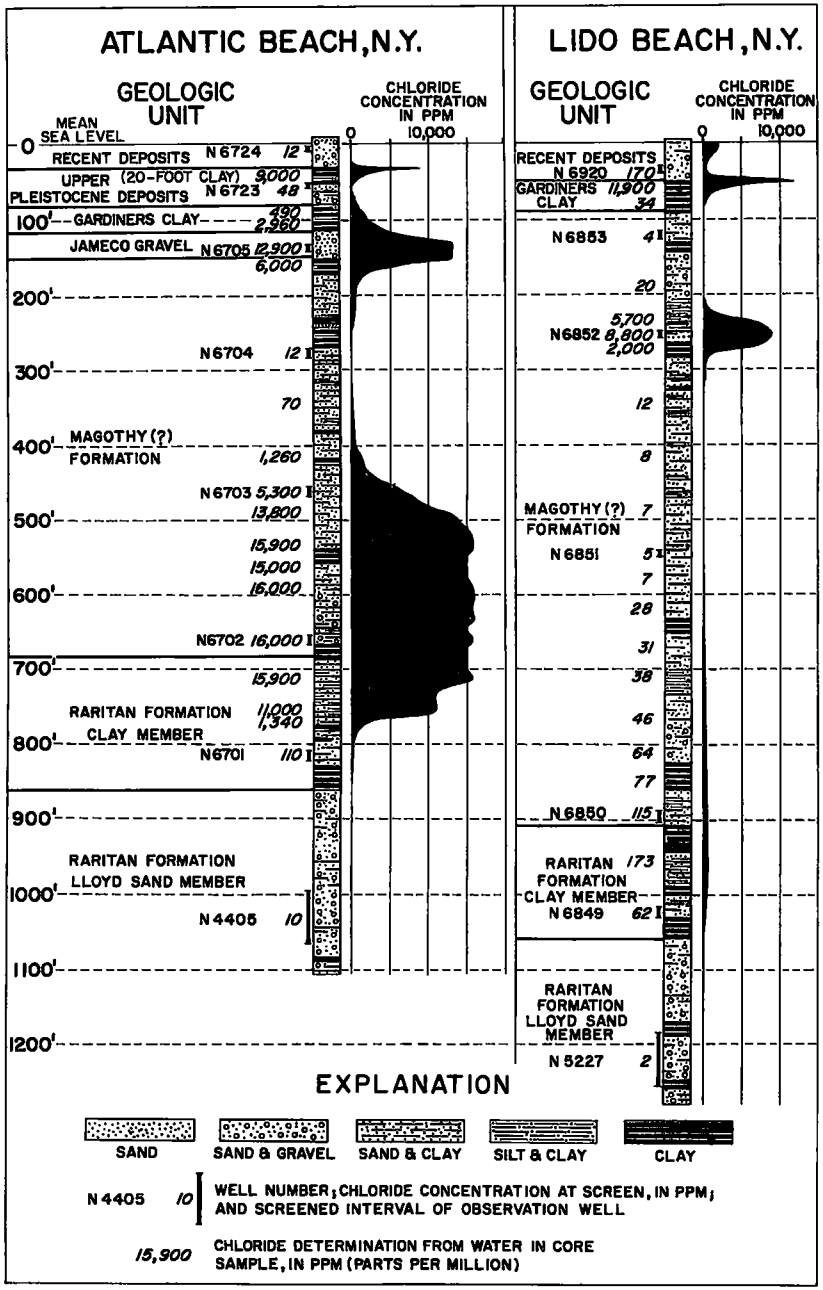


FIG. 3.—COLUMN PLOTS AND DISTRIBUTION OF CHLORIDE CONTENT IN GROUND WATER

consisting of environmental water from the point to the top of the zone of saturation and of an increment of fresh water (if needed) above or below the top of the zone of saturation, that balances the existing pressure at the point. If the hydrostatic pressure of the environmental water is less than the existing pressure at the point, environmental-water head is the elevation of the top of the increment of fresh water above the zone of saturation that compensates for the deficiency in pressure [Fig. 5(c)]. In this first case, the hydrostatic pressure of the increment of fresh water balances the existing pressure. If, on the otherhand, the hydrostatic pressure of the environmental water exceeds the existing pressure at the point, the environmental-water head is the elevation of the base of the increment of fresh water below the zone of saturation that compensates for the excess in pressure. In this second case, the hydrostatic pressure of environmental water minus the pressure of the increment of fresh water balances the existing pressure.

Environmental-water head must be computed, because it cannot be determined in the field. For fresh water above sea level, as well as any combination of fresh water, diffused water, and salty water zones below sea level, environmental-water head can be computed[9] from a freshwater or a point water head by use of the following equations:

$$\rho_f H_{in} = \rho_f H_{if} - Z_i (\rho_f - \rho_a) \quad \ldots\ldots\ldots \quad (1)$$

and

$$\rho_f H_{in} = \rho_f H_{ip} - Z_i (\rho_i - \rho_a) \quad \ldots\ldots\ldots\ldots \quad (2)$$

in which i is a point below sea level in ground water of variable density, ρ_f represents the density of fresh water, ρ_i is the density of water at i, ρ_a denotes the average density of water between sea level and i, H_{in} is the environmental-water head at i, H_{if} equals the fresh-water head at i, H_{ip} is the point-water head at i, and Z_i represents the depth of i (center of screen zone at well).

VERTICAL COMPONENTS OF THE HYDRAULIC GRADIENTS IN THE ROCKAWAY PARK-JONES BEACH AREA

The direction of the lateral component of movement of fresh and salty water between Atlantic Beach and Lido Beach (Fig. 4) is as follows: (1) Fresh water in the Lloyd sand member, toward the public-supply wells; (2) deep salty water in the lower Magothy (?) formation, eastward at Atlantic Beach and northeastward at Long Beach and Lido Beach; (3) fresh water between the deep and intermediate salty water, generally southwestward at Lido Beach and northwestward at Long Beach and Atlantic Beach, and (4) intermediate salty water in the upper Magothy (?) formation, generally northward at Long Beach. Details on the lateral movement of fresh and salty water in southern Nassau County are available.[10] Of specific interest in this paper are the vertical gradients and rates of vertical movement of the salty water in the clay member

10 "Encroachment of sea water in southern Nassau County, L. I., N. Y.," by N. J. Lusczynski and W. V. Swarzenski, (unpublished).

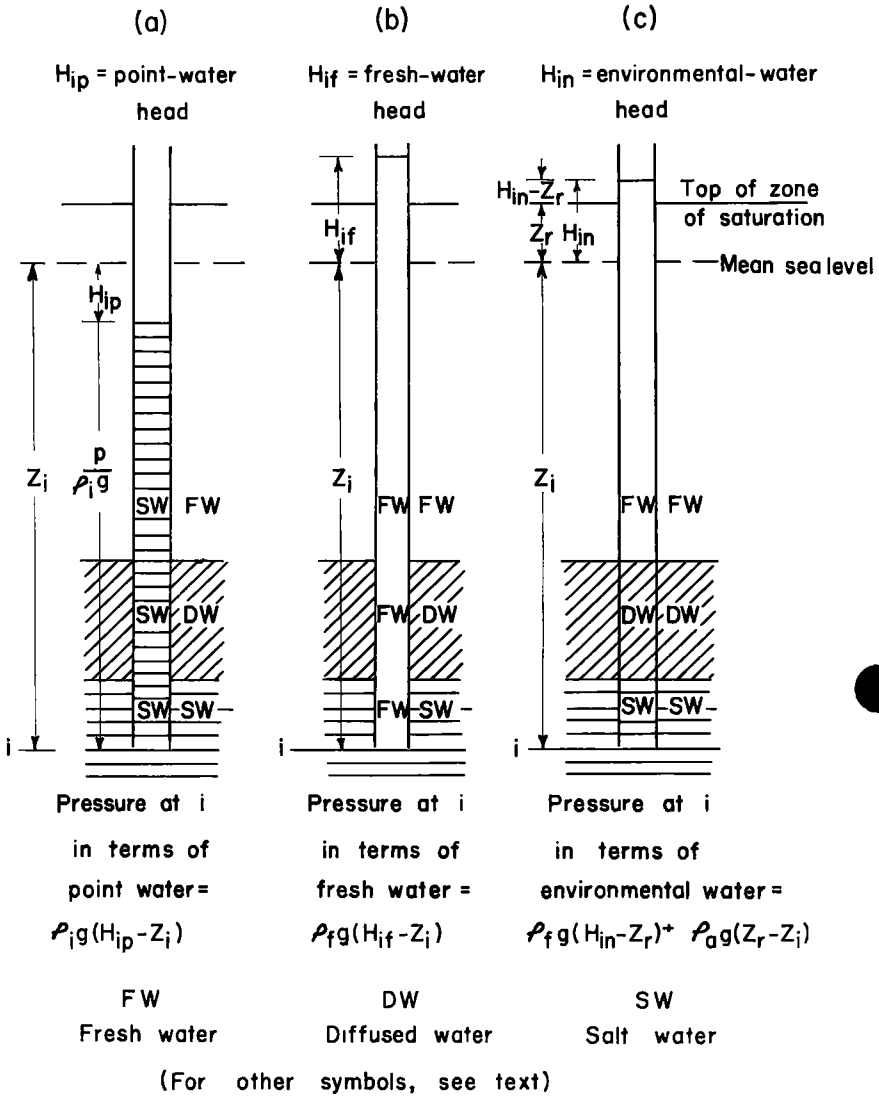


FIG. 5.—HEADS IN GROUND WATER OF VARIABLE DENSITY

basis of existing information. To the east, the Jameco gravel may be present in thin lenses in parts of Long Beach and Lido Beach, but it does not occur at well N6850 in Lido Beach and Jones Beach. The Jameco gravel is highly permeable and locally may be in direct contact with younger permeable deposits, as in the area between Atlantic Beach and Rockaway Park. Here the absence of continuous clay zones within the undifferentiated Pleistocene deposits facilitates the movement of salty water into the underlying deposits and into the Jameco gravel.

The Gardiners clay, a marine deposit of interglacial origin, overlies the Jameco gravel or the Magothy (?) formation. In the project area it is commonly less than 50 ft thick, the top of the formation occurring at -77 ft and -46 ft at Atlantic Beach and Lido Beach, respectively. At both localities, the formation consists of rather impermeable clay and silty clay. To the west of Atlantic Beach, the Gardiners clay is not recognized with certainty; available data suggest that the formation, if present, is generally sandier and more permeable than elsewhere in the area. In the central and eastern part of the project area, the Gardiners clay is believed to be present everywhere; locally it may be very thin or absent where the Cretaceous surface is high, as in the Long Beach area. Where only a few feet of Gardiners clay lie directly on the Magothy (?), identification of the formation from drillers' reports is difficult. The Gardiners clay and contiguous clays of the Magothy (?) formation appear to form a confining layer eastward from Atlantic Beach (Fig. 2).

The upper Pleistocene deposits in much of the project area consist of approximately 50 ft of stratified sand and gravel, occurring above the Gardiners clay. In the Atlantic Beach area, the upper Pleistocene deposits include the 20-ft clay, a marine deposit of greenish-gray silt and clay. The 20-ft clay was recognized only in the Atlantic Beach area and is apparently absent east of well N3448, along section A-A' (Fig 2) Wherever it is present and sufficiently impermeable it may retard the movement of brackish water from the shallower Pleistocene and Recent deposits into the strata below.

The great thickness of undifferentiated Pleistocene deposits west of Atlantic Beach, also shown in Fig. 2, may locally include the 20-ft clay and the Gardiners clay. However, it seems likely that much of the undifferentiated material which includes glauconitic sands, is derived from the erosion of the Gardiners clay, and, thus, may be part of the upper Pleistocene deposits.

CHLORIDE CONCENTRATIONS AT ATLANTIC BEACH AND LIDO BEACH

During the drilling of test wells at Atlantic Beach and Lido Beach, the vertical distribution of chloride content in the ground water was determined accurately at both sites. This information served to delineate bodies of fresh and salty ground water within the unconsolidated deposits; it served further to establish the average density of ground water between sea level and the screen of each well and thus permitted the calculation of vertical components of the hydraulic gradients in fresh water and salty water bodies.

Chloride determinations were made of water contained in core samples. The cores were taken with a split-spoon core barrel 2 in. in diameter and 18 in. to 24 in. long. The addition of fluorescein dye to the drilling fluid permitted the visual detection of samples that had been invaded by drilling mud. In general, the core samples taken in silt and fine clayey sand yielded enough

uncontaminated water for chloride analysis. Water was extracted from nearly all samples by means of a filter press. The application of this method, which yields reliable results if the proper precautions are taken, is described elsewhere.[7] The water content of small samples or highly compacted clay samples not suitable for the filter-press method, was determined, respectively, by the centrifugal-extraction and dilution methods developed[8] by W. V. Swarzenski. Although the dilution method is considered only a semiquantitative tool, fairly accurate chloride determinations were made from interstitial water in highly compacted clays. Fresh water and salty water bodies at each test site and the relation between chloride distribution and geologic environment are illustrated in Fig. 3; this illustration also shows spot determinations of chloride concentration at various depths.

At Atlantic Beach (N6701, N4405, Fig. 3), fresh water occurs under water-table conditions in a thin lens above the 20-ft clay (the uppermost Pleistocene clay). Fresh, or essentially fresh, water also occurs under artesian conditions in two thin zones, or (1) between the 20-ft clay and Gardiners clay and (2) within the upper part of the Magothy (?) formation. Fresh water is found also under artesian conditions in the Lloyd sand member of the Raritan formation, which is the only source of large supplies of fresh water at Atlantic Beach.

Three distinct salt-water bodies, intercalated with fresh water, are recognized in the Atlantic Beach area. The shallow salt-water body extends from approximately 20 ft above to nearly 5 ft below the 20-ft clay. The maximum chloride concentration of 9,000 ppm in this body occurs within the upper 5 ft of this clay unit in salty-clay material. The distribution of chloride within the 20-ft clay and occurrence of confined fresh water below the clay suggest that the salt water in this marine clay was being replaced by fresh water. Whether this is actually the case under present conditions will be determined when the predominant hydraulic gradient across the 20-ft clay is established. Limited information presently (1961) available indicates reversals in direction, with no predominant trend. An intermediate salt-water body, having a maximum chloride concentration of 12,900 ppm, occurs in the Jameco gravel. However, salty water, containing several thousand parts per million of chloride, extends upward into the Gardiners clay and downward into the clays of the Magothy (?) formation. The deep salt-water body at Atlantic Beach extends from -300 ft to -850 ft throughout most of the Magothy (?) and the clay member of the Raritan formation. The upper part of the deep salt-water body is characterized by a very thick zone of diffusion in which the chloride concentration increases from 40 ppm to nearly 500 ppm in the first 100 ft, and from 500 ppm to 15,000 ppm in the next 100 ft. A maximum chloride concentration of approximately 16,000 ppm occurs near the bottom of the Magothy (?) formation and also in the upper part of the clay member of the Raritan formation. As has been noted previously, these formations appear to be relatively more permeable at Atlantic Beach than elsewhere. A chloride concentration of about 110 ppm was found at the base of a sandy zone of the clay

[7] "Filter-press Method for Extracting Water Samples for Chloride Analysis," by N. J. Lusczynski, U. S. Geol. Survey Water-Supply Paper 1544-A, Dept. of the Interior, Washington, D. C., 1961.

[8] "Determination of Chloride in Water from Core Samples," by W. V. Swarzenski, American Association of Petroleum Geologists Bulletin, Vol. 43, No. 8, 1959, pp. 1995-1998.

more than 200 ft thick; it may be much less. At Atlantic Beach, near well N6701, the fresh-water body is only 65 ft thick. Fresh water is believed not to extend more than one-half mile west of well N6701. This fresh-water zone in the Magothy (?) is tapped by two commercial wells (N5768 and N5233 in Fig. 2) in the Lido Beach area. At these wells, chloride concentrations were less than 10 ppm in 1960. However, in 1959, chloride at well N5768 was as high as 16 ppm during periods of increased pumping. This suggests the presence of slightly brackish water close to the screen zones.

The second, and most important, fresh-water body of the project area is found in the Lloyd sand member of the Raritan formation. As shown in Fig. 2, chloride concentrations in water from that aquifer ranged from 2 ppm at Lido Beach to 10 ppm at Atlantic Beach, in 1960. In Rockaway Park, the chloride concentration of water from well Q1030 ranged from 40 ppm to 200 ppm in 1939, and other deep wells in the area showed increases of as much as several hundred parts per million during periods of pumping. Inasmuch as pumping from the Lloyd sand member ceased in the Rockaway Park area in 1940, water in the Lloyd sand member is believed to be nearly fresh at present (chloride content of water at well Q1030 was 26 ppm in March, 1961). The temporary increase in chloride content of water from the Lloyd sand member in Rockaway Park may have been caused by the downward movement of salty water from the overlying clay member, or to a lateral intrusion of salty water into the Lloyd sand member from seaward areas as a result of pumping prior to 1940.

ENVIRONMENTAL-WATER HEAD IN GROUND WATER OF VARIABLE DENSITY

The concept of environmental-water head was introduced during the investigation[9] for determining hydraulic gradients and velocity components along a vertical in ground water of variable density. All terms pertinent to this concept are explained as follows:

The head at a point in ground water of variable density varies with the datum and the kind of water used for measuring the head; in this paper, head and elevation are referred to mean sea level. Water at a point is called point water; point water may be fresh, diffused, or salt. Point-water head is defined as the elevation of column of point water balancing the existing pressure at the point [for example, head in well filled with point water, Fig. 5(a)]. Fresh-water head is defined as the elevation of a column of fresh water ballancing the existing pressure at the point [for example, head in well filled with fresh water, Fig. 5(b)].

Environmental water in a ground-water reservoir is defined[9] as water of variable or constant density between a point in question and the top of the zone of saturation. For example, environmental water at well N6704 at Atlantic Beach (Fig. 3) is the water with the chloride content and density, layer for layer, between the screen of well N6704 and the water table; environmental water at well N6702 is the water with the chloride content and density, layer for layer, between the screen of well N6702 and the water table.

Environmental-water head is defined as the elevation of a column of water,

[9] "Head and Flow of Ground Water of Variable Density," by N. J. Lusczynski, Journal of Geophysical Research, Vol. 66, No. 12, 1961, pp. 4247-4256.

within the clay member is a matter of conjecture. Available electric lc suggest that chloride concentrations are generally low, probably within the range from 100 ppm to 300 ppm, or even less, except at Atlantic Beach. As shown in Fig. 3, chloride concentrations of approximately 170 ppm within the clay member at Lido Beach are higher than those in the Magothy (?) directly above. Inasmuch as gradients in the underlying Lloyd sand member may be assumed to have been generally upward prior to pumping, at least east of Atlantic Beach, the clay member may contain wholly fresh water in local areas that are relatively more permeable than the unit as a whole.

Whereas fresh ground water in southern Nassau County generally contains less than 10 ppm of chloride, concentrations of 10 ppm to 170 ppm where noted at Lido Beach in a zone 450 ft thick (Figs. 2 and 3). The origin of the broad zone of diffusion in the lower part of the Magothy (?) and in the clay member is believed to be the result of the combination of several factors: (1) Opposing flow directions in adjacent bodies of fresh and salty ground water, (2) short-term variations and long-term variations of fresh-water outflow to the sea accompanying variations of gradients in fresh and salty ground water caused by oceanic tides and by changes in the ground-water recharge, (3) effects of movement of water in a heterogeneous geologic environment, and (4) molecular diffusion.

The deep salty-water body loses its identity in the area between Lido Beach and Jones Beach, where no chloride data are available. However, at Jones Beach, a fresh-water zone at least 300 ft thick exists in the basal Magothy (?) at wells N5129 and N128 (Fig. 2). In the same area, low resistivities shown by the electric log of well N5129 suggest a broad zone of diffusion, with chloride concentrations of less than 100 ppm, between -400 ft and -700 ft in the middle Magothy (?). However, no chloride analyses are available for these depths to confirm this suggestion. East of Lido Beach, the shallow deposits apparently contain fresh water, with the exception of the Recent deposits, and probably the Gardiners clay. Well N4547, at Jones Beach, is screened in fresh water at a depth of -230 ft.

The detailed information obtained at wells N6701 and N6850 (Fig. 3), show that fresh or nearly fresh water exists locally under artesian conditions within the upper prong, particularly below the 20-ft clay and the Gardiners clay. Inasmuch as the Pleistocene clays are not continuous in the project area and may be replaced locally by relatively permeable material, the distribution of fresh and salty water bodies at depths of less than -200 ft is highly irregular. The upper limit of salty water in the upper prong cannot be defined accurately by existing information, and no attempt was made to show isochlors in the uppermost 100 ft of the ground-water reservoir in Fig. 2. Lenses of unconfined fresh water are present in the uppermost deposits in Atlantic Beach and probably in parts of Long Beach. These lenses grade laterally into salty water near the shores of the barrier beaches; they are absent wherever the land area is of insufficient width and altitude to store fresh water that is derived from precipitation.

Two major fresh-water bodies of less than 40 ppm chloride occur within the project area. As shown in Fig. 4 and by the isochlors in Fig. 2, a wedge-shaped fresh-water body extends from the Jones Beach area, where most of the Magothy (?) is fresh, toward Atlantic Beach. This fresh-water body, lying between shallow and deep salty water in most of the area, is approximately 450 ft thick at Lido Beach. At Long Beach, it is estimated to be not

member. This zone is separated from fresh water in the Lloyd sand member below by 29 ft of clay of a low permeability (Fig. 3).

The chloride distribution at wells N6850 and N5227, at Lido Beach, is also shown in Fig. 3. Here, fresh water is found under artesian conditions in three separate zones, (1) in the uppermost Magothy (?) deposits, (2) in the middle part of the Magothy (?), and (3) in the Lloyd sand member of the Raritan formation. Because of the proximity of salty water to zone 1 and the relatively low permeability of deposits in zone 2, large-scale development of these fresh-water bodies appears unlikely. However, the Lloyd sand member is a source of large quantities of fresh water.

Three bodies of salty water were delineated at the test site in Lido Beach. Salty water of 160 ppm to 1,800 ppm of chloride occurs in the deposits of Recent age. This shallow salt water extends into the Gardiners clay. The maximum chloride concentration is 11,900 ppm, in the uppermost 5 ft of the Gardiners clay. The chloride-distribution curve suggests that salty water in the Gardiners clay was being displaced by fresh water moving upward from the Magothy (?) formation. Whether this is actually the case under present conditions will be determined when the predominant hydraulic gradient across the Gardiners clay is established. Limited information presently available indicates reversals in direction, with the downward trend predominating. The intermediate salt-water body, which has a maximum chloride concentration of approximately 8,800 ppm, occurs between -200 ft and -300 ft in the Magothy (?) formation. This salt water is in very fine clayey sand and solid clay, the more permeable strata of sand and gravel located above, and the fine to medium sand located below contain fresh water. A deep salt-water body is found in the lower part of the Magothy (?) throughout most of the clay member of the Raritan formation at Lido Beach. As shown in Figs. 2 and 3, chloride concentrations of 10 ppm to 40 ppm occur between -600 ft and -765 ft, marking a transition zone from the fresh water above (normally less than 10 ppm) to the saltier water below in the Magothy (?). However, chloride concentrations reach only about 115 ppm in the basal Magothy (?) and a maximum of from 150 ppm to 175 ppm in the clay member. A chloride concentration of 62 ppm was found in water from well N6849 that is screened in a sandy zone near the bottom of the clay member. This screen is separated from fresh water in the Lloyd sand member below by 30 ft of solid clay.

FRESH AND SALTY GROUND WATER IN THE ROCKAWAY PARK-JONES BEACH AREA

Fresh and salty ground-water bodies occurring along the barrier beaches from Rockaway Park to Jones Beach are shown in Figs. 2 and 4 in section A-A'. Information on chloride concentrations of water obtained during the test drilling at Atlantic Beach (N6701) and Lido Beach (N6805) defines the position of isochlor lines accurately at these sites. A detailed study of electric logs at these and other test sites, particularly regarding the relationship between apparent resistivities and samples of known lithology and salinity, was helpful in the interpretation of other electric logs. Thus, isochlors could be extended with a fair degree of confidence into areas where no chloride analyses were available, although their position is necessarily approximate. The isochlors are defined also by the chloride analyses of water from some public supply, industrial, and observation wells, as indicated in Fig. 2.

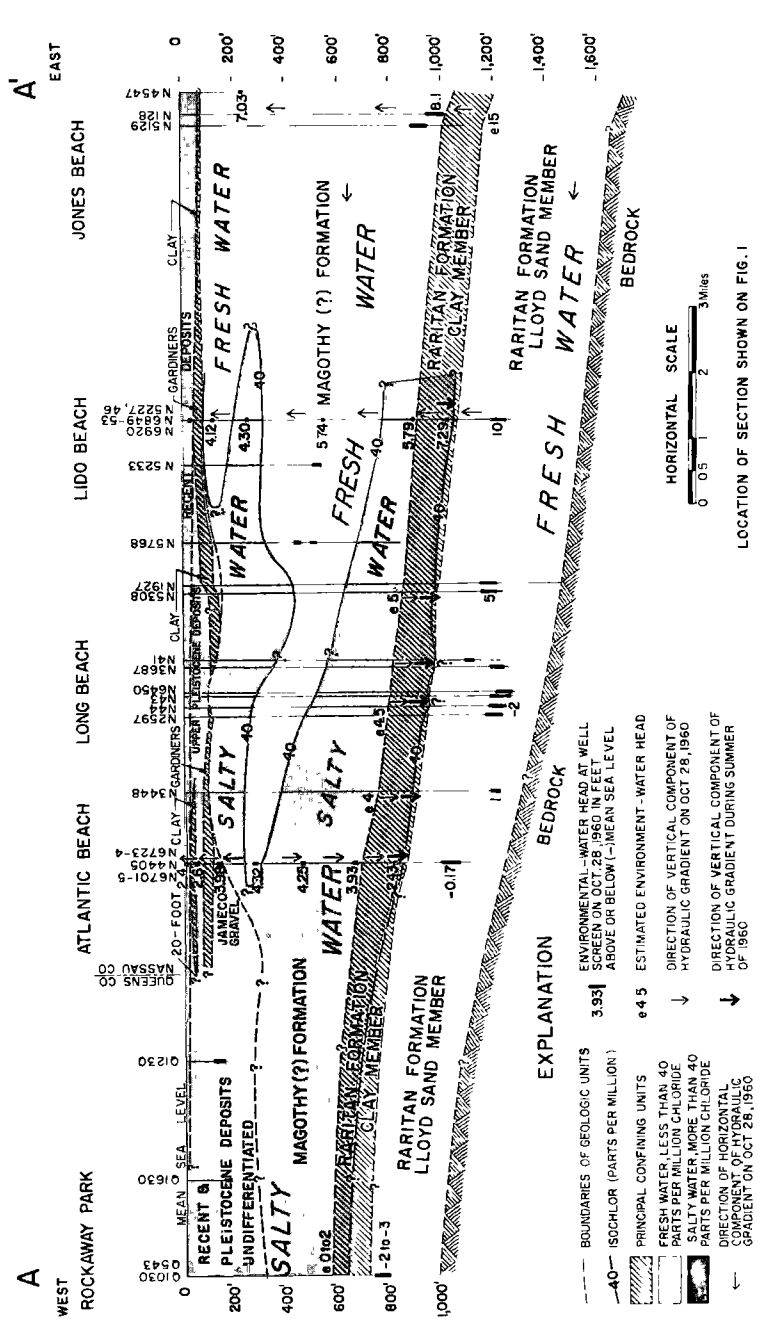


FIG. 4.—ENVIRONMENTAL-WATER HEADS AND DIRECTION OF VERTICAL COMPONENTS OF HYDRAULIC GRADIENTS

In the Rockaway Park area, salty ground water is believed to extend from near sea level downward to the clay member of the Raritan formation, probably occurring at least in its upper part and perhaps in its entire thickness. Between Atlantic Beach and Lido Beach (Fig. 4), an extensive wedge of fresh ground water in the Magothy (?) formation divides the salty ground water into an upper and a lower prong. The bifurcated upper prong contains salty ground water, generally to altitudes of -300 ft, and locally includes minor bodies of fresh or nearly fresh water. The lower prong, which forms the deep salt-water body in the Magothy (?) and the clay member of the Raritan formation, extends eastward from Atlantic Beach to the vicinity of Lido Beach.

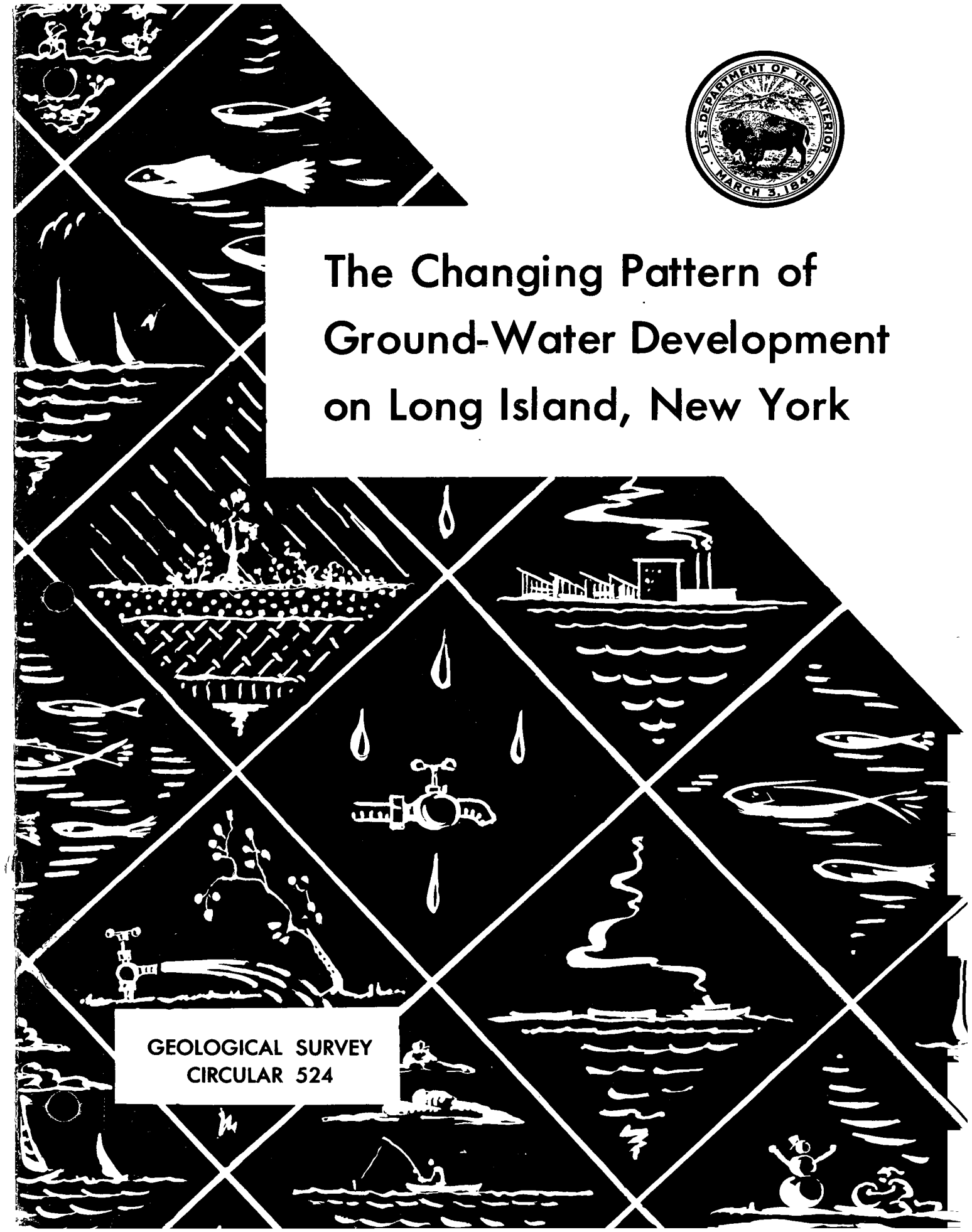
As indicated in Fig. 2, chloride concentrations in the project area range from less than 5 ppm to more than 16,000 ppm. The 40-ppm isochlor defines the boundary between fresh and salty ground-water bodies (Fig. 4). Sizable quantities of water having less than 10,000 ppm of chloride (which might be suitable for desalinization in the future), are delineated by the isochlors) Fig. 2).

At Atlantic Beach, the deep salt-water body is approximately 550 ft thick; its top is defined by the 40-ppm isochlor, which occurs at approximately -300 ft, as shown in Fig. 2. Most of the salty water west of Atlantic Beach has chloride concentrations of more than 15,000 ppm, whereas at Atlantic Beach the greater part of the deep salt-water body consists of salty water having chloride concentrations ranging from 40 ppm to 15,000 ppm. At Atlantic Beach, maximum chloride concentrations of about 16,000 ppm occur in the lower Magothy (?) formation and also in the clay member. Available data appear to indicate a rather rapid decrease in the chloride content of the water in an easterly direction, probably due, in part, to the presence of a relatively impermeable strata of solid clay in the lower Magothy (?) and in the clay member in Long Beach and Lido Beach (Fig. 2). Salty water, with chloride concentrations probably exceeding 5,000 ppm near the bottom of the Magothy (?) formation, is indicated by the electric log for well N2597 (Fig. 2). East of N2597, the resistivity curves of electric logs for wells N6450, N5308, N5768, and N6850 indicate a zone of diffusion in excess of 300 ft thick in the lower part of the Magothy (?). The relatively high apparent resistivities at these sites preclude the presence of very salty water. Thus, salty water in the lower Magothy (?) and in most of the clay member is believed to have chloride concentrations of less than 1,000 ppm in the eastern part of Long Beach and in Lido Beach, under conditions similar to those illustrated for well N6850 (Fig. 3).

The bottom of the deep salt-water body is defined by the 40-ppm isochlor, which occurs in the lowermost part of the clay member of Atlantic Beach and Lido Beach. The position of the 40-ppm isochlor in the Long Beach area is uncertain. It might be within the lowermost part of the clay member, as indicated in Fig. 2, or, possibly, in the upper part of the Lloyd sand member. Chloride concentrations in water from well N41, screened in the upper part of the Lloyd sand member, have been as high as 80 ppm on several occasions in 1960, whereas deeper wells in the same area show chloride concentrations of less than 10 ppm (Fig. 2). Although unusually high chloride concentrations at well N41 may be the result of a leaky casing or leakage along the annular space, there is a possibility that salty water from the deposits above has penetrated the upper part of the Lloyd sand member near well N41, where large withdrawals have been made since 1923.

Outside of the Atlantic and Lido Beach areas, the distribution of salty water

HE FOXWORTHY, COHEN—CHANGING PATTERN, GROUND-WATER DEVELOPMENT, LONG ISLAND, NEW YORK—GEOLOGICAL SURVEY CIRCULAR 524



The Changing Pattern of Ground-Water Development on Long Island, New York

GEOLOGICAL SURVEY
CIRCULAR 524

The Changing Pattern of Ground-Water Development on Long Island, New York

By R. C. Heath, B. L. Foxworthy
and Philip Cohen

Geological Survey Circular 524

Washington 1966

United States Department of the Interior
STEWART L. UDALL, *Secretary*

Geological Survey
William T. Pecora, *Director*

Free on application to the U.S. Geological Survey, Washington, D.C. 20242

hydrologic imbalance (fig. 7). The imbalance, which is accentuated because more than 70 mgd of water derived from the ground-water reservoir of these subareas currently is being discharged to the sea by way of sewage-treatment plants, is mostly clearly manifested in subarea D, where salty water is moving landward (Lusczynski and Swarzenski, 1960; Perlmutter and Geraghty, 1963). If the present trend continues, subarea D (the area of active salt-water encroachment) probably will expand at the expense of subarea E.

Subarea F, in northeastern Queens County, receives nearly its entire water supply from the New York City municipal-supply system. The subarea is sewered; however, because ground-water pumpage is negligible, the ground-water system is largely in balance.

Subarea G is the most highly urbanized and receives virtually all its water from the New York City municipal system. The entire subarea is sewered. As previously noted, large areas in Kings County were invaded by salty water because of substantial overdevelopment and the resulting decline in ground-water levels. Similarly, salty water had invaded the ground-water reservoir in parts of western Queens County. Water levels in Kings County have recovered appreciably since the mid 1940's, when the consumptive ground-water uses were drastically reduced. Presumably, the salty water is retreating seaward and is being diluted by recharge derived from precipitation, but precise data regarding these changes are lacking.

CONCLUSION

Ground water probably will continue to be the major source of water for most of Long Island (except for Kings and Queens Counties) for at least the next several decades. Moreover, if the present trends continue, the ground-water resources of the island probably will continue to be depleted—perhaps at an accelerated rate. The historic trends of ground-water development and the present status of development strongly suggest that such depletion will in time cause salt-water contamination of larger and larger parts of the ground-water reservoir. Moreover, the areas in which such contamination occurs, in addition to extending inward from the coasts, probably will also extend farther and farther eastward as the population continues to expand in that direction.

Several alternative methods of conserving and augmenting the ground-water resources of Long Island are currently being considered. These include, among others, desalting of sea water with the use of atomic energy, artificial recharge, and the reclamation of water from sewage. The consequences of such possible measures are highly significant inasmuch as the future well-being of several million people is at stake. However, even with the most promising of conservation methods, wise management will be required to gain the fullest use from the available fresh-water supply while also preventing undue hardships resulting from local overdevelopment of the ground-water reservoir. Fully effective management requires:

1. Recognition of the unity of the hydrologic system of Long Island.

2. The best obtainable scientific information about the system and how it functions.

3. Sound evaluation of the various alternative methods of water development and conservation, guided by available scientific information—including the hydrologic consequences of the historic and present-day changing pattern of ground-water development on Long Island.

REFERENCES CITED

Lusczynski, N. J., 1952, The recovery of ground-water levels in Brooklyn, New York from 1947 to 1950: U.S. Geol. Survey Circ. 167, 29 p.

Lusczynski, N. J., and Swarzenski, W. V., 1960, Position of the salt-water body in the Magothy(?) Formation in the Cedarhurst-Woodmere area of southwestern Nassau County: N.Y. Econ. Geology, v. 55, no. 8, p. 1739–1750.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–A, 205 p.

Pluhowski, E. J., and Kantrowitz, I. H., 1964, Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1768, 119 p.

Suter, Russell, de Laguna, Wallace, and Perl-Mutter, N. M., 1949, Mapping of geologic formations and aquifers on Long Island, New York: New York State Power and Control Comm. Bull. GW–18, 212 p.

Swarzenski, W. V., 1963, Hydrology of northwestern Nassau and northeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1657, 90 p.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1966 O—210-823

CONTENTS

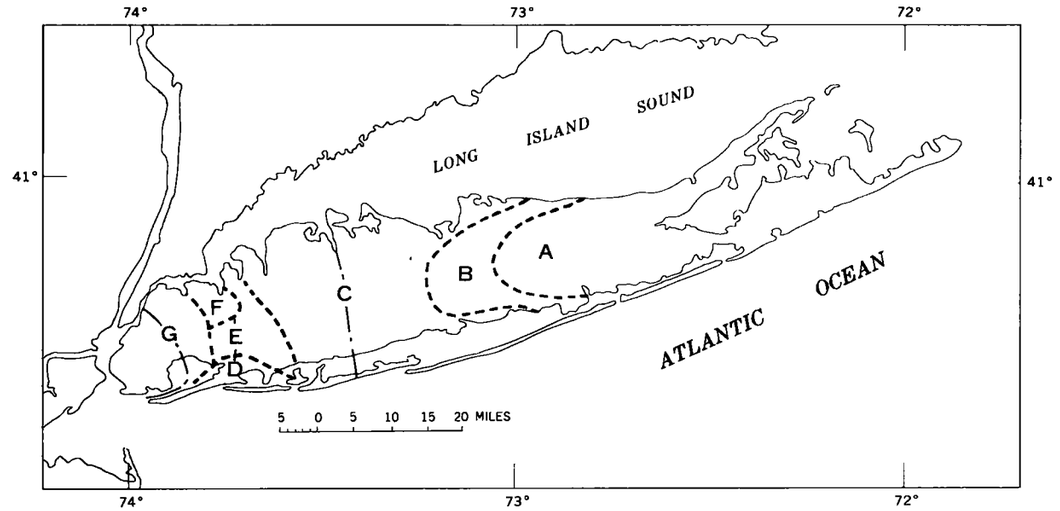
	Page
Abstract	1
Introduction	1
Geologic environment	1
Hydrologic system	3
Changes in ground-water development with time	4
Phase 1—predevelopment conditions	4
Phase 2	4
Changes in ground-water development with time—Continued	
Phase 3	5
Phase 4	5
Present areal differences in ground-water development	7
Conclusion	10
References cited	10

ILLUSTRATIONS

	Page
Figure 1. Map of Long Island and vicinity	2
2. Diagrammatic section showing general relationships of major rock units	2
3. Map showing generalized contours on the water table in 1961	4
4–7. Diagrammatic sections showing generalized ground-water conditions during various phases of development:	
4. Phase 1—predevelopment	5
5. Phase 2	6
6. Phase 3	7
7. Phase 4	8
8. Map showing water-development subareas in 1965	9

encroachment has not yet occurred. Plans are being made to install sewers throughout the subarea.

Subareas D and E, which include parts of western Nassau and southeastern Queens Counties, are moderately to highly urbanized and are almost completely sewered. Practically the entire water supply for these subareas is derived from wells tapping the Magothy Formation, Jameco Gravel, and the Lloyd Sand Member of the Raritan Formation. Thus, these subareas are mainly in phase 4 of development and are characterized by a



EXPLANATION

Subarea — *Characteristics*

A--- Phase 2 of development. Pumpage mainly from shallow privately owned wells. Waste water returned to shallow glacial deposits through cesspools; local contamination of glacial deposits by cesspool effluent. System virtually in balance; positions of salt-water fronts unchanged.

B--- Transition between phase 2 and 3. Pumpage from privately owned and public-supply wells. Waste water returned to shallow glacial deposits by way of cesspools; areas of cesspool-effluent contamination spreading. System virtually in balance.

C--- Phase 3 of development. Pumpage mainly from deep public-supply wells; waste water returned to shallow glacial deposits by way of cesspools. System locally out of balance, causing local salt-water intrusion.

D--- Phase 4 of development. Pumpage almost entirely from deep public-supply wells; waste water discharged to the sea by way of sewers. System out of balance; salty water actively moving landward.

E--- Phase 4 of development. Pumpage almost entirely from deep public-supply wells; waste water discharged to the sea by way of sewers. System out of balance; may be subject to salt-water intrusion in the future.

F--- Very little ground-water development. Water supply derived from New York City municipal-supply system; waste water discharged to the sea by way of sewers. System in balance.

G--- Very little ground-water development. Water supply derived from New York City municipal-supply system; waste water discharged to the sea by way of sewers. Large areas contain salty ground water owing to former intensive ground-water development and related salt-water intrusion.

Figure 8.—Water-development subareas in 1965.

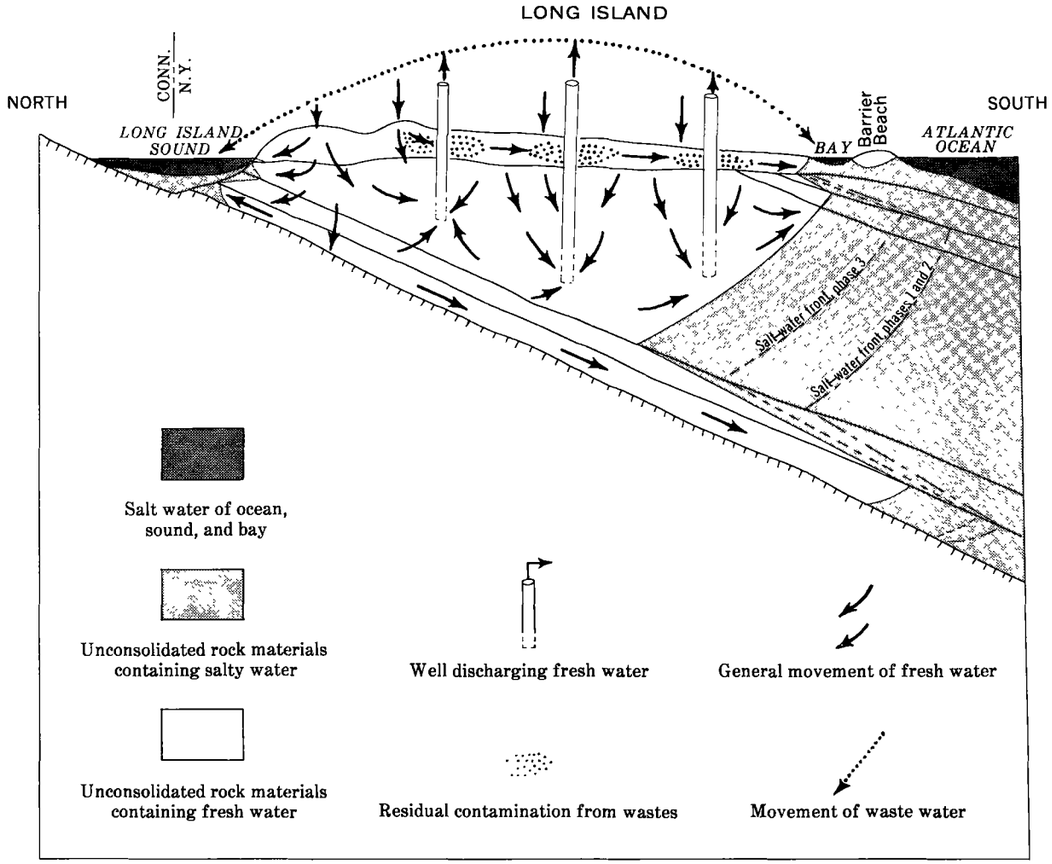


Figure 7.—Diagrammatic section showing generalized ground-water conditions during phase 4 of ground-water development (deep supply wells and waste disposal through sewers to adjacent salt-water bodies). Contacts between rock units are as shown in figure 2.

However, most of the sewage disposal is still through individually owned cesspools. Thus, the area is in a transition between phase 2 and phase 3 of development. Cesspool pollution still is not widespread, but is substantial enough to be of concern to local government agencies. Accordingly, plans are currently (1965) being made to construct sewers in the area and to gradually replace the wells that tap the glacial deposits with wells that will tap the Magothy Formation.

Subarea C includes the westernmost part of Suffolk County and the eastern two-thirds of Nassau County. Mainly because it is closer to New York City, this subarea was subjected to intensive suburban development earlier than was subarea B. Therefore, the population density and, accordingly, the water requirements in subarea C are substantially greater than in subarea B. Virtually the entire water supply for subarea C is obtained from large-capacity public-supply wells. The part of the subarea that is in western suffolk County obtains most of its water supply from public-supply wells, of which about half tap the glacial deposits and most of the remainder tap the Magothy Formation. In the part of the subarea that is in Nassau County, most of the public-supply wells tap the Magothy Formation.

Except for a few communities along the coast, most of subarea C is not sewered; practically all the domestic sewage is disposed of through individually owned cesspools. Thus, on the whole the subarea is in phase 3 of development (fig. 6). The system locally is out of balance owing to this development; however, substantial widespread salt-water

The Changing Pattern of Ground-Water Development on Long Island, New York

By R. C. Heath, B. L. Foxworthy, and Philip Cohen

ABSTRACT

Ground-water development on Long Island has followed a pattern that has reflected changing population trends, attendant changes in the use and disposal of water, and the response of the hydrologic system to these changes. The historic pattern of development has ranged from individually owned shallow wells tapping glacial deposits to large-capacity public-supply wells tapping deep artesian aquifers. Sewage disposal has ranged from privately owned cesspools to modern large-capacity sewage-treatment plants discharging more than 70 mgd of water to the sea.

At present (1965), different parts of Long Island are characterized by different stages of ground-water development. In parts of Suffolk County in eastern Long Island, development is similar to the earliest historical stages. Westward toward New York City, ground-water development becomes more intensive and complex, and the attendant problems become more acute. The alleviation of present problems and those that arise in the future will require management decisions based on the soundest possible knowledge of the hydrologic system, including an understanding of the factors involved in the changing pattern of ground-water development on the island.

INTRODUCTION

Even before the severe drought that is now (1965) affecting the Northeastern United States, Long Island was well known among water specialists for its underground-water resource, mainly as a result of both the magnitude of the ground-water resource and the unique aspects of man's utilization of that resource. The current drought has focused increased attention upon the vast amount of ground water in storage on Long Island and upon the large quantity of water being pumped from the system. In 1963, for example, an average of about 380 mgd (million gallons per day) was pumped from Long Island wells; these wells tap a fresh ground-water reservoir that has an estimated storage capacity of 10 to 20 trillion gallons. Nearly all the water pumped was for domestic and industrial use, and this pumpage probably represents one of the largest such uses of a single well-defined ground-water reservoir anywhere in the world.

The history of ground-water development on Long Island has been thoroughly documented, largely as a result of studies made by the U.S. Geological Survey in cooperation with the New York State Water Resources Commission and Nassau and Suffolk Counties. The water development has followed a general pattern which, although somewhat related to population density and local waste-disposal practices, has been controlled largely by the response of the hydrologic system to stresses that man has imposed upon the system. The purpose of this report is to summarize the highlights of the historical pattern of ground-water development on Long Island and to consider briefly the insight that the history of development affords regarding the future development and conservation of Long Island's most valuable natural resource.

GEOLOGIC ENVIRONMENT

Long Island (fig. 1) has a land area of about 1,400 square miles and is geographically a large detached segment of the Atlantic Coastal Plain. The island is underlain by crystalline bedrock, the uppermost surface of which ranges in altitude from about sea level at the northwest corner of the island to about 2,000 feet below sea level in the southeastern part of Suffolk County (fig. 2).

The bedrock is overlain by a wedge-shaped mass of unconsolidated sedimentary deposits

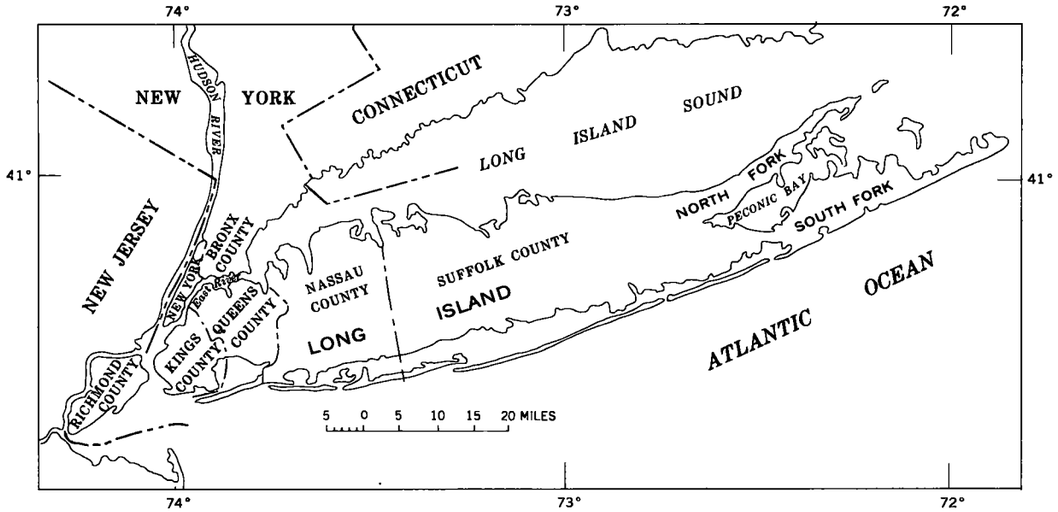


Figure 1.—Long Island and vicinity.

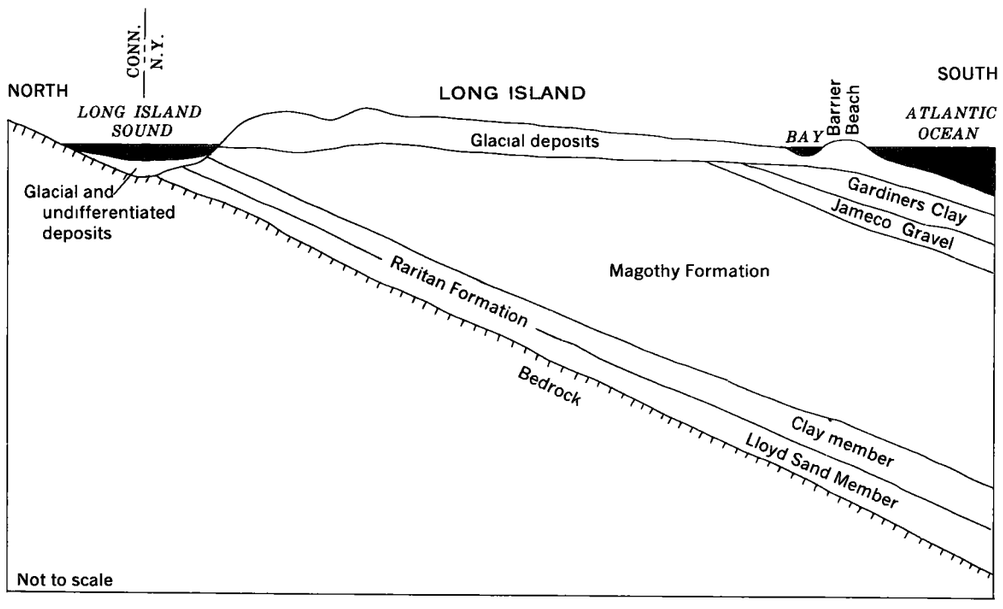


Figure 2.—Diagrammatic section showing general relationships of the major rock units of the ground-water reservoir in Nassau County.

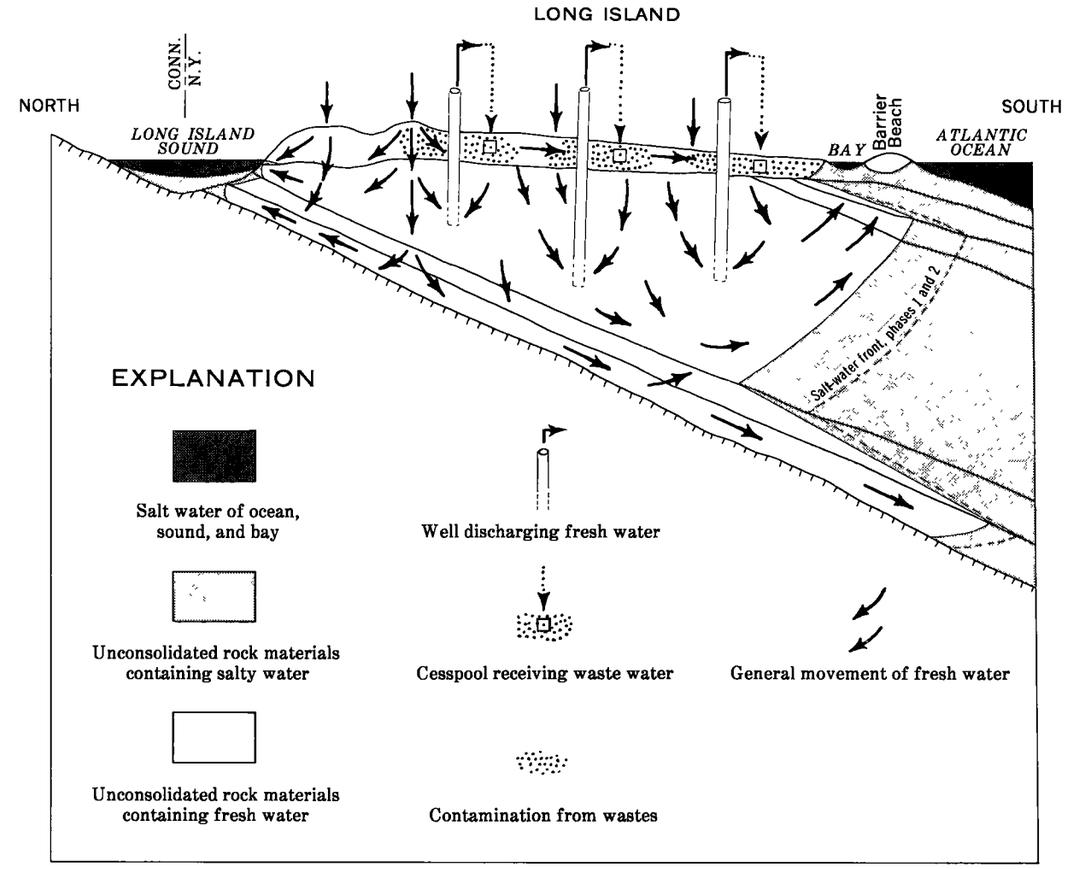


Figure 6.—Diagrammatic section showing generalized ground-water conditions during phase 3 of ground-water development (deep supply wells and waste disposal through cesspools). Contacts between rock units are as shown in figure 2.

PRESENT AREAL DIFFERENCES IN GROUND-WATER DEVELOPMENT

The present pattern of ground-water development on Long Island affords an excellent opportunity to observe and evaluate the historic trend of that development, because all the major phases of development described herein, except the predevelopment phase, can be observed now in different subareas of the island (fig. 8). Moreover, once the transitory status of present development in each subarea is recognized in relation to the pattern of historical trends, it becomes possible to predict and perhaps forestall some of the undesirable aspects of those trends.

Subarea A (fig. 8) includes roughly the eastern two-thirds of Suffolk County. Except for several small communities, the subarea is largely rural and has the lowest population density on Long Island. On the whole, the subarea can be characterized as being in phase 2 of ground-water development (fig. 5)—that is, most of the wells in the subarea tap the shallow glacial deposits and supply water to single-family dwellings. The bulk of this water is returned to the glacial deposits through individually owned cesspools, and in overall aspect the ground-water system is still in hydraulic balance.

Subarea B, in central Suffolk County, is experiencing the impact of the suburban expansion associated with the entire New York City metropolitan area. Farms and woodlands are giving way to housing developments, and most of the pumpage in the subarea is now from large-capacity public-supply wells that tap the glacial deposits.

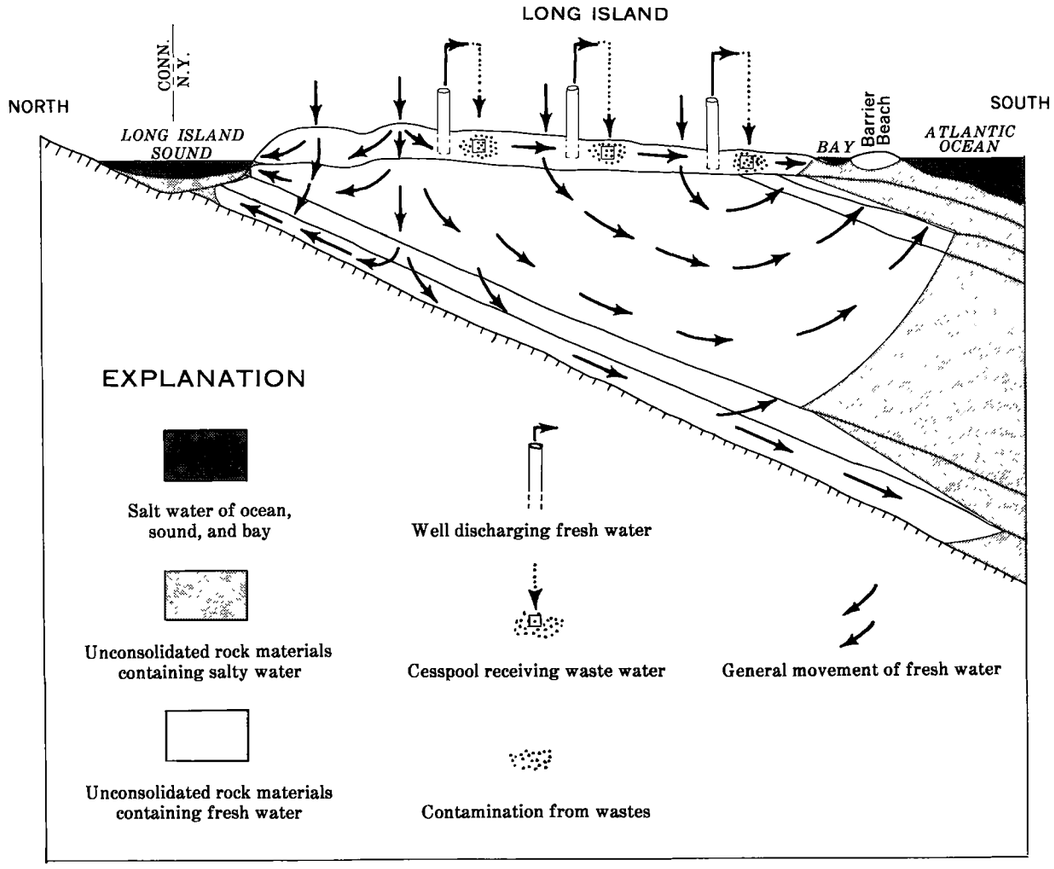


Figure 5.—Diagrammatic section showing generalized ground-water conditions during phase 2 of ground-water development (shallow supply wells and waste disposal through cesspools). Contacts between rock units are shown in figure 2.

the ground-water reservoir by means of cesspools was thereafter discharged to the sea through the sewers. Whereas the net draft on the ground-water system during the preceding phases of development was negligible, virtually all the ground water diverted to sewers during phase 4 represented a permanent loss from the system. The newly imposed stress on the ground-water system locally resulted in a rapid landward encroachment of salty water into the previously fresh ground-water reservoir. The most dramatic example occurred during the 1930's in Kings County (the Borough of Brooklyn), which by that time had been completely sewered for many years. In 1936, decreased natural recharge owing to urbanization and increased ground-water withdrawals, which during the previous few years averaged more than 75 mgd, caused ground-water levels in Brooklyn locally to decline to as much as 35 feet below sea level (Lusczynski, 1952, pls. 1 and 2). This local overdevelopment caused contamination of large parts of the ground-water reservoir in that area from sea-water encroachment.

In 1947 virtually all pumping for public supply in Kings County was discontinued and the Borough was thereafter supplied with water from the New York City municipal-supply system, which utilizes surface-water reservoirs in upstate New York. A notable exception was ground-water withdrawal for air-conditioning use. Such usage was permitted, however, only under the condition that the water was returned to the ground-water reservoir by means of injection wells (locally referred to as "diffusion" wells).

that attain a maximum thickness of about 2,000 feet. These deposits constitute the ground-water reservoir of Long Island and can be divided into six major stratigraphic units, which differ in their geologic ages, mineral composition, and hydraulic properties. These units are, from oldest to youngest, (1) Lloyd Sand Member of the Raritan Formation, (2) clay member of the Raritan Formation, (3) Magothy Formation, (4) Jameco Gravel, (5) Gardiners Clay, and (6) glacial deposits. (Suter and others, 1949). The first three units listed are of Cretaceous age, and the last three are of Pleistocene age.

The Lloyd Sand Member of the Raritan Formation has a maximum thickness of about 300 feet and consists mainly of fine to coarse sand and some gravel and interbedded clay. It forms the basal water-bearing unit of the ground-water reservoir. The clay member of the Raritan Formation is composed mainly of clay but locally contains considerable sand; it also has a maximum thickness of about 300 feet. Hydraulically, the clay member is a leaky confining layer for the Lloyd Sand Member—retarding, but not preventing, vertical leakage of water to and from the Lloyd.

The Magothy Formation on Long Island is partly correlative with the Magothy Formation in New Jersey. It consists of complexly interbedded layers of sand, silt, and clay and some gravel in the lower part. The complexity of the interbedding and the character of fossils it contains suggest that the formation was mainly laid down under continental (flood-plain) conditions. The Magothy Formation is the thickest unit of the ground-water reservoir on Long Island, attaining a maximum thickness of about 1,000 feet. Its horizontal permeability differs widely from place to place and is considerably higher than its vertical permeability. It commonly yields more than 1,000 gpm (gallons per minute) per well. Water in the formation is largely under artesian conditions.

Near the north and south shores of the island, the Magothy Formation locally is overlain by the Jameco Gravel. The maximum thickness of the Jameco is about 200 feet. It consists mainly of medium to coarse sand, but locally contains abundant gravel and some silt and clay. The Jameco Gravel is moderately too highly permeable and yields as much as 1,500 gpm per well. Water in the formation occurs under artesian conditions.

The Gardiners Clay is mainly restricted in extent to two moderately narrow bands that parallel the north and south shores, and it is commonly underlain by either the Jameco Gravel or the Magothy Formation.

The surface of Long Island is composed mostly of material deposited either directly by Pleistocene continental ice sheets or by melt water derived from the ice sheets. These glacial deposits consist mainly of sand and gravel outwash in the central and southern parts of the island, and mixed till and outwash atop and between the hills in the northern part of the island. The glacial outwash deposits are highly permeable and therefore permit moderately rapid infiltration of precipitation.

HYDROLOGIC SYSTEM

The four major water-bearing units of the ground-water reservoir of Long Island are the glacial deposits, Jameco Gravel, Magothy Formation, and Lloyd Sand Member of the Raritan Formation (fig. 2). These four units contain mostly fresh ground water; however, locally they contain salty ground water or they are hydraulically connected with salty water of the ocean, sound, or bays. Under natural conditions recharge to the ground-water reservoir resulted entirely from the infiltration of precipitation, which is estimated to have averaged roughly 1 mgd per square mile (Swarzenski, 1963, p. 35). Most of the ground water moved laterally through the glacial deposits and discharged into streams or into bodies of salt water bordering the island without first reaching deeper water-bearing zones. Most of the remainder of the ground water moved downward through the glacial deposits into the Jameco Gravel or Magothy Formation, and from there part flowed laterally to the ocean and the remainder flowed downward through the clay member of the Raritan Formation into the Lloyd Sand Member. (See fig. 4.)

Estimates of ground-water discharge under natural conditions can be developed by extrapolation of data listed by Pluhowski and Kantrowitz (1964, p. 38–55) for the Babylon-Islip area, a large and reasonably representative part of Long Island. Those data suggest

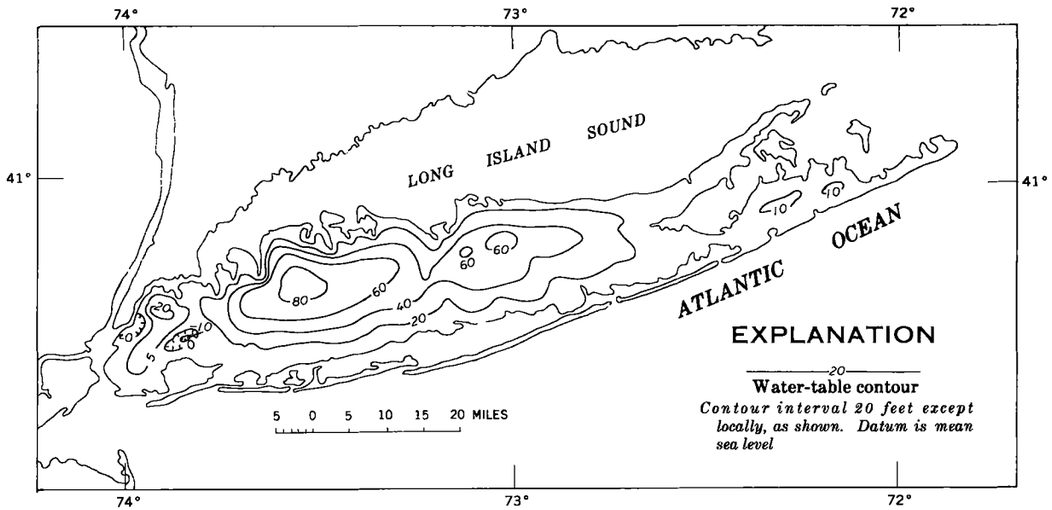


Figure 3.—Generalized contours on the water table (the upper surface of the ground-water reservoir) in 1961.

that about 90 percent of the total recharge ultimately discharged from the glacial deposits (mainly by seepage to streams), and about 10 percent discharged by subsurface outflow from the Magothy Formation, the Jameco Gravel, and the Lloyd Sand.

The water table on Long Island (fig. 3) and also the piezometric (pressure) surfaces of the underlying artesian aquifers (which have about the same general shape as the water table) form elongate mounds following roughly the configuration of the land surface. Two prominent highs characterize the water table—one centered in Nassau County and one centered in Suffolk County. Northwestern Queens County also has a small high in the water table. Other notable features are the cones of depression that extend below sea level in Kings and Queens Counties; these cones are in areas of past or current local overdevelopment of ground water.

CHANGES IN GROUND-WATER DEVELOPMENT WITH TIME

PHASE 1—PREDEVELOPMENT CONDITIONS

Ground-water development on Long Island has progressed and is progessing through several distinct phases. Under natural or predevelopment conditions (fig. 4), the hydrologic system was in overall equilibrium and long-term average ground-water recharge and discharge were equal. The general positions of the subsurface interfaces between fresh and salty water in each of the previously described geologic units were stable, reflecting the overall hydrologic balance. The interfaces were virtually at the coasts in the glacial deposits and were offshore in the underlying units.

PHASE 2

In the initial stage of development (fig. 5), which began with the arrival of the first European settlers, virtually every house had a shallow well drawing water from the glacial deposits and a cesspool returning waste water to the same deposits. As the population increased, individual wells were abandoned and public-supply wells were installed in the glacial deposits. The individual cesspools, however, were retained and little water was lost from the system during use. Although a considerable amount of ground water was being withdrawn, practically all of it was returned to the same aquifer from which it was removed. In general, therefore, the system remained in balance, and the positions of the interfaces between fresh and salt water remained practically unchanged. However, this cycle of ground-water development and waste-water disposal resulted in the pollution of the shallow ground water in the vicinity of the cesspools.

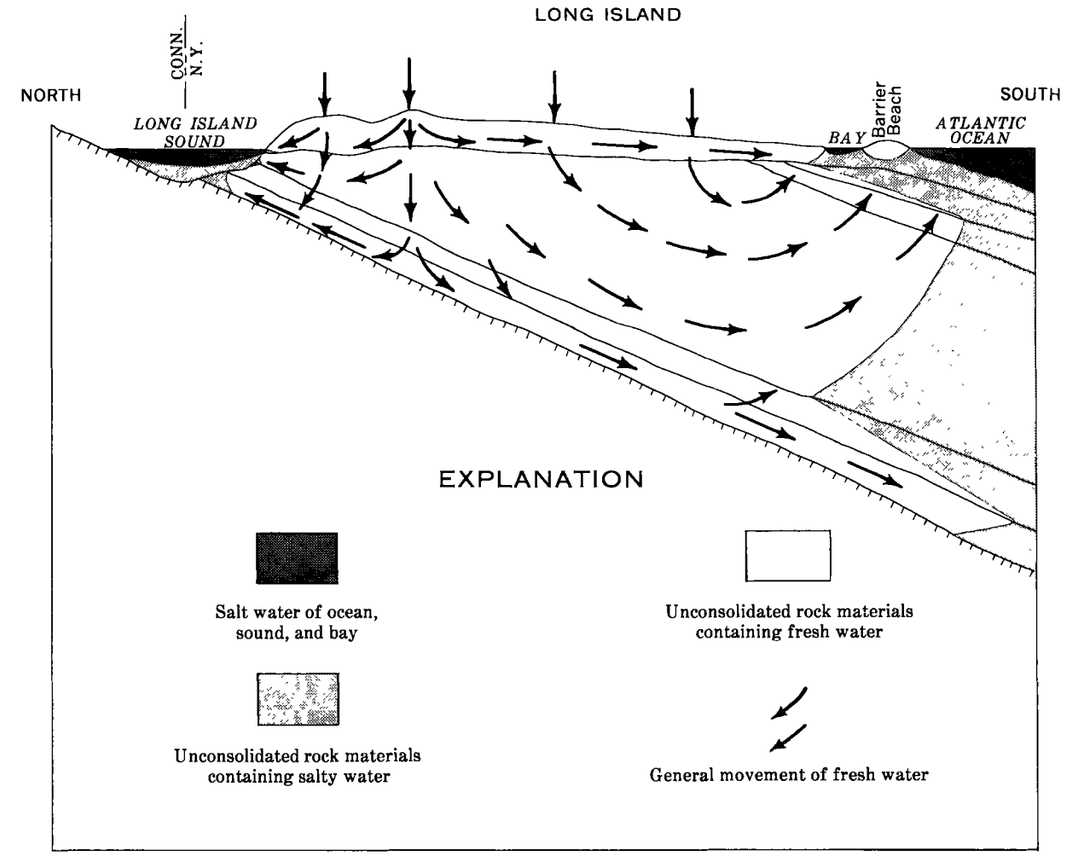


Figure 4.—Diagrammatic section showing predevelopment (phase 1) generalized ground-water conditions. Contacts between rock units are as shown in figure 2.

PHASE 3

In time, as the cesspool pollution spread, some shallow public-supply wells had to be abandoned and these were replaced with deeper public-supply wells, most of which tapped the Jameco Gravel and the Magothy Formation. Supply wells were also constructed in the deeper units at places where the glacial deposits contained water with objectionable amounts of dissolved iron or other troublesome natural constituents. Most of the water withdrawn from the deeper units was returned to the shallower glacial deposits by means of cesspools, and subsequently discharged to the sea by subsurface outflow or by seepage to streams (fig. 6).

As a result of the withdrawal of water from the Magothy Formation and the Jameco Gravel, and the concurrent decrease in hydraulic heads in these units, the downward movement of ground water from the overlying glacial deposits locally was increased. However, the increased downward movement only partially compensated for the withdrawals of water from the Magothy and Jameco deposits. Locally, a hydraulic imbalance developed in the Magothy and Jameco deposits and caused a decrease in the amount of fresh ground water in storage and a landward movement of salty water.

PHASE 4

The next major phase in the development of ground water on Long Island (fig. 7) was the introduction of large-scale sewer systems—notably in that portion of Long Island that is part of New York City (Kings and Queens Counties). Most of the pumped ground water that previously had been returned to

Extract of publication no. 70 of the I.A.S.H.
Symposium of Haifa, pp. 193-197

ARTIFICIAL-RECHARGE EXPERIMENTS UTILIZING RENOVATED SEWAGE-PLANT EFFLUENT— A FEASIBILITY STUDY AT BAY PARK, NEW YORK, U.S.A.[1]

PHILIP COHEN and C.N. DURFOR[2]

ABSTRACT

The U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, is conducting a series of artificial-recharge experiments on Long Island, New York. The experiments are designed to obtain scientific and economic data needed to evaluate the feasibility of injecting highly-treated sewage-plant effluent into a proposed network of "barrier" injection wells that are intended to prevent or retard the landward movement of salty water from the Atlantic Ocean into major aquifers beneath Long Island.

A tertiary sewage-treatment process has been developed to upgrade the quality of the effluent so that it meets the requirements that are commonly accepted for potability in the United States. In addition, a uniquely designed experimental injection well and injection plant have been completed. The injection-well complex, which is about 500 feet deep, consists of two adjacent fiberglass casings that surmount stainless-steel screens, and seven auxiliary plastic pipes. The casings and pipes, equipped with remote-sensing downhole geochemical probes, permit the measurement of hydraulic-head changes and related geochemical changes at several points within the injection well and the filterpack.

Data from the experimental injection well and from thirteen nearby observation wells are providing information regarding several aspects of the proposed artificial recharge, most notably (*a*) the design and hydraulic characteristics of injection wells, (*b*) hydraulics of the leaky artesian aquifers, and (*c*) geochemical controls on artificial ground-water recharge through wells.

RÉSUMÉ

Le Service Géologique des USA en coopération avec le Département des Travaux Publics du Comté de Nassau, réalise une série d'essais de recharge artificielle sur Long Island, New York. Les essais ont pour but d'obtenir les données sicentifiques et économiques nécessaires pour évaluer la possibilité d'injecter dans un réseau «barrière» de puits des eaux usées profondément traitées avec l'intention d'empêcher ou de retarder le mouvement vers l'intérieur des terres des eaux salines de l'Océan Atlantique dans les nappes principales sous Long Island.

Un traitement terriaire a été développé pour relever la qualité des eaux usées de façon à leur donner les caractères de potabilité généralement requis aux Etats-Unis. De plus, on a réalisé un nouveau puits d'injection expérimental ainsi qu'une installation d'injection. Le puits d'injection complexe, qui est profond d'environ 500 pieds, consiste en deux enveloppes adjacentes en fibre de verre qui surmontent un écran en acier inoxydable et sept tuyaux en plastique auxiliaires. Les enveloppes et les tuyaux sont équipés pour la prise d'échantillons géochimiques et permettent la mesure des changements de charge hydraulique et des modifications géochimiques en différents endroits du puits d'injection et de son enveloppe filtrante.

Les données des puits d'injection expérimental et de treize puits d'observation voisins fournissent des indications sur certains aspects de la recharge proposée et plus particulièrement (*a*) sur la consitution et les caractéristiques hydrauliques des puits d'injection; (*b*) sur l'hydraulique des nappes perdant leur eau et (*c*) sur les contrôles géochimiques de la recharge par puits.

[1] Publication authorized by the Director, U.S. Geological Survey.

[2] Geologist and chemical engineer, respectively, U.S. Geological Survey, Mineola, New York.

Ceuterick, Printers 153 Brusselse straat Louvain (Belgium)

Reasons for and objectives of the study

Long Island, which has an area of about 1,400 square miles, extends eastward from the northeast coast of the United States about 120 miles into the Atlantic Ocean (fig. 1). The Island is joined artificially to the mainland at New York City by several

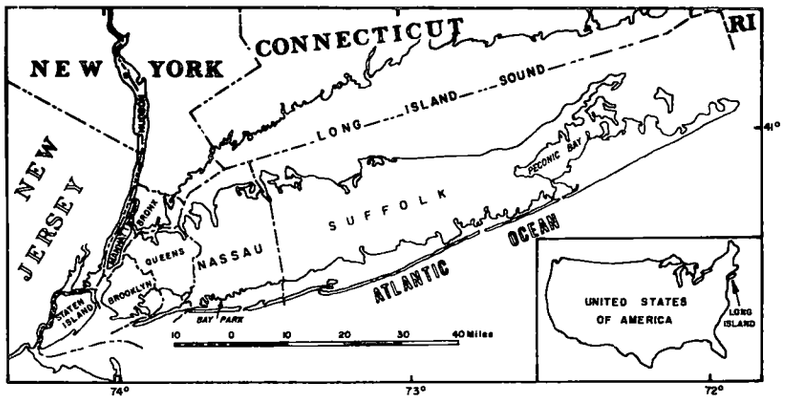


Fig. 1 — Long Island and vicinity.

bridges and tunnels. Roughly the western most one-fifth of Long Island comprises the boroughs of Brooklyn and Queens—two of the five boroughs of New York City.

Ground-water is the only source of fresh water for the more than 2 million people in the eastern four-fifths of Long Island. The ground water is obtained from sand and gravel aquifers in a wedge-shaped sequence of unconsolidated deposits as thick as 2,000 feet, which, in turn, is underlain by crystalline bedrock. Since shortly after the second World War, this part of Long Island has experienced a four-fold increase in population which has been accompanied by an equally dramatic increase in ground-water development. The resulting stress on the ground-water system locally accelerated and locally caused the encroachment of salty water into Long Island's fresh ground-water reservoir—most notably along the south shore of Queens and Nassau Counties (Lusczynski and Swarzenski, 1966).

Large-scale sewage-collection and treatment facilities are now short-circuiting significant amounts of fresh water to the sea. For example, somewhat more than 70 mgd (million gallons per day) of treated sewage effluent, virtually all of which is derived from ground-water pumpage, presently is being discharged into the sea in Nassau County (most of it through the Bay Park sewage-treatment plant). Nearly all this water represents a net draft on the ground-water system, and this draft is one of the major factors contributing to salt-water encroachment in southwestern Nassau County.

One of the proposals being considered by local governmental agencies to alleviate the problem of salt-water encroachment is a plan to construct a network of "barrier" injection wells across the entire breadth of Nassau County (about 15 miles), parallel to and near the south shore of the Island. The proposal is to ultimately recharge about 27 mgd of sewage water that has been purified to meet potability standards.

The study herein described was started in 1965 by the U.S. Geological Survey (an agency of the Federal Government) in cooperation with the Nassau County

Summary of the Results of the Study of date

As of the date of the preparation of this paper (August 1966), the injection experiments have not yet begun. The well-drilling activities have been completed and the injection facilities shown in figure 4 are mostly completed. The laboratory studies and the experience with the 30-gpm tertiary-treatment plant have demonstrated the scientific and economic feasibility of upgrading the quality of the secondary sewage-plant effluent so that it meets the standards of potability.

Two aquifer (pumping) tests have been completed. The data thereby obtained indicate that the strata into which the water will be injected function as a series of leaky artesian aquifers. Time-drawdown and distance-drawdown water-level data obtained from wells tapping beds of fine to medium sand adjacent to the injection screen have been analyzed by the application of several mathematical models. The model which seems to best fit the data (although it is only roughly analogous to the hydrologic conditions in the field) is the so-called "leaky artesian" model described by Hantush and Jacob (1955). By applying this model, the coefficient of transmissibility of the 62 feet of strata adjacent to the injection screen is estimated to be 87,000 gallons per day per foot, and the coefficient of storage is estimated to be 0.00016.

Preliminary geochemical studies indicate that the native ground water, which has a dissolved-solids content of about 50 mg/l (milligrams per liter), and the injected water, which will have dissolved-solids content of about 500 mg/l, will be moderately compatible. Iron compounds may be the only serious inorganic precipitates, and adjustments of Eh and pH probably will minimize clogging problems associated with such substances.

The injection experiments, as planned, show promise of providing quantitative answers to some of the significant problems that have beset previous workers in subsurface injection. The major accomplishment to date, in terms of broad applicability, is the highly successful utilization of large-diameter fiberglass pipes for well construction. Because of the ease of handling and high strength to weight ratio, fiberglass pipes seem to be ideally suited for multiple-casing experimental wells.

REFERENCES CITED

Cohen, Philip and Durfor, C.N., 1966, Design and construction of a unique injection well on Long Island, N.Y., *in* Geological Survey Research, 1966, Chapter D: *U.S Geol. Survey Prof. Paper 490-D*, p. D253-D257.

Hantush, M.S. and Jacob, C.E., 1955, Non-steady radial flow to an infinite leaky aquifer: *Am. Geophys. Union Trans.*, v. 36, no. 1, pp. 95-100.

Lusczynski, N.J. and Swarzenski, W.V., 1966, Salt-water encroachment in Southern Nassau and Southeastern Queens Counties, Long Island, New York: *U.S. Geol. Survey Water-Supply Paper 1613-F*, p. 76.

Three of the wells that have fiberglass casings are screened in the same zone as the injection well; two are screened about 100 feet above the injection zone; and two are screened about 55 feet below the injection zone. The remaining observation wells havemild-steel casings and screens that are made of various metals.

Injection Plant

The major elements of the injection plant are shown schematically in figure 4. Public-supply water (obtained from wells tapping the deep artesian aquifers several miles aways) will be used in the initial injection experiments. The public-supply water, the treated effluent, or mixtures of the two will be introduced into a storage tank having a capacity of 50,000 gallons. The pH and Eh of the water will be adjusted in the tank by adding appropriate chemicals. From the storage tank the water can be routed either through or around a vacuum degasifier. This arrangement will permit a series of experiments to evaluate the physical and chemical aspects of clogging related to gasses entrained or dissolved in the injection water.

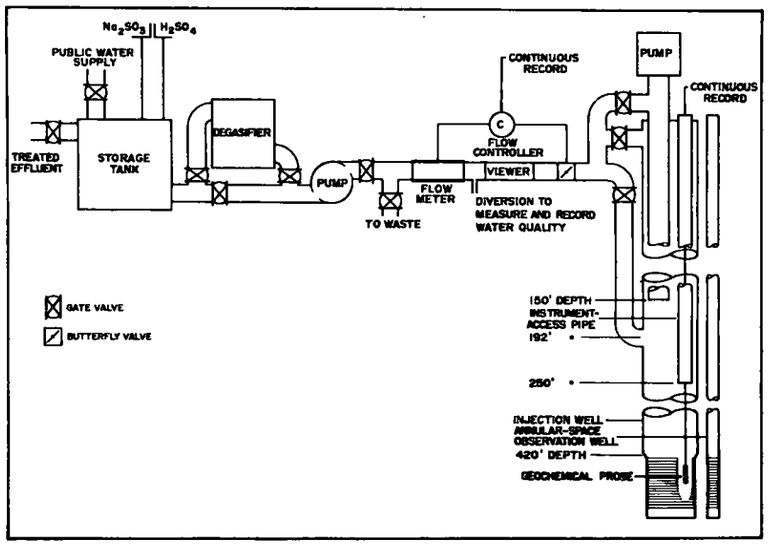


Fig. 4 — Injection Plant at Bay Park, Long Island, New York.

From the degasifier the water can be pumped into the injection well through the deep injection pipe, through the shallow injection pipe, or through the pump column of a deep-well turbine pump installed in the injection well. The injection well is equipped with a 50-horsepower deep-well turbine pump for hydraulic testing and to redevelop the well after it clogs. Previous workers have suggested or implied that, in many injection wells, permanently installed pumps for redevelopment purposes may be necessary. Accordingly, facilities are provided to investigate the feasibility of injecting through the pump column in addition to injecting through the shallow and deep injection pipes.

Department of Public Works—the local agency that is evaluating the desirability and feasibility of the proposed network of injection wells. It is being made at the site of a large activated-sludge type sewage-treatment plant in the community of Bay Park, Nassau County. The specific objectives of the Geological Survey's work are to provide information regarding (*a*) the physical and chemical factors that control the injection pressures at which treated sewage-plant effluent can be injected into deep artesian aquifers, and (*b*) the hydraulic and geochemical effects of such injection. The purpose of this paper is to describe briefly the progress made in the study to date (August 1966). The design of the experiments and some of the unique features of the experimental well and related equipment are emphasized. In addition, available preliminary data and interpretations thereof are considered briefly.

Design of the Study

Treatment of the Effluent

The artificial-recharge studies at Bay Park have been divided into two closely coordinated major phases: (*a*) the effluent-treatment phase, and (*b*) the experimental-injection phase. A private consulting firm, hired by the Nassau County Department of Public Works, recently completed an 18-month study to develop and test tertiary-treatment procedures for upgrading the quality of the secondary effluent produced at the Bay Park sewage-treatment plant to meet the physical, chemical, and biological standards of potability. A pilot tertiary-treatment plant, having a capacity of 30 gpm (gallons per minute), was built and operated for about a year. The information thus obtained was used as the basis for the design of a plant capable of producing 400 gpm of the highly treated effluent which will be used in the injection experiment. The larger plant is scheduled to be completed in 1967.

Briefly, the tertiary treatment of the sewage effluent involves (*a*) coagulation and sedimentation, (*b*) dual-media filtration, (*c*) activated-carbon adsorption, and (*d*) chlorination. The effluent thus produced is clear and sparkling, has no noticeable odor, and meets the physical, chemical, and biological standards for potability.

Details and Functions of the Wells

Fourteen wells, ranging in depth from 10 feet to 726 feet, are being used in the investigation (fig. 2). The experimental injection well (well 1) is the key well in the study (fig. 3). Details of its construction are described at considerable length in a previous report (Cohen and Durfor, 1966); its major features are reviewed briefly in the following text.

The injection-well complex consists of two wells (1 and 1A) completed in a single drill hole, 36 inches in diameter. The major element is an 18-inch-diameter fiberglass casing (the "injection casing") that extends to a depth of 420 feet below land surface. A stainless-steel screen (the "injection screen"), 16 inches in diameter and 62 feet in length, is attached to the bottom of the 18-inch casing. Stainless-steel and fiberglass were chosen so that the materials would be as chemically inert as feasible in order to facilitate geochemical and biochemical studies of clogging phenomena.

The casing and screen of the annular-space observation well are the same lengths and are made of the same materials as those of the injection casing and screen, but they are smaller in diameter. The injection screen and the screen of the annular-space observation well are separated by about 3 inches of filter-pack material. The filter pack is a mixture of well-rounded very coarse sand and very fine gravel.

The two 3-inch-diameter fiberglass tremie pipes, which extend about 5 feet into the filter pack, will be used to monitor the level of the filter pack and to add additional

filter-pack material should that be required. The 4-inch-diameter fiberglass injection pipe opens into the injection casing at a point 192 feet below land surface, and also at about land surface. The other pipe shown on figure 3, the 1-inch-diameter pressure-measuring pipe, opens into the injection casing 3 feet above the top of the injection screen. The well is equipped with three other pipes which, for the sake of clarity, are not shown in the illustration. These are 2-inch-diameter polyvinyl chloride pipes which will accommodate the counterweights of three level-monitoring instruments.

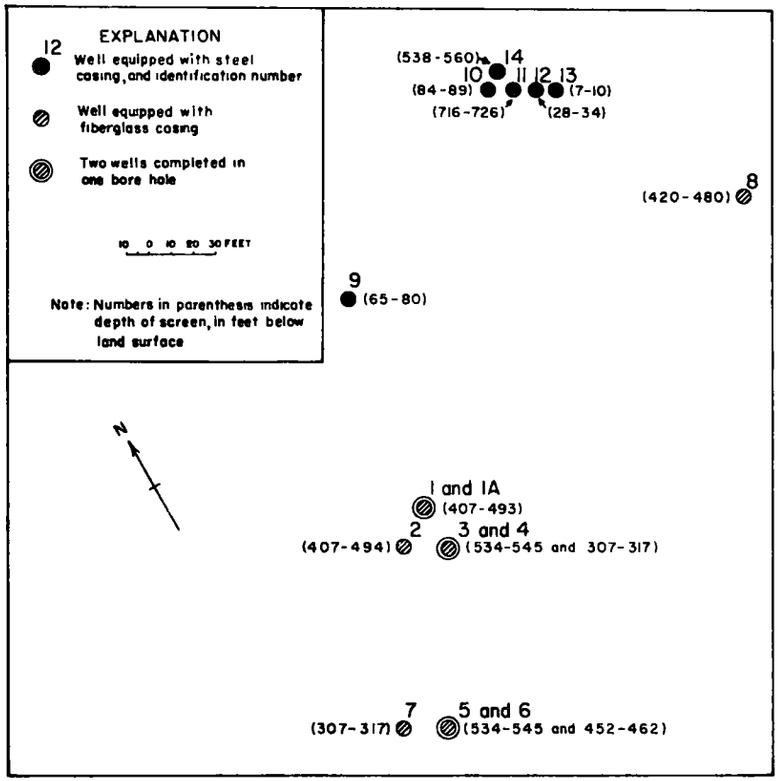


Fig. 2 — Location of wells at the Bay Park experimental site.

Water can be introduced into the injection casing, by means of a series of valves, either at land surface or at a depth of 192 feet, thereby permitting a series of experiments to study the effectiveness of deep injection pipes. Injection pressures will be measured immediately before the water moves through the injection screen into the filter pack by means of the deep 1-inch pressure-measuring pipe. At the same time, down-hole instruments will measure the pH, Eh, temperature, specific conductance, and the dissolved-oxygen content of the water immediately before the water flows outward through the screen. Similar waterquality determinations and head measurements made in the annular-space observation well will be used to study clogging phenomena associated with the flow of water through the injection screen and the immediately adjacent few inches of filter-pack material.

Seven of the other 12 observation wells have fiberglass casings; six of these have stainless-steel screens and the seventh (well 8) has a saw-slotted fiberglass screen.

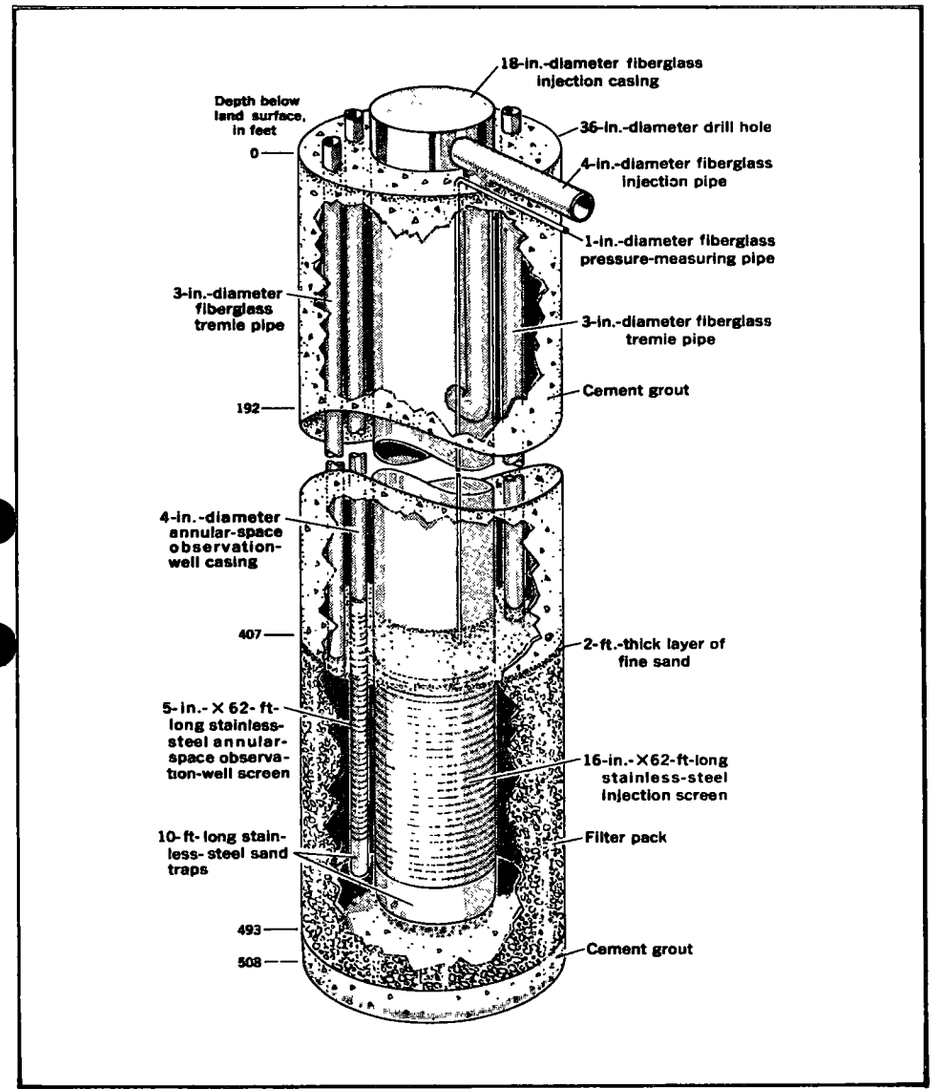
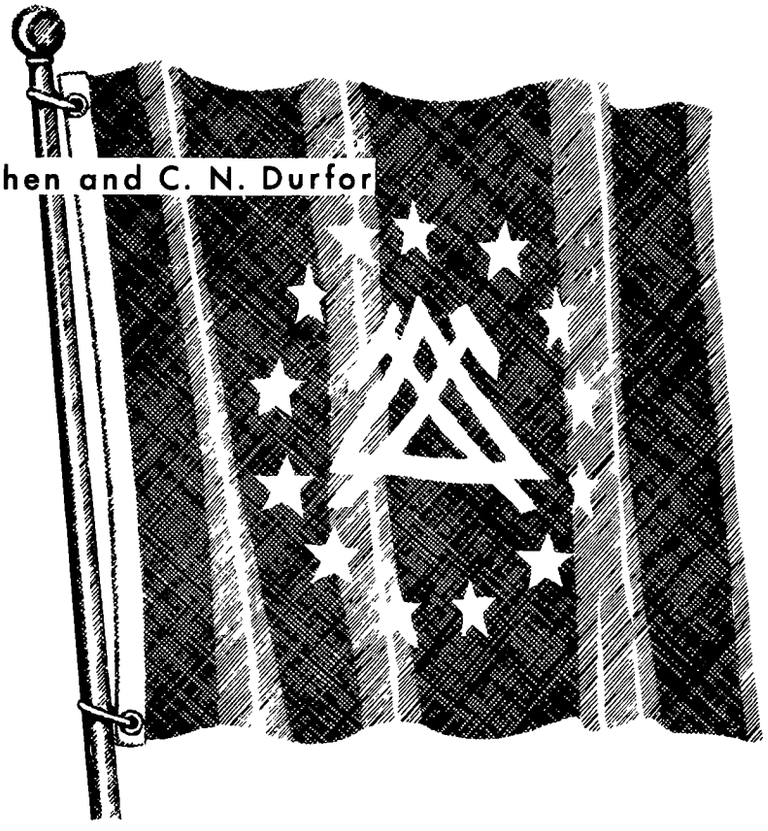


Fig. 3 — Details of the Bay Park experimental well. (After Cohen and Durfor, 1966, p. D 254.)

Design and Construction of a Unique Injection Well on Long Island, New York

By Philip Cohen and C. N. Durfor



Reprint from Geological Survey Research 1966
Geological Survey Professional Paper 550-D
p.253–257

WORK DONE IN COOPERATION WITH THE NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESIGN AND CONSTRUCTION OF A UNIQUE INJECTION WELL ON LONG ISLAND, NEW YORK

By PHILIP COHEN and C. N. DURFOR, Mineola, N.Y.

Work done in cooperation with the Nassau County Department of Public Works

Abstract.—An injection well of unique design and construction recently completed on Long Island, N.Y., will be used in making a series of artificial-recharge experiments with highly treated sewage-plant effluent. The well, about 500 feet deep, consists of two adjacent fiberglass casings (18 inches and 4 inches in diameter) and 7 auxiliary pipes, 4 of which are made of fiberglass and 3 of polyvinyl chloride. Fiberglass was used because of its advantageous chemical and strength characteristics. A stainless-steel well screen, 62 feet long, is attached to the bottom end of each casing. Water will be injected into the aquifer through the large casing and screen, and hydraulic-head changes will be measured at several points within the well and filterpack. Geochemical reactions related to the head changes will be monitored by means of instruments in each screen.

A unique experimental injection well, designed by personnel of the U.S. Geological Survey, was completed on Long Island, N.Y., in the autumn of 1965. The well, which is in the community of Bay Park, Nassau County, will be used in a series of artificial-recharge experiments during the next several years. The experiments are designed to help evaluate the feasibility of a proposed network of "barrier" injection wells intended to retard or prevent the landward movement of salty water from the Atlantic Ocean into fresh-water aquifers that underlie Long Island. More specifically, the artificial-recharge experiments will be designed to investigate the physical and chemical factors that affect the rates at which sewage-plant effluent—treated to meet the commonly accepted standards for drinking water—can be injected into deep saturated deposits of sand and silty sand.

Clogging of the well screen, the filterpack, or the adjacent aquifer materials is a major cause of failure of injection wells. Another common cause of failure is physical or chemical deterioration of the well screen or casing (Sniegocki, 1963, p. 3). Accordingly, many of the features of the Bay Park experimental injection well were designed to study these causes of failure and, if possible, to develop methods of minimizing or preventing them.

CONSTRUCTION OF THE WELL

The major elements of the experimental well (fig. 1) are the 18-inch-diameter[1] casing and the 16-inch-diameter screen attached thereto (hereafter termed the "injection casing" and "injection screen," respectively). Other elements of the well include (a) the so-called annular-space observation well adjacent to the injection casing and screen, in the space between them and the wall of the drilled hole; (b) a deep pressure-measuring pipe which enters the injection casing just above the screen; (c) two tremie pipes extending into the filterpack which surrounds the well screens; (d) an injection pipe for water; and (e) dry wells, each 2 inches in diameter, which will accommodate the counterweights of three float-operated measuring instruments. (For clarity, the dry wells are not shown in fig. 1.)

The first step in the construction of the well was the drilling of an 8-inch-diameter test hole by the standard hydraulic-rotary method to a depth of 742 feet below land surface. Ninety cores were obtained during the drilling, and electric and gamma-ray logs were made soon after the hole was completed. On the basis of data from the cores and logs, the injection zone was selected and other details of the well design were completed. The test hole was backfilled with sand and then was reamed to a diameter of 36 inches by the reverse-rotary method to a depth of 508 feet. A plug

[1] All diameters of pipes, casings, and screens listed in this report are nominal.

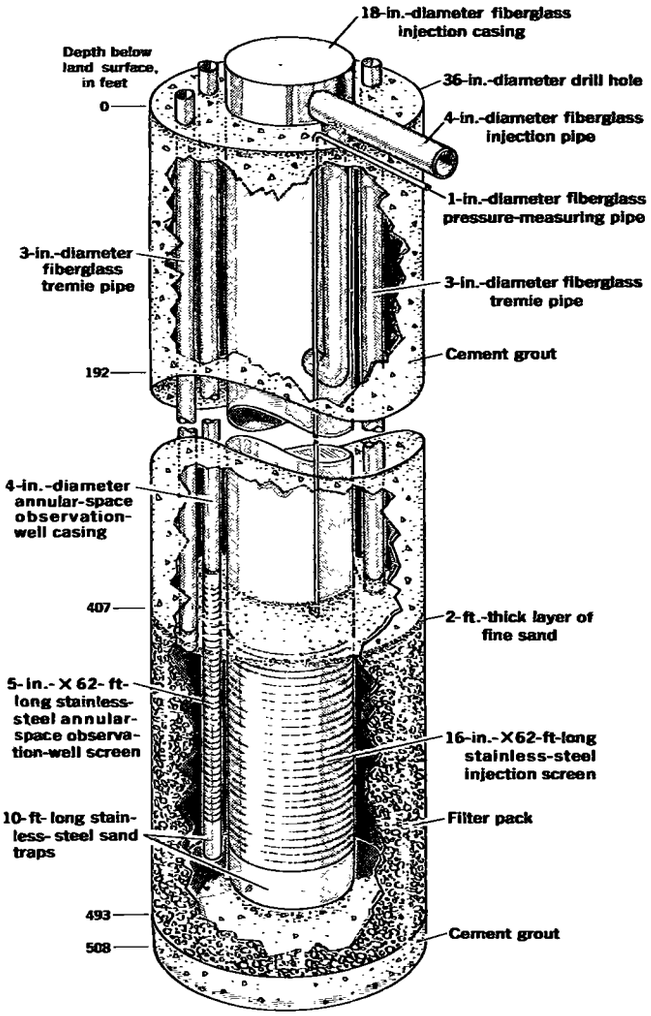


FIGURE 1.—Schematic diagram showing experimental injection well at Bay Park, Long Island, N.Y. Not to scale.

of cement grout, 15 feet thick, was emplaced in the bottom of the hole.

All casings, screens, and pipes shown in figure 1, plus pipes for the three dry wells, were lowered into the hole as a single bundle. The bundle was supported from above by a clamp attached to the 18-inch-diameter casing; the other pipes and casings were bound to the 18-inch casing with stainless-steel straps. After the bundle was in place, a filterpack consisting of very coarse sand and very fine gravel was emplaced in the annular space to a height of 11 feet above the screens. A layer of poorly sorted fine sand, 2-feet thick, was placed above the filterpack. Finally, the remainder of the hole was backfilled with cement grout.

Water will be injected through the 4-inch-diameter injection pipe into the injection casing, and thence through the injection screen into the aquifer. Valves will be installed in the 4-inch injection pipe at the land surface so that the water can be introduced into the injection casing either at land surface or at a depth of 192 feet below land surface. This arrangement will permit making a series of experiments to study the effectiveness of deep injection pipes (currently used in many injection wells) in reducing clogging. A depth of 192 feet was chosen so that the injected water can be introduced into the injection casing about 40 feet below the bowls of a turbine pump that will be installed in the well. This will avoid the possibility of turbulence associated with the flow of injected water past the pump column and bowls.

The 1-inch-diameter pressure-measuring pipe opens into the injection casing at a depth of 415 feet below land surface, or 3 feet above the top of the injection screen. At land surface the 1-inch pipe will be attached to a pressure-sensing instrument that will provide a continuous record of the changes in head in the well during the injection experiments. The pressure-measuring pipe was designed to open into the injection casing as close to the injection screen as feasible in order to measure the injection head immediately before the water moves through the screen into the filterpack and thence into the aquifer.

A portable geochemical-geophysical probe will be used in the injection screen during most of the experiments. This probe, with related equipment, will provide a continuous record of the temperature, specific conductance, dissolved oxygen, pH, and Eh of the water immediately before it moves through the screen into the filterpack. In addition, corrosion probes of the electrical-resistance type, similar to those described by Clarke (1963, p. 12–29), will be lowered into the injection screen to measure corrosion characteristics of different materials that could be used in the proposed network of injection wells.

The screen of the annular-space observation well is 5 inches in diameter, and the casing and sand trap are each 4 inches in diameter; they are the same lengths as those of the injection casing, screen, and sand trap. The screen of the annular-space observation well is roughly in the middle of the filterpack—that is, about midway between the injection screen and the wall of the drill hole. Head measurements and geochemical data, obtained from the annular-space observation well by means of a geochemical-geophysical probe identical to the one in the injection screen, will be used to study clogging, related geochemical phenomena, and accompanying head losses associated with the movement of water through the injection screen into the filterpack. If the need arises, the annular-space observation well will be used to add chemicals to the well.

The tremie pipes, each 3 inches in diameter, extend about 3 feet into the filterpack. These pipes will be used for continuous monitoring of the height of the filterpack, and, if necessary, for adding additional filterpack material to the annular space.

The 3 dry wells range in depth from 40 to 150 feet. The deepest dry well will accommodate the counterweight of a float-operated recorder that will monitor the water level in the annular-space observation well. The other 2 dry wells are for the counterweights of 2 instruments that will be used for monitoring the level of the filterpack in the tremie pipes.

A 50-horsepower turbine pump having an intake setting at 150 feet below land surface will be installed in the injection casing. The pump will be used in redeveloping the well after the injection experiments, in obtaining water samples for chemical and bacteriological analysis before and after the tests, and in studying the hydraulic effects of the recharge experiments on the well and the adjacent aquifer material—especially changes in permeability caused by clogging.

CHEMICAL AND PHYSICAL PROPERTIES OF MATERIALS USED IN THE WELL

The chemical properties of materials used in constructing the well were of special concern. On Long Island, since 1933, the drilling of industrial wells that yield more than 100,000 gallons per day has been prohibited by law unless the water is returned to the ground through "diffusion" wells or other approved structures (Johnson, 1948, p. 1160–1161). Accordingly, hundreds of recharge wells have been constructed. Many of them have failed because of chemical and biochemical reactions involving iron — that is, iron naturally in solution in the ground water, iron compounds (mainly FeS_2) in the aquifer materials, and iron in the mild-steel casings and pumps. Thus, in order to facilitate studies of corrosion, encrustation, and clogging—especially those involving the chemistry of iron—it was decided that, insofar as possible and practical, mild steel would not be used to construct and equip the experimental well.

Materials that were considered for the casings and other pipes in the well were stainless steel, vinyl-coated aluminum, mild steel coated with chemically stable liners such as epoxy resin and coal-tar enamel, polyvinyl chloride, fiberglass reinforced with epoxy or polyester resin (hereafter referred to as "fiberglass"), and asbestos cement. In addition to chemical properties, the other major factors that were considered were the strength of the material, its adaptability for use in well construction, and its cost. After considering these and other factors, the writers decided that fiberglass pipe, with watertight quick-disconnect couplings, would be the most satisfactory material for the casings and for most of the other pipes of the experimental well. Polyvinyl-chloride pipes were chosen for the dry wells.

The tensile strength of fiberglass pipe is closely related to the geometry of the fiberglass windings and is ordinarily much greater than that required in well construction. For example, the 18-inch-diameter fiberglass injection casing reportedly can withstand a pull of more than 250,000 pounds; the quick-disconnect couplings used to join the 40-foot lengths of 18-inch fiberglass pipe were designed to withstand a pull of 100,000 pounds. Similarly, the ability of the fiberglass pipe to withstand internal pressure exceeds the internal pressures anticipated during the planned experiments by more than an order of magnitude. The major element of concern regarding the strength of the fiberglass pipe, therefore, was its collapse pressure, or its ability to withstand differential external circumferential pressure.

Differential external pressure exerted on the casings by a given thickness of saturated porous deposits in which static ground-water levels are about at land surface (as is the case at the site of the experimental well) was estimated from the equation

$$P=\frac{K(Ws-Ww)h}{144},$$

where

P = differential external pressure, in pounds per square inch,
K = a dimensionless constant dependent mainly on the angle of internal friction of the material,
Ws = dry weight of the porous material, in pounds per cubic foot,
Ww = weight of water, in lb per cu ft, and
h = the height of the column of material, in feet.

The dry weight of the deposits was assumed to be 130 lb per cu ft. As a safety factor in the design of the casings and pipes, it was assumed that K would be equal to 0.50—that is, that the casings would have to withstand differential external pressure equivalent to at least half the weight of the column of saturated material. Curve 1 in figure 2 shows the differential external pressure to which the casings would be subject if the preceding assumptions are fulfilled. The curve shows that the maximum pressure on the bottom of the 18-inch casing (418 feet below land surface) that would result from the weight of the overlying saturated deposits is about 100 pounds per square inch.

If the injection screen should become severely clogged during an injection experiment, the water level in the

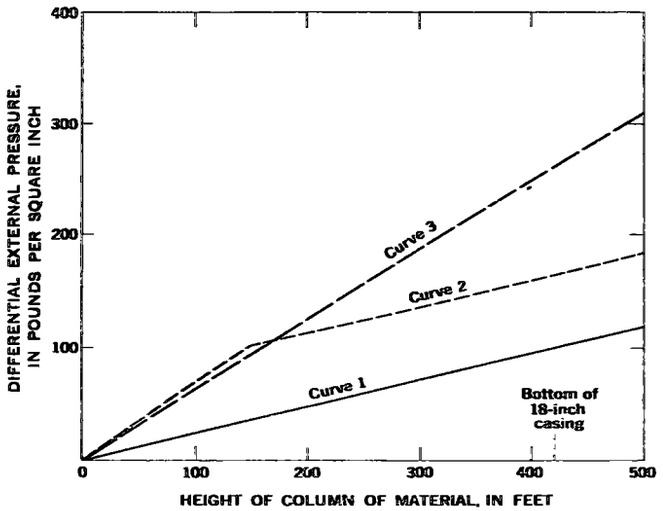


FIGURE 2.—Relation between the differential external pressures exerted on a casing and the height of a column of enclosing material. Curve 1 shows the pressure exerted by saturated sedimentary deposits. Curve 2 shows the pressure exerted by the saturated deposits plus differential hydrostatic pressure that would result if the well clogged during pumping (discharge) and the water level in the casing were drawn down to the pump intake. Curve 3 shows the pressure exerted by liquid cement grout weighing 150 lbs per cu ft.

injection casing might decline to the level of the pump intake (150 feet below land surface) during the pumping phases of the experiment. Under this condition, the difference between water levels inside and outside the casing, equivalent to a hydrostatic head of 150 feet, could cause a maximum differential external pressure on the casing wall of about 65 psi. The resulting differential pressure would increase (at a rate of about 0.43 psi per foot of depth) from zero at the land surface to about 65 psi at a depth of 150 feet and would remain constant below that depth. The sum of the differential external pressure resulting from the weight of the saturated deposits plus that resulting from pumping when the screen is severely clogged is shown as curve 2 in figure 2. The maximum differential pressure on the lowest parts of the casings and pipes from these causes would be about 160 psi.

After the annular space above the filterpack was filled with cement grout, only the lower few feet of the casings and pipes would be subjected to the pressures described in the foregoing paragraph; the remaining portions would be encased in cement and thereby would be protected. During the grouting procedure, however, the casings and pipes below a depth of 150 feet could have been subjected to an even greater pressure than that shown in curve 2 of figure 2. Before the cement hardened, the column of grout, which might weigh as much as 150 lb per cu ft, could have caused a differential pressure of about 0.6 psi per foot of column, or about 260 psi at the bottom of the casing (curve 3 of figure 2).

If the fiberglass pipe is assumed to have the physical properties of a thin-walled elastic tube, the collapse pressure (the differential external pressure at which the pipe would fail) can be computed from the equation (Roark, 1965, p. 354)

$$C=(1/4)\left(\frac{E}{1-\mu^2}\right)\left(\frac{t^3}{r^3}\right)$$

where

C=collapse pressure, in psi,
E=bulk modulus of elasticity, in pounds per square inch,
μ=Poisson's ratio,
t=wall thickness of the pipe, in inches, and
r=radius of the pipe, in inches.

The bulk modulus of elasticity of the fiberglass pipe used in the well is about 4 million psi; Poisson's ratio for the material is about 0.20.

It is apparent from the formula that the collapse pressure of the fiberglass pipe is directly proportional to the cube of the wall thickness and is inversely proportional to the cube of the radius of the pipe. Inasmuch as the cost of the fiberglass pipe is roughly proportional to the volume of fiberglass and resin, the use of pipes having the smallest possible wall thickness consistent with the collapse-pressure requirements was advantageous. Therefore, the contractor was required to pour the cement grout in two distinct phases—allowing sufficient time for the first batch to harden before adding the remainder of the cement. The casings and pipes were thereby subjected to only half the differential external pressure (about 130 psi) that would have resulted if the entire column of cement grout had been poured at one time and if the entire column had remained fluid for a finite period of time.

The wall thicknesses, computed collapse pressures, and other pertinent data regarding the fiberglass casing and pipes are summarized in table 1. The 18-inch

TABLE 1.—*Dimensions and collapse pressures of fiberglass pipes used in the Bay Park experimental injection well*

Designation of pipe	Nominal diameter (inches)	Wall thickness (inches)	Collapse pressure (psi)
Injection casing	18	0.55	240
Annular-space observation-well casing	4	.15	440
Injection pipe	4	.12	220
Tremie pipes	3	.11	405
Pressure-measuring pipe	1	[1] .06	1,800

[1] Standard wall thickness available from the factory.

casing was made of fiberglass reinforced with polyester resin; the other casing and pipes listed in the table were made of fiberglass reinforced with epoxy resin.

The screens of the injection well and the annular-space observation well are of the continuous wire-wrapped type and are made of type-304 stainless steel. The sand traps and the related fittings are also made of type-304 stainless steel. The slot sizes of the screens are 0.060 inch. This size was chosen in order to retain about 80 percent of the filterpack, which consists of about 71 percent very coarse sand and about 28 percent very fine gravel. The filterpack consists almost entirely of subrounded, moderately spherical particles of quartz, chert, and quartzite; it has a very high laboratory coefficient of permeability—about 18,000 gallons per day per square foot. Preliminary pumping-test data indicate that the screen and gravel pack are highly efficient and that well losses are minimal. The well had a specific capacity of 35 gallons per minute per foot of drawdown after 8 hours of pumping at a rate of 1,000 gpm. During development, the well had similar specific capacities after somewhat shorter periods of pumping at various rates ranging up to about 2,500 gpm. Even at the highest rate of pumping, the well yielded water that was virtually sediment free after only a few days of development.

Clarke (1963, p. 39) describes a successful experimental, gun-perforated small-diameter, fiberglass well, 1,000 feet in depth, in Libya. In addition, more than 400 wells equipped with 10-inch-diameter fiberglass casings and saw-slotted fiberglass screens reportedly have been completed in Pakistan during 1964–65. To the best of the writers' knowledge, however, the experimental well described in this report is the first water well constructed in the Western Hemisphere that has a fiberglass casing; and, the only water well in the world (as of 1965) that has multiple fiberglass casings and pipes, and a fiberglass casing as large as 18 inches in diameter.

Despite the fact that fiberglass presently is 2 to 4 times more expensive than mild steel, its use in experimental wells involving multiple casings and complex construction problems, and its use in special-purpose wells in highly corrosive environments, seems to be justified on the basis of the experience gained during the construction of the Bay Park injection well.

REFERENCES

Clarke, F. E., 1963, Appraisal of corrosion characteristics of western desert well waters, Egypt: U.S. Geol. Survey open-file rept., 65 p.

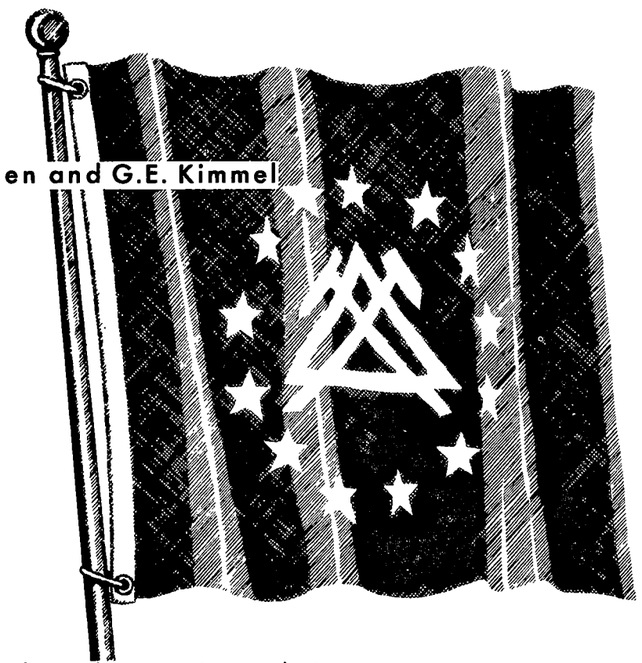
Johnson, A. H., 1948, Ground-water recharge on Long Island, New York: Am. Water Works Assoc. Jour., v. 47, no. 4, p. 1159–1166.

Roark, R. J., 1965, Formulas for stress and strain: New York, McGraw-Hill, 432 p.

Sniegocki, R. T., 1963, Problems in artificial recharge through wells in the Grand Prairie Region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615–F, 25 p.

STATUS OF SALT-WATER ENCROACHMENT IN 1969 IN SOUTHERN NASSAU AND SOUTHEASTERN QUEENS COUNTIES, LONG ISLAND, NEW YORK

By Philip Cohen and G.E. Kimmel



Reprint from Geological Survey Research 1970
Geological Survey Professional Paper 700-D
p. 281–286

WORK DONE IN COOPERATION WITH THE NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS AND THE NEW YORK STATE DEPARTMENT OF CONSERVATION, DIVISION OF WATER RESOURCES

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATUS OF SALT-WATER ENCROACHMENT IN 1969 IN SOUTHERN NASSAU AND SOUTHEASTERN QUEENS COUNTIES, LONG ISLAND, NEW YORK

By PHILIP COHEN and G. E. KIMMEL, Mineola, N.Y.

Work done in cooperation with the Nassau County Department of Public Works and the New York State Department of Conservation, Division of Water Resources

Abstract.—Chloride data obtained from "outpost" wells and other wells in southern Nassau and southeastern Queens Counties, Long Island, N.Y., indicate that landward movement of a deep wedge of salty ground water in the area has been minimal from 1960 to 1969. Significant changes in chloride content were noted in only 3 of 30 outpost wells. Chloride content of water from a well in southeastern Queens County increased from 34 mg/l in 1960 to 112 mg/l in 1969, as a result of intensive ground-water withdrawals in that county; chloride content in two wells in Nassau County increased from 8,520 to 11,000 mg/l and from 2,000 to 8,110 mg/l during the same period. These increases resulted from local heavy pumping near the zone of diffusion. No increase in chloride content was noted in water from the Lloyd aquifer, except where leaky casings permitted downward flow of salty water.

Salty ground water on Long Island, N.Y., especially in southeastern Queens and southern Nassau Counties (fig. 1), has been studied intensively for several decades. Among the more recent studies pertinent to the subject are those reported on by Lusczynski (1961a, b), Lusczynski and Swarzenski (1960, 1962, 1966), Perlmutter and Crandell (1959), Perlmutter and Geraghty (1963), Perlmutter, Geraghty, and Upson (1959), Soren (1970), and Swarzenski (1959). As a byproduct of much of this work, a network of so-called outpost wells was established to monitor the rate and extent of the landward movement of salty ground water (commonly referred to as salt-water encroachment) in the area.

The most recent report on salt-water encroachment in southeastern Queens and southern Nassau Counties (Lusczynski and Swarzenski, 1966) includes data from the outpost wells up to 1960–62. The major purpose of this paper is to review the chloride data obtained from 1960 to 1969 from the outpost wells and from other selected wells, and to consider the significance of these data, especially with regard to possible salt-water encroachment. Because salt-water encroachment into the deeper artesian aquifers is of primary concern to the Long Island water managers, the occurrence and movement of salty water in these aquifers are emphasized in this paper.

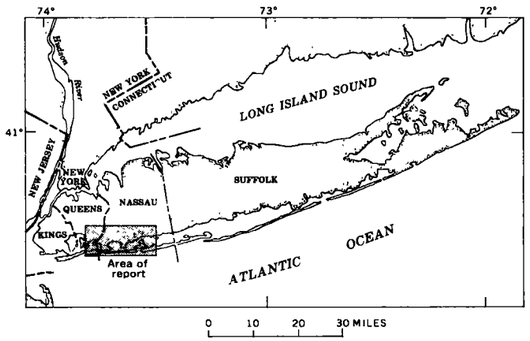


FIGURE 1.—Index map of Long Island, N.Y., showing area of report.

Acknowledgments.—Many individuals and agencies supplied much of the basic data given in this report. The authors are especially grateful to the

Nassau County Department of Health, the Nassau County Department of Public Works, and the New York State Department of Conservation, Division of Water Resources.

HYDROGEOLOGIC SETTING

The major hydrogeologic units beneath southeastern Queens and southern Nassau Counties and pertinent characteristics of these units are listed in table 1.

Under natural conditions, precipitation on Long Island was the source of all the fresh ground water beneath the study area (the shaded area in fig. 1). Ground water was discharged naturally by seepage to streams, which in turn flowed into the south-shore bays; by subsurface outflow to the bays and probably the Atlantic Ocean; and to a small extent by evapotranspiration near the shorelines.

At present (1969) ground-water recharge in the study area results mainly from (1) infiltration of precipitation through areas of bare soil, (2) subsurface inflow from upgradient areas, (3) infiltration of storm runoff through recharge basins, (4) injection of water used for industrial purposes into recharge wells, and (5) discharge of waste water into cesspools, septic tanks, and disposal basins (especially in the eastern part of the area). All the natural mechanisms of ground-water discharge are still operative in the area. In addition, a substantial quantity (several tens of millions of gallons per day) of ground water is artificially discharged by pumping and by the subsequent disposal of the pumped water to the sea by way of sewage-treatment plants.

Gross ground-water pumpage data for the period 1960–68 in selected subareas of Nassau and Queens Counties are listed in table 2.

TABLE 1.—*Major hydrogeologic units in southern Nassau and southeastern Queens Counties, Long Island, N.Y.*

Hydrogeologic unit [1]	Approximate maximum thickness in study area (feet)	Description
Upper glacial aquifer	100	Mainly sand and gravel of high hydraulic conductivity; some thin beds of clayey material of low hydraulic conductivity.
Gardiners Clay	100	Clay, silty clay, and a little fine sand of low to very low hydraulic conductivity.
Jameco aquifer	200	Mainly medium to coarse sand of moderate to high hydraulic conductivity.
Magothy aquifer	800	Mainly very fine sand, silt, and clay of low to very low hydraulic conductivity; some coarse to fine sand of moderate hydraulic conductivity; locally contains gravel of high hydraulic conductivity.
Raritan clay	200	Clay of very low hydraulic conductivity; some silt and fine sand of low hydraulic conductivity.
Lloyd aquifer	300	Sand and gravel of moderate hydraulic conductivity; some clayey material of low hydraulic conductivity.
Bedrock	---	Crystalline rock of very low interstitial hydraulic conductivity.

[1] Nomenclature after Cohen, Franke, and Foxworthy (1968).

TABLE 2.—*Gross pumpage in selected subareas of Long Island, N.Y., 1960–68*

[Data from the New York State Department of Conservation, Division of Water Resources]

Year	Pumpage (million gallons per day)				
	Nassau County	Queens County	Study area (fig. 1)	Mill Road well field	Long Beach
1960	146	67	35	4.9	5.6
1961	153	71	35	5.0	6.2
1962	172	74	40	5.1	7.1
1963	180	77	42	5.2	6.4
1964	194	78	46	5.6	6.8
1965	209	78	45	5.1	7.2
1966	215	75	47	5.0	7.6
1967	181	73	45	4.5	7.2
1968	208	78	50	5.0	8.0

Four bodies of salty ground water are found near and beneath parts of the study area—a shallow body in the upper glacial aquifer, an "intermediate wedge" that extends downward from the Gardiners Clay through the Jameco aquifer and into the upper part of the Magothy aquifer, a "deep wedge" that locally is in the Jameco aquifer but mainly is in the lower and middle parts of the Magothy aquifer, and a wedge in the Lloyd aquifer (Lusczynski and Swarzenski, 1966, p. F1 and pl. 3).

The shallow salty ground water is associated with, and is more or less freely connected with, the salty bays and estuaries and with the Atlantic Ocean. The intermediate and deep wedges thicken appreciably and ultimately merge in a seaward direction. Little is known about the wedge of salty ground water in the Lloyd aquifer except that it is believed to be seaward of the barrier beaches in the study area (see below). The three deepest wedges are moderately to highly confined (the salty ground water is under artesian pressure), and are, in one manner or another, hydraulically connected with the sea.

declined from 1960 to 1969. In well Q1237, the decline in head is probably related to a widespread cone of depression, more than 10 square miles of which is below sea level, in southern Queens County. The landward encroachment of salty ground water in the area is thought to be fairly widespread (Soren, 1970). A much smaller cone of depression exists near well N6581, which partly reflects intensive pumping at the Mill Road well field. The salt-water encroachment seems to be limited to a small tongue of salty ground water in the immediate vicinity of the well field.

The increased chloride content in outpost well N6701 is mainly related to intensive pumping on Long Beach, which in turn is causing salty ground water in the Raritan clay to move downward toward the underlying Lloyd aquifer. To date, no firm evidence is available to conclude that salty ground water has invaded the Lloyd aquifer beneath Long Beach (either laterally or by downward leakage from the Raritan clay), except locally by downward flow through several abandoned wells having ruptured casings.

The positions of the landward limits of the intermediate and deep wedges of salty ground water as shown in figure 2 are those given by Lusczynski and Swarzenski (1966, pl.5, and fig. 12), and none of the presently available data can be used as a basis for shifting these positions either landward or seaward. In other words, if the toes of the wedges have moved landward since 1960, as they probably have locally (for example, in the vicinities of wells Q1237 and N6581), the coarseness of the network of available sampling points presently precludes a more exact delineation of the positions of the toes of the wedges and a clear recognition of movement of the wedges since 1960.

Finally, the data obtained since 1960 do not contradict the conclusions of Lusczynski and Swarzenski (1966, p. F56 and F71–72) that: (1) "The present (1961) occurrence, position, alignment, and even the sizable thickness and width of the zone of diffusion of the deep wedge of salt water as well as the intermediate wedge, therefore, are phenomena attributable mainly to natural conditions that prevailed long before the start of ground-water development in the report area;" (2) regionally, the deep wedge of salty ground water, "***is apparently moving no faster than 10 feet a year;" and (3) the intermediate wedge of salty ground water, "***is apparently moving landward at less than 10 to 20 feet a year."

REFERENCES

Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York Water Resources Comm. Bull. 62, 117 p.

Cohen, Philip, Franke, O. L., and McClymonds, N. E., 1969, Hydrologic effects of the 1962–66 drought on Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1879–F, 18 p.

Franke, O. L., 1968, Double-mass-curve analysis of the effects of sewering on ground-water levels on Long Island, New York *in* Geological Survey Research 1968: U.S. Geol. Survey Prof. Paper 600–B, p. B205–B209.

Lusczynski, N. J., 1961a, Filter-press method of extracting water samples for chloride analysis: U.S. Geol. Survey Water-Supply Paper 1544–A, 8 p.

——— 1961b, Head and flow of ground water of variable density: Jour. Geophys. Research, v. 66, no. 12, p. 4247–4256.

Lusczynski, N. J., and Swarzenski, W. V., 1960, Position of the salt-water body in the Magothy(?) Formation in the Cedarhurst-Woodmere area of southwestern Nassau County, Long Island, N.Y.: Econ. Geology, v. 55, no. 8, p. 1739–1750.

——— 1962, Fresh and salty ground water in Long Island, New York: Am. Soc. Civil Engineers Proc. v. 88, no. 3207, p. 173–194.

——— 1966, Salt-water encroachment in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–F, 76 p.

Perlmutter, N. M., and Crandell, H. C., 1959, Geology and ground-water supplies of the southshore beaches of Long Island, N.Y.: New York Acad. Sci. Annals. v. 80, art. 4, p. 1060–1076.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southeastern Queens Counties, Long Island, N.Y.: U.S. Geol. Survey Water-Supply Paper 1613–A, 205 p.

Perlmutter, N. M., Geraghty, J. J., and Upson, J. E., 1959, The relation between fresh and salty ground water in southern Nassau and southeastern Queens Counties, Long Island, New York: Econ. Geology, v. 54, no. 3, p. 416–435.

Soren, Julian, 1970, Ground-water and geohydrologic conditions in Queens County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 2001–A. [In press]

Swarzenski, W. V., 1959, Determination of chloride in water from core samples: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 8, p. 1995–1998.

The landward extent of the intermediate and deep wedges of salty ground water, as mapped by Lusczynski and Swarzenski in 1961 (1966, fig. 5), is shown in figure 2. Sufficient data were not available in 1961 and are not presently available to map the landward limits of the other bodies of salty ground water accurately.

Mixtures of fresh and salty water form so-called zones of diffusion that separate the fresh and highly salty ground water in the study area. According to Perlmutter and Geraghty (1963, p. A92), the chloride content of the zones of diffusion on Long Island ranges from 10 to 40 mg/l (milligrams per liter) on the fresh-water sides to about 18,000 mg/l on the salt-water sides. Lusczynski and Swarzenski (1966, p. F19–F20) state that the chloride content of fresh ground water on Long Island is about 10 mg/l or less and that, "***a chloride concentration of more than 40 ppm [mg/l] in shoreline areas is assumed to indicate contamination by salty water."

CHLORIDE CONTENT OF WATER FROM WELLS

The chloride content of water from the outpost wells from 1960 through 1969 is listed in table 3. Significant trend-indicating changes in chloride content were noted in only 3 of the 30 wells—wells N6581, N6701, and Q1237.

Well N6581 is screened in the zone of diffusion near the leading edge of the deep wedge of salty ground water (fig. 2). The well is near the southern margin of the Mill Road well field, where pumpage during the past decade (table 2) has averaged about 5 mgd (million gallons per day). The moderately intensive local pumpage, a continual increase in regional pumpage, regional effects of a severe drought in 1962–66 (Cohen and others, 1969), decreased recharge resulting from urban development, and perhaps to some extent the effects of sewering in the area (Franke, 1968) have resulted in a decline in the water level in the well of about 2

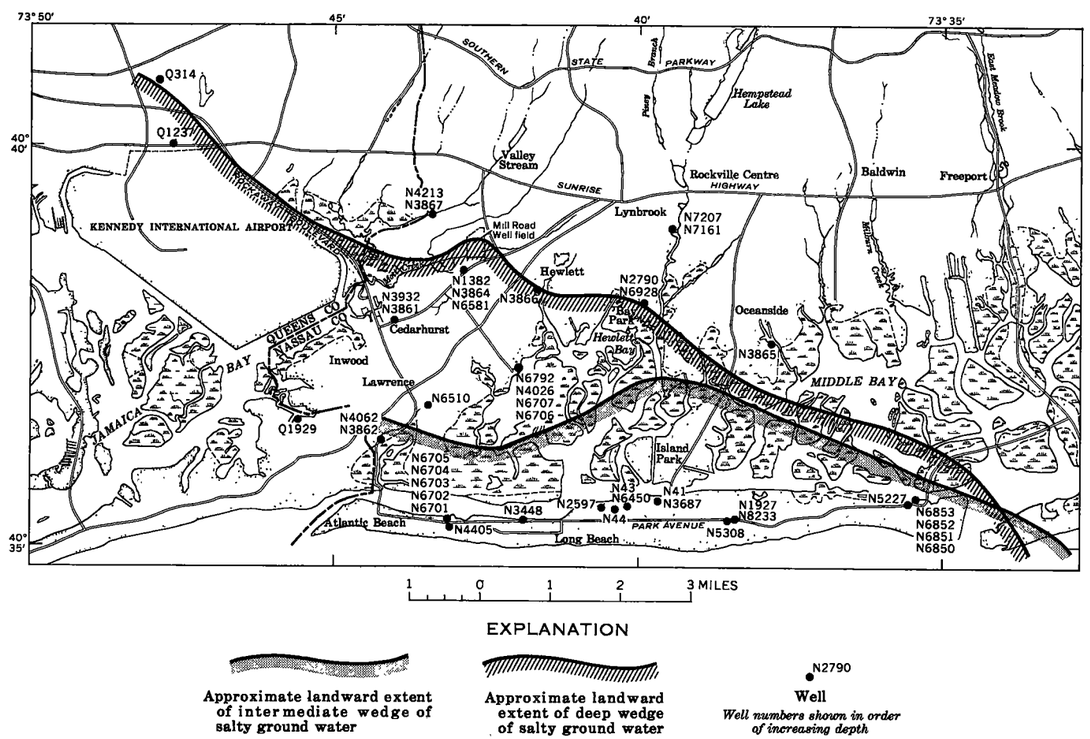


FIGURE 2.—Location of selected wells and the landward extent of the intermediate and deep wedges of salty ground water in southern Nassau and southeastern Queens Counties, Long Island, N.Y. Position of deep and intermediate wedges of salty ground water after Lusczynski and Swarzenski (1966, fig. 5).

TABLE 3.—*Chloride content of water from outpost wells in southern Nassau and southeastern Queens Counties, Long Island, N.Y.*

[Hydrogeologic units: Qug, upper glacial aquifer; Qg, Gardiners Clay; Qj, Jameco aquifer; Km, Magothy aquifer; Krc, Raritan clay. Analyses by several agencies. Rounding of data and use of decimals partly reflect the policy of the reporting agency]

Well No.	Hydrogeologic unit tapped	Depth of screen below sea level (feet)	Chloride (milligrams per liter)						
			1960	1961	1962	1963	1965	1967	1969
N1382	Qj	168–188	---	---	---	5	7	3.5	---
N2790	Km	535–557	3	4	4.5	5	5	3.3	3.0
N3861	Km	515–526	15,500	---	16,500	---	15,600	15,000	15,500
N3862	Km	289–299	---	---	---	2,200	2,030	2,000	2,000
N3864	Km	455–466	---	---	---	5.0	---	2.8	3.5
N3865	Km	548–558	4	---	---	5	---	4.1	5.5
N3866	Km	395–405	4	---	---	---	---	---	4.6
N3867	Km	499–509	5	---	---	5	6	3.8	4.0
N3932	Qj	165–169	5	---	---	5	5	3.7	3.8
N4026	Km	144–148	5.8	---	---	5	5	2.4	4.1
N4062	Qg	130–135	40	---	33	26	24	24	25
N4213	Qj	125–129	4	---	---	5	---	6.8	5.7
N6510	Km	447–452	14,500	---	14,600	14,200	11,840	---	---
N6581	Km	565–575	8,520	8,710	9,100	9,100	9,640	9,720	11,000
N6701	Krc	811–821	2,000	3,800	4,600	4,500	5,320	7,800	8,110
N6702	Km	656–666	15,800	15,900	16,000	15,000	14,700	16,000	16,000
N6703	Km	457–467	4,830	6,000	6,100	6,300	5,280	5,600	5,870
N6704	Km	273–283	9	8	7	8	6.0	7.0	6.6
N6705	Qj	136–146	12,200	12,500	11,900	11,000	10,800	12,200	12,400
N6706	Km	618–623	15,000	15,000	15,100	15,200	14,200	15,500	---
N6707	Km	487–497	1,150	1,400	1,700	1,600	1,420	1,400	1,580
N6792	Qug	42–44	---	---	6	7	---	6.1	7.9
N6850	Km	891–902	106	111	109	102	121	110	111
N6851	Km	544–549	3.6	6	6	6	---	4.0	4.0
N6852	Km	251–256	8,900	9,200	8,600	8,300	8,000	8,700	8,600
N6853	Km	120–125	4	4	4.5	5	---	3.6	3.4
N6928	Krc	710–720	13	---	11	12	---	13	12
N7161	Km	654–659	---	5	---	5	8	4	3.8
N7207	Km	87–90	---	---	4.5	6	5	4.3	3.7
Q1237	Qj	178–202	34	---	---	54	68	---	112

feet[1] since 1960. Accompanying the decline in water level, the chloride content of water in the well increased from 8,520 mg/l in 1960 to 11,000 mg/l in 1969.

Well Q1237, which is screened in the Jameco aquifer, taps the zone of diffusion near the upper part of the deep wedge of salty ground water. The water level in the well declined about 3 feet since 1960, to a point about 3 feet below sea level in 1969. During the same period the chloride content increased from 34 mg/l to 112 mg/l (table 3).

The chloride content of water from well N6701, which also taps the zone of diffusion, increased from 2,000 mg/l in 1960 to 8,110 mg/l in 1969. The well is screened near the bottom of the Raritan clay, very close to the base of the deep wedge of salty ground water (Lusczynski and Swarzenski, 1966, pl. 2, sec. *A–A'*). Since 1960, the water level in this well declined about 4 feet, to a point about 8 feet above sea level in 1969. To some extent, all the regional factors that affected the water level in well N6581 probably also affected the water level in this well. However, local pumpage from the Lloyd aquifer, which is only about 10–20 feet beneath the screen of well N6701, probably was the major cause of the decline.

The chloride content of water from selected public-supply, industrial, and private wells is listed in table 4. The first group of 12 wells listed, wells N41–N8233, are public-supply or abandoned public-supply wells on Long Beach, the barrier beach along the south shore of western and central Nassau County, and all tap the Lloyd aquifer. Most of the water in the upper glacial and Magothy aquifers beneath Long Beach is salty. However, water in the underlying Lloyd aquifer is fresh and, therefore, that aquifer is the sole source of fresh water for the communities on Long Beach. Pumpage on Long Beach increased from 5.6 mgd in 1960 to 8.0 mgd in 1968 (table 2).

[1] All water levels and changes in water levels in wells described in this report are expressed in terms of equivalent fresh-water heads (Lusczynski and Swarzenski, 1966, p. F41).

The chloride content of water from 10 of the 12 wells in the group has been less than 15 mg/l since 1960, and the chloride content of the water from the 10 wells showed no particular upward or downward trend during the period 1960–69. Prior to 1960, the chloride content of water from well N41 was as high as 80 mg/l, but since 1960 it has decreased steadily to 5.6 mg/l in 1968. The casing of the well reportedly had failed (presumably because of rusting), and salty water was entering the well from one of the shallower aquifers. The ruptured casing was repaired in 1962. Nonetheless, the well was abandoned that same year, and since then has been pumped infrequently only to obtain samples for chemical analyses.

Well N1927 also was abandoned because a ruptured casing allowed salty ground water from the shallower aquifers to enter. Well N8233, which is about 100 feet from abandoned well N1927, was constructed as a replacement well; the chloride content of water from this well is only 4.4 mg/l.

Well Q314 is of particular interest because Perlmutter and Geraghty (1963, pl. 5) and Lusczynski and Swarzenski (1966, pl. 5) showed the leading edge of the deep wedge of salty ground water to be at or near the well in 1961. In 1940, the chloride content of water from the well was about 5 mg/l, and it increased at a fairly steady rate to about 20 mg/l in the late 1950's. Since 1960, it has fluctuated by about 1–3 mg/l, and in 1969 it reportedly was 2 mg/l greater than in 1960 (table 4). This slight increase in chloride content obviously cannot be considered to be indicative of significant landward movement of the wedge of salty ground water in the vicinity of the well since 1960.

A marked rise in chloride content, from 17 mg/l in 1961 to 1,300 mg/l in 1969, was noted in well Q1929 (table 4). The shallower aquifers in the vicinity of the well largely contain salty ground water. Down-hole photographic equipment was used to determine if a ruptured casing was allowing salty ground water to leak downward into the Lloyd aquifer. No break was found in the casing; however, a recent detailed chemical analysis indicates that the salty ground water pumped from the well apparently contains a small amount of detergent constituents (0.17 mg/l), which is probably characteristic of much of the shallow ground water in the area. Detergent constituents are not found in water from the Lloyd aquifer where that aquifer is more than several hundred feet below the water table, except in the vicinity of wells that are known or suspected to have ruptured casings. Accordingly, despite the negative evidence furnished by photographs, the increase in the chloride content of water from well Q1929 is believed to be related largely or entirely to leaks in the casing rather than more widespread salt-water encroachment into the Lloyd aquifer.

CONCLUSIONS

Increases in the chloride content of water from outpost wells Q1237 and N6581 from 1960 to 1969 are believed to have been caused by the landward movement of parts of the deep wedge of salty ground water beneath southern Nassau and southeastern Queens Counties. The heads in both wells

TABLE 4.—*Chloride content of water from selected production wells on Long Island, N.Y.*

[Hydrogeologic units: Qj, Jameco aquifer; Krl, Lloyd aquifer. Data largely from Nassau County Health Department. Rounding of data and use of decimals partly reflect the policy of the reporting agency]

Well	Hydrogeologic unit tapped	Depth of screen below sea level (feet)	Chloride (milligrams per liter)									
			1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
N41	Krl	1,190–1,250	24.8	19.2	16.8	---	12.0	7.4	8.0	6.2	5.6	---
N43	Krl	1,188–1,259	5.8	2.4	5.6	6.8	6.0	5.8	---	---	---	---
N44	Krl	1,184–1,254	9.8	6.2	8.0	8.8	8.4	7.5	6.2	7.2	7.2	8.2
N1927	Krl	1,149–1,209	2.0	---	---	12.4	11.8	41.0	---	---	---	---
N2597	Krl	1,169–2,129	6.0	3.8	7.2	6.4	7.4	7.6	7.4	6.6	6.0	6.2
N3448	Krl	1,187–1,227	9.0	---	9.0	7.8	8.6	9.0	8.2	10.4	8.6	8.4
N3687	Krl	1,190–1,240	4.8	3.6	5.4	4.8	---	5.0	6.2	5.0	4.6	5.2
N4405	Krl	991–1,061	10.2	---	11.4	9.4	11.8	11.0	10.4	12.8	11.0	12.6
N5227	Krl	1,190–1,250	2.0	2.6	---	3.2	2.6	3.6	3.6	2.2	2.0	3.2
N5308	Krl	1,150–1,210	3.4	---	4.8	2.8	3.2	2.9	3.0	3.0	4.2	6.8
N6450	Krl	1,210–1,270	5.0	---	6.2	5.8	5.6	6.4	5.6	6.0	4.8	5.8
N8233	Krl	1,170–1,220	---	---	---	---	---	---	---	---	---	4.4
Q314	Qj	209– 269	19	19	18	18	19	18	18	20	20	21
Q1929	Krl	961–1,012	---	17	16	18	---	65	180	---	215	1,300

GROUNDWATER (L.I.)

RECEIVED
JUL 28 1967
U. S. GEOLOGICAL SURVEY
MINEOLA, N. Y.

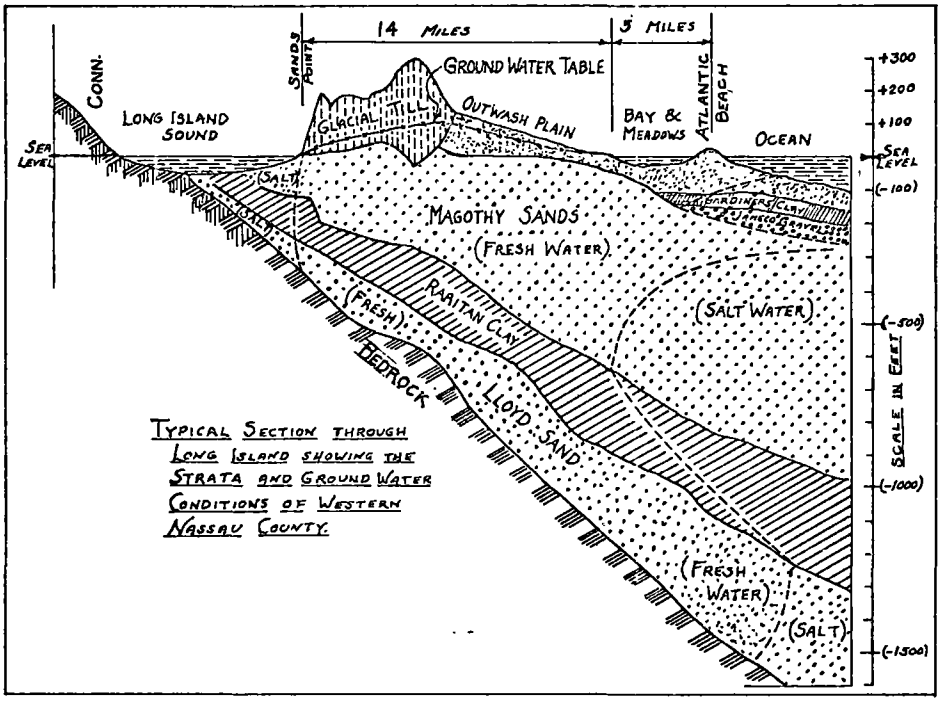
GES

THE GROUND WATER SITUATION IN NASSAU & SUFFOLK COUNTIES, LONG ISLAND, N.Y.

A DISCUSSION PRESENTED BEFORE
THE LONG ISLAND ASSOCIATION OF COMMERCE & INDUSTRY
At The Breakfast Meeting On July 18, 1967

by

ANGUS D. HENDERSON
HENDERSON & CASEY, CONSULTING ENGINEERS
WESTBURY, N.Y.



PROPERTY OF U. S. GEOLOGICAL SURVEY
MINEOLA OFFICE LIBRARY

WHAT IS THE SOURCE OF LONG ISLAND'S WATER SUPPLY?

Long Island's water supply is drawn from a vast underground reservoir fed entirely by the rain which falls on the surface of the island. Because no water-bearing beds extend under Long Island Sound, there exist no natural connections between the island's water resources and mainland's. Long Island HAS its OWN water.

Nassau and Suffolk Counties secure their entire water supply from the island's ground water reservoir. About half of Queens County draws upon this source. The rest of Queens and all of Brooklyn is served by New York City's aqueduct system.

The annual rainfall on Long Island averages about 42 or 43 inches per year on the catchment area of Nassau and Suffolk Counties. This is equivalent to about 730 million gallons per year (or an average 2 million gallons per day per square mile). Rainfall during drought periods is much less. The average rainfall during the recent five-year drought has only been 33½ inches, or about 78% of normal.

HOW MUCH OF THE RAINFALL PERCOLATES INTO THE GROUND?

Most investigators assume that the present time about 50%, or an average 1 million gallons per day square mile, percolates into the ground. The amount of percolation varies greatly on the different parts of Long Island. On the south shore as much as 1¼ million gallons per day per square mile reaches the ground water table, while on the north shore the percolation rate may be as low as 400,000 gallons.

The difference is caused by the nature of the ground surface. On the south shore the surface is mostly a loose, pervious sandy loam and the land slopes gently. Rain percolates easily into this material and the run-off is slight. On the north shore, much of the surface is a tight clay loam and the surface slopes are much steeper. Consequently, in this area a larger part of the rainfall becomes surface run-off.

The amount of percolation is also affected by the duration and intensity of the rainfall. Little, if any percolation occurs from a light, short rain on dry soil; but a heavy rainfall of long duration, on an already saturated surface, may result in percolation of as much as 85% of the rainfall in certain favorable areas.

Thirty to forty per cent of the rainfall is returned to the atmosphere through evaporation and transpiration (the life process of plants and grasses).

HOW MUCH OF THE AREA OF NASSAU COUNTY IS AVAILBLE FOR PERCOLATION OF RAINFALL?

The total area of Nassau County is about 285 square miles, but part of this (low-lying islands and beaches on the south shore) is not available for percolation. The area receptive to percolation (catchment area) totals about 200 square miles. With an average percolation rate of 1 million gallons per square mile, the total percolation into the underlying water-bearing beds of Nassau County is about 200 million gallons daily.

HOW MUCH OF THE AREA OF SUFFOLK COUNTY IS AVAILBLE FOR PERCOLATION OF RAINFALL?

The total area of Suffolk County is more than 900 square miles, but part of this (low-lying islands and beaches) is not available for percolation. The catchment area can be safely estimated at about 730 square miles. With an average percolation rate of 1 million gallons, the total percolation into the underlying water-bearing beds of Suffolk County would be about 730 million gallons daily.

IS THERE A DIFFERENCE BETWEEN TOTAL PERCOLATION INTO THE GROUND AND "SAFE YIELD"

Yes. Estimates of "safe yield" must be much more conservative, and cannot consider generalities such as an average percolation rate of 1 million gallons per square mile (which is only a rough average of the differing percolation rates on the various land areas). In estimating "safe yields" it is necessary to consider the surface geology of the island, and to use conservative figures for the average annual replenishment from rainfall.

HOW DOES THE SURFACE GEOLOGY AFFECT THE PERCOLATION RATES AND THE "SAFE YIELD"?

Twice, during comparatively recent geologic time, Long Island was invaded by continental glaciers, which left behind them when the ice melted, two terminal moraines (the Harbor Hills and Ronkonkoma Moraines) and the ground moraines behind them. These moraines are mixtures of sand, clay, and silt, with some boulders, and are relatively impermeable, forming a partial barrier to percolation. In a general way, the moraines cover the northern half of the island with a mantle of clay and silt.

Percolation rates in the moraine areas have been estimated by various investigators at from 0.4 to 0.8 million gallons daily per square mile. In the estimates which follow, the percolation rate in the moraines has been assumed at 0.5 million gallons daily per square mile.

The area north of the terminal moraines, and between the Harbor Hill and Ronkonkoma terminal moraines, is covered with ground moraine, as previously described.

The area to the south of the terminal moraines is known as "outwash plain," and this outwash plain was covered by sediments deposited by running water travelling from the melting front of the glaciers toward the sea.

These sediments covered roughly the southern half of the island. They consist, essentially, of uniformly classified fine gravels and medium to coarse sands, almost entirely free of clays and silts, and with extremely high permeability.

Various investigators have assigned percolation rates ranging from a low of 1.0 million gallons daily, to more than 1.25 million gallons daily, to the sediments composing the surface of this outwash plain. In the estimates which follow, an average value of 1.0 million gallons daily of percolation per square mile has been assigned to the outwash plain area. It is probably higher.

WHAT ARE THE FIGURES ADOPTED IN THIS MEMORANDUM FOR "SAFE YIELD"?

1.0 million gallons daily of percolation per square mile in the outwash plain areas, and 0.5 million gallons daily of percolation per square mile in the moraine areas.

In eastern Suffolk, at the present time, there is some question as to whether or not these figures can actually

be obtained. Descriptions relating to the special conditions affecting eastern Suffolk "safe yield" will be found in the detailed discussions of the Townships of Riverhead, Southold, Southampton, East Hampton and Shelter Island.

However, based on the overall criteria of outwash plain and moraine conditions, a "safe yield" from Nassau County of 165 million gallons daily can be counted upon. Similarly, a "safe yield" from western Suffolk of 343 million gallons daily is the minimum dependable supply.

The "safe yield" from Easter Suffolk may be as low as 107 million gallons daily, or as high as 175 million gallons daily.

For Nassau and Suffolk counties, developed as a combined unit, the "safe yield" is between 615 and 683 million gallons daily. This will support a population of about 6,500,000 people at a consumptive use of 100 gallons per day per person.

(See the discussions which follow concerning population growth and consumptive use.)

WHAT ARE THE WATER-BEARING BEDS UNDER LONG ISLAND?

There are three main water-bearing beds. The uppermost bed is known as the Glacial. On the south shore it is immediately beneath the surface topsoil and furnishes an excellent source of water. However, there are very few locations on the north shore where the glacial strata is a good source of water supply, as on the north shore these strata are mainly glacial clay and glacial till.

Beneath the Glacial lies the Magothy strata, which extends under virtualy all of Long Island and comprises the island's most important source of water supply. These beds have a thickness of about 200 feet on the north shore and become progressively thicker toward the south. At Wantagh, they have a thickness of about 700 feet, and at Jones Beach, 1,000 feet. At Quogue, they may be as thick as 1,400 feet.

Beneath the Magothy is a bed of clay (100 feet to 300 feet thick) known as Raritan clay. Some water passes through this clay to the lowest water-bearing bed, the Lloyd sand, which lies immediately above bedrock. Because percolation into the Lloyd is severely limited by the overlying Raritan clay, only limited quantities of water can be withdrawn from the Lloyd sand.

DO THE SUBSURFACE STRATA OF LONG ISLAND CONSTITUTE A TRUE RESERVOIR?

Yes, and an enormous one. As the rain percolates into the ground it reaches the ground water table (the ground water table is the top of the zone of saturated sands) and flows laterally toward the sea and sound.

At the Queens County line, in the center of Nassau County, the water table is about 40 feet above mean sea level. Just north of Hicksville it is about 80 feet above mean sea level, and at the shore lines of Nassau County it is everywhere at, or just above, mean sea level.

The sands (subsurface strata) of Long Island are porous. Thirty to forty per cent of their total volume below the ground water table is filled with fresh water.

The average thickness of the water-bearing beds is about 600 feet. If we use an area of 200 square miles, Nassau County's catchment, a depth of 600 feet and a water content of one-third the total volume, we find that 8,000 billion gallons of fresh water are stored in the sands under Nassau County. Of this amount, about 500 billion gallons are stored above sea level! In Nassau and Suffolk counties combined, more than, 1,500 billion gallons of fresh water are stored above sea level.

The presence of this vast storage reservoir makes it possible to design water supply works based on the average rainfall over long periods of time. When drought conditions prevail, the water withdrawn from storage reservoir supplements the rainfall. A return of average and above rainfall — with similar consumption levels prevailing — replenishes this natural reservoir.

HOW MUCH WATER DOES NASSAU COUNTY NEED?

At the present time, the consumption of water from the public systems of Nassau County is about 100 gallons per person per day, and this per capita consumption is slowly increasing.

Certain industries and commercial establishments own and operate their own wells.

Total pumpage in Nassau County in 1965 was estimated at 170 million gallons daily, of which about 87 million gallons daily was consumptive use (i.e.—net withdrawal).

HOW MUCH WATER DOES SUFFOLK COUNTY NEED?

At the present time, the consumption of water from the public systems of Suffolk County is about 80 gallons per person per day, and this per capita consumption is slowly increasing.

Total pumping in Suffolk County in 1965, including water used for irrigation on farms, was estimated at 123 million gallons daily, of which about 35 million gallons daily was consumptive use.

THESE ARE AVERAGES FIGURES. WHAT HAPPENS DURING A HOT DRY SUMMER?

During any year, much more water is used during the summer months than during the winter months, and when the summer is hot and dry, even more water is needed. During a hot dry summer month the average daily use of water may be twice the average for the year, and on some days even as much as four times the yearly average. During the early evening hours of such a day, the hourly consumption rate may be as much as ten times the average hourly rate for the year.

ARE THE WATER SUPPLY RESOURCES OF NASSAU COUNTY ADEQUATE FOR TODAY'S NEEDS?

Yes. At the present time (using 1965 figures) carefully designed and operated works could withdraw an average of about 200 million gallons daily. The public supply pumpage is about 142 million gallons daiy, and the industrial pumpage about 28 million gallons daily.

Of the total pumpage (170 MGD) about 83 million gallons is returned to the ground water each day, so that actual water consumed is about 87 million gallons daily. The resource, therefore, has a surplus capacity of about 100 million gallons daily at the present time.

ARE THE WATER SUPPLY RESOURCES OF SUFFOLK COUNTY ADEQUATE FOR TODAY'S NEEDS?

Yes. At the present time, carefully designed and operated works could withdraw an average of at least 450 million gallons daily. The public supply pumpage is about 70 million gallons daily and the industrial pumpage about 35 million gallons daily. Agricultural irrigation use averages about 18 million gallons daily.

Of the total pumpage (123 MGD) about 88 million gallons daily is returned to the ground, so that the actual water consumed is about 35 million gallons daily. The resource, therefore, has a surplus capacity of more than 400 million gallons daily at the present time.

WHAT ABOUT THE FUTURE?

Nassau County's water supply must be considered in relation to its population, which is steadily growing. With this growth, new problems will present themselves; several factors will act to reduce the available source of water supply.

Thirty years ago most of Nassau County was farm land. Now it is really a thriving suburban complex.

In the past, sewer systems were almost non-existent. Water used by the people was returned to the ground, and there was little net loss. Today, about 40% of the population of Nassau County has sewer service and by the year 2000 at least 80% will be so served.

Water discharged through sewers reaches salt water without helping to maintain ground water levels.

Proposed sewer systems in Suffolk County will cause the same heavier consumptive use that is occurring in Nassau County.

Increased growth means more buildings, more roads, more paved areas and more storm sewers. Thus, surface run-off of the rainfall will increase and the amount of rain entering the ground to become available as water supply will decrease.

And, meanwhile, the population and the demand for water continues to grow!

WHAT IS BEING DONE TO CONSERVE, AND SAVE AS MUCH AS POSSIBLE, OF THE SEWER AND STORM WATER RUN-OFF?

Storm water is being intercepted and returned to the ground in large quantities by means of recharge basins. These are the artificially dug ponds which dot the landscape of Nassau County. Most of them are normally dry, open pits into which storm sewers discharge during rains, and thereafter, the water which they hold slowly percolates into the ground. There are now about 600 such recharge basins in Nassau County, and a great number in Suffolk.

In cooperation with the Federal Government, experiments are now being conducted on the south shore in an endeavor to find the best ways to return treated and purified waste waters to the ground. The problem to be solved is not to find a way to do this; it has been accomplished in many areas, including Long Island. Rather, the problem is simply that of finding the best ways to do it.

WHAT IS THE APPARENT FUTURE SITUATION, SAY FOR THE YEAR 2000, IN NASSAU COUNTY?

Fram data presently available, it appears that our water source will be able to furnish about 165 to 190 million gallons daily in that year, and that the consumptive use of water will be about 217 million gallons daiy.

The resulting water deficit will be made up in one of three possible ways:

(a) Desalinization of sea water

(b) Purifying waster water and injecting it into the ground

(c) Importing water via pipe lines from outside the county

WHAT IS THE APPARENT FUTURE SITUATION, SAY FOR THE YEAR 2000, IN SUFFOLK COUNTY?

Assuming county-wide sewer construction in Western Suffolk begins in 1970 and in Eastern Suffolk in 1985, and progresses at the same rate as in Nassau County, and assuming certain high rates of population growth (more detailed descriptions of these assumptions follow), Suffolk County will have a consumptive use of water in the year 2000 of about 300 million gallons daily. The resource can furnish at least 450 million gallons daily.

If the forecasted growth in consumptive use continues, the capacity of the resource may be exceeded by the year 2020.

WHAT SPECIAL PROBLEMS NOW EXIST?

Long Island is entirely surrounded by salt water. The pressure of the fresh water in the sands is the agent which keeps the salt water out. When a high capacity well near the shore line is heavily pumped, the pressure of the fresh water is reduced and that location becomes endangered by the possibility of salt water intrusion. Certain areas (Great Neck Peninsula, Port Washington Peninsula, the Hewlett area on the south shore, and the City of Long Beach) are already facing this problem. As the demand for water increases, and total withdrawal increases, more and more shore areas must face this problem.

In Queens County, heavy withdrawals in the Woodhaven and Jamaica areas have lowered the ground water.

In Woodhaven, water levels are now some 15 feet below sea level. Salt water is thus coming into the sands and contaminating the fresh water supply with salt.

The effect of heavy pumpage in Woodhaven and Jamaica is felt in western Nassau County. As a result of this, and also of heavy local withdrawal, water levels in the New Hyde Park-Floral Park area have been lowered 15 to 20 feet. However, there is no foreseeable danger of any salt water intrusion in this area — it is far from salt water, and the water table is still 40 feet above sea level.

ARE THERE SOLUTIONS TO THESE SPECIAL PROBLEMS?

Yes. The immediate solution is restricted pumping near the shores, increased pumping inland near the center of the island, and a strong system of large diameter transmission water mains to carry water from the center of the island to the shore areas. In the Town of North Hemp-

Whee!

stead, the Manhasset-Lakeville Water District and the Port Washington Water District are already using such mains. This allows for the transportation of large quantities of water from inland wells to the shore.

Eventually, many of the wells near the shore may have be shut down and purified waste waters injected into the sands near the shore, in order to build up a fresh water barrier and thus keep the salt water out. Future well development should be concentrated inland, away from the shore line.

WHAT BODY REGULATES WITHDRAWALS OF GROUND WATER ON LONG ISLAND?

The Water Resources Commission of the State of New York. A permit is required for all wells constructed, and if their capacity is more than 45 gallons per minute, a formal hearing on the application is held. This requires formal proceedings for all public water supply wells and almost all of the privatey-owned industrial and commercial wells.

The effects of the proposed new well on the resource, and on the needs for water supply in the area, are carefully studied and used by the Commission when determining whether or not to issue permission for construction of the new well.

In general, applications for public supply wells are approved, except when they are to be located in areas which are considered critical. Applicants for commercial and industrial wells, and for wells whose water is used for air-conditioning and refrigeration, are usually required to return all water pumped back into the ground in an uncontaminated condition. This is accomplished on the applicant's own premises by constructing a second well through which the used water is injected into the ground. This practice is an extremely effective conservation measure.

Much of the data in this memorandum has been abstracted from reports of the Water Resources Commission.

WHAT HYDROGEOLOGICAL FACTORS MUST BE CONSIDERED WHEN ANALYZING THE CONDITIONS IN LOCAL AREAS?

As the deeper-water-bearing beds are essentially continuous under all of Nassau and Suffolk counties, and form an enormous reservoir, rain which falls on, and percolates into the ground in one area travels slowly, laterally, to other areas where it may be pumped out. Pumping operations change the pressures in the aquifers and pumping in one area increases the flow toward it from other areas.

As an example, a well in the moraine area pumping from the Magothy strata may be securing a large part of its supply from percolation which took place months or years before in the outwash plains several miles to the south.

Movement of ground water pays absolutely no respect to political boundaries.

WHAT IS THE SITUATION IN THE TOWN OF HEMPSTEAD, NASSAU COUNTY?

With a catchment area of 80 square miles, all of which is outwash plain with an average permeability of 1.0 MGD/square mile, the safe yield is 80 MGD. At forecasted rates of growth, the consumptive use will be exceeded before 1980.

Salt water intrusion is already beginning in the extreme southwest corner of the Town (in the Hewlett, Cedarhurst, Lawrence area) as a result of the extremely heavy mithdramals in the southern half of adjoining Queens County.

Additionally, the Long Beach-Atlantic Beach area may soon be in danger of salt intrusion as upland pumping reduces the fresh water pressure in the deep artesian strata. The fresh water pressure is the factor which prevents salt water moving inland in these beds.

WHAT IS THE SITUATION IN THE TOWN OF OYSTER BAY, NASSAU COUNTY?

Oyster Bay has a total catchment area of about 75 square miles, of which about 40 square miles are in moraine areas with a safe yield of 0.5 MGD/square mile and the remainder in outwash plains with a safe yield of 1.0 MGD/square mile. The safe yield of the catchment area considered as a whole, is about 55 MGD. At forecasted rates of growth, consumptive use will equal safe yield about 1990.

This forecast considers only the consumption of water within the town and does not include possible withdrawals of water by the south shore system of New York City, which, if used continuously for a year, would increase the consumptive use in the area by about 30 MGD.

Long-term use by New York City's south shore infiltration galleries could cause the consumptive use in the Town of Oyster Bay to exceed the safe yield by 1970, with the resulting danger of salt water intrusion in the Seaford-Wantagh-Massapequa area.

WHAT IS THE SITUATION IN THE TOWN OF NORTH HEMPSTEAD?

North Hempstead has a catchment area of about 45 square miles, of which about 30 square miles are moraine with a safe yield of 0.5 MGD/square mile and the remainder is outwash plain with a safe yield of 1.0 MGD/square mile. The safe yield of the catchment area in the Town of North Hempstead is estimated at 30 MGD.

At forecasted rates of growth, consumptive use will equal the safe yield by about 1990.

Local difficulties in securing sufficient water are already present in the northerly part of the moraine area. It appears that consumptive use has already reached the safe yield on both the Port Washington peninsula and the Great Neck peninsula.

Port Washington Water District has been importing water through long pipelines from the south for several years.

The Citizens Water Supply Company in Great Neck will have to do this soon.

WHAT ABOUT THE TOWN OF BABYLON, SUFFOLK COUNTY

The catchment area in Babylon Town is about 40 square miles, all in the outwash plain, with an estimated safe yield of 1.0 MGD/square mile or a total of 40 MGD.

At forecasted rates of growth, consumptive use will not exceed demand before 2020.

Sewers are necessary in the densely populated low-lying areas in the southerly part of the town.

New York City's south shore works (see Town of Oyster Bay, Nassau County discussion) could cause local salt intrusion problems in the Amityville area if they should be operated continuously.

AND HUNTINGTON TOWN, SUFFOLK COUNTY?

Huntington Town has a catchment area of about 81 square miles, of which some 54 are in the moraine area with an estimated safe yield of 0.5 MGD/square mile and the remainder in outwash plain with an estimated safe yield of 1.0 MGD/square mile.

Estimated safe yield for the Town of Huntington is 54 MGD.

At forecasted rates of growth, consumptive use will equal safe yield about the year 2000.

Certain highly built-up areas need sewers now. Other areas do not need sewers, and probably will not need them for many years.

AND THE TOWN OF SMITHTOWN?

Catchment area of about 44 square miles is almost entirely moraine with a safe yield of 0.5 MGD/square mile. Safe yield for the Town of Smithtown is estimated at 23 MGD.

At forecasted rates of growth, consumptive use will equal safe yield about 1990.

WHAT IS THE SITUATION IN THE TOWN OF ISLIP, SUFFOLK COUNTY?

The catchment area is about 85 square miles, of which only some 8 square miles are in moraine, the remainder being outwash plain. Estimated safe yield for the Town of Islip is about 81 MGD.

At forecasted rates of growth, consumptive use will equal safe yield about 2005.

WHAT IS THE SITUATION IN THE TOWN OF BROOKHAVEN, SUFFOLK COUNTY?

Of the catchment area of about 215 square miles, some 140 square miles are moraine with an estimated safe yield of 0.5 MGD/square mile and some 75 square miles are outwash plain with an estimated safe yield of 1.0 MGD/square mile. The estimated safe yield for Brookhaven Town is 145 MGD.

At forecasted rates of growth, consumptive use will equal safe yield about 2005.

ARE THE HYDROGEOLOGICAL CONDITIONS IN EASTERN SUFFOLK DIFFERENT FROM THOSE OF WESTERN SUFFOLK?

Yes. Although the deep water beds are continuous in this area, it is known that certain portions of them are filled with salt or brackish water because the pressure of the fresh water above them is not sufficient to keep the salt water out. The exact limits of the fresh water — salt water interfaces are not known, but it is believed that brackish water is present in the deep beds over a large portion of the five eastern towns, and that pumping operations might quickly increase the salt content of the deep strata.

For that reason, most of the water needed by eastern Suffolk will either have to be secured from the shallow strata near the surface, or be transported from the west through pipe lines.

Shallow ground waters are much more subject to contamination from sewage disposal and industrial wastes (cesspools and leaching fields) than are the deeper ground waters. For that reason, and in spite of its almost completely rural character and comparatively slow forecasted growth, comprehensive sewer systems may be needed in eastern Suffolk long before they are essential in western Suffolk.

ONE TOWN AT A TIME— SOUTHAMPTON TOWN, SUFFOLK COUNTY?

Catchment area of about 105 square miles is about equally divided between moraine and outwash plain. Safe yield on the basis of catchment areas is about 77 MGD, but because of the salt water problems in the deeper beds, it may really be as low as 50 MGD.

Consumptive use is not expected to equal safe yield in the foreseeable future. Nevertheless, local problems of salt water intrusion will occur, possibly within the next 20 years.

Very careful development of the ground water sources is required. (See, also, the following discussion on the Town of Riverhead.)

TOWN OF RIVERHEAD, SUFFOLK COUNTY?

The catchment area is about 57 square miles, all on moraine area. The estimated safe yield is 29 MGD, but because of salt water problems it may really be as low as 20 MGD.

At forecasted rates of growth, consumptive use will not equal safe yield in the foreseeable future, BUT, ALL THAT HAS BEEN SAID ABOUT SALT PROBLEMS AND THE NEED FOR CAREFUL DEVELOPMENT OF GROUND WATER APPLIES EQUALLY TO RIVERHEAD TOWN.

Additionally, should a bridge be built from the Town of Southold to Connecticut, much more rapid growth both in population and consumptive use can be expected, and serious water supply difficulties could be expected within 10 years after the opening of such bridge.

The situation could be very greatly improved by a dam, or series of dams, on the Peconic River, together with recharge basins or storm water spreading fields which would raise the ground water table and make more water available for use in both Riverhead and Southampton Towns.

TOWN OF SOUTHOLD, SUFFOLK COUNTY?

This town is entirely dependent upon shallow ground waters! The catchment area is all behind the Ronkonkoma moraine and a safe yield of 0.5 MGD/square mile on 25 miles of area has been assumed. Safe yield is not more than 12 MGD, and is possibly as low as 5 MGD. At pro-

jected rates of growth, consumptive use might equal safe yield about 2020, BUT—

Construction of the proposed bridge to Connecticut would cause the area to develop very rapidly; consumptive use would rise rapidly. Transportation of water from the west, reuse of purified used waters, or desalinization plants would be needed within a very few years after the opening of such bridge.

TOWN OF EAST HAMPTON, SUFFOLK COUNTY?

This town has a catchment area of about 71 square miles, half in outwash plain and half on moraine. Estimated safe yield of not more than 53 MGD, and may be as low as 30 MGD.

Although for the overall town, consumptive use will probably not equal safe yield in the immediate future, local salt intrusion is already causing problems in some areas. The entire area east of Amagansett will require transportation of water from the west as it becomes more fully developed.

Very careful development of the water supplies of this town is essential.

TOWN OF SHELTER ISLAND, SUFFOLK COUNTY?

This town is itself a small island. Only limited supplies of ground water are available, and any sizeable growth would require importation of water.

Only shallow ground water is available locally. Catchment area is about 8 square miles of moraine deposits. Safe yield does not exceed 4 MGD and may be less than 2 MGD.

It is believed that the rural character of this small, lightly populated town should be maintained, by special zoning regulations if necessary, to prevent growth.

APPENDIX A

NOTES ON THE COMPUTATION METHODS

Factors included in computing safe yield and consumptive use included:

(a) The average rainfall on Long Island.

(b) The extent and permeability of the island's catchment areas.

(c) The rate of population growth.

(d) The effect of sewer systems on a county-wide basis.

(e) Artificial recharge of the aquifers.

(f) The rate of growth of consumptive use.

In order to arrive at results believed to be fully safe, all assumptions of watershed area, permeability and recharge have been kept conservative. Conversely, although for the same reason, assumptions as to population growth and increased consumptive use have been assumed at higher rates than are likely to occur.

Inasmuch as the assumptions made are solely a matter of judgment based on available data, and could vary widely and still be reasonable, no attempt has been made to secure great mathematical precision in the forecasts.

(a) *Average Rainfall on Long Island*

Based on past records, this has been assumed at 42 to 44 inches depth per year, which equals about 2 million gallons daily per square mile.

(b) *Extent and Permeability of the Catchment Areas*

The extent of the catchment areas has been estimated very conservatively.

A small scale topographic map of the island was used as a base, and the catchment areas outlined on it. All marsh land and much other low-lying land near the shores was discounted as not useful for percolation. The outlined areas were then planimetered, by town, to determine the usable catchment area. The areas so determined are shown in Tables 2, 3 and 4.

Permeability of the outwash plain areas was assumed at 1.0 million gallons daily per square mile, even though much of the outwash plain has higher permeability, possible in some areas as high as 1,25 million gallons daily per square mile.

Permeability in the moraine areas varies greatly, depending on the nature of the moraine surface and its thickness. Where the moraine cover is thick and ground surface slopes are steep, the permeability may be as low as 0.4 million gallons daily per square mile; while in the area between the two terminal moraines, where the moraine cover is relatively thin and slopes are gentle, permeabilities in the order of 0.8 million gallons per square mile appear reasonable.

In this study an average permeability of 0.5 million gallons per square mile has been assumed for the entire moraine area.

Tables 2, 3 and 4 show the number of square miles of each type of surface and the estimated safe yield of each town's catchment area.

It must not be forgotten that there is a flow of ground water, underground, across political boundaries, and that the natural flow can be accelerated by heavy pumping in any particular area. Thus, Smithtown on the north shore, for example, could draw part of its water supply from rain falling in Islip Town on the south shore of the island.

(c) *The Rate of Population Growth*

Many careful estimates of population growth of Nassau County have been made by competent investigators, and the past record of population growth in Nassau furnishes a useful guide to what can be expected in western Suffolk.

The rate of growth of Nassau County has been applied to the western Suffolk County towns, graphically.

A generalized growth curve was prepared from the Nassau County data and transferred to each of the 5 western Suffolk towns, with a time lag as follows:

Babylon	20 years
Huntington	30 years
Islip	35 years
Smithtown	35 years
Brookhaven	50 years

. The growth curve is steepest during the earlier years and flattens in later years, so that the time delay interval acts to postpone the date when population approaches saturation and not to reduce the growth rate in the immediate future.

Curves for the western Suffolk towns begin in 1960 at the known population in that year.

Eastern Suffolk County populations have been forecast on the basis of extending their present annual percentage rate of growth into the future, as it is not believed any of them will reach a saturation point prior to 2020.

It is believed very unlikely that Suffolk County population will grow as rapidly as is indicated by these curves.

Population data taken from the curves, has been transferred to Table 1.

(d) *The Effect of Sewer Systems on a County-wide Basis*

When an area is essentially rural there are no comprehensive sewer systems and almost all water used by the inhabitants is returned to the ground through cesspools and leaching fields.

As population increases, paved streets and other paved areas reduce the surface area available for percolation, brooks and streams are straightened and improved, and storm drains are built; more water is carried away directly to the sea and percolation into the ground is reduced.

Further growth in population brings about the construction of sanitary sewer systems and the water formerly returned to the ground is carried through the sewers and discharged to the sea.

As population density increases, less and less fresh water is able to percolate into the ground and more and more of both fresh and used water is discharged directly into salt water.

(e) *Artificial Recharge of the Aquifers*

A great deal of success has been achieved in recharging water used for air conditioning and refrigeration into the ground. This is accomplished through recharge or diffusion wells and is an important conservation measure.

The recharge basins which are found throughout Nassau and western Suffolk are also quite successful in returning storm rainfall into the ground. Drainage pipes from the surrounding storm-sewered areas discharge into these basins, and the water slowly percolates into the ground. This is also an important conservation measure.

Experiments are now being conducted at the Bay Park Sewage Disposal Plant on methods of returning fully purified sewage to the deeper aquifers. It is believed these experiments will be successful.

Generally, the ground waters just beneath ground surface are subject to sewage contamination, but, in passing down through the sands, gravels and clays to the deeper aquifers, all fecal contamination is removed.

It appears entirely practical, in many areas of the island, to return sewage after tertiary treatment at comparatively small sewage plants located far from the shores, to the uppermost water-bearing strata by means of recharge basins or wells, and to pump out pure water from the lower aquifers.

(f) *The Rate of Growth of Consumptive Use*

Water used and returned to the ground is not "consumptive use," as when used and returned it does not diminish the resource.

Water taken from the ground water resource and not returned to the ground diminishes the resource and is "consumptive use." All water sent to the sea through sewers is "consumptive use."

Prior to construction of sanitary sewers, the consumptive use per person can be taken as not more than 35 gallons per person per day. This represents, mainly, evaporation and transpiration from water used to irrigate gardens and lawns. In many unsewered areas the consumptive use is probably less than 10 gallons per person per day as an annual average! Much too hi.

When an area becomes fully sewered, the consumptive use (1965) may become as high as 100 gallons per day per person.

(As a side note, the Bay Park Sewage Disposal Plant in southwestern Nassau County is discharging some 55 million gallons daily to salt water.)

Careful estimates have been made of the present and future consumptive use in Nassau County.

The consumptive use in the Suffolk County towns has been calculated graphically in the same manner as was used for populations, assuming the beginning of construction of a county-wide sewer system in the year 1970, with construction progressing generally from west to east.

Tables 2, 3 and 4 show the estimates of consumptive use for various future years.

APPENDIX B

SUGGESTIONS FOR MANAGEMENT OF THE RESOURCES

(a) *Observation Wells*

Much more data is needed on the elevations of the ground water table and of the artesian pressure in the deeper water-bearing beds, together with changes in such levels due to seasonal variations in rainfall and pumpage.

The network of observation wells now existing in Nassau County should be extended to cover all of Suffolk, and a regular program of measuring and recording the water levels in such wells should be instituted.

(b) *Outpost Wells*

Additional outpost wells, equipped with pumps, should be installed in areas where salt water intrusion can be expected, and regular chloride readings taken on such wells.

(c) *Recharge Basins*

As Suffolk County develops, every available opportunity to construct recharge basins should be utilized.

Wherever possible, storm drains when installed should discharge into recharge basins, or through holding and seepage ponds, rather than directly to the sea.

(d) *Recharge Wells (Diffusion Wells)*

The present practice of requiring industries using ground water to return all uncontaminated used water to the ground should be continued.

(e) *Sanitary Sewer Systems*

Construction of sanitary sewer systems should be restricted to areas which truly need them, such as densely populated areas, industrial parks and shopping centers.

Wherever possible, the construction of large sewage plants discharging their effluent to salt water should be avoided, as this practice is the one which most rapidly increases consumptive use.

Small plants, upland, and equipped for tertiary treatment, will permit recharging of the effluent to the shallow ground water through wells or spreading ponds.

Cesspools and leaching fields for individual houses on large plots can furnish a satisfactory method for sewage disposal into the upper sand layers of the island.

(f) *Protection of the Quality of the Water Supply*

Public water supply systems must be extended and the use of shallow private wells for individual home supplies eliminated.

Public water supplies should be restricted, wherever possible, to the Magothy strata and the other deep beds so as to eliminate the risk of pollution from sewage systems.

The time is near when all public water supplies of Long Island should be chlorinated.

(g) *Multiple Use of Land Areas*

Continuing growth is making it extremely difficult to secure plots for new wells and other waterworks structures in many sections of Long Island.

Consideration should be given to multiple use of publicly owned land. School grounds and parks could often accomodate underground well stations and underground reservoirs.

Conversely, many water supply properties could be used for needed playgrounds and little league ball fields.

COUNTY OR SECTION	TOWN	POPULATION 1960	ESTIMATED POPULATION 1970	1980	1990	2000	2010	2020
NASSAU COUNTY:								
	Hempstead	767,211	870,000	1,000,000	1,009,000	1,150,000	1,200,000	1,270,000
	North Hempstead	219,088	250,000	280,000	305,000	315,000	330,000	345,000
	Oyster Bay	313,872	360,000	460,000	560,000	630,000	680,000	715,000
GROUP TOTAL		1,300,171	1,480,000	1,740,000	1,874,000	2,095,000	2,210,000	2,330,000
5 WESTERN SUFFOLK TOWNS:								
	Huntington	126,221	215,000	345,000	485,000	620,000	710,000	750,000
	Babylon	142,309	225,000	285,000	330,000	340,000	350,000	360,000
	Smithtown	50,347	130,000	225,000	305,000	365,000	410,000	450,000
	Islip	172,959	295,000	460,000	615,000	760,000	830,000	870,000
	Brookhaven	109,900	200,000	390,000	630,000	1,180,000	1,560,000	1,900,000
GROUP TOTAL		601,736	1,065,000	1,705,000	2,365,000	3,265,000	3,860,000	4,330,000
5 EASTERN SUFFOLK TOWNS:								
	Southampton	27,095	39,000	56,000	80,000	115,000	165,000	240,000
	Riverhead	14,519	20,000	28,000	39,000	55,000	78,000	108,000
	East Hampton	8,827	13,000	20,000	30,000	44,000	66,000	98,000
	Southold	13,295	17,000	22,000	28,000	35,000	45,000	58,000
	Shelter Island	1,312	2,000	2,500	3,000	3,500	4,500	6,000
GROUP TOTAL		65,048	91,000	128,500	180,000	252,500	358,500	510,000
ENTIRE SUFFOLK COUNTY		666,784	1,156,000	1,833,500	2,545,000	3,517,500	4,218,500	4,840,000
COMBINED TOTAL FOR NASSAU AND SUFFOLK		1,966,955	2,636,000	3,573,500	4,419,000	5,612,500	6,428,500	7,170,000

TABLE 1
POPULATION PROJECTIONS

AREA	CATCHMENT AREA IN SQUARE MILES	SAFE YIELD IN MGD PER SQUARE MILE	SAFE YIELD MGD	ESTIMATED CONSUMPTIVE USE MGD — YEARS 1960	1970	1980	1990	2000	2010	2020	NOTES
HEMPSTEAD TOWN											Safe yield will be exceeded before 1980. Salt intrusion starting now in Hewlett-Cedarhurst Area. Potential salt intrusion on barrier beach.
Moraine Area	0	-	-								
Outwash Plain	80	1.0	80								
TOTAL FOR TOWN	80		80	38	65	89	109	119	127	133	
NORTH HEMPSTEAD TOWN											Safe yield reached about 1990. Great Neck and Port Washington Areas critical now.
Moraine Area	30	0.5	15								
Outwash Plain	15	1.0	15								
TOTAL FOR TOWN	45		30	11	18	26	30	34	35	41	
OYSTER BAY TOWN											Safe yield will be reached about 1990.
Moraine Area	40	0.5	20								
Outwash Plain	35	1.0	35								
TOTAL FOR TOWN	75		55	17	28	42	55	64	73	76	
NASSAU COUNTY											Safe yield will be reached about 1983. Certain local areas already critical.
Moraine Area	70	0.5	35								
Outwash Plain	130	1.0	130								
TOTAL FOR COUNTY	200		165	66	111	157	194	217	239	250	

TABLE 2
SAFE YIELD VS.
CONSUMPTIVE USE
NASSAU COUNTY AREAS

AREA	CATCHMENT AREA IN SQUARE MILES	SAFE YIELD IN MGD PER SQUARE MILE	SAFE YIELD MGD	ESTIMATED CONSUMPTIVE USE MGD — YEARS 1960	1970	1980	1990	2000	2010	2020	NOTES
BABYLON TOWN											Safe yield reached about 2020.
Moraine Area	0	0.5	0								
Outwash Plain	40	1.0	40								
TOTAL FOR TOWN	40		40	5	8	12	23	30	34	37	
HUNTINGTON TOWN											Safe yield reached about 2000.
Moraine Area	54	0.5	27								
Outwash Plain	27	1.0	27								
TOTAL FOR TOWN	81		54	5	8	18	34	54	68	77	
SMITHTOWN TOWN											Safe yield reached about 1990.
Moraine Area	43	0.5	22								
Outwash Plain	1	1.0	1								
TOTAL FOR TOWN	44		23	3	4	10	21	32	40	48	
ISLIP TOWN											Safe yield reached about 2005.
Moraine Area	8	0.5	4								
Outwash Plain	77	1.0	77								
TOTAL FOR TOWN	85		81	9	13	24	44	67	85	91	
BROOKHAVEN TOWN											Safe yield reached about 2005.
Moraine Area	140	0.5	70								
Outwash Plain	75	1.0	75								
TOTAL FOR TOWN	215		145	4	7	20	53	100	155	192	
5 WESTERN SUFFOLK TOWNS											Safe yield reached about 2005.
Moraine Area	245	0.5	123								
Outwash Plain	220	1.0	220								
TOTALS	465		343	26	40	84	175	283	382	445	

TABLE 3
SAFE YIELD VS.
CONSUMPTIVE USE
WESTERN SUFFOLK

AREA	CATCHMENT AREA IN SQUARE MILES	SAFE YIELD IN MGD PER SQUARE MILE	SAFE YIELD MGD	ESTIMATED CONSUMPTIVE USE MGD — YEARS 1960	1970	1980	1990	2000	2010	2020	NOTES
SOUTHAMPTON TOWN											Special problems - see text. Safe yield may be as low as 50 MGD.
Moraine Area	56	0.5	28								
Outwash Plain	49	1.0	49								
TOTAL FOR TOWN	105		77	1	2	2	4	8	13	24	
RIVERHEAD TOWN											Special problems - see text. Safe yield may be as low as 20 MGD.
Moraine Area	57	0.5	29								
Outwash Plain	0	1.0	0								
TOTAL FOR TOWN	57		29	1	1	1	2	4	6	11	
EAST HAMPTON TOWN											Special problems - see text. Safe yield may be as low as 30 MGD.
Moraine Area	36	0.5	18								
Outwash Plain	35	1.0	35								
TOTAL FOR TOWN	71		53	1	1	1	2	3	5	9	
SOUTHOLD TOWN											Special problems - see text. Safe yield may be as low as 5 MGD.
Moraine Area	25	0.5	12								
Outwash Plain	0	1.0	0								
TOTAL FOR TOWN	25		12	1	1	1	2	2	4	5	
SHELTER ISLAND TOWN											Special problems - see text. Safe yield may be as low as 2 MGD.
Moraine Area	8	0.5	4								
Outwash Plain	0	1.0	0								
TOTAL FOR TOWN	8		4	1	1	1	1	1	1	1	
5 EASTERN SUFFOLK TOWNS											Special problems - see text. Safe yield may be as low as 107 MGD.
Moraine Area	182	0.5	91								
Outwash Plain	84	1.0	84								
	266		175	5	6	6	11	18	29	50	

TABLE 4

SAFE YIELD VS. CONSUMPTIVE USE EASTERN SUFFOLK

PROPERTY OF U. S. GEOLOGICAL SURVEY
MINEOLA OFFICE LIBRARY

long island water resources

State of New York, Nelson A. Rockefeller, Governor / Office of Planning Coordination, Dr. David Brandon, Director

The preparation of this report
was financed in part through a
comprehensive planning grant
from the U.S. Department of Housing
and Urban Development.

long island water resources

Prepared by:
the Division of Water Resources
State Conservation Department

For the:
State Office of Planning Coordination
D. David Brandon, Director
488 Broadway
Albany, New York 12207

January 1970

foreword

This study is a broad analysis of fresh-water resources on Long Island, now and through 1990. Its scope is between that of a broader reconnaissance study and that of a detailed comprehensive study which a regional water resources planning board might prepare.

The report describes such a regional water resources board as one mechanism for preparing the comprehensive appraisal which is prerequisite to a 50-year development and management plan.

The broad interests of a board's membership which the law requires; its work with advisory committees like the Nassau-Suffolk Marine Resources Council; a close working relationship with the Regional Planning Board, through joint or interlocking membership, for example; and active participation by local citizens – all these can lay the groundwork for a comprehensive, multi-purpose plan to bring about the prompt and orderly development of water resources for all beneficial uses.

Despite the many local, state and federal studies done on Long Island's fresh water resources, unanswered questions remain – especially ones concerning the interrelationship of the fresh water and marine environment to the related land resources. This whole area points up the necessity for cooperation between water resource planning and broad comprehensive planning.

The Division of Water Resources in the State Conservation Department, through its staff in the division's district office in Melville, prepared this study for the State Office of Planning Coordination.

It is presented as part of OPC's broad program of research and publication, on subjects and geographical areas of interest particularly to planners but also to many other citizens of the state.

D. David Brandon
Director

January 1970

TITLE:

~~Fresh Water Resources of~~ *Long Island* Water Resources

AUTHOR:

New York State Office of Planning Coordination
Division of Water Resources, New York State
Conservation Department

SUBJECT:

Water supplies, use, projections of demand, problems and possible new sources

DATE:

January 1970

LOCAL PLANNING AGENCY:

New York State Office of Planning Coordination

SOURCE OF COPIES:

Clearinghouse for Federal Scientific
and Technical Information
2285 Port Royal Road
Springfield, Virginia 22151

New York State Office of Planning Coordination
488 Broadway
Albany, New York 12207

For reference:

HUD Library
451 Seventh Street SW
Washington, D.C. 20410

HUD Regional Office Library, Region I
26 Federal Plaza
New York, New York 10007

Project URBANDOC
City University of New York
133 West 42 Street
New York, New York 10035

Planning depository libraries

Planning school libraries

HUD PROJECT NUMBER:

NYP 116

SERIES NUMBER:

NA

NUMBER OF PAGES:

64

ABSTRACT:

Discusses the unique problems of Long Island, stemming from its reliance upon a ground water reservoir. Supplemented by tables, maps and graphs, the text explains available supplies, man-made problems which influence supplies, present and future water demands for diverse purposes and alternative methods of meeting future demands.

Also included are sections from the State Conservation Law, describing the procedure for forming a regional water resources planning board.

contents

Introduction 1

Availability of Water 2
Climatology 2
Topography 3
Surface Water 5
Ground Water 6

Man-Made Problems 14
Pollutants 14
Water Supply Systems 15

Present Water Use 15
Summary 15
Residential 15
Manufacturing, Commercial and Institutional 22
Agricultural 22
Recreational 23
Other Water Uses 24

Future Water Demands 25

Supply and Demand 36

New Sources of Supply 40
Other Regions 40
Desalination 41
Water Reuse 42
Decreased Future Water Use 43

Policy Guidelines 45
Management Alternatives 45
Regional Water Resources Planning and Development Boards. 45
Legislative Considerations 46

Summary and Conclusions 47
Nassau County 47
Suffolk County 48
Conclusions 48

Bibliography 49

Excerpts from Conservation Law, Article 5 51

tables

1 Major Streams and Lakes 6
2 Average Yield of High-capacity Wells 12
3 Withdrawal of Water for Public Water Supply 13
4 Water Use Summary in Nassau County 16
5 Water Use Summary in Nassau County (per capita per day) 18
6 Water Use Summary in Suffolk County 18
7 Water Use Summary in Suffolk County (per capita per day) 19
8 Growth in Active Water Services, Suffolk County 21

9 New Well Permits Issued 22
10 Past and Projected Populations 26
11 Projected Water Use in Nassau County 28
12 Projected Water Use in Nassau County (per capita per day) 29
13 Projected Water Use in Suffolk County 30
14 Projected Water Use in Suffolk County (per capita per day) 33
15 Projected Consumptive Water Use in Nassau County 38
16 Safe Yield Estimate, Nassau County 39

plates

1 Average Annual Precipitation 3
2 Average Monthly Precipitation 4
3 Major Streams and Lakes 8
4 Generalized Water-Table Contours 10
5 General Relationships-Major Geologic Units, Nassau County 11
6 Population Served by Private Domestic Wells, Suffolk County 17
7 Comparison of Water Use and Median Income 20
8 Distribution of All New Wells 23
9 Distribution of New Wells with Capacity Less than 45 GPM 23
10 Population Trend, Nassau County 25
11 Population Trend, Suffolk County 26
12 Projected Water Use, Nassau County 27
13 Projected Water Use, Suffolk County 27
14 Water Budget, Nassau County 39
15 Consumptive Use vs. Safe Yield, Nassau County 40

A two-volume appendix to this study is not being reprinted. Its contents is listed below, and copies are available for reference use at:

OPC Library, 488 Broadway, Albany
OPC Metropolitan District Office, 1841 Broadway, New York
DWR Library, ~~855 Central Avenue,~~ Albany, 50 Wolf Road
DWR Eastern Regional Office, ~~1236 Central Avenue,~~ Albany, 50 Wolf Road
DWR District Office, Melville, 150 Broadhollow Road

Appendix Volume 1:

Foreword
Previous Reports and Studies
Summaries of Reports and Studies
Current Programs
Mapping
Hydrogeology

Appendix Volume 2:

Analysis of Present Demand – 1965
Projection of Future Demand
Consumptive Use and Safe Yield
Desalination

introduction

Long Island is unique in many ways. One significant feature is the tremendous quantity of water stored in its underground reservoir, estimated by the U.S. Geological Survey at 60 trillion gallons, enough to cover the island to a depth of 200 feet. This fresh water is like a bubble floating partly submerged upon a sea of salt water. If more water is taken out of the ground than is put in, the bubble shrinks and the surrounding salt water pushes farther inland; if water is added, the bubble expands. Shrinkage has already occurred in ings and Queens Counties (New York City), where salty water has partly replaced the formerly fresh ground water supply, and now about 83 percent of the supply comes from upstate sources through the New York City system.

It remains to be seen if the pattern will be similar in Nassau and Suffolk Counties as rapidly expanding population and accelerating economic development require more and more water. Various alternative courses of action are identified in this report, but further study and evaluation are needed to determine the best course before time runs out or irrevocable decisions are made.

Of the many changes on Long Island since its settlement by European immigrants in the 1600s, none are more dramatic than those of the last 15 to 20 years. During this period the population has skyrocketed, pushing out onto the island from the New York City hub. Nassau County doubled in population and Suffolk County more than doubled from 1950 to 1965, and the expansion wave is continuing into Suffolk County.

People need water, and so water supply development has expanded rapidly. People also generate wastes and use water to dispose of part of them, and so waste disposal has become a critical problem. The interrelationship of water supply and waste disposal is nowhere more complex than on Long Island, surrounded as it is by salt water.

Quantity and quality are inseparable in a water resources ppraisal. This study defines the availability of fresh water resources, present and probable future use and alternative ways to meet future demands. This water supply information must be integrated with water quality considerations and, of course, into the broader context of natural resources on Long Island and their importance in population growth and economic development.

Major study elements investigate:

- available surface and ground water supplies,
- man-made problems influencing the supplies,
- present and future water demands for diverse purposes, and
- alternative methods of meeting future demands.

Water demands are projected to the year 1990 and policy guidelines are suggested for water resources development and management on the island.

A prerequisite to understanding this study is to recognize the interrelationship of the water resources of the two counties. The ground water reservoir does not recognize political boundaries, and the hydrological problems caused in one area by a higher rate of development can affect the total resource. For this study, water use analysis and projections have followed political subdivisions, because the history of water supply development and other considerations make the political unit the most expeditious to use.

Reference information and knowledge were drawn from a number of significant reports and studies, which provided the bases for portions of this study. In some cases specific references are included. These reports are the *1963 Report on Water Supply, Nassau County*, by Greeley and Hansen; *Reconnaissance of Water Resources Potentials, 1966*, prepared for the Water Resources Commission by Tippetts-Abbott-McCarthy-Stratton; and *An Atlas of Long Island's Water Resources, 1968*, prepared by the U.S. Geological Survey in cooperation with the New York State Water Resources Commission, Bulletin No. 62.

availability of water

Climatology

Geographically Long Island is a large detached segment of the Atlantic Coastal Plain, separated from the mainland on the north by the broad but shallow trough of Long Island Sound and on the west by the narrow East River and New York Harbor. The Atlantic Ocean completes its salt water encirclement on the south and east.

Long Island has an overall length of about 120 miles and a maximum width of about 20 miles, a total land area of about 1,373 square miles. Politically, it is divided into four counties – Kings (Brooklyn), 71 square miles; Queens, 108 square miles, Nassau, 274 square miles; and Suffolk, 920 square miles. Kings and Queens are also boroughs of New York City.

The Long Island climate is characterized by mild winters and relatively cool summers. The moderating influence of the Atlantic Ocean gives comparative freedom from sudden, extreme changes in temperature. The mean annual temperature is about 50 degrees fahrenheit with only slight variations because of the small differences in land elevation. January and February are the coldest months, with mean January temperatures of about 30 degrees fahrenheit. July is the warmest, with a mean temperature of about 72 degrees fahrenheit. Temperature extremes range from -10 degrees fahrenheit to about 100 degrees fahrenheit. An average of about 180 days a year are frost free.

Prevailing winds are from the southwest from April through October, from the west in November and December and from the northwest in January, February and March.

Long Island receives precipitation from continental cyclonic storms in the winter, spring and fall, from thunderstorms in the summer and occasionally from hurricanes in the late summer and fall. Average annual precipitation is about 44 inches, from a maximum of 50 to a minimum of 40 inches (Plate 1), based on precipitation data for 46 stations for 15 years (water years 1950-1964). The estimates indicate long-term averages because the 15-year data are reasonably comparable with long-term data available for a few stations.

Precipitation is distributed fairly evenly throughout the year, average monthly precipitation ranging from 2.5 to nearly 5 inches. The long-term monthly average is about 3.7 inches. Average monthly precipitation for five representative stations (Plate 2) indicates that seasonal variations are nearly the same from place to place.

Although averages are fairly uniform, precipitation for specific months may vary widely. For example, LaGuardia Airport has experienced a high of 16.05 inches in August, when the average is about 4.8 inches, and a low of 0.06 inches in October, when the average is 3.5 inches.

Most of this is rainfall. The average annual depth of snowfall is 30 inches, 10 to 15 percent of the average annual precipitation, and normally snow does not accumulate for longer than a few weeks. The average annual precipitation of 44 inches is equivalent to about 2.1 mgd per square mile.

What happens to this precipitation is particularly relevant to water supply. The precipitation may be divided into three components – evapotranspiration, direct runoff and ground water recharge.

Evapotranspiration includes all the natural processes by which water on and beneath the land surface is returned to the atmosphere as water vapor. The three major elements are evapotranspiration of precipitation soon after if falls, evaporation from permanent or semi-permanent surface water bodies and evapotranspiration of ground water. Evapotranspiration of precipitation soon after if falls, the largest loss of fresh water through the hydrologic system by natural processes, includes mainly evaporation from vegetation and land surfaces that have been wetted by precipitation, and transpiration from the uppermost zone of soil mositure that is derived directly from precipitation. The estimated average annual evapotranspiration for all three elements is about 21 inches per year on Long Island.

Direct runoff is the water that flows into streams, Long Island Sound and bays from the land promptly after rainfall or snowmelt. On Long Island, direct runoff is normally only a small part of the annual stream flow. Direct runoff, which varies with the intensity of precipitation and other factors, may account for 2 to 6 percent of the total rainfall from an individual storm. The estimated average *annual* direct runoff on Long Island is about 1 inch.

Precipitation that is not lost through evapotranspiration or direct runoff is available for ground water recharge – precipitation which infiltrates into the ground and recharges the ground water reservoir. Sufficient data are not available to estimate directly the quantity on Long Island, but this can be approximated by deducting the evapotranspiration and direct runoff amounts from the total precipitation. On this basis, about 22 inches of water are available for ground water recharge on Long Island, a supply of about a million gallons per day per square mile.

Topography

Long Island is made up of unconsolidated deposits of sand, gravel and clay that were laid down in more or less parallel beds on the surface of hard, crystalline bedrock. Two glacial moraines are the most prominent features of the surface topography. The older, the Ronkonkoma Moraine, runs along the north shore of Queens to an area just south of Hempstead Harbor, then diagonally across the

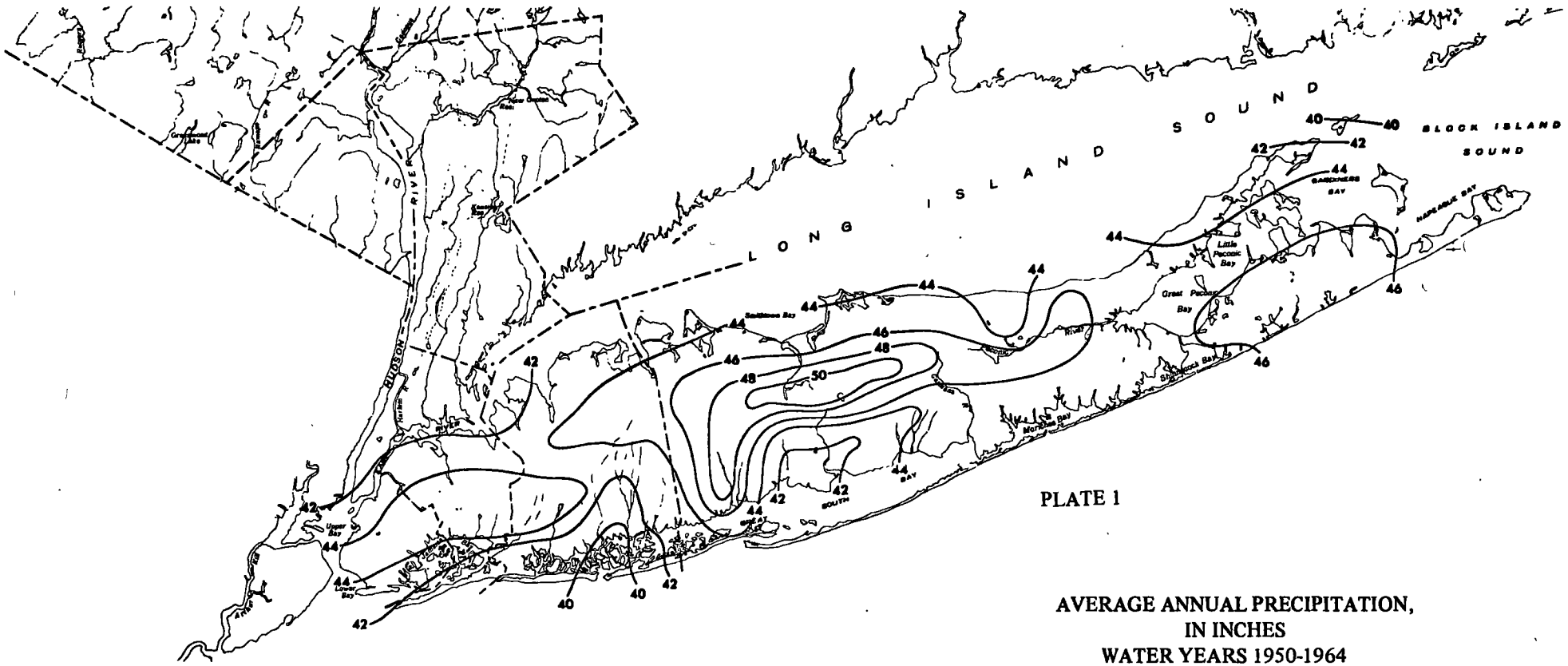
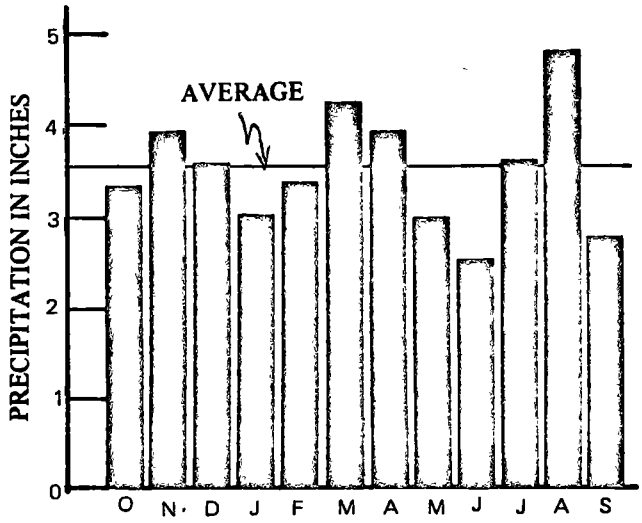


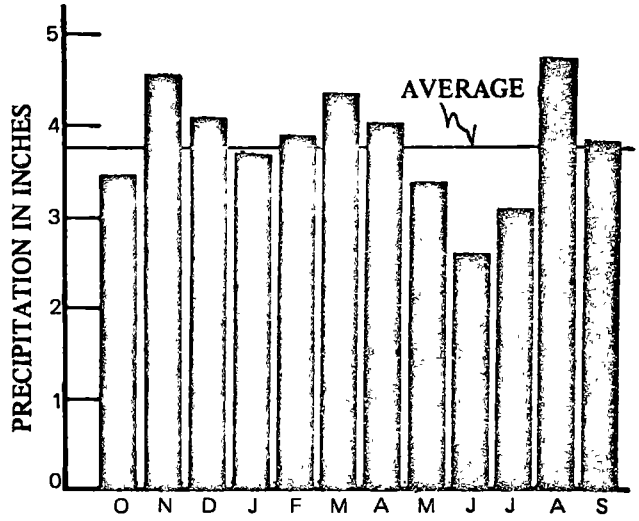
PLATE 1

AVERAGE ANNUAL PRECIPITATION,
IN INCHES
WATER YEARS 1950-1964

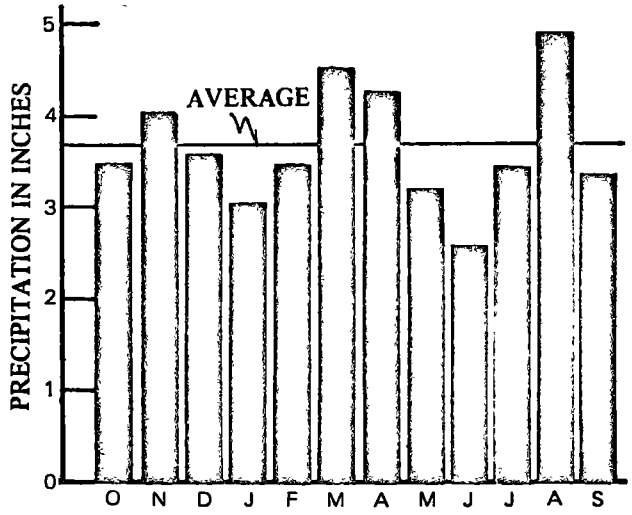
Source: U.S. Weather Bureau and U.S. Geological Survey, 1967



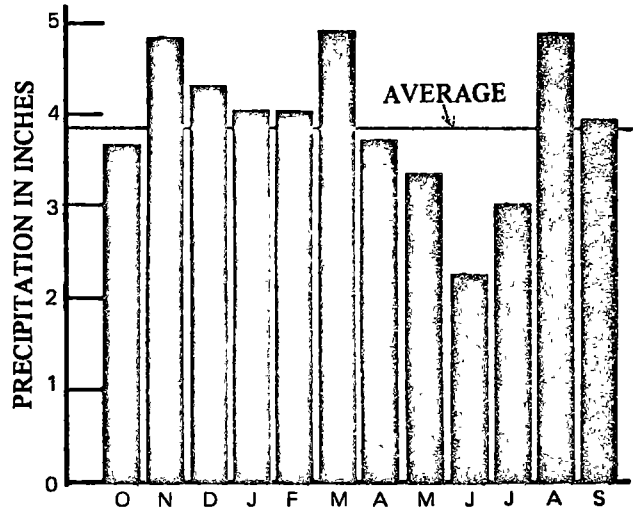
La Guardia Airport



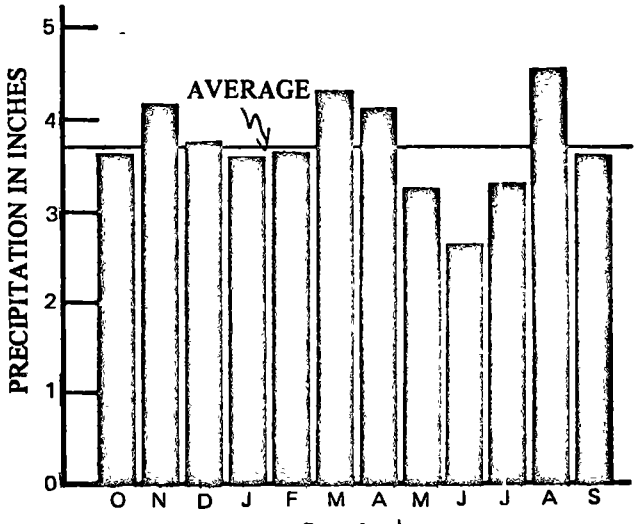
Riverhead Research Laboratory



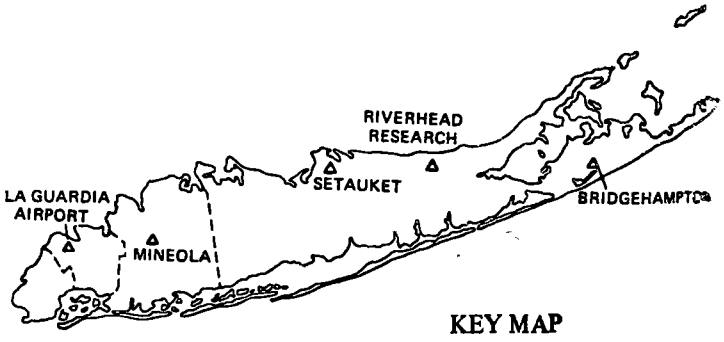
Mineola



Bridgehampton



Setauket



KEY MAP

PLATE 2

AVERAGE MONTHLY PRECIPITATION
WATER YEARS 1950 – 1964

Source: U.S. Weather Bureau and U.S. Geological Survey, 1967

island to the south fork and Montauk Point. The more recent, the Harbor Hill Moraine, forms the main ridge in Brooklyn and Queens from the Narrows to just south of Hempstead Harbor, then runs easterly, following closely the heads of the various harbors to Port Jefferson and along the north shore to the extremity of the north fork. The two moraines cross in the vicinity of Hempstead Harbor and Lake Success. They form the backbone of the island and contain the points of highest elevation, reaching a maximum of 420 feet above mean sea level at High Hill in western Suffolk County. A slight valley between the moraines is composed largely of glacial till grading into glacial outwash as the distance between the moraines increases in Suffolk County.

The north shore is somewhat abrupt, frequently characterized by a bluff and often rising to hills of a few hundred feet, particularly in Nassau and western Suffolk County. Many bays indent the western part of the north shore.

From the southernmost moraine, the land surface slopes gently southward toward the Atlantic Ocean, having been formed generally by glacial outwash. The actual south shore line is poorly defined, merging into salt marshes. Along all but the easterly end of the island, the south shore is bordered by a succession of bays separated from the ocean by barrier beaches. These beaches (Fire Island, Jones Beach, etc.) are sand spits and dunes with sandy beaches on the ocean side and salt marshes or wetlands on the bay side. This barrier is largely continuous, broken only by a few inlets into the bays.

Bedrock outcrops are found only in a small area along the East River in northwest Queens. Elsewhere the island's surface formations are composed of unconsolidated sands, gravels and some clays. As a result, precipitation infiltrates relatively rapidly and streams are generally small, with nearly steady flow from underground sources. Lakes and ponds occur in depressions where ground elevations are below ground water levels, except for several like Lake Success where a layer of impervious material has created a perched water table.

Surface Water

For purposes of this study, the surface water on Long Island includes the fresh water streams and lakes, but most of the streams are estuarine, salty in their lower reaches where they flow into the bordering bays, ocean or sound.

The 19 major streams on Long Island for which stream flow data are available are identified on Plate 3 and in Table 1. The Peconic River, with a drainage area of 75 square miles, is the largest stream, followed closely by Carmans River with a drainage area of 71 square miles. The Peconic River flows into Peconic Bay at the eastern end of Long Island, the Carmans River into the eastern end of Great South Bay on the south shore. The next largest stream is Massapequa Creek, with a drainage area of 38 square miles, and the others range in size down to Valley Stream with a drainage area of only 4 square miles.

Long Island has no major lakes (the largest are shown on Plate 3 and listed in Table 1) and two types of natural lakes and ponds. One type is a perched lake or pond whose water is separated from the water table by a layer of clay or other impervious material. The second type, most common, is the water table lake, the surface level of which is at the same elevation as the water table under the surrounding land area. Many small artificial ponds and lakes have been built by constructing low dams across streams.

Streamflow, a major element of fresh water discharge on Long Island, has two components – flow from the ground water reservoir and direct runoff. The former is by far the greater, an estimated 95 percent of streamflow. Direct runoff, immediately following rainfall or snowmelt, makes up the other 5 percent.

The U.S. Geological Survey has maintained an extensive streamflow measuring program on Long Island for about 30 years and for some streams continuous records are available for the entire period. The gaged area totals 427 square miles, almost 36 percent of Nassau and Suffolk Counties, with gaging stations at points upstream from any tidal influence from the Atlantic Ocean, the inner bays or Long Island Sound. Therefore, they do not measure total streamflow because fresh ground water, an estimated 25 to 30 percent of the total streamflow, seeps into the estuarine reaches below the gages.

Because of the highly permeable character of Long Island's soils and the small differences in elevation, runoff is relatively uniform from month to month. The average streamflow in the month of maximum flow, usually April, is only two to three times the flow in the low water months, May to October. Flash floods follow heavy rains, but between storms the normal flow fluctuates slowly and is mainly ground water outflow. The construction of reservoirs to develop surface water supplies is not practicable because of the lack of impermeable reservoir sites and the small total yields of the streams.

Streamflow records for gaging stations on the 19 major streams on Long Island show that the combined average flow for the water years 1940-65 ranged from 208 cfs (cubic feet per second) in 1965 to 401 cfs in 1956 and averaged 306 cfs. Streamflow was below average in seven of the first eight years, above average in nine years during the 11-year period, 1952-62, considerably below average during the drought years of 1963-65 and by the end of 1968 had

TABLE 1

MAJOR STREAMS AND LAKES,
LONG ISLAND (See Plate 3)

No.	Name of Stream	Drainage Area (sq. miles)	1940-1965 Average Flow (cfs)
1	Cedar Swamp Creek	11	7.2
2	Mill Neck Creek	12	9.5
3	Cold Spring Brook	7	4.6
4	Nissoquoque	27	42.2
5	Peconic River	75	35.5
6	Carmans River	71	24.2
7	Swan River	9	13.0
8	Patchogue Creek	14	21.2
9	Connetquot	24	39.4
10	Champlain Creek	7	7.5
11	Penataquit Creek	5	6.2
12	Sampawams Creek	23	9.8
13	Carlls River	35	27.7
14	Santapogue River	7	4.6
15	Massapequa Creek	38	11.9
16	Wantagh Stream	17	11.2
17	East Meadow Brook	31	17.5
18	Pines Brook	10	5.1
19	Valley Stream	4	4.8
	Total	427	306.1

Ident. Letter	Name of Lake	Area (acres)	Type of Lake
A	Lake Success	27	Perched
B	Hempstead Lake	210	Artificial
C	Lake Ronkonkoma	245	Water-Table
D	Belmont Lake	28	Artificial
E	Lake Panomoka	59	Water-Table

not recovered completely from the effects of the drought. For example, streamflow on Massapequa Creek at Massapequa continues at or near record low levels.

In addition to continuous flow measurements on the 19 major streams, the U.S. Geological Survey obtains several single measurements each year on other streams. For these the estimated combined flow is about 55 percent of the continuously measured flow. In total, the measured flows are 90 to 95 percent of the fresh water streamflow from Long Island. On the basis of these relations, it is estimated that the average annual streamflow for 1940-65 is 520 cfs or 340 mgd and that an additional 85 mgd is discharged as seepage into the estuarine reaches below the stream gaging stations.

Ground Water

Ground water is water found underground below a certain level, called the water table, completely filling the open spaces between particles of sand, gravel, clay and silt. This part of the earth is called the zone of saturation and may be referred to as a ground water reservoir or aquifer. The water table conforms generally to the land surface (Plate 4), with its highest elevation underneath the terminal moraines and at or near sea level close to the shorelines.

Ground water occurs under two distinct conditions – water table and artesian. Under the former, the aquifer is unconfined and the ground water moves freely in response to hydraulic gradient or slope. Changes in atmospheric pressure, tidal effects and pumping effects also influence the movement. Under the artesian condition, the aquifer is confined and the ground water is under pressure. This results commonly when relatively impermeable layers of silt and clay confine the top of the aquifer.

Relatively impervious clay beds beneath much of the ground surface greatly retard the vertical movement of water within aquifers and from one aquifer to another. These clay beds may be widespread and more or less continuous, or they may be lens-like in form with no widespread lateral continuation. The beds of permeable sand and gravel, the best water producing formations, are more or less interconnected laterally, laid on the surface of hard crystalline bedrock composed mainly of impervious schist and gneiss.

Geologically, Long Island is more similar to the coastal regions of New Jersey than to nearby New York and New England. It is believed that the bedrock surface was once a nearly level, highly eroded and decomposed plain at about sea level. In the middle of the Cretaceous Period, this plain was tipped sharply toward the southeast in a general upheaval of the earth's crust centered along what is now the crest of the Appalachian Mountains. The tipping action sank the bedrock on Long Island to compensate for the rise along the center line, it also accelerated erosion of the upland areas and increased the sediment transport capabilities of the streams. The resulting deposit of sediments at the seashore and on the lower, more gently sloping areas, probably continued for several million years, bringing hundreds of feet of sand, gravel and clay to Long Island from the north and west. This deposition reaches to the seaward extremity of the continental shelf.

The Cretaceous deposits along the Atlantic Coastal Plain are wedge-shaped, increasing in thickness away from the axis of uplift, on Long Island increasing from northwest to southeast. The cause of the wedge-shaped deposition is believed to have been a steady sinking of the bedrock at about the same rate as the deposition. The final result is that the bedrock has a convex slope with the individual Cretaceous deposits wedge-shaped, each succeeding layer extending farther inland. The bedrock under Long Island slopes from outcrops slightly above sea level in northwestern Queens to about 2,000 feet below sea level in southern Suffolk County.

Most of the fresh ground water supply on Long Island is contained in four major water-bearing formations: the Lloyd sand member of the Raritan formation, the Magothy formation, Jameco gravel and Upper Pleistocene deposits.

LLOYD SAND MEMBER OF THE RARITAN FORMATION – This formation (Plate 5) is the basal aquifer and the oldest of the Cretaceous deposits under Long Island. Fine to coarse quartzose sand and gravel form much of this deposit, interbedded in places with layers of clay. The decrease of water pressure in all beds of the Lloyd when water is withdrawn from one bed indicates that clay deposits are not continuous.

The sand member is wedge-shaped, varying in thickness from 60 feet or less along the north shore to 300 feet along the barrier beach. It does not outcrop at the surface, but is overlain by the clay member, which is from 50 to 300 feet thick.

Considerable erosion noted in the upper surface of the clay member leads to the theory that the valleys, now filled with more pervious material, have been cut through the clay member and are a source of recharge. Slow percolation may also occur through the clay. The net result is that the Raritan clay acts as a leaky confining layer that retards but does not prevent recharge of the Lloyd sand. The clay member produces artesian conditions in the Lloyd sand at the north and south shore lines. This, in turn, holds back salt water farther from the mainland than in the upper aquifers.

Thus the Lloyd sand member is an important aquifer at places such as Long Beach on the south shore and on the various peninsulas along the north shore, but its use as an aquifer has been limited to the shore areas because the clay member restricts recharge. In eastern Suffolk County, the Lloyd sand is not very productive. The artesian pressure in this formation is high enough for the hydraulic head to be above land surface, causing some wells to flow. The permeability of the formation is very low and yields are not

MAGOTHY FORMATION – This is one of the most important aquifers on Long Island. Its use as a public water supply source has increased greatly in recent years and this is expected to continue. The Magothy is wedge-shaped, varying in thickness from 100 to 1,200 feet, and outcrops at several points along the north shore.

Extensive beds of coarse sand and gravel near the bottom of the Magothy make this an important water-bearing horizon. Above the lower horizons, it has no consistent composition or typical cross section. Individual beds of sand, sandy clay and clay occur, but do not extend far laterally. Quartz sand is the predominant constituent.

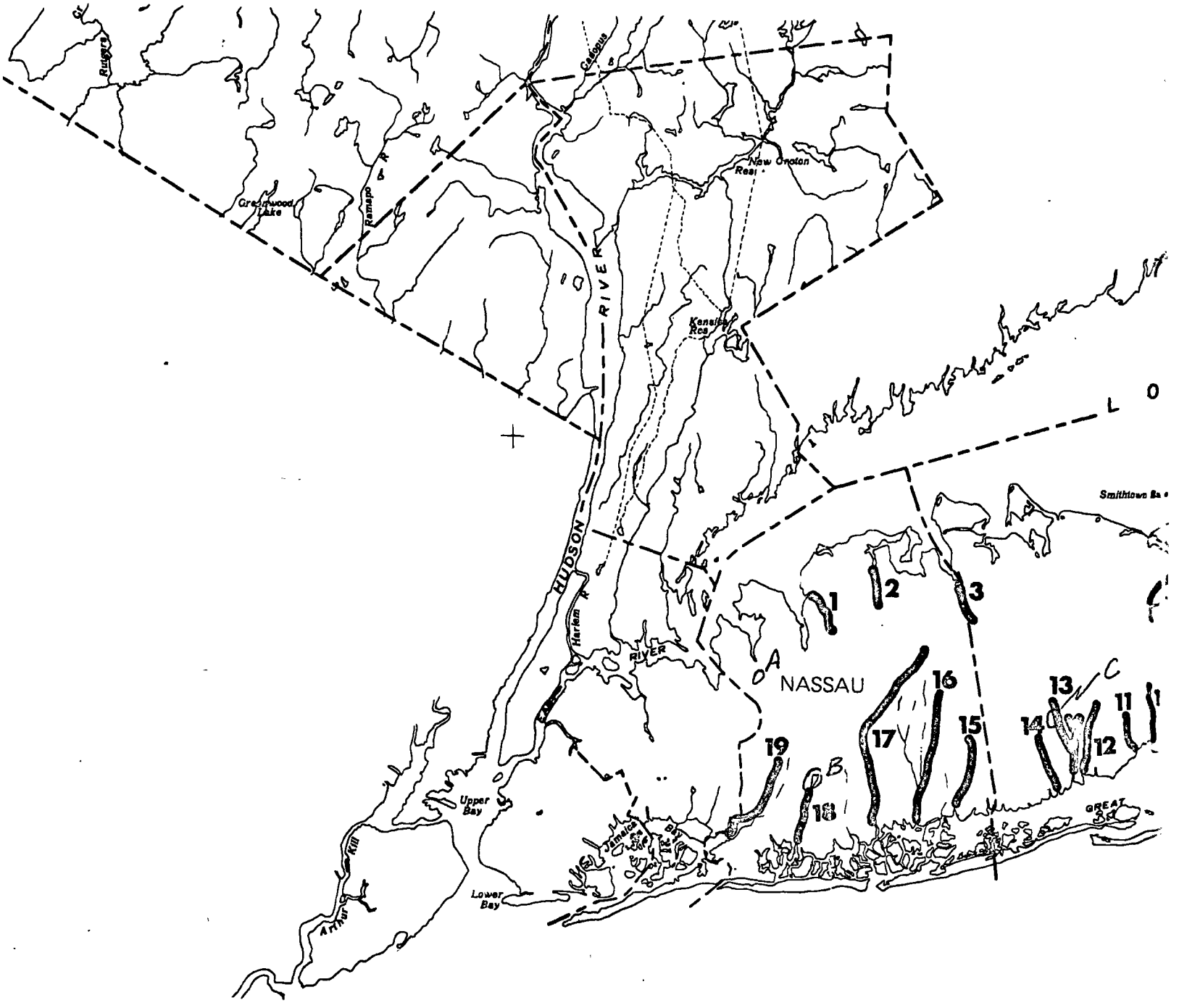
Ground water is confined by clay layers within the formation, and it is categorized as an artesian aquifer. In most areas, the hydraulic head in the Magothy ranges from several feet below the water table to nearly 20 feet above.

The deposition of the Magothy was followed by a geologic period called the Tertiary, when erosion was more important than deposition, Long Island Sound was formed and topographic features characteristic of present-day Long Island were created.

Following this period came the Pleistocene epoch, commonly referred to as the Ice Age. The dominant erosion forces in the Tertiary period brought an abrupt change generally in lithology and mineralogy between the Cretaceous and overlying Pleistocene deposits. The Cretaceous deposits are characterized by silty clays, fine sands and solid clays, the overlying Pleistocene deposits by coarse, clean sands and gravels. Also, Cretaceous sands are composed of minerals subjected to long periods of weathering and consist only of chemically stable minerals or the highly altered equivalent of the less stable minerals. Pleistocene deposits usually contain a significant amount of rock fragments and less stable minerals in addition to the minerals found in the Cretaceous deposits.

The upper geologic strata on Long Island, though of different glacial origin, were all deposited some time during the Pleistocene epoch. These are named the Jameco gravel, Gardiners clay and Upper Pleistocene deposits. The first and third are aquifers.

JAMECO GRAVEL – This glacial outwash deposit of the early Pleistocene epoch overlies the Cretaceous deposits, most notably the Magothy, near the north and south shores of the western end of Long Island. In extreme western Kings and northwestern Nassau, the Jameco gravel rests on bedrock. It is virtually continuous through Kings, southern Queens and southwestern Nassau, where it is overlain by Gardiners clay. Jameco gravel is typically about 100 feet thick, its upper surface about 100 feet below sea level, and does not crop out on the land surface. The



NOTE: Refer to Table 1 for identification

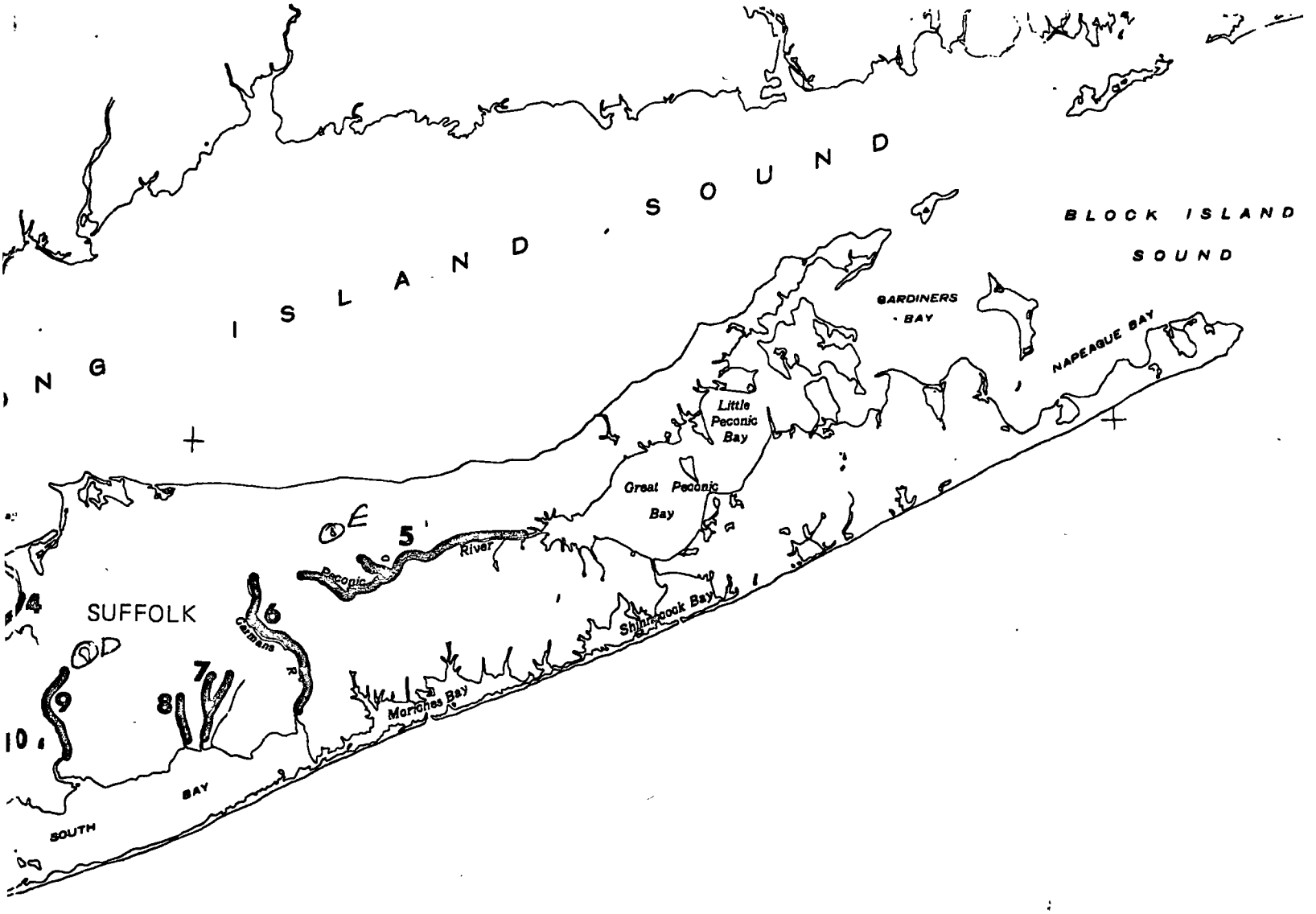


PLATE 3

MAJOR STREAMS AND LAKES
MAY, 1969

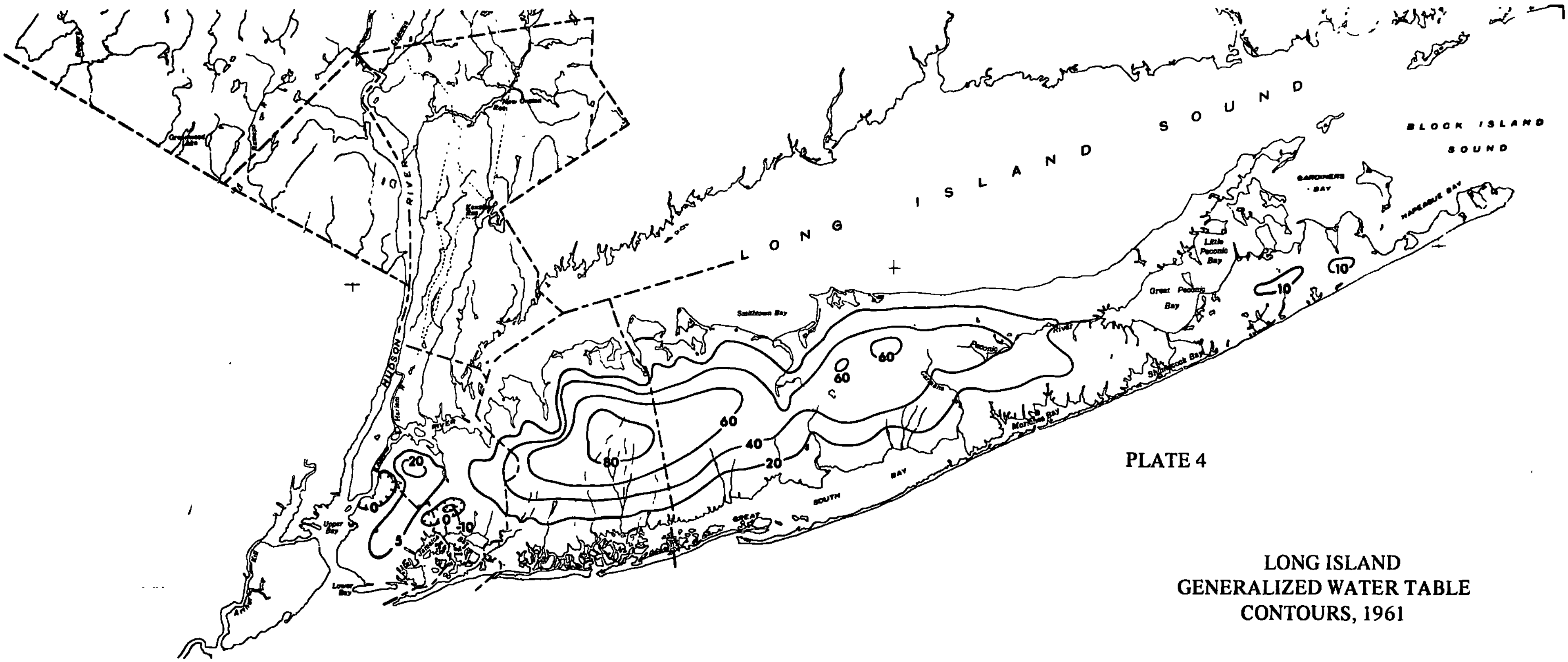


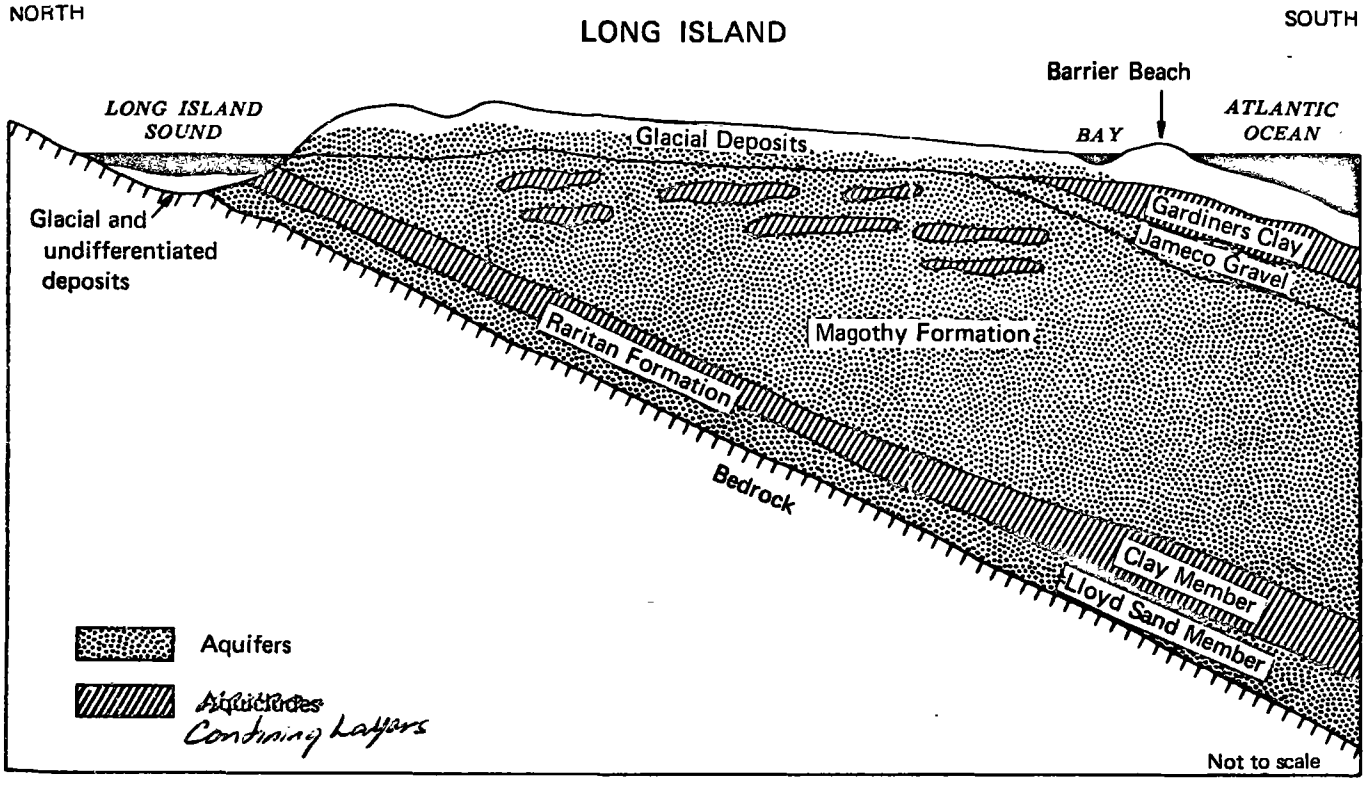
PLATE 4

LONG ISLAND
GENERALIZED WATER TABLE
CONTOURS, 1961

Source: U.S. Geological Survey Circular 524, 1966

GENERAL RELATIONSHIPS – MAJOR GEOLOGIC UNITS, NASSAU COUNTY

PLATE 5



MAY 1969

Source: U.S. Geological Survey Circular 524, 1966

maximum thickness is 200 feet except locally in buried valleys where it may be more than 300 feet thick.

The Jameco gravel consists mainly of medium to coarse sand, but locally contains abundant gravel and some silt and clay and in places is interbedded with fine sand and lignite that has probably been reworked from Cretaceous deposits. This moderately to highly permeable aquifer is highly productive, yielding as much as 1,500 gpm per well, but total pumpage is relatively low because the formation does not occur extensively. In the southwestern part of Long Island, the Jameco gravel was extensively developed in earlier years but in many of these areas heavy pumping resulted in salt water intrusion and it is not a major aquifer now.

The Gardiners clay is restricted mainly to two rather narrow bands along the north and south shores and to the western end of the island. Relatively impermeable, it forms an effective confining bed which creates artesian conditions in the Jameco formation.

UPPER PLEISTOCENNE DEPOSITS – Almost all of Long Island is covered with material deposited directly or indirectly by Pleistocene ice sheets. These glacial deposits overlying the Magothy and Gardiners clay, called Upper Pleistocene deposits, are made up of glacial till and glacial outwash and reach a maximum thickness of about 300 feet.

Glacial till of generally low permeability forms most of the two moraines that run the length of the island. Glacial outwash of stratified sand and gravel covers much of the north shore peninsulas and the southern and central part of Long Island south of the moraines. It is the most permeable water-bearing formation on Long Island and allows moderately rapid infiltration of precipitation.

A mixture of glacial till and outwash lies between the two moraines, the proportions dependent to a large extent on the distance between the moraines – till predominates in Nassau County, where the moraines are close together, and glacial outwash predominates in eastern Suffolk, where the moraines are five or six miles apart.

The Upper Pleistocene deposits are the best water-bearing formation for permeability and water extraction. The relatively shallow wells cost less to construct, but unfortunately this aquifer is also more subject to contamination from detergents and other pollutants and many private and public water wells have been abandoned.

Glacial outwash is still used extensively for public, industrial and agricultural water supplies, but recent new developments, particularly ones for public supplies, have more frequently been made in the deeper Magothy formation because of actual or suspected contamination of the shallower formations by industrial and sanitary wastes.

Summary data on high-capacity wells in the different water-bearing formations on Long Island (Table 2) were based on the record of wells that have been tested at rates of 700 gpm or more. The figures for maximum and average yield do not truly represent the production capabilities of the formations because most of the pumping tests were run at rates that did not utilize all of the available drawdown. Moreover, most of these wells were drilled in earlier years when well construction was less efficient.

TABLE 2

AVERAGE YIELD OF HIGH-CAPACITY WELLS ON LONG ISLAND

County	Formation*	Average Yield (gpm)	Maximum Yield (gpm)	Average Specific Capacity (gpm/ft of drawdown)	No. Wells
Queens	UP	1,139	1,555	60	24
	J	1,168	1,250	51	4
	M	1,030	1,150	36	4
	L	1,300	2.210	29	8
Nassau	UP	1,223	1,800	42	10
	M	1,228	2,000	36	121
	L	1,153	1,400	22	11
Suffolk	UP	887	1,600	39	80
	M	1,499	1,850	52	53
Three counties combined	UP	968	1,800	44	114
	J	1,168	1,250	51	4
	M	1,304	2,000	41	78
	L	1,215	2,210	24	19

*UP – Upper Pleistocene; J – Jameco; M – Magothy; L – Lloyd
Source: Reconnaissance of Water Resources Potentials for Hudson, Mohawk and Long Island Areas, 1966.

In earlier years, most of the water used on Long Island was withdrawn from the shallow glacial deposits, but some 40 years ago, withdrawals from the deeper formations began to increase and this pattern of changing withdrawal has continued. The trend from 1950 to 1964 (Table 3) indicates little change in the rate of withdrawal from the Jameco and Lloyd aquifers during recent years, a moderate increase in withdrawal from the Upper Pleistocene deposits, and a large increase in withdrawal from the Magothy:

Formation	Percent Withdrawal 1950	1964
Upper Pleistocene	42	26
Jameco	8	3
Magothy	35	64
Lloyd	15	7

As additional water supplies are needed, withdrawals from the Jameco and the Lloyd are not likely to increase greatly and most new supplies will doubtless be from the Magothy formation. If contamination of the Upper Pleistocene deposits can be overcome, their greater development would be highly desirable to supply the increasing demands. These deposits over most of the island are less subject to salt-water encroachment than the Magothy formation and are by far the island's most permeable water-bearing formations.

Since all the ground water formations are connected hydraulically with the salt water of the ocean, bays and sound, fresh water floats on a base of salt water near the shore areas. Consequently, over-pumage of these areas can replace the fresh water by salty water.

A U.S. Geological Survey estimate of the storage otential of these major aquifers for a significant portion of Long Island (not including the north and south forks and south shore areas adjacent to salt water) is 54 cubic miles or 60 trillion gallons. The water that may be recovered from storage, or the specific yield, is considerably less – estimated to be possibly only 10 to 20 trillion gallons – but even this is a substantial quantity. For example, 20 trillion gallons would supply the City of New York for 40 years at its present rate of use of about 1,300 mgd.

Long Island's ground water is generally of excellent quality. The concentration of dissolved constituents in general is considerably below the limits set by the U.S. Public Health Service for potable water supplies. In most parts of the island, total dissolved solids are less than 100 ppm (parts per million). The ground water is generally soft; the water from shallow glacial wells has a hardness from 20 to 40 ppm, that from deeper wells is less than 10 ppm. The sulfate content is commonly no greater than 25 ppm and the chloride content of water from the deeper wells is generally less than 10 ppm in areas not affected by salt water encroachment and less than 20 ppm from shallower wells. The ground water is somewhat acidic. Values for pH range from about 5.3 to 6.3 and the water from many wells requires treatment to raise the pH.

In some parts of Long Island the chief natural water quality problem is excessive iron or, less commonly, manganese. Concentrations may be considerably above the U.S. Public Health Service standards, ranging from less than 0.02 ppm to more than 1 ppm.

TABLE 3

WITHDRAWAL OF WATER ON LONG ISLAND FOR PUBLIC WATER SUPPLY FROM DIFFERENT SOURCE FORMATIONS

(In million gallons per day)

Formation and Year	Queens*	Nassau*	Suffolk**	Total
Upper Pleistocene				
1950	25.8	10.3	7.0	43.1
1964	32.1	10.8	23.3	66.2
Jameco				
1950	2.6	6.3	0	8.9
1964	2.3	6.2	0	8.5
Magothy				
1950	3.6	32.2	0.5	36.3
1964	19.8	131.0	14.6	165.4
Lloyd				
1950	5.5	9.4	0.3	15.2
1964	4.1	14.1	0.6	18.8

*Withdrawals by New York City not included.
**Includes only withdrawals from wells of the Suffolk County Water Authority.
Source: Reconnaissance of Water Resources Potentials for Hudson, Mohawk and Long Island Areas, 1966.

man-made problems

Pollutants

Ground water supplies on Long Island may have various pollutants, principally salt water and domestic, commercial and industrial wastes.

The threat of salt water intrusion is constant. Excessive ground water pumpage in the Borough of Brooklyn in the 1930s lowered ground water levels as much as 35 feet below sea level, permitting salt water to contaminate large parts of the ground water reservoir and forcing almost a complete stop to pumping for public water supply. Since then, New York City has supplied the borough from its surface reservoirs in upstate New York. Even now, after 35 years, the aquifers cannot generally be used for public water supply although in some areas public supply withdrawals might be allowed under extremely close management. The water table elevation has risen, but salt water pollution is still present in many areas. Replenishment of the ground water acquifer is slow because high urbanization limits infiltration of surface water; also, Brooklyn is completely sewered and waste water is discharged through ocean outfalls.

At Cedarhurst, on Long Island's south shore, the salt water front has moved several miles inland in recent years and the Water Resources Commission has restricted higher capacity wells in this formation to forestall further encroachment. Another instance is in the Port Washington area of Nassau County, where intrusion dangers led the Water Resources Commission to require that water supplies be obtained from outside the assigned service area of the water district. At Greenport, on the north fork in Suffolk County, the limited ground water is almost entirely surrounded by salt water. The increasing salinities of wells require closely controlled pumping and forced the requirement that wells be located some miles away. The fresh-salt water interface is believed to have moved landward in several other areas on Long Island.

The geologic structure of Long Island raises the possibility of salt water intrusion all along the salt water interface. Because its slightly inclined strata have greater horizontal than vertical permeabilities, water movement in the aquifers is more lateral than vertical. With recharge at the surface from infiltration of precipitation and in the uppermost strata from cesspools and recharge basins, pumpage from the lower aquifers needs careful control to guard against lateral movement of salt water into them. Sewers that discharge into the bay or ocean reduce the recharge and increase the problem.

Injection wells may prove effective in stabilizing the salt water interface in the various aquifers, and may help to restore former fresh water supply areas, such as at Cedarhurst. An experimental injection well to recharge highly treated sewage effluent, at Nassau County's Bay Park Sewage Treatment Plant, is testing this method.

Another positive step taken in Nassau and Suffolk Counties is a system of recharge basins for disposal of storm water, separate storm water drains carrying runoff to local recharge basins for infiltration into the ground. In Nassau County alone the water that would otherwise be lost through ocean outfalls is estimated at 40 mgd and the ultimate potential saving is about 70 mgd.

Domestic, commercial and industrial wastes are another source of contamination – in a dramatic example during the 1940s in Farmingdale, chromium wastes recharged into the ground contaminated the upper aquifer over almost 100 acres.

Detergents in ground water are evidence of general pollution because they are associated with waste water. A relatively small amount of detergent produces foaming and affects the taste of water, physical and sensory indications of contamination to many household domestic well owners.

The problem was originally due to the basic substance previously used in detergents – the branched-chain alkylate benzene sulfonate (ABS) which had low biodegradability, or relative resistance to breakdown, in soil and water.

Although sewage treatment plants can be equipped to eliminate detergent wastes, a hope for the large segment of Long Island that is unsewered seems to be in using a basic detergent substance more readily degradable in cesspools and septic tanks. Testing in this field is in progress with the cooperation of public agencies and detergent producers. One step is the now universal use of a straightchain alkylate sulfonate or LAS, which tests show is biodegradable in air. Unfortunately, in the sections where detergent pollution of the glacial aquifer is a problem, a great number of cesspools operate anaerobically (without air), so that the change only reduces the visible evidence of pollution without controlling it.

The serious problem of ground water pollution because of recharge through cesspools has to date been solved chiefly by installing wells in lower aquifers. Control of waste discharges into recharge basins has also been attempted, taking into account adjacent well locations and subsurface flow patterns. A more permanent solution is heavy treatment of wastes before they are discharged into a recharge basin, another is to discharge wastes through ocean outfalls. The former sustains the ground water supply; the latter makes the water use entirely consumptive and causes supply depletion. Considerable thought and planning must be given to treatment that will produce a sewage effluent of suitable quality for recharge, to reduce the consumptive use of water as more sewers are installed.

Water Supply Systems

The rapid urban growth has had a marked effect on individual water supplies. Nassau County grew so rapidly from 1945 to 1965 that drilling wells for individual homes within the county became impracticable. Health Department regulations prohibited the use of domestic wells where public supplies were available and water supply systems were installed as housing developments were built.

The same condition has occurred in areas of Suffolk County, particularly in the western part, but many houses built in more isolated areas had private wells installed and in the older communities many people had individual supplies. As the population density increased, detergents began to appear in the water, indicating pollution from cesspools and septic tanks, and in some areas where public supplies were adjacent to private wells, the increased pumpage lowered water levels. In many instances homeowners had to install deeper wells or connect to the public water supply systems.

The public water suppliers were also victims of rapid expansion. Pollution caused wells in the glacial aquifer to be abandoned and a larger percentage of public water supply now comes from the lower Magothy formation. This has increased the costs of well drilling and pumping equipment and the difference in natural water quality has required more extensive chemical treatment.

Until the 1950s a large part of the water used in Long Island was returned to the shallow aquifer through cesspools and septic tanks. Pollution was noted and in western Nassau County a sewerage system was installed. Since 1953 discharge from this area has averaged 31 mgd, increasing to 50 mgd in 1966, into the salt water bays. A recent U.S. Geological Survey study of a 50 square mile area in Nassau County sewered in the early 1950s shows that ground water levels have declined an average of about 10 feet more than in an adjacent unsewered area (about seven feet attributed to sewering, the rest to the drought) and that two streams in the area have sharp decreases in flow.

present water use

Summary

For this study, a town-by-town inventory of water use in 1965 was made for Nassau and Suffolk Counties. Available basic data for that year were supplemented through questionnaires sent to all municipal and private water suppliers in the two counties (Table 4 for Nassau County, Table 6 for Suffolk County). Water use in Nassau County in 1965 totalled almost 70,000 mg (million gallons) or an average of 190 mgd (million gallons per day), compared with a 1960 estimate of 145 mgd by Greeley and Hansen. In Suffolk County, the total water use in 1965 was 50,500 mg or an average of 141 mgd. Per capita daily water use in Nassau County totals 135 gallons (Table 5) and in Suffolk County about 178 gallons per capita per day (Table 7).

It is difficult to categorize all water use on Long Island, but separate estimates were made for residential, manufacturing, non-manufacturing and non-agricultural business, agricultural, recreational and major self-supplied institutional uses.

Residential

Water for residential use comes from public water supply systems and from individual domestic wells. Except for about 1,800 persons in a 3,400 acre area near Oyster Bay Harbor, with 500 domestic wells, Nassau County has only 260 domestic wells. It had 43 public water supply systems in 1965, according to records of the State Water Resources Commission – 37 municipally operated serving a population of 863,000, and six privately owned serving 602,000 persons.

The picture in Suffolk County is entirely different. About 28 percent of the population is outside the public water supply service areas and even within the service areas, many residents are not supplied with public water, either by choice or because of the systems' limited distribution capabilities. According to 1965 records of the Water Resources Commission, 13 municipally operated installations and 56 private water companies in Suffolk County served 188,700 persons. The County Water Authority had 67 pumping stations at various locations which, directly or indirectly, served about 491,500 persons. The remaining 259,000 persons depended on private domestic wells.

The percent of population served by domestic wells is greatest in the east and south (Plate 6), decreasing in the north and mid-island portions. The depth to the water table is generally greatest in the latter areas, so the greater cost of domestic wells provides a major incentive for more public water supply development.

Population density is also a major factor. Development in the more densely populated areas in the western part of Suffolk County is nearly complete, based on a comparison of the distribution system and franchised service area maps of the Suffolk County Water Authority. In the eastern part of the county, the West Hampton, Southampton, Sag Harbor and East Hampton plants distribute to their immediate areas and are not expected to be expanded until population density increases.

The natural quality of shallow ground water in Nassau and Suffolk Counties is generally good, but in some areas relatively high iron content and corrosiveness cause problems in shallow household domestic wells and these areas tend to be served through public water supply systems. In recent years, another major factor in the decrease in private domestic wells has been the increase in pollution of the shallow ground water aquifer, particularly by detergents in the Babylon-Islip area. County Health Department and other regulations also encourage or require centralization of water supply.

A comparison of 1965 data with a 1960 survey by the Suffolk County Health Department shows that the percentage of population served by private wells has declined sharply in western Suffolk County despite a large increase in population during the five-year period. Records of active services of the various plants of the Suffolk County Water Authority for 1960 and 1965 also show a tremendous growth in these services in the five western townships in relation to the population increases, indicating the abandonment of private domestic wells (Table 8).

Another significant feature is the general decrease in per capita use from the public water supply systems in a west to east and north to south direction in Nassau and Suffolk Counties. A major reason is the direct relationship of water use to income – more water is used in higher income families. A comparison of 1960 U.S. Census median family income figures with 1965 water use figures shows that this relationship holds exactly for the three towns in Nassau County and for the five western towns in Suffolk

TABLE 4

WATER USE SUMMARY IN NASSAU COUNTY, 1965
(in million gallons)

Manufacturing use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Water Use MG*	MGD	
Hempstead	1,063.1	5,317.2	65.8	614.5	28,635.0	33,795.6	97.8
North Hempstead	1,142.0	2,735.1	1.0	215.0	10,006.1	14,189.2	38.9
Oyster Bay	4,180.6	2,079.9	25.4	673.9	12,094.2	19.349.0	53.0
Nassau County	6,385.7	10,132.2	92.2	1,503.4	50,735.3	69,233.7**	189.7

NOTE:
*Totals include water usage not tabulated above
for Fish & Game 275.0 MG
Self-Supplied Institutions 109.9 MG

**Total does not include New York City withdrawals from Nassau County of 3468.OMG

Total does not include industrial-commercial pumpage which is returned via diffusion wells.

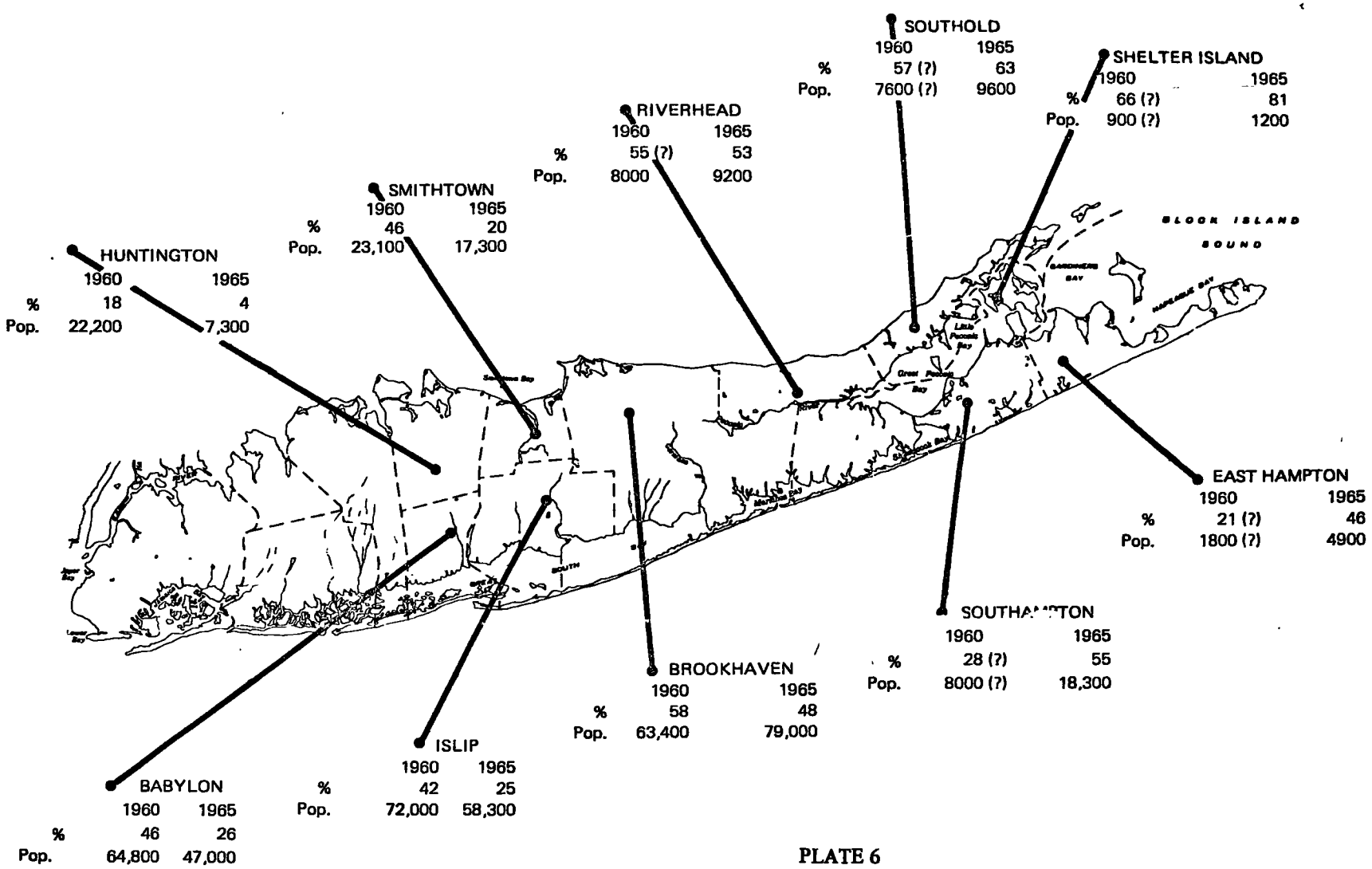


PLATE 6

POPULATION SERVED BY PRIVATE DOMESTIC WELLS, SUFFOLK COUNTY, 1960 AND 1965

TABLE 5

WATER USE SUMMARY IN NASSAU COUNTY, 1965
(In gallons per capita per day)

Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Recreational Use	Residen-Use	Total Water Use GPCD*
Hempstead	813,974	4	18	2	96	120
North Hempstead	235,615	13	32	3	116	165
Oyster Bay	352,102	33	16	5	94	151
Nassau County	1,401,691	12	20	3	99	135.

NOTE:
*Totals include water usage for agriculture, fish and game, and self-supplied institutions not tabulated above.

TABLE 6

WATER USE SUMMARY
IN SUFFOLK COUNTY, 1965
(In million gallons)

	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Self-Supplied Institutions	Residential Water Use*	Total Water Use MG	MGD
Babylon	1602	1009	10	32	115	4450	7218	19.8
Brookhaven	325	3579	3532	47	–	7916	11604	31.8
Easthampton	24	67	85	6	–	694	876	2.4
Huntington	320	894	364	89	125	5683	7465	20.4
Islip	506	1147	86	92	1210	4346	7387	20.2
Riverhead	481	193	4882	15	–	506	6077	16.6
Shelter Island	–	10	4	–	–	127	141	.4
Smithtown	183	442	135	65	581	2266	3672	10.0
Southampton	17	174	1557	29	–	1517	3294	9.0
Southold	13	75	2166	7	–	536	2797	7.7
Suffolk County	3471	7580	12,821	382	2031	24,246	50,531	138.3

NOTE:
*Residential Water Use includes estimated amount for "lost-water" which covers leakage, illegal connections, hydrant openings, fires, etc., usually amounting to 10 to 20 percent of water pumped.

TABLE 7

WATER USE SUMMARY
IN SUFFOLK COUNTY, 1965
(In gallons per capita per day)

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricul-Use	Recreational Use	Self-Supplied Institutions	Residential Water Use*	Total Water Use GPCD
Babylon	183,981	23.8	15.0	0.2	0.5	1.7	66.2	107.4
Brookhaven	164,370	5.4	59.6	58.9	0.8	–	68.6	193.3
Easthampton	10,570	6.2	17.2	22.0	1.5	–	180.1	227.0
Huntington	165,659	5.3	14.6	6.0	1.4	2.1	94.0	123.4
Islip	236,819	5.8	13.3	1.0	1.1	14.0	50.2	85.4
Riverhead	17,384	76.1	30.6	772.1	2.4	–	79.8	961.0
Shelter Island	1,478	–	18.5	7.4	–	–	235.4	261.4
Smithtown	87,336	5.7	13.9	4.2	2.0	18.2	71.1	115.1
Southampton	33,142	1.4	14.4	128.7	2.4	–	125.3	272.2
Southold	15,208	2.3	13.5	390.8	1.2	–	96.7	504.5
Suffolk County	915,887	10.3	22.7	38.4	1.1	6.1	72.4	151.0

NOTE:

*Residential Water Use includes estimated amount for "lost water" which covers leakage, illegal connections, hydrant openings, fires, etc., usually amounting to 10 to 20 percent of water pumped.

County (Plate 7). The north to south relationship of per capita water use to family income also holds true for Oyster Bay and Brookhaven, which include areas on both the north and south shore, if these towns are divided at about mid-island.

At first glance the five eastern towns in Suffolk County do not appear to conform to this pattern, but census figures do not reflect their large seasonal increase in population. For example, the maximum summer population in East Hampton, about four times the census population, combined with the higher than average water use during the summer, explains the high water use in relation to income. Southampton and Shelter Island are exceptions – Southampton, long famous as a wealthy resort area, has a higher than normal family income and Shelter Island, connected to the mainland only by ferry, has a lower income per family than might be expected, because of its lation.

The direct relationship between income and water use per capita has long been recognized. With higher incomes, more families own automatic washing machines and dishwashers, do more lawn sprinkling and use more water in other ways. Automatic washing machines, for example, use 30 gallons of water or more per load and lawn sprinkling may consume 40,000 gallons a year per residence.

Among other factors which influence the daily per capita use of water from public water supplies are the extent of commercial and industrial uses, the water quality, the charge by meter or at a flat rate, leakage from the supply systems and other controlling measures such as low pressures and lawn sprinkling restrictions. Along the south shore, per capita water use figures are generally lower because the closeness of the water table to the surface makes it relatively easy and inexpensive to install wells for lawn sprinkling, otherwise using a public water supply system.

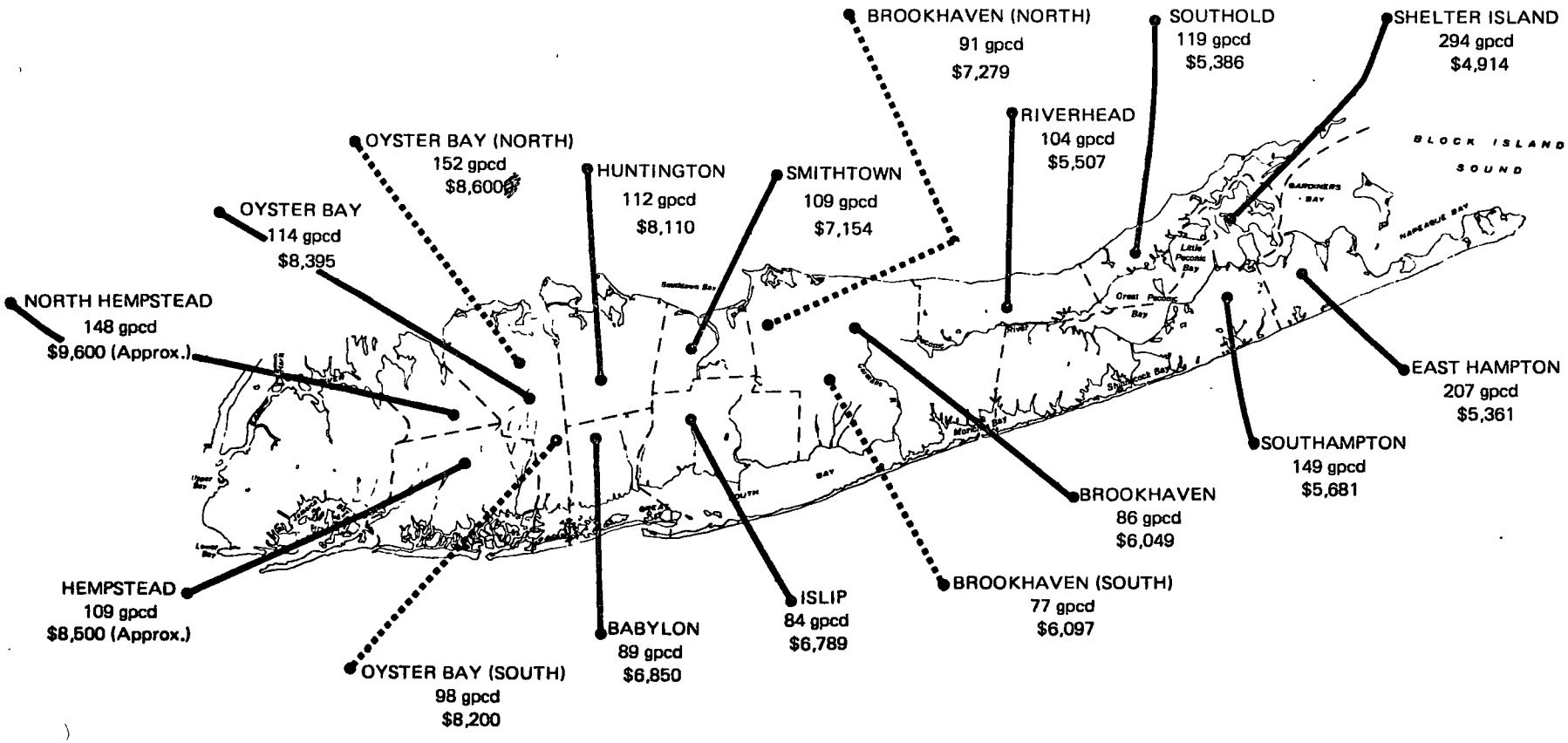


PLATE 7

Note: Top figure represents gallon per capita per day consumption and bottom figure represents median income per family (1960).

COMPARISON OF WATER USE
AND MEDIAN INCOME
May 1969

The tremendous increase in ground water development on Long Island in recent years is indicated by the number of well drilling permits issued by the Water Resources Commission from 1945 through 1965 (Table 9). These data were segregated by permits issued for wells of less than 45 gallons per minute capacity and ones with greater capacities. For the most part, the smaller wells are for residences, the larger wells for public water supplies, or industrial and commercial purposes (Plates 8 and 9).

In Kings and Queens Counties, an increase in well drilling after World War II was followed by a decline in the early 1950s as a result of the serious water situation in the late 1940s, especially in Kings County where over-pumping made water levels extremely low. New York City's increased service to these areas from upstate sources relieved the need for new wells. Following this decline, drilling activity stabilized during the middle and late 1950s, when New York City supplies were adequate. The recent

TABLE 8

GROWTH IN ACTIVE WATER SERVICES
SUFFOLK COUNTY WATER AUTHORITY
June 5, 1960 to June 5, 1965

SWCA Plant	Active Services June 1965	Active Services June 1960	New Services 6/60-6/65	% Increase in Services 6/60-6/65	Est. % Increase in Service Area Population
Amityville	8280	6032	2248	37	22
Babylon	25431	12923	12508	97	31
Bay Shore	29730	18855	10875	58	36
Huntington	11763	10343	1420	14	16
Northport	10472	8090	2392	30	37
Patchogue	12170	9343	2872	30	37
Port Jefferson	8373	2843	5530	195	97
Sag Harbor	783	727	56	8	18
Smithtown-Kings Park	7100	4493	2607	58	70
Southampton	1807	1605	202	13	16
Westhampton	1895	1624	271	17	18
East Hampton	81	–	81	–	–
Totals	117885	76878	41007	53	38

Acquisitions 6/60-6/65

10/31/61 – Eastwood Water Works, Inc. – 1452 services – to Smithtown-Kings Park Plant
4/18/62 – Harbor Hill Estates, Inc. – 145 services – to Port Jefferson Plant
5/28/63 – Marlboro Acres – 69 services – to Smithtowh-Kings Park Plant
5/31/63 – Home Water Co. – 2048 services – re-named East Hampton Plant
8/1/63 – Village of Belle Terre – 120 services – to Port Jefferson Plant
8/28/63 – Smithtown Water Co. – 154 services – to Smithtown-Kings Park Plant
1/7/64 – Green Meadows Water Co. – 886 services – to Patchogue Plant
8/11/64 – Shorehaven Water Corp. – 72 services – to Patchogue Plant

upswing in the number of wells drilled in Kings and Queens Counties results primarily from increased demands for air conditioning.

Well drilling in Nassau County did not peak until the mid-1950s, with the phenomenal growth in population and residential building which started after World War II. A slow decline in well drilling followed until a slight increase in the 1960s, when drastic reductions might have been expected because of drought conditions. The increase is explained in part by the available ground water supply in Nassau County. Urbanization is a related factor, in that consumptive water use for agricultural irrigation has been almost eliminated.

The well drilling pattern in Suffolk County is entirely different, with no significant decline during the entire study period. The population has grown steadily, expanding from west to east, and many eastern areas do not have public systems. Many homeowners have installed supplemental wells for sprinkling, and the rapid population growth has also necessitated continued expansion of public water supplies.

TABLE 9

NEW WELL PERMITS ISSUED
ON LONG ISLAND
BY WATER RESOURCES COMMISSION
1945 – 1965

Well Permit Numbers

Year	Suffolk	Total	Nassau	Total
1945	2142 - 4560	418	2023 - 2085	62
1949	7273 - 8182	909	3147 - 3459	312
1950	8183 - 8992	809	3460 - 3677	217
1955	13452 - 14547	1095	5154 - 5696	542
1960	18339 - 19537	1198	6817 - 7028	211
1963	21485 - 22391	906	7397 - 7518	121
1964	22392 - 23690	1298	7519 - 7779	260
1965	23691 - 26995	3304	7780 - 8009	229

Year	Queens	Total	Kings	Total
1945	1377 - 1402	25	1489 - 1512	23
1949	1495 - 1621	136	1626 - 1675	49
1950	1622 - 1766	144	1676 - 2047	371
1955	2137 - 2193	56	2291 - 2344	53
1960	2330 - 2355	25	2516 - 2551	35
1963	2407 - 2425	18	2579 - 2593	14
1964	2426 - 2445	19	2594 - 2616	22
1965	2445 - 2704	258	2617 - 2704	87

Source: Westbury Office
Water Resources Commission

Manufacturing, Commercial and Institutional

Water used for manufacturing purposes in Nassau and Suffolk Counties comes mainly from private wells, particularly in Suffolk County, where about 85 percent is self-supplied. The 65 percent figure in Nassau County indicates a somewhat greater reliance on public systems.

The so-called wet industries, such as paper mills, refineries and steel mills, have not located in these counties. Water for manufacturing is used primarily for sanitary and housekeeping purposes, for process cooling and for air conditioning. The three largest water-using manufacturers in Nassau County are Grumman Aircraft, Sperry Gyroscope and Circle Wire and Cable, which used 2,058 mg, 948 mg and 214 mg, respectively, in 1965. In Suffolk County the largest manufacturing water users were Airborne Instruments, 694 mg; the Republic Division of Fairchild-Hiller, 584 mg; and Grumman Aircraft (Calverton), 373 mg.

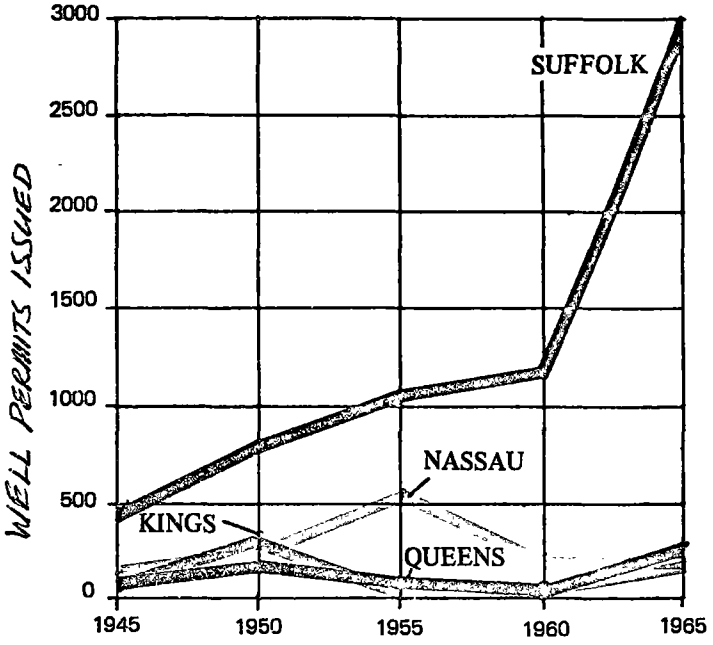
Considerably more water is used for business or commercial purposes than for manufacturing in Nassau and Suffolk Counties. In Nassau County, about 80 percent of the water comes from public systems, but in Suffolk County, almost 60 percent is self-supplied. As with manufacturing, much of the water is used for sanitary and housekeeping purposes and for air conditioning. The largest users in this classification in Nassau County are the Long Island Lighting Company at Hicksville, 154 mg; at Glenwood, 120 mg; and R. H. Macy at Roosevelt Field, 113 mg. In Suffolk, by far the largest use is by Associated Industries, Inc. (Brookhaven Laboratory), 2,256 mg, and the State University at Stony Brook, 379 mg.

Agricultural

Major quantities of water are used for agricultural purposes on Long Island, principally for irrigation of potatoes, truck crops and nurseries, and for duck raising. Irrigation is particularly significant because it is almost entirely a consumptive use. The main agricultural water use is in Suffolk County, where farming is a $70 million per year business. The bulk of agricultural land still remaining on Long Island is in the five eastern Suffolk towns. Nassau County has only 100 farms totalling 1,238 acres – former farmland is now sprouting housing developments, shopping centers or industrial complexes, with rapidly rising land values. Surprisingly, the relatively small agricultural acreage in Suffolk County ranks the county first in New York State

DISTRIBUTION OF ALL NEW WELLS,
1945-65

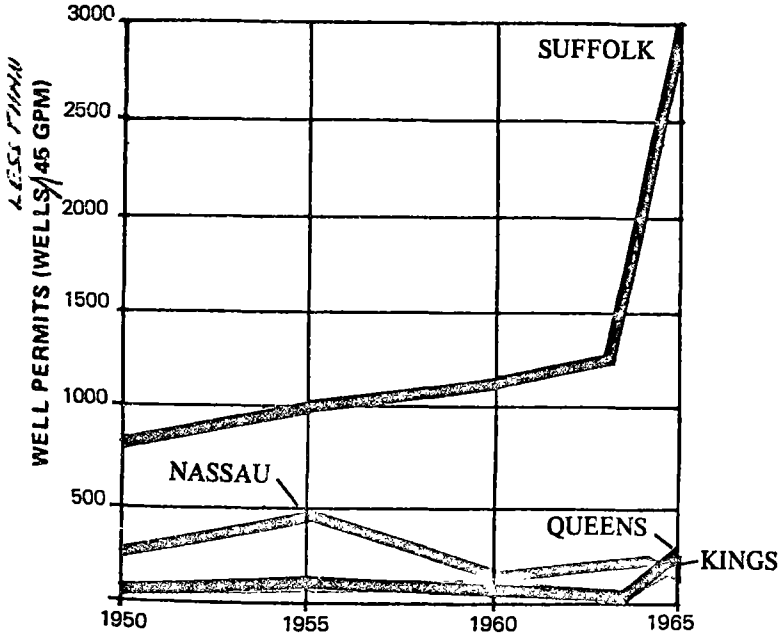
PLATE 8



MAY 1969

DISTRIBUTION OF NEW WELLS
WITH CAPACITY OF LESS THAN 45 G.P.M.
1945-65

PLATE 9



in the value of total income from agriculture, indicating the intensive and specialized nature of farm enterprises.

An analysis of present irrigation practices in Suffolk County shows that an estimated 200,000 to 208 000 gallons per year are used per irrigated acre. The 1964 Agricultural Census lists the county's irrigated acreage at 36,415 acres, but local agricultural officials believe that possibly as many as 39,000 acres were irrigated in 1965, a drought year. Based on the maximum of 208,000 gallons per acre per year and 36,415 acres irrigated, annual water use for irrigation totals 7,575 million gallons.

The Long Island duck industry, producing about 7 million ducks annually, also uses considerable water. A recent study in Suffolk County determined that water usage varied considerably from farm to farm, ranging from 14 to 120 gallons per day per duck on five typical farms (out of 48). A figure of 15 gallons per day per duck was generally representative, used mainly for sanitary purposes. Duck farmers are attempting to decrease the use of water in order to decrease the cost of treatment facilities for duck wastes. It is expected that water use can be reduced about four to 10 gallons per day per duck for a 50-day growing season, but for the present, the duck industry uses about 5,246 million gallons per year.

Total agricultural water use for irrigation and raising ducks amounts to 12,821 million gallons per year, an average use of 35 mgd. The use does not continue throughout the year, but occurs in the 150 days from May to September for irrigation and in the 170 days from March to November for raising ducks. On this basis, the maximum daily water use through the relatively dry summer months averages 70 mgd.

Recreational

Long Island has experienced a great growth in population, industry and housing over the past 20 years, and is now undergoing a recreation boom. People have become increasingly recreation-minded in the past five years, as reflected in the rapid expansion of recreation programs, mostly government sponsored.

In Nassau and Suffolk Counties, the need for more and varied recreation has become a prime concern of various governmental agencies, whose jurisdiction is complex and overlapping. In Nassau County, about 93 different agencies are involved in recreation – 64 incorporated villages, 24 park districts and other special districts that serve unincorporated areas. In Suffolk County, 10 towns, 28 incorporated villages and 82 school districts provide recreation of varying kinds. Both counties are served by state parks and

in Suffolk County the National Park Service is now developing the Fire Island National Seashore.

Land costs will make expansion of recreational facilities in Nassau County difficult. Less than 10 percent of its total land area is still vacant, and inflation of land values precludes immediate major acquisitions. In Suffolk County, with only slightly more than 40 percent of the land area developed, it is not too late to formulate a meaningful recreation program.

Estimates of recreational water use include a broad variety of uses – public parks, beaches and other recreation areas, irrigation of public and private golf courses and filling and maintaining public swimming pools. In Nassau County this use is estimated at about 1,500 mg per year or about 4 mgd. Suffolk County's recreational water use is considerably less, amounting to about 380 mg per year or slightly more than 1 mgd. During a 100-day recreation season in June, July and August, the recreational water use is 150 mgd and 38 mgd, respectively, in Nassau and Suffolk Counties.

Although these amounts are small in comparison with residential water use, the importance of recreation cannot be minimized. In Nassau County almost 9 percent of the land area is devoted to recreation, including 5,000 acres in state parks, 6,000 acres in local parks and 6,000 acres in private clubs. In Suffolk County about 5 percent of the total land area is used, 27,000 acres in parks and recreation areas.

Other Water Uses

The scope of this study did not permit meaningful quantitative estimates for other water uses which may be significant. Fish and wildlife and fire protection can be discussed only in general qualitative terms, since no specific data are available and no satisfactory analytical techniques have been developed to derive estimates of quantities.

Fresh water is obviously necessary for the fresh water fishery on Long Island and for wildlife needs – in general, the more fresh water the better. Long Island is known for its salt water fishing, but fresh water fishing is also important. Several streams and some lakes and ponds are stocked with trout and many ponds and lakes, particularly in Suffolk County, are fished for panfish, bass and pickerel. The only available estimate of fresh water use for fishing is that at the Cold Springs Fish Hatchery, which amounted to 275 mg in 1965.

The relation of streamflow and lake levels to the adjoining water table level has been discussed, and it has been noted that 95 percent of the streamflow represents ground water discharge. The importance of maintaining ground water levels to satisfy in-stream water demands is obvious, but no estimate of optimum or desirable minimum streamflow has been made, nor have methods been investigated for augmenting flows. The potential for flow augmentation is probably not great.

Water for fire protection in Suffolk County comes largely from the hydrants of a public water supply system or from fire wells installed specifically for fire fighting. Even before 1950, the more densely populated areas had hydrants on the public water system, but the less dense areas sometimes had fire wells. When these areas developed, public distribution systems were installed by the developer or by a public supplier. Fire hydrants were then installed in accordance with local fire district regulations and with few notable exceptions, such as the incorporated village of Lindenhurst, individual fire wells were abandoned.

About 860 fire wells remain in use in Suffolk County, generally with 4-inch or 6-inch diameter well castings sunk to approximately 45 feet. The wells do not have permanently installed pumps, but are connected temporarily to pumps on fire engines during fire-fighting. A 4-inch fire well yields from 200 to 300 gallons per minute, a 6-inch well a maximum of 450 gallons per minute. No estimate of the amount of water withdrawn through fire wells is available, but with the continued population growth in Suffolk County and the extension of public water supply mains, their use will be discontinued.

future water demands

Fresh water demands on Long Island will be closely linked to the population growth and expanding industry and economy. Per capita water use is also trending upward.

Making projections is a hazardous undertaking at best, and is even more speculative in a rapidly changing area like Long Island. Among the population projections developed by many public and private agencies, the most important are those by the Nassau-Suffolk Regional Planning Board, State Conservation Department, State Office of Planning Coordination, Tri-State Transportation Commission, Regional Plan Association, New York Port Authority, and National Planning Association. Most available projections extend to about 1985, and a few long-range estimates – particularly those developed specifically for water supply studies – extend to 2020.

Projections vary considerably depending upon their inherent assumptions and judgments. In Nassau County, for example, where most available land has been developed, the extent to which zoning regulations inhibit changes in the present land use patterns will determine how much farther the county population grows. If present residential zoning restrictions are maintained or strengthened, population growth rates will diminish and the total population will reach a relatively stable level. If zoning regulations are changed to permit high rise apartments with greater concentrations of people, the population will continue to expand.

In Suffolk County, with large areas still available for development, the rate of growth may be influenced in many other ways – for example, construction of a bridge or bridges across Long Island Sound, or a jet port for the New York metropolitan area.

The population projections made to 1990 as a basis for projecting water demands in general represent median values falling within the range of spread of available projections. These estimates, made in consultation with the Nassau-Suffolk Regional Planning Board and with the Office of Planning Coordination, are believed to be a reasonably firm basis for evaluating future water demands.

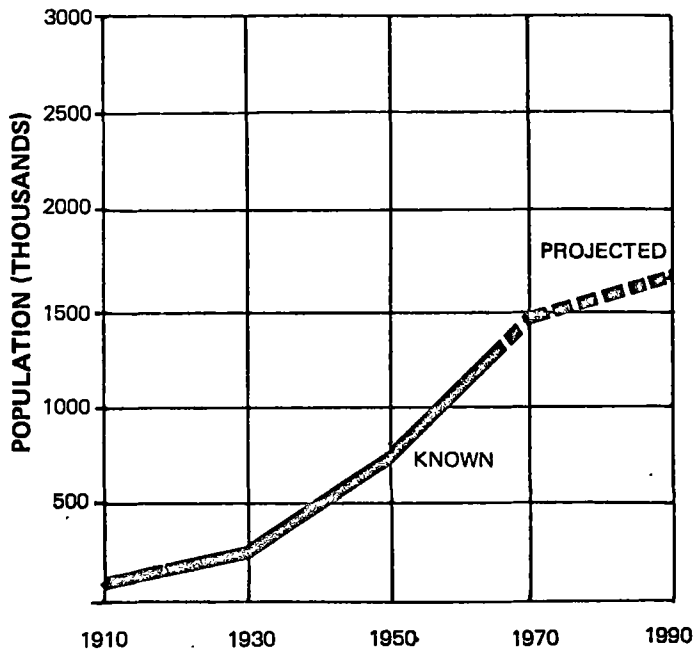
Available town and county population data by decades from 1910 through 1960 and projections by decades through 1990 (Table 10 and Plates 10 and 11) clearly show the rapid population growth in Nassau County from 1950 to 1960 and a tapering off from 1960 through 1965. The same growth is evident for Suffolk County from 1950 to 1960, with a slightly greater rate of growth from 1960 to 1965 expected to continue through 1990.

Water use in Nassau and Suffolk Counties was evaluated for 1965, selected as a base year, but drought conditions made water use, particularly for sprinkling and irrigation, unusually high then.

Based on the 80-year period of record at Setauket, precipitation on Long Island in 1965 was at a record low of 26.5 inches, compared to an average of 44.6 inches. It was also the third year during the four-year drought of 1963 to 1966, in which low precipitation records were established successively for one-year, two-year, three-year and four-year periods. The cumulative effect of the drought on ground water conditions, in addition to the low 1965 precipitation, intensified water use.

POPULATION TREND, NASSAU COUNTY
MAY 1969

PLATE 10



Accordingly a study was made to determine what Nassau County's fresh water use would have been with average precipitation. Adjusted water use values were derived that would be more representative of average conditions, and as a check, the adjusted values with allowances for actual precipitation and water use trends were applied to Nassau County for 1960 through 1966. The

results, compared with actual reported pumpages, showed an average difference of less than 2 percent with a high of 3.9 percent in 1960. These differences are believed insignificant, and so the adjusted 1965 water use estimates provide a reliable base for the projections. (Tables 11 and 12 and Plate 10 for Nassau County, Tables 13 and 14 and Plate 11 for Suffolk).

Total water use in Nassau County is projected to increase about 45 percent from 161 mgd (adjusted to normal precipitation) in 1965, to 206 mgd in 1980 and 234 mgd in 1990. The projected value for 1980 is somewhat lower than the Greeley and Hansen projection of 223 mgd, made in 1963, primarily because of a lower projected population for Nassau County in the current study: 1.575 million compared with 1.8 million in the Greeley and Hansen report. Per capita use for the same period increases from 115 gpcd in 1965 to 135 gpcd in 1990.

Suffolk County water use is projected to increase about two and a half times, from 126 mgd (adjusted to normal precipitation) in 1965 to 307 mgd in 1990. Per capita use here increases from 137 gpcd to 149 gpcd in 1990. In both counties the greatest percentage increase is in manufacturing water use; however, the base use for this purpose in 1965 is lower than for business or residential use. In Nassau County the small amounts of water identified for agricultural, recreational, fish and game and institutional purposes are expected to decrease slightly. In Suffolk County these uses are expected to increase at a lesser percentage than are the other uses.

POPULATION TREND SUFFOLK COUNTY
MAY 1969

PLATE 11

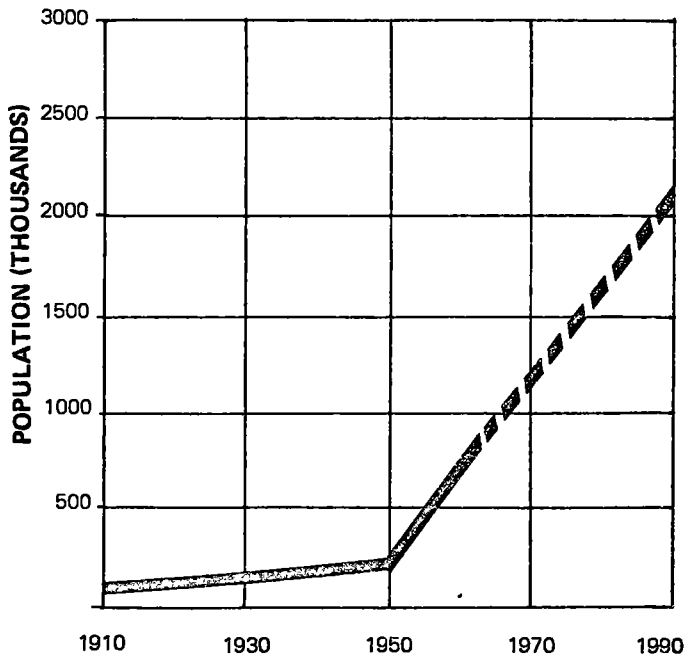


TABLE 10

PAST AND PROJECTED POPULATION
1900-1910 TO 1990
LONG ISLAND

	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990
Nassau County	55,400	83,900	126,100	303,100	406,700	672,800	1,300,200	1,465,000	1,575,000	1,720,000
Hempstead		44,300	71,100	192,600	268,400	448,100	767,200	850,000	916,000	1,003,000
North Hempstead		17,800	26,400	62,200	83,400	142,600	219,100	247,000	264,000	289,000
Oyster Bay		21,800	29,000	48,300	55,000	82,100	313,900	368,000	395,000	428,000
Suffolk County	72,600	96,100	110,200	161,100	197,400	276,100	668,800	1,140,000	1,500,000	2,059,000
Babylon		9,000	11,300	19,300	24,300	45,600	142,300	215,000	262,000	283,000
Huntington		12,000	13,900	25,600	31,800	47,500	126,200	200,000	282,000	313,000
Islip		18,300	20,700	33,200	51,200	71,500	173,000	286,000	357,000	380,000
Smithtown		7,100	9,100	11,900	14,000	21,000	50,300	115,000	160,000	170,000
Brookhaven		16,700	21,800	28,300	32,100	44,500	109,900	230,000	378,000	695,000
Riverhead		5,300	5,800	8,000	8,900	10,000	14,500	21,000	36,000	63,000
Southold		10,600	10,100	11,700	12,000	11,600	12,300	17,000	23,000	35,000
Southampton		11,200	11,700	15,500	15,500	16,800	27,100	36,000	55,000	87,000
East Hampton		4,700	4,900	6,600	6,500	6,300	8,800	12,500	21,000	35,000
Shelter Island		1,100	900	1,100	1,100	1,400	1,300	1,700	2,300	3,400

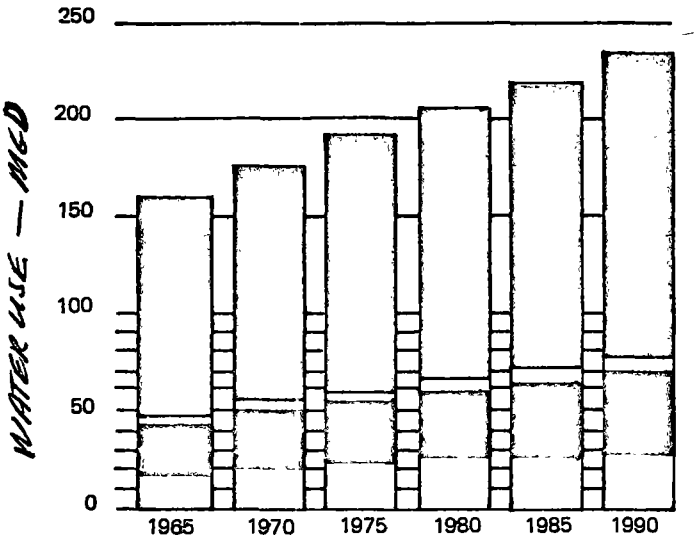
NOTES:

These projections, prepared by the Division of Water Resources, differ somewhat from the OPC *Demographic Projections.*

Figures do not add to totals because of graph interpretation and rounding.

PLATE 12

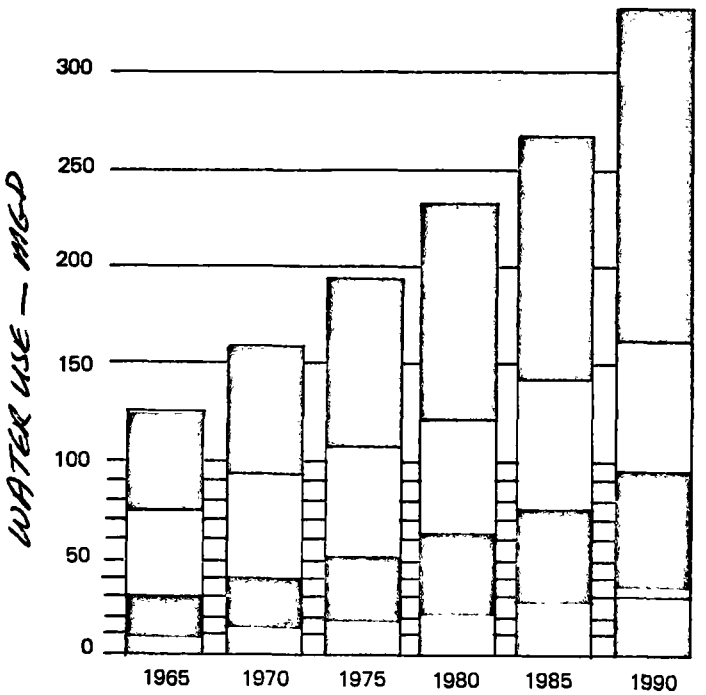
PROJECTED WATER USE
NASSAU COUNTY



	1965	1970	1975	1980	1985	1990
Manufacturing	16.9	20.0	22.0	23.9	25.8	28.1
Non-Mfg., Non-Agr. Bus.	26.2	29.9	32.8	35.4	38.3	41.2
Agri., Rec. Fish & Game, Inst.	4.0	3.6	3.7	3.6	3.6	3.6
Residential	114.1	124.7	134.0	142.9	152.2	161.0
Total MGD	161.2	178.3	192.5	205.7	219.9	233.8

PLATE 13

PROJECTED WATER USE
SUFFOLK COUNTY



	1965	1970	1975	1980	1985	1990
Manufacturing	9.3	13.3	17.5	21.8	27.6	35.1
Non-Mfg., Non-Agr. Bus.	20.0	26.3	33.2	39.7	49.0	59.2
Agri., Rec., Inst., Lost Water	44.9	51.7	56.1	60.2	64.6	66.6
Residential	51.7	68.3	86.5	104.0	125.8	146.4
Total MGD	125.9	159.6	193.3	225.7	267.0	307.3

TABLE 11

PROJECTED WATER USE IN NASSAU COUNTY
(In million gallons per day)

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Recreational Use	Residential Water Use	Total Projected Use – MGD
Hempstead						
1965 – Actual Precipitation	813,974	2.9	14.6	1.7	78.4	97.8
Normal Precipitation	813,974	2.8	14.0	1.1	66.3	84.2
1970	850,000	3.3	16.0	1.1	72.0	92.4
1975	883,000	3.8	17.7	1.1	77.3	99.9
1980	916,000	4.1	19.0	1.1	82.3	106.6
1985	959,000	4.5	20.7	1.1	87.7	114.1
1990	1,003,000	5.0	22.5	1.1	92.4	121.1
North Hempstead						
1965 – Actual Precipitation	235,615	3.1	7.5	0.6	27.4	38.9
Normal Precipitation	235,615	3.0	7.1	0.4	22.1	32.8
1970	247,000	3.5	7.9	0.4	24.2	36.0
1975	255,000	3.7	8.5	0.4	25.7	38.4
1980	264,000	4.1	9.0	0.4	27.2	40.7
1985	275,000	4.5	9.4	0.4	28.7	43.0
1990	289,000	4.8	9.9	0.4	30.5	45.6
Oyster Bay						
1965 – Actual Precipitation	352,102	11.4	5.7	1.8	33.1	53.0
Normal Precipitation	352,102	11.1	5.2	1.2	25.7	44.2
1970	368,000	13.2	6.1	1.2	28.5	49.8
1975	382,000	14.4	6.7	1.2	31.0	54.2
1980	395,000	15.7	7.3	1.2	33.4	58.4
1985	411,000	16.8	8.1	1.2	35.8	62.8
1990	428,000	18.3	8.7	1.2	38.1	67.2
Nassau County						
1965 – Actual Precipitation	1,401,691	17.5	27.8	4.1	139.0	189.7
Normal Precipitation	1,401,691	16.9	26.2	2.7	114.1	161.2
1970	1,465,000	20.0	29.9	2.7	124.7	178.3
1975	1,520,000	22.0	32.8	2.7	134.0	192.5
1980	1,575,000	23.9	35.4	2.7	142.9	205.7
1985	1,645,000	25.8	38.3	2.7	152.2	219.9
1990	1,720,000	28.1	41.2	2.7	161.0	233.8

TABLE 12

PROJECTED WATER USE IN NASSAU COUNTY
(In gallons per capita per day)

	Population	Manufac-Use	Non-Manufacturing and Non-Agricultural Business Use	Recre-ational Use	Residential Water Use	Total Projected Use – GPCD
Hempstead						
1965 – Actual Precipitation	813,974	3.6	17.9	2.0	96.4	120.1
Normal Precipitation	813,974	3.4	17.2	1.3	81.4	103.5
1970	850,000	3.9	18.8	1.3	84.7	108.7
1975	883,000	4.3	20.0	1.2	87.5	113.1
1980	816,000	4.4	20.8	1.2	89.9	116.4
1985	959,000	4.7	21.6	1.1	91.4	118.9
1990	1,003,000	5.0	22.5	1.1	92.1	120.7
North Hempstead						
1965 – Actual Precipitation	235,615	13.3	31.8	2.5	116.4	165.0
Normal Precipitation	235,615	12.7	30.0	1.7	93.8	139.2
1970	247,000	14.3	32.0	1.6	97.9	145.9
1975	255,000	14.9	33.4	1.5	100.7	150.6
1980	264,000	15.6	34.1	1.5	102.9	154.1
1985	275,000	16.3	34.3	1.4	104.5	156.5
1990	289,000	16.5	34.4	1.3	105.4	157.7
Oyster Bay						
1965 – Actual Precipitation	352,102	32.5	16.2	5.2	94.1	150.6
Normal Precipitation	352,102	31.6	14.8	3.5	73.1	125.4
1970	368,000	35.8	16.5	3.3	77.4	135.5
1975	382,000	37.8	17.4	3.2	81.2	141.8
1980	395,000	39.7	18.5	3.1	84.6	147.9
1985	411,000	40.9	19.7	3.0	87.1	152.7
1990	428,000	42.9	20.4	2.9	89.0	156.9
Nassau County						
1965 – Actual Precipitation	1,401,691	12.5	19.8	2.9	99.2	135.3
Normal Precipitation	1,401,691	12.1	18.7	1.9	81.4	115.0
1970	1,465,000	13.7	20.4	1.8	85.1	121.7
1975	1,520,000	14.5	21.6	1.8	88.2	126.6
1980	1,575,000	15.1	22.5	1.7	90.7	130.6
1985	1,645,000	15.7	23.3	1.6	92.5	133.7
1990	1,720,000	16.4	24.0	1.6	93.6	135.9

TABLE 13

PROJECTED WATER USE IN SUFFOLK COUNTY
(In million gallons per day)

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use – MGD
Babylon							
1965 – Actual Precipitation	183,981	4.4	2.8	–	0.1	12.2	19.8
Normal Precipitation	183,981	4.3	2.7	–	0.1	10.6	18.0
1970	215,000	6.4	3.5	–	0.1	14.1	24.5
1975	241,000	6.9	4.3	–	0.2	16.3	28.2
1980	262,000	7.3	4.9	–	0.2	18.1	31.3
1985	275,000	7.8	4.7	–	0.4	20.2	35.0
1990	283,000	8.1	6.0	–	0.5	20.9	36.6
Brookhaven							
1965 – Actual Precipitation	164,370	1.0	9.8	9.6	0.1	11.3	31.8
Normal Precipitation	164,370	0.9	9.4	9.3	0.1	9.9	29.6
1970	230,000	1.3	12.5	10.0	0.1	13.3	37.2
1975	300,000	2.6	14.6	10.3	0.3	19.4	47.2
1980	378,000	4.1	17.0	10.7	0.5	26.5	38.9
1985	545,000	7.7	22.5	10.4	0.9	40.8	82.3
1990	695,000	12.2	28.9	10.1	1.1	55.1	107.6
Easthampton							
1965 – Actual Precipitation	10,570	0.1	0.2	0.2	–	1.9	2.4
Normal Precipitation	10,570	0.1	0.2	0.2	–	1.6	2.0
1970	12.500	0.1	0.2	0.2	–	1.9	2.3
1975	16,500	0.2	0.3	0.3	0.1	2.2	3.0
1980	21,000	0.3	0.5	0.3	0.1	2.5	3.7
1985	27,000	0.4	0.7	0.3	0.1	2.8	4.3
1990	35,000	0.7	1.1	0.3	0.1	3.6	5.8
Huntington							
1965 – Actual Precipitation	165,659	0.[illegible]	2.4	1.0	0.2	15.6	20.4
Normal Precipitation	165,659	0.8	2.3	0.8	0.2	13.5	18.1
1970	200,000	1.1	3.1	0.9	0.3	18.0	23.7
1975	239,000	1.8	4.2	0.8	0.4	21.2	29.0
1980	282,000	2.7	5.6	0.7	0.5	25.0	35.1
1985	304,000	3.2	6.3	0.7	0.6	27.2	38.8
1990	313,000	3.4	6.7	0.4	0.7	27.8	40.2

Islip	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use – MGD
1965 – Actual Precipitation	236,819	1.4	3.1	0.2	0.3	11.9	20.2
Normal Precipitation	236,819	1.3	3.0	0.2	0.2	10.3	18.3
1970	286,000	1.8	4.0	0.2	0.3	13.7	24.2
1975	327,000	2.6	5.2	0.2	0.4	17.2	30.6
1980	353,000	3.1	6.0	0.2	0.5	19.5	34.9
1985	370,000	3.5	6.6	0.2	0.7	21.1	38.4
1990	380,000	3.8	7.0	0.2	0.7	22.1	40.7
Riverhead							
1965 – Actual Precipitation	17,324	1.3	0.5	13.3	–	1.4	16.6
Normal Precipitation	17,324	1.3	0.5	12.4	–	1.1	15.4
1970	21,000	1.8	0.7	13.4	–	1.7	17.6
1975	28,000	1.9	0.9	13.5	0.1	2.3	18.7
1980	36,000	2.1	1.1	13.6	0.1	3.1	20.0
1985	44,000	2.3	1.4	13.6	0.2	3.8	21.3
1990	63,000	2.9	2.3	13.2	0.2	5.6	24.2
Shelter Island							
1965 – Actual Precipitation	1,478	–	–	–	–	0.3	0.4
Normal Precipitation	1,478	–	–	–	–	0.2	0.3
1970	1,700	–	–	–	–	0.4	0.5
1975	2,000	–	0.1	–	–	0.4	0.5
1980	2,300	–	0.1	–	–	0.5	0.6
1985	2,800	–	0.2	–	–	0.6	0.8
1990	3,400	–	0.2	–	–	0.6	0.7
Smithtown							
1965 – Actual Precipitation	87,336	0.6	1.2	0.4	0.2	6.1	10.1
Normal Precipitation	87,336	0.5	1.1	0.2	0.1	5.4	8.8
1970	115,000	0.7	1.5	0.2	0.2	7.2	11.8
1975	144,000	1.2	2.4	0.3	0.3	9.8	16.4
1980	160,000	1.5	2.9	0.3	0.3	11.3	19.1
1985	167,000	1.7	3.2	0.3	0.4	11.9	20.8
1990	170,000	1.9	3.5	0.2	0.4	12.5	22.2
Southampton							
1965 – Actual Precipitation	33,142	0.1	0.5	4.3	0.1	4.2	9.1
Normal Precipitation	33,142	0.1	0.4	4.0	0.1	3.6	8.2
1970	36,000	0.1	0.6	4.4	0.1	4.8	9.5
1975	45,000	0.2	0.9	4.7	0.1	5.0	10.9
1980	55,000	0.4	1.2	4.9	0.2	6.0	12.7
1985	70,000	0.7	1.7	4.9	0.3	7.4	15.0
1990	87,000	1.2	2.4	4.7	0.4	9.0	17.5

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use – MGD
Southold							
1965 – Actual Precipitation	15,208	0.1	0.2	5.9	0.1	1.5	7.7
Normal Precipitation	15,208	0.1	0.2	5.3	0.1	1.2	6.9
1970	17,000	0.1	0.3	6.2	0.1	1.8	8.4
1975	20,000	0.1	0.4	6.3	0.1	2.1	9.0
1980	23,000	0.2	0.5	6.4	0.1	2.4	9.7
1985	28,000	0.4	0.7	6.4	0.1	3.0	10.6
1990	35,000	0.7	1.0	6.1	0.2	3.5	11.5
Suffolk County							
1965 – Actual Precipitation	915,887	9.5	20.7	35.1	1.0	66.4	138.3*
Normal Precipitation	915,887	9.3	20.0	32.5	0.7	58.0	125.9
1970	1,140,000	13.3	26.3	35.6	1.2	76.3	159.6
1975	1,375,000	17.5	33.2	36.4	1.8	96.1	193.3
1980	1,566,000	21.8	39.7	37.2	2.4	114.9	225.7
1985	1,829,000	27.6	49.0	37.0	3.6	138.5	267.0
1990	2,059,000	35.1	59.2	35.2	4.2	160.8	307.3

***Note:**

Total includes water use by major self-supplied institutions which does not appear in the tabulation. For Suffolk County this is as follows:

1965	Actual Precipitation	5.6
	Normal Precipitation	5.4
1970		6.9
1975		8.3
1980		9.6
1985		11.3
1990		12.8

TABLE 14

PROJECTED WATER USE IN SUFFOLK COUNTY
(In gallons per capita per day)

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use ~~MGD~~ GPCD
Babylon							
1965 – Actual Precipitation	183,981	23.8	15.0	0.2	0.5	66.2	107.4
Normal Precipitation	183,981	23.7	14.5	0.08	0.3	57.6	97.9
1970	215,000	29.6	16.4	0.08	0.4	65.6	113.9
1975	241,000	28.7	17.8	0.09	0.7	67.8	117.1
1980	262,000	28.0	18.8	0.08	0.8	69.3	119.4
1985	275,000	28.5	20.7	0.08	1.5	73.5	127.4
1990	283,000	28.5	21.3	0.06	1.8	73.9	129.4
Brookhaven							
1965 – Actual Precipitation	164,370	5.4	59.6	58.9	0.8	68.6	193.3
Normal Precipitation	164,370	5.3	57.4	56.5	0.5	60.1	180.0
1970	230,000	5.7	54.2	43.5	0.6	57.8	161.9
1975	300,000	8.6	48.6	34.2	1.1	64.7	157.4
1980	378,000	10.9	44.8	28.3	1.4	70.2	155.7
1985	545,000	14.1	41.3	19.1	1.7	74.9	151.1
1900	695,000	17.5	41.4	14.5	1.6	79.3	153.7
Easthampton							
1965 – Actual Precipitation	10,570	6.2	17.2	22.0	1.5	180.1	227.0
Normal Precipitation	10,570	5.9	16.6	17.3	1.0	157.7	198.8
1970	12,500	6.6	11.2	17.5	1.2	138.0	180.2
1975	16,500	10.0	19.6	14.9	1.7	123.5	170.5
1980	21,000	13.6	23.4	12.5	2.0	111.6	164.1
1985	27,000	15.6	25.9	10.6	2.7	104.7	160.5
1990	35,000	19.6	30.7	7.8	2.7	103.8	165.5
Huntington							
1965 – Actual Precipitation	165,659	5.3	14.6	6.0	1.4	94.0	123.5
Normal Precipitation	165,659	5.0	14.1	5.0	1.0	82.0	109.1
1970	200,000	5.6	15.3	4.4	1.4	90.4	118.4
1975	239,000	7.6	17.7	3.4	1.6	89.0	121.5
1980	282,000	9.6	19.8	2.4	1.7	89.0	124.7
1985	304,000	10.5	20.9	2.3	2.0	89.3	127.8
1990	313,000	10.9	21.4	1.8	2.2	89.1	128.4

Islip	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use ~~MGD~~ GPCD
1965 – Actual Precipitation	236,819	5.8	13.3	1.0	1.1	50.2	85.4
Normal Precipitation	236,819	5.7	12.8	0.8	0.7	43.7	77.3
1970	286,000	6.4	13.9	0.8	1.0	48.1	84.6
1975	327,000	7.8	15.9	0.7	1.2	52.9	93.7
1980	353,000	8.7	16.9	0.6	1.3	55.2	98.8
1985	370,000	9.4	17.8	0.6	1.7	56.9	103.6
1990	380,000	10.4	18.9	0.4	1.9	59.6	110.1
Riverhead							
1965 – Actual Precipitation	17,324	76.1	30.6	772.1	2.4	79.8	961.0
Normal Precipitation	17,324	74.5	29.4	718.0	1.6	71.0	894.6
1970	21,000	85.2	32.1	636.7	2.3	79.9	836.1
1975	28,000	69.5	31.7	482.8	2.4	82.7	669.2
1980	36,000	58.7	31.1	376.8	2.6	87.4	556.7
1985	44,000	52.7	32.0	309.1	2.9	86.7	484.8
1990	63,000	46.7	36.4	209.7	3.4	89.0	385.2
Shelter Island							
1965 – Actual Precipitation	1,478	–	18.5	7.4	–	235.4	261.4
Normal Precipitation	1,478	–	16.7	5.5	–	200.1	224.5
1970	1,700	–	18.3	6.1	1.5	213.1	242.0
1975	2,000	–	19.1	4.8	2.4	171.6	197.7
1980	2,300	–	29.4	4.9	2.9	147.7	184.9
1985	2,800	–	39.9	3.9	3.9	131.4	179.1
1990	3,400	–	39.8	2.0	3.9	122.6	168.3
Smithtown							
1965 – Actual Precipitation	87,336	5.7	13.9	4.2	2.0	71.1	115.1
Normal Precipitation	87,336	5.6	13.3	2.8	1.4	61.8	102.8
1970	115,000	6.0	13.4	2.4	1.8	62.6	103.4
1975	144,000	8.5	16.8	2.3	1.9	67.8	114.0
1980	160,000	9.7	18.2	2.1	1.9	70.0	119.2
1985	167,000	10.3	18.9	2.1	2.3	71.0	124.3
Southampton							
1965 – Actual Precipitation	33,142	1.4	14.4	128.7	2.4	125.2	272.2
Normal Precipitation	33,142	1.3	13.9	120.3	1.6	109.2	246.2
1970	36,000	1.5	15.2	121.7	2.5	122.0	263.2
1975	45,000	3.4	18.6	103.5	2.3	114.3	242.3
1980	55,000	7.4	21.5	89.7	2.5	110.7	231.7
1985	70,000	10.5	24.1	70.4	2.9	105.0	213.0
1990	87,000	14.9	28.3	53.5	2.8	102.3	201.8

Southold	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Agricultural Use	Recreational Use	Residential Water Use	Total Projected Use - ~~MGD~~ GPCD
1965 – Actual Precipitation	15,208	2.3	13.5	390.8	1.2	96.7	504.5
Normal Precipitation	15,208	2.1	12.8	350.1	0.9	86.0	452.1
1970	17,000	3.1	15.1	366.6	1.3	105.4	491.5
1975	20,000	5.3	17.5	315.1	1.5	104.1	443.7
1980	23,000	9.4	21.6	279.9	2.1	106.5	449.3
1985	28.000	12.3	24.7	229.9	2.5	104.5	374.0
1990	35,000	17.0	30.0	176.1	2.8	103.3	329.5
Suffolk County							
1965 – Actual Precipitation	915,887	10.3	22.7	38.4	1.1	72.4	151.0
Normal Precipitation	915,887	10.2	21.8	35.5	0.8	63.3	137.5
1970	1,140,000	11.6	23.1	31.2	1.1	67.0	140.0
1975	1,375,000	12.7	24.2	26.5	1.3	69.6	140.6
1980	1,566,000	13.9	25.4	23.7	1.5	73.3	144.1
1985	1,829,000	15.2	26.7	20.2	1.9	75.8	146.0
1990	2,059,000	17.0	28.7	17.1	2.0	78.1	149.2

NOTE:

Total includes water use by major self-supplied institutions which does not appear in the tabulation. For Suffolk County this is as follows:

1965	Actual Precipitation	6.1
	Normal Precipitation	5.9
1970		6.1
1975		6.0
1980		6.1
1985		6.2
1990		6.2

supply and demand

Long Island depends upon precipitation to replenish subsurface aquifers that are the only source of fresh water in Nassau and Suffolk Counties. The land and the fresh water aquifers are surrounded by salt water that would destroy these aquifers if it were allowed to intrude. Because of this, the relation between the consumptive use of fresh water in the two counties and the safe yield of the aquifers is critical.

Consumptive use is the use made of water so that it is not available for use again until it has passed through the precipitation part of the hydrologic cycle. On Long Island this use includes water discharged through sewage disposal systems to the sea, infiltration of ground water into the sewage disposal system, lawn sprinkling, irrigation and a relatively small amount consumed and evaporated during use. In this comparison water returned to ground water through cesspools and septic tank leaching fields is not consumed.

A classic definition of safe yield is "the rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible." It has also been defined more generally as "the safe yield of a ground water basin is the amount of ground water which can be withdrawn from it annually without producing an undesired result."

In this study the estimated safe yield is the maximum quantity that can be withdrawn annually in perpetuity within reasonable economic limits while still maintaining the ground water basin at a consistent quality level and at a reasonably productive size. Any additional withdrawals, planned or otherwise, would be "mined" water, a one-time withdrawal whose minimum consequence would be a compensatory loss in aquifer size. It was assumed that the amount of storm water recharged to ground water would be maintained at present levels, and that sanitary sewers would be discharged to salty water, their flows a part of the total consumptive use.

Nassau County

Because the water supply and demand relationship in Nassau County indicates the possibility of an overdraft during the study period, a relatively complete study of water use and safe yield was made. The totals for estimated comsumptive water use (from Table 15) are:

		MGD
1965	Actual Precipitation	134.5
	Normal Precipitation	109.5
1970		119.2
1975		144.1
1980		168.5
1985		196.3
1990		213.9

This estimate represents water not available for reuse, including sewage disposal to the sea, infiltration of ground water into the sewage system and sprinkling use, and recognizes the sanitary sewer installations just starting in southeastern Nassau County, an area now populated by 560,000 persons. The Town of Hempstead, accounting for 55 to 60 percent of the total consumptive water use in Nassau County but only 40 percent of the area from which water may be withdrawn at present, is one of the most critical areas in the relation of consumptive use to safe yield. For the county as a whole, consumptive use is expected to increase almost 60 percent by 1990. The above estimates are 6 to 10 percent higher than the 1963 estimates by Greeley and Hansen – 112.2 mgd in 1970, 156.6 mgd in 1980 and 193.7 mgd in 1990.

The first step in estimating the safe yield of ground water in Nassau County was to determine the part of the county that contributes most directly to aquifer recharge. This area, termed the water budget area, includes all the county except a portion south of Sunrise Highway and localized parts of the north shore peninsulas. This water budget area conforms reasonably well with the practical limits of the available ground water basin. The next step was to estimate the quantities of water that make up ground water basin inflows and outflows. A schematic diagram and calculations were used for making these estimates (Plate 14), the figures representing an average of conditions during 1940 to 1965. Of the various elements considered in the water budget, only the stream flow has been measured with any degree of accuracy.

Utilizing the water budget, an estimate of natural safe yield of ground water was made (Plate 14), based on the assumption that certain quantities of the water budget can be effectively recovered or utilized and then discharged to the ocean. The natural safe yield figures shown are considered to be maximum practical estimates for the worst possible condition – eventual salt water intrusion into the water budget area. The location of the salt water-fresh water interface is known specifically now only in limited areas. If equilibrium under present conditions were established outside the water budget area, the natural safe yield would be increased a minimum of 8 mgd. Also, "mining" fresh water from outside the suggested ground water reservoir would postpone the need for additional water supplies.

It has been suggested that the New York City infiltration galleries and shallow wells along Sunrise Highway be used to recover part of the subsurface outflow. Other outflows could be tapped by dams, direct pumping and induced or natural recharge to the ground water reservoir (Plate 14).

The estimated natural safe yield of ground water for Nassau County is 159 mgd, compared with the Greeley and Hansen estimate of 154 mgd (Plate 15). The natural safe yield is estimated as increasing to 170 mgd by the year 1990, when increased urbanization is expected to affect the water budget. Evapotranspiration will be decreased from 190 mgd to about 178 mgd, direct runoff to streams will increase to 7 mgd, human consumptive use will increase and recoverable quantities will also increase.

The comparison of safe yield and consumptive water use totals (Plate 15) indicates that water demands will reach this limit by about 1980, postponable to the extent that additional ground water recharge is made and outflows are reduced. The Greeley and Hansen Study, indicating that the natural yield would be exceeded about 1979, proposed injection of waste water in a series of injection wells as a salt water barrier along the south shore of Nassau County to obtain the additional 27 mgd that would be adequate until 1987.

Suffolk County

A comparison of consumptive water use in Suffolk County with the estimates of safe yield of the fresh water aquifers (U.S. Geological Survey and others) indicates fresh water resources adequate for an estimated population of 3 million. With a projected 1990 population in Suffolk County of slightly over 2 million, an overdraft appears unlikely through 1990, although local problems may occur. Consequently, this report does not include a more detailed evaluation of water use and safe yield for Suffolk County.

Still, water supply problems will begin or intensify in certain areas of the county. Probably most critical is the north fork, with the Town of Southold and about half the Town of Riverhead. The fresh ground water reservoir underlying the north fork is only in the glacial or Upper Pleistocene deposits. The long and narrow peninsula is divided into five island-like areas, each with its own fresh ground water lens which is relatively thin. Withdrawal of water from these lenses is restricted to shallow wells of low capacity and limited pumpage; well spacing and their distance from the sea is of great importance.

Unregulated use for irrigation causes a heavy seasonal withdrawal of ground water. Agricultural pumpage has already created potential problems of salt water intrusion which could cause public water supply wells to be abandoned in this area. As a result of the drought, agricultural pumpage on the north fork was 82 percent greater in 1966 than in 1965 and at present it consumes 75 to 80 percent of the ground water pumped. However, a decrease in the area used for agriculture is predicted, and so agricultural water use may decline. This decline would depend on the efforts made to preserve agriculture in terms of the economy and the scenic amenities. Water demands for non-agricultural purposes, such as domestic use, may be computed with reasonable accuracy from estimated population growth. Available data indicate that reclamation of waste water from treated sewage effluent would be a prime means of conservation and replenishment of water to the underground reservoir. More detailed studies of methods and costs of reclamation and recharge have been considered in the comprehensive sewer study and will be undertaken in future studies.

The north fork water supply problem could be aggravated by construction of a bridge to Connecticut, which would cause rapid development if the terminus were in the eastern end of the county. As consumptive use of water increased correspondingly, measures would be needed for transmission mains from the west, increased use of treated waste water or desalination plants.

The south fork's underlying fresh water reservoir is also in the Upper Pleistocene or glacial formation, and withdrawal of water must be restricted to small capacity wells, located carefully with reference to adjacent salt water bodies. Future water requirements here will depend primarily on population growth, not on industrial expansion.

The Town of East Hampton has a catchment area of approximately 71 square miles, of which about half is outwash plain and half in the Ronkonkoma Moraine. The safe yield, respectively, is generally assumed to be about 1 mgd and 0.5 mgd per square mile. The moraine yield may vary greatly depending on its character, thickness and slope, and the overall safe yield on the south fork may not exceed 30 mgd. The area east of Amagansett will require additional supplies of water from the west if its present rate of development continues. The portion of the Town of Southampton within the south fork is divided about equally between moraine and outwash plain and its safe yield is estimated to be about 38 mgd, although salt water problems may make this yeild as low as 25 mgd.

If additional supplies are required in both the north and south forks, the most feasible solution appears to be through long distance transmission mains from other parts of Suffolk County.

TABLE 15

PROJECTED CONSUMPTIVE USE IN NASSAU COUNTY
(In million gallons per day)

Consumptive Use "Sub-Totals" are estimated to be composed of two elements; "Sanitary Sewage Flows" and "Other Consumptive Uses." The latter includes sprinkling which represents the largest portion. To these two elements Infiltration must be added as follows:

	Population	Manufacturing Use	Non-Manufacturing and Non-Agricultural Business Use	Recreational Use	Residential Use	*Sub-Totals	Sanitary Sewage Flows	Other Consump-Use	Infiltration In Sanitary Sewers	Total Projected Consumptive Use-MGD
Hempstead										
1965 – Actual Precipitation	813,974	2.5	11.4	1.7	54.2	70.0	36.6	33.4	7.8	77.8
Normal Precipitation	813,974	2.4	10.8	1.1	43.7	58.0	36.6	21.4	7.8	65.8
1970	850,000	2.8	12.3	1.1	47.3	63.6	40.3	23.3	8.0	71.6
1975	883,000	3.4	15.6	1.1	57.9	78.0	52.9	25.1	10.2	88.2
1980	916,000	3.7	18.1	1.1	67.5	90.4	63.8	26.6	12.0	102.4
1985	959,000	4.1	19.9	1.1	73.8	98.8	70.3	28.5	12.6	111.4
1990	1,003,000	4.5	21.5	1.1	77.7	104.9	74.6	30.3	12.9	117.8
North Hempstead										
1965 – Actual Precipitation	235,615	1.8	5.9	0.6	19.1	27.7	13.0	14.7	4.6	32.3
Normal Precipitation	235,615	1.7	5.5	0.4	14.6	22.4	13.0	9.4	4.6	27.0
1970	247,000	2.0	6.1	0.4	16.0	24.5	14.4	10.1	4.8	29.3
1975	255,000	2.2	6.6	0.4	17.1	26.2	15.5	10.7	5.0	31.2
1980	264,000	2.3	7.0	0.4	18.1	27.8	16.5	11.3	5.2	33.0
1985	275,000	3.4	8.5	0.3	20.9	33.1	21.2	11.9	5.8	38.9
1990	289,000	3.7	9.0	0.3	23.1	36.1	23.3	12.8	6.4	42.5
Oyster Bay										
1965 – Actual Precipitation	352,102	1.7	2.2	1.8	17.2	23.8	2.7	21.1	0.6	24.4
Normal Precipitation	352,102	1.4	1.7	1.2	10.9	16.1	2.7	13.4	0.6	16.7
1970	368,000	1.6	1.9	1.2	12.0	17.5	3.0	14.5	0.7	18.2
1975	382,000	1.8	2.9	1.2	16.0	22.7	7.2	15.5	2.0	24.7
1980	395,000	4.0	4.3	1.2	19.4	29.7	13.5	16.2	3.3	33.0
1985	411,000	8.0	6.3	1.2	24.6	40.8	23.7	17.1	5.1	45.9
1990	428,000	9.6	7.4	1.2	28.7	47.8	29.9	17.9	5.8	53.6
Nassau County										
1965 – Actual Precipitation	1,401,691	6.1	19.5	4.1	90.6	121.5	52.3	69.2	13.0	134.5
Normal Precipitation	1,401,691	5.5	18.0	2.7	69.2	96.5	52.3	44.2	13.0	109.5
1970	1,465,000	6.5	20.3	2.7	75.3	105.7	57.8	47.9	13.5	119.2
1975	1,520,000	7.4	25.0	2.7	91.0	126.9	75.6	51.3	17.2	144.1
1980	1,575,000	10.1	29.4	2.7	105.0	148.0	93.8	54.2	20.5	168.5
1985	1,645,000	15.4	34.6	2.7	119.2	172.8	115.2	57.6	23.5	196.3
1990	1,720,000	17.8	38.0	2.7	129.6	188.8	127.7	61.1	25.1	213.9

*Sub-Totals include agricultural and institutional uses not tabulated above.

PLATE 14

WATER BUDGET
NASSAU COUNTY

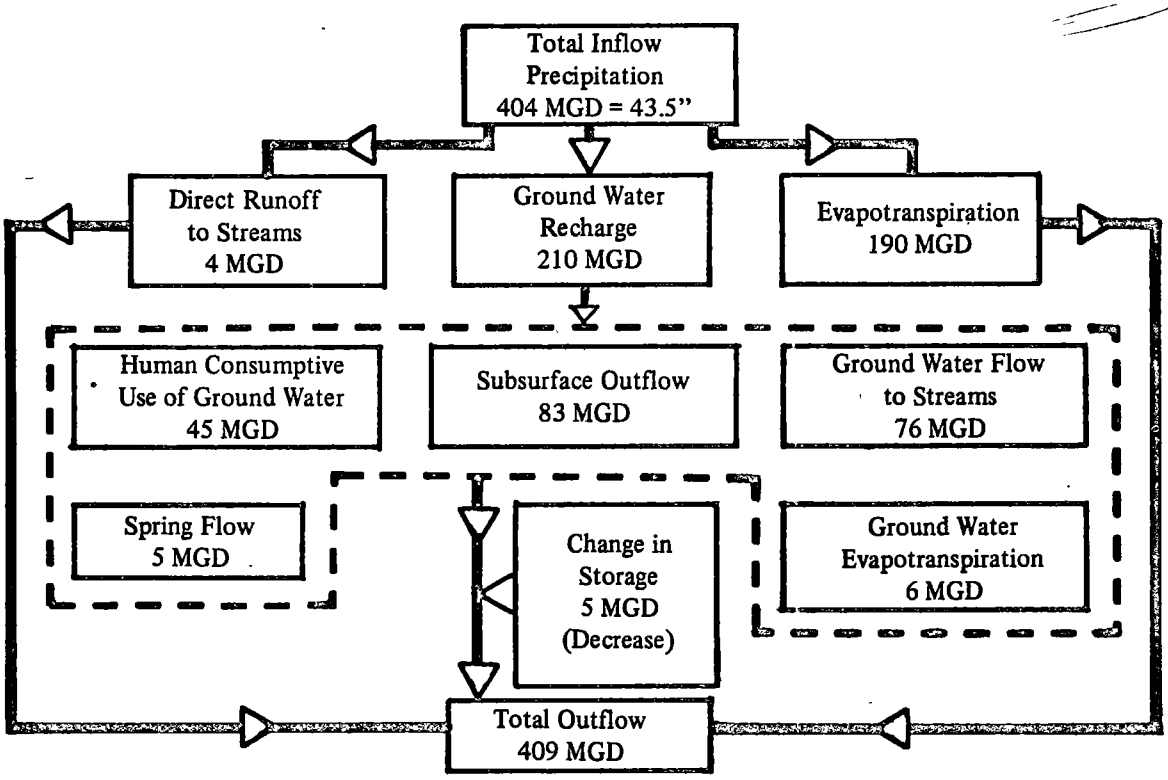


TABLE 16

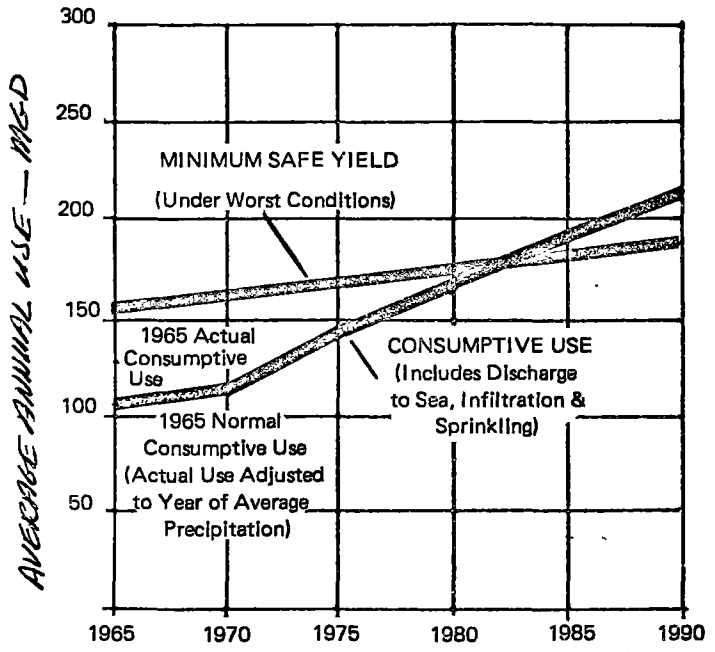
SAFE YIELD ESTIMATE
NASSAU COUNTY

	Quantity MGD	Estimated Availability Percent	Yield MGD
Direct Runoff	4	80	3.2
Human Consumptive Use	45	80	36.0
Spring Flow	5	60	3.0
Subsurface Outflow	88*	50	44.0
Ground Water to Streams	76	90	68.4
Ground Water to Evapotranspiration	6	70	4.2
Total Safe Yield			158.8 MGD

*Subsurface Outflow plus 5 MGD Change in Storage. This represents estimated rate of decrease of ground water reservoir since equilibrium is not established at the perimeter of the water budget areas under present outflows. Estimated 88 MGD needed to establish outflow equilibrium.

PLATE 15

CONSUMPTIVE USE vs. SAFE YIELD
NASSAU COUNTY



MAY 1969

new sources of supply

The possibility of new sources of water for Long Island was considered, using available information. Ultimately the ground water resources for the whole of Long Island will be insufficient for total water demands. Ground water potentials are negligible in Kings and Queens Counties and by about 1980, Nassau County will need to supplement its supply. The critical date for Suffolk County is into the next century, but inevitably will arrive. The new sources considered include other regions, desalination and water reuse.

Other Regions

Long Island is already supplied from upstate New York. With few exceptions, Kings and about half of Queens Counties are supplied through the New York City water supply system which draws upon the Croton, Catskill and Delaware River Basins for water supply. About 60 percent of the water used on Long Island comes from New York City. Nassau County receives no upstate water, but limited quantities could be furnished to New York City from Nassau County through the city's Ridgewood system. Much of this system, formerly a series of wells, ponds and infiltration galleries from near Idlewild in Queens across the south shore of Nassau County to the Suffolk County line, was built before 1900 to supply Brooklyn before it became a borough of New York City. The supply was transferred to New York City and was used to capacity until the Catskill supply became available, but now most of the supply works have been dismantled and it can be depended upon for about 30 mgd, less than a fourth of the production 50 years ago. In recent years, the Ridgewood system has been used only during water shortages, in 1949-50 and in 1965-66, when the output averaged less than 20 mgd.

New York City has no definite legal obligation to furnish water to Nassau County as it does to other upstate counties where its reservoirs and aqueducts are located. Therefore, any water it furnished would probably be surplus to the city system's demands and mutual advantages would be necessary. Major new transmission facilities would be needed to transport the water to Nassau County.

Before the drought, it was believed that New York City would have a safe yield of about 1,800 mgd from its water supply systems upon completion of Cannonsville Reservoir. A re-evaluation of these estimates indicates that the safe

yield is 35 to 40 percent lower, or about 1,350 mgd. With this reduction, and projected increases in demands, New York City must develop new sources of supply for about 500 mgd more by 1990 and another 500 mgd by 2020. The likelihood of surplus water for distribution and sale to Nassau County is improbable, but it should not be overlooked in the detailed studies of major new project developments. It has been suggested that the New York metropolitan area, including portions in New York State, Connecticut and New Jersey, should ultimately be supplied through a regional water system, which would apparently include Long Island.

Long Island is divided politically, but not hydrologically. The fact that the ground water basin is an integral part of the entire island suggests that water supply systems in Nassau and Suffolk Counties should be interconnected. Suffolk County might benefit economically by selling its excess water to Nassau County and both counties could benefit from joint development of common facilities. Any such arrangement obviously requires intensive study and close cooperation between the two counties, but inter-county ties seem likely to become stronger as interests become more closely allied.

Off-island sources outside the New York City system do not hold much promise. Inclusion of a transmission main in the design of any bridge from Long Island to Connecticut, presumably to bring water across from Connecticut, has been suggested, but Connecticut does not have excess quantities. Like New York, its sources were in short supply during the recent drought, and inter-state problems would be difficult to surmount. Similarly, northeastern New Jersey suffered severely during the drought, and projected demands indicate that water supply will be critical there. More distant areas offer no significant potential for Long Island's needs.

Desalination

With three-fourths of the earth's surface covered by salt water, the conversion of sea water and brackish water offers a partial solution to the problem of fresh water shortages. Some methods of conversion have been known for years, others have been discovered recently – the Office of Saline Water in the U.S. Department of the Interior lists 13 different methods, several developed commercially, others in the pilot plant or laboratory stages. Possible methods of desalination are:

Distillation

- Long tube vertical
- Flash distillation
- Vapor compression
- Multi-effect, multi-stage

Membranes

- Reverse osmosis
- Electrodialysis

Freezing

- Secondary freezing
- Direct freezing

Humidification

- Solar
- Diffusion

Chemical

- Hydrates
- Ion exchange

Most operating desalination plants yield 1 mgd or less at an average cost of $1 per 1,000 gallons of fresh water, far above the present cost for fresh water supply by conventional means. More competitive are estimated costs of about 21 cents per 1,000 gallons of fresh water from dual-purpose desalination plants, not including costs for transporting the fresh water. To produce fresh water at the indicated price, a dual-purpose plant would need a capacity of 100 to 200 mgd, far above any present plant capacity, although the technology of desalination has progressed so that such plants could be built.

There is considerable interest in desalination on Long Island. Since early 1964, the State Atomic and Space Development Authority has cooperated with the Long Island Lighting Company toward establishing a nuclear desalination facility on eastern Long Island. The proposed SURFSIDE plant, at Riverhead, would be a dual-purpose plant supplying an initial yield of 1 mgd of fresh water and 2,500 kilowatts of saleable electricity. At full development, to be reached in four steps, it would produce 5 mgd of fresh water with all the electrical power to run the salt water conversion unit. The Riverhead Water District has agreed to purchase the converted salt water at 35 cents per 1,000 gallons, to be increased annually by 1 cent to a price of 45 cents per 1,000 gallons, which would then remain constant for 15 years. The Long Island Lighting Company has agreed to purchase all available electric power at 15 mils per kilowatt hour.

The towns on the north fork of Long Island have a more immediate need for desalted water because of salt water intrusion into local wells. Long-range plans are to supply the north fork with fresh water from the SURFSIDE plant, but to supply the Town of Riverhead first.

Estimated desalination costs do not normally include transmission and distribution costs, which could materially increase the cost of water supply. Another aspect not considered fully is the method and cost of cooling desalted

water. The fresh water from the SURFSIDE plant will be about 95 degrees fahrenheit, compared with normal ground water temperature of about 55 degrees fahrenheit.

Recent developments indicate additional problems. The aerated, distilled pure water, particularly if run in a way to reverse the flow, can cause catastrophic purging of existing accumulations in distribution mains, leading to delivery of water with high turbidity, color and possibly unacceptable taste. The water will attack cast iron and soften the portland cement in asbestos-cement pipes. The solution is treatment and carefully controlled mixing with water from other sources.

Technological advances in desalination are expected to bring costs down to reasonable levels. Ultimately, desalination may compete with other supplies, particularly if fresh water conveyance becomes relatively expensive because of large distances. This potential should be considered in long-range planning.

Water Reuse

At present, reuse of water on Long Island results from expediency rather than careful planning. Waste water is discharged into cesspools or recharge basins, relying on natural filtration through the sands and gravels to remove impurities that could contaminate the ground water aquifer. After the recharge water has reached the aquifer, it may be withdrawn and used for any purpose, the same as precipitation which reaches the water table naturally.

More than 2,000 recharge basins in Nassau and Suffolk Counties, to receive direct surface runoff, range in size from about one-fourth acre to 15 acres and in depth from 10 to 40 feet. The U.S. Geological Survey is studying two recharge basins to determine design criteria. It is generally believed that most recharge basins are over-designed, and so portions of this land may be converted to other uses and smaller recharge basins may be designed. Maintenance is a problem in recharge basins which collect storm water runoff. The basin bottom, clogged with silt, other particles, debris and oil carried by the runoff, must be cleaned periodically. If the basin size could be decreased, the savings in land costs might finance settling tanks, screens and possible oil removal equipment, so that water entering the basins would be relatively clear and free of silt and debris. Provisions must be made in the design of recharge basins for relatively easy removal of silt and debris. Existing recharge basins which may not be needed could be converted to ponds by being lined with impervious material. The stored water could then be used for cooling and possibly for lawn sprinkling or irrigation.

Recharge of waste water poses many more problems than recharge of storm water runoff – the method of recharge, whether by surface recharge basins or injection through recharge wells, the degree of treatment, the location of recharge facilities and, finally, the uses of recharge water.

Intensive study is needed to determine the most feasible method of recharging treated effluent, including economic as well as engineering considerations of injection wells and recharge basins. Two experimental projects are under way on Long Island to determine the feasibility of injecting treated sewage effluent into deep aquifers through recharge wells. Riverhead, using effluent from the Riverhead sewage treatment plant, has a ground simulator constructed of a double-shelled steel tank 27 feet high and 9 feet in diameter, with a duplicate of an injection well in the center. The tank is filled with layers of soil to duplicate natural conditions around the injection well, as well as any other desired conditions. The double wall permits duplicating any desired depth of ground water in the unit. Horizontal core samples of the soil from the tank wall to the well screen can be extracted to see what occurs in the soil and to determine reasons for any clogging.

The second project, in Nassau County, using treated effluent from the Bay Park sewage treatment plant, is carrying out an experimental program of tertiary treatment. The renovated water will be injected into the ground through a 21-inch diameter, 450-foot deep fiberglas injection well with satellite observation wells for observation and data collection. The project will help to determine the ultimate spacing and number of wells required for a proposed barrier injection line along the south shore in Nassau County.

The location of recharge areas requires careful study and evaluation. Proposals have been made for recharge in the mid-Long Island area, and barrier injection wells along the shoreline, or a combination system. Costs will be a determining factor. In California, a seven and one-half mile barrier of 77 injection wells is used for injecting 45,000 acre-feet of water per year at a cost of $46 per acre-foot, or a total annual cost of $2.07 million – about $142.60 per million gallons. This includes $23 per acre-foot of water purchased from the Colorado River system but not redevelopment costs for the system, which amount to $4,850 per well for approximately 25 wells per year, or a total annual cost of $121,250. By contrast, the average cost of basin recharge of water diverted from streams and storm water is $18 per acre-foot or $5 less than recharge by injection wells.

Another factor is the location of treatment facilities in relation to the recharge areas. Treated waste water might be used for specific purposes which require less treatment than household use – such as agricultural irrigation or lawn sprinkling. Waste water is being used directly for these

purposes successfully in some areas, after primary and secondary treatment followed by oxidation ponds. Treatment facilities would have to be near agricultural or residential areas, but such developments would allow use of the higher quality ground water for domestic purposes.

Waste water might also be used directly for cooling. The practice on Long Island is to use special wells, coupled with recharge wells, for cooling water for air conditioning. In some cases these cause localized increases in ground water temperature – not an immediate problem, but one which may become so as urbanization increases. Waste water could be used for air conditioning, in conjunction with recirculating systems utilizing cooling towers. Industries which need large quantities of water for cooling in manufacturing might use waste water stored in artificial ponds and recycled through aeration or cooling towers.

Industrial development on Long Island has followed a common pattern. Water supply facilities are usually nearby and new sewage treatment facilities may be near industrial areas. Industrial wastes which are unique or impose heavy and unusual loadings on conventional waste treatment plants might be treated by separate industrial facilities designed to handle their particular needs, costs being shared by the industries on a use basis. Special tax relief under existing legislation might be an incentive for this type of installation.

Treated effluent might be used for new ponds or lakes in park and recreational developments. In a project of this kind at Santee, California, treated effluent has created a lake used for boating and swimming and also serving as a storage basin connected with recharge basins. Treated effluent could also increase or maintain the level of existing lakes or ponds. The drought for the past six years has lowered some lake levels on Long Island as much as eight feet; treated effluent could raise the level or the lake could serve as a ready-made recharge facility.

Decreased Future Water Use

Decreasing water use would have the same net effect as increasing the water supply. Methods of decreasing water use include regulation of water pressures, improved technology, increasing water rates, metering and leakage elimination.

Pressures of various water supply systems are optimized on the basis of operational factors unique to each system – well characteristics, pumping equipment capacities and operating characteristics, frictional factors in the distribution system, storage facility capacities and elevations, and many others. Operating pressures might be considerably higher than the minimum for fire flow requirements. It has been found that water use is directly related to water pressures, as the following example illustrates:

	System A	System B
Operating Pressure	80 psi.	40 psi.
Number of Services	1,000	1,000

For illustration, each customer is sprinkling his lawns through a one-half inch diameter hose over a 24-hour period.

Delivery (Approx.)	7.5 gpm	6 gpm
Consumption per customer (gpm x 1440)	10,800 gpd	8,640 gpd
Consumption per 1000 services	10.8 mgd	8.64 mgd

Difference = 2.16 mgd.

By decreasing operating pressures to 40 psi, System B would use 2.16 million gallons per day less than System A. This example is an exaggeration, but operating experience has shown that whether pressures are at 80 or 40 psi, people tend to use water for sprinkling and other purposes on a time basis. All other factors being equal a system will have a significantly lower total consumption when operated at lower pressure.

In actual practice systems could be best operated using pressure regulators on each service, to allow for higher system pressures needed for fire flow or other emergency conditions and to make the entire system self-limiting with a minimum of maintenance or operation. The economic factor in installation costs would have to be considered. Another approach might be to use a lower standard pressure, while providing for increased pumpage and pressure for fire flow demands.

Operation of all public water supply systems at uniform pressures would have advantages and disadvantages. Uniform pressure systems, lending themselves readily to interconnection in a network, would provide the public with a constant water supply. Low pressures and diminished flow during peak pumpage periods would be negated. This type of operation, however, might increase usage by eliminating the self-limiting factor of low pressure – low flow. One major disadvantage is the cost of additional equipment such as booster pump stations and pressure regulating installations.

Technology specifically for decreasing water use is in an early stage: in most populated areas, water is readily

available at a relatively low cost and so there is no incentive to reduce water use. However, per capita water use is constantly increasing and ultimately increased costs may dictate that technology be improved so that less water is required.

Three possibilities are suggested. One is sonic cleaning – the use of high frequency sound waves, plus possibly a small self-contained device designed for home use. Specifically designed fabrics might also be required. Industry now uses this method to clean small parts. Since the conventional washer uses an average of 25 to 35 gallons per load, household use for washing clothes might amount to as much as 1,000 gallons per week and reduction or elimination of this use would mean a substantial saving of water.

Another area is water for sanitary purposes, an estimated 40 to 70 gallons per day per person. Redesign of toilets and adoption of flush valves instead of the commonly used tank units would considerably reduce water use. Reuse of water within the home is another possibility. An experimental home recycling system has reduced average family water use by 39 percent. This system utilizes laundry and shower waste water to flush the toilet, wash the car and water the lawn. The recycled water is slight grey but has no odor and does not stain. Installation costs are high and savings in water use costs are nominal, but the reduction in demand is significant. The major problem would be to get public acceptance of using lower quality water.

Water use is inversely related to water cost – increased rates generally bring decreased use. The relationship between median income and per capita consumption indicates the strong bearing of socio-economic factors on per capita use. Another study found that in an area of high incomes, where zoning regulations prescribe two or more acres per residence, per capita consumption is sometimes two and a half times that in a moderate income area where the zoning requirement is a quarter acre per residence. This pattern seems to be common throughout Nassau and Suffolk Counties.

Present rate structures would have to be modified to use them to control water use. Most billing systems are based on a minimum charge with decreasing rates as water use increases. In order to restrict water use, the rates would have to increase with water use. One approach in an area of high per capita water use might be a base figure determined by the number of persons per service (perhaps 100 gpcd, generally used as an estimating figure) and an estimated total use for the billing period. A standard decreasing scale rate might be used for all water use up to the base, and use above the base could be billed on a sharply increasing sliding scale. This would put a premium on so-called luxury uses, such as swimming pools and excessive sprinkling. Billing would be complex, but computerized facilities should reduce this problem. Increased rates for greater use is perhaps the easiest, most economical and most equitable way to reduce water use, since most people are influenced by costs, but a workable system would require metering of all water supplies.

Much attention has been given to the effect of metering – metering of a previously unmetered system generally decreases water use, for economic reasons. A recent study of residential water use by the U.S. Department of Housing and Urban Development showed that domestic use is about the same in metered as in flat rate areas, but peak demands in the flat rate areas are more than double those in metered areas, with lawn sprinkling the main reason for this variation. During these periods of peak demand, which generally coincide with drought, the effect of metering is to limit use. Another study, in 1957, concluded that meters alone do not appreciably decrease per capita consumption. A graphic comparison of data for 497 American cities indicated very little difference in consumption per capita among cities without meters, partially metered and fully metered. But a rate structure comparison showed per capita consumption to be inversely proportional to water rates. The conclusion is that, to limit water use, the rate structure must be scaled to discourage excessive use. Metering is also desirable to make charges equitable on the basis on consumers' water use, in effect curbing excessive use.

Leakage from water supply systems usually takes the largest amount of unaccounted-for water. Estimates of unaccounted-for water, which includes leakage, meter slippage, unauthorized connections and other wastes, amount to about 20 gallons per capita per day in most systems, leakage representing 10 to 25 percent of the total withdrawal. The leakage problem exists on Long Island; to a measure this is self-compensating because the water is recharged through the glacial aquifer, but eliminating leakage would reduce total pumpage and pumping costs.

policy guidelines

Long Island's fresh water resources have been studied, developed and used extensively for many years. As problems have been recognized, various actions have been taken to minimize or control them. Sometimes these have been regulatory or control measures prescribed by legislation, in other cases prudent practices adopted by local water suppliers and users, to safeguard available supplies and promote conservation and wise use. Now the rapidly increasing demands for water have focused attention on the urgent need for additional steps to ensure optimum development and beneficial use of the island's remaining resources.

This section suggests certain measures. Some may be undertaken within the scope of existing policies; others may serve as guidelines for new policies. These measures or management alternatives have been detailed in the *Atlas of Long Island's Water Resources,* New York State Water Resources Commission Bulletin 62, and are given here for further emphasis.

Management Alternatives

The first prerequisite to a sound water resources management program for Long Island is an objective. Alternative management programs can be undertaken, depending upon what this objective is. For example, the available fresh ground water resources can be overexploited, as they were in Kings and Queens Counties, and supplies then obtained from other sources. On the other hand, development can be controlled and limited to conserve and maintain ground water resources, and various methods of augmenting supplies are available to meet this objective. The following listing indicates the scope of possible alternative management programs:

Limited Overdevelopment – This term best characterizes the present ground water situation on Long Island. The major features are: (a) withdrawal of ground water from the shallow unconfined aquifers and from the deeper confined aquifers, (b) artificial recharge with polluted waste water through cesspools and septic tanks, (c) injection of relatively uncontaminated waste water through diffusion wells, (d) artificial recharge with direct-runoff water through shallow basins, (e) discharge into the sea of large amounts of treated sewage water derived principally from the ground water reservoir, and (f) importation, for use in Kings and Queens Counties, of large quantities of surface water from upstate sources.

Permissive Salt Water Intrusion – Under this program additional quantities of fresh ground water beyond the rate of replenishment would be withdrawn, allowing the surrounding salty water to move inland. If carried to an extreme, this could eventually deplete the entire ground water resource, but controlled salt water intrusion to predetermined locations would allow additional quantities of water to be withdrawn and used consumptively. Less subsurface outflow of fresh ground water would be required to maintain the fresh-salt water interface at locations farther inland.

Barrier Injection Wells – This proposal would mainly alleviate the problem of salt water intrusion and allow increased withdrawals of ground water. This plan envisions injection of highly treated sewage effluent into a line of wells parallel to the shore. A large proportion of the injected water could be recovered under a carefully planned program of development.

Pumping Troughs – This proposal would also limit salt water intrusion, but instead of creating a fresh water barrier, the continuous pumping would create a hydraulic depression in the water table surface and intercept the salt water that would normally move inland. Creating pumping troughs does not add fresh water to the ground water system, but prevents salt water encroachment in areas of over-development.

Treated Waste Injection Through Recharge Basins – This program envisions higher levels of waste treatment and upgrading of sewage treatment plant effluent that would then be recharged through a network of mid-island recharge basins. The recharge basins would roughly parallel proposed barrier injection wells, but would be much farther inland.

Shallow Skimming Wells – A network of carefully spaced shallow skimming wells could recover fresh water from the top of the ground water reservoir which is normally lost through subsurface outflow and evapotranspiration. Substantial quantities might be obtained in this way, but quality could be less than desirable and withdrawals could adversely affect streamflow and change salinities in the adjoining bays and estuaries.

Regional Water Resources Planning and Development Boards

Selection of a basic concept for a comprehensive plan for managing and developing Long Island's fresh water resources requires detailed studies beyond the scope of any made so far. It will require expertise and judgments from many disciplines in all sections of government and private enterprise. How best to coordinate these interests and focus their efforts is a major challenge.

Fortunately, a mechanism does exist under state law for achieving this required representation, coordination and integration. This mechanism is a regional water resources planning board established under provisions of Article V, Part V of the Conservation Law. Such a board may be established by the State Water Resources Commission upon local request following public hearings.

This board has seven members whom the commission selects from locally submitted nominees. The statute specifies that these interests be represented: agriculture, industry, public water supply, municipal corporations, and outdoor recreation and wildlife.

This broad representation, combined with the use of such advisory committees as the Nassau-Suffolk Marine Resources Council and joint or interlocking membership with the Nassau-Suffolk Regional Planning Board, can achieve broad representation of water related interests and proper consideration of land use planning, marine resources and other development and conservation programs.

A water resources planning board is responsible for conducting a study to evolve a comprehensive plan for management of its area's water resources, and the commission provides office space, equipment, clerical, engineering, legal and other personnel and services. There are obvious benefits in a broad-based regional study group assisted by the state and many federal agencies which the state can call on. The State bears 75 percent of the total cost (exclusive of federal costs) of the comprehensive study and the participating counties bear 25 percent.

A regional water resources board is a mechanism for developing a plan to satisfy the short-range and long-range need of public water supply in a particular region. But more than this, the plan can satisfy other diverse water resources requirements, including industrial and agricultural water supply; flood prevention and control, water quality management; water-based recreation, fish and wildlife enhancement and management, navigation, erosion and sedimentation control, and related land use and treatment.

The comprehensive, multi-purpose plan evolved from cooperative studies under a regional board is of a scope to assure prompt and orderly development of the water resources for all beneficial uses. It would establish priorities for certain projects and study all practical alternatives for solving major water resources problems, to determine the most economical and advantageous solutions. The local people through the board members would be involved in planning at every stage.

The process of selecting a management alternative is not speedy. Many additional studies are needed, the best scientific information about the hydrologic system and its functions must be obtained. Two areas of investigation are suggested in the interim:

– Additional studies of the geology and hydrology are needed in many areas. Additional test wells, coupled with a digital computer model, can test management alternatives. Depending on its sophistication, this computer model could calculate and draw periodic ground water contour maps.

– A system of outpost wells could delineate the salt-fresh water interface location. Some mapping of this interface has been done, but more positive methods of monitoring are required. Changes in salinities, water levels and other data are invaluable in making management decisions.

Legislative Considerations

The need for effective management of the Long Island ground water basin has been emphasized and the state can make a major contribution toward this, as well as in developing it through a regional board. Regulatory measures specifically applying to Long Island, in effect for more than 30 years, have been enforced by the Water Resources Commission and its predecessor agencies. Additional requirements to meet the unique island conditions deserve consideration:

Consolidation of Public Water Supply Systems

NASSAU-SUFFOLK WATER AUTHORITY – There has been and probably will continue to be legislative activity to create a Nassau County Water Authority similar to the existing Suffolk County Water Authority, but the various municipal and private water suppliers that would be consolidated have resisted this action.

The existing authorities in New York State function as public water suppliers and are created by the State Legislature to acquire, construct, develop and operate these supply systems. They are empowered to survey and prepare plans for developing these systems, subject to the approval of the Water Resources Commission. Since the responsibility for development and management of the state's water resources ultimately rests with the commission, the creation of a bi-county water authority under multi-purpose water resources guidelines could facilitate this management. A bi-county water supply system could distribute water across the county line, if this represents the best use of the ground water basin.

Public Water Suppliers – Municipal and Private

MANDATORY METERING OF SERVICES – This would require all water suppliers to meter their systems. Separation of industrial, commercial and domestic accounts would provide data from which to develop usage guidelines for future management of the ground water reservoir.

ANNUAL PUMPAGE REPORTING – This would strengthen existing requirements for reporting pumpage to the Water Resources Commission. Pumpage should be reported monthly by account categories, as outlined above, and such additional information as total services, area and population served would be useful.

PERIODIC MONITORING OF WATER LEVELS – This would require regular reporting of static water levels within all public water supply wells on a quarterly or semi-annual basis. Data could be computerized and water level contour maps drawn by the computer.

WATER SAMPLE ANALYSIS – This would require submission of laboratory analysis of well water samples annually or semi-annually for all systems not presently reporting such data. All tests should include sampling for detergents, a good indicator for changes in water quality. Presently, water suppliers are required to submit only reports on bacteria and a complete chemical analysis yearly, or as ordered by the local health department.

Individual Residential Wells

PRIVATE WELLS – Regulatory procedures for the installation of all private wells with capacities of less than 45 gpm should be strengthened, with enforcement mechanisms provided through legislation. Problem areas, where salt water intrusion is existing or imminent, for example, could be subject to exclusions or restrictions on individual private well development.

Industrial and Commercial Wells

REGULATORY CONTROL OF PROCESS WATER – Presently there is no real control on the return of process water, and existing regulations should be strengthened. Monthly reports on pumpage and periodic analysis of waste water should be required.

PROCESS PLANT WATER TREATMENT – All new industrial plants using process water should be required to construct appropriate treatment facilities, so that recharge water meets acceptable standards.

Agricultural Wells

REGULATION – Agricultural wells should be under the same regulations as public supply wells. Applications should be filed for all wells in excess of 45 gpm, and installation reports should be filed on all wells under 45 gpm.

METERING – Regulations on agricultural wells should require metering of all installations and monthly reports on pumpage.

Other

LICENSING OF WELL DRILLERS – Present licensing requirements for Long Island well drillers should include a method for qualifying the drillers, in degrees according to the type of drilling or well installations. The present system provides a license to anyone who pays a nominal fee.

STREAM PROTECTION ACT – Nassau and Suffolk Counties should be included under provisions of the Stream Protection Act (Section 429-b) and there should be provision for Water Resources Commission approval of deep harbor dredging and coastal or inland sand mining operations which might affect the ground water table.

STREAM CHANNEL ENCROACHMENT – To prevent increased flood damages, legislation should be provided to prevent further encroachment on areas adjacent to stream channels. All dwellings, garden apartments, etc., constructed in the vicinity of stream channels should be required to prevent contamination of the streams.

RECHARGE – The recharge of treated effluent should be included in any plans for sewage treatment facilities as a prerequisite for eligibility for state grants or loans, if this is found to be a feasible alternative for maintaining Long Island's water supply.

summary and conclusions

Because political boundaries (county and township) influenced the development of water supply systems, thereby influencing the analysis and projections of water use within these limits, this summary is presented by counties. This in no way means that the ultimate decisions on management and development can continue under the same political constraints. The hydrologic unity of the ground water reservoir mandates a regional approach.

Nassau County

The population of Nassau County will increase to an estimated 1,720,000 by 1990. Average water use is expected to increase from the present 161 mgd (million gallons per day) to 234 mgd in 1990, not including water used for air conditioning or cooling. As ground water pumpage increases, consumptive use will also increase, from an average of 110 mgd to 214 mgd. Consumptive use

represents water lost by direct discharge to the surrounding salt water through sewage treatment plant outfalls, sprinkling and other minor losses.

Without any additional recharge of treated sewage effluent, consumptive use will exceed the safe yeild in about 1980 (Plate No. 15) and a supplemental water supply will be needed. A program of sewage effluent recharge or increased storm water recharge would delay the need for additional sources.

Salt water encroachment is taking place slowly in the Magothy formation in the southwestern part of Nassau County and has also taken place in artesian aquifers in some areas along the county's north shore. However, additional ground water can be withdrawn in other parts of Nassau County, even without artificial recharging, if the rate of withdrawal is reduced in the critical shore areas.

Careful management of Nassau County's water resources is necessary. A first step is an injection well experiment at the Bay Park Sewage Treatment Plant. This tests the feasibility of a barrier injection well system to control salt water intrusion and permit additional ground water development, as suggested in the Greeley and Hansen study.

In the long view, the county's water supply requirements cannot be adequately met without extensive artificial recharging operations. If these were effectively operated in shore and mid-island areas, properly dispersed additional developments could supply substantial quantities above the present rate of withdrawal.

Suffolk County

The population of Suffolk County is expected to increase to 2,059,000 by the year 1990 and average water use to increase from the present 126 mgd to 307 mgd in 1990, not including water pumped for air conditioning or cooling. However, since the existing ground water reservoir is considered adequate for a population of 3 million without supply depletion, Suffolk County is in a good position to meet increased demands throughout the study period and beyond.

With new developments, salt water encroachment will undoubtedly become evident in certain shore areas, both in the upper glacial formations and the Magothy formation, long before the ultimate development potential is utilized. Large developments can be made if the wells are located so as to avoid salt water encroachment.

Even though these problems may not become critical in most of Suffolk County for many years, recharging in mid-island areas would be desirable now to delay the ultimate encroachment in shore areas. Careful periodic observations should be made in shore areas to detect the first signs, with extensive artificial recharging operations instituted in the affected areas to arrest encroachment before salting is extensive.

Conclusions

Water supply in Nassau County is of immediate concern. With projections that present supplies are adequate only until about 1980, action must be taken now to develop additional supplies. Various management alternatives have been suggested: continued limited overdevelopment as at present, permissive salt water intrusion, installation of barrier injection wells, development of pumping troughs, treated waste injection through recharge basins and installation of shallow skimming wells. Early decisions are needed to implement one or a combination of these alternatives.

However, these alternatives could not supply additional water in large quantity. Ultimately, and in the near future, Nassau County must turn to other sources outside the county to meet its growing needs: principally the New York City system (or at least upstate sources), Suffolk County and desalination. Water use possibilities and methods of reducing future demands have also been suggested, although their potential is for only a part of the demand. All these alternatives must be investigated objectively and in detail for sound management and development decisions.

Suffolk County will experience no great difficulty in obtaining adequate water supplies for the population and economic growth expected during the study period, except in the north and south forks, which already have problems. Other studies indicate that Suffolk County will have more than enough fresh ground water supplies on a gross basis for the next 50 years and beyond. The magnitude of excess will depend in part on the extent of recharge efforts. Development and use of the basic ground water resource for Nassau County during the interim when Suffolk does not need the supplies might benefit both counties significantly. This alternative also needs objective and detailed investigation.

Nassau and Suffolk Counties are linked together physically, economically and socially. Politically they are separate, but this is not an insurmountable barrier for joint study, planning and development. Proof is in the creation of a Nassau-Suffolk Regional Planning Board and its effective operation to formulate plans and programs in the best interests of both counties.

Water does not follow political boundaries. On Long Island the ground water resources are common to the entire island, part of the hydrologic system that functions as a single unit. Historically, various portions of the island have

progressed through different stages of development and exploitation of the resource – in broad terms, overdevelopment and exploitation in Kings and Queens Counties, nearly full development in Nassau County and partial development in Suffolk County, although western Suffolk is rapidly approaching the nearly full development stage of Nassau County. This pattern suggests that the counties have a common interest in conserving, developing and wisely using the basic ground water resources, and that they should plan and work together to utilize the tremendous fresh water supply for optimum mutual benefits to people in both counties.

Although fresh water is a basic resource, it is not isolated from other resources in the ecological system on Long Island. The interrelationship of fresh water and salt water and the land dictates that all be considered in planning for water resources development and management.

The multiplicity of governmental and non-governmental entities with a direct interest in water resources dictates broad representation from all these interests in the planning effort. The mechanism for meeting both requirements exists under Article V, Part V of the Conservation Law, which encourages and provides for creation of a Regional Water Resources Planning Board to direct the formulation of a comprehensive multi-purpose plan for the protection, control, conservation, development and beneficial utilization of the water resources of a region like Nassau and Suffolk Counties. Through legally-mandated major interests of the board members and by means of advisory committees (the Nassau-Suffolk Marine Resources Council, for example), broad representation can be achieved and the local people can actively participate at every stage of the planning process. Through a close working relationship with the existing Nassau-Suffolk Regional Planning Board (joint or interlocking membership, for example), adequate consideration can be given to land use planning, transportation and other economic programs. State, federal and local expertise can be provided for in a cooperative planning program.

A regional water resources planning board is a mechanism for optimum development and management of the precious resources of Nassau and Suffolk Counties. It can be taken advantage of now by the people of this important area of the state.

bibliography

Abrams, Irving M., "Removal of ABS by Anion Exchange," presented at meeting of ASCE Sanitary Engineering Division, Houston, Texas, 1962.

American Machine and Foundry Company, for Office of Saline Water, U.S. Department of Interior, *SURFSIDE Desalination Plant Description,* 1965.

Andres, Barr D., Flynn, J.M. and Davids, Herbert W., "Effect of Synthetic Detergents on the Ground Waters of Long Island, New York," New York State Department of Health, Water Pollution Control Board, Research Report 6, 1960.

Bechtel Croporation, San Francisco, for Metropolitan Water District of Southern California, United States Department of Interior, Office of Saline Water, United States Atomic Energy Commission, *Engineering and Economic Feasibility Study for a Combination Nuclear Power-Desalting Plant Summary* United States Atomic Energy Commission, Division of Technical Information, 1965.

Bureau of the Census, U.S. Department of Commerce, "1964 Minor Civil Division Data for Suffolk County, New :, unpublished data, 1967.

California, State of, "Detergent Report, a Study of Detergents in California – The Effects of Synthetic Detergent Residuals in Waters of the State", State Water Quality Control Board; State Department of Water Resources, State Department of Public Health, 1965.

Cohen, P., Franke, O.L. and Foxworthy, B.L. *An Atlas of Long Island's Water Resources,* New York State Water Resources Commission, Bulletin 62, 1968.

Cosulich, William F., "Treatment of Wastes from Long Island Duck Farms," March, 1966.

Davids, H.W., "Report on Status of Ground Water Quality and Related Factors in Suffolk County," Suffolk County Department of Health, 1959.

Eckenfelder, W. Wesley, Jr., Barnhart, Edwin and Kemper, Arthur B., "Removal of Synthetic Detergents from Laundry and Laundromat Wastes," New York State Department of Health, Civil Engineering Department of Manhattan College, 1957.

Flynn, John M. and Andreoli, Aldo, "Survey of Industrial Wastes, Town of Babylon, Suffolk County;" Suffolk County Department of Health, 1958.

Flynn, John M. and Villa, Robert A., "Study on Ground Water Contamination, Town of Brookhaven, Suffolk County," Suffolk County Department of Health, 1960.

Flynn, John M., "Highlights of Symposium on Ground Water Contamination," U.S. Public Health Service, Cincinnati, Ohio, 1961.

Flynn, John M., "Impact of Suburban Growth on Ground Water Quality," Suffolk County Health Department, 1961.

Flynn, John M., "Sewage Treatment Practices and Water Reclamation Program, Los Angeles, California," Suffolk County Health Department, 1964.

Gates, Charles D., "Treatment of Long Island Duck Farm Wastes," New York State Water Pollution Control Board, School of Civil Engineering, Cornell University, 1959.

Gausmann, R. W., "Water Consumption – Meters and Rates," an inhouse study, The J. G. White Engineering Corporation, 80 Broad Street, New York City.

Greeley, S. A. and Hansen, Paul, "Report on Water Supply, Nassau County;" Nassau County Department of Public Works, 1963.

Heath, R. C., Foxworthy, B. L. and Cohen, Philip, "The Changing Patterns of Ground Water Development on Long Island, New York;" U.S. Geological Survey, Circular 524, 1966.

Lieber, Maxim and Welsch, W. Fred, "Contamination of Ground Water with Cadmium through Industrial Wastes," Nassau County Department of Health, Nassau County Department of Public Works, 1953.

Linaweaver, F. P., Gyger, John C. and Wolff, Jerome B., "A Study of Residential Water Use," U.S. Department of Housing and Urban Development, HUD TS-12, February, 1967.

Lusczynski, Norbert J. and Swarzenski, W. F., "Salt Water Encroachment in Southern Nassau and Southeastern Queens Counties, Long Island, New York," U.S. Geological Survey, Water Supply Paper 1613-F, 1966.

Nassau County Planning Commission, "Parks and Recreation," July, 1964.

New York State Water Pollution Control Board "Comprehensive Plan for Abatement of Pollution from Waters of Moriches Bay Drainage Basin in Suffolk County, New York," 1951.

Office of Saline Water, U.S. Department of the Interior, *The A-B-Seas of Desalting*, U.S. Government Printing Office, 1966.

Perlmutter, N.M., Lieber, Maxim, Frauenthal, H.L., "Contamination of Ground Water by Detergents in a Suburban Environment – South Farmingdale Area, Long Island, New York," U.S. Geological Survey, Professional Paper 501-C, 1964.

Perlmutter, N.M., Lieber, Maxim, Frauenthal, H.L., "Movement of Waterborne Cadmium and Hexavalent Chromium Wastes in South Farmingdale, Nassau County, Long Island, New York," U.S. Geological Survey, Article 105, 1963.

Suffolk County Cooperation Extension, "Comparative Importance of Suffolk County, New York, Agriculture," 1965.

Suffolk County Department of Planning, "A Plan for Open Space in Suffolk County," May, 1964.

Suffolk County Department of Planning, *County Catalog*, August, 1964.

Suffolk County Extension Service, "Outlook for Commercial Agriculture, Suffolk County, New York," 1966.

Suter, Russell, de Laguna, Wallace and Perlmutter, N.M., "Mapping of Geologic Formations and Aquifers on Long Island, New York," New York State Water Power and Control Commission, Bulletin GW-18, 1949.

Suter, Russell, "Engineering Report on the Water Supplies of Long Island," New York State Water Power and Control Commission, Bulletin GW-2, 1937.

Swarzenski, W. V., "Hydrogeology of Northwestern Nassau and Northeastern Queens Counties, Long Island, New York," U.S. Geological Survey, Water Supply Paper 1657, 1963.

Wiggin, Thomas H., "Report on a Comprehensive Plan for the Development and Distribution of the Available Water Supply of Suffolk County," Suffolk County Water Authority, 1957. Section on geology by R.M. Leggette.

excerpts from state conservation law article 5

WATER RESOURCES PLANNING AND DEVELOPMENT

Section 435. Legislative purpose

In addition to the powers vested in the Commission by this Article V, and in order to stimulate and encourage local participation and assistance, comprehensive planning for the protection, control, conservation, development and beneficial utilization of the water resources of the state may be undertaken as provided in Part V of this article. Nothing contained herein shall be deemed to repeal, amend or modify the powers and duties of the Commission as now or hereafter provided by this Article V or by any other statute or to repeal the procedures authorized thereby.

Section 436. Petition; proceedings; exclusion of certain counties

(1) Any county, city, town or village, when duly authorized to do so, or any combination thereof, except as provided in subdivision (7) hereof, may submit to the Commission a verified petition requesting the Commission to consider a proposal for a survey and study of the water resources of a specified region of which the petitioning municipality is a part, for the purpose of preparing and providing a comprehensive plan or plans for the protection, conservation, development and beneficial use of such resources. Any such petition, prior to its submission to the Commission, must be approved by the board of supervisors of each county wholly or partly within the specified region. The petition shall set forth the facts upon which the petitioner or petitioners rely to show that it is necessary and in the public interest and benefit to undertake such survey, study and comprehensive planning. The petition shall list the persons, public corporations and state agencies engaged in receiving, collecting, storing, transmitting, distributing, processing or otherwise dealing with water for a public purpose, within the region set forth in the petition, and the names and addresses of the clerks or other executive officers thereof. There shall be attached to the petition a certified copy of the resolution, ordinance or other evidence of authority authorizing the execution of the petition.

(2) Upon receipt of a petition, the Commission with reasonable diligence shall cause public notice to be given that on a day therein named it will hold a public hearing at such place, within the region specified in the petition, as is designated in the notice for the purpose of hearing all persons, public corporations and state agencies in favor of or opposed to the proposal. Such public notice shall be given by publication as provided in subdivision one of Section 431.

(3) In addition to such public notice, the Commission shall give notice of the time and place of the public hearing in writing, at least fifteen days prior to the date thereof, to the state Departments of Agriculture and Markets, Commerce, Conservation, Health and Transportation, the Water Pollution Control Board, the Temporary State Commission on Flood Control and the State Soil Conservation Committee; also to the clerks or other executive officers of the public corporations and state agencies, persons and other agencies as listed in the petition. The Commission may also give similar written notice to any other person, body or agency it may deem would have an interest in or would be affected by any comprehensive planning. Any public corporation, acting through any executive officer authorized to take such action by its governing body or board, may file with the Commission a written request that such public corporation be notified in writing of any hearing under Part V of this article in relation to any region embraced in whole or in part within any area or areas of the state designated by such public corporation in its written request. After the filing of such request, where any petition shall be filed with the Commission setting forth any such region, but not listing such public corporation, the Commission shall give notice to such public corporation of any hearing on such petition, in the same manner as if it had been listed in the petition pursuant to subdivision one of this section. For the purpose of any hearings or proceedings under Part V of this article or to review a decision in the manner provided by article seventy-eight of the civil practice law and rules relating to any region embraced within the area or areas designated in such request, any public corporation entitled to notice by reason of having filed such request shall be deemed to be and shall have all of the rights of a party to the same extent as if such public corporation had been listed in the petition pursuant to subdivision one of this section. A modification or withdrawal of any such request may be filed by any public corporation in the same manner as an original request. Any such modification shall have the same force and effect as an original request. Failure of the Commission to give notice pursuant to such written request shall not invalidate any proceedings had or action taken by the Commission.

(4) The Commission shall, upon the day specified in the notice, or upon such subsequent day or days to which it may adjourn the hearing, proceed to take testimony and proof and to hear arguments submitted in support of and in opposition to the proposal. If in the course of the hearing, it shall appear to the Commission that the region specified in the petition should be enlarged in order to undertake a more comprehensive and beneficial study, survey and planning, the Commission shall adjourn the hearing a sufficient period of time in order to obtain the approval of the board or boards or supervisors of the county or counties in which the additional area is located for the inclusion of such additional area in the proposal. If such approval is given, the Commission shall give, within the

additional area, similar public and written notice, and shall give similar written notice to public corporations which have filed requests, and in like manner, as provided by subdivisions (2) and (3) of this section, of the time and place fixed by the Commission for the resumption of the public hearing. The hearing shall resume and proceed at such time and place as if the additional area had been included in the petition as part of the region.

(5) Within thirty days after the taking of testimony and proofs, any person, public corporation or state agency, who or which has appeared at the hearing, may file with the Commission written objections to the proposal or parts thereof as petitioned for or as enlarged as above provided. Such objections shall specify the grounds and reasons upon which they are made. Briefs in support of and in opposition to the proposal may be filed with the Commission within the same thirty day period. Upon expiration of the period, the hearing shall be deemed closed, unless the Commission determines that the hearing should be reopened for the taking of further testimony or other proof.

(6) Thereafter and with all convenient speed, the Commission shall render its decision, determining if it is or is not in the public interest or benefit to undertake the proposal. If the proposal is found to be in the public interest or benefit the Commission shall determine the region of the state to be included in the study, survey and comprehensive planning, the minimum number of specific purposes for which the planning should be undertaken, the extent of the study, survey and planning involved and an approximate estimate of the cost of the study and survey.

(7) Following this determination by the Commission, and before proceeding thereon, the petitioner for the survey and study shall decide within six months after the date of the Commission's determination whether to proceed with the survey and study or to withdraw its request therefor. Notice of its decision shall be given promptly to the Commission. The Commission may grant one or more extensions of six months each to the petitioner to make its decision.

(8) The area of the state within the corporate limits of the city of New York shall not be included, in whole or in part, in any region proposed by a petition, or as enlarged or as determined by the Commission under this section, which region includes in whole or in part the counties of Nassau or Suffolk, or either of them.

Section 437. Regional planning board; meetings; quorum; powers and duties

(1) Initial appointments. If the Commission shall determine that the proposal should be undertaken, the Commission, after the expiration of the time in which a review of its decision may be had or, in the event such a review has been instituted, after a final judgment or order affirming the Commission's decision has been entered therein, shall appoint a regional planning board, hereinafter referred to as "the board."

(2) Composition. The board shall consist of seven members residing in the region of the proposal and of whom:

(a) at least one member shall be representative of the municipal corporations within the region of the proposal, and service as a member of the board shall not be deemed as service rendered to any municipal corporation;

(b) at least one member shall be representative of the agricultural and farming interests within the region of the proposal and shall be actively interested in the improvement and development of agricultural and farming processes and techniques,

(c) at least one member shall be representative of industry within the region of the proposal and actively engaged or employed in an industrial or commercial pursuit;

(d) at least one member shall be representative of groups within the region of the proposal interested in the needs of fisheries and waterfowl and in forms of outdoor recreation made possible by the state's waters; and

(e) at least one member shall be actively engaged in or connected with the acquisition, operation or management of public water supplies within the region, and service as a member of the board shall not be deemed as service rendered to any municipal corporation.

(3) Members, nomination and appointment. Appointments to the board shall be made by the Commission from lists of nominations submitted to it, at the Commission's request, by the board or boards of supervisors of the county or counties within the region of the proposal. Each list of nominations shall contain fourteen names including two for each of the five representative classes specified by subdivision (2) of this section. Where more than one county is included, the boards of supervisors shall make all reasonable effort to agree upon a single list of nominations. The Commission when making its requests for nominations shall specify a date, fixed so as to permit action on the requests by the boards of supervisors, on or before which such nominations must be submitted, unless the Commission shall extend such time. The persons so appointed by the Commission shall within ten days following the date of their appointments and before entering upon the performance of their duties, take and subscribe an oath of office in the manner and form prescribed by law, and shall file the same in the office of the Secretary of State of the

State of New York. Each appointee shall notify the Commission in writing of the date of filing his oath of office. A vacancy shall be filled from the appropriate representative class and in like manner as an original appointment.

(4) First meeting. The board shall hold its first meeting not later than thirty days after the oaths of office of all members have been so filed for the purpose of organization and the appointment of its officers. The board shall select from among its members a chairman, vice chairman and secretary.

(5) Name. The board shall be known and transact its affairs as the "..... Regional Water Resources Planning Board" (insert in the name of such board a word or words, chosen by the board at its first meeting, descriptive of the region of the proposal).

(6) Expenses. The members of the board shall serve without compensation but shall be reimbursed for their actual and necessary expenses incurred in the performance of their duties. Vouchers for such expenses shall be prepared on forms provided by the Commission and shall be approved by the chairman of the board. Such vouchers shall be submitted in duplicate to the Commission, which shall transmit one copy of each voucher to the Comptroller of the state of New York for payment and shall retain the other copy in its files.

(7) Termination. The board shall expire and the terms of office of its members shall terminate thirty days after the Commission has finally approved or disapproved a plan as hereinafter in Part V of this article provided. However, the Commission, with the concurrence of the board or boards of supervisors of the county or counties within the region, may terminate the existence of the board and the terms of office of its members at any time it deems it in the public interest to do so; and the Commission, with the concurrence of the board or boards of supervisors of such county or counties, may continue the existence of the board and the terms of office of its members for a specified additional period of time after the Commission has finally approved a plan, for the purpose of furthering the objectives of the plan.

(8) Regular meetings. The board shall:

(a) meet at least monthly;

(b) keep a record of all its proceedings, and

(c) determine the rules of its own proceedings.

(9) Special meetings. Special meetings may be called by the chairman upon his own initiative and must be called by him upon receipt of a written request therefor signed by least two members of the board. Written notice of the time and place of such special meeting shall be given by the secretary to each member at least four days before the date fixed by the notice for such special meeting.

(10) Quorum. Four members of the board shall constitute a quorum to transact the business of the board at both regular and special meetings.

(11) Commission assistance. The board shall request the Commission within appropriations available to the Commission therefor, to provide office space and equipment, and to select and employ or retain clerical, technical, scientific, engineering, legal and other personnel and services to assist the board in carrying out its duties and performing its functions under Part V of this article.

(12) Investigations and surveys. The board, using the personnel so selected and employed or retained by the Commission, shall proceed to investigate, study, examine and survey the water resources of the region of the proposal to ascertain the present uses being made thereof, and to determine the feasibility of their future development by proper conservation and control measures, to provide a greater supply for, and an equitable distribution among domestic, municipal, agricultural, commercial, industrial and recreational users, to the end that the water resources of the region shall not be wasted and shall be conserved and utilized for the beneficial interests of all the people of the state. Particular consideration shall be given to the impounding and retention of flood waters for their future use and distribution.

(13) Board hearings. The board may conduct informal hearings and meetings at any place or places within the region for the purpose of obtaining necessary information or other data to assist it in the proper performance of its functions and duties. The board may delegate to any member, to the secretary or to any agent of the board the power and authority to conduct such hearings and meetings, and all reasonable efforts shall be made to ascertain the views, wishes and opinions of the inhabitants of the region.

(14) Access. The board and its authorized agents may enter upon any lands as in its judgment may be necessary for the purpose of making surveys and examinations to accomplish its functions and duties under this article, without liability. Liability only for actual damage done during any such entry, survey and examination is hereby assumed by the state and consent is hereby granted to any owner of such lands to pursue his remedy for any such actual damage pursuant to the Court of Claims Act.

(15) Cooperation and reports. The board shall cooperate with legislative committees and commissions, and shall make available to such committees and commissions, upon request, any records and other data, and shall file monthly with the Commission a report of its activities and

progress. Upon termination of the board's existence, the board shall deposit all records of its proceedings with the Commission.

(16) Comprehensive planning. The board, based upon its investigations and studies, shall prepare a comprehensive plan or plans for the protection, conservation, development and utilization of the water resources of the region of the proposal, and shall submit the plan or plans to the Commission for its approval.

Section 438. Plans; approval; changes, modifications and rescission

(1) Such plan or plans:

(a) shall in all cases be so drawn and of such scope as is best calculated to assure prompt or orderly development of the water resources for the beneficial use of the people of the region involved and of the state as a whole;

(b) shall show the available and feasible sites for the installation and operation of protective, conservation and regulatory works, and the benefits estimated to be derived from such installation and operation. The plan or plans shall be accompanied by such maps, profiles and other data and descriptions as will set forth and show the location and character of the works and of the property required to be taken for or to be damaged by such installation or operation or for the protection and maintenance of the works to be installed, together with an estimate of the cost thereof;

(c) shall estimate the minimum annual amount of water which would be available for all purposes if the plan or plans were to be put in operation;

(d) shall not, in the computations of water estimated to become available as a result of the execution of the plan or plans, include any amount of water, the use of which has theretofore been duly acquired or authorized pursuant to approval, license, permit or other official sanction;

(e) shall, whenever feasible and economically justified, provide for the storage of sufficient water for distribution and use for all the purposes and uses contemplated by this article;

(f) shall not include in any plan or plans, any proposal or project providing for any action or steps which would impair or diminish any right protected by Section 441;

(g) shall list possible sources of income, including the sale of water, from the operation of such works, and estimate the amount thereof, and

(h) shall recommend whether the plan or plans should be carried out as a single or multiple stage project, and shall also recommend an agency, existing or proposed, to undertake the project.

(2) Hearings. Upon receipt of a plan from the board, the Commission shall cause public notice to be given that on a day therein named it will hold a public hearing at such a place as is specified in the notice and within the region covered by the plan, for the purpose of hearing all persons, public corporations and agencies of the state which may be affected by the plan. Such notice shall be published pursuant to subdivision one of Section 431. In addition to such publication, the Commission shall give written notice of the public hearing, as required by subdivision (3) of Section 436, and may give written notice thereof to additional persons, public corporations or agencies of the state, as authorized by such subdivisions. At any time prior to the day specified in such notice, specified objections in writing to the plan or parts thereof may be filed in the office of the Commission. The Commission shall, upon the day specified in the notice, or upon such subsequent day or days to which it may adjourn the hearing, proceed to take testimony and proof and to hear arguments submitted in support of and in opposition to the plan, but no objectors shall be heard unless they have filed written objections as authorized by this section. At the close of the hearing, the Commission may fix a date or dates for the filing of briefs.

(3) Action by the Commission. The Commission, within ninety days after the last date fixed for the filing of briefs and with all convenient speed shall render its decision. The Commission, upon the proofs and evidence submitted at the public hearing:

(a) shall determine whether the plan as proposed by the board conforms to and complies with the purposes of Part V of this article and would serve the public interest and benefit, or whether it should be modified in any respect, detail or part to accomplish such purposes;

(b) shall determine whether the plan as proposed by the board interferes or conflicts with the plans of any other regional water resources planning board, and would be just and equitable to the interests of other areas of the state;

(c) shall approve such plan as submitted by the board or as modified by the Commission; or shall disapprove the plan; or shall remit the proposal to the board for further investigation, study, survey and planning; and

(d) shall recommend which public corporations, private corporations or agencies of the state, existing or proposed, would, in its opinion, be best qualified to

carry out expeditiously and efficiently the project proposed by the plan, as approved by the commission, and to construct, maintain and operate the works in connection therewith. If the commission recommends that a new public corporation or state agency should be established for such purposes, it shall transmit a recommendation to the legislature and the governor for the enactment of legislation to create and establish such body or agency, or to grant authority to existing public corporations or state agencies.

(4) General plan. Upon the filing of the Commission's decision or, in the event such decision is reviewed in the manner provided by article seventy-eight of the civil practice law and rules, upon the final determination of such review proceeding, the plan as approved by the Commission or as approved or modified by the court in a review proceeding, shall be the general plan for the conservation, development and utilization of the water resources of the region, and such general plan shall be given consideration by the Commission in any future application before it and over which it has jurisdiction by virtue of this article or other provision of law. None of the works or projects, included in the general plan, nor any part or parts thereof shall be undertaken, constructed or put into operation until detailed and specific maps and plans therefor have been submitted to the Commission for approval upon the petition of an agency authorized to undertake or construct such works or projects or parts thereof. The Commission shall determine, after public hearing, if the detailed and specific plan before it for approval conforms to and is consistent with the general plan, and whether it is in the public interest to undertake the construction and operation of the works or projects as proposed. The Commission shall have the power to approve or disapprove the detailed and specific maps and plans, or to so modify them as will, on the evidence presented, bring them into conformity with the general plan.

(5) Procedure for changes, modifications or rescission. Any municipality or combination of municipalities may, except as provided in subdivision (7) of Section 436, file with the Commission a verified petition requesting the Commission to modify, change or rescind any general plan approved by it. The petition shall set forth the facts on which the petitioner or petitioners rely to show that it is necessary and would be in the public interest to change or modify such plan as requested in the petition, or to rescind such plan. Upon receipt of such a petition, the Commission shall give public notice of hearing, shall give written notice of hearing to parties and persons, shall hold a public hearing on such petition, and shall take testimony and proof, in the same manner as if the Commission were holding a public hearing on the original submission of the plan which such petition seeks to change, modify or rescind. The Commission, within ninety days after the last date fixed for the filing of briefs and with all convenient speed, shall render its decision changing, modifying or rescinding such plan, or denying the petition, as the public interest shall require.

(6) Initiation of proceedings. The Commission may, on its own motion, initiate proceedings to change, modify or rescind any approved plan. The proceedings and procedure with respect to any such proposal, including notice, hearing and judicial review, shall be the same as in the case of a petition for change, modification or rescission of a plan.

(7) Costs and expenses. Except as hereinafter in this subdivision provided, the provisions of Sections 439 and 440 shall apply to the sharing and apportionment of costs and expenses incurred by the Commission under this section. In any case where an application under this section is filed with respect to any plan by any municipality or municipalities outside of the region specified in such plan, the share of the Commission's costs and expenses which would otherwise be paid by the county or counties of such region, shall be paid by such municipality or municipalities.

Section 439. Additional powers and duties of Commission

(1) The Commission shall, if appropriations are available therefor, provide the board with such office space and equipment, clerical, technical, scientific, engineering, legal and other personnel and services as are reasonably necessary to assist the board in carrying out its functions, and shall fix the compensation, within appropriations available therefor, of such personnel. The Commission may enter into and execute contracts in the manner and form prescribed by law for technical, scientific, engineering and legal services to be made available for the board's functions, and may enter into cooperative agreements with federal agencies for research, the investigation, collection, compilation, study and analysis of information and data on the water resources and the hydrology of the state, and for the preparation and publication of reports thereon.

(2) The Commission shall cooperate with the board and render to it advisory and consultant services whenever practicable.

(3) The Commission shall endeavor to coördinate the activities of existing agencies and departments of the state charged with functions involving waters and to secure their cooperation with and assistance for the board in carrying out its functions, and provide the means for coordination of the studies and development plans of all regional boards;

(4) The Commission shall keep a true and accurate account of all expenditures incurred on behalf of the board including, but not limited to, those incurred for all

proceedings, hearings (except the hearing required by Section 436), notifications, clerical, technical, engineering, legal and other services and expenses;

(5) The Commission shall, within a reasonable time after the plan has been approved or disapproved, submit an itemized statement of the costs and expenses so incurred and expended to the board or boards of supervisors. Notice shall be attached to such statement that, under Part V of this article, twenty-five per cent of the cost and expenses is a county charge which, if more than one county is involved, is to be equitably apportioned among them; that the counties may by agreement determine such equitable apportionment within sixty days from the date of such notice, and, that in the failure of the counties so to agree, the Commission, on a specified date after such sixty day period has expired, will hear the counties at its office and proceed to make an equitable apportionment of the county charge;

(6) The Commission shall recommend legislation to accomplish and further the planning and development program of the water resources of the state.

Section 440. Duties of county; county charge; counties included within a city

(1) The board or boards of supervisors shall comply promptly with the Commission's request for lists of nominations for membership on the board. The county or counties shall cooperate with and assist, so far as is reasonable and practicable, the board in carrying out its functions.

(2) Of the total costs and expenses incurred by the Commission, twenty-five per cent shall be a county charge and shall be audited and paid as such in the manner prescribed by the board or boards of supervisors. If more than one county is included within the region of the project, the county charge of twenty-five per cent shall be equitably apportioned among them, consideration being given to, but not limited to, prospective benefits to accrue to each in the event that the project is undertaken. If the counties fail to agree within sixty days after the statement of costs and expenses from the Commission, upon an equitable apportionment of the county charge, the Commission, after hearing the counties, shall make such apportionment.

(3) With respect to any or all of the counties within the city of New York, except as provided and limited by subdivision (7) of Section 436:

(a) all rights, powers and privileges granted to, and all duties, obligations, and charges imposed upon any county by the provisions of Part V of this article, are granted to or imposed upon such city; and

(b) all rights, powers and privileges granted to the board of supervisors of any county by the provisions of Part V of this article (including, but not limited to the power to approve a petition for a survey and study and establishment of a regional planning board) and all duties and obligations imposed upon any such board by Part V of this article, are granted to or imposed upon the board of estimate of such city.

Section 441. Existing rights and remedies preserved; limitations

(1) Nothing in Part V of this article contained is intended to or shall be construed to alter, impair, diminish or enlarge any existing or hereafter acquired public or private right, riparian or otherwise, or to create any new public or private right, riparian or otherwise, with reference to water resources and the use of the waters thereof and such rights hereby preserved shall include, but not be limited to any such right of the state or any agency thereof or any person or public corporation. Any reference in this section to a public or private right with reference to water resources and the use of the waters thereof shall include, but shall not be limited to, any right to receive, collect, store, control, transmit, consume, supply, sell, discharge or dispose of water, any right to own, construct, operate and maintain any water supply or water treatment facilities, including reservoirs, dams, aqueducts, chlorinating and aeration plants and pumping stations, and any right to exercise control over the level, flow, discharge or disposition of waters, including water in reservoirs, rivers, streams and aqueducts.

(2) Nothing in Part V of this article contained is intended to alter or abridge any right of action or other remedy now or hereafter existing nor shall any act done by virtue of Part V of this article be construed as estopping the exercise of such rights.

(3) Nothing in Part V of this article contained shall be held to repeal, limit or modify the jurisdiction, powers and duties of any state or local department, board, district, commission or authority, or any public corporation, or other agency, now or hereafter possessed, or to invalidate or modify, in whole or in part, any decision, order, license, permit, approval, or other act, issued or taken heretofore or hereafter by such department, board, district, commission, authority, or public corporation or other agency, or to nullify, abate or otherwise affect any rights acquired or action taken heretofore or hereafter pursuant to such decision, order, license, permit, approval, or other act.

(4) Nothing contained in Part V of this article shall be construed as requiring that a plan hereunder be approved for any region before any project utilizing, affecting or involving the water resources of such region in whole or in part may be authorized, approved, initiated or carried out within or without such region.

OFFICE OF PLANNING COORDINATION
488 Broadway, Albany, New York 12207
Telephone (518) 474-7053

DIRECTOR–D. DAVID BRANDON

DEPUTY DIRECTOR–Henry G. Williams, Jr.

ASSISTANT DIRECTORS–
Charles L. Crangle
William W. Horne
John L. Moore
Vincent Stallone

ASSISTANT DIRECTOR AND COUNSEL–
Richard A. Persico

BUREAU CHIEFS
COMPREHENSIVE PLANNING
Robert L. Horn
FUNCTIONAL COORDINATION
R. J. T. Longabaugh
PLANNING RESEARCH
Charles R. Guinn

DISTRICT OFFICE DIRECTORS

METROPOLITAN NEW YORK–Howard S. Quinn
1841 Broadway, Room 711
New York, New York 10023
(212) 586-7800

CAPITAL DISTRICT–James K. VanDervort
488 Broadway
Albany, New York 12207
(518) 474-8640

CENTRAL NEW YORK–Robert C. Hansen
State Tower Building
109 S. Warren Street, Room 302
Syracuse, New York 13202
(315) 474-5951 Ext. 291

WESTERN NEW YORK–Myron J Elkins
General Donovan State Office Building
125 Main Street
Buffalo, New York 14203
(716) 842-2393

This study was prepared by the State Division of Water Resources through its district office in Melville, directed by Randolph M. Stelle, district engineer. General supervision was by Edward A. Karath, eastern regional engineer, and staff of the division's headquarters in Albany. OPC supervision was by Otto Mertz of the Metropolitan New York District Office, directed by Howard S. Quinn.

POPULATION (LILCO-69)

POPULATION SURVEY

1969

CURRENT POPULATION ESTIMATES FOR NASSAU AND SUFFOLK COUNTIES

LILCO
LONG ISLAND LIGHTING
AN INVESTOR-OWNED, TAXPAYING COMPANY

PROPERTY OF U. S. GEOLOGICAL SURVEY
MINEOLA OFFICE LIBRARY

Frinke Jr
Seaburn ✓

LONG ISLAND LIGHTING COMPANY

Executive Offices 250 OLD COUNTRY ROAD MINEOLA, N.Y. 11501

Library

March 1969

The Long Island Lighting Company is pleased to present you with this copy of our comprehensive population estimates for Nassau and Suffolk Counties as of January 1, 1969.

With this fifteenth in a series of continuing studies of population, we have instituted the annual publication of a complete distribution of the population by communities and by definitive geographic areas.

We warmly welcome your comments. Your acknowledgment will continue your name on our mailing list to receive future editions.

Very truly yours,

Economic Research Department
Long Island Lighting Company
250 Old Country Road
Mineola, New York 11501

LONG ISLAND LIGHTING

AN INVESTOR OWNED
TAXPAYING COMPANY

POPULATION SURVEY

1969

Current Population Estimates For Nassau and Suffolk Counties

We express our appreciation to the U. S. Department of Commerce, Bureau of the Census, the Nassau County Planning Commission and the Suffolk County Department of Planning for their co-operation and assistance in the work underlying these population studies and to the Villages of Freeport, Rockville Centre and Greenport for supplying their electric meter data to make this work complete.

ADDRESS COMMUNICATIONS TO: Long Island Lighting Company
Economic Research Department
250 Old Country Road
Mineola, New York 11501

Permission to reprint statistical and written matter, with credit to Long Island Lighting Company, is granted.

FOREWARD

With this, the fifteenth in a series of population estimates by Long Island Lighting Company, we institute a long awaited development in their issuance, the total LILCO "Population Survey" every year. Heretofore, this 1969 format of LILCO's "Population Survey" was released only every other year (on even numbered years), interspersed, on odd numbered years, with an outline report containing just the Town, County and Rockaway Peninsula totals.

Advance estimates of the area's power needs is essential. How much electric generation and gas volume as well as transmission and distribution lines will be needed to supply Long Island's future demands for energy must be ascertained. It takes, for example, about four years from planning to completion to produce an electric plant of about 400,000 kilowatts. Population trends, therefore, are an important factor in our decisions, not only of how much and when, but where.

Our need for immediate and up-to-date population information guided us into these statistics as you note them here. Adaptation of our electronic data processing to population statistics based on our meter and customer data now enables us to publish our population survey in detail every year.

The total population of the LILCO service area is greater than the individual populations of 24 states and more than 1% of the total United States population.

LILCO's estimate for Suffolk County at January 1, 1969 is 1,059,322, an increase of 392,538 or 58.9% since the 1960 census. The estimate for Nassau County at January 1, 1969 is 1,445,609, an increase of 145,438 or 11.2% since the 1960 census. Suffolk County's population increase in 1968 was 45,746, over 3 1/2 times that of Nassau County which added 1[illegible],363 in the one year.

At January 1, 1969 the combined Nassau and Suffolk Population was estimated to be 2,504,931. This is an increase of 537,976 or 27.4% above 1960. Including the 91,598 people of the Rockaway Peninsula of Queens, LILCO serves an estimated total population of 2,596,529.

With the substantial recovery in 1968 of the home building industry from the decline in 1967, the population gain in Nassau County, as well as Suffolk County, exceeded the gain of the previous year. Apartment unit construction in LILCO's service area again exceeded 3,000 units in 1968, about 18% of the total increase in residential units occupied. Our incremental method of estimating by type of new dwelling unit, house or apartment, compensates for the increasing trend of multi-family unit construction which results in fewer occupants per meter.

Essentially, LILCO's estimating method is a relationship between population and residential electric meters in use at the time of census. During the years between censuses, new meters installed (representing new family units) are recorded. Estimates of people per household based on previous census data are used to develop the added population figure for each community. We do not estimate the effects of migration, urban renewal or natural increase. However, we are aware of their influence, as well as that of building trends and land saturation.

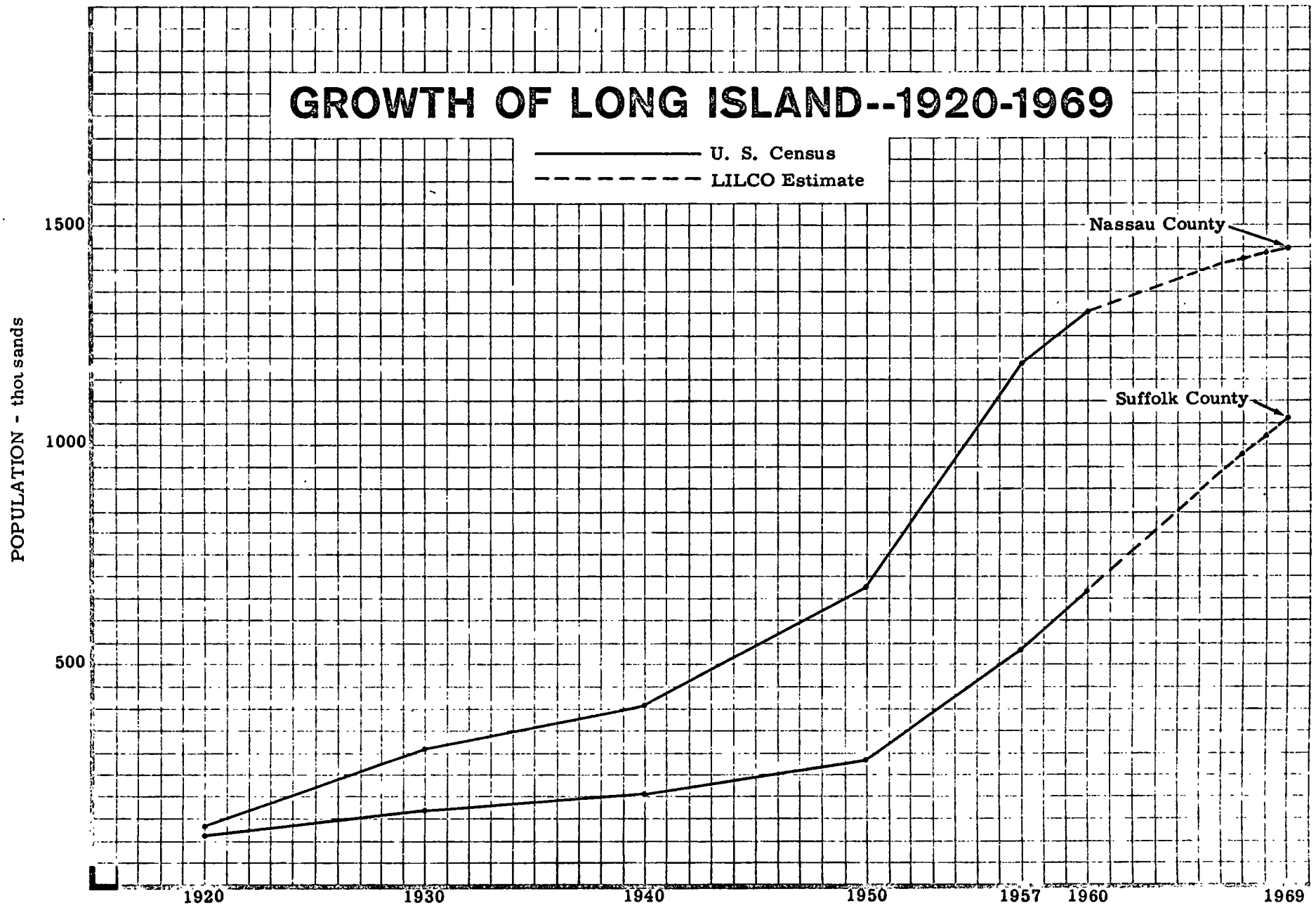
The material has been arranged to follow the general political subdivisions of county, town, and village. Unincorporated communities and hamlets have no legal boundaries. Those given are to be used as guide lines only. We have included a map of each county and a detailed boundary map of each town. The tabular grouping of villages and communities into general geographic areas is an arrangement of convenience only.

Because this "Population Survey" is important to so many activities and enterprises, we share it with you. Unless the reader is expert in demography we suggest great care in interpretation or extrapolation of these statistics.

TABLE OF CONTENTS

	Page
Growth of Long Island 1920-1969	1
Population of Long Island by Township	2
Growth of Nassau County by Township	3
Key Map of Nassau County	
MAP OF NORTH HEMPSTEAD SECTOR	
Great Neck Area	4
Port Washington-Manhasset Area	4
Roslyn-Albertson Area	5
New Hyde Park-Mineola Area	5
Westbury Area	5
MAP OF HEMPSTEAD SECTOR	
Floral Park-Franklin Square Area	6
Garden City-Hempstead Area	6
East Meadow-Levittown Area	6
Valley Stream-Lynbrook Area	7
Rockville Centre-Freeport Area	7
Merrick-Seaford Area	7
The Branch Area	8
Long Beach Area	8
MAP OF OYSTER BAY - UPPER PORTION	
Glen Cove Area	9
Oyster Bay Area	9
Brookville Area	9
Syosset-Plainview Area	9
MAP OF OYSTER BAY - LOWER PORTION	
Hicksville-Jericho Area	10
Farmingdale-Bethpage Area	10
Massapequa Area	10
Growth of Western Suffolk by Township	11
Key Map of Suffolk County	
Growth of Eastern Suffolk by Township	12
MAP OF HUNTINGTON SECTOR	
Huntington Area	13
Northport-Commack Area	13
Melville-Dix Hills Area	13
MAP OF BABYLON SECTOR	
Amityville-Lindenhurst Area	14
Babylon Area	14
Maywood-Deer Park Area	14

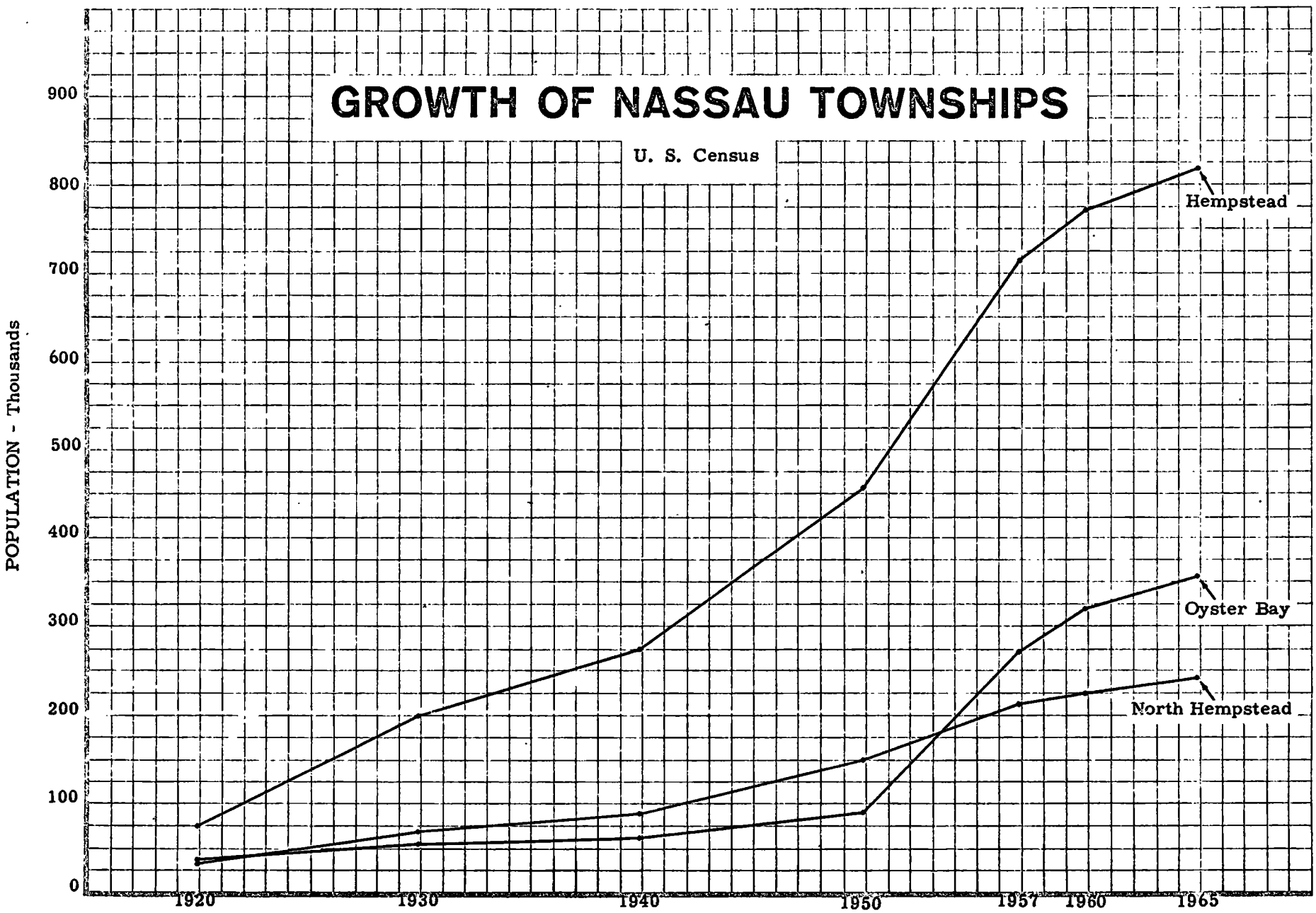
	Page
MAP OF ISLIP SECTOR	
Bay Shore Area	15
Islip Area	15
Sayville Area	16
MAP OF SMITHTOWN SECTOR	
Smithtown Area	17
MAP OF NORTH BROOKHAVEN SECTOR	
Northern Brookhaven Area	18
MAP OF SOUTH BROOKHAVEN SECTOR	
Southern Brookhaven Area	19
MAP OF RIVERHEAD SECTOR	
Communities in Riverhead	20
MAP OF SOUTHAMPTON SECTOR	
Villages and Communities in Southampton	21
MAP OF SOUTHOLD SECTOR	
Villages and Communities in Southold	22
MAP OF EAST HAMPTON SECTOR	
Villages and Communities in East Hampton	23
Town of Shelter Island	23
MAP OF SHELTER ISLAND SECTOR	


GROWTH OF LONG ISLAND--1920-1969
U. S. Census
LILCO Estimate
POPULATION - thousands
1500
1000
500
Nassau County
Suffolk County
1920
1930
1940
1950
1957
1960
1969

Population Summary Table

NASSAU AND SUFFOLK COUNTIES BY TOWNS

NASSAU COUNTY TOWNS	U.S. Census 1950	U.S. Census 1960	LILCO Estimate Jan. 1, 1968	LILCO Estimate Jan. 1, 1969
North Hempstead	142,613	219,088	241,450	243,131
Hempstead	448,092	767,211	831,698	839,590
Oyster Bay	82,060	313,872	360,098	362,888
Total County	672,765	1,300,171	1,433,246	1,445,609
SUFFOLK COUNTY TOWNS				
Huntington	47,506	126,221	182,027	189,873
Babylon	45,556	142,309	192,156	196,462
Islip	71,465	172,959	258,358	267,400
Smithtown	20,993	50,347	99,249	105,770
Brookhaven	44,522	109,900	199,639	214,928
Riverhead	9,973	14,519	17,771	18,436
Southampton	17,013	27,095	34,442	35,469
Southold	11,632	13,295	16,315	16,714
East Hampton	6,325	8,827	12,009	12,568
Shelter Island	1,144	1,312	1,610	1,702
Total County	276,129	666,784	1,013,576	1,059,322
Queens Fifth Ward (Rockaway Peninsula)	51,103	68,787	89,055	91,598


GROWTH OF NASSAU TOWNSHIPS
U. S. Census
POPULATION - Thousands
900
800
700
600
500
400
300
200
100
0
1920
1930
1940
1950
1957
1960
1965
Hempstead
Oyster Bay
North Hempstead

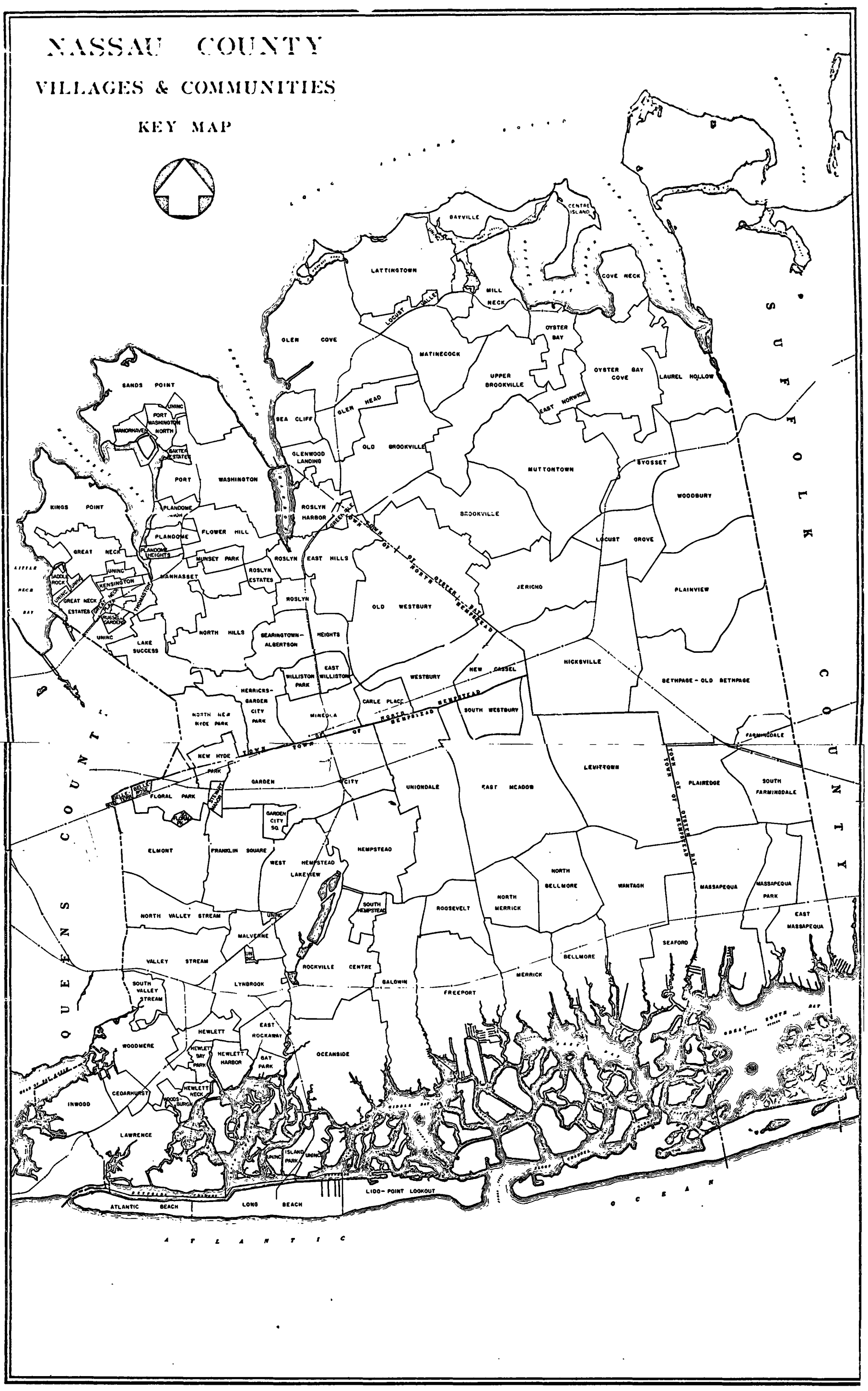
NASSAU COUNTY

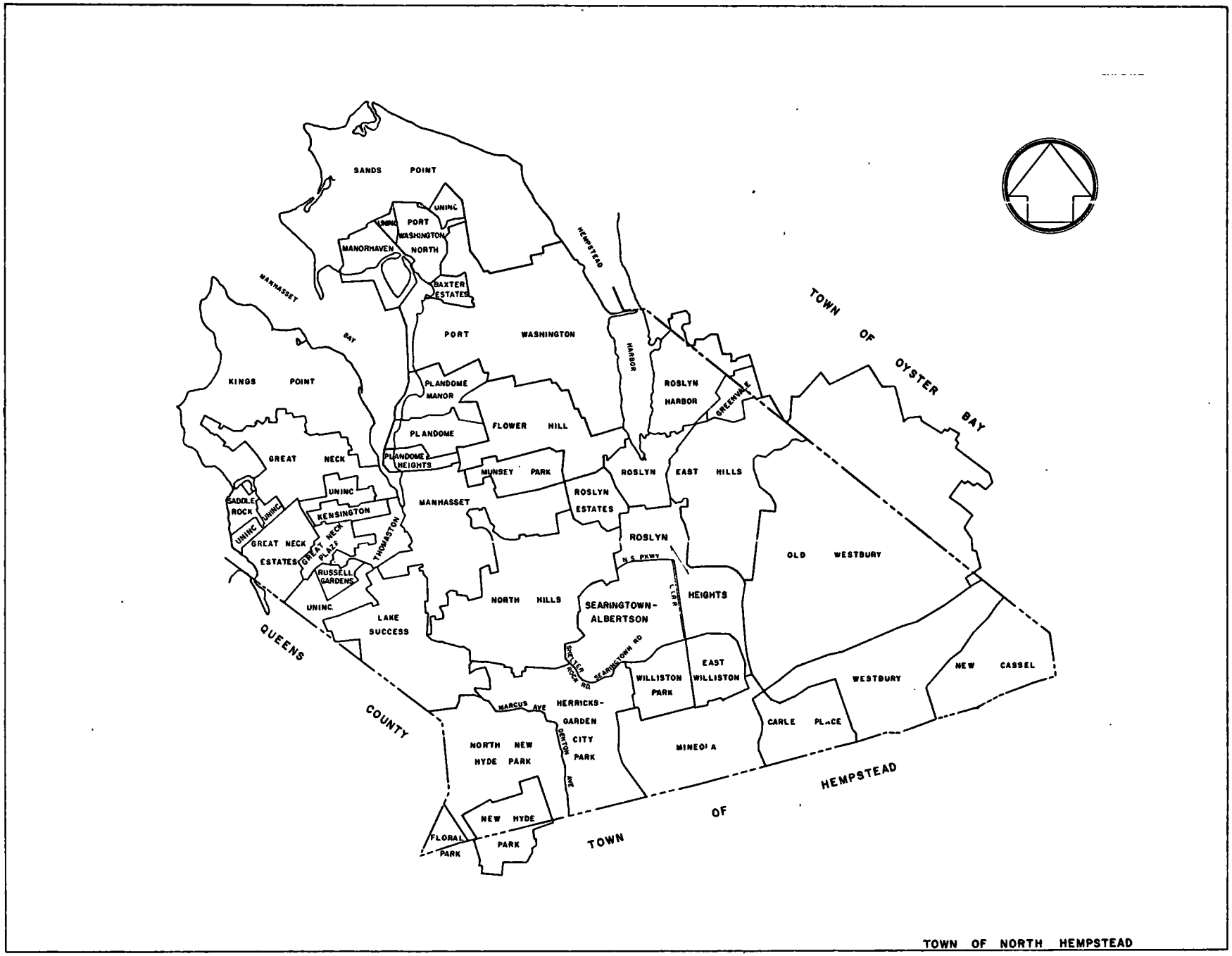
Detail of the Population
Of the Villages and Communities
Of Nassau County

NASSAU COUNTY

VILLAGES & COMMUNITIES

KEY MAP





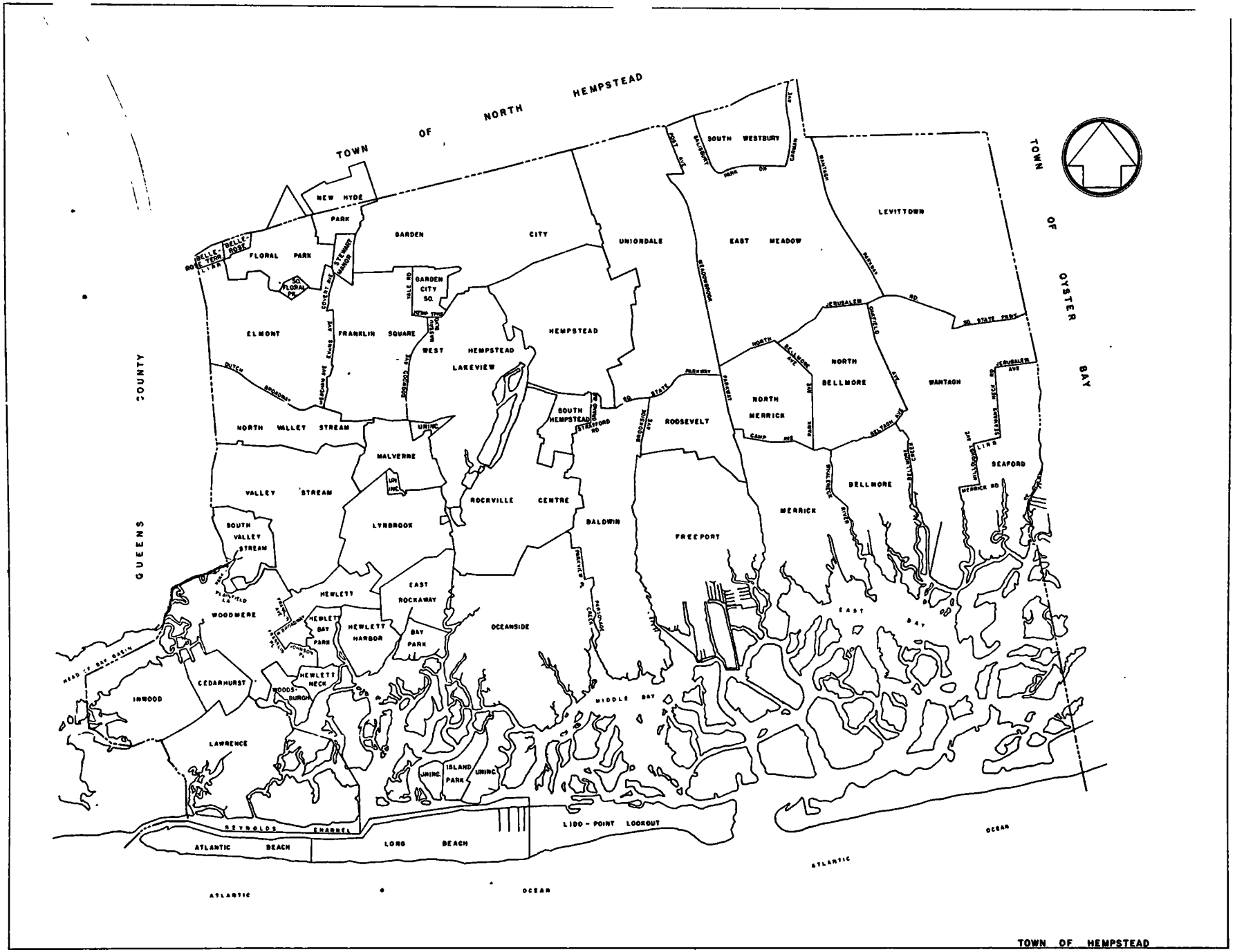
TOWN OF NORTH HEMPSTEAD

TOWN OF NORTH HEMPSTEAD

	Population		
GREAT NECK AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Kings Point (Inc.)	5,410	5,930	5,950
Great Neck (Inc.)	10,171	10,436	10,443
Saddle Rock (Inc.)	1,109	1,038	1,038
Kensington (Inc.)	1,166	1,167	1,163
Great Neck Estates (Inc.)	3,262	3,430	3,453
Great Neck Plaza (Inc.)	4,948	6,116	6,190
Thomaston (Inc.)	2,767	2,937	2,930
Russell Gardens (Inc.)	1,156	1,368	1,364
Lake Success (Inc.)	2,954	3,210	3,222
Great Neck (Uninc.)	7,971	8,362	8,389
Total Area	40,914	43,994	44,142
PORT WASHINGTON - MANHASSET AREA			
Sands Point (Inc.)	2,161	2,640	2,726
Manorhaven (Inc.)	3,566	5,358	5,454
Port Washington North (Inc.)	722	2,591	2,722
Baxter Estates (Inc.)	932	1,180	1,191
Plandome Manor (Inc.)	705	893	907
Plandome (Inc.)	1,379	1,561	1,561
Plandome Heights (Inc.)	1,025	957	970
Flower Hill (Inc.)	4,594	4,923	5,062
Munsey Park (Inc.)	2,847	3,016	3,024
Port Washington	17,358	17,123	17,177
Manhasset	8,914	9,085	9,098
Total Area	44,203	49,327	49,892

	Population		
ROSLYN-ALBERTSON AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Roslyn (Inc.)	2,681	2,558	2,828
Roslyn Harbor (Inc.)			
In North Hempstead	804	990	994
In Oyster Bay	121	191	179
Roslyn Estates (Inc.)	1,289	1,524	1,532
East Hills (Inc.)	7,184	8,765	8,806
North Hills (Inc.)	359	326	322
Roslyn Heights	7,473	7,594	7,598
Greenvale			
In North Hempstead	931	897	903
In Oyster Bay	276	262	265
Albertson-Searingtown	9,514	12,452	12,431
Total Area	30,632	35,559	35,858
NEW HYDE PARK - MINEOLA AREA			
New Hyde Park (Inc.)			
In North Hempstead	6,379	6,508	6,516
In Hempstead	4,429	4,522	4,570
Mineola (Inc.)	20,519	22,491	22,819
Williston Park (Inc.)	8,255	9,036	9,070
East Williston (Inc.)	2,940	2,971	2,975
North New Hyde Park	17,929	17,492	17,496
Garden City Park - Herricks	15,364	18,332	18,387
Total Area	75,815	81,352	81,833
WESTBURY AREA			
Westbury (Inc.)	14,757	14,994	15,044
Old Westbury (Inc.)			
In No. Hempstead	1,756	2,134	2,205
In Oyster Bay	308	460	460
Carle Place	5,625	6,506	6,494
New Cassel	7,686	9,920	10,015
Total Area	30,132	34,014	34,218
*TOTAL TOWN OF NORTH HEMPSTEAD	219,088	241,450	243,131

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.


TOWN OF NORTH HEMPSTEAD
TOWN OF OYSTER BAY
QUEENS COUNTY
NEW HYDE PARK
FLORAL PARK
GARDEN CITY
CITY
UNIONDALE
EAST MEADOW
SOUTH WESTBURY
LEVITTOWN
ELMONT
FRANKLIN SQUARE
GARDEN CITY SO.
WEST HEMPSTEAD
LAKEVIEW
HEMPSTEAD
NORTH BELLMORE
WANTAGH
NORTH VALLEY STREAM
MALVERNE
SOUTH HEMPSTEAD
ROOSEVELT
NORTH MERRICK
SEAFORD
VALLEY STREAM
ROCKVILLE CENTRE
BALDWIN
FREEPORT
BELLMORE
MERRICK
SOUTH VALLEY STREAM
LYNBROOK
HEWLETT
EAST ROCKAWAY
WOODMERE
HEWLETT BAY PARK
HEWLETT HARBOR
BAY PARK
OCEANSIDE
EAST BAY
CEDARHURST
INWOOD
HEWLETT NECK
WOODSBURGH
MIDDLE BAY
LAWRENCE
ISLAND PARK
LIDO - POINT LOOKOUT
ATLANTIC BEACH
LONG BEACH
ATLANTIC OCEAN
TOWN OF HEMPSTEAD

TOWN OF HEMPSTEAD

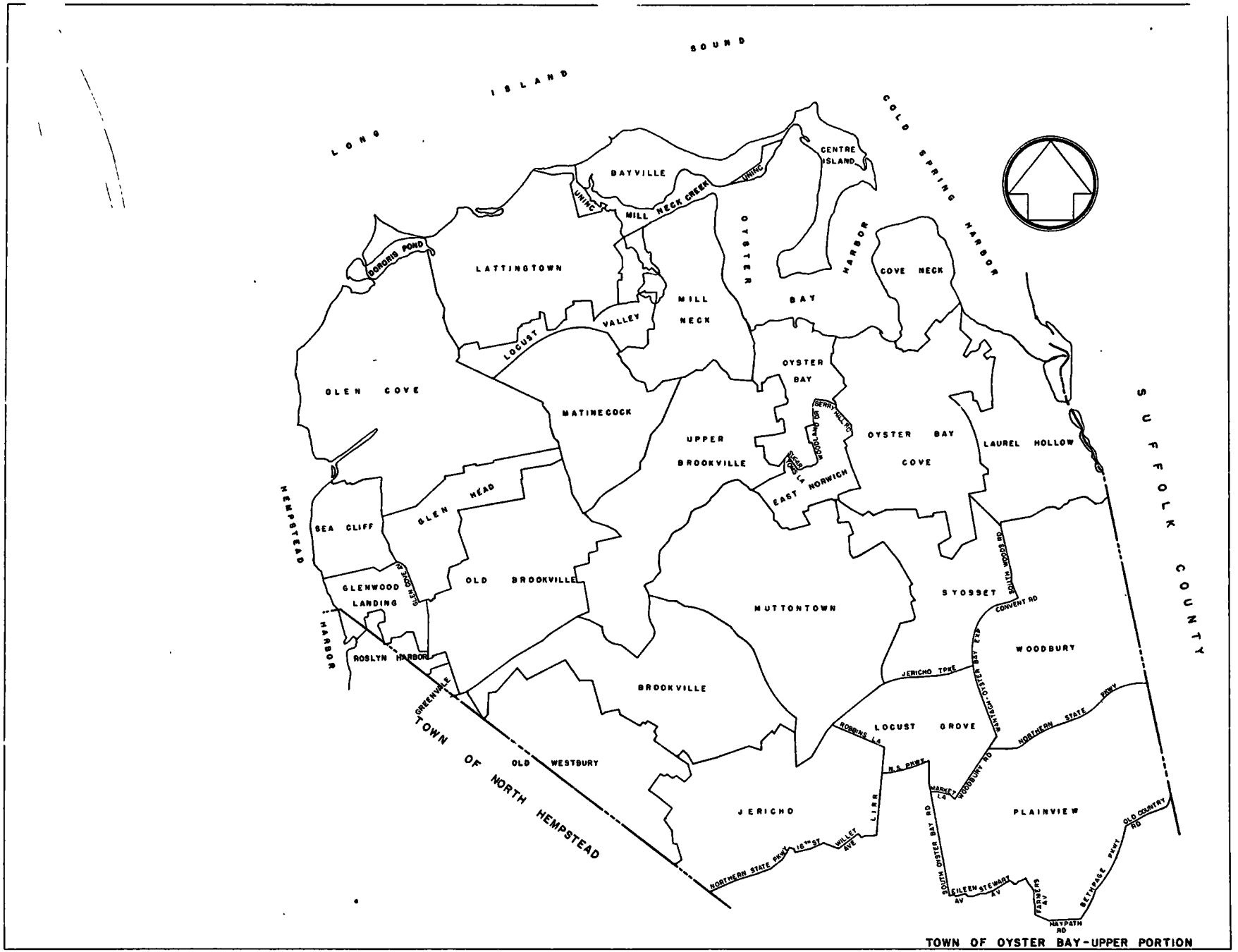
	Population		
FLORAL PARK - FRANKLIN SQUARE AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Bellerose (Inc.)	1,083	1,149	1,146
Floral Park (Inc.)			
In Hempstead	15,121	15,676	15,702
In No. Hempstead	2,378	2,430	2,457
Stewart Manor (Inc.)	2,422	2,525	2,525
South Floral Park (Inc.)	1,090	1,383	1,436
Bellerose Terrace	2,314	2,299	2,325
Elmont	30,138	30,808	30,946
Franklin Square	32,483	32,656	32,790
Total Area	87,029	88,926	89,327
GARDEN CITY - HEMPSTEAD AREA			
Hempstead (Inc.)	34,641	39,567	39,463
Garden City (Inc.)	23,948	24,798	24,943
West Hempstead - Lakeview	24,783	26,156	26,251
Uniondale	23,040	22,605	22,601
Garden City South	5,133	5,037	5,047
Total Area	111,545	118,163	118,305
EAST MEADOW - LEVITTOWN AREA			
East Meadow	46,036	44,755	44,807
Levittown	65,276	67,165	67,741
Westbury South	11,977	12,329	12,359
Total Area	123,289	124,249	124,907

	Population		
VALLEY STREAM - LYNBROOK AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Valley Stream (Inc.)	38,629	40,007	40,185
Malverne (Inc.)	9,968	10,117	10,172
Lynbrook (Inc.)	19,881	21,534	21,971
Valley Stream North	17,239	16,993	17,116
Valley Stream South	6,222	6,921	6,938
Malverne (Uninc.)	1,317	1,332	1,332
Total Area	93,256	96,904	97,714
ROCKVILLE CENTRE - FREEPORT AREA			
Rockville Centre (Inc.)	26,355	26,546	27,101
Freeport (Inc.)	34,419	38,780	40,231
South Hempstead	3,685	3,660	3,394
Roosevelt	12,883	13,961	14,057
Oceanside	30,448	35,688	35,915
Baldwin	30,204	34,175	34,523
Total Area	137,994	152,810	155,221
MERRICK-SEAFORD AREA			
Merrick	18,789	26,364	26,569
North Merrick	12,976	14,147	14,237
Bellmore	12,784	16,985	17,555
North Bellmore	19,639	22,968	23,294
Wantagh	34,172	37,054	37,021
Seaford	14,718	17,045	17,232
Total Area	113,078	134,563	135,908

	Population		
THE BRANCH AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
East Rockaway (Inc.)	10,721	11,981	11,974
Hewlett Bay Park (Inc.)	520	519	537
Hewlett Harbor (Inc.)	1,610	1,685	1,701
Hewlett Neck (Inc.)	507	557	557
Woodsburgh (Inc.)	907	949	941
Cedarhurst (Inc.)	6,954	6,881	6,906
Lawrence (Inc.)	5,907	6,259	6,333
Hewlett	7,398	7,619	7,598
Woodmere	14,011	19,455	19,543
Inwood	10,362	8,972	8,809
Bay Park	2,467	2,603	2,659
Total Area	61,364	67,480	67,558
LONG BEACH AREA			
City of Long Beach (Inc.)	26,473	31,195	32,789
Island Park (Inc.)	3,846	4,973	5,027
Atlantic Beach (Inc.)	(a)	1,103	1,144
Island Park (Uninc.)	2,555	3,608	3,733
Atlantic Beach (Uninc.)	2,280	1,879	1,940
Lido-Point Lookout	2,385	3,751	3,904
Total Area	37,539	46,509	48,537
* TOTAL TOWN OF HEMPSTEAD	767,211	831,698	839,590

(a) Incorporated After 1960.

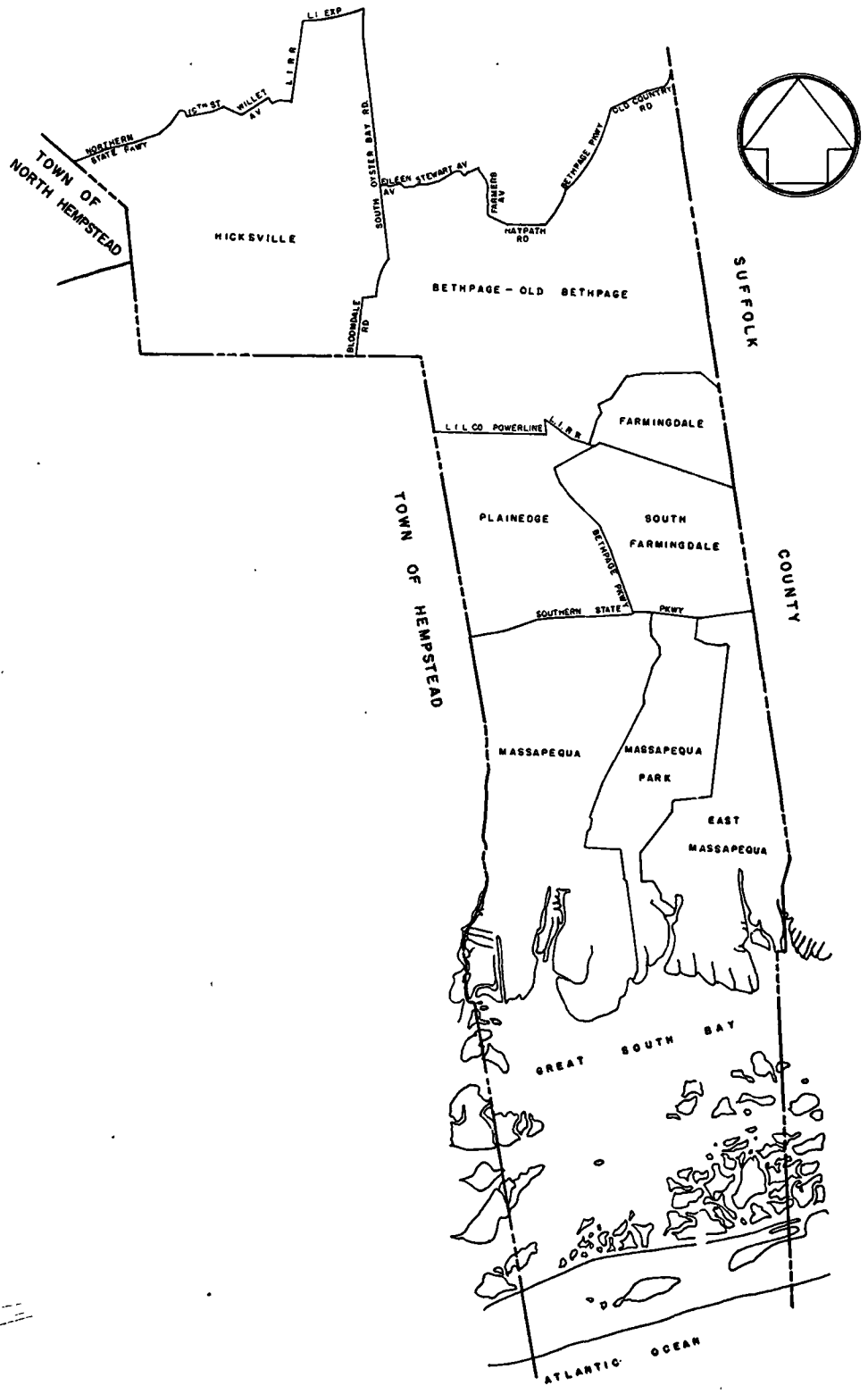
* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.



TOWN OF OYSTER BAY-UPPER PORTION

TOWN OF OYSTER BAY

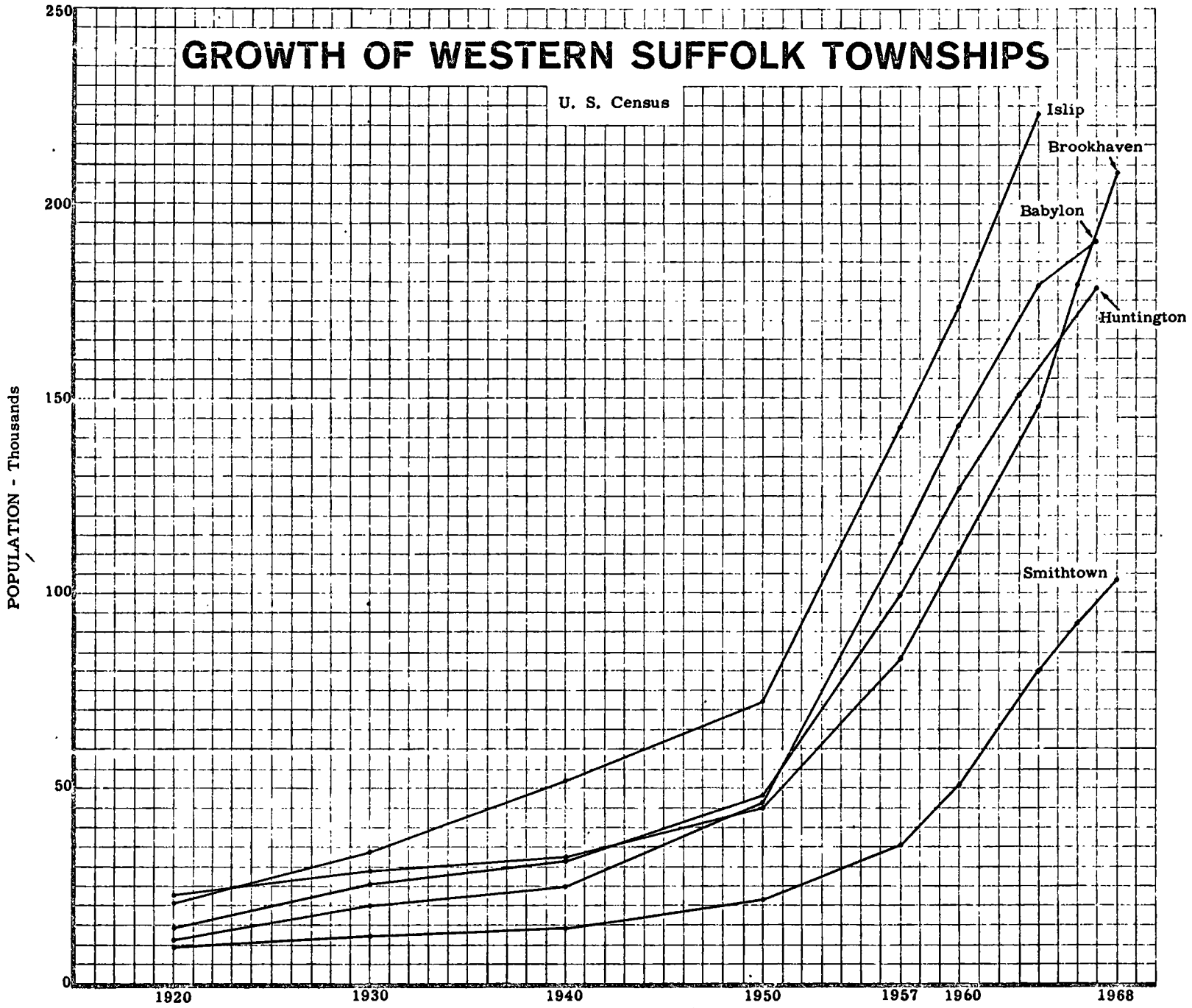
	Population		
GLEN COVE AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
City of Glen Cove (Inc.)	23,817	25,643	25,899
Sea Cliff (Inc.)	5,669	5,962	5,955
Lattingtown (Inc.)	1,461	1,707	1,745
Matinecock (Inc.)	824	894	905
Locust Valley	3,321	3,745	3,788
Glenwood Landing			
In Oyster Bay	3,693	3,829	3,853
In North Hempstead	214	211	205
Glen Head	4,235	4,618	4,783
Total Area	43,234	46,609	47,133
OYSTER BAY AREA			
Bayville (Inc.)	3,962	5,297	5,494
Mill Neck (Inc.)	701	1,063	1,089
Centre Island (Inc.)	270	313	318
Cove Neck (Inc.)	299	321	336
Oyster Bay Cove (Inc.)	988	1,283	1,345
Laurel Hollow (Inc.)	834	1,369	1,436
Bayville (Uninc.)	208	402	400
Oyster Bay	6,064	6,603	6,615
East Norwich	2,810	3,519	3,532
Total Area	16,136	20,170	20,565
BROOKVILLE AREA			
Brookville (Inc.)	1,468	2,744	2,876
Old Brookville (Inc.)	1,126	1,456	1,522
Upper Brookville (Inc.)	1,045	1,260	1,300
Muttontown (Inc.)	1,265	1,867	1,941
Total Area	4,904	7,327	7,639
SYOSSET - PLAINVIEW AREA			
Syosset	8,560	9,791	9,974
Woodbury - Cold Spring	1,904	3,878	4,049
Plainview	27,941	32,851	33,003
Total Area	38,405	46,520	47,026



TOWN OF OYSTER BAY-LOWER PORTION

	Population		
HICKSVILLE - JERICHO AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Hicksville	50,405	52,490	52,482
Jericho	10,795	14,545	14,536
Locust Grove	11,558	11,358	11,350
Total Area	72,758	78,393	78,368
FARMINGDALE - BETHPAGE AREA			
Farmingdale (Inc.)	6,128	7,840	7,826
Bethpage - Old Bethpage	21,113	26,690	26,768
Plainedge	21,973	22,965	23,095
South Farmingdale	16,318	19,182	19,257
Total Area	65,532	76,677	76,946
MASSAPEQUA AREA			
Massapequa Park (Inc.)	19,904	22,153	22,677
Massapequa	32,900	39,156	39,374
East Massapequa - West Amityville	19,608	22,391	22,461
Total Area	72,412	83,700	84,512
* TOTAL TOWN OF OYSTER BAY	313,872	360,098	362,888
NASSAU COUNTY TOTAL	1,300,171	1,433,246	1,445,609

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.


GROWTH OF WESTERN SUFFOLK TOWNSHIPS
U. S. Census
POPULATION - Thousands
250
200
150
100
50
0
1920
1930
1940
1950
1957
1960
1968
Islip
Brookhaven
Babylon
Huntington
Smithtown

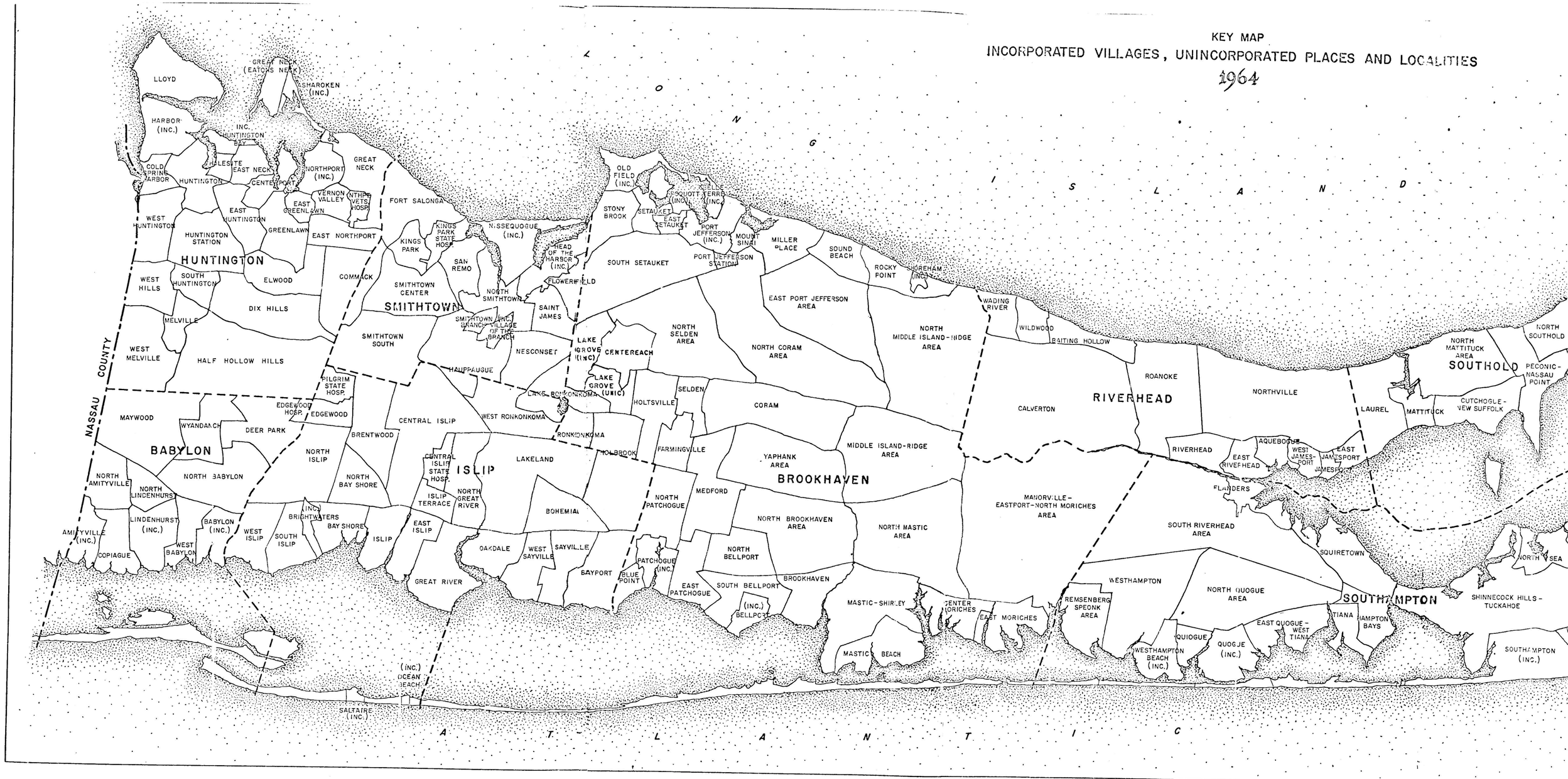
SUFFOLK COUNTY

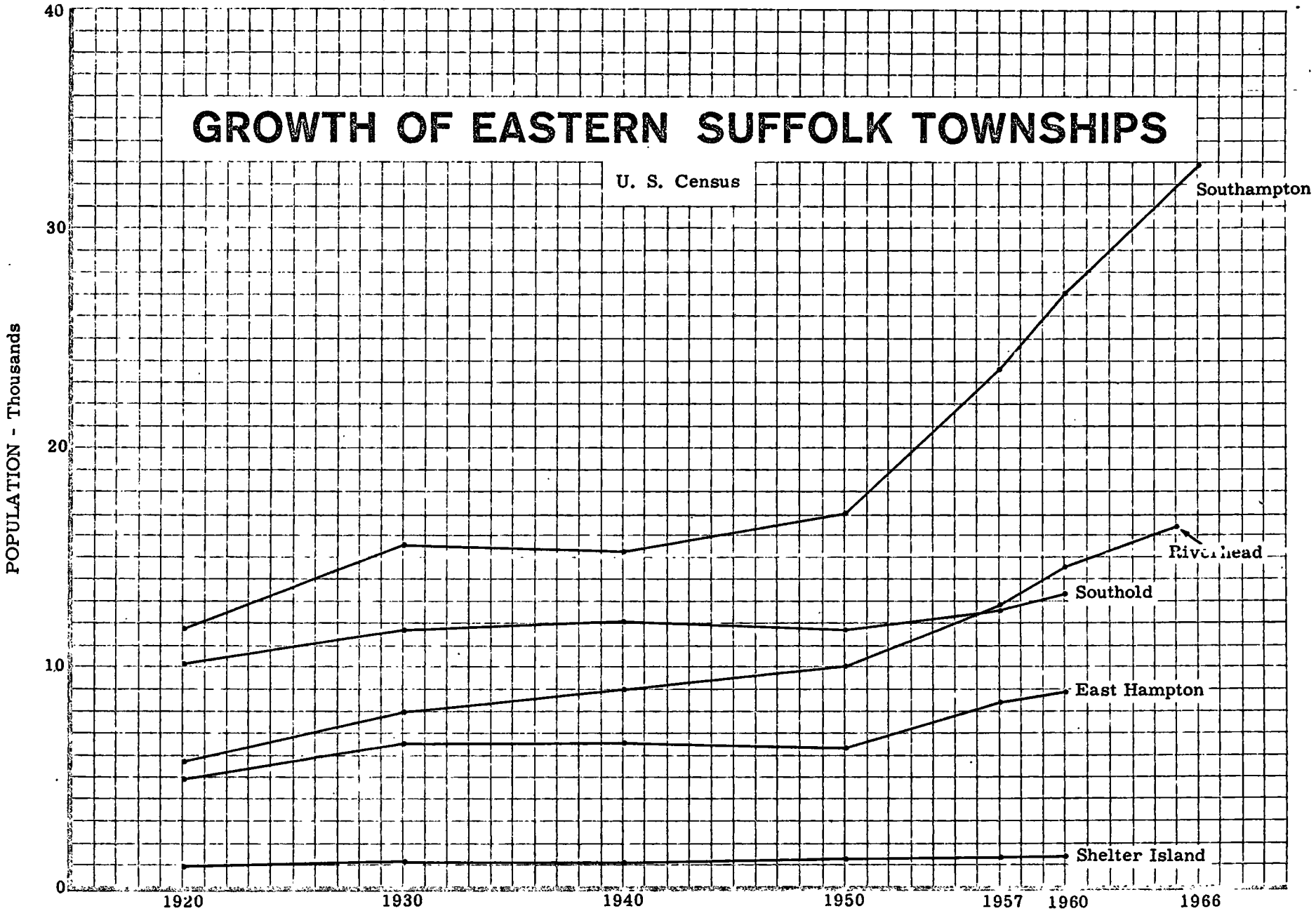
Detail of the Population
Of the Villages and Communities
Of Suffolk County

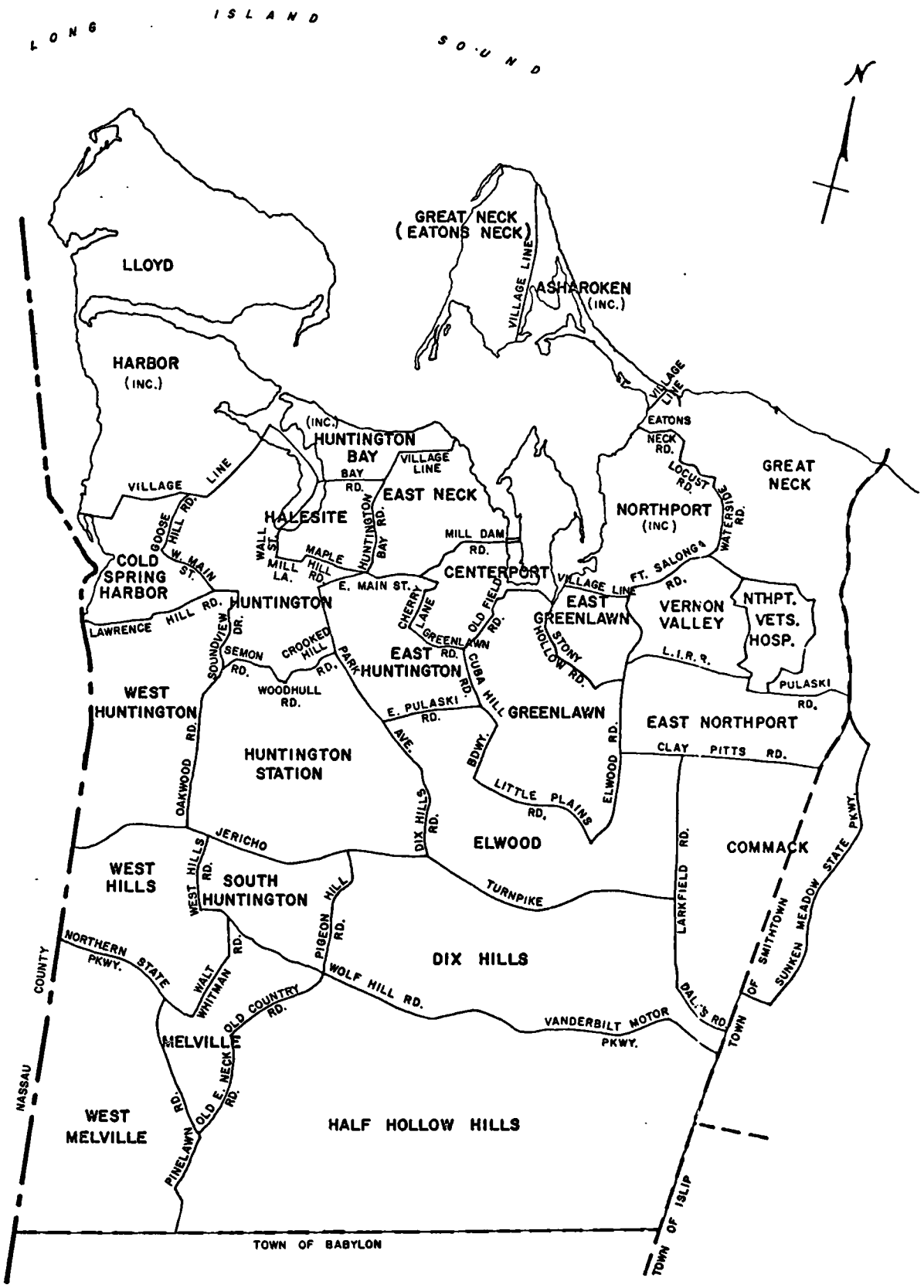
KEY MAP

INCORPORATED VILLAGES, UNINCORPORATED PLACES AND LOCALITIES

1964




GROWTH OF EASTERN SUFFOLK TOWNSHIPS
U. S. Census
POPULATION - Thousands
40
30
20
10
0
1920
1930
1940
1950
1957
1960
1966
Southampton
Riverhead
Southold
East Hampton
Shelter Island



HUNTINGTON SECTOR

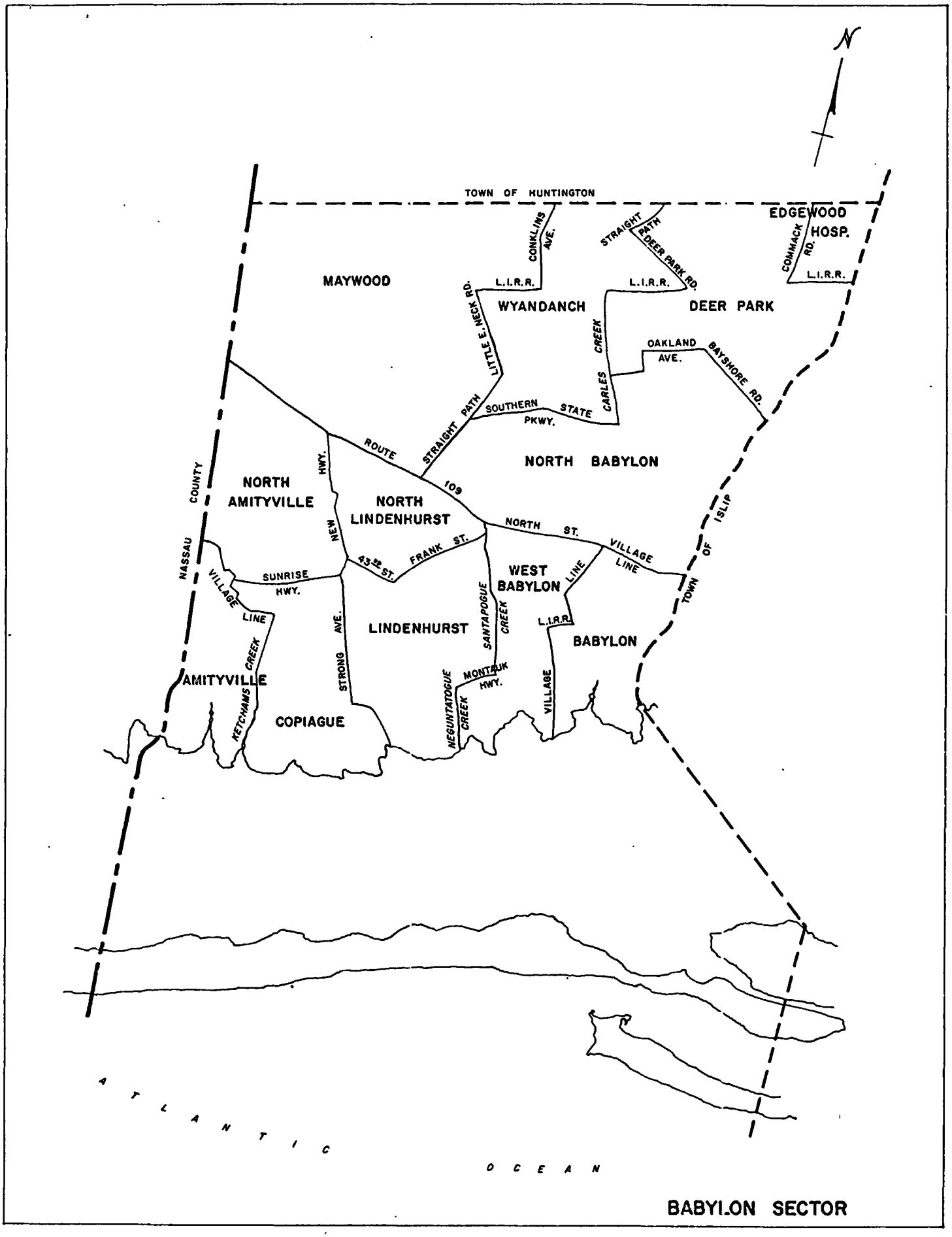
POPULATION DENSITY
1940 AND 1960

CIVIL DIVISION	AREA (SQMI)	POPULATION 1940	POPULATION 1960	DENSITY 1940	DENSITY 1960	PERCENT CHANGE
NEW YORK CITY	319.80	7454995	7781984	23310.74	24333.19	4.38
KINGS COUNTY	78.50	2698285	2627319	34368.95	33465.03	2.63-
QUEENS COUNTY	114.70	1297634	1809578	11313.28	15776.61	39.45
NASSAU COUNTY	313.98	406748	1300171	1295.44	4140.89	219.65
HEMPSTEAD TOWN	142.60	259318	740738	1818.49	5194.51	185.64
NORTH HEMPSTEAD	53.78	83385	219088	1550.35	4073.45	162.74
OYSTER BAY TOWN	117.59	42594	290055	362.19	2466.48	580.97
SUFFOLK COUNTY	1057.59	197355	1059322	186.60	1001.63	436.75
BABYLON TOWN	70.90	24297	142309	342.66	2007.00	485.70
BROOKHAVEN TOWN	325.57	32117	109900	98.64	337.55	242.18
EAST HAMPTON TOWN	72.75	6529	8827	89.74	121.33	35.19
HUNTINGTON TOWN	93.92	31768	126221	338.23	1343.89	297.32
ISLIP TOWN	135.76	51182	172959	376.98	1273.95	237.92
RIVERHEAD TOWN	68.10	8922	14519	130.99	213.17	62.73
SHELTER ISLAND	11.48	1073	1312	93.43	114.24	22.27
SMITHTOWN TOWN	53.87	13970	50347	259.30	934.51	260.39
SOUTHAMPTON TOWN	171.14	15451	27095	90.28	158.32	75.36
SOUTHOLD TOWN	54.06	12046	13295	222.81	245.91	10.36

TOWN OF HUNTINGTON

	Population		
HUNTINGTON AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Lloyd Harbor (Inc.)	2,521	3,157	3,233
Huntington Bay (Inc.)	1,267	1,705	1,725
Cold Spring Harbor	1,705	1,987	2,008
Halesite	2,857	3,062	3,105
East Neck	3,789	4,571	4,701
Huntington	11,255	11,736	11,840
Huntington Station	23,438	28,069	28,632
East Huntington	2,206	2,840	2,955
South Huntington	7,084	8,849	8,879
West Huntington	4,722	6,216	6,523
West Hills	2,322	2,807	2,848
Total Area	63,166	74,999	76,449
NORTHPORT - COMMACK AREA			
Northport (Inc.)	5,972	6,891	7,053
Asharoken (Inc.)	253	557	557
Great Neck-Eatons-Veterans Hosp.	5,598	7,410	7,738
Centerport	3,628	4,915	5,037
Greenlawn	5,422	7,538	7,876
East Greenlawn	912	1,092	1,108
Vernon Valley	5,998	7,665	7,794
East Northport	8,381	11,853	12,260
Elwood	7,080	14,163	14,431
Commack			
In Huntington	6,247	15,102	16,327
In Smithtown	3,366	7,190	7,237
Total Area	52,857	84,376	87,418
MELVILLE - DIX HILLS AREA			
Melville	5,400	7,229	7,304
West Melville	539	1,132	1,107
Dix Hills	4,464	7,905	8,399
Half Hollow Hills	3,161	13,576	16,433
Total Area	13,564	29,842	33,243
* TOTAL TOWN OF HUNTINGTON	126,221	182,027	189,873

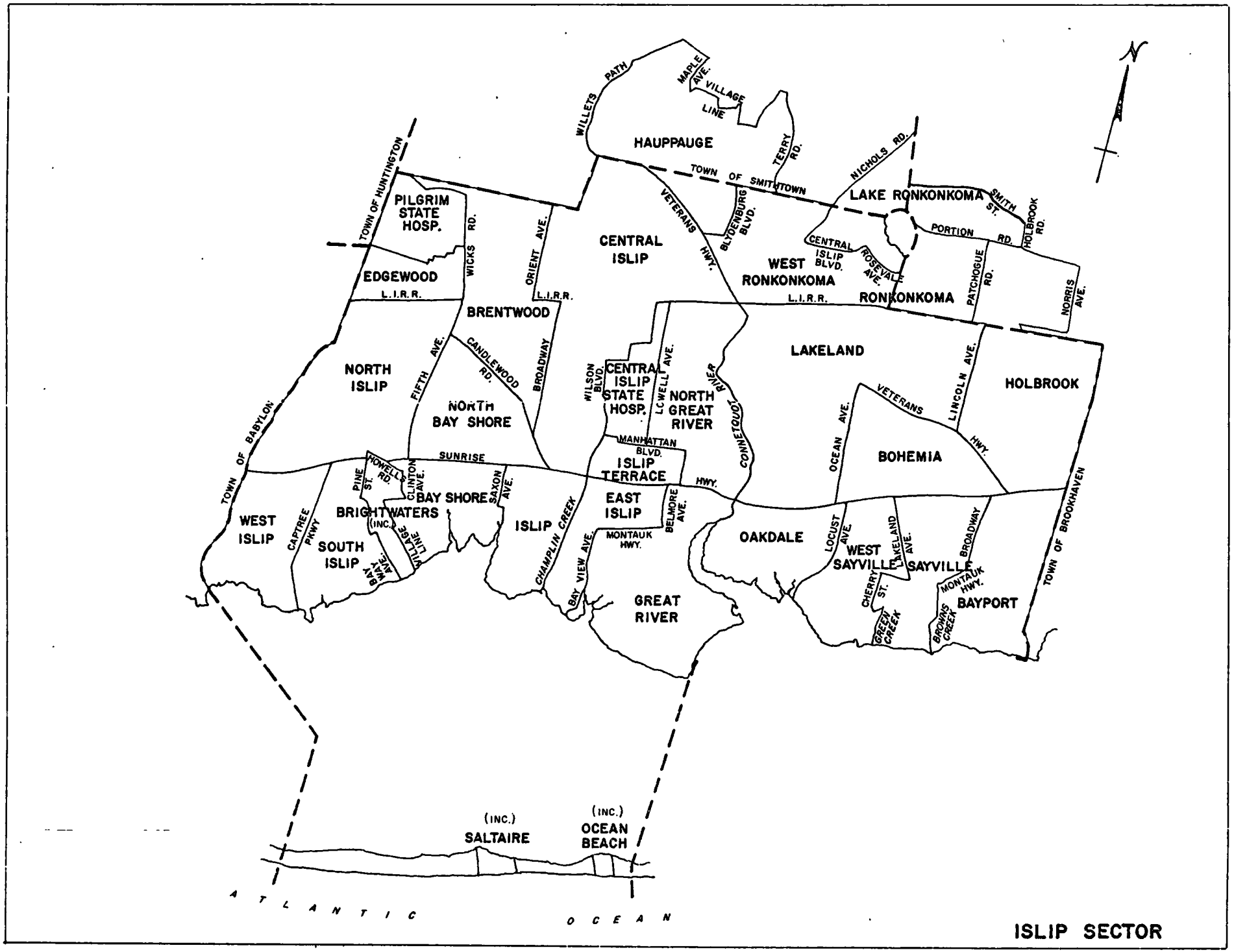
* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.



BABYLON SECTOR

TOWN OF BABYLON

	Population		
AMITYVILLE - LINDENHURST AREA	Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Amityville (Inc.)	8,318	8,707	8,798
Lindenhurst (Inc.)	20,905	26,112	26,432
North Amityville	8,369	11,079	11,795
Copiague	14,081	18,567	18,821
North Lindenhurst	9,111	10,873	11,272
Total Area	60,784	75,338	77,118
BABYLON AREA			
Babylon (Inc.)	11,062	12,865	13,033
West Babylon	8,051	11,773	12,322
North Babylon	30,445	40,988	41,551
Oak Beach & Gilgo	175	185	186
Total Area	49,733	65,811	67,092
MAYWOOD - DEER PARK AREA			
Deer Park (Incl. Edgewood Hosp.)	16,726	27,419	28,216
Wyandanch	6,930	13,329	13,556
Maywood (East Farmingdale & Pinelawn)	8,136	10,259	10,480
Total Area	31,792	51,007	52,252
TOTAL TOWN OF BABYLON	142,309	192,156	196,462

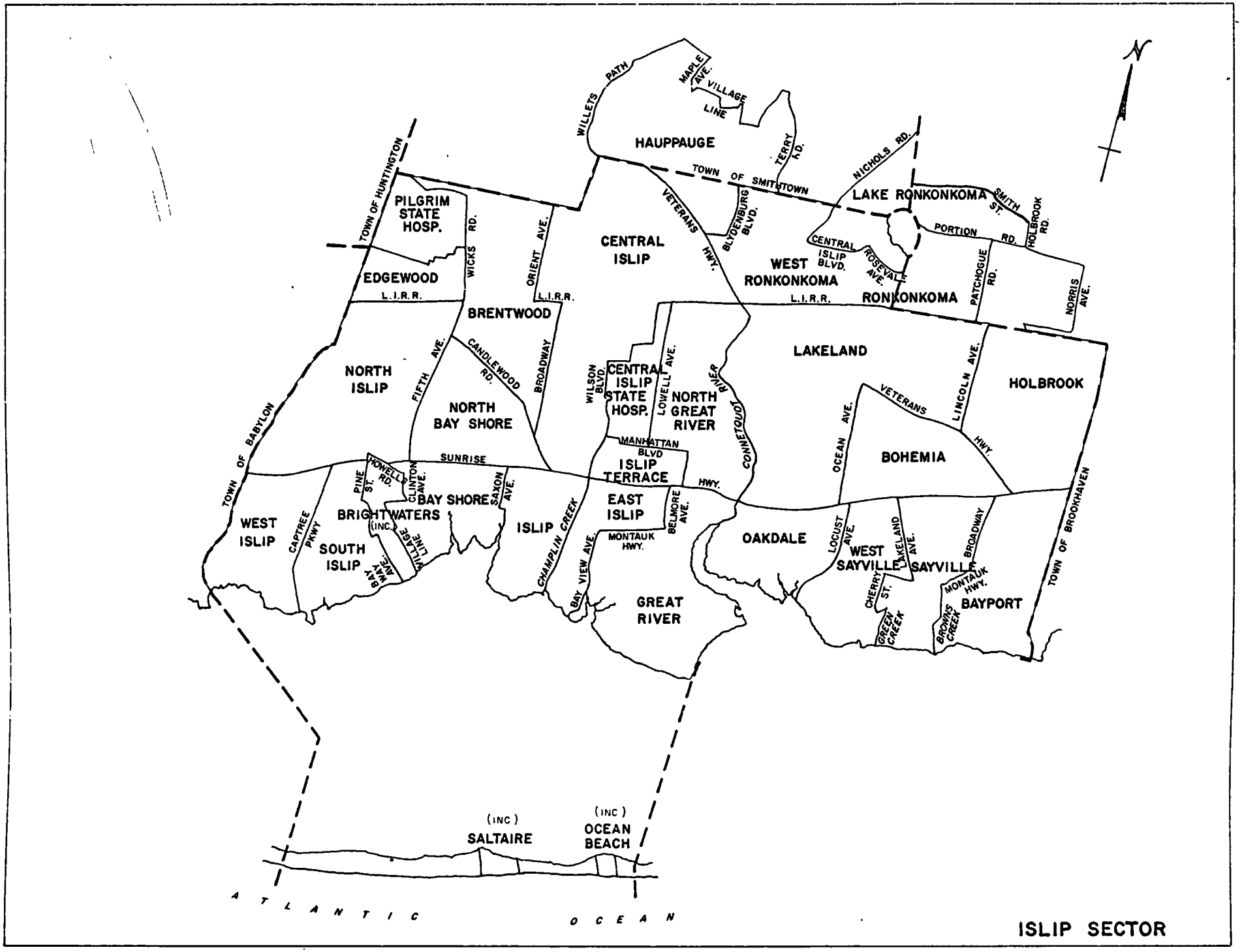


ISLIP SECTOR

TOWN OF ISLIP

BAY SHORE AREA	Population: Census 1960	Population: Estimate Jan. 1, 1968	Population: Estimate Jan. 1, 1969
Brightwaters (Inc.)	3,193	3,606	3,651
Bay Shore	9,802	11,255	11,173
South Islip	6,589	8,417	8,750
West Islip	13,924	16,883	17,222
North Islip	18,819	28,022	28,400
North Bay Shore	7,160	13,503	13,942
Brentwood	15,387	26,940	27,303
Edgewood (Incl. Pilgrim State Hosp.)	14,851	15,120	15,293
Total Area	89,725	123,746	125,734

ISLIP AREA			
Ocean Beach (Inc.)	111	109	107
Saltaire (Inc.)	28	67	71
Islip	6,362	8,526	8,858
East Islip	4,946	6,636	6,860
Islip Terrace	2,532	6,241	6,346
Central Islip (Incl. C.I. State Hosp.)	27,068	44,131	45,767
Great River	6,554	8,538	8,707
North Great River	6,280	9,142	9,299
Total Area	53,881	83,390	86,015



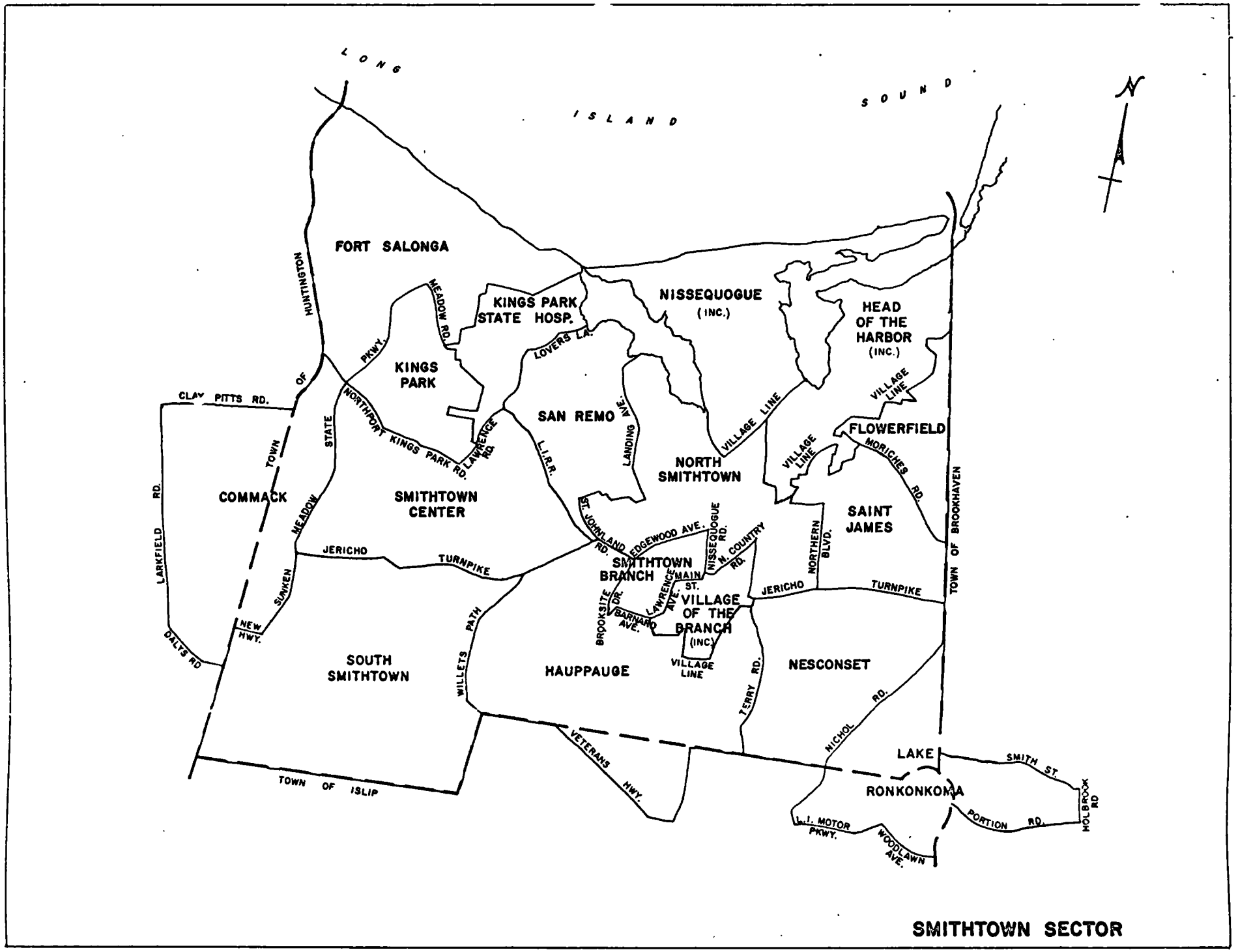
ISLIP SECTOR

SAYVILLE AREA	Population: Census 1960	Population: Estimate Jan. 1, 1968	Population: Estimate Jan. 1, 1969
Oakdale	2,774	5,338	6,015
West Sayville	5,849	8,012	8,209
Sayville	6,485	10,212	10,707
Bayport	5,009	7,463	7,847
Bohemia	2,375	4,639	5,266
Lakeland	1,397	3,354	3,859
West Ronkonkoma	2,371	5,950	6,303
Holbrook			
In Islip	1,273	3,028	4,071
In Brookhaven	2,389	5,744	6,163
Lake Ronkonkoma			
In Islip	1,577	2,278	2,389
In Smithtown	1,106	(a) 2,175	2,275
(b) In Brookhaven	2,158	3,280	1,538
Total Area	34,763	(a) 61,473	64,642
* TOTAL TOWN OF ISLIP	172,959	258,358	267,400

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.

(a) Revised to reflect the special census of 1968.

(b) Boundary change due to incorporation of Lake Grove.



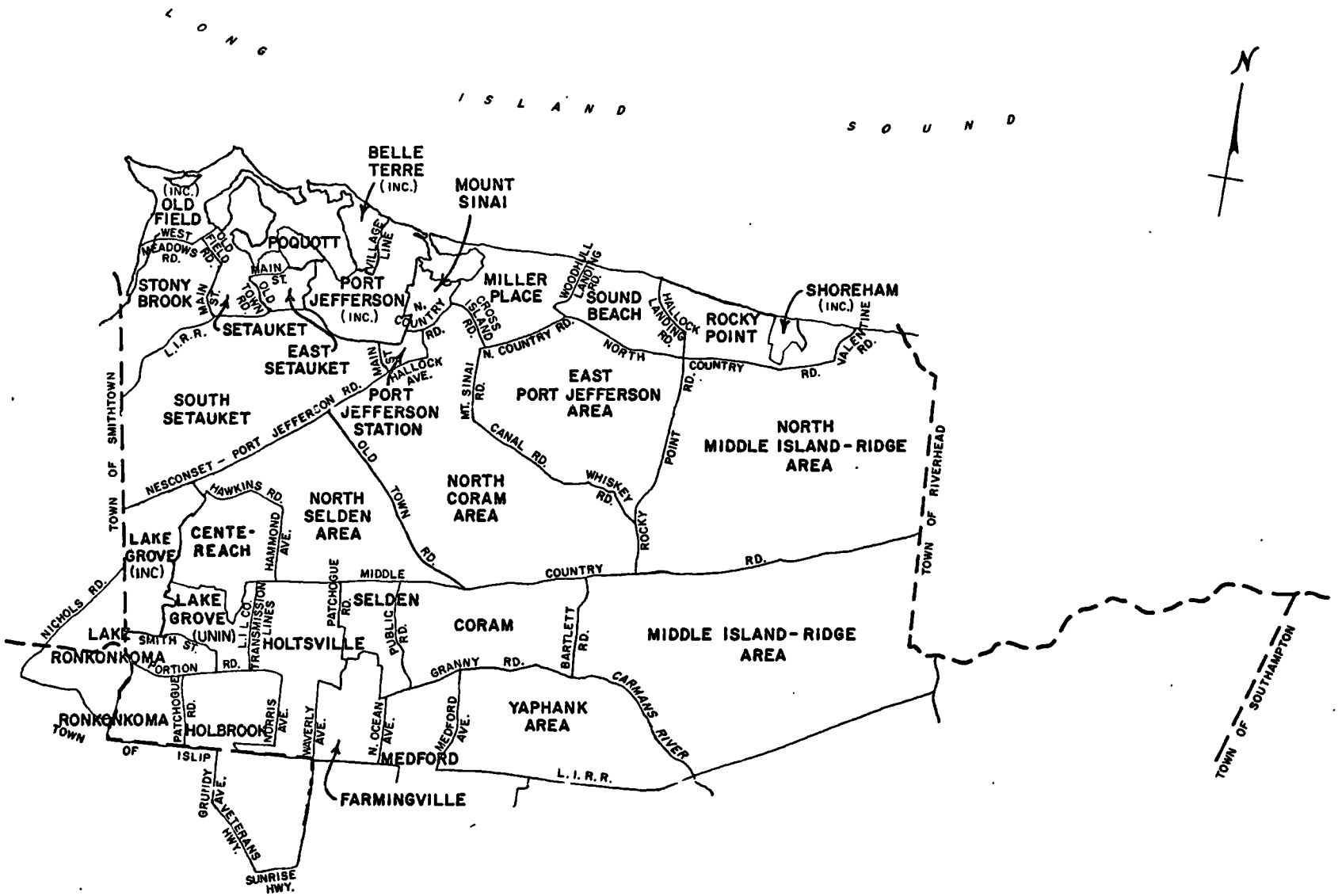
SMITHTOWN SECTOR

TOWN OF SMITHTOWN

SMITHTOWN AREA	Population: Census 1960	Population: Estimate (a) Jan. 1, 1968	Population: Estimate Jan. 1, 1969
Head of Harbor (Inc.)	524	856	875
Village of the Branch (Inc.)	886	1,653	1,658
Nissequogue (Inc.)	332	785	865
Kings Park (Incl. State Hosp.)	13,785	13,373	14,022
Fort Salonga	1,820	3,557	3,931
San Remo	3,160	9,796	10,886
Smithtown Center	4,075	11,432	12,262
Smithtown South	4,981	17,495	18,489
Smithtown Branch	1,986	2,200	2,245
North Smithtown	2,561	5,552	6,065
Flowerfield	1,064	1,276	1,321
Saint James	3,524	5,453	5,609
Nesconset	1,964	4,414	5,171
Hauppauge			
In Smithtown	5,213	12,042	12,859
In Islip	243	948	985
Total Area	46,118	90,832	97,243
* TOTAL TOWN OF SMITHTOWN	50,347	99,249	105,770

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.

(a) Revised to reflect the special census of 1968.



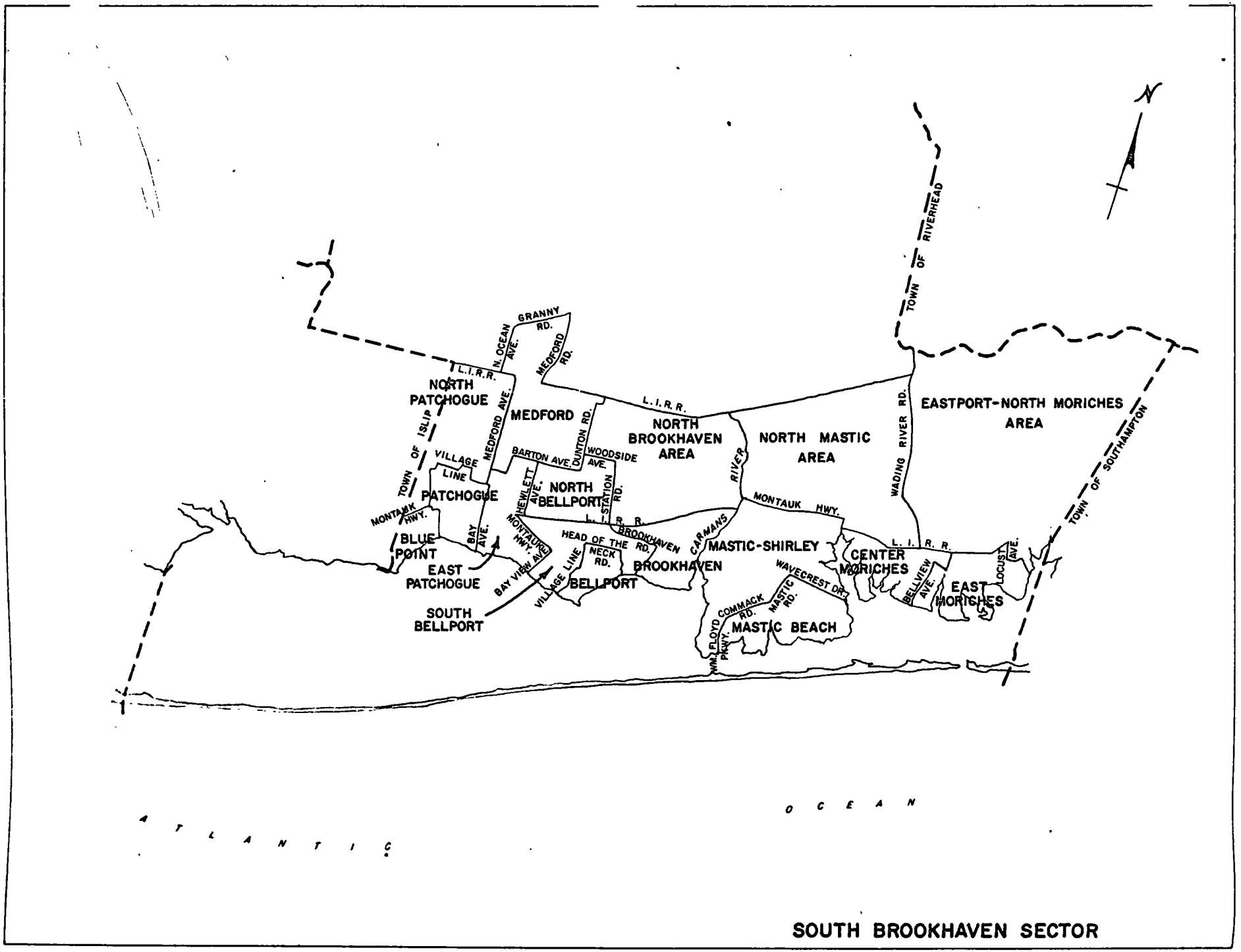
NORTH BROOKHAVEN SECTOR

TOWN OF BROOKHAVEN

NORTHERN BROOKHAVEN AREA	Population: Census 1960	Population: Estimate (b) Jan. 1, 1968	Population: Estimate Jan. 1, 1969
Lake Grove (Inc.)	(a)	(a)	6,741
Old Field (Inc.)	373	688	709
Poquott (Inc.)	295	441	453
Belle Terre (Inc.)	295	496	540
Shoreham (Inc.)	164	410	449
Stony Brook	3,548	5,540	5,680
Setauket	1,207	1,607	1,674
East Setauket	1,127	1,160	1,167
South Setauket	2,004	19,851	23,331
Port Jefferson (Inc.)	2,336	4,932	5,272
Port Jefferson Station	1,041	1,087	1,087
East Port Jefferson	940	1,496	1,642
Mount Sinai	875	401	582
Miller Place	1,230	2,277	2,700
Lake Grove	2,302	6,437	(a) 3,106
Centereach	8,524	12,433	(a)11,466
Holtsville	2,843	5,542	6,046
Farmingville	2,134	3,826	3,877
Ronkonkoma	4,220	5,856	6,168
Selden	1,604	2,463	3,343
North Selden	2,749	15,740	18,105
North Coram	4,068	9,576	10,874
Sound Beach	1,625	2,959	3,743
Rocky Point	2,234	3,175	3,558
North Middle Island - Ridge Area	1,509	2,225	2,509
Middle Island - Ridge	1,151	2,135	2,175
Yaphank	2,385	6,728	6,931
Coram	1,775	2,390	2,591
Total Area	54,558	121,871	136,519

(a) Boundary changes resulting from incorporation of Lake Grove in 1968.

(b) Revised to reflect the special census of 1968.

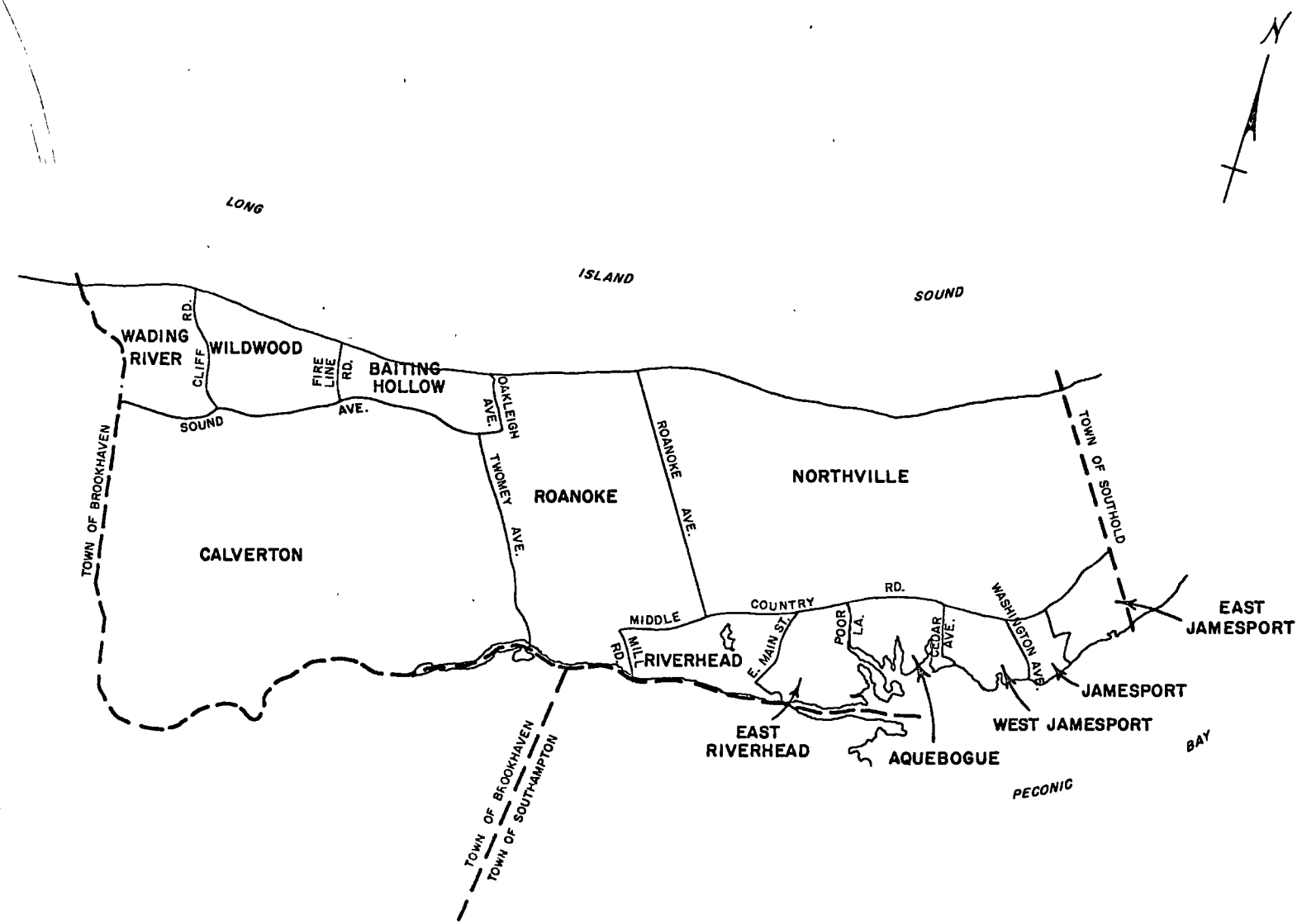


SOUTH BROOKHAVEN SECTOR

SOUTHERN BROOKHAVEN AREA	Population Census 1960	Estimate (a) Jan. 1, 1968	Estimate Jan. 1, 1969
Patchogue (Inc.)	8,838	10,005	10,410
Bellport (Inc.)	2,461	2,784	2,830
Blue Point	2,358	2,836	2,876
North Patchogue	4,847	6,402	6,610
East Patchogue	6,108	7,370	7,459
Medford	2,271	5,483	5,701
South Bellport	2,548	3,548	3,675
North Bellport	3,769	5,313	5,593
Brookhaven	713	1,327	1,359
North Brookhaven	1,314	1,653	1,698
Mastic Beach	3,114	4,331	4,454
Mastic-Shirley	3,397	5,767	5,884
North Mastic	3,591	4,858	4,993
Center Moriches	2,521	3,379	3,382
East Moriches	1,210	1,574	1,634
Eastport - North Moriches	1,735	2,114	2,150
Total Area	50,795	68,744	70,708
* TOTAL TOWN OF BROOKHAVEN	109,900	199,639	214,928

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.

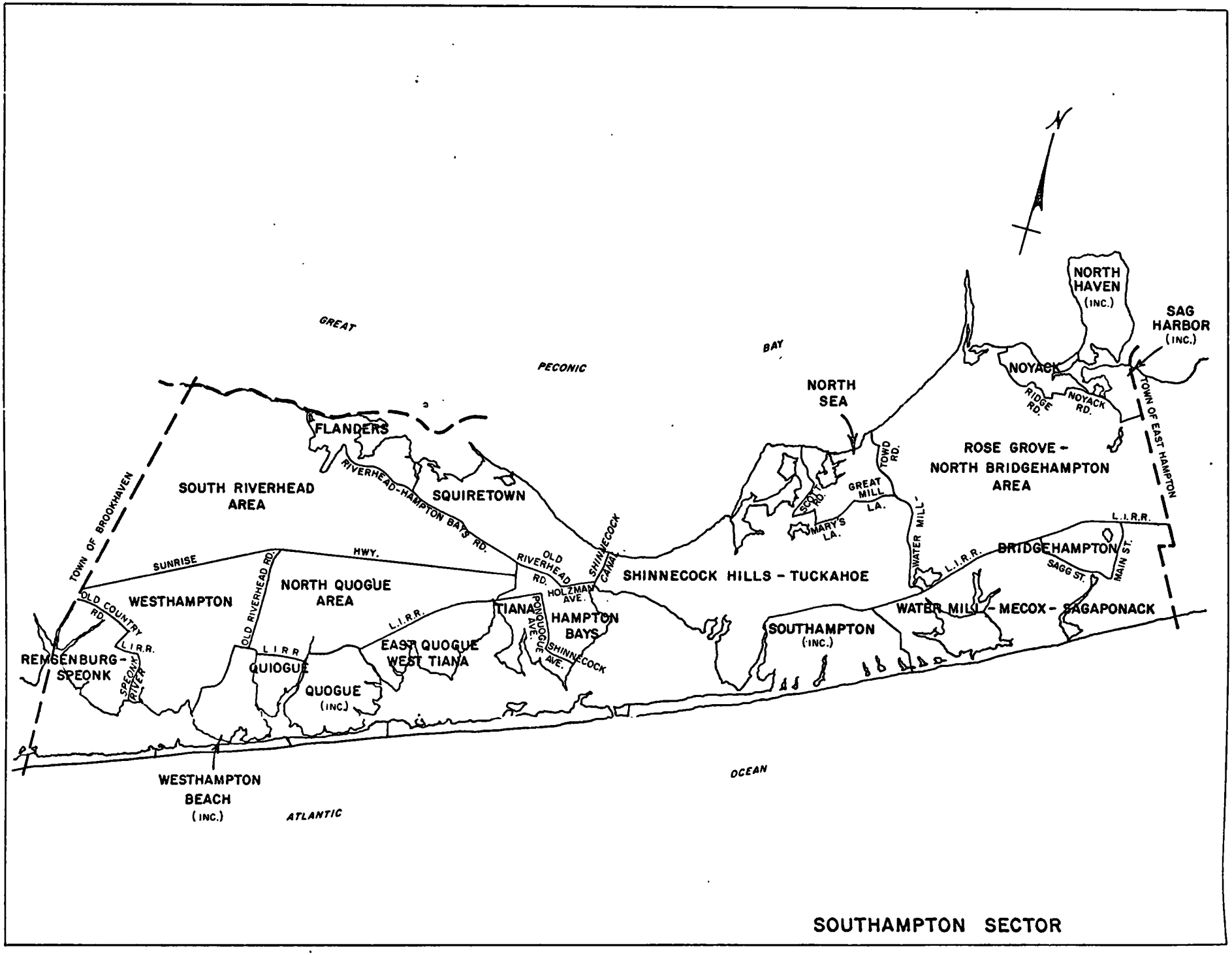
(a) Revised to reflect the special census of 1968.



RIVERHEAD SECTOR

TOWN OF RIVERHEAD

COMMUNITIES	Population Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Riverhead	5,830	6,383	6,376
Aquebogue	569	632	641
Jamesport	468	493	525
Wildwood	471	656	690
Baiting Hollow	140	153	158
Calverton	965	1,441	1,587
Roanoke	1,413	2,270	2,474
Northville	2,022	2,338	2,390
East Riverhead	1,443	1,962	2,062
West Jamesport	348	325	340
East Jamesport	205	241	248
Wading River	645	877	945
Total	14,519	17,771	18,436
TOTAL TOWN OF RIVERHEAD	14,519	17,771	18,436

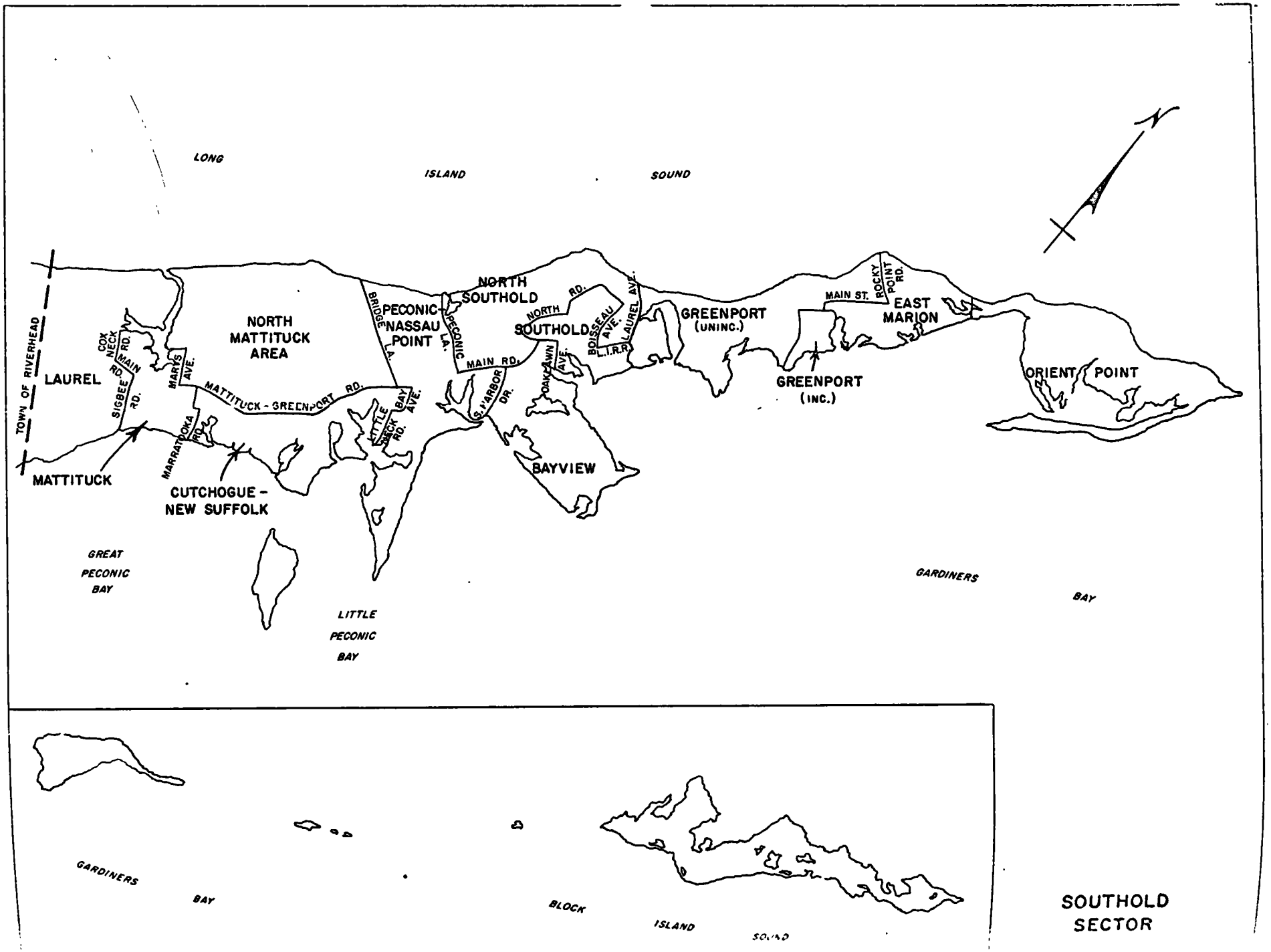


SOUTHAMPTON SECTOR

TOWN OF SOUTHAMPTON

VILLAGES & COMMUNITIES	Population Census 1960	Estimate Jan. 1, 1968	Estimate Jan. 1, 1969
Westhampton Beach (Inc.)	1,460	1,835	1,914
Quogue (Inc.)	692	796	815
Southampton (Inc.)	4,582	4,863	5,015
North Haven (Inc.)	450	622	628
Sag Harbor (Inc.)			
In Southampton	1,472	1,532	1,576
In East Hampton	874	1,148	1,167
South Riverhead	1,572	1,759	1,804
North Quogue	1,612	1,773	1,805
Westhampton	1,102	1,298	1,345
Quiogue	413	476	473
Squiretown	996	1,490	1,555
Shinnecock Hills - Tuckahoe	2,486	2,897	3,044
Watermill - Mecox - Sagaponack	1,022	1,309	1,342
Rose Grove - No. Bridgehampton	1,400	1,941	2,047
Remsenburg - Speonk	1,505	1,907	1,939
Tiana	865	1,187	1,217
West Tiana - East Quogue	1,285	2,856	2,955
Hampton Bays	1,431	1,993	2,042
Flanders	1,248	2,075	2,080
North Sea	389	583	593
Noyack	251	315	331
Bridgehampton	862	935	949
Total Area	27,969	35,590	36,636
* TOTAL TOWN OF SOUTHAMPTON	27,095	34,442	35,469

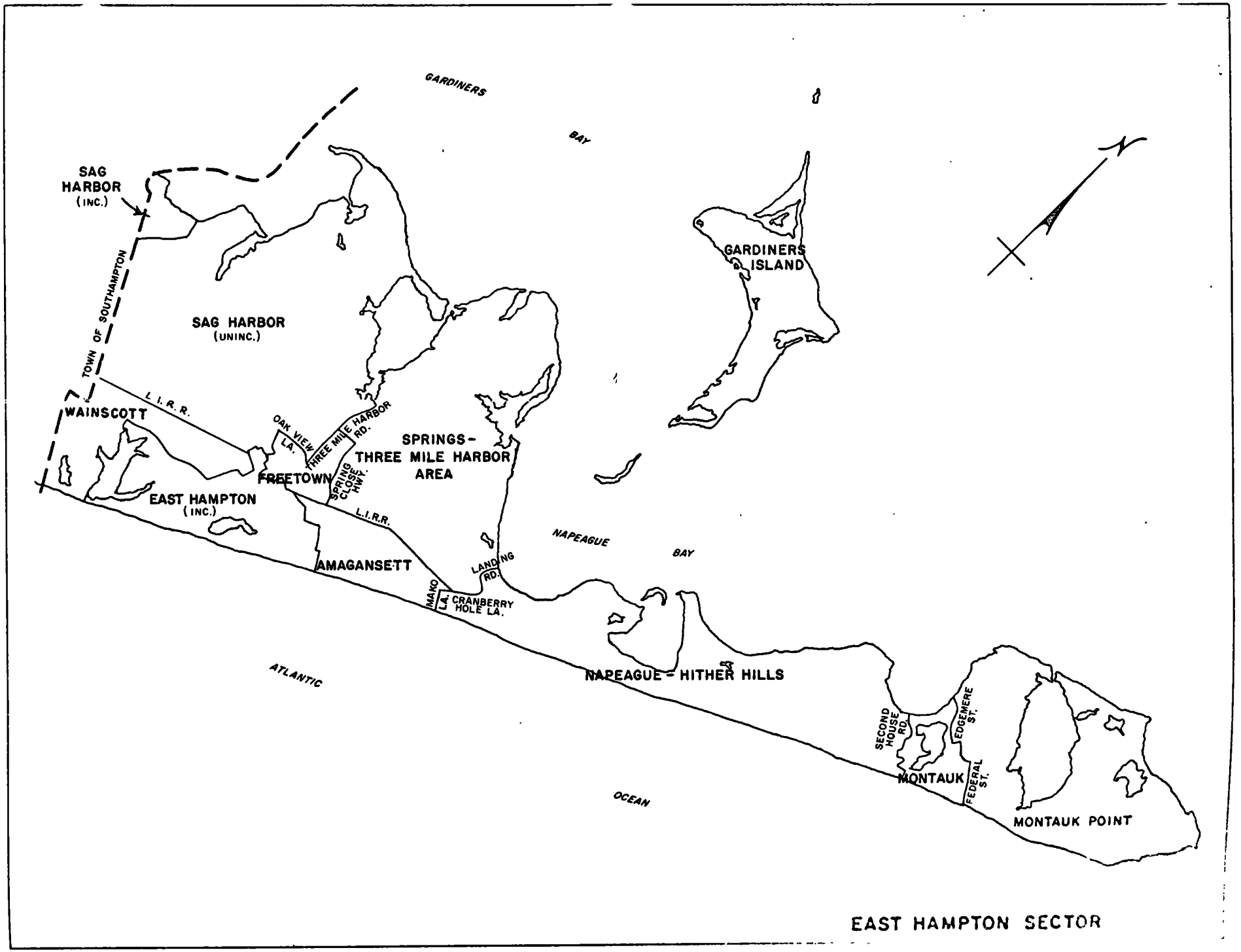
* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.



SOUTHOLD SECTOR

TOWN OF SOUTHOLD

VILLAGES & COMMUNITIES	Population Census 1960	Population Estimate Jan. 1, 1968	Population Estimate Jan. 1, 1969
Greenport (Inc.)	2,608	2,928	2,986
Southold	982	1,263	1,278
Mattituck	1,274	1,581	1,586
Fishers Island	508	530	530
Laurel	999	1,193	1,237
North Mattituck	662	829	845
Cutchogue - New Suffolk	1,085	1,467	1,523
Peconic - Nassau Point	976	1,247	1,283
North Southold	874	1,127	1,141
Bayview	1,105	1,544	1,631
Greenport (Uninc.)	980	1,179	1,216
East Marion	637	735	757
Orient Point	605	692	701
Total	13,295	16,315	16,714
TOTAL TOWN OF SOUTHOLD	13,295	16,315	16,714



EAST HAMPTON SECTOR

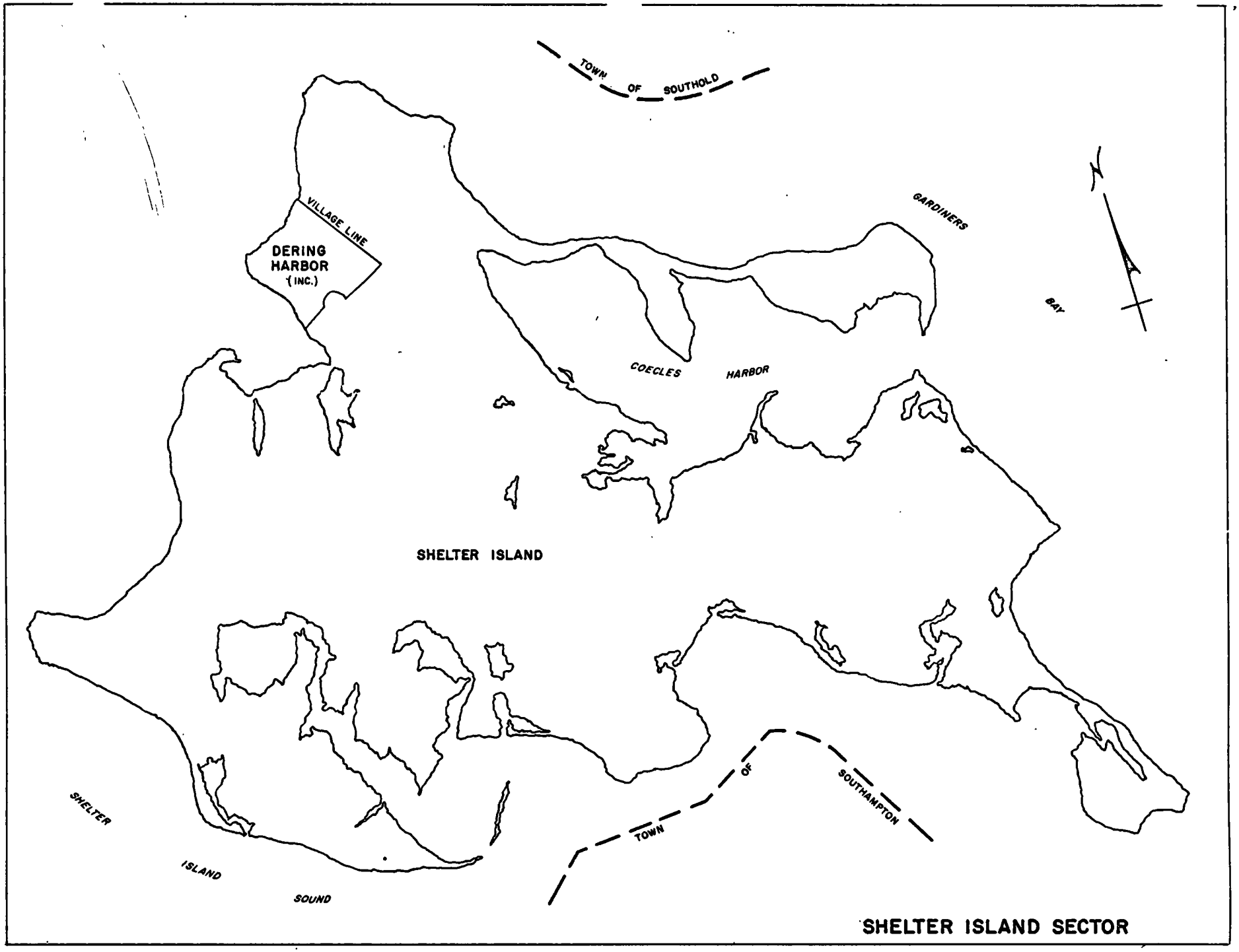
TOWN OF EAST HAMPTON

VILLAGES & COMMUNITIES	Population Census 1960	Population Estimate Jan. 1, 1968	Population Estimate Jan. 1, 1969
East Hampton (Inc.)	1,772	2,156	2,204
Amagansett	1,095	1,525	1,600
Freetown	1,365	1,643	1,659
Montauk	483	554	584
Sag Harbor (Uninc.)	418	924	1,034
Wainscott	517	653	672
Springs-Three Mile Harbor	1,320	2,026	2,172
Napeague - Hither Hills	269	507	552
Montauk Point	714	873	924
Total Area	7,953	10,861	11,401
* TOTAL TOWN OF EAST HAMPTON	8,827	12,009	12,568

TOWN OF SHELTER ISLAND

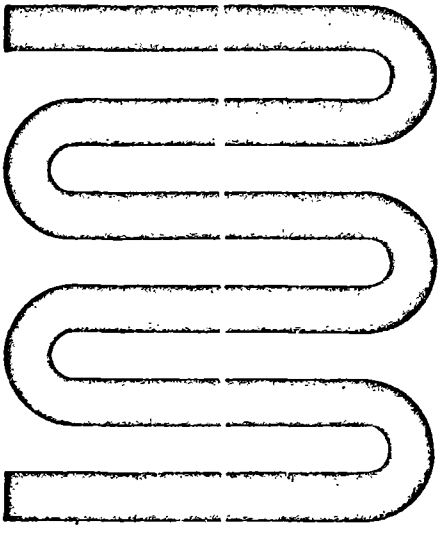
TOTAL TOWN OF SHELTER ISLAND	1,312	1,610	1,702
SUFFOLK COUNTY TOTAL	666,784	1,013,576	1,059,322

* Villages and Communities overlapping Town Boundaries are listed in the Town containing the major portion. The summation of Area Totals will not agree with Town Totals which exclude these overlaps.



SHELTER ISLAND SECTOR

In the year 2000 . . . .



this will still be the symbol for the most modern heating fuel

Electric heat is as modern as tomorrow, yet it is here today. More and more Long Island homes, apartments, industrial plants, offices, supermarkets, theatres, hospitals, schools and retail stores are kept warm in the winter and cool in the summer by electricity. Electric heating is adaptable to any architectural style or building design, and it is space-saving. It is clean, dependable and trouble free. And with LILCO's new electric heating rates it is lower priced than ever. Want more information? Call LILCO at 516 PI 7-1047.

LILCO
LONG ISLAND LIGHTING
AN INVESTOR-OWNED, TAXPAYING COMPANY

HYDROLOGY (L.I.)

Cohen and others—HYDROLOGIC EFFECTS OF 1962–66 DROUGHT ON LONG ISLAND, N.Y.—Geological Survey Water-Supply Paper 1879–F

Hydrologic Effects of the 1962–66 Drought on Long Island, New York

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1879–F

Prepared in cooperation with the New York State Department of Conservation, Division of Water Resources; the Nassau County Department of Public Works; the Suffolk County Board of Supervisors; and the Suffolk County Water Authority

Hydrologic Effects of the 1962–66 Drought on Long Island, New York

By PHILIP COHEN, O. L. FRANKE, *and* N. E. McCLYMONDS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1879-F

Prepared in cooperation with the New York State Department of Conservation, Division of Water Resources; the Nassau County Department of Public Works; the Suffolk County Board of Supervisors; and the Suffolk County Water Authority

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 20 cents (paper cover)

Franke, O. L., 1968, Double-mass-curve analysis of the effects of sewering on ground-water levels on Long Island, New York *in* Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600–B, p. B205–B209.

Mitchell, J. M., 1968, Some remarks on the statistical predictability of drought and related climatic anomalies *in* Proceedings of the Conference on the Drought in the Northeastern United States: New York Univ. School Eng. and Sci., Geophysical Research Lab. TR–68–3, p. 129–159.

Parker, G. G., Cohen, Philip, and Foxworthy, B. F., 1967, The role of artificial recharge in the scientific management of water resources: Am. Water Resources Assoc. Proc. National Symposium on Ground-Water Hydrology, San Francisco, Calif., p. 193–213.

Thomas, H. E., 1962, The meteorologic phenomenon of drought in the Southwest: U.S. Geol. Survey Prof. Paper 372–A, 43 p., 1 pl.

Yevdjevich, V. M., 1968, Objective definitions of hydrologic droughts *in* Proceedings of the Conference on the Drought in the Northeastern United States: New York Univ. School Eng. and Sci., Geophysical Research Lab. TR–68–3, p. 182–201.

U. S. GOVERNMENT PRINTING OFFICE · 1969 O - 329-637

CONTENTS

	Page
Introduction	F1
Purpose and content of report	1
Meaning of "drought"	3
Acknowledgments	3
Deficient precipitation	4
Annual precipitation	4
Monthly precipitation	7
Declining ground-water levels	7
Annual water levels	7
Monthly water levels	10
Decreased streamflow	10
Annual streamflow	10
Monthly streamflow	10
Decreased water in storage	12
Conclusions	16
References cited	17

ILLUSTRATIONS

	Page
FIGURE 1. Map of Long Island and vicinity showing location of selected hydrologic-data-collection points	F2
2–9. Graphs showing—	
2. Long-term annual precipitation at Setauket	5
3. Cumulative departure from average annual precipitation at Setauket	5
4. Percentage of time that various values of annual precipitation were equaled or exceeded at Setauket for the period of record	6
5. Monthly precipitation, water years 1960–67, and long-term average monthly precipitation at Setauket	8
6. Average annual ground-water levels in 14 key observation wells	9
7. Average monthly ground-water levels in 14 key observation wells	11
8. Combined annual average streamflow of 19 principal streams	12
9. Combined monthly average streamflow of 19 principal streams	13
10. Net change of ground-water levels in the unconfined aquifer	15

a negligible effect on the total volume of fresh ground water in storage beneath the island and on the yield of the hundreds of large-capacity public-supply wells. A few small-capacity shallow wells became dry, and the capacity of a few others was reduced markedly; but the decreases in the total water supply related to these factors were negligible. Nevertheless, where such events did occur, there was an adverse economic impact.

Deficient precipitation and soil moisture adversely affected some of the farms and nurseries on Long Island during the drought. In some places, additional agricultural costs were incurred because of the need to increase the use of ground water for irrigation. In many places, however, the fact that ground water was readily available minimized the economic loss.

The ground-water reservoir of Long Island has long been recognized as a vital and major economic asset. The 1962–66 drought very dramatically confirmed this recognition. In the midst of the most severe drought of record, residents in Nassau and Suffolk Counties were still able to water their lawns at will because of the large amount of water available from the Long Island ground-water reservoir. In contrast, their less fortunate neighbors in Kings and Queens Counties faced, first, severe restrictions on lawn watering and, eventually, during the last 2 years of the drought, complete curtailment.

Finally, in terms of precipitation, the drought seemingly ended in the winter of 1967. However, streamflow and ground-water levels are still (Sept. 1968) near record lows. Under conditions of average precipitation and average recharge rates, it may take years for ground-water levels and streamflow conditions to return to normal. Of course, abnormally high amounts of precipitation or certain changes in the hydrologic regimen resulting from the activities of man (artificial recharge, for example, see Parker and others, 1967) would shorten the time required. Other changes in the hydrologic regimen, such as increased pumpage or changes that cause decreased recharge, could result in a situation in which ground-water levels and streamflow on Long Island might never return to their pre-1961 values.

REFERENCES CITED

Barksdale, H. C., O'Bryan, Deric, and Schneider, W. J., 1966, Effect of drought on water resources in the Northeast: U.S. Geol. Survey Hydrol. Inv. Atlas HA–243.

Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York State Water Resources Comm. Bull. 62, 117 p.

decrease in ground-water recharge. Because the ground-water system of Long Island is hydraulically connected to the surrounding ocean, ground-water levels can decline only slightly, if at all, in the unconfined aquifer near the shorelines, and any islandwide declines will increase with increasing distance from the shorelines.

The computed volume of aquifer material that was dewatered from 1961 to 1966 was about 0.7 cubic mile. Assuming that the specific yield of the dewatered aquifer material is 0.20, it follows that the net decrease of ground water in storage during the drought in Nassau and Suffolk Counties was about 0.14 cubic mile, or about 155 billion gallons. An estimated 60 trillion gallons of fresh ground water is stored beneath the mainland of Nassau and Suffolk Counties, excluding the forks (Cohen and others, 1968, p. 26), and an estimated 35 trillion gallons of fresh ground water is stored beneath the salty bays and ocean adjacent to Long Island. Therefore, it is apparent that the most severe drought of record on Long Island caused a decrease in the amount of fresh ground water in storage that was equal to only a small fraction of 1 percent of the total fresh ground water in storage beneath the island.

CONCLUSIONS

The cumulative departure from average precipitation at Setauket during the drought years of 1962–66 was nearly 42 inches (fig. 3). In other words, during the 5-year drought period, the deficiency in precipitation was nearly equal to the entire amount of precipitation normally expected in a given year. Expressed solely in terms of deficient precipitation, the drought was the most severe of record for Long Island.

Much of the water supply for the two westernmost counties on Long Island, Kings and Queens Counties, is derived from mainland surface-water sources, and that supply was seriously affected by the drought (Barksdale and others, 1966). Virtually none of the public-supply water used on Long Island is drawn directly from surface-water sources on the island. Accordingly, the marked decrease in streamflow and the decline in lake levels had practically no effect on Long Island's water supply. However, the decreased streamflow and the decline in lake levels did impair the aesthetic and recreational features of those bodies of surface water and, therefore, caused a moderate amount of economic loss, inconvenience, and displeasure.

The ground-water reservoir of Long Island is the sole source of fresh public-supply water for the roughly 2.5 million people in Nassau and Suffolk Counties. Despite the fact that ground-water levels declined markedly in these counties, the decline had

CONTRIBUTIONS TO THE HYDROLOGY
OF THE UNITED STATES

HYDROLOGIC EFFECTS OF THE 1962–66 DROUGHT ON LONG ISLAND, N.Y.

By PHILIP COHEN, O. L. FRANKE, and N. E. MCCLYMONDS

ABSTRACT

The hydrologic system of Long Island, N.Y., showed a marked response to deficient precipitation in the years 1962–66. By 1966, streamflow was the lowest of record in many Long Island streams, and ground-water levels had declined a maximum of about 10 feet in the central part of the island. Although the drought apparently ended in the early months of 1967 and ground-water levels and streamflow recovered somewhat since then, ground-water levels and streamflow were still considerably below long-term average values in September 1968.

INTRODUCTION

PURPOSE AND CONTENT OF REPORT

Hydrologic records of various kinds have been collected on and near Long Island, N.Y. (fig. 1), for more than a hundred years. Since the mid-1930's, when the U.S. Geological Survey began a continuing program of water-resources studies on Long Island in cooperation with several State and county agencies, the collection of hydrologic records on Long Island has been more intensive than in most places in the United States.

The truly vast amount of hydrologic data obtained on Long Island has afforded unusually good opportunities to document and evaluate hydrologic phenomena—both natural phenomena and phenomena associated with the activities of man. One natural hydrologic phenomenon, the recent (1962–66) northeast drought, was especially well documented on Long Island and is the subject of this report. The report considers, largely in a graphic format, the deficiency in precipitation during the period 1962–66 and the hydrologic consequences of that deficiency—namely, declines of ground-water levels and related decreases in streamflow and ground-water storage in Nassau and Suffolk Counties. Kings and

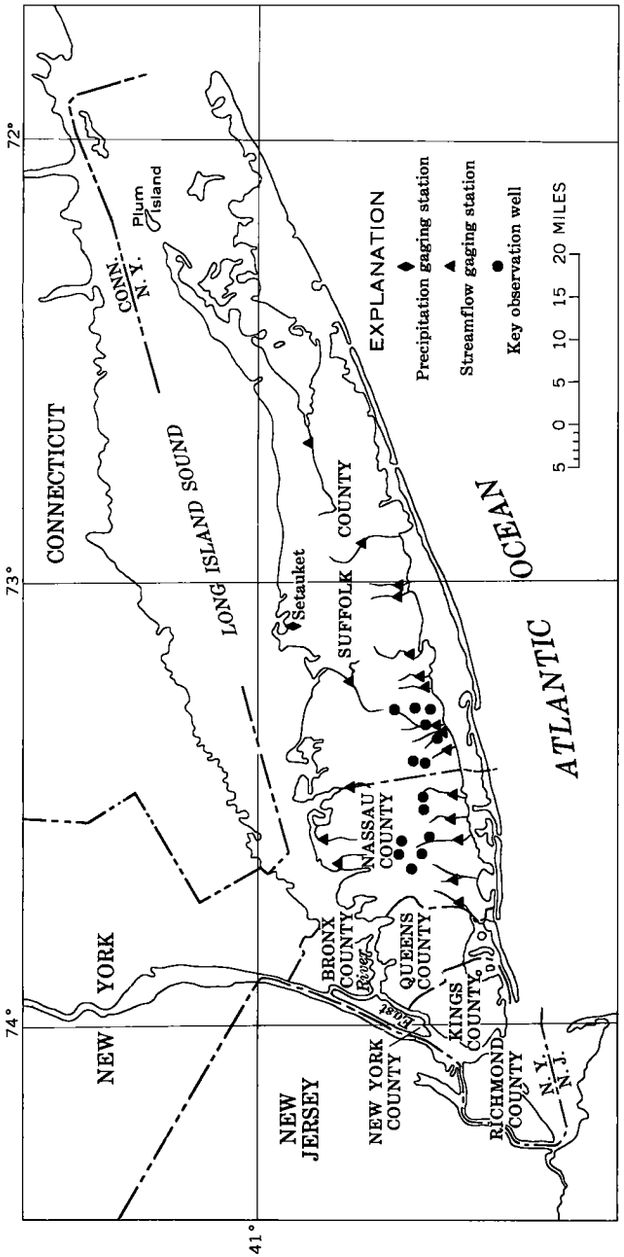


FIGURE 1.—Long Island and vicinity showing location of selected hydrologic-data-collection points.

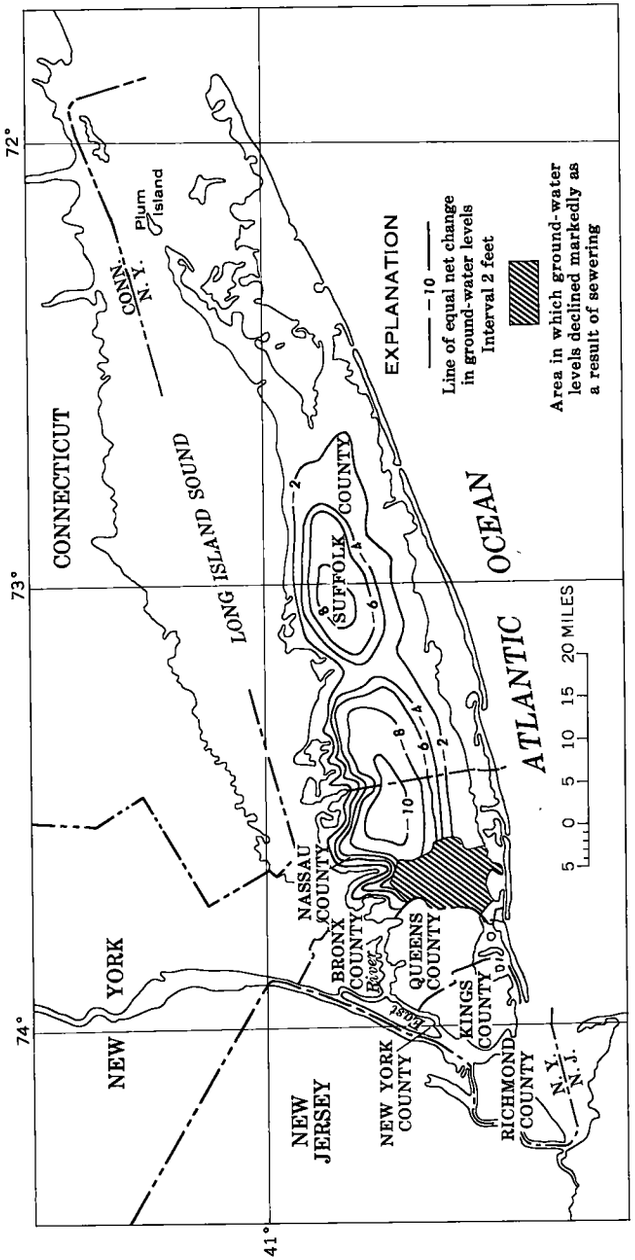


FIGURE 10.—Net change of ground-water levels in the unconfined aquifer, 1961–66.

lakes are in direct hydraulic continuity with the shallow unconfined aquifer. Accordingly, the levels of most of the lakes are at about the same altitude as the water table adjacent to the lakes, and the lake levels fluctuate in response to changes in the altitude of the water table. Inasmuch as the lakes are shallow, declines of the water table and of the lake levels of only a few feet, such as those that occurred in water years 1962–66, caused large parts of many of Long Island's lakes to become dry and caused a decrease in the amount of water in storage therein. Unfortunately, data are not available to compute the decrease in storage in the lakes during the drought.

As the ground-water levels declined during the drought, parts of the upstream reaches of many of Long Island's streams also became dry. In addition, the depth of water in those parts of the streams in which there was perennial flow was below average during the drought. Thus, the amount of water stored in the stream channels during water years 1962–66 was below average. Again, sufficient data are not readily available to compute this decrease of surface water in storage. However, the total decrease of surface water in storage (in both the lakes and streams) during the drought was small relative to the decrease of subsurface water in storage.

The net decrease in soil moisture during the drought undoubtedly was many times greater than the decrease of surface water in storage; data again, however, are not available to evaluate quantitatively this parameter.

Sufficient data are available to estimate the net decrease of ground water in storage from water years 1961–66. As shown in figure 10, the declines in ground-water levels ranged from somewhat more than 10 feet in northeastern Nassau County and northwestern Suffolk County to less than 2 feet near the shorelines. Larger declines were noted in southwestern Nassau County (shaded area in fig. 10), largely as a result of decreased artificial recharge related to widespread sewering (Franke, 1968), but consideration of these declines is beyond the scope of this report.

The contours showing the net declines of ground-water levels (fig. 10) approximately parallel the water-table contours (not shown); the largest declines were in the area of the regional ground-water divide on Long Island which is in north-central Nassau and Suffolk Counties. This relation between the altitude of the water table and the magnitude of the decline in the water table is consistent with the theoretically expected response of the ground-water system to any factor that causes an islandwide

Queens Counties are excluded from the analysis mainly because factors related to urbanization make a precise quantitative analysis of the effects of the drought on the hydrologic system in these counties virtually impossible.

For the most part, the approach taken in this report is to consider, largely in a descriptive manner, the drought and its effects as they are illustrated on the accompanying graphs, diagrams, and maps. The few statistical techniques used (except perhaps the technique of frequency analysis) and the parameters that are cited are simple and should be readily understood by most laymen.

MEANING OF "DROUGHT"

Most technical reports concerned with one or more aspects of a drought carefully develop the point that the word "drought" has many different meanings, and in one place or at one time the word may be used to describe a very different set of circumstances than in another place or time. (See Thomas, 1962, for an excellent review of the meaning of "drought".) Droughts commonly, but not always, are defined in terms of one or more of the following factors: (1) precipitation, (2) soil moisture, (3) public-water supply, (4) above-ground or underground storage capacity, (5) crop failures, and (6) general economic hardship. Almost always, regardless of the specific definition used, a "drought" is related to, or is caused by, having less water available than is desired or expected. (See Yevdjevich, 1968, for methods of determining whether a "drought" has occurred or is occurring.) Within this context the drought described in this report represented a series of events closely related to, and largely caused by, inadequate precipitation—inadequate in terms of the amount desired by local residents and the amount normally expected.

ACKNOWLEDGMENTS

Virtually all the data on ground-water levels and streamflow used to develop the information given in this report were obtained as part of a program of water-resources studies that is being carried on by the U.S. Geological Survey in cooperation with the New York State Division of Water Resources, the Nassau County Department of Public Works, the Suffolk County Water Authority, and the Suffolk County Board of Supervisors. We are grateful to our colleagues in those agencies whose support included, but was not limited to, the collection of many of the data presented in this report.

The report was prepared under the immediate supervision of B. L. Foxworthy, former Hydrologist-in-Charge of the Geological

Survey Subdistrict Office on Long Island, and under the general supervision of Garald G. Parker, District Hydrologist, U.S. Geological Survey, Albany, N.Y.

DEFICIENT PRECIPITATION

ANNUAL PRECIPITATION

During the past two decades, precipitation data have been collected at nearly 30 stations on Long Island. The maximum average annual precipitation, about 51 inches, occurs near the middle of the island, and the minimum average annual precipitation, about 40 inches, occurs along the coast in southern Nassau County and on Plum Island. The long-term average precipitation for all Long Island is about 44 inches per year (Cohen and others, 1968, p. 30).

Data collected at Setauket (fig. 1) provide the longest continuous record of precipitation on Long Island. The average for the 81-year period of record at that station, water years 1887–1967, is 44.5 inches, nearly the same as the long-term average for all stations on Long Island. (The "water year" is the 12-month period beginning October 1; it is designated by the calendar year in which the 12-month period ends.) Accordingly, precipitation data from Setauket are emphasized in this report.

Annual precipitation at Setauket ranged from a low of 30.8 inches in water year 1966 to a high of 56.4 inches in water year 1898, and, in general, years of above- and below-average precipitation seem to have been randomly distributed (fig. 2). Only twice during the entire period of record was precipitation above or below average for 5 consecutive years. It was above average from 1887 through 1891, when the cumulative excess was 33.0 inches (fig. 3), and it was below average from water years 1962 through 1966, when the cumulative deficiency was 41.7 inches.

Largely because water year 1962 was the first year of below-average precipitation in the 5-year sequence, the drought is somewhat arbitrarily assumed to have begun on Long Island in that year. The qualification "somewhat arbitrarily assumed" is used mainly because precipitation in water year 1962 was only slightly below average (1.2 in.), and because, for all practical purposes, virtually none of the adverse features associated with a drought were noted on Long Island during that year.

Two additional noteworthy features of the recent drought can be deduced from figures 2 and 3. First, the 1962–66 drought was the most severe of record in terms of the total deficiency in precipitation and in terms of its duration. The next largest deficiency in precipitation for a consecutive number of years, about 23 inches, occurred in the 3-year period, water years 1909–11. Second, the

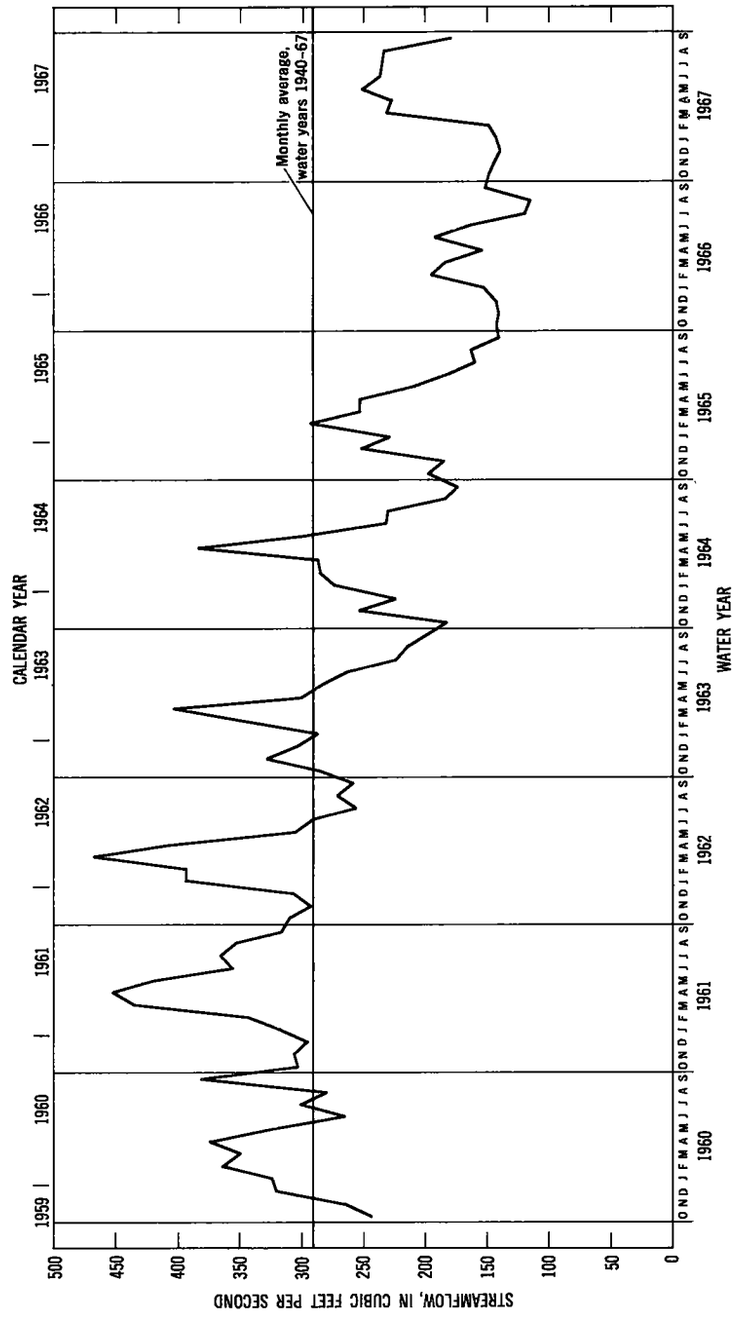


FIGURE 9.—Combined monthly average streamflow of 19 principal streams.

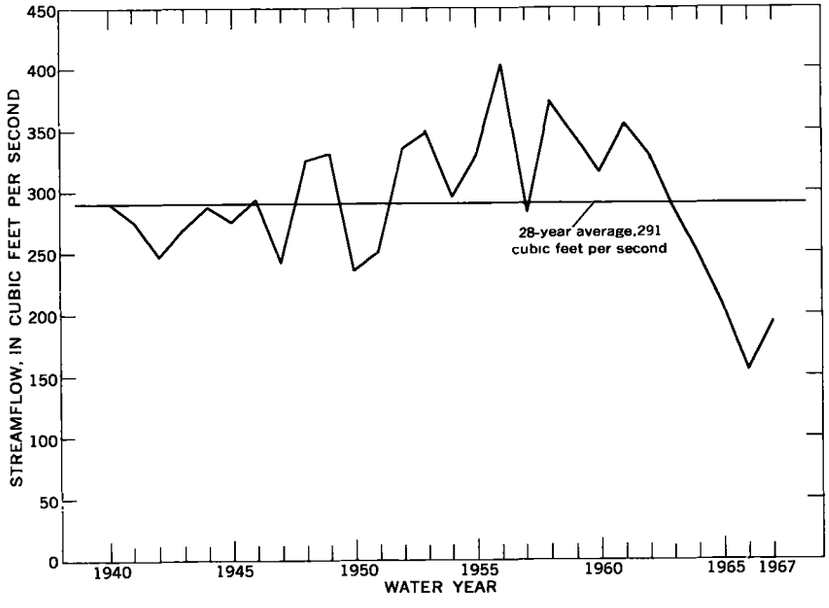


FIGURE 8.—Combined annual average streamflow of 19 principal streams.

levels. (Compare figs. 7 and 9.) In addition, the slight but distinct upturn in the streamflow hydrograph in the winter of 1967 also seems to have signaled the possible end of the drought. Despite the increase in streamflow, however, the discharge of many of Long Island's streams in 1967 was considerably below average, and record-low flows were noted in three of the streams in that year.

DECREASED WATER IN STORAGE

The amount of fresh water stored on and beneath the surface of Long Island decreased markedly as a result of the drought conditions in water years 1962–66. The decreases involved surface water, soil moisture, and ground water.

Most of Long Island's lakes are small and shallow (less than a square mile in area, and commonly only a few tens of feet or less in depth), and although a few of the lakes are perched and, therefore, their levels are not related to the water table, most of the

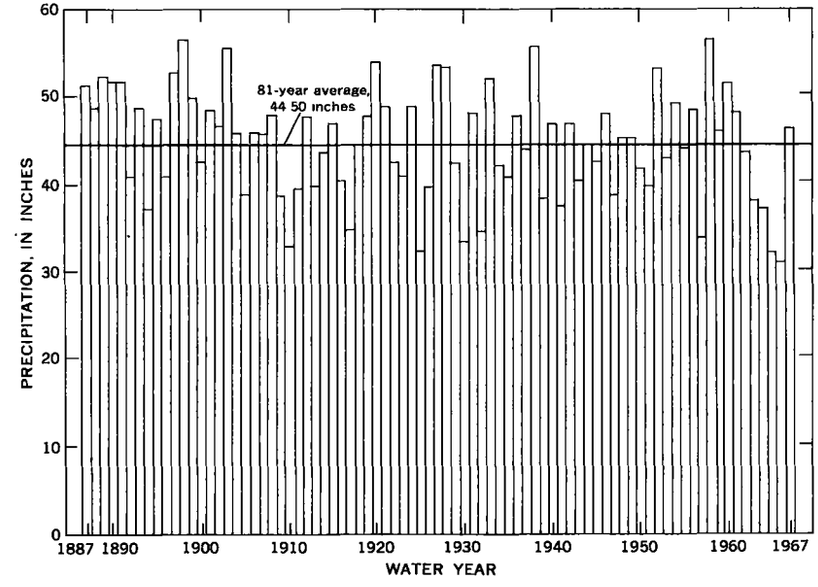


FIGURE 2.—Long-term annual precipitation at Setauket.

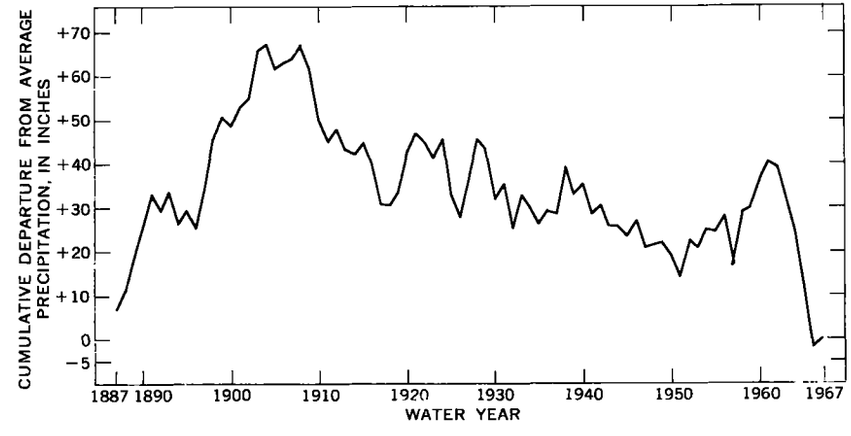


FIGURE 3.—Cumulative departure from average annual precipitation at Setauket.

increasing deficiency in annual precipitation with each succeeding year of the 1962–66 drought intensified the severity of the drought.

Sufficient data for Long Island are not available to evaluate the probable frequency of occurrence of the 5-year 1962–66 drought, and an analysis of the frequency of that multiyear event, based

329-637 O - 69 - 2

on regional or worldwide data, is beyond the scope of this report. Sufficient data are available, however, to evaluate the frequency of occurrence of annual precipitation (fig. 4). For example, annual precipitation probably will be equal to, or greater than, 30.8 inches, as it was in 1966, about 99 percent of the time. Similarly, annual precipitation probably will be equal to, or greater than, 31.9 inches, as it was in 1965, about 98 percent of the time. (See Mitchell, 1968, for an additional discussion of the frequency of occurrence of droughts with special reference to the drought described in this report.)

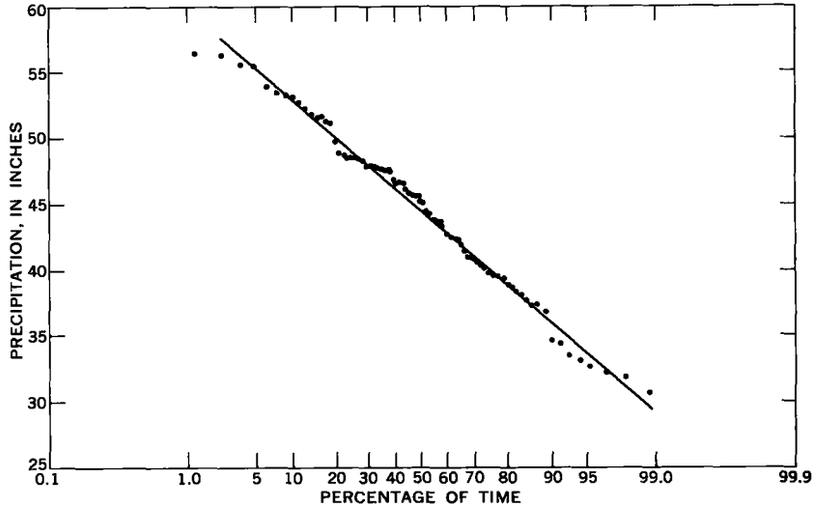


FIGURE 4.—Percentage of time that various values of annual precipitation were equaled or exceeded at Setauket for the period of record.

The odds against the annual precipitation being as little as it was in 1966 are roughly 60–80 to 1, and the odds against precipitation being as little as it was in 1965 are roughly 35–40 to 1. Thus, if the simplifying assumption is made that annual precipitation at Setauket is randomly distributed, the odds against the precipitation being as low as it was in the 2 successive years, 1965 and 1966, are considerably more than 100 to 1. The validity of the assumption of total random distribution of annual precipitation undoubtedly is questionable. However, the preceding discussion is useful inasmuch as it illustrates (1) the difficulties involved in estimating how frequently a drought of the length and severity of that experienced on Long Island in 1962–66 might occur, and

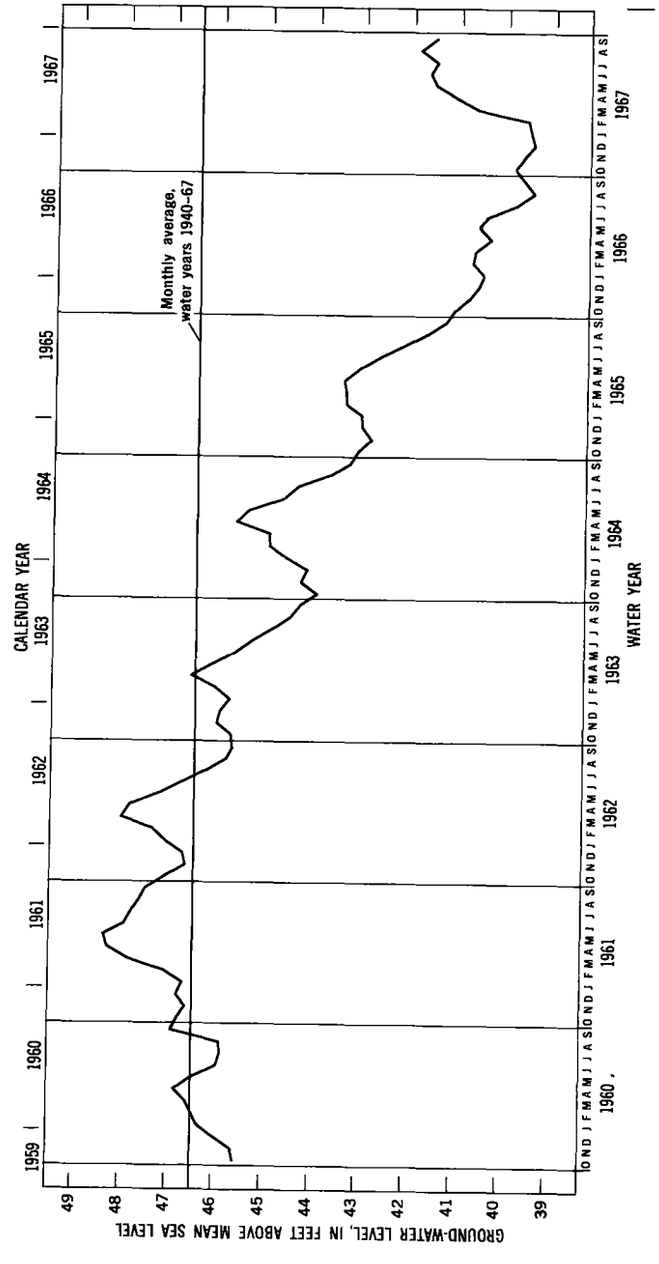


FIGURE 7.—Average monthly ground-water levels in 14 key observation wells.

MONTHLY WATER LEVELS

Monthly water-level data from the key observation wells (fig. 7) provide additional insight into the effects of the drought on the hydrology of Long Island. The seasonal trend in water-level fluctuations—highest water levels in the winter and late spring, and lowest water levels in the late summer and early fall—can be attributed largely to seasonal variations in natural recharge rates and partly to seasonal pumping patterns. The downward trend in ground-levels from 1962 to 1966 is clearly visible. Also, the decline in ground-water levels was abruptly halted and reversed in the winter of 1967 when, as previously noted, the drought seems to have been broken by sustained average and above-average precipitation in several consecutive months.

DECREASED STREAMFLOW

ANNUAL STREAMFLOW

On the average, more than 95 percent of the streamflow on Long Island is derived by seepage into the stream channels from the ground-water reservoir. In other words, less than 5 percent of the streamflow is overland runoff (Cohen and others, 1968, p. 40). Accordingly, the flows of Long Island's streams closely reflect changes in ground-water levels in the shallow unconfined aquifer (the part of the ground-water reservoir that is in direct hydraulic continuity with the streams). The close relationship between streamflow and ground-water levels on Long Island is confirmed by the fact that the shape of the curve in figure 8, which shows the combined average flows of the 19 principal streams on Long Island, is very similar to the shape of the curve showing average annual ground-water levels (fig. 6).

In water years 1940–67 the combined flows of the principal streams averaged 291 cfs (cubic feet per second), and ranged from a high of 401 cfs in 1956 to a low of 155 cfs in 1966. The lowest flows of record were noted in 14 of the 19 streams in July or August of water year 1966, the same months in which record-low ground-water levels were noted in many of the observation wells. Flows in 1967 generally were only slightly more than those in 1966; nonetheless, a distinct upturn in the combined-flow hydrograph was noted in that year, corresponding to increased precipitation (fig. 2) and to a slight recovery of ground-water levels (fig. 6).

MONTHLY STREAMFLOW

Monthly flow data for the 19 principal streams for water years 1960–67 (fig. 9) confirm many of the observations made in the preceding text. For example, seasonal streamflow fluctuations correspond fairly closely to seasonal fluctuations in ground-water

(2) the probable large order of magnitude of the odds against such an occurrence.

MONTHLY PRECIPITATION

Average monthly precipitation on Long Island is fairly uniform, and for the period of record at Setauket it ranged from a low of 3.1 inches for June to a high of 4.1 inches for August (fig. 5). The long-term monthly average was about 3.7 inches (44.50 in. per yr divided by 12 months).

Monthly averages for water years 1960–67 also are shown in figure 5 (dashed lines). Below-average precipitation and an increasing deficiency from year to year in water years 1962–66 are clearly indicated by the dashed lines. As is shown on the graph, however, precipitation was above average in some months in each of the 5 drought years.

It is significant to note that it is virtually impossible to select readily the specific month when the drought began. On the other hand, the monthly data seem to indicate that, at least with respect to precipitation, the drought may have ended in February or March 1967.

DECLINING GROUND-WATER LEVELS

ANNUAL WATER LEVELS

Ground-water levels have been measured in 14 key observation wells on Long Island (fig. 1) since the late 1930's. These wells tap the uppermost unconfined aquifer on Long Island and, accordingly, water levels in these wells respond rapidly to changes in the rate of ground-water recharge. All the natural fresh-water recharge on Long Island results from the infiltration of precipitation falling on the island. Thus, ground-water levels in the 14 wells responded markedly to the 1962–66 drought (fig. 6).

The average altitude of the water levels in the 14 key wells for the period 1940–67 was nearly 46.5 feet. The annual average level was about 1 foot above the long-term average in 1961, and it declined to a point about 1 foot below the long-term average in 1963. By 1966 the annual average level had declined about 7 feet below the 1961 level to a point about 6 feet below the long-term average level. In 1967, when the drought apparently was broken, the annual average level recovered about 0.3 foot.

The ground-water reservoir of Long Island is intensively developed for public-supply and other uses, and ground-water withdrawals, which have been on the order of 400 million gallons per day in recent years, have been increasing steadily, especially since the mid-1940's (Cohen and others, 1968). The fluctuations of

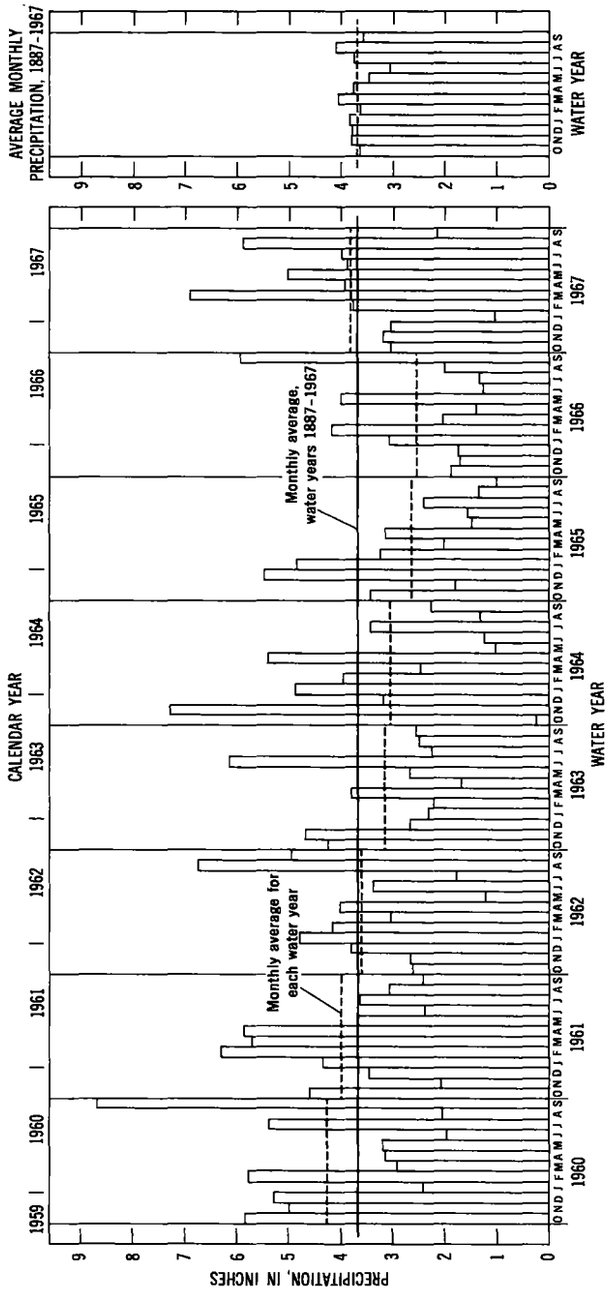


FIGURE 5.—Monthly precipitation, water years 1960–67, and long-term average monthly precipitation at Setauket.

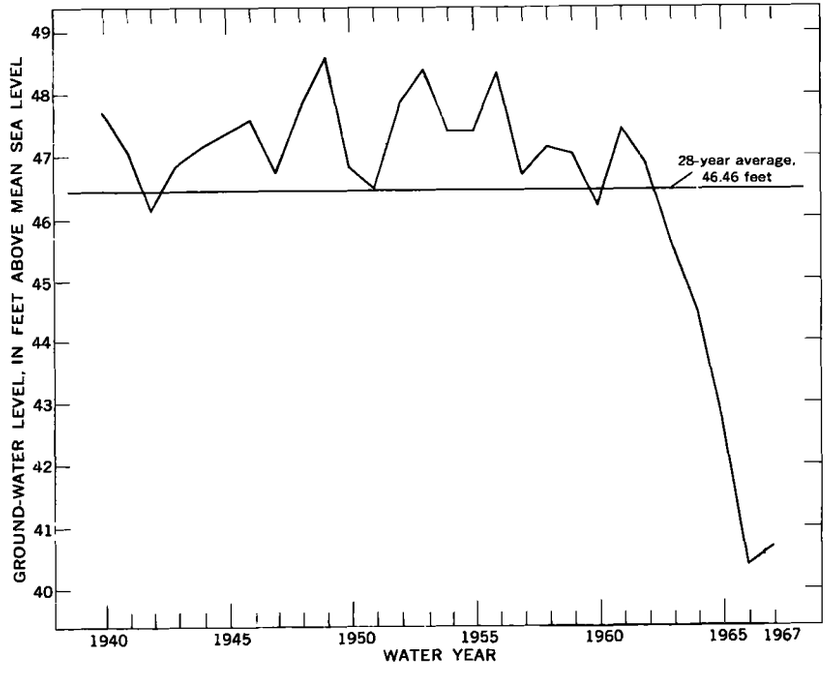


FIGURE 6.—Average annual ground-water levels in 14 key observation wells.

ground-water levels shown in figure 6 undoubtedly reflect in part the effects of pumping. In addition, other factors, such as decreased natural recharge related to urban development and decreased artificial recharge related to the discontinued use of cesspools and the construction of sanitary sewers (Franke, 1968), have been partly responsible for the declines of ground-water levels on Long Island, especially since the mid-1950's.

Sufficient data are not available to determine accurately what proportion of the decline in water levels during 1962–66 was caused (1) directly by the drought as a result of decreased precipitation and related decreased recharge, (2) indirectly by the drought as a result of increased ground-water withdrawals for lawn sprinkling and other needs related to abnormally low precipitation, or (3) by factors unrelated to the drought. Nevertheless, the striking similarity between figures 3 and 6, especially for 1961–67, strongly suggests that most of the changes in the annual average ground-water levels were related to below average precipitation and the resulting decreased recharge.

Availability of Fresh Ground Water Montauk Point Area Suffolk County Long Island, New York

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1613-B

Prepared in cooperation with the U.S. Air Force

Perlmutter, DeLuca—GROUND WATER, MONTAUK POINT AREA, NEW YORK—Geological Survey Water-Supply Paper 1613-B

Availability of Fresh Ground Water Montauk Point Area Suffolk County Long Island, New York

By NATHANIEL M. PERLMUTTER *and* FRANK A. DELUCA

RELATION OF SALT WATER TO FRESH GROUND WATER

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1613-B

Prepared in cooperation with the U.S. Air Force

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

REFERENCES

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, John Wiley & Sons, Inc., 553 p.

Fuller, M. L., 1914, The geology of Long Island, N.Y.: U.S. Geol. Survey Prof. Paper 82, 231 p.

Hubbert, M. K., 1940, The theory of ground-water motion: Jour. Geol., v. 40, no. 8, p. 924–926.

Lohman, K. E., 1939, Pleistocene diatoms from Long Island, New York: U.S. Geol. Survey Prof. Paper 189–H, p. 229–237.

MacClintock, Paul and Richards, H. G., 1936, Correlation of Late Pleistocene marine and glacial deposits of New Jersey and New York: Geol. Soc. America Bull., v. 27, p. 289–338.

Perlmutter, N. M., and Crandell, H. C., 1959, Geology and ground-water supplies of the south-shore beaches of Long Island, N.Y.: Annals N.Y. Acad. Sci., v. 80, art. 4, p. 1060–1976.

Suter, Russell, deLaguna, Wallace, and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers of Long Island, N.Y.: N.Y. State Water Power and Control Comm. Bull. GW–18, 181 p.

U.S. Public Health Service, 1946, Public Health Reports, reprint 2697.

Wells, F. G., 1934 (1935), Reconsideration of the Pleistocene geology of Long Island: Proc. Geol. Soc. America, p. 121–122.

○

of 40 feet below land surface to the bottom of the hole. After drilling the pilot hole, a supply well, 6 to 8 inches in diameter and finished with 15 to 20 feet of screen, can be installed at a depth selected on the basis of the samples. If the pilot hole is constructed of suitable diameter, it can be converted to a supply well readily, regardless of the method of drilling. If the supply well is drilled by the rotary method, the area around the screen should be gravel packed. A pumping test of 8 hours duration at a rate of about 50 gpm should be made upon completion of the well. Frequent measurement of the pumping level and collection of samples of water for analysis should be required during the pumping test. If necessary, a fourth well similar in construction to the well described above could be drilled in the eastern part of the area near wells S19492, and S19493 (pl. 1). As this report was being prepared for publication in August 1962, a new supply well, S21084, was being installed at a depth of 120 feet near S19489.

4. Another supplementary source of water, which may be available, at least on a part-time basis, is abandoned well S19496 (pl. 1), about one-quarter of a mile south of supply well S17859. The well reportedly yields 20 to 30 gpm and was used for a short period during an emergency in 1960, but no records were made of the pumpage or of the chloride content of the water. A sample of water collected after 10 minutes of pumping in September 1960 had 30 ppm chloride, about normal for the area. As this well is closer to the shore than any other possible supply well, it is not known what effect continuous pumping may have on the chloride content of the water. If this well is tied into the existing system through temporary mains it can be pumped intermittently throughout the summer months. Samples of water should be collected periodically for chloride determination, which would provide a basis for determining whether it would be feasible to incorporate this well into the system permanently. After this report was submitted to the Air Force, well S19496 was operated intermittently during the fall of 1961 and the summer of 1962. The chloride content of the water was about 40 ppm when the well was shut down, but during periods of continuous heavy pumping, as in July 1962, the chloride content was as high as 150 ppm.

5. Continuation of the water-level measurement and chemical sampling program for about a year would determine the trend of water-level fluctuations and would indicate any changes in the chloride content of the water, especially during the period of low recharge in the summer and fall and under conditions resulting from the installation of one or more new supply wells.

CONTENTS

	Page
Abstract	B1
Introduction	1
Purpose and scope of the investigation	1
Location and development of the area	2
Topography and drainage	4
Climate	5
Methods of investigation	5
Previous investigations	6
Acknowledgments	6
Geology	7
Precambrian bedrock	7
Cretaceous formations	7
Pleistocene deposits	10
General character and stratigraphy	10
Pleistocene stratigraphy of the Montauk Point area	11
Lower unit of stratified drift	11
Undifferentiated deposits of till and stratified drift	11
Recent deposits	14
Ground water	14
Source and occurrence	14
Water in the undifferentiated deposits of till and stratified drift	15
Perched water bodies	15
Minor water-bearing zones	16
Confining beds	16
Water in the lower unit of stratified drift	17
Principal aquifer	17
Piezometric surface	18
Movement of fresh water	18
Fluctuations of water levels	19
Short-term fluctuations	19
Long-term fluctuations	22
Pumpage and utilization	23
General	23
History of withdrawals	25
Relation of pumpage to recharge	26
Quality of water	27
Chemical quality	27
Temperature	27
Salt-water encroachment	31
Boundary of fresh water and salt water	31
Movement of salt water	32
Deterioration of the chemical quality of the water	32
Relation of pumpage to salt-water encroachment	33

	Page
Summary	B34
Measures for control of water quality and proposed sites of new supply wells	37
References	39

ILLUSTRATIONS

[Plates are in pocket]

PLATE 1. Map of Montauk Point, showing wells, sampling points, stream gaging stations, and water-level contours.
2. Geohydrologic sections.

	Page
FIGURE 1. Map of Long Island, showing area of investigation	B3
2. View of outcrop showing till above stratified drift	12
3. Close-up view of till and underlying stratified drift	12
4. View of outcrop showing stratified drift, above till	13
5. Fluctuations of water level in wells screened in fresh water	20
6. Fluctuations of water level in a well screened in salt water	21
7. Range in water-level fluctuations, 1959–61	23
8. Daily pumpage by months, 1960–61	24
9. Relation between chloride content of water and pumping rate	25

TABLES

	Page
TABLE 1. Miscellaneous stream-discharge measurements, Montauk Point area, March 31, 1961	B4
2. Precipitation and temperature at Bridgehampton, Long Island, N.Y., 1931–60	5
3. Records of wells, Montauk Point area	8
4. Chemical analyses, in parts per million, of water from wells, Montauk Point area	28
5. Chloride content of ground water, 1946–61	29
6. Chemical quality of surface water	30
7. Chemical analysis, in parts per million, of Atlantic Ocean water at Montauk Point	31

of the supply wells was about 35 gpm the chloride content of the water was generally less than 100 ppm, but when larger pumps were installed and pumping rates ranged from 50 to 100 gpm at individual wells, the chloride content of the water increased to about 450 ppm. The increase in chloride content was accompanied by large increases in the content of iron and dissolved solids and in the hardness of the water.

MEASURES FOR CONTROL OF WATER QUALITY AND PROPOSED SITES OF NEW SUPPLY WELLS

1. Ideally, about four widely separated wells each operating at low pumping rates (30 gpm or less) probably could supply fresh or nearly fresh water continuously at the Montauk Air Force Station, if the pumping load were distributed equally among the wells. By operating the wells together at low rates or alternately for short periods, the drawndown of water level and reduction of fresh-water head would be kept to a minimum, which would lessen the tendency of salt water to move up toward the well screens.

2. Under the present (1961) system, wells S17231 (1A) and S17859 (3A) are the only operating units at Montauk Air Force Station. The wells have been pumped individually from time to time at rates of 50 to 100 gpm, and both have yielded water of high chloride content intermittently. Reduction of the pumping rate to about 30 gpm at these wells should result in marked improvement in the quality of the water. Wells S17231 and S17859 were replaced by nearby wells S20766 and S21077 in April and August 1962, respectively.

3. To compensate for this suggested reduction in pumpage, a third well as remote as possible from the existing wells is needed to meet peak demands, especially during the summer months, in order to maintain low pumping rates and to act as a standby well in the event of a breakdown of one of the present installations. The results of this investigation suggest that the best site for a new supply well would be in the extreme west-central part of the Military Reservation near observation well S19489 (pl. 1). At this site the top of the principal aquifer is about 30 feet below sea level, and the bottom of the fresh-water lens is about 100 feet below sea level. A production well, drilled by either the cable-tool or rotary method, probably could be completed at about 80 to 120 feet below the land surface, depending on the depth and character of the deposits.

To set the well screen as high above the top of the zone of diffusion as possible and to select the most productive zone, a pilot hole should be drilled to a depth of about 150 feet. Bailer-type or core samples of the deposits should be collected at 10-foot intervals from land surface to 40 feet below land surface and at 5-foot intervals from a depth

bearing zones in this report (pl. 2). The lower 20 to 65 feet of the undifferentiated deposits consists predominantly of clay, silt, and perhaps some till and is of low permeability in most places. These beds also are saturated with water, but their low permeability makes them unsuitable as a source of supply. However, they are important hydrologically in helping to confine the water in the underlying principal aquifer under artesian pressure.

The beds of sand and gravel in the lower unit of stratified drift constitute the principal aquifer, which is the source of supply for all existing wells in the report area. Water reaches the principal aquifer by slow downward percolation through the overlying beds. Wells screened in the principal aquifer yield as much as 100 to 150 gpm, but sustained pumping at these rates causes encroachment of salt water and generally contamination of the wells. Because of the artesian character of the principal aquifer, water levels fluctuate from several tenths of a foot to nearly a foot per day in some wells owing to tidal and barometric changes. The pressure surface to which water in wells tapping the principal aquifer rises is called the piezometric surface. A contour map (pl. 1) shows that the piezometric surface has a maximum altitude of about 3 to 4 feet. A cone of depression, about 0.5 mile in diameter and of unknown depth, exists around the present supply wells at the Air Force station. Pumpage at the station averages generally about 50,000 gpd, but at times it has been as high as 140,000 gpd. Withdrawals at the higher rates have caused salt water to move toward the pumping wells.

The natural chloride content of the fresh water in most of the area is about 25 to 30 ppm. The concentration of other constituents is also low, except for iron, which may be excessive locally. Results of analyses of water from the test wells constructed during the investigation show that salt water, having a chloride content of a least 11,300 ppm and probably as high as about 17,000, underlies the report area.

A zone of mixed water, the zone of diffusion, lies between the fresh water and the highly salty water. The top of the zone of diffusion ranges from sea level at the shoreline to about 130 feet below sea level just west of the Air Force station. The boundary between fresh water and salt water is an equilibrium position related to the respective heads and densities of the fresh and salt water. The lowering of water levels in the principal aquifer due to pumping of the Air Force supply wells has caused salt water to move upward toward the well screens. When pumping rates are reduced the fresh-water head rises and the boundary between the fresh and the salt water begins to move down. This movement is reflected in the wide range in the chloride content of the water pumped from supply wells at the station. Results of water analyses made in 1951 show that when the combined pumping rate

RELATION OF SALT WATER TO FRESH GROUND WATER

AVAILABILITY OF FRESH GROUND WATER, MONTAUK POINT AREA, SUFFOLK COUNTY, LONG ISLAND, NEW YORK

By Nathaniel M. Perlmutter and Frank A. DeLuca

ABSTRACT

Ground water is the only source of supply at the Montauk Air Force Station in eastern Suffolk County. The water is contained in the upper 200 feet of deposits of late Pleistocene age, which are broadly divided into an upper unit of undifferentiated till and stratified drift and a lower unit of stratified drift.

Fresh water in the principal aquifer, which is in the lower unit, is a lens-shaped body, which lies above salty water containing as much as 11,300 ppm of chloride. The fresh water is under artesian pressure and has a head ranging from about sea level to 3.5 feet above sea level. Pumping rates of 50 to 100 gpm cause salty water to move toward the supply wells from below.

The optimum pumping rate of most wells is about 30 gpm. New wells should be drilled as remote as possible from existing wells, and the well screens should be set as high above the zone of diffusion as the deposits permit.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

Ground water is the only source of supply for general use and air conditioning at the Montauk Air Force Station in eastern Suffolk County. Owing to proximity of Block Island Sound and the Atlantic Ocean, the fresh-water bearing beds are readily susceptible to salt-water encroachment. In the fall of 1960, the U.S. Air Force requested the U.S. Geological Survey to make an investigation of ground-water conditions at the Montauk Air Force Station where the water supply was being contaminated by encroaching salt water.

The investigation was limited to the Station and nearby hydrologically related areas. It included studies of (1) the areal extent, thickness, character, and hydraulic properties of the fresh-water bearing beds; (2) movement of the fresh water; (3) quality of the

water; (4) delineation of the boundary between fresh water and salt water beneath the area; (5) the relation between pumping and salt-water encroachment; and (6) proposed sites of new supply wells at the Station.

LOCATION AND DEVELOPMENT OF THE AREA

The Montauk Point area is in the town of Easthampton, Suffolk County, at the extreme eastern point of Long Island (fig. 1).

The investigation, covering a total area of about 3.5 square miles, was concentrated chiefly in the Montauk Air Force Station (about 0.15 square mile) and in the unused part of the U.S. Military Reservation (about 0.55 square mile), which adjoins the station on the west and the east (pl. 1). As this report was nearing completion, the authors were informed by the U.S. Air Force (written communication, May 1961) that the Air Force Station would be enlarged to include a substantial part of the area now designated as Military Reservation on plate 1. The area is bounded on the north by Block Island Sound and on the east and the south by the Atlantic Ocean. The western boundary is arbitrary and is about 0.3 mile east of Montauk Harbor (fig. 1), which is another large body of salt water.

Prior to 1941, the Montauk Point area was occupied chiefly by a small number of summer homes, a resort hotel and restaurant, several dude ranches, Montauk State Park, and Montauk Lighthouse, which is maintained by the U.S. Coast Guard. All these places were supplied with water by individual wells. About 1941, much of the central and eastern part of the report area was acquired by the U.S. Army for the construction of Camp Hero. At least five wells (S3259, S3260, S3261, S19496, and S19498) were constructed for use by the Army; several former private wells included in the land purchase also may have been pumped from time to time. Wells on Long Island are numbered serially by counties generally in the order in which wells are drilled. The letter prefixing the number is the initial of the county. All numbers are assigned by the New York State Water Resources Commission. No records of the quality or quantity of ground water pumped at Camp Hero from 1941 to 1946 are available.

Shortly after the end of World War II, Camp Hero was shut down except for use as a reserve training center. About 1951, a rectangular strip of land in the western part of the former camp was taken over by the U.S. Air Force for construction of the Montauk Air Force Station. At first the original supply wells and pumps were used; later larger capacity pumps were installed. By 1959, all the original wells were abandoned. The chief supply in 1961 was from wells, S17231 and S17859 (replaced in 1962 by wells S20766 and S21077).

to 200 feet of deposits of Pleistocene age as the underlying beds are believed to contain water nearly as salty as the ocean and as the Recent deposits are too thin and scattered to provide significant amounts of water.

The Pleistocene deposits were laid down by melting ice sheets as glacial till (poorly sorted mixture of boulders, gravel, sand, and clay) and by streams as stratified drift (beds of well sorted gravel, sand, silt, and clay). In this report the Pleistocene deposits have been divided broadly (pl. 2) into two geologic units: (1) a lower unit of stratified drift, which consists predominantly of beds of highly permeable medium to coarse sand and gravel, and (2) an overlying unit of undifferentiated deposits of till and stratified drift, which consists predominantly of material of relatively low permeability such as beds of sandy clay, clay, silt, and glacial till. Some scattered beds and lenses of permeable sand and gravel occur in parts of the upper unit. The boundary between the upper and lower units is irregular and cannot be sharply defined everywhere, but on the basis of present data, it is estimated to be about 30 to 40 feet below sea level in most of the area (pl. 2).

Precipitation is the source of all ground water in the Montauk Point area. It is estimated that about one-fourth of the total precipitation of 48 inches reaches the ground-water reservoir. The remainder is lost through evaporation, plant use, and runoff. After seeping through the soil zone, the water moves down through the pore spaces in the deposits of undifferentiated till and stratified drift. Below a certain depth, which varies from place to place, the deposits are completely saturated with water. The top of the zone of saturation is called the water table. Few data were collected on the altitude of the water table as it lies mainly in deposits of low permeability and as nearly all the wells in the report area are finished at greater depth in the principal aquifer in the lower unit of stratified drift. The few available data suggest that the water table may be as much as 10 to 17 feet above sea level near the center of the area; under normal conditions, the water table should slope radially from a central high point to sea level at the shoreline.

Ground water occurs in the upper unit in (1) perched water bodies above the water table and (2) in minor water-bearing zones below the water table. Perched water bodies are common at depths of 5 to 30 feet below the land surface in permeable lenses surrounded by silt and clay but are too thin and temporary to be considered as a source of supply. On the other hand, lenses and beds of sand and gravel a short distance below the water table are permanently saturated, but because most of these seem to be too thin and too discontinuous to yield substantial amounts of water they are considered minor water-

ride content of the water reached a peak of about 440 ppm. The chloride content dropped sharply in November and December 1960 when the pumping rate was reduced to about 40 gpm per well. At the end of April 1961, when well S17231 was the only unit in operation, the pumping rate was 40 to 50 gpm; daily withdrawals were about 40,000 gpd; and the chloride content of the water was about 180 ppm. On July 5, 1961, the chloride content of the water in well S17231 rose to 380 ppm as the use of water for air conditioning and other purposes increased. From August to October 1961, the chloride content of the water was about 250 ppm. The chloride content decreased to 50 ppm on November 17, after the well had been shut down for repairs, but the concentration increased to 100 to 150 ppm after the well was restored to service.

SUMMARY

Ground water is the only source of supply for general use and air conditioning at the Montauk Air Force Station in extreme eastern Suffolk County (pl. 1). Because of the proximity of the Atlantic Ocean and the presence of salty ground water beneath a relatively thin lens-shaped body of fresh ground water, the supply wells at the station have been contaminated intermittently through encroachment of salt water; at times the chloride content of the water has been as high as 440 ppm. As a result of this deterioration in the quality of the water, the U.S. Air Force requested the U.S. Geological Survey to make a study of the ground-water conditions at and near the station, to determine the availability of fresh water, and to suggest locations for new supply wells.

The availability of the fresh ground water at Montauk Air Force Station is directly related to the depth, distribution, thickness, lithology, and hydraulic characteristics of the various deposits constituting the ground-water reservoir, and to the depth to the contact and the hydraulic relation between fresh and salty ground water. Prior to the present investigation, information on most of these elements was scanty or unknown. The investigation therefore included the collection and the study of well logs and samples, the examination of outcrops in the bluffs at the south side of the station, the drilling of 13 small-diameter test wells to depths of about 80 to 160 feet below land surface, the collection of water samples for analysis of chloride content, and the periodic measurement of water levels in all available wells.

Crystalline bedrock lies about 1,000 to 1,300 feet beneath the area. The overlying unconsolidated deposits consist of sand, gravel, and clay of Cretaceous, Pleistocene, and Recent age. This report is concerned mainly with the water-bearing properties of the upper 100

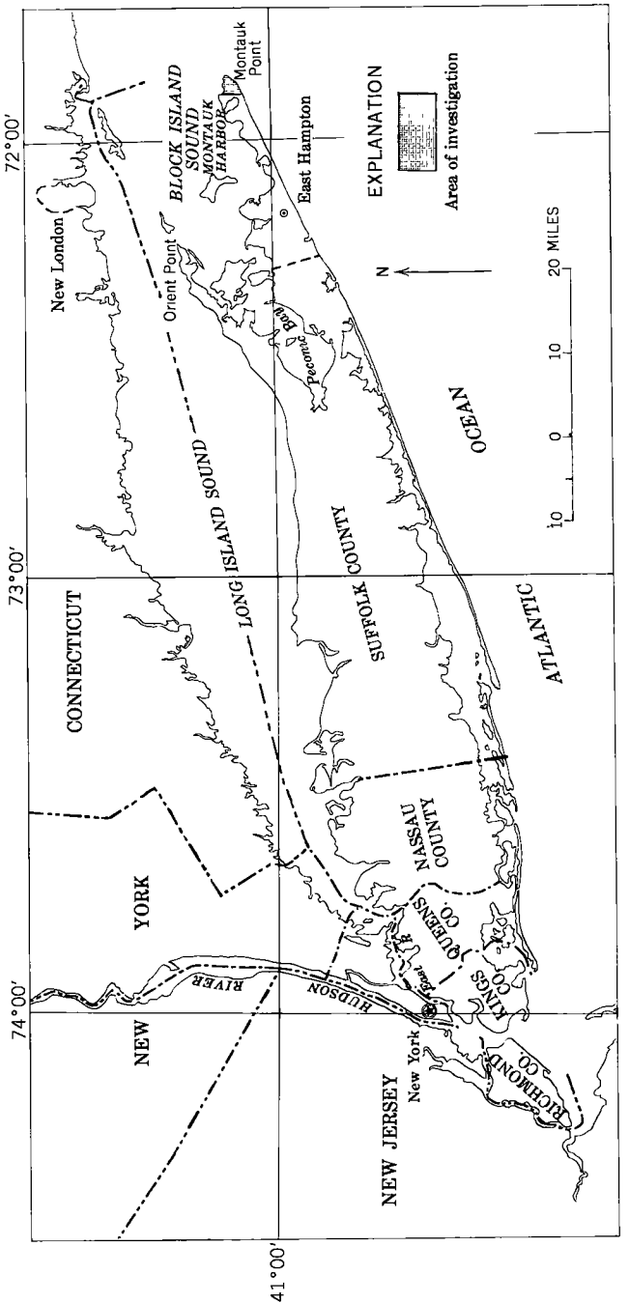


FIGURE 1.—Map of Long Island, New York, showing area of investigation.

TOPOGRAPHY AND DRAINAGE

Montauk Point is at the eastern extremity of the Ronkonkoma moraine. The moraine forms a ridge of coalescing hills traversing Long Island from west to east and marks the maximum advance of an ice sheet during late Pleistocene time.

The land surface, characterized by knob-and-kettle topography, ranges in altitude from sea level to about 100 feet above sea level. Steep wave-cut bluffs rise abruptly from 30 to 80 feet above narrow boulder-strewn beaches (figs. 2 and 4) along the eastern and southern shores. The land surface along the north shore declines gradually to sea level, and low wave-cut cliffs, where present, are less than 20 feet high. A few isolated low hills separated by marshy lowlands occur just north and west of the Montauk Lighthouse.

More than 50 kettle holes of various sizes and depths are occupied by swamps and ponds (pl. 1). Most of these are readily discernible in the field and on aerial photographs, but only a few of the larger ones are shown on plate 1. The kettle holes were occupied by detached masses of ice, which were partly or entirely covered by glacial deposits. Melting of the ice blocks and collapse of surrounding material left depressions, or kettle holes, in the land surface.

Most of the surface runoff is through four small unnamed streams (pl. 1). Three of the streams flow northwestward to Oyster Pond; the fourth flows southward to the Atlantic Ocean. Miscellaneous stream-discharge measurements made on March 31, 1961, are given in table 1. The measurements were made probably under low-flow conditions as no significant amount of rain had fallen since March 24, 1961. In much of the area precipitation runs off in temporary channels and in gullies to the Atlantic Ocean, to Block Island Sound, and into kettle holes.

TABLE 1.—*Miscellaneous stream-discharge measurements, Montauk Point area, Mar. 31, 1961*

[Measurements by Surface Water Branch, U.S. Geol. Survey; see pl. 1 for location of stations]

Station	Discharge		
	Cubic feet per second	Million gallons per day	Gallons per minute
1	0.65	0.42	292
2	.23	.15	103
3	.13	.09	60
4	.04	.03	20
5	.24	.15	106
Total	1.29	0.84	581

water from well S3261 (table 4) in 1953 and 1958 showed the following changes:

	1953	1958
Chloride (Cl) ppm	26	302
Dissolved solids (Residue at 180°C) do	124	596
Hardness as $CaCO_3$ do	48	113
pH	6.9	6.1

The analysis of salty water from well S19492 (table 4) shows that if salt-water encroachment were to proceed unchecked, water having as much as 11,300 ppm of chloride, 21,300 ppm of dissolved solids, 50 ppm of iron, a hardness of 5,680 ppm as $CaCO_3$, and a pH of 5.8 would ultimately reach the pumping wells. The relative concentration of the constituents in the salty ground water, except for iron, is virtually the same as that in water from the Atlantic Ocean (table 7).

An unusual characteristic of the water from well S19492 is the high content of nitrate (46 ppm of NO_3), the highest reported in the area. Because sea water has a negligible nitrate content (table 7) and because the minerals constituting the deposits are not known to contain nitrate in any form, it is suggested that the high nitrate may be due to local pollution. However, the origin is still uncertain as the nitrate content of a nearby shallow well, S19493, was only 1.7 ppm (table 4) and that of water in a nearby swamp was only 4.2 ppm (table 6).

RELATION OF PUMPAGE TO SALT-WATER ENCROACHMENT

Owing to the sequence and lithology of the beds and the relative thinness of the fresh-water zone in the principal aquifer, the screens of supply wells at Montauk Air Force Station generally have been set less than 100 feet above the top of the zone of diffusion. As thick beds of clay do not intervene between the salty ground water and the well screens, encroachment occurs relatively quickly when pumping exceeds a certain rate for prolonged periods.

The graphs in figure 9 show that so long as the combined pumping rate of wells at the Montauk Air Force Station did not exceed about 35 gpm the chloride content of the water did not rise above about 100 ppm.

After the installation of pumps rated at 64 gpm and with presumably higher rates of withdrawal than previously, the chloride content of the water in well S3261 (well 3) rose from 26 to 300 ppm. In 1960, when pumping rates occasionally reached 80 to 110 gpm and daily withdrawals ranged as high as 85,000 to 140,000 gpd, the chlo-

the water were not in motion, the contact would be depressed to a depth directly proportional to the fresh-water head and inversely proportional to the difference in the density of the two waters. Stated another way, the contact between fresh water and water as salty as the ocean (density 1.025 g per ml) would be depressed 40 feet below sea level for each foot of fresh-water head above sea level. This 40:1 relation is usually termed the Ghyben-Herzberg ratio. Hubbert (1940, p. 924–926) has shown that the Ghyben-Herzberg relationship is based on the assumption of hydrostatic equilibrium and may not even be approximately correct where hydraulic gradients are high such as in the vicinity of pumping wells or near the shore. As both the fresh and salt water in the project area are in motion and a sharp interface does not exist, the theoretical 40:1 ratio is not strictly applicable to the report area.

MOVEMENT OF SALT WATER

Salt water has existed under natural conditions beneath the project area probably since Pleistocene time. Under natural conditions some water from the main salt-water body probably moves slowly and continuously into the zone of diffusion and from there to discharge zones at the shoreline (pl. 2).

Natural gradients in the salt water and the pattern of flow of the salt water have been modified by pumping of the supply wells at the Montauk Air Force Station so as to cause upward movement of salt water and contamination of the wells (see flow arrows, pl. 2). The velocity of the movement of the salt water toward the wells is directly proportional to the permeability of the deposits and the hydraulic gradient of the water and inversely proportional to the porosity of the deposits. Flow is radial toward the well screens from both the fresh water and salt water. This accounts for large variations in the chloride content of the water pumped at wells S17231 and S17859 (table 5), which reflect changes in the relative volume of fresh and salt water reaching the wells under different pumping rates.

DETERIORATION OF THE CHEMICAL QUALITY OF THE WATER

The quality of the water in the principal aquifer has varied widely since 1951 owing to salt-water encroachment. The original chloride content of the fresh water in the principal aquifer near the center of the Montauk Air Force Station was as low as 26 ppm in 1953 (table 5); in July 1960 it was 438 ppm, and in May 1961 it was 250 ppm.

Concentrations of other constituents also have varied widely during the same period. For example, comparison of the results of analyses of

CLIMATE

The Montauk Point area has a temperate marine climate, which is influenced greatly by the Atlantic Ocean and Block Island Sound. Moderate temperatures prevail; the mean annual temperature at Bridgehampton, about 25 miles west of the Montauk Lighthouse, was 50.9°F (table 2) during the period 1931–60. The mean annual precipitation during the same period was 47.73 inches. Mean monthly precipitation ranges from a low of 2.9 inches in July to a high of 4.7 inches in November.

A nonrecording rain gage was operated at Montauk Air Force Station from October 1960 to April 1961. Its records were compared with records of the Bridgehampton station, and showed a general correspondence, although the total precipitation was 27.09 inches at Montauk Air Force Station and 30.12 inches at Bridgehampton during the period of record.

METHODS OF INVESTIGATION

After a brief reconnaissance of ground-water conditions at Montauk Air Force Station and vicinity by the writers in September 1960, the U.S. Air Force requested the U.S. Geological Survey to make a more detailed investigation of the ground-water resources. During November 1960, a power auger was used to drill 13 auger holes to depths of about 80 to 160 feet below land surface. Geologic samples were obtained at most of the holes, but owing to contamination from caving and contact of the augers with the wall of the hole, as they were raised and lowered, the samples were considered to be only approximately representative of the deposits.

TABLE 2.—*Precipitation and temperature at Bridgehampton, Long Island, N.Y., 1931–60*

[Annual precipitation: absolute minimum, 32.28 in. in 1957; absolute maximum, 66.87 in. in 1958; mean 1931–60, 47.73 in. Annual temperature (° F): mean maximum, 58.6; mean minimum, 43.3; mean annual 50.9. Compiled from U.S. Weather Bur. reports]

Month	Precipitation				Mean monthly (inches)	Temperature		
	Minimum		Maximum			Mean monthly maximum (° F)	Mean monthly minimum (° F)	Mean monthly (° F)
	Inches	Year	Inches	Year				
January	0.55	1955	9.25	1958	4.20	38.9	25.1	32.0
February	1.65	1941	6.76	1939	3.61	39.0	24.9	31.9
March	2.28	1947	9.99	1953	4.61	44.7	30.6	37.7
April	1.28	1942	6.24	1947	3.65	54.5	38.9	46.7
May	1.07	1939	7.09	1948	3.45	64.4	47.9	56.2
June	0.22	1957	6.90	1941	2.86	73.5	57.1	65.3
July	0.52	1944	6.85	1959	2.88	79.3	63.4	71.4
August	0.73	1935	13.19	1952	4.25	78.6	62.8	70.7
September	0.08	1941	10.28	1960	3.41	72.3	56.5	64.4
October	0.51	1946	5.87	1939	3.57	63.1	46.9	55.0
November	0.77	1931	10.22	1944	4.73	52.8	37.9	45.4
December	1.58	1943	9.81	1936	4.08	42.1	27.7	34.9

674838 O—63——2

Thirteen observation wells, 2 inches in diameter and ranging in depth from about 70 to 150 feet, were installed at nine sites (test well symbols, pl. 1). At four of these sites, pairs of shallow and deep wells were installed to observe heads at different depths in fresh and salt water. The wells were developed and pumped by compressed air with a gasoline-driven jet pump.

Water from four of the observation wells was analyzed for chemical content. About 100 analyses were made of the chloride content of water from the observation wells and pumping wells in the report area. A water-level measurement program, begun immediately after the construction of the observation wells, was continued through September 1961. Water-stage recorders were installed on several wells for periods ranging from a few days to several weeks. The altitude of measuring points on observation wells were related to mean sea level by spirit leveling, and a water-level contour map (pl. 1) was prepared.

Thirty-four active and abandoned wells were inventoried (table 3), and a brief examination was made of the surficial geology, particularly of the exposures in cliffs along the south shore.

PREVIOUS INVESTIGATIONS

The surficial geology of the Montauk Point area has been described briefly by Fuller (1914) in a report, which contains a geologic map of Long Island and a few sketches of outcrops at Montauk Point. As part of another island-wide study of the ground-water resources, Suter, deLaguna, and Perlmutter (1949) prepared contour maps showing the depth to the Cretaceous deposits and bedrock beneath Long Island, including the Montauk area. A report by Perlmutter and Crandell (1959, p. 1064) presents generalized sections of the southshore beaches of Long Island, which suggest the presence of salt water in the deep aquifers beneath Montauk Point. However, no detailed study of the water resources of the area had been made prior to the present investigation.

ACKNOWLEDGMENTS

The writers acknowledge the cooperation of the U.S. Army Corps of Engineers, who supplied large-scale maps and other engineering data on former Camp Hero; the New York State Water Resources Commission, which provided records of existing wells; land owners who gave permission to enter their property to measure and install observation wells; and several well drilling firms which provided advice in planning the construction of the observation wells. The close cooperation of military and civilian personnel at both the Suffolk

TABLE 7.—*Chemical analysis, in parts per million, of Atlantic Ocean water at Montauk Point*

[Date of Collection: Jan. 19, 1961. Analysis by U.S. Geol. Survey]

Silica (SiO_2)	1.1
Iron (Fe)	.03
Manganese (Mn)	.0
Calcium (Ca)	356
Magnesium (Mg)	1,160
Sodium (Na)	9,470
Potassium (K)	353
Bicarbonate (HCO_3)	132
Carbonate (CO_3)	0
Sulphate (SO_4)	2,390
Chloride (Cl)	17,100
Fluoride (F)	.8
Nitrate (NO_3)	.2
Dissolved solids:	
Residue on evaporation at 180° C	32,500
Hardness as $CaCO_3$ (calcium, magnesium)	5,660
Noncarbonate hardness as $CaCO_3$	5,560
Specific conductance micromhos at 25°C	43,500
ph	7.3
Density g per ml	1.0220

SALT-WATER ENCROACHMENT

Salt-water encroachment is the movement of salt water so as to displace fresh water in an aquifer. The movement may be landward from the sea or upward from an underlying body of salt water. Contamination occurs when the salt water reaches a pumping well.

BOUNDARY OF FRESH WATER AND SALT WATER

The boundary between fresh and salt water in the report area is not a sharp interface but is a transitional zone of mixed water, commonly termed the "zone of diffusion." The zone of diffusion extends beneath the entire project area (pl. 2), and, in turn, is underlain by water that is nearly as salty as the Atlantic Ocean. The top of the zone of diffusion is concave upward, except for the area of upconing beneath pumping wells. Water at the top of the zone of diffusion has a chloride content of about 25 to 45 ppm. The chloride content increases downward to about 17,000 ppm. Below the bottom of the zone of diffusion, the salt water has a uniform density and contains about 17,000 ppm of chloride.

Theoretically, if the contact between fresh ground water of density 1.000 g per l and salt water of density 1.025 g per ml were sharp and if

TABLE 5.—*Chloride content of ground water, 1941–61*—Continued

[Analyses by U.S. Geol. Survey, unless otherwise indicated. See table 3 for other well data]

Well	Depth of well (feet)	Date sampled	Chloride (Cl) (ppm)	Remarks
S17859	126	Apr. 19, 1962	80	Well out of service due to low yield. Replaced by S21077 in August 1962.
S18512	95	Aug. 5, 1957	[2] 56	
		Sept. 12, 1960	46	
S19482	82	Dec. 8, 1960	25	
S19484	70	Dec. 9, 1960	95	
S19485	140	Dec. 2, 1960	2, 850	
S19487	80	Dec. 10, 1960	120	
S19488	82	Nov. 10, 1960	46	
S19489	125	Nov. 30, 1960	25	Supply well S21084, 120 ft. deep, installed nearby, August 1962.
S19490	103	Dec. 2, 1960	26	
S19491	71	Dec. 2, 1960	34	
S19492	151	Nov. 17, 1960	11, 500	
		Dec. 1960	11, 300	
S19493	71	Mar. 22, 1960	46	
S19494	87	Dec. 10, 1960	44	
		Apr. 19, 1961	37	
S19495	70–100(?)	Mar. 8, 1961	25	
S19496	----------	Sept. 12, 1960	30	
S19497	100	Apr. 1, 1961	45	Bailer sample.
S19499	96	Oct. 19, 1960	23	

[1] Analysis by Long Island State Park Commission.
[2] Analysis by C. W. Lauman & Co., Inc.

TABLE 6.—*Chemical quality of surface water*

[Analyses by U.S. Geol. Survey. See pl. 1 for location of sampling points]

Sampling point		Date sampled	Chloride (Cl) (ppm)	Nitrate (NO_3) (ppm)
No.	Location			
1	Block Island Sound	Dec. 2, 1960	17, 500	------
2	Atlantic Ocean	Nov. 30, 1960	18, 500	------
		Jan. 19, 1961	17, 100	0. 2
3	Stream, U.S. Military Reservation	Nov. 30, 1960	50	------
4	Swamp, U.S. Military Reservation near S19493	----------	--------	4. 2
5	Oyster Pond	Dec. 2, 1960	13, 500	------
		Apr. 12, 1961	10, 000	------
6	Stream near S19483	Nov. 30, 1960	40	------
7	Pond near S1245	Apr. 20, 1961	36	------
8	Montauk Harbor, about 0.3 mile west of report area	Dec. 2, 1960	16, 500	------

County Air Force Base, Westhampton, N.Y., and the Montauk Air Force Station expedited the drilling of the test wells and the collection of hydrologic data.

GEOLOGY

The Montauk Point area is underlain by crystalline bedrock of Precambrian age upon which rest, in succession, unconsolidated deposits of Cretaceus, Pleistocene, and Recent age. As the bedrock and the Cretaceous formations are believed to contain salt water and are not penetrated by any wells in or near the project area, only a brief description of them, condensed from Suter, deLaguna, and Perlmutter (1949, p. 13–46 and pls. 10, 13), is given.

PRECAMBRIAN BEDROCK

The bedrock probably consists of gneiss and schist. Its surface is about 1,000 to 1,300 feet below sea level and slopes southeastward about 80 feet per mile. Very salty water is probably contained in openings along joints and other fractures in the rock. Because the bedrock has low permeability and contains only salty water, it is not considered an aquifer.

CRETACEOUS FORMATIONS

Immediately above the bedrock is the Raritan formation, which is about 300 to 400 feet thick. The Raritan is divided into a lower unit called the Lloyd Sand Member and an upper unit called the clay member. The Lloyd Sand Member is an artesian aquifer that contains fresh water in the western part of Long Island, but at Montauk Point it probably contains salty water only. The overlying clay member confines the water in the Lloyd.

The Raritan Formation is overlain by undifferentiated deposits of Cretaceous age that include the Magothy and probably several younger Cretaceous formations (Perlmutter and Crandall, 1959). These deposits contain permeable zones partly separated by lenticular beds of silt, sandy clay, and clay. The permeable zones probably could yield as much as 1,000 gpm to individual large wells, but the water is believed to be nearly as salty as the ocean. The Cretaceous surface in western Long Island is dissected by channels as deep as 300 to 500 feet below sea level. Similar deep channels probably exist beneath parts of the Montauk Point area, but the data are scanty as the deepest test well in the report area is terminated in glacial deposits at a depth of 130 feet below sea level.

TABLE 3.—*Records of wells, Montauk Point area*

[All wells screened in late Pleistocene deposits]

Depth of well: Reported depths given in feet; sounded depths given in feet and tenths.
Top of well within 1 ft of land surface, unless indicated otherwise in Remarks column.
Use of water: A, abandoned; AFS, Air Force supply well; D, domestic; N, not used; O, observation; S, stock.
Measuring point: Ag, air gage; Hc, hole in cover; Ls, land surface; Pb, pump base; Ta, top of angle iron; Tc, top of casing; Tf, top of flange; Tn, top of nipple.
Water level: Reported depths given in feet; measured depths given in tenths and hundredths.
Remarks: gpm (gallons per minute).

Well	Owner or tenant	Depth of well (feet)	Diameter of well (inches)	Use of water	Measuring point		Water level		Temperature of water		Remarks
					Description	Altitude (feet above mean sea level)	Depth below measuring point (feet)	Date	(°F)	Date	
S1202	U.S. Coast Guard	35.6	6	A	Hc	32.80	27.63	Apr. 12, 1961			
S1245	Deep Hollow Ranch	113	6	D, S	Tn	55.93	52.58	Apr. 8, 1961			Yield, 10 gpm.
S1473	Mr. Lewis Kayel	109	6	A		75					Driller reports indication of salting.
S2149	Montauk Water Supply Corp.	112	8	A		45					
S2150	do	70	8	A	Tc	30	23.98	Apr. 7, 1961			Top of well 1.6 ft above land surface.
S2151	do	74	8	A	Ls	38	21	June 1927			Yield, 75 gpm.
S2440	Mr. Lewis Kayel	117	4	D	Tn	70					Yield, 5 gpm. Measuring point about 7 ft below land surface.
S3259	U.S. Air Force	106	6	A			58	May 1942			Formerly U.S.A.F. well 1. Yielded 40 gpm with drawdown of 6 ft after pumping 8 hr in 1941. Replaced by S17231.
S3260	do	112	6	A	Ta	65.03	60	June 1942			Formerly U.S.A.F. well 2. Yielded 40 gpm with drawdown of 5 ft after pumping 8 hr in 1941. Measuring point about 8 ft below land surface.
S3261	do	123	6	A	Pb	72.69	70.27	Apr. 12, 1961			Formerly U.S.A.F. well 3. Yielded 40 gpm with drawdown of 6 ft in 1941. Specific capacity 4.8 gpm per ft. Measuring point about 8 ft below land surface.
S3599	U.S. Coast Guard	69	6	A	Tn	27.14	25.85	do			Specific capacity 10.7 gpm per ft. Measuring point about 5 ft below land surface.
S7421	Long Island State Park Comm.	95	6	N	Tc	31.45	[1] 29.23	do			

TABLE 5.—*Chloride content of ground water, 1946–61*

[Analyses by U.S. Geol. Survey, unless otherwise indicated. See table 3 for other well data]

Well	Depth of well (feet)	Date sampled	Chloride (Cl) (ppm)	Remarks
S1202	37	Sept. 16, 1960	46	
S1245	113	Apr. 8, 1961	21	
S2150	70	Mar. 13, 1946	18	
S2240	117	Oct. 19, 1960	32	U.S.A.F. well 1.
S3259	106	Mar. 20, 1951	27	
		Apr. 10, 1952	36	
		Oct. 1, 1953	78	
		Nov. 27, 1956	99	
		Dec. 13, 1956	103	
		Dec. 3, 1957	69	
S3260	112	Oct. 1, 1953	99	U.S.A.F. well 2.
		Nov. 27, 1956	26	
		Dec. 13, 1956	26	
S3261	123	Oct. 1, 1953	26	U.S.A.F. well 3.
		Dec. 13, 1956	29	
		Dec. 13, 1957	104	
		Sept. 30, 1958	302	
S3599	69	Sept. 16, 1960	88	
		Mar. 31, 1961	95	
S7421	95	Aug. 7, 1952	[1] 46	
S15812	95	Sept. 12, 1960	46	
S17231	118	Sept. 9, 1960	160	U.S.A.F. well 1A.
	126	Dec. 9, 1960	70	U.S.A.F. well 1A; well deepened Oct. 1960. Replaced by well S20766 (1B) in April 1962. Chloride content of water in 1B was 300 ppm in July 1962.
		Mar. 1, 1961	175	
		Mar. 9, 1961	200	
		Mar. 27, 1961	200	
		Mar. 29, 1961	140	
		Mar. 30, 1961	110	
		Mar. 31, 1961	180	
		Apr. 1, 1961	195	
		Apr. 13, 1961	150	
		Apr. 25, 1961	180	
		Feb. 20, 1962	90	Well not being pumped due to low yield.
S17859	126	Feb. 16, 1960	245	U.S.A.F. well 3A.
		Feb. 25, 1960	250	
		Mar. 1960	400	Pumping rate reported to be 100 gpm.
		May 1960	145	Pumping rate reported to be 65 gpm.
		July 13, 1960	438	Pumping rate reported to be 100 gpm.
		Sept. 9, 1960	405	
		Sept. 12, 1960	405	
		Oct. 19, 1960	232	
		Nov. 11, 1960	250	
		Nov. 30, 1960	190	
		Dec. 10, 1960	180	
		Mar. 2, 1961	170	
		Mar. 23, 1961	50	Well out of service.
		Mar. 30, 1961	80	
		Apr. 1, 1961	50	

See footnotes at end of table.

TABLE 4.—*Chemical analyses, in parts per million, of water from wells, Montauk Point area*

[Analyses by U.S Geol. Survey except where indicated otherwise]

Well	Depth (feet)	Date sampled	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium [1] (Na)	Potassium [1] (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Remarks
S3259	106	Mar. 20, 1951	20	0.11	------	10	3.7	------	------	52	10	27	0.1	0.2	121	39	0	198	7.2	U.S.A.F. well 1
S3259	106	Apr. 10, 1952	23	3.1	------	11	6.3	------	------	51	14	36	.2	.3	139	53	12	139	7.0	
S3259	106	Oct. 1, 1953	20	16	------	15	6	49		53	14	78	.1	.5	215	63	19	369	6.8	
S3259	106	Nov. 27, 1956	24	3.7	1 1	16	7.4	60		58	13	99	.3	.2	258	72	24	460	6.8	
S3259	106	Dec. 13, 1956	25	7.6	1 0	16	7.4	62		57	13	103	.2	.1	265	71	24	472	6.7	
S3259	106	Dec. 3, 1957	28	5.9	.9	14	5.3	44		58	8.8	69	.3	.8	200	57	10	349	6.0	
S3260	112	Oct. 1, 1953	19	7.1	------	16	6.3	58		46	14	99	.2	.5	251	66	29	437	6.8	U.S.A.F. well 2
S3260	112	Nov. 27, 1956	24	1 0	.5	9	4.8	24		55	12	26	.2	.1	128	44	0	198	7.2	
S3260	112	Dec. 13, 1956	23	2	.6	9	4.9	22		55	10	26	.2	.2	124	44	0	196	7.0	
S3261	123	Oct. 1, 1953	21	2 5	------	10	4.6	21		53	13	26	.2	.3	124	48	5	192	6.9	U.S.A.F. well 3
S3261	123	Dec. 13, 1956	17	1.5	.6	10	4.2	24		54	9.7	29	.3	.1	127	43	0	203	7.0	
S3261	123	Dec. 3, 1957	25	5.9	.9	14	7.1	60		43	14	104	.2	.7	247	64	29	454	6.0	
S3261	123	Sept. 30, 1958	19	2 8	1.3	22	14	168		29	29	302	.3	.1	596	113	89	1,070	6.1	
S15812 [2]	95	Aug. 5, 1957	------	1	------	------	------	------		------	------	56	------	8 4	------	24	------	------	6.8	
S17231	126	Nov. 1, 1960	22	------	------	15	4.4	48		71	14	64	.2	.7	205	56	0	364	7.5	U.S.A.F. well 1A
S17859	126	Feb. 16, 1960	20	2.0	.9	24	16	146		42	61	245	.4	.4	536	126	92	917	6.8	U.S.A.F. well 3A
S17859	126	Nov. 1, 1960	21	------	------	22	14	139		43	27	250	.2	.6	533	113	78	969	6.8	Do.
S19491	71.5	Dec. 10, 1960	18	------	1.4	9	3.6	23	3.1	45	8.3	30	.3	.2	129	37	0	205	7.3	
S19492	150.5	Dec. 10, 1960	3.0	50	7.9	746	928	5,530	94	56	1,690	11,300	.5	46	21,300	5,680	5,640	30,200	5 8	
S19493	70 9	Mar. 22, 1961	27	3.2	1	10	7.6	29	2.4	59	12	46	.2	1.7	167	57	8	276	7.1	
S19494	87	Dec. 10, 1960	16	------	7.9	13	8.1	37	3.8	97	11	44	.4	.6	183	66	0	356	7.1	

[1] Sodium, potassium calculated as sodium (Na).

[2] Analysis by C. W. Lauman & Co., Inc.

S15812	do	95	10	D	Tc	31	29	Nov. 15, 1957			Specific capacity 11 gpm per ft. Measuring point about 5 ft below land surface. Yielded 150 gpm with drawdown of 14 ft in 1957.
S17231	U.S. Air Force	126	8	AFS	Pb	66.88	64.34	Oct. 13, 1960	52	Jan. 5, 1961	U.S.A.F. well 1A. Deepened 10 ft, October 1960. Screen length, 20 ft. Replaced by S20766(1B), 127 ft deep, in April 1962. Water contained 300 ppm of chloride in July 1962.
S17859	do	126	8	AFS	Ag	76.34	69	July 14, 1959	52	Sept. 9, 1960	U.S.A.F. well 3A. Yields 100 gpm with drawdown of 26 ft after pumping 8 hr. Replaced by nearby well S21077 in August 1962. Water is salty.
S19482	do	82.3	2	O	Tc	47.68	44.88	Apr. 12, 1961	52	Dec. 10, 1960	
S19483	do	82.0	2	O	Tc	16.69	13.45	do	[2] 52.5	Apr. 8, 1961	
S19484	do	70.4	2	O	Tc	50.85	47.33	do	[2] 52.5	do	
S19485	do	140.0	2	O	Tc	51.04	48.13	Apr. 19, 1961	[2] 53	do	
S19486	do	76.8	2	O	Tc	69.32	66.66	Apr. 12, 1961			
S19487	do	80.0	2	O	Tc	31.84	29.01	do			
S19488	do	87.3	2	O	Tc	49.17	46.59	do	[2] 52.3	Apr. 8, 1961	New supply well S21084, 118 ft deep, installed nearby in August 1962.
S19489	do	124.6	2	O	Tc	48.83	46.29	do	[2] 52.1	do	
S19490	do	103.5	2	O	Tc	31.91	[3] 30.01	do	[2] 52.4	do	
S19491	do	71.5	2	O	Tc	32.33	[3] 30.53	do	[2] 53	do	
S19492	do	150.5	2	O	Tc	44.95	44.22	do	51	Dec. 9, 1960	Temperature, 52.5°F,[2] Apr. 8, 1961.
S19493	do	70.9	2	O	Tc	44.86	[1] 42.42	do	50	Mar. 22, 1961	
S19494	do	87.4	2	O	Tc	58.60	56.05	do	[2] 51.9	Apr. 8, 1961	
S19495	American Telephone and Telegraph Co.	70–100(?)		D							Depth uncertain; submersible pump.
S19496	U.S. Air Force			N					52	Sept. 8, 1960	Used occasionally for emergency supply; yields 20 to 30 gpm. Chloride content of water increased to 150 ppm by July 1962 after several months of intermittent pumping.
S19497	do	100.4	4	A	Tf	65.45	[1] 63.60	Apr. 12, 1961			
S19498	do		4	A							Formerly U.S. Army well 4. Obstruction in well at 78 ft.
S19499	Indian Field Ranch	96	2	D, S	Tc	25.6	22	1950			
S19500	do	26	1¼	A	Tc	25.66	9.75	Apr. 19, 1961			

[1] Mean daily water level from recorder graph.
[2] Temperature measured by electronic thermometer.
[3] Water level estimated.

PLEISTOCENE DEPOSITS

GENERAL CHARACTER AND STRATIGRAPHY

The Pleistocene deposits of Long Island are end products of the advance and melting of several ice sheets during the Pleistocene Epoch. Because of the complex geologic history of these deposits, which are important sources of ground water, a summary of the general character of glacial deposits and of the sequence of glacial units in Long Island is given below, followed by a description of the strata in the Montauk Point area.

Glacial deposits may be divided into two principal types: (1) till and (2) stratified drift. Till is predominantly composed of unsorted or poorly sorted deposits of boulders, gravel, sand, silt, and clay, dropped directly from melting ice. Till deposited as an irregular surficial mantle is called ground moraine. A ridge composed chiefly of till and marking the former front of an ice sheet is called an end moraine. Stratified drift is deposited by meltwater streams as outwash deposits, in lakes as glaciolacustrine deposits, and in the sea as glaciomarine deposits. Stratified drift is generally distinctly bedded and well graded, owing to the sorting action of the water from which it is deposited. The beds may range in texture from gravel to clay size, depending on the velocity of the water and the size of the source material. A detailed account of the origin and nature of glacial deposits is given in Flint (1957).

The lowermost formation of Pleistocene age on Long Island is the Jameco Gravel, a coarse-grained outwash deposit. Above the Jameco is the Gardiners Clay, a fossiliferous marine interglacial formation composed chiefly of beds of silt and clay. The beds above the Gardiners Clay consist of several sequences of outwash and till. Fuller (1914, p. 114–157) divided these units into the Jacob Sand and the Manhasset Formation. He subdivided the Manhasset Formation into two outwash members separated by a till member called the Montauk Till, after the type area at Montauk Point. According to Fuller, erosion of the Manhasset Formation was followed by deposition of more outwash and till during the last, or Wisconsin Stage of glaciation. The uppermost deposits of till were laid down as part of the Ronkonkoma end moraine, which forms the surface of most of the Montauk Point area.

Because of the difficulty in recognizing discrete units of till and outwash in many well logs and outcrops, the Geological Survey generally uses the informal name upper Pleistocene deposits for glacial deposits of post-Gardiners age. Although Fuller believed that the post-Gardiners deposits were partly Illinoian and partly Wisconsin in age, later workers, including Wells (1934, p. 121–122), and Mac-

age from the existing wells will reduce the size of the cone of depression, and constructon of new supply wells at the western and eastern limits of the station will distribute the pumping so as to improve the balance between recharge and pumpage.

QUALITY OF WATER

CHEMICAL QUALITY

Precipitation, which is the source of all fresh ground water in the Montauk area, is nearly pure; the chloride content of a sample of rainwater taken in December 1960 was only 5 ppm. Thus, it is apparent that nearly all the chemical constituents in the water shown by the analyses in table 4 were derived from interaction of the water with the minerals and organic constituents of the soil and underlying beds through which the water moved. Locally water may contain a high chloride and nitrate content where wastes from sanitary systems or fertilizer compounds have percolated down to the zone of saturation. Also, near the bottom of the principal aquifer, some fresh water moves into the zone of diffusion and mixes with salt water.

Most of the normal fresh water in the project area has about 25 to 30 ppm chloride, but in a few places the content may be about 45 ppm (tables 5 and 6). Concentration in excess of about 45 ppm indicates salt-water encroachment, unless attributable to other causes such as activities of man or residual salt-water contamination. The fresh ground water has less than 50 ppm of hardness as $CaCO_3$, less than 130 ppm of dissolved solids, and is neutral to slightly basic. The results of analyses of fresh ground water given in table 4 indicate that the iron plus manganese content of all but two samples exceeded 0.3 ppm, which is recommended by the U.S. Public Health Service (1946) as the maximum allowable limit for domestic use.

The streams and ponds in the Montauk area generally are fresh; most water from these sources contains less than 50 ppm chloride (table 6). The larger surrounding bodies of water are very salty. A chemical analysis of Atlantic Ocean water at Montauk Point is given in table 7.

TEMPERATURE

The temperature of water in 14 wells screened in the principal aquifer ranges from about 51° to 53°F (table 3). The average temperature of the water is about 52°F, which is 1° higher than the mean annual air temperature. The perennial low temperature of the ground water makes it highly suitable for air conditioning and cooling.

(well 2), and S3261 (well 3), were put back into service, using the original low-capacity pumps (15 gpm or less). No data on pumpage were collected, but reportedly the combined installed pump capacity of the wells did not exceed about 35 gpm (fig. 9). In 1956 or 1957, deep-well turbine pumps rated at about 64 gpm were installed on wells S3259 and S3261. No records of pumpage were kept. In January 1959 well S17231 (well 1A) was drilled as a replacement for nearby well S3259 (well 1). In February 1959 wells S17231 and S3261 (3) were the only wells in operation. In June 1959 wells S17231 and S3261 were out of service frequently owing to well failure. In July 1959 well S17859 (3A) was installed as a replacement for nearby well S3261. The new well was equipped with a deep-well turbine pump rated at about 100-gpm capacity. From September 1959 to November 1960 well S17859 was the principal pumping unit. Pumping rates averaged about 80 gpm during much of this period, but at times were as high as 110 gpm (fig. 9). Average daily pumpage ranged from about 30,000 to about 60,000 gpd (fig. 8). In November 1960 well S17231, which had been out of service since February 1960, was deepened about 10 feet and was put back into use shortly thereafter. In January and February 1961 well S17231 was the chief source of water as the yield of well S17859 dropped so low that it was put out of service entirely in March 1961. In April 1961 S17231 was the only well in operation at Montauk Air Force Station and rehabilitation of well S17859 was being considered. In April 1962, S17231 was replaced by S20766(1B). In August 1962, S17859 was replaced by S121077, and a new supply well S21084 was being drilled near S19489 at the west side of the Air Force Station.

RELATION OF PUMPAGE TO RECHARGE

In the section dealing with the hydrologic cycle (p. 14), it was estimated that about 25 percent of the precipitation reaches the zone of saturation. On this basis, recharge at the Montauk Air Force Station (pl. 1) may be about 80,000 to 100,000 gpd. However, not all the recharge at the Air Force Station is available for withdrawal, as some must discharge to the sea in order to maintain the boundary between fresh and salt water close to its natural position. Recharge within the area of the cone of depression shown on plate 1 may be as low as 40,000 to 50,000 gpd. Comparison of these estimates with the average withdrawal of about 50,000 gpd shows that any surplus of recharge over present withdrawals may be small. Reduction in pump-

Clintock and Richards (1936, p. 332), have suggested that they were laid down entirely during the Wisconsin Stage.

PLEISTOCENE STRATIGRAPHY OF THE MONTAUK POINT AREA

Because the evidence from generalized well logs and well samples was scanty and because not enough time was available to make a detailed examination of the lithology and structural features of the outcrops along the south shore, the glacial deposits in the report area were not correlated specifically with known Pleistocene formations but have been broadly divided into (1) a lower unit of stratified drift and (2) an upper unit consisting of undifferentiated deposits of till and stratified drift (pl. 2).

LOWER UNIT OF STRATIFIED DRIFT

The lower unit of stratified drift is composed chiefly of nonmarine grayish-brown medium to coarse sand and gravel and some thin lenses of clay and silt. It does not crop out, hence is known entirely from well logs and a few samples. A sample from a depth of 120–126 feet below land surface at well S17231 (pl. 1) consists chiefly of angular to subangular clear and iron-stained quartz (about 80 percent) and miscellaneous grains (about 20 percent), which include granite, gneiss, schist, and the minerals garnet, biotite, chlorite, and hornblende, and other dark minerals. Because of their high permeability, thickness, and extensive distribution, the beds of the lower unit comprise the principal aquifer in the report area (see "Ground Water").

UNDIFFERENTIATED DEPOSITS OF TILL AND STRATIFIED DRIFT

Immediately above the lower unit of stratified drift is an undifferentiated unit of varied lithology composed of interbedded deposits of till and stratified drift about 30 to 100 feet thick (see diagonally ruled area on pl. 2). Although not clearly discernible in plate 2, a study of the well logs and outcrops suggests that, in general, the lower 20 to 40 feet of the undifferentiated deposits consists of interbedded gray and brown clay, laminated green and gray silt and clay, and some thin lenses of fine brown sand (figs. 2, 3, pl. 2). Samples of micaceous silt from depths of 55–75 feet below land surface, near S19849, consisted chiefly of quartz, biotite, and muscovite. No forams or diatoms were found in the material. The middle part of the undifferentiated deposits is probably composed largely of gray and brown compact clayey and gravelly till, which grades laterally into fine-grained stratified drift in some places. Immediately above the compact till is generally stratified drift, which ranges in thickness from a featheredge to about 30 feet and is composed chiefly of beds and lenses of brown and gray silt, fine to medium sand, and clayey

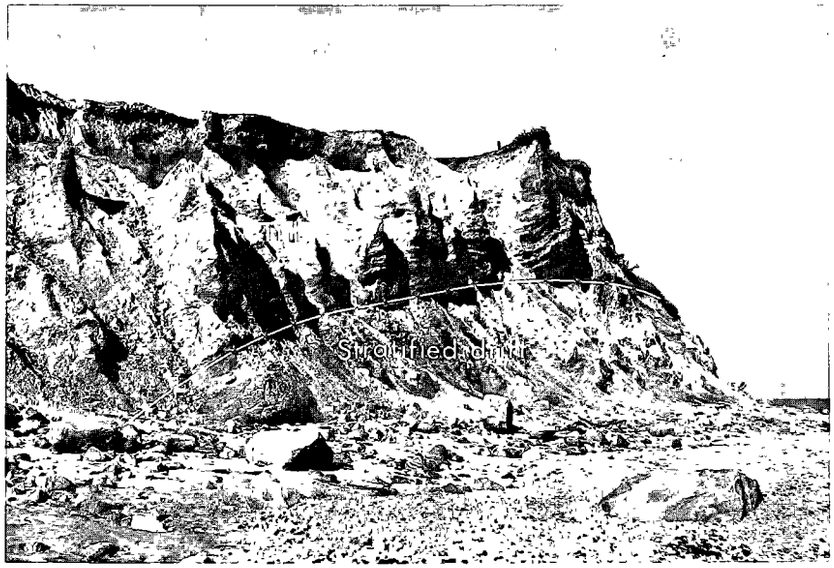


FIGURE 2.—Outcrop showing till above stratified drift composed chiefly of interbedded silt and clay, south side of Montauk Air Force Station. (Photograph by U.S. Geological Survey.)

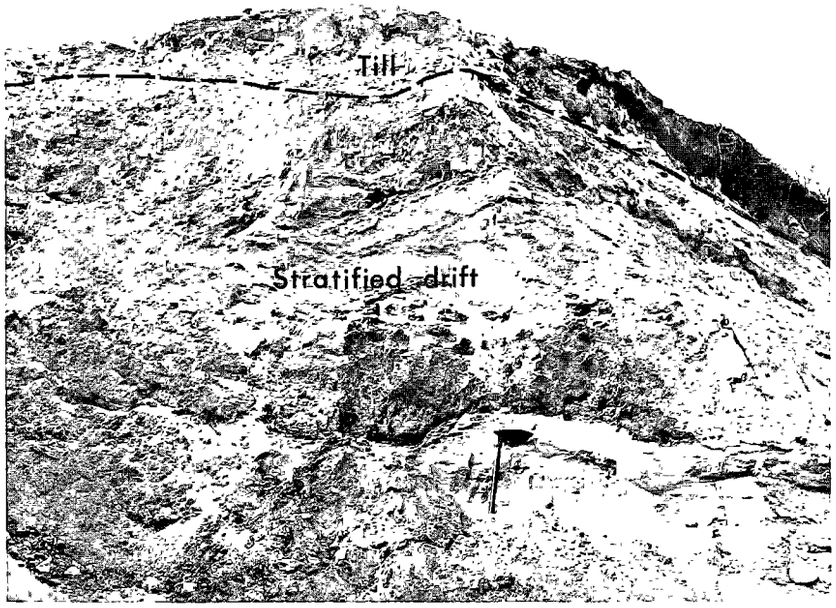


FIGURE 3.—Close-up view of till and underlying stratified drift composed chiefly of silt and clay, south side of Montauk Air Force Station. The trencher is lying against a lens of fine sand. (Photograph by U.S. Geological Survey.)

The largest individual withdrawals in 1961 were made from two supply wells (S17231 and S17859) at the Montauk Air Force Station. These wells, which were operated together or singly during 1960–61, pump an average of about 50,000 gpd, but, rarely, peak pumpage has been about 150,000 gpd. The water is used for general purposes and air conditioning. The next largest withdrawals are made at Montauk State Park (well S18512, pl. 1), where pumpage averages about 9,000 gpd during the summer months. About 86,000 gallons were pumped for use at the park in 1960. A small number of year-round homes, summer homes, and two dude ranches in the southwestern part of the area are supplied by individual wells; the total pumpage is small. Well S3599 supplies a small amount of water for maintenance and domestic use at Montauk Lighthouse in the extreme eastern part of the area.

Most of the production wells range from about 90 to 126 feet deep and are 2 to 8 inches in diameter. The depth to water is generally below suction limit; consequently, the most common types of pumps are deep-well turbine, submersible, and force.

HISTORY OF WITHDRAWALS

The number of privately-owned domestic wells and the amount of water pumped by them have changed little during the past 20 to 30 years. During World War II from 3 to 5 wells supplied former Camp Hero (U.S. Military Reservation, pl. 1). No records were obtained of the pumpage during that period.

When Montauk Air Force Station was established in part of Camp Hero in 1951, three former U.S. Army wells, S3259 (well 1), S3260

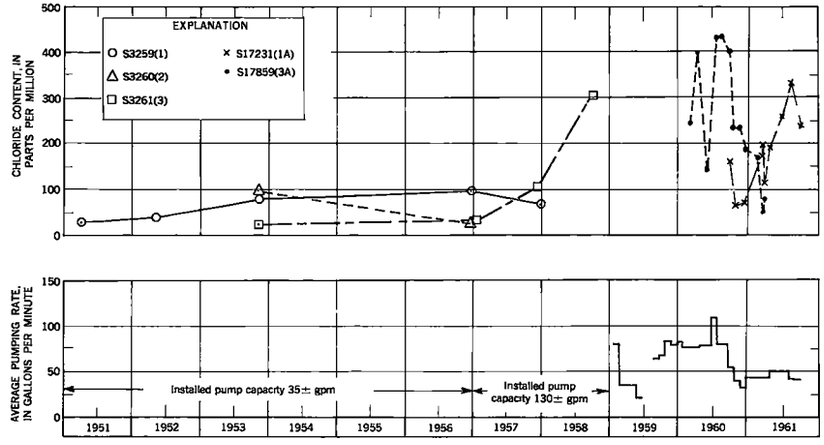


FIGURE 9.—Relation between chloride content of water and pumping rate. See text for well numbers.

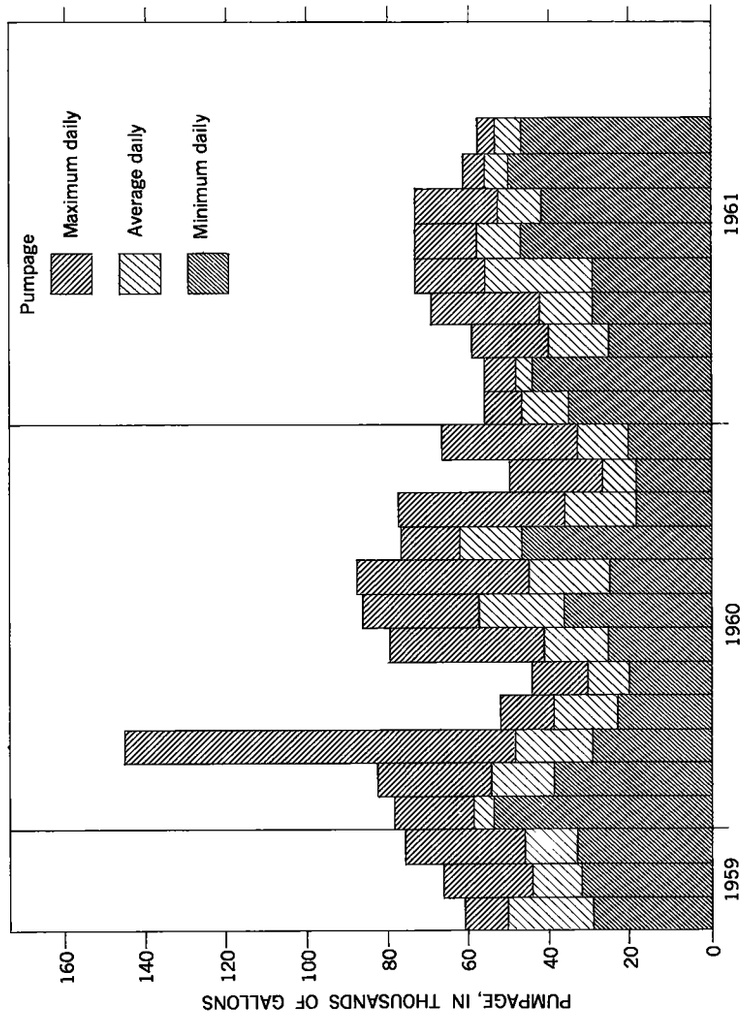


FIGURE 8.—Daily pumpage by months at Montauk Air Force Station, 1959–61.

sand (fig. 4 and pl. 2). The uppermost part of the undifferentiated unit is generally a loose brown clayey till, about 5 to 20 feet thick, which contains some boulders. In some outcrops the intervening stratified drift is missing, and the upper till apparently rests directly on the lower till.

The till sheets and stratified drift, which crop out and are penetrated by wells in the report area, are probably correlative mostly with the upper Pleistocene deposits of western Long Island, but conceivably older Pleistocene units such as the Gardiners Clay and Jameco Gravel also may be present. Lohman (1939, p. 231–232) reports an assemblage of marine, brackish-water and fresh-water species of Pleistocene diatoms in a greenish-gray clay, reported to be the Gardiners, collected at an outcrop about half to three-quarters of a mile west of Montauk Lighthouse (pl. 1). The assemblage represents climatic conditions similar to or warmer than those of the present, which suggests an interglacial stage. As most of the species are living at present in the same region, Lohman concluded that the stage could not be named with the data on hand. It is not certain whether the clay examined by Lohman is correlative with the Gardiners Clay or "20-foot" clay found in western Long Island or neither. Additional field examination of the outcrops and more detailed laboratory study of samples are required before more specific correlations of the beds can be made.

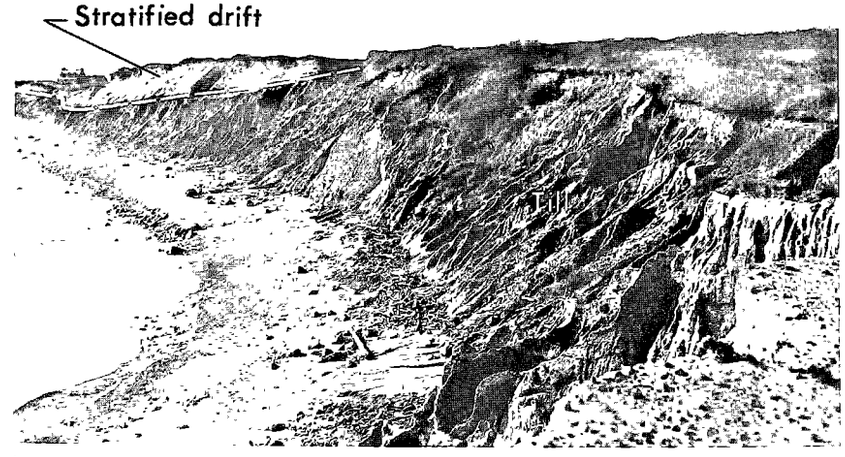


FIGURE 4.—Outcrop showing stratified drift above till, south side of Montauk Air Force Station. (Photograph by U.S. Geological Survey.)

674838 O—63——3

RECENT DEPOSITS

Thin deposits of sand, gravel, and boulders deposited in Recent time are distributed along the narrow beaches of Montauk Point. Large boulders and cobbles are most common on the southern and eastern shores (figs. 2 and 3). Sand and swamp deposits are more common along the low-lying north shore. Reddish lenses of garnet and ilmenite-rich sand can be seen in many places in beach deposits bordering the bluffs. The Recent deposits are uninmportant as aquifers because of their thinness, small intake area, and proximity to sea water.

GROUND WATER

SOURCE AND OCCURRENCE

The source of all fresh ground water in the report area is precipitation on the land surface, which averages about 48 inches annually. If all the precipitation were available for ground-water recharge, it would be equivalent to 2.3 million gallons per day per square mile. However, part is lost by direct evaporation from the soil and plants and from ponds and swamps that occupy numerous kettle holes; part is transpired by numerous trees and other forms of vegetation; part runs off to the sea in several small streams (pl. 1) whose discharge reaches a peak during and immediately after heavy precipitation; part is lost by seepage from cliffs along the south shore; and part percolates downward to replenish the ground-water reservoir.

Although no detailed studies have been made, general comparison of conditions at Montauk Point with those in western Long Island suggests that about 25 percent of the precipitation (12 inches, or about 570,000 gpd per sq mi) reaches the water table during a year of average precipitation. During years of above- or below-average precipitation, ground-water recharge is proportionately greater or lesser than average.

After seeping through the soil zone the water percolates downward through the pore spaces in the sand, gravel, silt, and clay to the main zone of saturation in the lower part of the undifferentiated deposits of till and stratified drift (pl. 2). The upper surface of the zone of saturation is called the water table. Scattered perched water bodies are found above the main water table, owing to lenses and beds of silt and clay, which retard downward movement of water. Some water in the upper part of the main zone of saturation moves to discharge areas at the shoreline, and some percolates slowly downward through confining beds of till, silt, and clay to the underlying principal aquifer. Water in the principal aquifer is under artesian pressure owing to the relatively low permeability of the overlying beds. The imaginary surface to which water in wells tapping the principal aquifer rises is

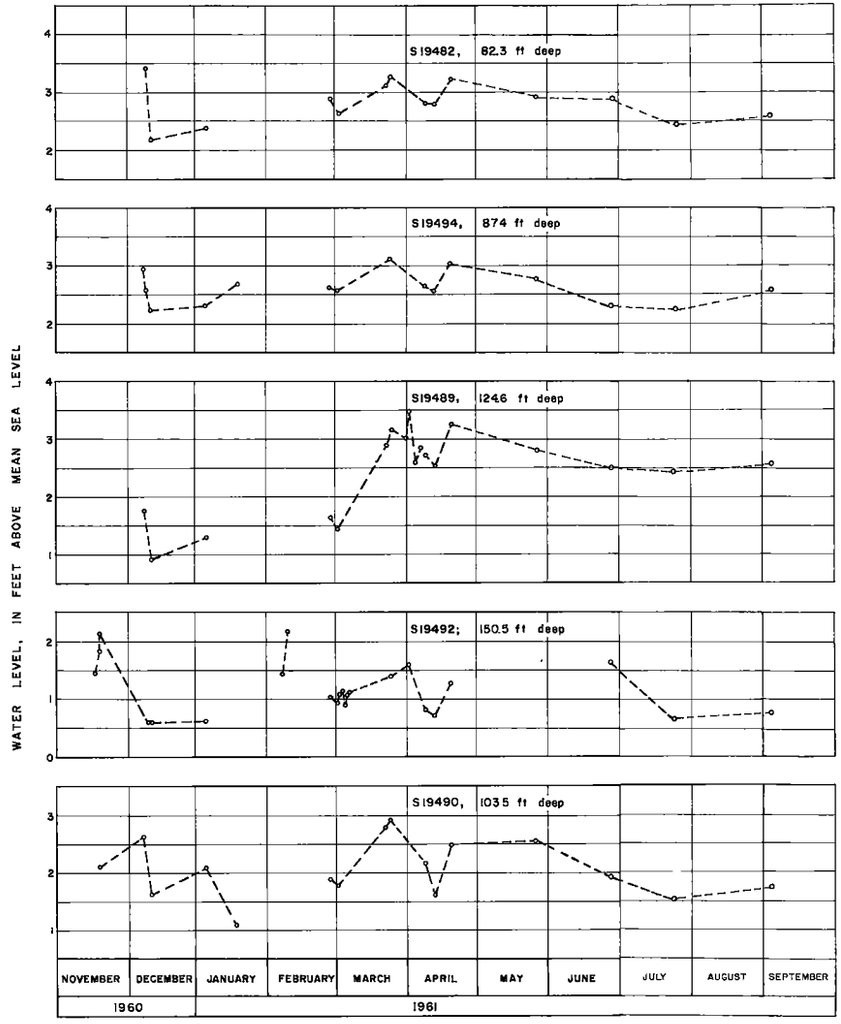


FIGURE 7.—Range in water-level fluctuations, November 1960 to September 1961.

PUMPAGE AND UTILIZATION

GENERAL

Gross pumpage, all from deposits of Pleistocene age, averages about 50,000 gpd. At times, however, daily peak pumpage may be as much as 150,000 gallons, as in March 1960 (fig. 8). Public supply systems do not operate in the report area; the nearest one is the Montauk Water Co. which supplies the village of Montauk, about 3 miles west of the report area.

LONG-TERM FLUCTUATIONS

Net changes in water levels over long periods of time, resulting from changes in climatic conditions or prolonged pumping at relatively high rates, are more significant than short-term fluctuations, because they indicate changes in the long-term balance between recharge and discharge. Such changes, as discussed in a later section, may shift the natural fresh-salt-water boundary (pl. 2), landward or seaward. The fluctuations of water levels described are of the piezometric surface, as data on fluctuations of the water table are too scanty for interpretation.

Periodic monitoring of the water levels in the Montauk Point area began about November 1960, after the construction of observation wells for this investigation. Comparison of a water level reported by a driller in 1941 for former supply well S3261, near the center of the Montauk Air Force Station, with its present (1961) level suggests a decline of about 5 feet in the static water level near the cone of depression shown on plate 1.

The period of record of water-level measurements in the observation wells is too short to detect any significant trends. The decline in water levels of about 1.5 feet in December 1960 and January 1961, shown by the hydrographs on figure 7, suggests a decrease in recharge during the winter months. The rise, which began about February 1961 and continued into March and April, shows the effect of increased precipitation and consequent increase in recharge during that period. These fluctuations correlate closely with natural seasonal fluctuations observed in artesian wells in western Long Island. Long-term records in observation wells 20 miles or more west of the report area indicate that piezometric levels in some parts of Montauk Point may decline several feet during the summer when evaporation, use of water by plants, and pumping are at a maximum. Conceivably, water levels in some wells tapping the principal aquifer at and near the Air Force station may decline to about sea level or possibly to below sea level. A permanent decline in piezometric levels will cause a rise in the fresh-salt-water boundary (pl. 2), which will be indicated by an increase in the chloride content of the water.

called the piezometric surface (pl. 1). Except for withdrawals through wells, most water in the principal aquifer discharges to the sea by upward seepage at and near the shoreline.

WATER IN THE UNDIFFERENTIATED DEPOSITS OF TILL AND STRATIFIED DRIFT

Undifferentiated deposits of till and stratified drift form the upper unit shown on plate 2. Owing to the poor sorting and clay content of the till and to the predominance of silt and sandy clay in the stratified part of the unit, the undifferentiated deposits probably cannot yield substantial amounts of water to individual wells in most parts of the area. Some water occurs in the undifferentiated deposits as perched water bodies above the main water table, and some is contained in minor permeable zones below the water table. The lower part of the undifferentiated unit consists chiefly of saturated deposits of till, silt, and clay, which serve mainly as confining beds for the underlying principal aquifer.

PERCHED WATER BODIES

Perched water bodies are generally small isolated bodies of water temporarily stored above the main water table in scattered lenses of permeable material underlain by clay and silt. During the drilling of most of the observation wells and during the foundation test borings for several structures at the Montauk Air Force Station, water was reported at depths ranging from about 5 to 25 feet below land surface, or about 35 to 100 feet above sea level. These altitudes, which are as much as 40 to 95 feet above the water level in the principal aquifer (pl. 1), are a strong indication of the existence of perched water bodies as they are too high to represent the main water table.

The fact that perched water is common was verified further by the history of test well S19486 in the northeast corner of the U.S. Military Reservation (pl. 1). Land surface at the well is about 70 feet above sea level. During the drilling of the auger hole for the well, the material from 0–8 feet was reported as dry; 8–16 feet as moist; and at 16 feet as a perched water zone of unknown thickness. A well driven in the auger hole to a depth of 65 feet below land surface remained dry for several months. To determine whether the well was plugged, it was filled with water, which seeped out through the screen in a few days. In March 1961 the well was driven about 12 feet deeper and penetrated the main zone of saturation between about 68 and 70 feet below land surface.

Perched water bodies may yield sufficient water for intermittent domestic use, but they generally are not dependable if large amounts are required for long periods. During months of low precipitation, wells tapping perched water-bearing zones may go dry, owing to the

large declines in water level in short periods of time, which are characteristic of these zones. An example of the large fluctuations which may be expected in perched water tables is given by the record of a test boring for a building near well S19495 in the center of the Montauk Air Force Station. When the boring was completed at a depth of 30 feet on November 22, 1955, the water level was 10 feet below land surface (about 50 feet above sea level). The water level declined during the next several days and by November 26 it was 23 feet below the land surface, a decline of 13 feet.

MINOR WATER-BEARING ZONES

Scattered minor water-bearing zones occur below the main water table in lenses of sand and gravel in the undifferentiated deposits of till and stratified drift. The location, thickness, extent, and continuity of these zones in most of the area is not apparent from present data. The upper limit of these zones is the main water table; the lower limit is unknown. As nearly all the wells terminate in the underlying principal aquifer, the altitude and configuration of the water table can only be estimated. Scanty data from test holes, drilled with a power auger, suggest that it may be as high as 10 to 17 feet above sea level in the central part of the area, about 16 feet above sea level in the southwestern part (S19500, table 3), and about at sea level at the shoreline. The water table is mainly in beds of silt, clay, and till, which are not suitable for development of large supplies.

In some shallow minor water-bearing zones, the water is under watertable, or unconfined, conditions; but at greater depths where these zones are overlain by thick beds of silt and clay, the water may be confined. Indirect evidence of the low yield of the minor water-bearing zones is the fact that all the active wells, including those constructed for domestic use, were drilled through these zones and completed in the principal aquifer. Two wells, S19500 and S1202, originally completed in the shallow beds were abandoned and replaced by wells screened in the principal aquifer. However, as the data are scanty and to make the maximum use of all available supplies, all future wells should be logged carefully and samples should be taken at 5-foot intervals to evaluate further the possible existence of productive zones at shallow depths.

CONFINING BEDS

The data shown on plate 2, and records of other wells not on the line of these sections, indicate that the lower part of the undifferentiated deposits consists chiefly of beds of silt, clay, sandy clay, and possibly some deposits of till. At several wells (for example, S17231, pl. 2) the confining beds are at least 20 to 30 feet thick, and at one

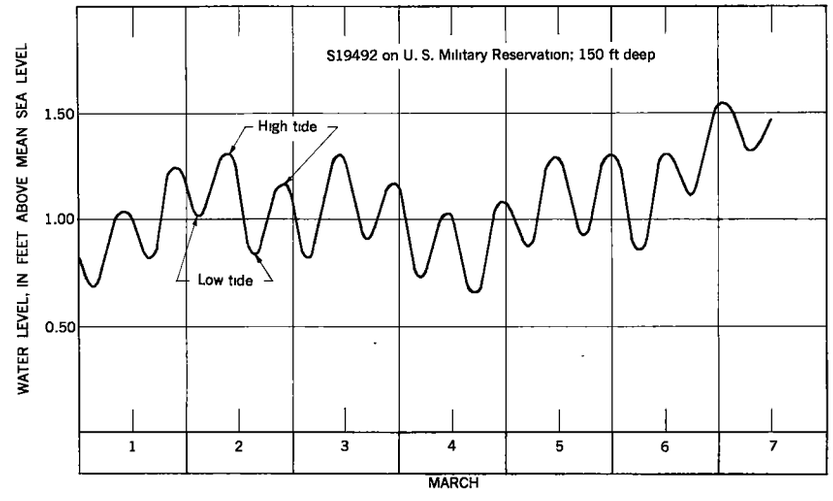


FIGURE 6.—Fluctuations of water level in a well screened in salt water in stratified drift, March 1–7, 1961.

Sound. In the examples shown, the daily fluctuations normally range from about 0.3 foot in the inland area (well S19493) to about 0.8 foot near the extreme eastern (well S7421) and southern (well S19497) shorelines. The combination of high tide and low barometric pressure accompanying the storm on April 10 resulted in an unusual peak in the water level; the fluctuation for the day in well S19497 was about 1.5 feet.

The hydrograph of well S19492 (fig. 6) screened in salty ground water also shows tidal and barometric effects similar to those illustrated in figure 5. The daily fluctuation in water level in well S19492 is normally about 0.4 foot, which is of about the same magnitude as that in nearby shallow well S19493, which is screened in the overlying fresh ground water. Comparison of the water-level records for the two wells shows that changes in levels in the fresh and salt water are simultaneous, as well as similar in magnitude, indicating that the fresh and salty ground waters are in hydraulic continuity.

Intermittent pumping of a well also causes fluctuations in water levels as illustrated by the hydrograph (fig. 5) of observation well S7421 at Montauk State Park. The well is about 10 feet from well S15812, which operates automatically in accordance with changes in pressure in a storage tank. On April 8 and 9, 1961, the pump was started and stopped five times as shown by the series of rapid drawdowns and recoveries, which appear as vertical lines on the hydrograph of well S7421.

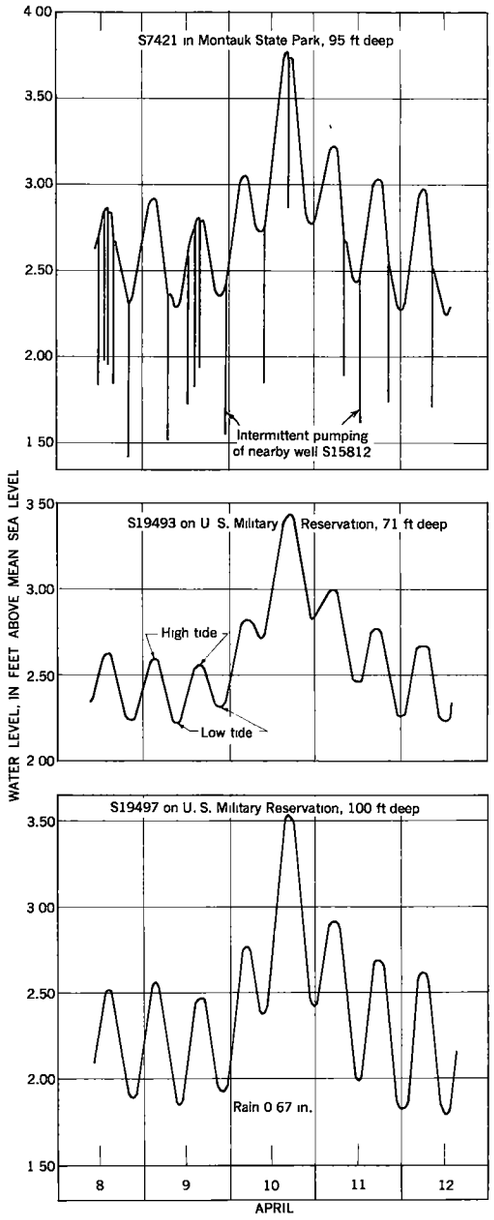


FIGURE 5.—Fluctuations of water level in three wells screened in fresh water in stratified drift, April 8–12, 1961.

place they are about 65 feet thick (S1245, pl. 2). The effectiveness of these confining beds is confirmed hydraulically by the differences in head between the water table and the piezometric surface of the principal aquifer, which are estimated to be as much as 8 to 12 feet in the central part of the area. At well S19500 (26 feet deep) in the southwestern part of the area, the water table is about 16 feet above sea level, or about 13 feet above the piezometric surface (pl. 1). The barometric effects and the distinct tidal effects shown by the hydrographs (figs. 5 and 6) of wells which are as much as 0.4 mile from the shore and screened in the principal aquifer, is additional evidence of the wide extent and low permeability of the confining beds.

WATER IN THE LOWER UNIT OF STRATIFIED DRIFT

PRINCIPAL AQUIFER

The principal aquifer is in the lower unit of stratified drift shown in plate 2. The upper limit of the aquifer, which is the bottom of the overlying confining beds, ranges in altitude from about sea level to 40 feet below sea level. The lower limit, for purposes of this report, is set at the top of the zone of diffusion between fresh and salty water, which ranges in altitude from about sea level to 130 feet below sea level. The principal aquifer consists chiefly of beds of medium to very coarse sand and gravel, about 10 to 80 feet thick. Scattered thin lenses of silt and silty clay are interbedded in some places with the more permeable beds.

Water in the principal aquifer is replenished by slow downward leakage from the overlying confining beds. The amount and rate of leakage per unit area of confining beds probably is small owing to their low permeability; however, the leakage over a large area may be substantial. Water in the principal aquifer is under artesian pressure, but the head is not sufficient to cause wells to flow. The depth to the static water level in existing wells ranges from about 13 to 70 feet below land surface (table 3). The depth to water is greatest in the center of the area where the altitude of the land surface is highest, and is least at the shoreline.

The principal aquifer is the only source of fresh water tapped by active wells. Wells 8 to 10 inches in diameter and finished with screens 10 to 20 feet long yield as much as 150 gpm. Reported specific capacities of wells range from 4 to 11 gpm per foot of drawdown. The history of pumping at Montauk Air Force Station suggests that sustained pumping at rates of 50 gpm or more will probably induce salt-water encroachment laterally or from below in most of the area.

PIEZOMETRIC SURFACE

The imaginary surface to which water in wells tapping the principal aquifer will rise is called the piezometric surface. The piezometric surface responds to changes in pressure in the aquifer caused by tidal and barometric fluctuations and by variations in natural recharge and discharge, and pumping. Plate 1 shows contours on the piezometric surface for April 12, 1961. The surface generally mirrors the shape and, in a very subdued manner, the topographic profile of the Montauk peninsula, except for the cone of depression formed around the pumping wells at the Montauk Air Force Station. The cone was roughly circular and had a diameter of about 0.5 mile in 1961. Its diameter and depth varies with the duration and rate of pumping, as well as with changes in natural recharge and discharge. The maximum depth of the cone is unknown as no readings were obtained in the main supply well S17231.

The contours shown on plate 1 are based on the measurements of water levels made chiefly on April 12, 1961. The measurements were adjusted to a common tidal stage. A few, made on April 7 and 8, were adjusted by comparison of regional water-level trends, to conform with the April 12 measurements. The highest known points on the piezometric surface of April 12 were about 3.5 feet above sea level at well S19484 at the north side of the Montauk Air Force Station and at well S2150 in the western part of the project area. The lowest measured altitude was about 1.3 feet above sea level in well S3599 near Montauk Lighthouse. The altitude in the center of the cone of depression was not determined but probably was as low as several feet below sea level.

MOVEMENT OF FRESH WATER

The following description of movement of water applies chiefly to water in the principal aquifer as few or no data were collected on flow in the shallow minor water-bearing zones in the upper part of the main zone of saturation.

In general, ground water moves from points of high head to points of low head (that is, from areas of recharge to areas of discharge). Before the start of pumping at the Montauk Air Force Station, ground water in the principal aquifer probably moved radially away from a mound on the piezometric surface near the center of the Montauk Air Force Station. The mound may have been as much as 7 feet above sea level, according to estimates from drillers' records. As a result of relatively heavy intermittent pumping, a cone of depression has formed around supply well S17231 (pl. 1) at the Air Force Station. The arrows oriented perpendicular to the piezometric contours show the horizontal component of movement of the water

and indicate that a part of the flow which formerly discharged to the sea now moves inland toward the center of the cone of depression.

Plate 2 illustrates the pattern of movement in the vertical section. The arrows show that during pumping some fresh water and salt water move radially toward the screen of supply well S17231. The remainder of the fresh water moves toward discharge areas at and near the shoreline. Some mixes with salt water to form the zone of diffusion and ultimately discharges to the sea. (See "Salt-water encroachment.") The hydraulic gradient under which the fresh water is moving probably ranges from about 2 to 10 feet per mile in most of the area, but near pumping wells it is higher.

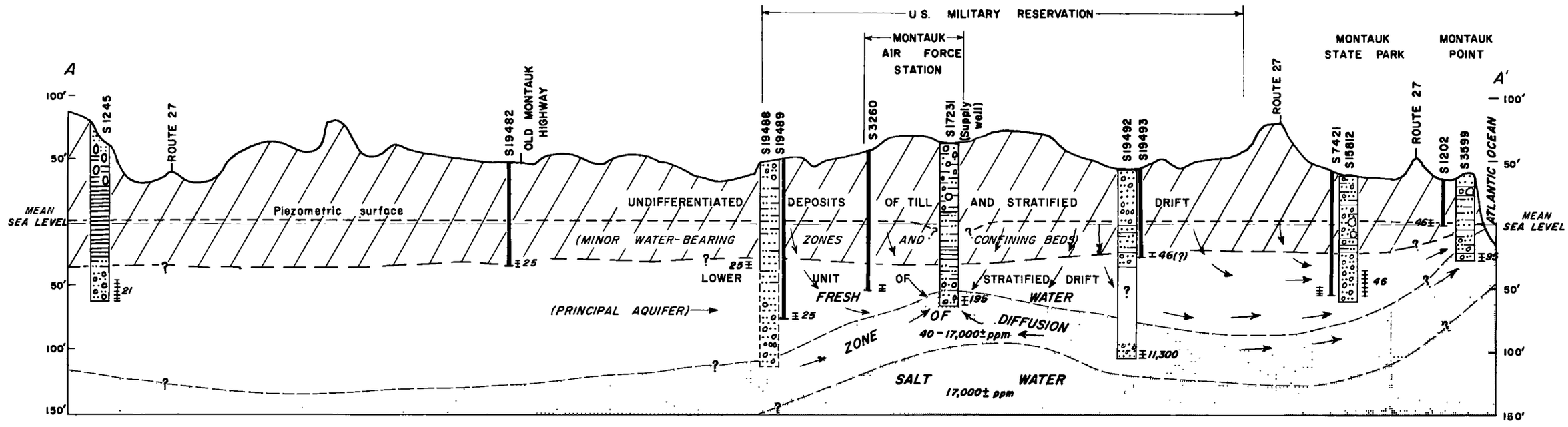
Measurements in the observation wells and continuous records from waterstage recorders show that the artesian heads in the principal aquifer are constantly changing, owing to tidal, barometric, and pumping effects. Although the altitude of the piezometric surface fluctuated a foot or two during the period of record, the shape remained about the same, and consequently the general pattern of movement of fresh water was approximately as shown on plates 1 and 2.

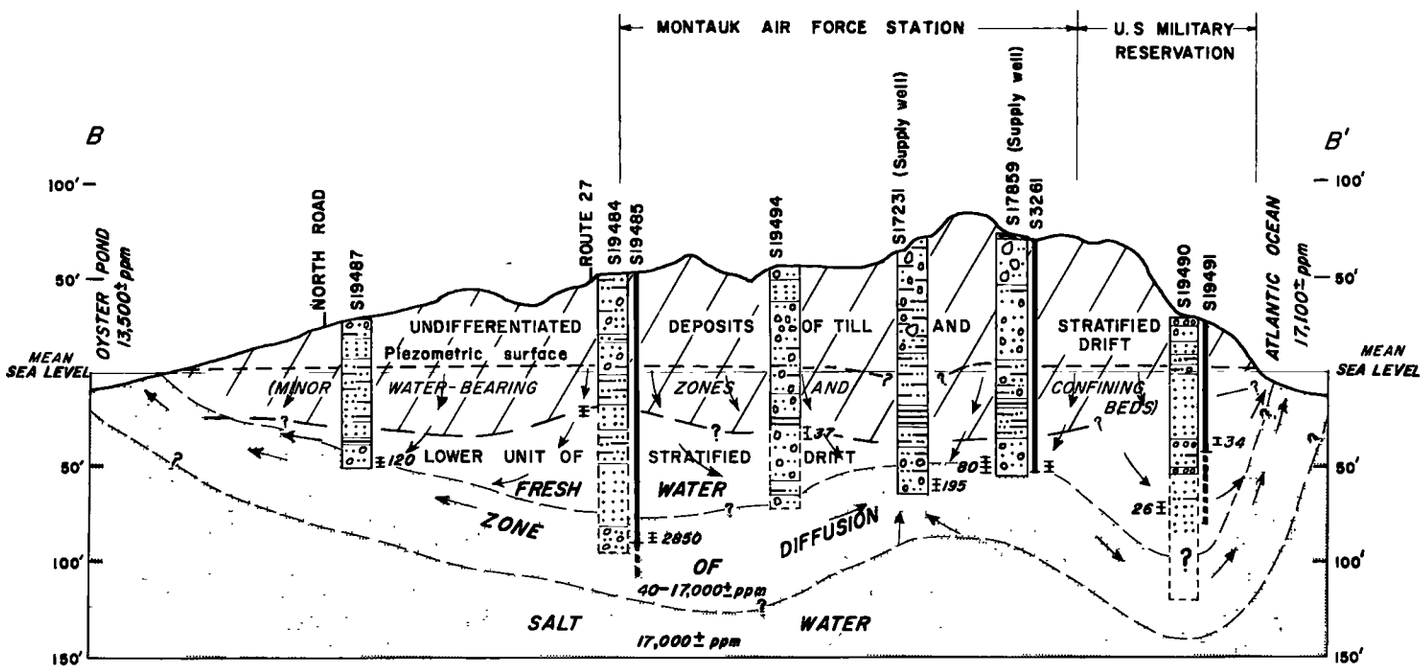
FLUCTUATIONS OF WATER LEVELS

Fluctuations of water levels in wells are the result of changes in the balance between recharge and discharge in aquifers. Analysis of both short- and long-term fluctuations provides important data on the hydraulic characteristics of an aquifer. For example, the altitude and character of the fluctuations of water levels in wells screened at different depths give evidence of hydraulic interconnection or of separation between aquifers and indicate whether the water in the aquifer is confined or unconfined.

SHORT-TERM FLUCTUATIONS

Minor and recurring fluctuations of water levels in the principal aquifer in the report area, are caused by transient influences such as changes in barometric pressure and oceanic tides. A rise in barometric pressure causes water levels in wells to decline; a decline in pressure causes water levels to rise. Tidal effects produced by the pull of the moon and the sun on the oceans cause pressure changes in both the fresh and salty ground-water bodies as illustrated by the water-level fluctuations shown on the hydrographs in figures 5 and 6. The magnitude of the fluctuations is due partly to the tidal efficiency and partly to the barometric efficiency of the well, which are related to the degree of confinement of the aquifer. Tidal effects diminish with increased distance from the shoreline. The hydrographs show typical pairs of high and low water levels in fresh-water wells produced chiefly by daily tidal changes in the Atlantic Ocean and Block Island





EXPLANATION

Boulders

Gravel

Sand

Silt, silty sand, and sandy clay

Clay

Direction of movement of ground water

S19490

Well symbol and number
Solid line is cased part of well; dashed line is drilled depth

Well symbol
Log not shown

Geologic boundary

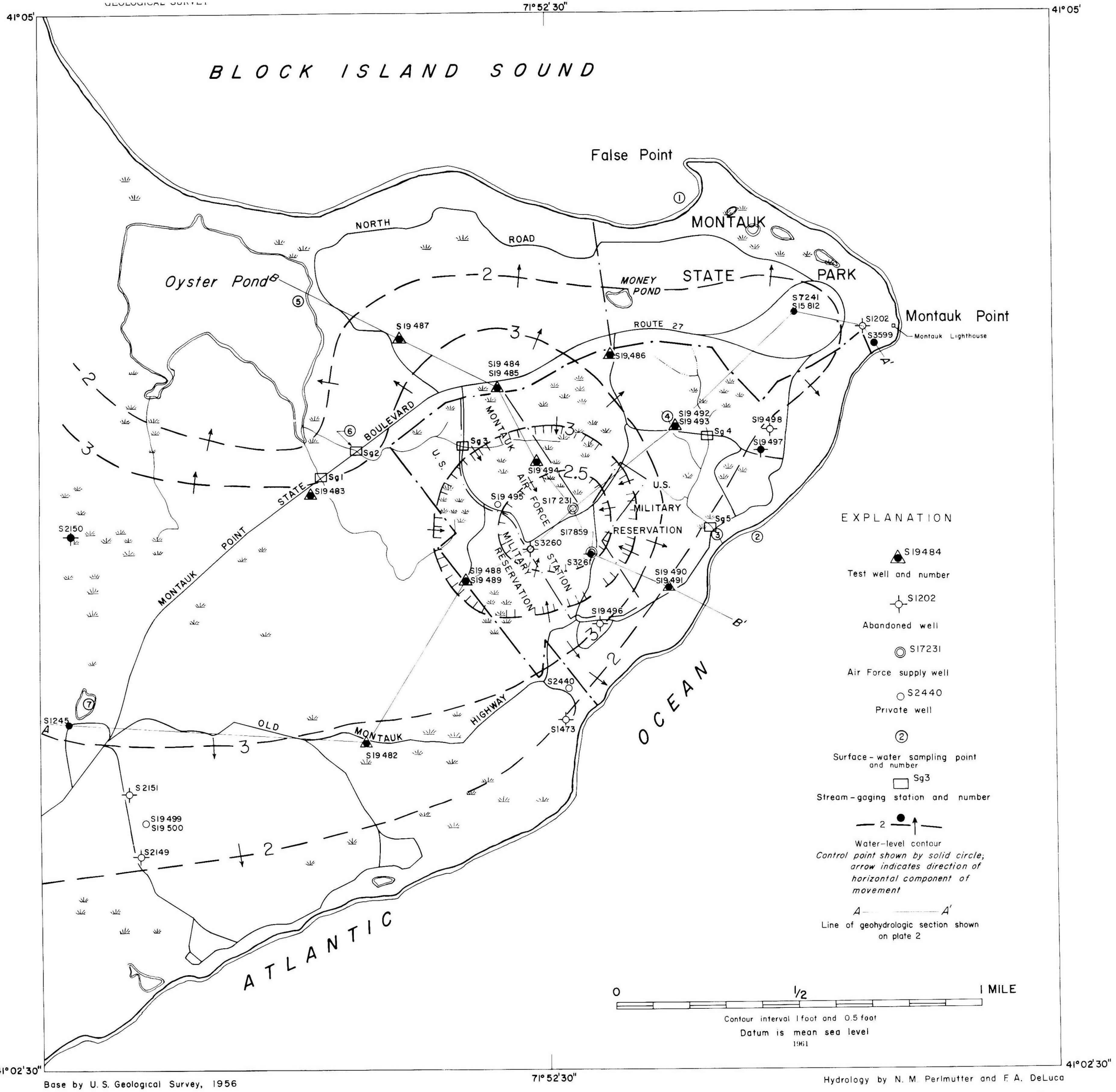
26

Well screen and chloride concentration, 1960-61. Results in parts per million (ppm)

GEOHYDROLOGIC SECTIONS *A-A'* AND *B-B'*, MONTAUK POINT, NEW YORK

0 ½ 1 MILE

674838 O - 63 (In pocket)



Base by U. S. Geological Survey, 1956

Hydrology by N. M. Perlmutter and F. A. DeLuca

MAP OF MONTAUK POINT, NEW YORK, SHOWING LOCATION OF WELLS, SURFACE-WATER SAMPLING POINTS, STREAM-GAGING STATIONS, AND WATER-LEVEL CONTOURS ON THE PIEZOMETRIC SURFACE OF THE PRINCIPAL AQUIFER

674838 O - 63 (In pocket)

Foxworthy, B.L., Page 216

Session IX

Regional Problem Situations

Introduction

Robert L. Ketter, Chairman*

Introductory Remarks

The format used in this session purposely will differ with those used in the preceding sessions, which were concerned with the gross overall problems of the fresh water of New York State. They have dealt both philosophically and practically with the problem, but have, by and large, been concerned with overall problems. Having an engineering background and being concerned with engineering problems, I appreciate the necessity eventually of getting down to case studies. The discussions this morning are more of this nature, and you will probably note the similarity of this session to technical sessions of professional societies. The papers will be presented by individuals rather than panels, and I will ask for discussion following each paper.

*Dean, Graduate School, State University of New York at Buffalo.

Long Island, N. Y.—A Challenge to Man's Water-Management Skills*

B. L. Foxworthy**

Summary

Despite the current drought, the major "water problem" of Long Island is not one of current shortages, but rather is a problem of protecting and managing the island's huge reservoir of fresh ground water. The future well-being of millions of people will be vitally affected by the degree of man's success in meeting this water-management challenge.

The scientific information now available and that expected from current studies is not adequate for selecting a "best" water-management scheme for Long Island. Thorough, scientifically rigorous appraisals of various alternative water-management plans, and the probable hydrologic consequences of each, are urgently needed. However, the effects to date of man's development of the ground-water resources affords valuable guidance. Intensive withdrawals have caused local imbalances in the system, such that the outflow exceeds inflow; the resulting removal of fresh ground water from storage has been manifested by declines of ground-water levels and by salt-water encroachment. The "yield" of the hydrologic system—that is, the amount of water available for use—is controlled largely and directly by the methods of water development, use, and disposal.

Introduction

Despite the current drought, the major "water problem" of Long Island, New York, is not one of current or imminent shortages; it is instead a problem of protecting and managing a huge but vulnerable reservoir of ground water so as to obtain the fullest use of this water to meet future demands. However, the absence of imminent shortages, or of severe hardships resulting from current shortages, does not diminish the importance of this problem. At the present time, Long Island's ground-water reservoir probably supplies more water for high-priority human requirements than does any other single well-defined aquifer system in the world, and it is destined to supply water for countless millions of people in the future. However, its usefulness to man can be greatly diminished by indiscriminate or unwise development within a few decades; conversely, its value can be greatly enhanced by wise management—which perhaps will be fostered by some of the attendees of this conference.

Efficient and effective management of Long Island's water will require not only an abundance of wisdom and regulatory strength, but also an equally important commodity—valid information. Fortunately, far-sighted water-management officials of New York State and Nassau and Suffolk Counties have recognized the vulnerability of the ground-water system and the necessity for "lead time" to put into operation effective methods of management and conservation. Consequently, sophisticated and far-reaching water-management plans are being sought, and some recommendations already have been received. Several methods of conserving and augmenting the ground-water resources of Long Island are being considered. These include desalting of sea water by the use of atomic energy, artificial recharge, reclamation of water from sewage, and others. Unfortunately, the scientific information needed to select a "best" water-management plan is incomplete at this time.

At present, the conditions of occurrence and the general extent and magnitude of the fresh-water resources are fairly well understood, largely as a result of studies made by the U. S. Geological Survey in cooperation with the New York State Water Resources Commission and Nassau and Suffolk County agencies. These same agencies are now engaging in studies to develop a better quantitative understanding of how the entire hydrologic system of Long Island functions, and of the changes that take place in the quality of the fresh water as it moves through the system. These current studies probably will not, in themselves, indicate a "best" water-management scheme. However, they are fundamental requisites to what is most urgently needed—thorough, scientifically rigorous appraisals of various alternative water-management plans, and the probable long-term hydrologic consequences of each.

*Publication authorized by the Director, U. S. Geological Survey.

**Hydrologist in charge of Long Island Program, Water Resources Division, U. S. Geological Survey.

The Hydrologic System

The scope and complexity of the Long Island water problem may be seen from the following brief outline of the hydrologic system, the course and consequences of man's development of it, and the broad limitations and conditions that must be satisfied for fully effective management of it in the future.

The main fresh-water reservoir is a huge wedge-shaped mass of sedimentary rock materials that are saturated with water. The reservoir extends from the water table (fig. 1), which locally rises to altitudes of more than 80 feet above sea level, down to an impermeable bedrock which is as deep as about 2000 feet in the southcentral part of Long Island.

The huge mass of sedimentary rock materials that contain the fresh water consists largely of silt and clay of low permeability, within which are layers of sand of moderate to high permeability. However, the lowermost beds—as thick as 300 feet—are mainly permeable sand, and the uppermost part consists largely of highly permeable sand and gravel. The saturated beds – singly and collectively – are many times more permeable to water moving parallel to the beds than to water moving across them. Thus, within the natural flow system lateral movement of the ground water is enhanced and vertical movement is greatly retarded.

The fresh ground-water reservoir is enclosed by salty ground water on all sides. It is hydraulically connected with salt water of the surrounding ocean, sound, and bays near the shores and locally overlies the salty ground water at depth. The sides of the fresh ground-water reservoir are zones of diffusion wherein the fresh water mixes with and dissipates into the adjacent salty water. Figure 2 is a highly generalized north-south cross-section through Long Island, showing the general relations of the fresh and salty water, and the movement of fresh water through the hydrologic system.

The volume of the sedimentary rock materials that are saturated with fresh water is truly huge. Although the southernmost extent of fresh ground water beneath the Atlantic Ocean is not adequately known, a conservative estimate is that the volume of rock materials—from bedrock to the water table —that is saturated with fresh water is about 300 cubic miles. The volume of fresh water that is available for man's use is much less, because the ground water occupies only the interstices between the grains of these materials, and because not all of that water could ever be pumped out. However, at least 20 trillion (million-million) gallons can be considered as "recoverable storage." At the present average rates of withdrawal on Long Island (about 400 million gallons per day), this amount represents nearly a 150-year supply, even under the assumption of no additional replenishment.

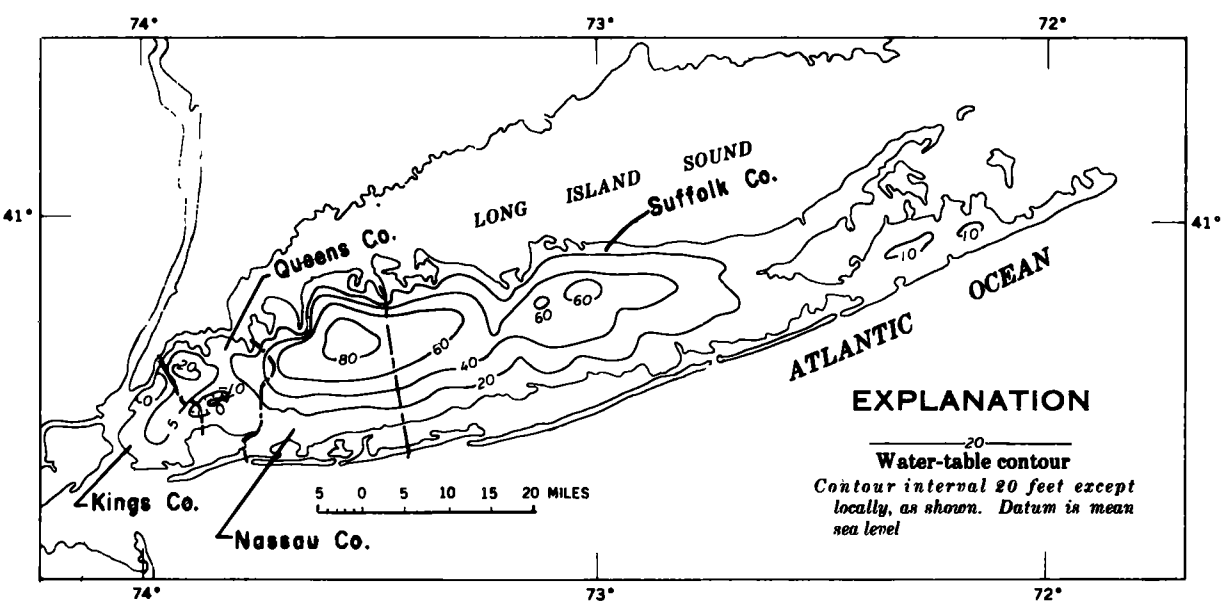


Figure 1—Map of Long Island, N.Y., showing generalized contours on the water table (upper surface of the ground-water reservoir).

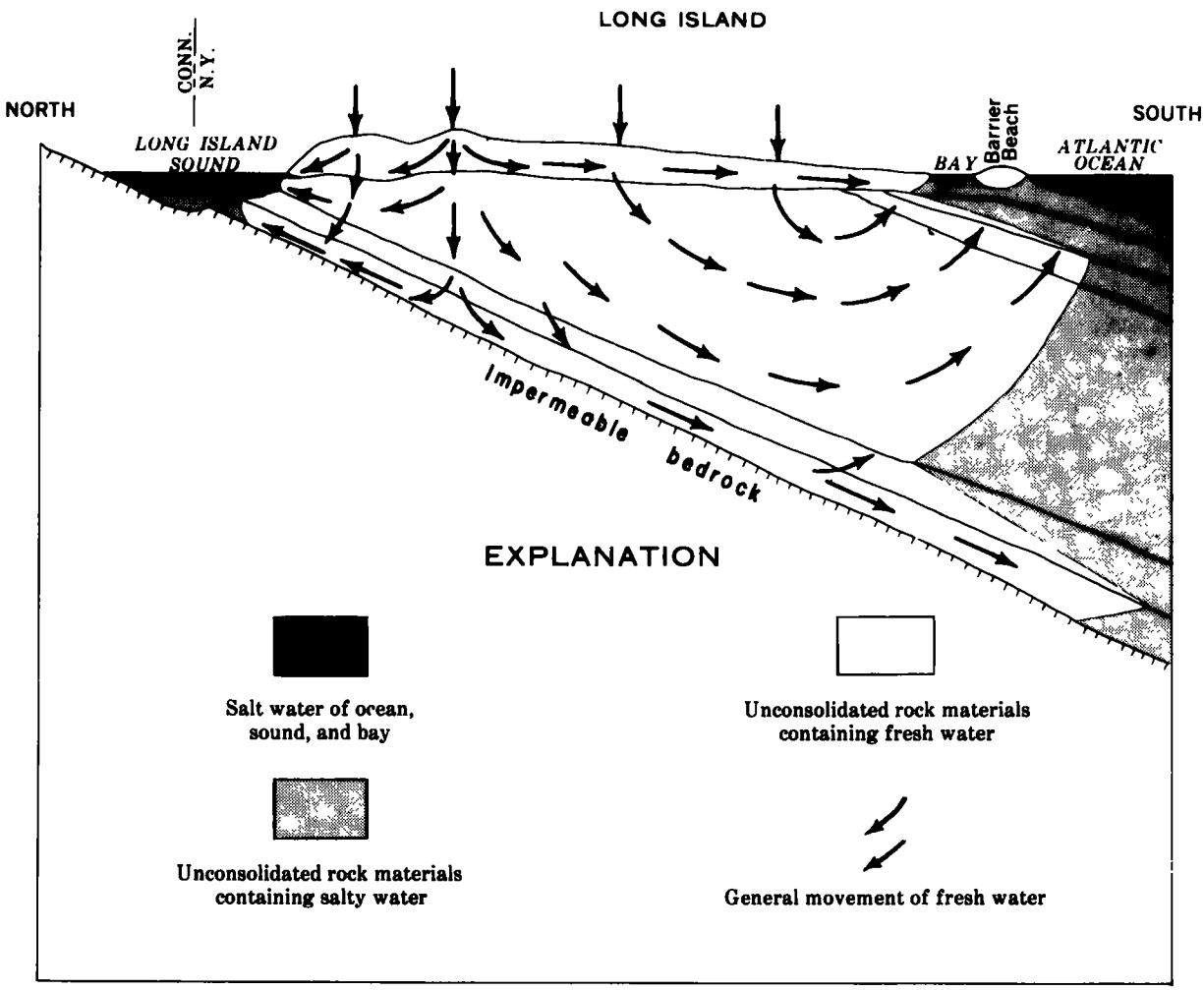


Figure 2—Schematic cross section through Long Island, N.Y., showing general ground-water conditions prior to development.

Natural Conditions

The ground-water system on Long Island, at the beginning of man's development of it, represented a balanced dynamic system (fig. 2). Average annual inflow to the system—that is, recharge from precipitation—was exactly balanced by average annual outflow from the system. Outflow comprised discharge of ground water to streams, evapotranspiration losses from the ground-water system, and submarine discharge of fresh water into salty water. A large percentage of the outflow—perhaps as much as 90 percent—discharged from the highly permeable shallow deposits, mostly to the streams that flow into the ocean, bays and sound. The streams functioned as ground-water drains and, except during heavy storms and periods of rapid snowmelt, their flow consisted entirely of ground-water seepage. In the terms of the simplest form of the equation of hydraulic continuity, wherein:

$$\text{Outflow} = \text{Inflow} \pm \Delta \text{ Storage},$$

the average outflow from the Long Island system under natural conditions was equal to the average inflow; there was no net change in amount of fresh ground water in storage (Δ Storage $= 0$).

Current Development

Man's development of the ground water on Long Island has followed a pattern that has reflected changing population trends, attendant changes in the use and disposal of water, and the response of the hyldrologic system to these changes. The historic pattern of development, which is described in a recent Geological Survey report by R. C. Heath and others,[1] has ranged from individually owned shallow wells

[1]Heath, R. C., Foxworthy, B. L., and Cohen, Philip, 1966, The changing pattern of ground-water development on Long Island, N. Y., U. S. Geol. Survey Circular 524.

tapping the uppermost deposits to large-capacity public-supply wells tapping deep artesian aquifers. Sewage disposal has ranged from privately owned cesspools to modern large-capacity sewage-treatment plants discharging more than 70 million gallons per day of water to the sea.

In Nassau and western Suffolk Counties, which have the greatest population density on the island outside of New York City, the water supplies are now obtained mostly from the deep artesian aquifers. The water from the deep zones, following its use, is either discharged into the shallow deposits through cesspools, or is collected in sewer systems, treated, and then discharged into one of the adjacent salt-water bodies (fig. 3). Intensive pumping from the deeper aquifers has resulted in water being withdrawn from them at a rate greater than they are replenished naturally by vertical leakage, and that part of the fresh-water system is unbalanced. Inasmuch as no "new" water is being created in the system, the quantity of water represented by the difference between pumpage and recharge is being removed from storage in the reservoir of fresh ground water. This removal from storage is reflected in a decrease in ground-water levels and, locally, a landward movement of salty water. In the terms of the continuity equation, we would say that the outflow from this part of the system has been increased considerably while the inflow has remained virtually unchanged; the inevitable result has been a corresponding decrease in the amount of fresh water in storage.

The Yield of the System

Public officials who are faced with far-reaching water-management decisions for Long Island have

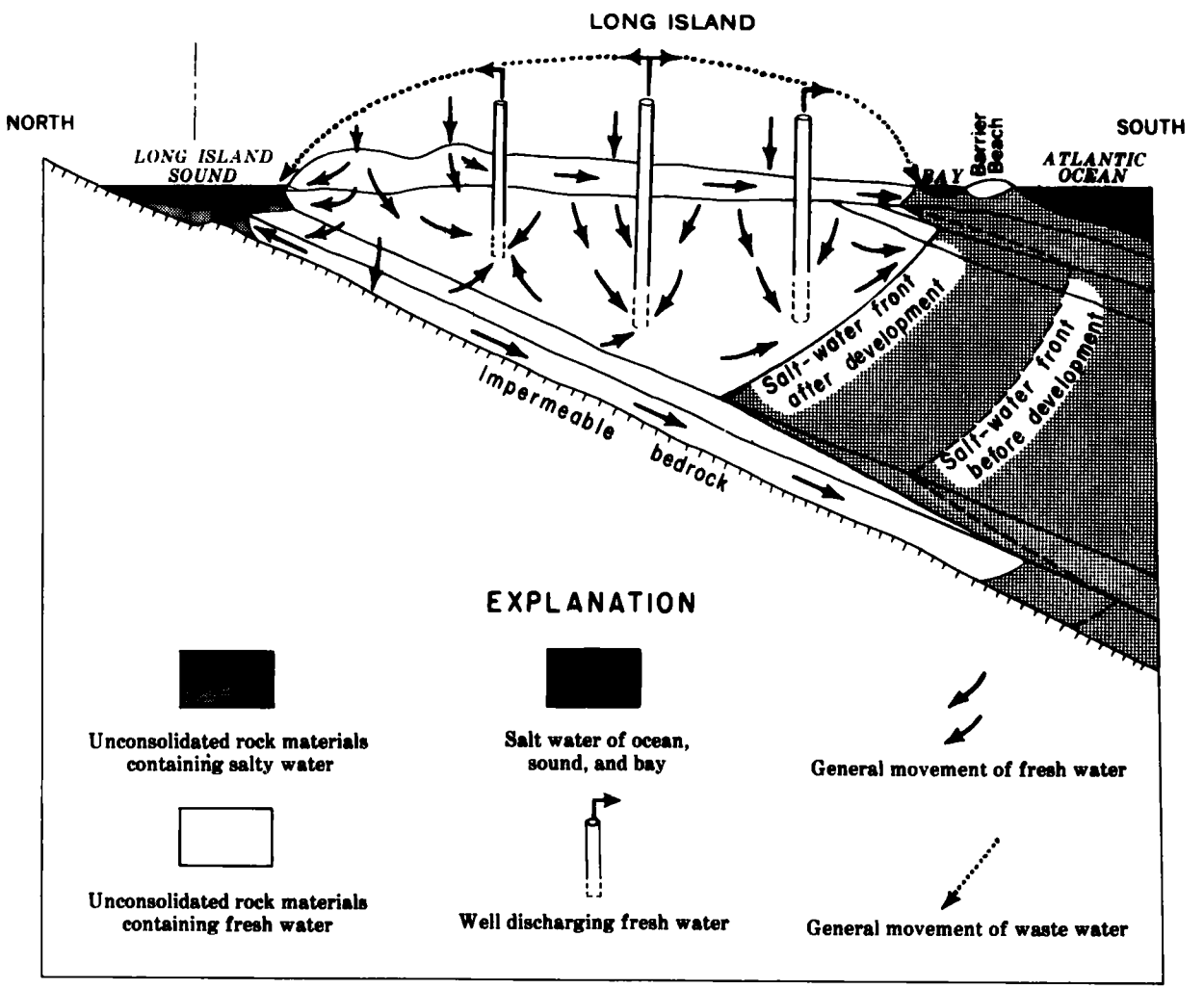


Figure 3—Schematic cross section through Long Island, N.Y., showing the general ground-water situation under conditions of water development from deep supply wells and waste disposal to adjacent salt-water bodies.

sought a figure for safe, sustained yield of fresh water from this system, the implication being that such a yield could be obtained perennially without undue problems. Some estimates of yield have been developed for specific projected courses of water development, and those estimates invariably are tied to estimates of the total inflow (recharge) to the system.

Although the amount of water moving through the hydrologic system ultimately is controlled by the inflow, the "yield" of the system for man's use can be much less than the average inflow, or it can be (at least for some time) even greater than the average inflow. The reason is that the "yield"—that is, the amount of water available for our use—is controlled largely and directly by the manner in which the water is developed, used, and disposed of following use. In other words, the "yield" of the system depends largely upon the water-management rules imposed.

Under any water-management scheme, whether or to what extent the mining of fresh ground water from storage is tolerated, the continuity equation (Outflow = Inflow $\pm$ Δ Storage) must be satisfied. This equation tells us that the only additional fresh water available for our use without further depletion of ground water in storage is the outflow which can be diverted to beneficial purposes, and the additional inflow that can be induced. That is, if the volume of fresh water in the ground-water reservoir is to be held essentially constant, any increase in artificial discharge from the system, as by increased consumptive use by humans, must be balanced by an increase in the inflow (such as artificial recharge) or by a reduction of the natural outflow (such as stream discharge to salt water).

If, however, temporary overdraft of fresh water from the ground-water reservoir is accepted as a valid management concept, the management choices are broader. Increased artificial discharge from the system then can be temporarily balanced, partly or completely, by removal of fresh ground water from storage, provided that the consequences of decreased storage, such as the landward movement of the salt-water boundaries or declining ground-water levels, can be tolerated.

The huge volume of the fresh ground-water reservoir and the capability of that reservoir for sustaining temporary local overdrafts have allowed the ground-water users of Long Island to weather the current severe drought with relatively little inconvenience. More important, the immensity of the ground-water reservoir represents time—time during which the current heavy demands for water can be met while sound water-management plans are being formulated, selected, and put into effect. Ultimately, of course, large and protracted overdrafts must be paid for in terms of a diminished fresh ground-water reservoir and, therefore, less flexibility in future water-management choices.

Conclusions

Ground water probability will continue to be the major source of water for most of Long Island (except for Kings and Queens Counties) for at least the next several decades. Furthermore, if present trends continue, the ground-water resources of the island probably will continue to be depleted, perhaps at an accelerated rate.

Several possible methods for conserving and augmenting the fresh-water resources of Long Island currently are being considered. The consequences of such measures are highly significant inasmuch as the future well-being of millions of people is at stake. Even with the most promising of conservation methods, however, fullest use of the available fresh-water supply, while also preventing undue hardships resulting from local overdrafts, will severely challenge our water-management capabilities. Fully effective management must be guided by the best obtainable scientific information about the hydrologic system and how the system functions. It must be based on sound evaluation of the various alternative methods of water development and conservation, and the hydrologic consequences of each. And it must include recognition of the immutable equation of hydraulic continuity—Outflow = Inflow $\pm$ Δ Storage.

Discussion

Professor Robert Gemmell asked if any consideration had been given to the return of the waste water by deep-injection, rather than surface-injection, and the removal of the water supply from nearer the surface, so that the increased salinity of the wastes might be taken advantage of to further counteract intrusion, and to creat a more stable environment for the water.

Mr. Foxworthy replied that one of the water management—water conservation schemes that have been proposed is that of deep-subsurface injection of highly treated sewage-plant effluent to either build up a hydraulic pressure ridge that would act as a barrier to the landward movement of the sea water, or simply to try to affect the hydrologic balance needed to offset the increased withdrawals. At the present time, he said they were engaged in a cooperative study

with the Nassau County Department of Public Works, in which several other agencies are involved in an indirect manner through a local water resources advisory group. The objective of this study is to experimentally determine the feasibility of injecting highly treated water from sewage down into the deep water-bearing zones on the seaward side of the places where the major water-supply developments are take place. With regard to the other part of the question, about taking water from the more shallow, highly permeable zones, this is, of course, a future possibility that is very attractive. Unfortunately, because of the long history of waste disposal in this shallow ground-water, it is presumed that there will have to be a considerable lag time following the complete sewering of this part of Long Island before the water in the shallow-ground water body would again be suitable, quality-wise, to serve as a public supply.

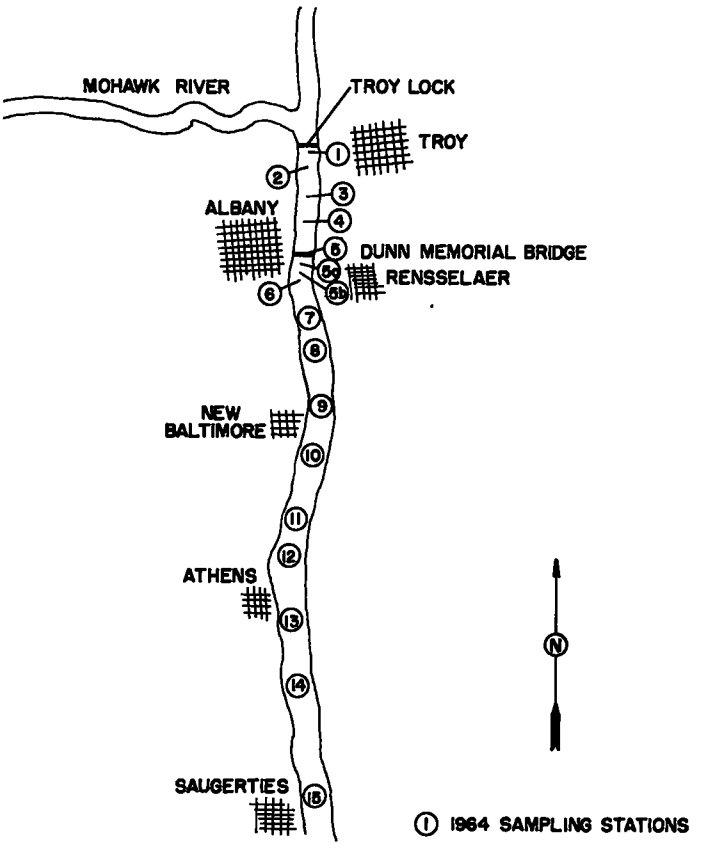
Pollutional Analysis of the Upper Hudson River Estuary

Donald J. O'Connor* and John P. St. John**

Summary

The upper Hudson River Estuary extends from the location of the Federal dam and lock at Troy approximately 50 miles downstream to the vicinity of Saugerties, New York. The major sources of municipal and industrial waste discharge are located in the vicinity of Albany and Troy. These waste water discharges and a considerable amount of pollutional material entering the system from sources above the lock seriously depress Hudson River water quality at present. A mathematical model was developed to reproduce observed water quality conditions along the axis of flow. The cross-sectional area of the Hudson River which increases linearly below Troy was included in the mathematical analysis. The effects of carbonaceous and nitrogenous oxidation were considered. On the basis of limited quantitative information on nitrogenous oxidation in the study area, the oxidation of ammonia and organic nitrogen appear to represent an important demand on the oxygen resources of the upper Hudson River Estuary. Further surveys and analyses should be conducted to more precisely evaluate the effects of this demand.

The upper Hudson River Estuary extends from the location of the Federal dam and lock at Troy approximately 50 miles downstream to the vicinity of Saugerties, New York. This reach is characterized by water stage elevation changes and flow reversals but is primarily fresh water in nature. The major sources of municipal and industrial waste discharge are located in the vicinity of Albany and Troy. A considerable amount of pollutional material is also discharged into the system from sources above the lock. A general location map of the area is presented in Figure 1.



LOCATION MAP

Figure 1

Mathematical Development

The upper Hudson River Estuary in the study area is characterized by variable cross-sectional area and depth. The forty mile reach of the Hudson River below Troy is periodically examined by the U. S. Army Corps of Engineers for changes in the channel cross-section. Cross-sectional areas were determined from depth measurements across the channel width taken at numerous stations in the study area. Figure 2 illustrates the relationship of area with distance from the Federal lock. A line of correlation between the parameters may be expressed in the following form:

$$A = A_o \frac{x}{x_o} \qquad (1)$$

in which A is the cross-sectional area at any distance, x, and A_o represents the area at a specific location, x_o. In this case, all distance terms are measured from an arbitrary origin at which point the cross-sectional area is zero by projection.

The average depth at each station was computed from the cross-sectional area and stream width. The

*Professor of Civil Engineering, Manhattan College.
**Sanitary Engineer, Hydroscience, Inc.

Summary of the Hydrologic Situation on Long Island, New York, as a Guide to Water-Management Alternatives

GEOLOGICAL SURVEY PROFESSIONAL PAPER 627-F

Prepared in cooperation with the New York State Department of Conservation, Division of Water Resources; the Nassau County Department of Public Works; the Suffolk County Board of Supervisors; and the Suffolk County Water Authority

Summary of the Hydrologic Situation on Long Island, New York, as a Guide to Water-Management Alternatives

By O. L. FRANKE *and* N. E. McCLYMONDS

HYDROLOGY AND SOME EFFECTS OF URBANIZATION ON LONG ISLAND, NEW YORK

GEOLOGICAL SURVEY PROFESSIONAL PAPER **627-F**

Prepared in cooperation with the New York State Department of Conservation, Division of Water Resources; the Nassau County Department of Public Works; the Suffolk County Board of Supervisors; and the Suffolk County Water Authority

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Driector*

Library of Congress catalog-card No. 71-180655

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 65 cents (paper cover)
Stock Number 2401-1150

CONTENTS

	Page
Abstract	F1
Introduction	1
Background, purpose, and scope of the water-budget study	1
Purpose and scope of this report	2
Location and general geographic features of the area	2
Location and extent of area	2
Topographic and general physiographic features	4
Summary of climatic conditions	4
Population and land use	4
Related investigations	6
Acknowledgments	7
The natural hydrologic system	7
How and where the water occurs	8
Bodies of surface water	8
Zone of aeration	8
Ground-water reservoir	10
Hydrogeologic features of the ground-water reservoir	10
Boundaries of the fresh ground-water reservoir	11
Size of the fresh ground-water reservoir	15
Source of the water and inflow to the hydrologic system	16
Precipitation	16
Disposition of precipitation	19
Direct runoff	19
Evapotranspiration	19
Infiltration to the zone of aeration	20
Recharge to the ground-water reservoir	20
Movement within the ground-water reservoir	22
Discharge from the ground-water reservoir	25
Streamflow and springflow	25
Ground-water evapotranspiration	29
Subsurface outflow of ground water	30
Summary of relations between components of the hydrologic system	33
Water quality	34
How man has modified the natural hydrologic system	F37
History and present stage of development	37
Effects of man's activities on the movement and discharge of water	38
Disposal of direct runoff	39
Recharge basins	39
Streams	41
Pumping and distribution of ground water	42
Pumping of ground water	42
Leaky water pipes	42
Exported water	44
Lawn sprinking and irrigation	44
Disposal of used water	44
Recharge wells	44
Cesspools and septic tanks	45
Sanitary sewers	45
Summary of effects of man's activities on the movement and discharge of water	48
Summary of artificial recharge	48
Loss of water from the hydrologic system as a result of man's activities	48
Effects of man's activities on the quality of the water	49
Water-management implications of the hydrologic analysis	51
The present dilemma	51
Some concepts related to water management	51
Principle of continuity	51
Yield of the system	52
Conservation of ground water	52
Water-management alternatives	52
Increase inflow to the hydrologic system	52
Salvage outflow from the hydrologic system	53
Permit a planned decrease of fresh ground water in storage	53
Maintain approximate balance between inflow and outflow by means of artificial recharge	54
Concluding comments on water-management alternatives	55
Selected references	56
Tentative water budgets	58

ILLUSTRATIONS

	Page
FIGURES 1–4. Map showing—	
1. Location and general geographic features of Long Island, N.Y.	F2
2. Location of areas and subareas used in this report	3
3. Landforms, location of major surface-water bodies, and location of start of flow in selected streams in June 1967	5
4. Average population density in 1965	6
5. Graph showing land use in the early 1960's	7

Page

FIGURE 6. Graph showing distribution of depths to the water table in the water-budget and adjacent nearshore areas based on ground-water levels in September 1965 F8
7. Map showing depth to water table in southeastern Nassau County, in October 1961 9
8. Generalized section showing geologic features of ground-water reservoir 10
9. Estimated average position of the water table under natural conditions 13
10. Geohydrologic section showing occurrence of salty ground water in southwestern Nassau County in 1961 14
11. Contour map of the bedrock surface 15
12. Map showing thickness of unconsolidated deposits saturated with fresh ground water in 1965 15
13. Flow diagram of the hydrologic system under natural conditions 17
14. Maps showing (*A*) average annual, (*B*) average cool-season, and (*C*) average warm-season precipitation, water years 1951–65 18
15. Graph showing composite average monthly precipitation for selected stations for the normal period 1931–60 19
16. Graphs showing daily precipitation, average water content in the soil profile at one measuring site, and depth to water in an adjacent well, Brookhaven National Laboratory in 1966 21
17. Idealized cross section showing potential and flow lines in part of a homogeneous ground-water reservoir 22
18. Map showing water-table contours near Massapequa Creek in October 1961 23
19. Diagrammatic cross section of the southern half of the ground-water reservoir showing the part of the reservoir with primarily two-dimensional flow and the part of the reservoir with three-dimensional flow to streams 24
20. Geohydrologic section of the ground-water reservoir in northeastern Nassau County in March 1961 24
21. Geohydrologic section of the ground-water reservoir in southwestern Suffolk County in October 1960 25
22. Profiles of the water table and piezometric surfaces at the base of the Magothy aquifer and in the Lloyd aquifer in 1963 26
23. Graph of magnitude and frequency of annual average discharge of streams from the water-budget area 27
24. Graph showing estimated duration curve of daily streamflow from the water-budget area 27
25. Hydrographs of composite average monthly ground-water levels in selected wells and composite average monthly discharge of selected streams in Nassau County for the period 1940–50 28
26. Graph of average monthly discharge of selected streams and average monthly ground-water levels in selected wells in Nassau County for the period 1940–50 29
27. Graph of relation between average monthly discharge of selected streams and average monthly ground-water levels in selected wells in Nassau County for the period 1940–50 30
28. Summer and winter recession curves for Carmans River 30
29. Maps showing estimated transmissivity of (*A*) upper glacial aquifer, (*B*) Magothy aquifer, and (*C*) Lloyd aquifer 31
30. Graph of relation between a modified specific capacity factor (Q/sL) and the percentage of total number of wells for the principal aquifers 32
31. Block diagram showing changes in the chemical quality of the water under natural conditions 34
32. Map showing status of water development in 1966 38
33. Flow diagram of the hydrologic system in Nassau and Suffolk Counties in the 1960's 39
34–36. Graph of—
34. Relation between rainfall and inflow to the Westbury recharge basin, Nassau County, 1966–67 40
35. Cumulative curves of annual direct runoff in East Meadow Brook and annual precipitation at Mineola 41
36. Relation between rainfall and runoff for individual storms in the East Meadow Brook drainage area, Nassau County, for urban (1964–66) and preurban (1934–43) periods 43
37. Graph showing total treated sewage effluent discharged from Nassau and Suffolk Counties for the period 1950–65 46
38. Maps showing ground-water levels in Kings and Queens Counties in (*A*) 1903, (*B*), 1936, and (*C*) 1965 47
39. Graph showing estimated discharge of water from Nassau and Suffolk Counties as a result of man's activities, 1940–65 49

TABLES

Page

TABLE 1. Population by county and total population of Long Island, N.Y., 1900–65 F4
2. Summary of the rock units and their water-bearing properties, Long Island, N.Y 12
3. Estimated volume of fresh ground water in storage beneath parts of Long Island, N.Y 16
4. Average annual and average seasonal precipitation on Long Island, N.Y., and the water-budget area, water years 1951–65 19
5. Mean and extreme values of precipitation at Setauket, Long Island, N.Y., water years 1888–1967 19
6. Annual direct runoff of selected streams on Long Island, N.Y., whose drainage areas closely approximate natural conditions, water years 1958 and 1964 19

Page

TABLE 7. Relation of depth to the water table and average time lag in response to recharge in till-covered areas of northeastern Nassau County, Long Island, N.Y. F22
8. Surface drainage areas and average flows of the 19 continuously gaged streams in the water-budget area of Long Island, N.Y., water years 1940–65 27
9. Average transmissivity of the principal aquifers for the water-budget area, Long Island, N.Y. 32
10. Estimated average subsurface outflow of ground water from the principal aquifers and total average subsurface outflow from the northern part, the southern part, and the entire water-budget area of Long Island, N.Y. 33
11. Water budgets of the northern and southern parts and the entire water-budget area of Long Island, N.Y., water years 1940–65 33
12. Selected chemical analyses of natural water on Long Island, N.Y. 36
13. Annual direct runoff of the 19 continuously gaged streams on Long Island, N.Y., for water years 1958 and 1964 42
14. Gross ground-water pumpage in Nassau and Suffolk Counties, Long Island, N.Y., 1940–65 42
15. Selected chemical analyses of water contaminated by man's activities on Long Island, N.Y. 50
16. Water budget of the northern part of the water-budget area within Nassau County, Long Island, N.Y., water years 1940–65 59
17. Water budget of the northern part of the water-budget area within Suffolk County, Long Island, N.Y., water years 1940–65 59
18. Water budget of the southern part of the water-budget area within Nassau County, Long Island, N.Y., water years 1940–65 59
19. Water budget of the southern part of the water-budget area within Suffolk County, Long Island, N.Y., water years 1940–65 59

SUMMARY OF THE HYDROLOGIC SITUATION ON LONG ISLAND, NEW YORK, AS A GUIDE TO WATER-MANAGEMENT ALTERNATIVES

By O. L. Franke and N. E. McClymonds

ABSTRACT

Long Island has a total area of about 1,400 square miles and includes four counties—Kings, Queens, Nassau and and Suffolk. This report describes mainly the "water-budget area," which includes about 760 square miles of Nassau and Suffolk Counties.

The ground-water reservoir of Long Island is a wedge-shaped mass of saturated unconsolidated deposits that overlie nearly impermeable consolidated bedrock and attain a maximum thickness of about 2,000 feet. The boundaries of the fresh ground-water reservoir are the water table, the fresh-salt water interfaces, the bedrock surface, and the streams. The estimated volume of material saturated with fresh ground water in the water-budget area is about 180 cubic miles, and an estimated 10–20 trillion gallons of fresh water would drain from these deposits if they could be unwatered.

Under natural conditions, precipitation was the ultimate source of virtually all the fresh water on Long Island. The average annual precipitation on the island is about 44 inches, which averages about 1,600 mgd (million gallons per day) for the water-budget area. About 5 percent of the streamflow (roughly 20 mgd) that discharges into the sea is direct runoff. Evapotranspiration of precipitation, which averages about half the average annual precipitation, represents the largest element of fresh-water discharge from the hydrologic system of the water-budget area. Evaporation from open bodies of water is negligible in terms of the overall water budget.

The principal elements of discharge from the ground-water reservoir are base flow of streams, subsurface outflow of ground water, and evapotranspiration of ground water; these elements are estimated to average about 320, 450, and 15 mgd, respectively, in the water-budget area. One of the most significant features of the fresh water on Long Island is its very low dissolved-solids content—less than 50 milligrams per liter under natural conditions.

At present, more than 2,000 recharge basins in Nassau and Suffolk Counties recharge the ground-water reservoir with substantial quantities of direct runoff. The estimated average annual inflow to these basins is about 80 mgd. An estimated additional 60 mgd of direct runoff from urban areas discharges on the average to streams or directly to salty water in Nassau and Suffolk Counties.

Gross ground-water pumpage in the two counties increased from about 100 mgd in 1940 to about 330 mgd in 1965. The total treated sewage effluent discharged from Nassau and Suffolk Counties increased from about 15 mgd in 1950 to about 75 mgd in 1965. Most of this increased sewage effluent was derived from the ground-water reservoir in the southwestern part of Nassau County, and has caused a lowering of ground-water levels in that area. Much of the shallow ground water is contaminated with domestic wastes that were discharged into the ground through cesspools and septic tanks.

The hydrologic system of Long Island must respond to any water-management program in a way that is consistent with the water-budget equation. The amount of fresh ground water in storage ultimately will be depleted if total outflow perpetually exceeds total inflow. The safe yield of the ground-water reservoir of Long Island—the amount of water which can be withdrawn from it annually without producing an undesired result—can range between wide limits depending upon (1) future management decisions, (2) the amount of natural discharge that is salvaged, and (3) the amount of additional ground-water recharge that is induced. Proposals to manage the water resources of Long Island include barrier injection wells, shallow skimming wells, recharge of treated sewage effluent through wells or shallow basins, and planned encroachment of salty ground water.

INTRODUCTION

BACKGROUND, PURPOSE, AND SCOPE OF THE WATER-BUDGET STUDY

Long Island, which extends from the southeastern part of the mainland of New York State eastward about 120 miles into the Atlantic Ocean, has a total area of about 1,400 square miles (fig. 1). Kings and Queens Counties, which are part of New York City, occupy slightly less than 200 square miles of the western part of the island, and have a combined population of more than 4.5 million people. Nassau and Suffolk Counties have areas of about 290 and 920 square miles, respectively, and had a combined population of about 2.3 million people in 1965.

Although the New York City part of Long Island derives most of its water supply from surface-water sources in central New York State, the people of Nassau and Suffolk Counties derive their entire water supply from wells tapping the underlying ground-water reservoir. Because of present large demands on the local ground-water system, particularly in Nassau and Suffolk Counties, and because of the prospect of

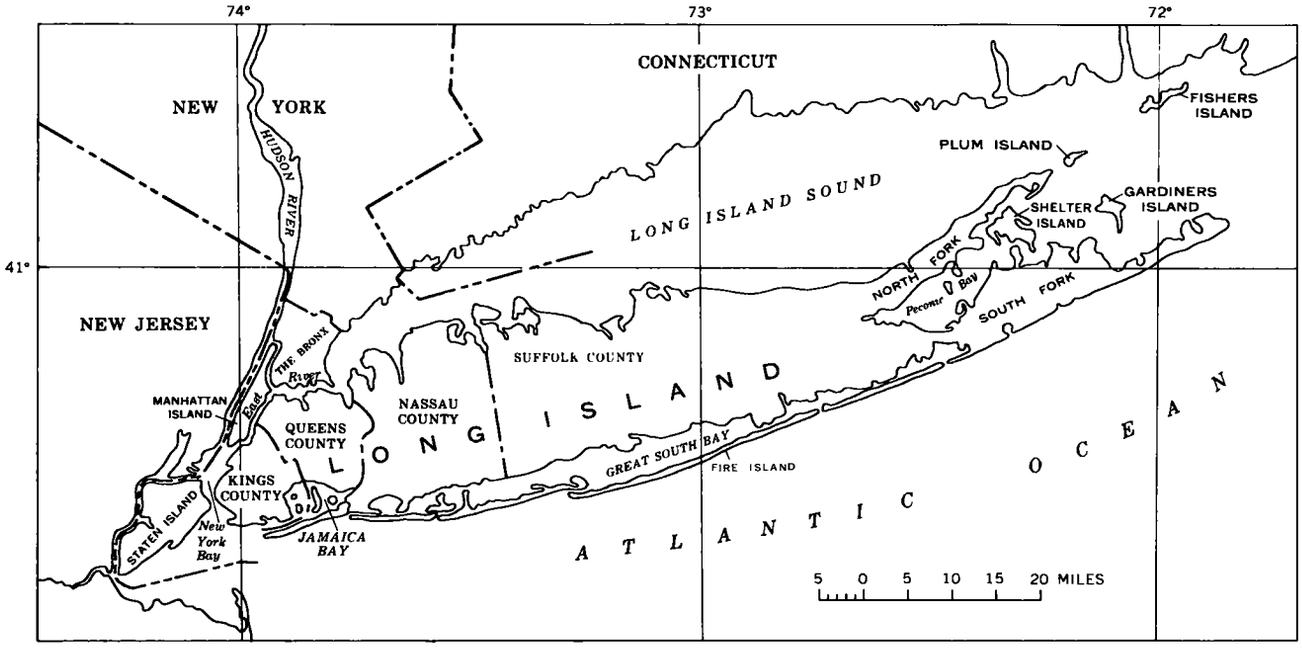


FIGURE 1.—Location and general geographic features of Long Island, N.Y.

increased demands as Long Island continues to rapidly develop, knowledge about the hydrologic system—with special emphasis on water conservation and management—is a matter of vital concern to the present population and to the millions of people who will depend on the ground water in the future.

Considerable information is available about the water resources of Long Island as a result of studies made during more than 30 years by the U.S. Geological Survey in cooperation with New York State and county agencies. Although those studies meet many of the needs for information on specific problems and areas of Long Island, better quantitative information about the islandwide hydrologic system, and the relations between the various components of the system, is needed for water-management purposes. To provide that water information, a comprehensive water-budget study presently is being made by the U.S. Geological Survey in cooperation with the New York State Department of Conservation, Division of Water Resources; Nassau County Department of Public Works; Suffolk County Board of Supervisors; and Suffolk County Water Authority.

The major objectives of the water-budget study are (1) to summarize and interpret pertinent existing information about the hydrologic system of Long Island and (2) to fill several gaps in the knowledge of the hydrologic system. The results of these studies are being published in a series of coordinated reports. In some of the reports, information is developed for all of Long Island; in others, however, the primary area of concern is limited to most of Nassau and Suffolk Counties.

PURPOSE AND SCOPE OF THIS REPORT

The present report, which is the summary report of the series, describes and discusses (1) how the hydrologic system of Long Island functioned under natural conditions, (2) how man has modified the natural hydrologic system, and (3) the water-management implications of this hydrologic analysis with particular reference to the concept of "yield" of the system and long-term responses of the system to various water-management alternatives.

LOCATION AND GENERAL GEOGRAPHIC FEATURES OF THE AREA

LOCATION AND EXTENT OF AREA

Long Island is bounded on the north by Long Island Sound, on the east and south by the Atlantic Ocean, and on the west by New York Bay and the East River (fig. 1). Several smaller islands are included in the political boundaries of Long Island; the better known of these are Fire, Shelter, Gardiners, Fishers, and Plum Islands. The total area of Long Island (including the smaller islands within the political boundaries of the island, but excluding the bordering bays) is about 1,400 square miles; its maximum width is about 23 miles.

Fire Island is the longest of several barrier beaches

that parallel the south shore of Long Island. It ranges from about a quarter of a mile to a mile in width, and is separated from the main island by Great South Bay, a shallow body of salty water that has a maximum width of about 5 miles. The other barrier beaches along the south shore are also separated from the main island by salty bays, the best known of which is Jamaica Bay along the south shore of Kings and Queens Counties.

The northern and eastern coast lines of Long Island are indented by deep bays that form excellent harbors. Peconic Bay, which is about 30 miles long, divides the eastern end of the island into two long, narrow peninsulas that are locally referred to as the North and South Forks.

Some of the succeeding hydrologic information presented in this report relates to all of Long Island. Most of the information, however, relates primarily to the "water-budget area." The various areas and subareas of Long Island (fig. 2), which are defined in this report to facilitate the hydrologic analyses, are as follows: (1) The water-budget area—subdivided into a northern part and a southern part; (2) the nearshore area—also subdivided into northern and southern parts; (3) the North and South Forks; and (4) the New York City part of Long Island.

The water-budget area, which includes about 760 square miles, is bounded on the west by the border between Nassau and Queens Counties; the eastern boundary is long 72°40′ W., which is near the stream-gaging station on the Peconic River; the northern boundary generally follows the northern shoreline; and the southern boundary is a curved line that joins the streamflow-measuring stations on the major streams that drain into the bays along the south shore. The northern and southern parts of the water-budget area are separated by the ground-water divide on the water-table coutour map for September 1965 (Cohen and others, 1968, p. 23), and have areas of about 310 and 450 square miles, respectively.

The nearshore areas are located just north and south of the water-budget area and comprise those parts of the mainland of Long Island lying between the northern and southern boundaries of the water-budget area and the adjacent salty water of Long Island Sound and the bays adjacent to the south shore. The areas of the northern and southern nearshore areas are about 15 and 80 square miles, respectively.

The North and South Forks, as here designated, include all the parts of the main island areas east of long 72°40′ W., which total about 240 square miles. The New York City part of Long Island (Kings and Queens Counties) has an area of slightly less than 200 square miles.

The water-budget area comprises the bulk of that part of Long Island where public-supply water is derived from the underlying ground-water reservoir. Furthermore, most of the fresh ground-water reservoir of Long Island is located beneath the water-budget area, and therefore, most of the subsequent development of the local water resources will take place within this area. The Forks have been designated as a separate area because, hydrologically, they are virtually independent of the main part of Long Island. Finally, the New York City part of Long Island is a logical area for separate discussion because most of its water supply is imported from upstate surface-water sources.

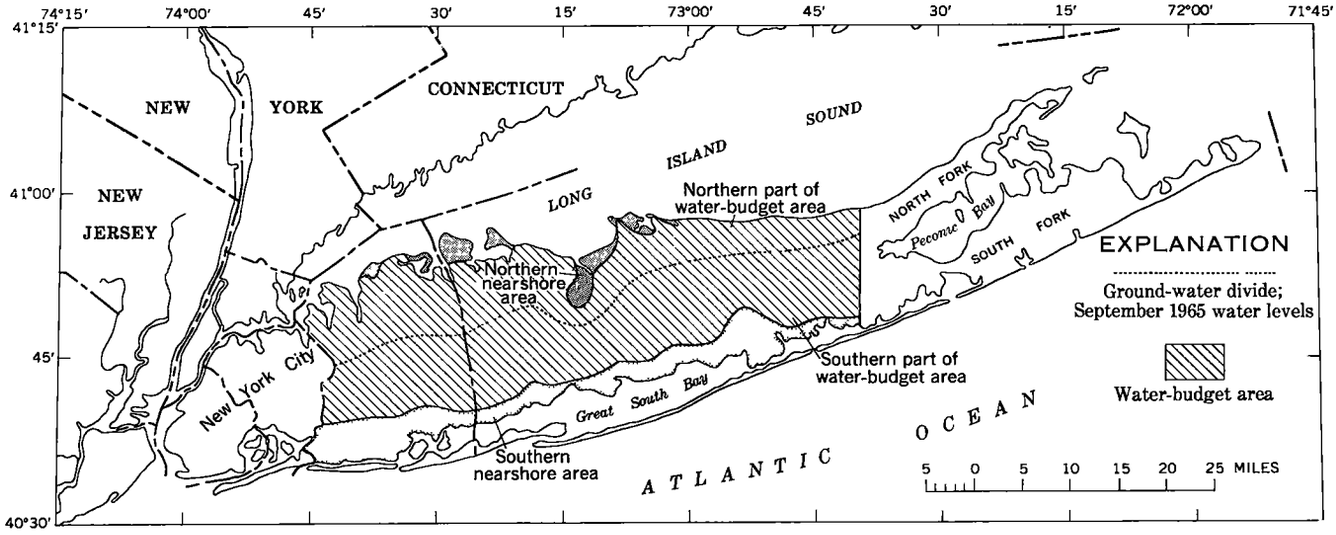


FIGURE 2.—Location of areas and subareas used in this report.

TOPOGRAPHIC AND GENERAL PHYSIOGRAPHIC FEATURES

Most of the major features of the present-day topography of Long Island (fig. 3) are related to the last ice age, which ended about 10 thousand years ago. The most prominent physiographic features are (1) the east-trending hills in the northern and central parts of the island, and their eastward extensions which form the "Forks," (2) the gently sloping plain that extends southward from the hills, (3) the deeply eroded headlands along the north shore, and (4) the barrier beaches along the south shore.

The two lines of hills, which are terminal moraines and which reach a maximum altitude of about 400 feet, are separate and distinct in the central and eastern parts of the island, but they converge in the western part. The southernmost line of hills, the Ronkonkoma moraine, extends eastward to form the South Fork. The northern line of hills, the Harbor Hill moraine, extends eastward to form the North Fork.

The moderately flat surface that extends southward from the Ronkonkoma moraine to the south-shore bays is a glacial-outwash plain. It generally heads at an altitude of about 100–150 feet, and slopes southward at about 20 feet per mile until it merges with Holocene lagoonal deposits along the coast.

The eroded headlands along the north shore are composed mainly of various types of glacial deposits. After the ice sheets melted, the land surface of Long Island rose slightly with respect to sea level, the headlands were deeply eroded, and the many wide and deep harbors along the north shore were carved by northward-flowing streams. Wave erosion has steepened the northern slopes of the headlands into nearly vertical bluffs that, in places, are about 100 feet high.

Along the south shore, waves and ocean currents have formed offshore bars, or "barrier beaches." In terms of geologic time, these bars are ephemeral features that are gradually being eroded by wave action. Sand and silt deposited by the wind, streams, and tidal currents, as well as organic deposits, have partially filled and are continuing to fill the shallow bays behind the barrier beaches.

SUMMARY OF CLIMATIC CONDITIONS

Long Island is located between 40° and 42° north latitude in a temperate-climate belt. The mean annual temperature on the island, about 51°F (11°C), is several degrees higher than the average for all of New York State because of the modifying influence of the bordering Atlantic Ocean and Long Island Sound. Minimum average monthly temperatures on Long Island occur in February and range from about 28° to 32°F (−2°–0°C); maximum average monthly temperatures occur in July and range from about 69° to 75°F (21°–24°C). In general, average temperatures decrease from west to east, and south-shore temperatures are slightly less than north-shore temperatures at the same longitude. Maximum and minimum temperatures of record on Long Island are 103°F and −14°F (39° and −26°C), respectively.

Precipitation averages about 44 inches per year and is fairly evenly distributed thoughout the year on Long Island.

The prevailing wind direction on Long Island is northwest during most of the year, except during the summer months when south and southwest winds prevail.

POPULATION AND LAND USE

Population figures for Kings, Queens, Nassau, and Suffolk Counties and totals for all of Long Island are given in table 1 for the period from 1900 to 1965. During the first three decades of the century, both magnitude of population and rate of population growth on Long Island were greatest in Kings County, which, at that time, was moderately industrialized and was characterized mainly by multiple-family dwellings; Queens County was largely suburban, and Nassau and Suffolk Counties were rural. In the next decade (the 1930's), the largest increase in population occurred in Queens County, mainly as a result of the rapid increase in construction of multiple-family dwellings and the growth of industry in that county.

Beginning soon after the end of World War II and extending into the late 1940's and the 1950's, marked suburban expansion into Nassau County caused a dramatic increase in the population of that county. The wave of suburban expansion, characterized mainly by large-scale developments of single-family homes, has been moving eastward with time. As a result, the population of central and eastern

TABLE 1.—*Population by county and total population of Long Island, N.Y., 1900–65* [1]

[In thousands of people]

Year	County				Total
	Kings	Queens	Nassau	Suffolk	
1900	1, 167	153	55	78	1, 453
1910	1, 634	288	84	96	2, 102
1920	2, 018	469	126	110	2, 723
1930	2, 560	1, 079	303	161	4, 103
1940	2, 698	1, 298	407	197	4, 600
1950	2, 738	1, 551	673	276	5, 238
1960	2, 627	1, 810	1, 300	667	6, 404
1965			1, 418	893	--------

[1] Data from U.S. Census Bureau.

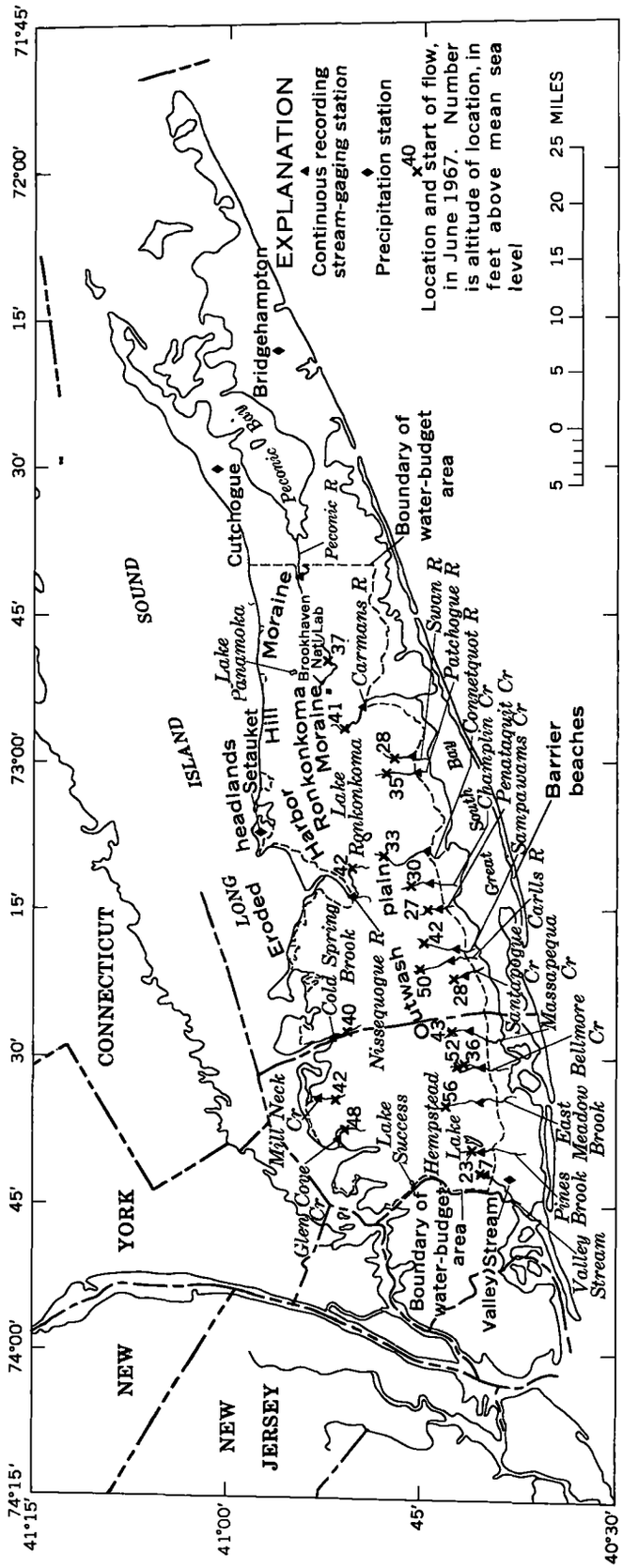


FIGURE 3.—Landforms, location of major surface-water bodies, and location of start of flow in selected streams in June 1967.

Nassau County increased rapidly in the mid-1950's. The population of western Suffolk began to increase markedly in the late 1950's, and has been increasing more rapidly than the population of any other area on Long Island during the past few years.

The present (1968) population density on Long Island ranges from very dense in the western part to sparse in the eastern part. The pattern of population density (fig. 4) mainly reflects the gradual eastward transition from highly urban communities characterized by high-rise apartment buildings in Kings County, to suburban communities in Nassau and western Suffolk Counties, and finally to the rural areas in eastern Suffolk County. In addition to the general pattern of progressive eastward decrease in population density, there has been a trend of preferential urban development along the north and south shores.

A summary of land use for each county on Long Island is shown in figure 5. This information was compiled from reports prepared by the Nassau County Planning Commission (1959), the Suffolk County Planning Commission (1962), and the New York City Department of Planning (1962), and the data are not for exactly the same time. Furthermore, the three agencies did not use precisely the same land classifications nor the same methods of obtaining and evaluating the data. Despite these inconsistencies, the data shown in figure 5 are reasonably representative for the early 1960's, and provide considerable insight to the general characteristics of land use on Long Island at present (1968).

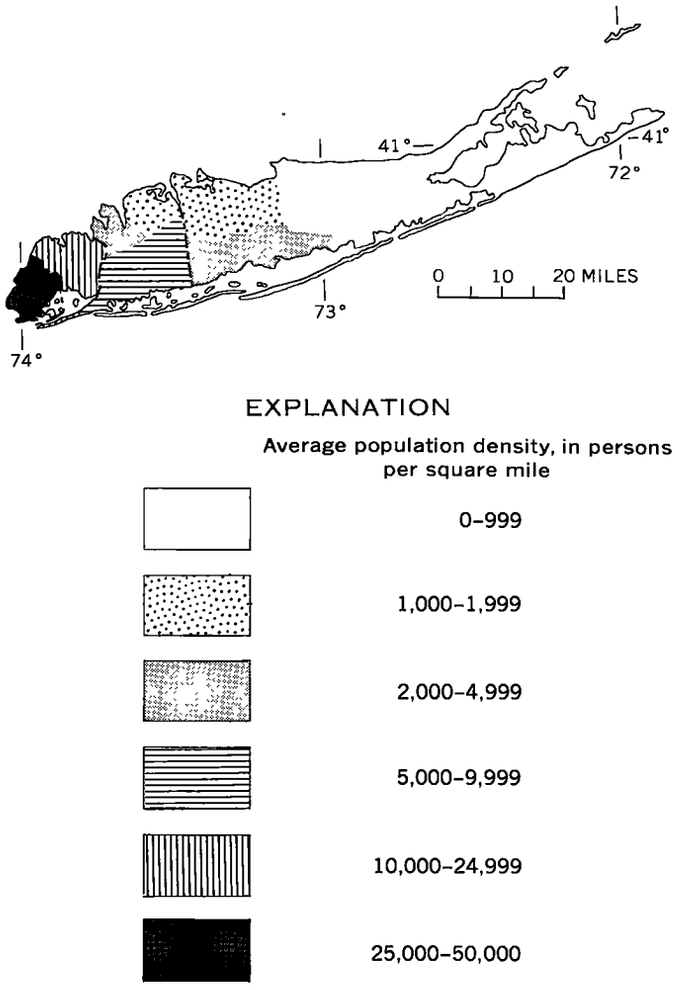


FIGURE 4.—Average population density in 1965. After Cohen, Franke, and Foxworthy (1968, pl. 1C).

The percentage of land occupied by streets and parkways, which is a reasonably accurate measure of the intensity of urban development, is greatest in Kings County (about 30 percent), decreases progressively to the east, and is least in Suffolk County (less than 10 percent). Conversely, the percentage of vacant land and land that is classified as "open" increases toward the east—from less than 10 percent in Kings County to nearly 75 percent in Suffolk County. The highly suburban character of Nassau County is indicated by the fact that nearly 50 percent of the land is classified as residential, and that land is occupied mainly by single-family homes.

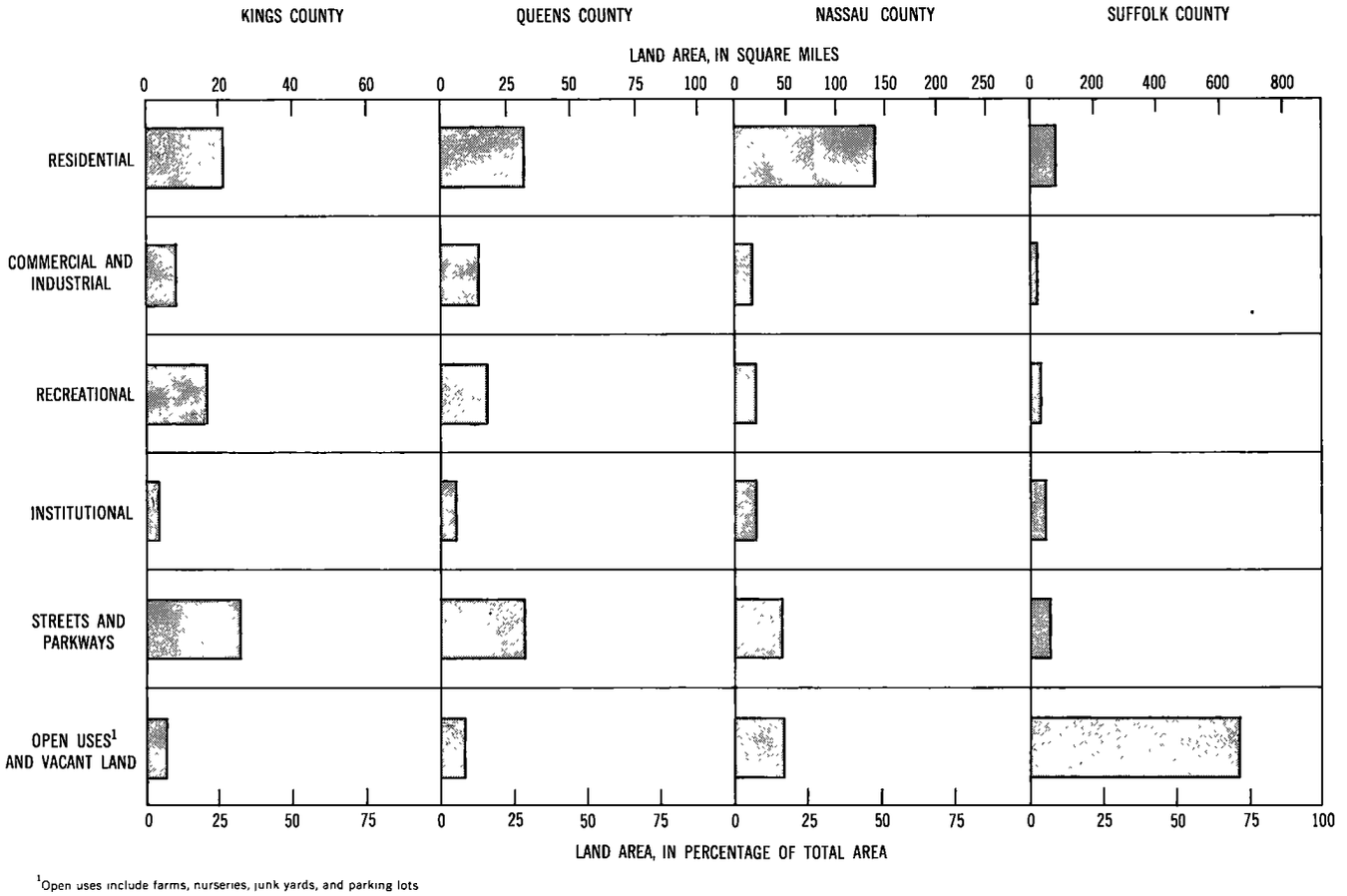
At present (1968), very little land is devoted to agriculture in Nassau County; in Suffolk County in 1966 slightly less than 65,000 acres, or about 101 square miles, was classified as agricultural land by the Suffolk County Planning Commission. Much of this farmland is in the northeastern part of Suffolk County and on the adjacent North Fork.

The major industries of Nassau and Suffolk Counties are aviation, instruments, electronics, and fabrication of metals; smaller industries include furniture, printing and publishing, textiles, and apparel. Most concerns are small, employing fewer than 100 people; several aviation plants, however, employ several thousands of persons.

RELATED INVESTIGATIONS

Considerable information in this report was derived from previously published reports of the U.S. Geological Survey, as well as from published reports by other agencies and individuals. Many of these reports are referred to in the text, and major sources of additional information are listed among the references.

The water-budget area was first defined and studied in moderate detail in, "An Atlas of Long Island's Water Resources," by Cohen, Franke, and Foxworthy (1968). The present report contains much information that is not available in the atlas and evaluates many



[1]Open uses include farms, nurseries, junk yards, and parking lots

FIGURE 5.—Land use in the early 1960's. After Cohen, Franke, and Foxworthy (1968, pl. 1*D*).

aspects of the hydrology of Long Island in considerably more detail than was possible in the atlas.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the generous assistance and the data received from many individuals and public agencies. Unpublished data not contained in the files of the U.S. Geological Survey were obtained primarily from the New York State Water Resources Commission, Nassau County Department of Public Works, Nassau County Planning Commission, Suffolk County Planning Commission, and the Brookhaven National Laboratory.

The report was prepared under the immediate supervision of Bruce L. Foxworthy, former Hydrologist-in-Charge, and Philip Cohen, Hydrologist-in-Charge of the Long Island subdistrict, and under the general direction of Ralph C. Heath and Garald G. Parker, formerly District Chiefs, and Robert J. Dingman, District Chief, New York District of the U.S. Geological Survey. Special thanks is due to our colleague Philip Cohen, who played an important role in initiating, and gave invaluable assistance in, the course of this study.

THE NATURAL HYDROLOGIC SYSTEM

The following section of the report briefly summarizes how the hydrologic system of Long Island functioned under natural conditions. The discussion relates primarily, but not exclusively, to the previously defined water-budget area of central Long Island. Man's activities have markedly altered the hydrologic system in some parts of the water-budget area during the past 50 years, and have affected the hydrologic system in virtually the entire water-budget area. However, the effects of man's activities on most of the data presented in the following discussion are small or negligible, unless otherwise noted.

Those aspects of the hydrologic system which are particularly important from the point of view of water management are emphasized in the following discussion, and the information presented in some sections of the report is directed primarily to the information needs of the water manager.

In this section of the report the basic time unit for presenting hydrologic information is the water year, which is the 12-month period beginning on October 1 and ending on September 30; it is designated by the calendar year in which it ends.

HOW AND WHERE THE WATER OCCURS

On Long Island and its environs, water occurs as vapor, as a liquid, and at times during the winter as a solid in the form of ice or snow. The water vapor occurs primarily in the atmosphere and in the zone of aeration. In this study the water vapor of the atmosphere is not of concern until it condenses and reaches the land surface as precipitation.

Liquid water occurs mainly in bodies of surface water and as ground water. Fresh surface-water bodies include lakes and streams. In addition, Long Island is surrounded by the salty water of Long Island Sound and the Atlantic Ocean. Brackish surface water occurs in the estuaries and bays between the fresh-water streams and ocean water.

Most of the fresh ground water occurs from the bedrock surface to the water table beneath the entire mainland of Long Island, except for the Forks where only the upper layers contain fresh ground water. Locally, small, and probably insignificant, amounts of fresh ground water occur in fractures and in the upper part of the bedrock where it is highly weathered. The occurrence of fresh ground water beneath the adjacent bays and barrier beaches varies with depth and specific location, and salty ground water occurs seaward of fresh ground water around the entire perimeter of Long Island.

BODIES OF SURFACE WATER

Several lakes and most of the principal streams on Long Island are shown in figure 3. Lake Ronkonkoma, with an area of about 0.35 square mile, is the largest lake on Long Island. The northward-flowing Nissequogue River has the greatest average discharge—about 42 cfs (cubic feet per second) for the period 1940–65—of any stream on Long Island. The eastward-flowing Peconic River is the longest stream, having a main wet-channel length of about 9–10 miles upstream from the gaging station. The remaining larger streams flow southward into Great South Bay. Relative to the southward-flowing streams—except for the Nissequogue River—the northward-flowing streams are short, few in number, and discharge relatively small amounts of water.

ZONE OF AERATION

The zone of aeration is that part of the solid earth lying above the water table. The interstices in this zone are largely filled with atmospheric gases (including water vapor) and liquid water. The extremely significant process of evapotranspiration occurs primarily on and within several feet of the upper surface of the zone of aeration (land surface), and most of the water that recharges the ground-water reservoir passes through the zone of aeration.

The volumes of the zone of aeration for all of Long Island and for the water-budget area were about 11 and 10 cubic miles, respectively, in September 1965. If the specific retention of the deposits in the zone of aeration is assumed to be 10–15 percent (see section on "Infiltration to the Zone of Aeration," p. F20), an average of about 1 cubic mile of water was stored in this zone on Long Island at that time. However, this water cannot move into a well and, therefore, is not available for direct use by man.

The distribution of areas with various depths to the water table in the water-budget area and the immediately adjacent nearshore areas is shown in figure 6. The data show that the depth to the water table is less than 10 feet for about 14 percent, or for about 120 square miles of this area. Within the water-budget area, however, the depth to the water table is less than 10 feet in only about 50 square miles.

Figure 7 shows the depth to the water table in a typical area in the southern part of Long Island, based on water levels in October 1961. An appreciable area near the south shore is characterized by depths to the water table that are less than 10 feet; the depth to the water table generally increases gradually northward to the terminal moraine. In most of the areas

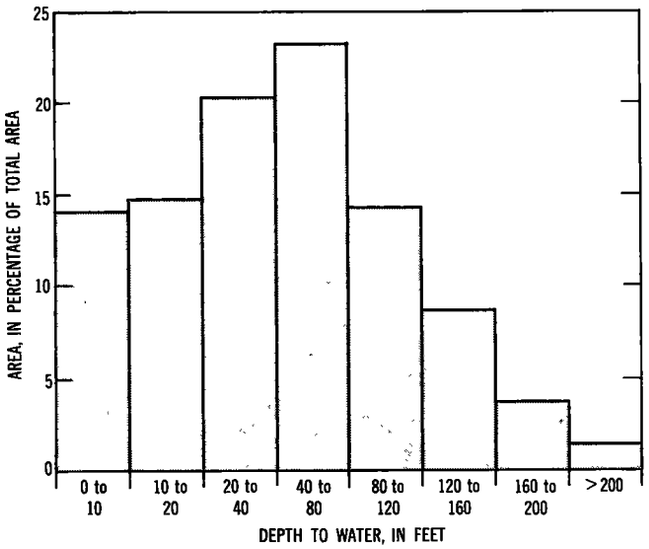


FIGURE 6.—Distribution of depths to the water table in the water-budget and adjacent nearshore areas, based on ground-water levels in September 1965.

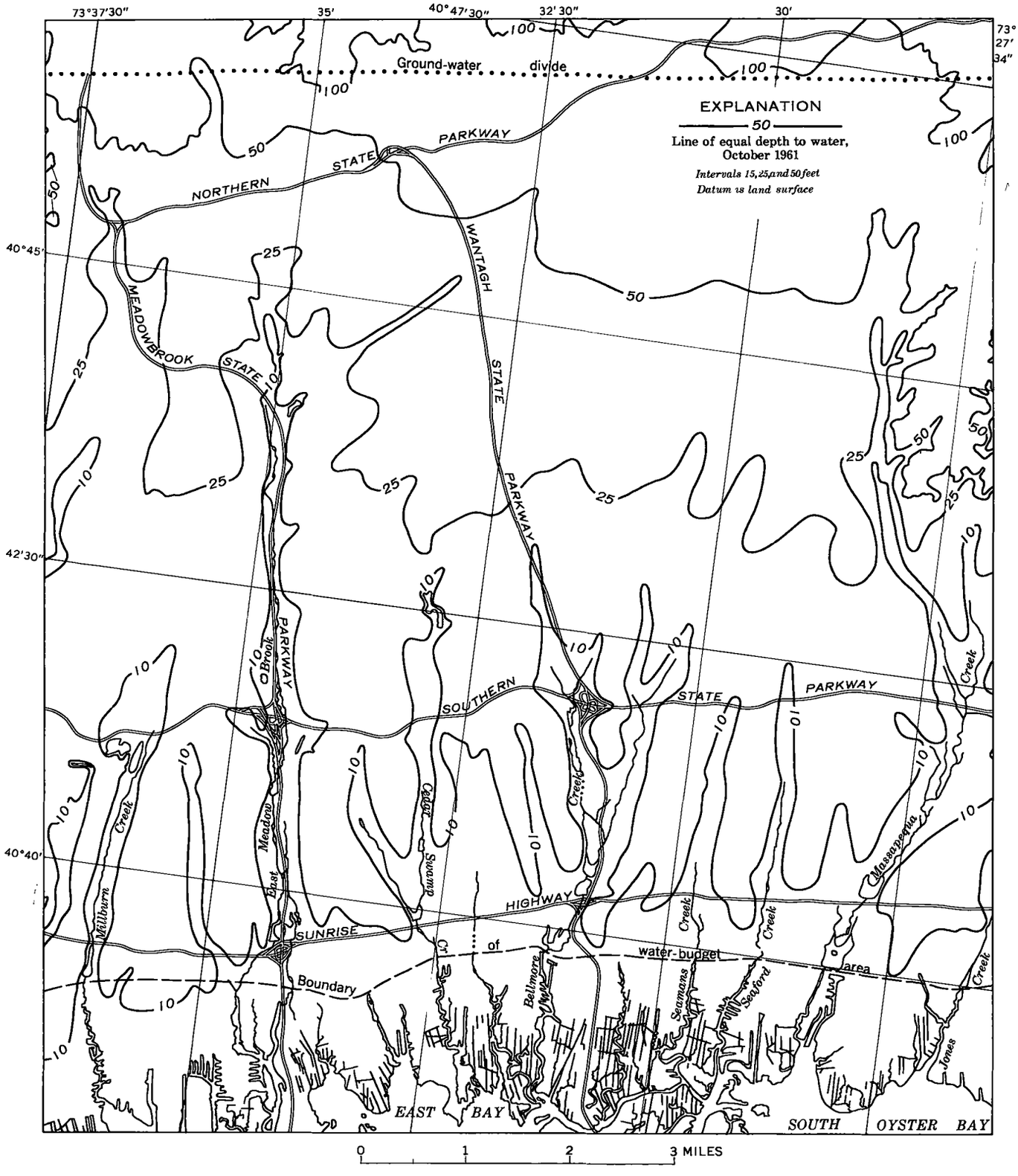


FIGURE 7.—Depth to the water table in southeastern Nassau County in October 1961.

underlain by terminal-moraine deposits, the depth to the water table is more than 50 feet, and in small areas the depth to the water table is more than 200 feet. Depths to the water table near the northern coast of the island generally are more than 20 feet, except adjacent to stream channels or in narrow bands near the shoreline.

GROUND-WATER RESERVOIR

HYDROLOGIC FEATURES OF THE GROUND-WATER RESERVOIR

The overall hydrogeologic setting of Long Island was described in considerable detail by Veatch (1906), Fuller (1914), and Suter, De Laguna, and Perlmutter (1949). The geology and related hydrology of several smaller areas of Long Island have been studied in greater detail by others, including De Laguna (1963), Isbister (1966), Lubke (1964), Lusczynski and Swarzenski (1966), Perlmutter and Geraghty (1963), Pluhowski and Kantrowitz (1964), and Swarzenski (1963).

Long Island is underlain by consolidated bedrock, which, in turn, is overlain by a wedge-shaped mass of unconsolidated rock materials (fig. 8).[1] These materials, which constitute Long Island's ground-water reservoir, consist primarily of a series of Pleistocene glacial deposits and Cretaceous fluvial or deltaic deposits composed of gravel, sand, silt, clay, and mixtures thereof. The Cretaceous deposits were eroded by

[1] The actual dip of the upper bedrock surface is slightly less than 1° to the southeast. The much greater inclination of the bedrock surface and the Magothy aquifer shown in figure 8 is due to the large vertical-scale exaggeration of this cross section.

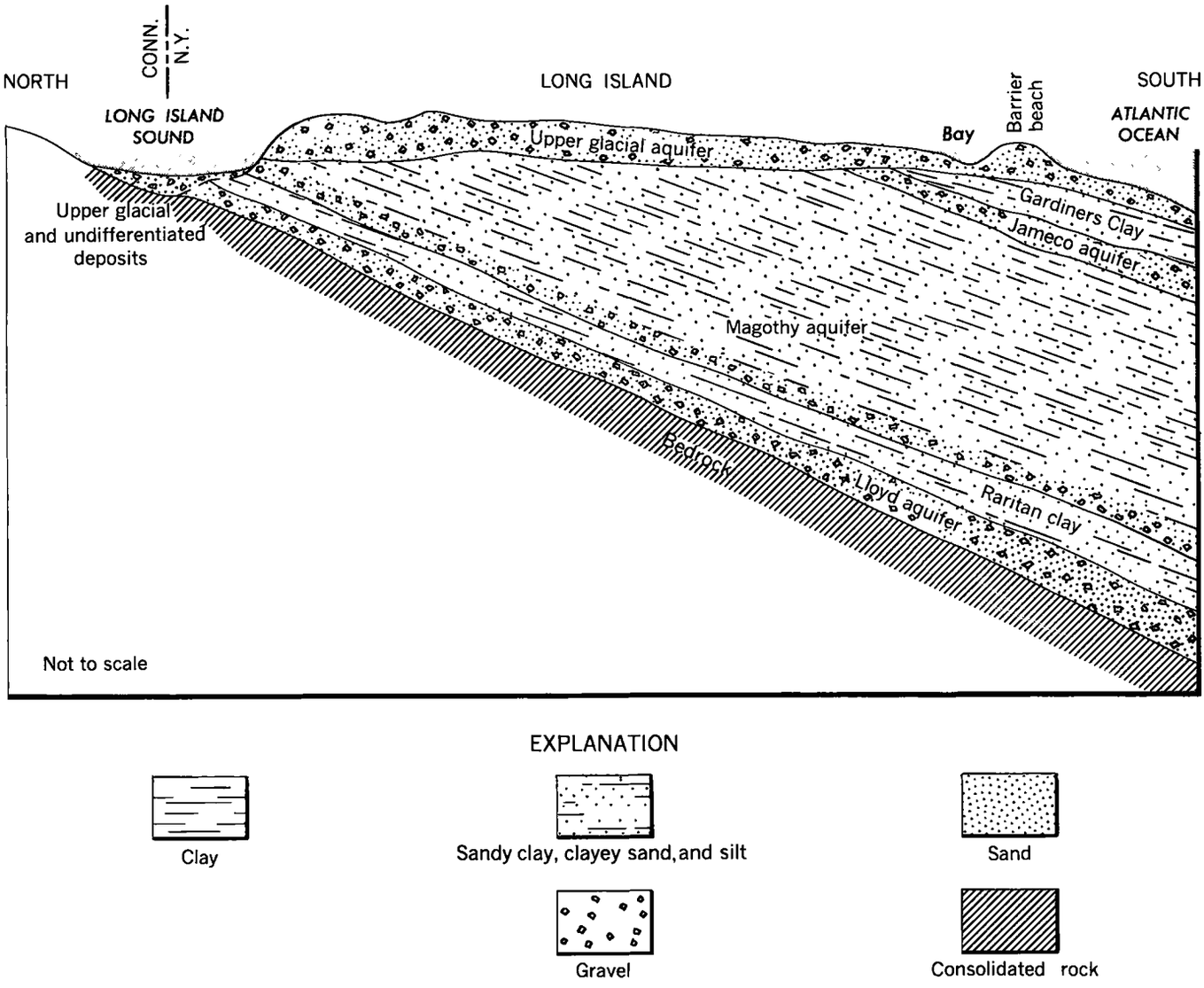


FIGURE 8.—Geologic features of the ground-water reservoir.

streams and glaciers so that the Pleistocene deposits lie on an irregular Cretaceous surface, and in places the Pleistocene deposits fill valleys cut by preglacial and glacial streams. These valleys have been fairly well defined in Kings and Queens Counties and along the northern margin of the island eastward to the middle of Suffolk County. In eastern Suffolk County, however, data on the contact between the Pleistocene and the Cretaceous are very sparse.

The upper surface of the Cretaceous deposits is above sea level in a large area in northern Nassau and western Suffolk Counties, and in all but a few small areas, the Pleistocene deposits cover the Cretaceous deposits throughout Long Island. Pertinent information concerning the principal hydrogeologic units within the ground-water reservoir are briefly summarized in table 2.

Ground water in the uppermost part of the zone of saturation on Long Island (mainly in the upper glacial aquifer, but locally also in the Magothy aquifer) is generally under water-table conditions. Artesian conditions predominate in most of the other parts of the ground-water reservoir of Long Island, where the saturated deposits are overlain and confined by silty and clayey layers of low hydraulic conductivity. The hydraulic head in the confined aquifers ranges from several feet below the water table to nearly 20 feet above it. At places along the north and south shores and on the barrier beaches, the head in the Lloyd aquifer is high enough to cause some wells which penetrate this aquifer to flow.

In addition to the Raritan clay, which confines water in the Lloyd aquifer, the other major well-defined confining layer in the ground-water reservoir is the Gardiners Clay. This unit locally confines water in the Jameco and Magothy aquifers. Numerous clayey and silty layers in the Magothy aquifer and clay beds in the glacial deposits also are significant confining layers. Normally, the degree of confinement in the Magothy aquifer increases with depth as more and more clayey layers intervene between the deep zone and the water table.

BOUNDARIES OF THE FRESH GROUND-WATER RESERVOIR

The boundaries of the fresh ground-water reservoir are the water table, the fresh-salt water interface, and the bedrock surface. The estimated average position of the water table under natural conditions is shown in figure 9. The position of the contours is based on a map of the water table in Kings, Queens, and Nassau Counties in 1903 (prepared by Veatch in 1906), and on later water-table maps of Suffolk County. Major features of this map are the two areas of highest ground-water altitude (represented by closed 80-ft and 60-ft contours) which extend approximately westward in the north-central parts of Nassau and Suffolk Counties. Also noteworthy are the steep water-level gradients near the north shore of Long Island compared to the gradients near the south shore.

The water table, which is the upper boundary of the ground-water reservoir, is a dynamic (moveable) feature. Present information indicates that recharge to the water table occurs throughout virtually all of Long Island. Therefore, the water table is not, from the point of view of potential theory, a stream surface. It is instead a surface characterized by a constantly varying potential which is equal to the altitude of the water table at any point. Because the water table on Long Island is largely a recharging potential boundary of the ground-water reservior, streamlines flow perpendicularly from the water table into the ground-water reservoir. Locally, as near the shorelines where ground water is lost by evapotranspiration, the water table is a discharging potential boundary.

The ground-water reservoir is bordered laterally by a second moveable boundary—the fresh-salt water interface. The position of this interface (or these interfaces) is fairly accurately known only in southwestern Nassau and southeastern Queens Counties as a result of an intensive investigation by Lusczynski and Swarzenski (1966). A north-south cross section through the ground-water reservoir in this area (fig. 10) shows three separate salt-water wedges—a shallow wedge in the glacial aquifer and intermediate and deep wedges in the Magothy aquifer. Furthermore, a fourth wedge exists in the Lloyd aquifer somewhere seaward of the barrier beaches.

The occurrence of fresh ground water in the Lloyd aquifer below salty ground water in the lower part of the Magothy aquifer has never been adequately explained. However, this occurrence must be related in some way to the relatively impermeable Raritan clay overlying the Lloyd aquifer. At least four separate wedges of salty ground water with relative positions approximately as indicated in figure 10 probably occur for a considerable distance eastward from western Nassau County (on the order of tens of miles) along the south shore of Long Island.

Very scanty information indicates that the Lloyd aquifer and the deep Magothy aquifer contain salty ground water beneath the Forks of Long Island. The fresh ground water beneath the Forks occurs in a lens ranging in thickness from a few feet to several hundred feet.

427-144 O - 71 - 3

TABLE 2.—*Summary of the rock units and their water-bearing properties, Long Island, N.Y.*

[After McClymonds and Franke, 1971]

System	Series	Geologic unit	Hydrogeologic unit	Approximate maximum thickness (feet)	Depth from land surface to top (feet)	Character of deposits	Water-bearing properties
Quaternary	Holocene	Artificial fill, salt marsh deposits, stream alluvium, and shoreline deposits.	Holocene deposits	50	0	Sand, gravel, clay, silt, organic mud, peat, loam, and shells. Colors are gray, brown, green, black, and yellow. Holocene artificial-fill deposits of gravel, sand, clay, and rubbish.	Permeable sandy beds beneath barrier beaches yield fresh water at shallow depths, brackish to salty water at greater depth. Clay and silt beneath bays retard salt-water encroachment and confine underlying aquifers. Stream-flood-plain and marsh deposits may yield small quantities of water, but are generally clayey or silty and much less permeable than underlying upper glacial aquifer.
	Pleistocene	Upper Pleistocene deposits	Upper glacial aquifer	600	0–50	Till (mostly along north shore and in moraines) composed of clay, sand, gravel, and boulders. Forms Harbor Hill and Ronkonkoma terminal moraines. Outwash deposits (mostly between and south of terminal moraines, but also interlayered with till) consist of quartzose sand, fine to very coarse, and gravel, pebble to boulder sized. Glaciolacustrine deposits (mostly in central and eastern Long Island) and marine clay (locally along south shore) consist of silt, clay, and some sand and gravel layers; includes "20-foot clay" in southern Nassau County and Queens County. Colors are mainly gray, brown, and yellow; silt and clay locally are grayish green. Contains shells and plant remains, generally in finer grained beds; also contains Foraminifera. Contains chlorite, biotite, muscovite, hornblende, olivine, and feldspar as accessory minerals; "20-foot clay" commonly contains glauconite.	Till is poorly permeable; commonly causes perched-water bodies and impedes downward percolation of water to underlying beds. Outwash deposits are moderately to highly permeable; specific capacities of wells tapping them range from about 10 to more than 200 gpm per foot of drawdown. Good to excellent infiltration characteristics. Glaciolacustrine and marine clay deposits are mostly poorly permeable, but locally have thin moderately permeable layers of sand and gravel; generally retard downward percolation of ground water. Contains fresh water, except near the shorelines. Till and marine deposits locally retard salt-water encroachment.
		Unconformity?					
		Gardiners Clay	Gardiners Clay	300	50–400	Clay, silt, and few layers of sand and gravel. Colors are grayish green and brown. Contains marine shells, Foraminifera, and lignite; also glauconite, locally. Altitude of top generally is 50–80 ft below mean sea level. Occurs in Kings and Queens Counties, southern Nassau County, and Suffolk County; similar clay occurs in buried valleys near north shore.	Poorly permeable; constitutes confining layer for underlying Jameco aquifer. Locally, sand layers yield small quantities of water.
		Unconformity?					
		Jameco Gravel	Jameco aquifer	300	50–550	Sand, fine to very coarse, and gravel to large-pebble size; few layers of clay and silt. Gravel is composed of crystalline and sedimentary rocks. Color is mostly dark brown. Contains chlorite, biotite, muscovite, hornblende, and feldspar as accessory minerals. Occurs in Kings and Queens Counties, and southern Nassau County; similar deposits occur in buried valleys near north shore.	Moderately to highly permeable; contains mostly fresh water, but brackish water and water with high iron content locally in southeastern Nassau County and southern Queens County. Specific capacities of wells in the Jameco range from about 20 to 150 gpm per foot of drawdown.
		Unconformity					
Tertiary(?)	Pliocene(?)	Mannetto Gravel	(Commonly included with upper glacial aquifer.)	300	0–120	Gravel, fine to coarse, and lenses of sand; scattered clay lenses. Colors are white, yellow, and brown. Occurs only near Nassau-Suffolk County border near center of island.	Highly permeable, but occurs mostly above water table. Excellent infiltration characteristics.
		Unconformity					
Cretaceous		Magothy Formation	Magothy aquifer	1,100	0–600	Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal 50–200 ft. Sand and gravel are quartzose. Lignite, pyrite, and iron oxide concretions are common; muscovite, magnetite, rutile, and garnet are accessory minerals. Colors are gray, white, red, brown, and yellow.	Most layers are poorly to moderately permeable; some are highly permeable locally. Specific capacities of wells in the Magothy generally range from 1 to about 30 gpm per foot of drawdown, rarely are as much as 80 gpm per ft. Water is unconfined in uppermost parts, elsewhere is confined. Water is generally of excellent quality but has high iron content locally along north and south shores. Constitutes principal aquifer for public-supply wells in western Long Island, except Kings County where it is mostly absent. Has been invaded by salty-ground water locally in southwestern Nassau County and southern Queens County, and in small areas along north shore.

TABLE 2.—*Summary of the rock units and their water-bearing properties, Long Island, N.Y.*—Continued

System	Series	Geologic unit		Hydrogeologic unit	Approximate maximum thickness (feet)	Depth from land surface to top (feet)	Character of deposits	Water-bearing properties
		—Unconformity—						
Cretaceous	Upper Cretaceous	Raritan Formation	Clay member	Raritan clay	300	70–1,500	Clay, solid and silty; few lenses and layers of sand; little gravel. Lignite and pyrite are common. Colors are gray, red, and white, commonly variegated.	Poorly to very poorly permeable; constitutes confining layer for underlying Lloyd aquifer. Very few wells produce appreciable water from these deposits.
			Lloyd Sand Member	Lloyd aquifer	500	200–1,800	Sand, fine to coarse, and gravel, commonly with clayey matrix; some lenses and layers of solid and silty clay; contains thin lignite layers and iron concretions locally. Locally, has gradational contact with overlying Raritan clay. Sand and most of gravel are quartzose. Colors are yellow, gray, and white; clay is red locally.	Poorly to moderately permeable. Specific capacities of wells in the Lloyd generally range from 1 to about 25 gpm per foot of drawdown, rarely are as much as 50 gpm per ft. Water is confined under artesian pressure by overlying Raritan clay; generally of excellent quality but has high iron content locally. Has been invaded by salty ground water locally in necks near north shore, where aquifer is mostly shallow and overlying clay discontinuous. Called deep confined aquifer in some earlier reports.
		—Unconformity—						
Precambrian		Bedrock		Bedrock	----------	0–2,700	Crystalline metamorphic and igneous rocks; muscovite-biotite schist, gneiss, and granite. A soft clayey zone of weathered bedrock locally is more than 100 ft thick.	Poorly permeable to virtually impermeable; constitutes virtually the lower boundary of ground-water reservoir. Some hard, fresh water is contained in joints and fractures, but is impracticable to develop at most places; however, a few wells near the western edges of Queens and Kings Counties obtain water from the bedrock.

The fresh-salt water interface is not a sharp boundary. The horizontal distance over which the dissolved-solids content of ground water changes from completely fresh to completely salty is generally on the order of 2–3 thousand feet near the south shore of Long Island. Over this distance, the dissolved-solids content of the ground water increases at first gradually in the direction of the salty ground water and then more rapidly.

The fresh-salt water interface is a complex streamline surface, and fresh ground water discharging into the ocean and bays moves parallel to the interface and not across it. The hydrodynamics of a stable interface and, to an even greater degree, an unstable interface that changes position in response to changes in head within the ground-water reservoir, is complicated and beyond the scope of this report. (See Lusczynski, 1961; Cooper, 1964; and Kohout, 1964.)

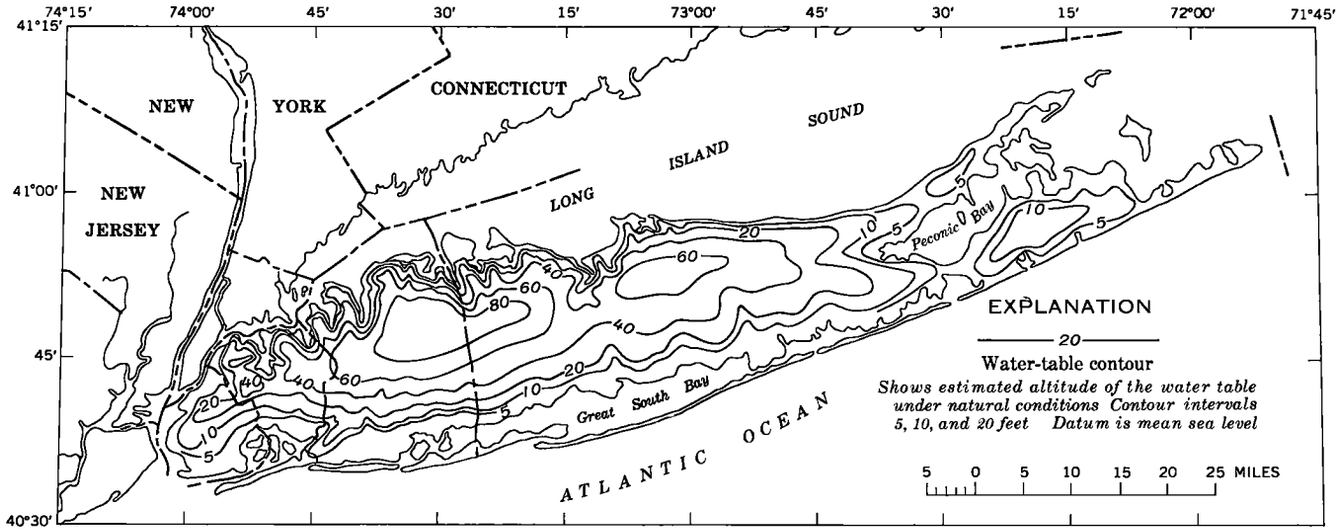


FIGURE 9.—Estimated average position of the water-table under natural conditions.

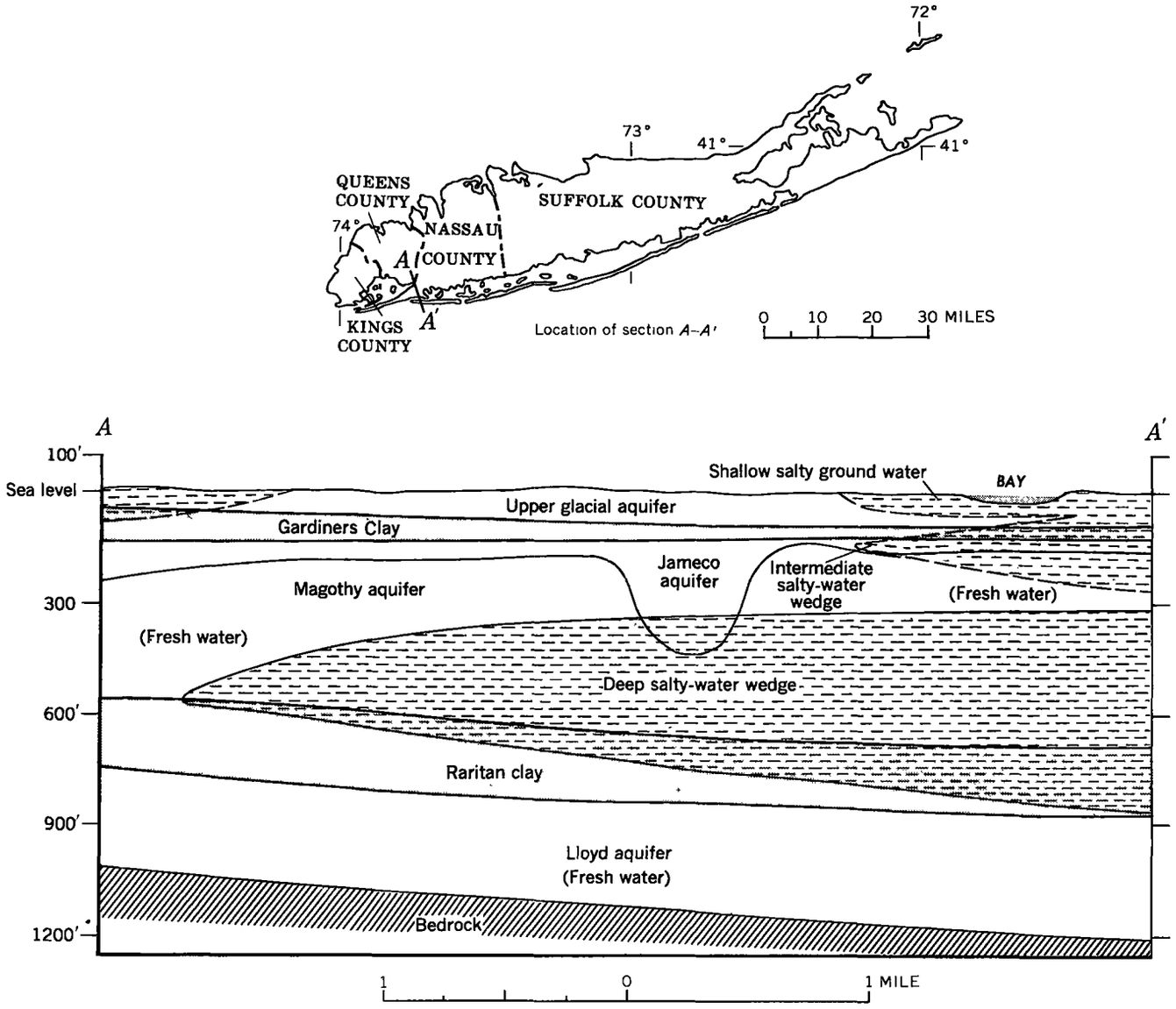


FIGURE 10.—Occurrence of salty ground water in southwestern Nassau County, in 1961. Adapted from Lusczynski and Swarzenski (1966, pl. 3).

The top of the bedrock surface, which outcrops in western Queens County, dips southeast on the average about 65 feet per mile, or slightly less than 1°, to an estimated depth of about 2,000 feet in south-central Suffolk County (fig. 11). The number of control points on the bedrock surface, particularly in Suffolk County, is small; therefore, the surface undoubtedly is more irregular than is indicated in figure 11.

For practical purposes the bedrock surface is the impervious bottom of the ground-water reservoir. Hydraulically, therefore, the top of the bedrock is a stream surface; ground water flows parallel to the bedrock and not across it, and equipotential lines or surfaces intersect the bedrock at right angles.

Generally, the flowing parts of the streams on Long Island are ground-water drains, and the ground water continually discharges into these parts under natural conditions. Therefore, in relation to the ground-water reservoir, the streams are discharging potential boundaries. The potential at a given point on the stream is equal to the altitude of the stream at that point. Thus, the potential along the stream channel varies continuously from the altitude of start of flow of the stream to the altitude of the surrounding bay or ocean.

The approximate location and altitude of the points of start of flow for several streams in June 1967 are shown in figure 3. Because ground-water levels and

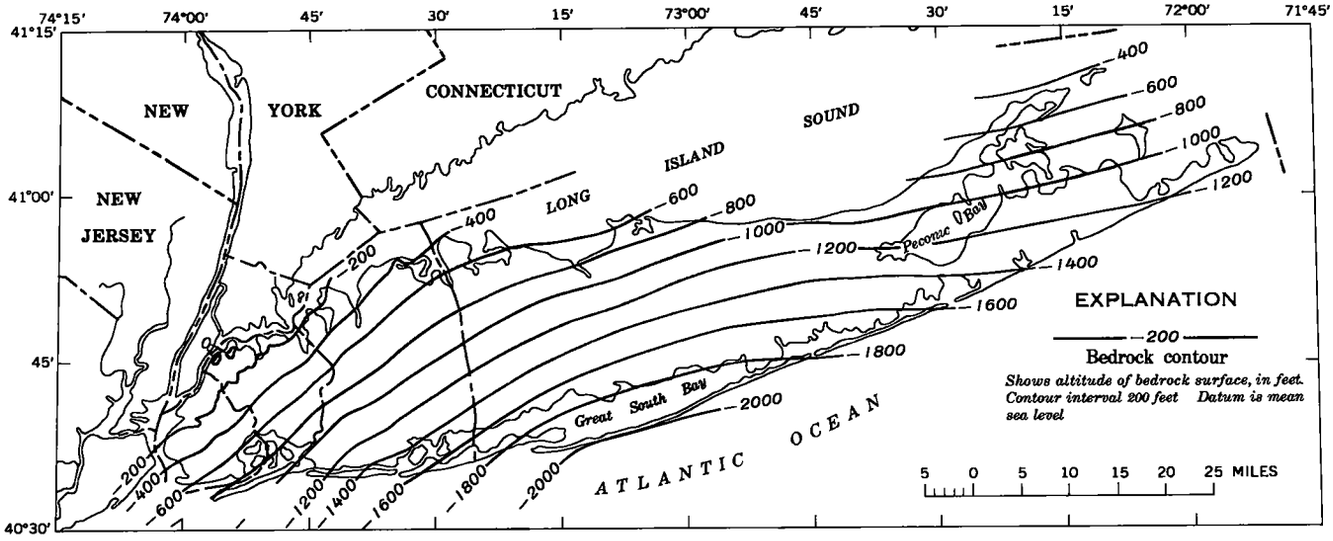


FIGURE 11.—Contour map of the bedrock surface. Modified from Suter, De Laguna, and Perlmutter (1949, pls. 8–10).

streamflow were below average for this month, these altitudes are slightly lower than (on the order of 5 ft) and the points of start of flow are slightly seaward (on the order of several hundred feet) of their average positions. The points of start of flow of the streams are points on the water table, and the locations of these points reflect local conditions relating to topography and position of the water table.

SIZE OF THE FRESH GROUND-WATER RESERVOIR

The volumes of various parts of the fresh ground-water reservoir are given in table 3. The estimates of the volumes of unconsolidated deposits saturated with fresh ground water (col. 2) were derived mainly from a map showing the saturated thickness of the ground-water reservoir in 1965 (fig. 12). The water table at this time, particularly in Kings, Queens, and western Nassau Counties, was considerably lower than the water table under natural conditions. However, the difference in the total volume of fresh ground water in the ground-water reservoir in 1965 compared to the volume under natural conditions is negligible compared to the total volume of fresh ground water in the ground-water reservoir.

The values in column 2 of table 3 are probably accurate to within about 10 percent, except for one entry—the volume of deposits "beneath areas adjacent to the water-budget area" (item *c*). The magnitude

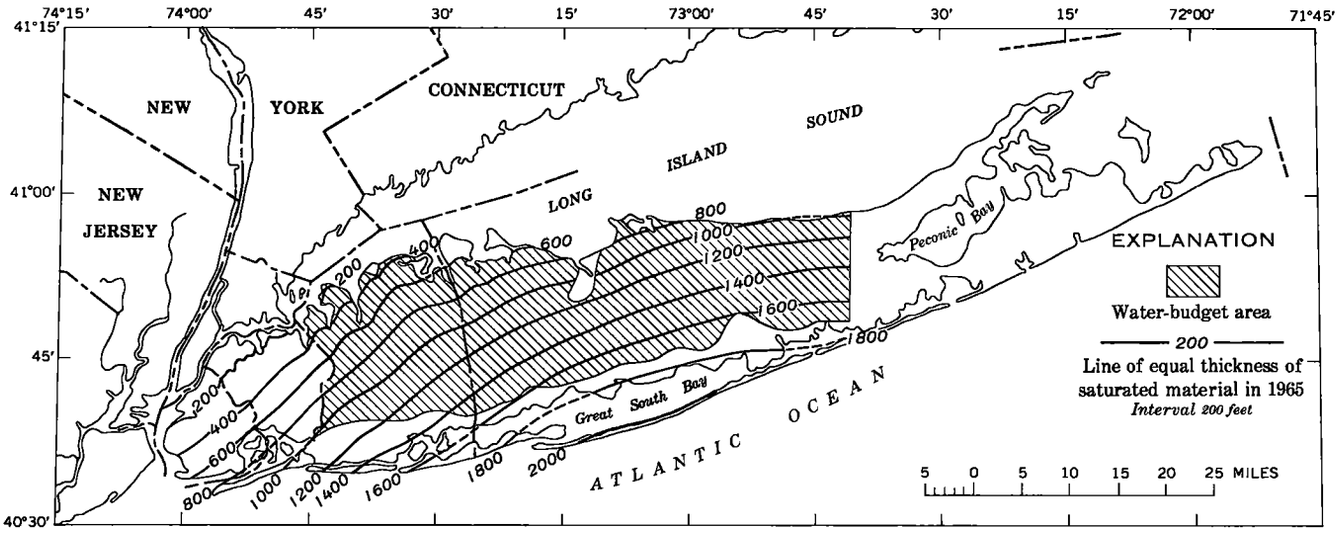


FIGURE 12.—Thickness of unconsolidated deposits saturated with fresh ground water in 1965. After Cohen, Franke, and Foxworthy (1968, pl. 2*G*).

TABLE 3.—*Estimated volume of fresh ground water beneath parts of Long Island, N.Y.*

Volume designation		Volume of deposits saturated with fresh ground water (cubic miles)	Total volume of fresh ground water (gallons)	Range in estimated storage capacity (gallons)
Item	(1)	(2)	(3)	(4)
(a)	Above sea level in water-budget area	5	1,600,000	280,000-560,000
(b)	Beneath entire water-budget area	180	59,000,000	10,000,000-20,000,000
(c)	Beneath areas adjacent to water-budget area [1]	100	33,000,000	5,500,000-11,000,000
(d)	Sums of items *b* and *c* (rounded)	280	92,000,000	15,000,000-31,000,000
(e)	Beneath mainland Kings and Queens Counties	10	3,300,000	550,000-1,100,000
(f)	Sums of items *d* and *e* (rounded)	290	95,000,000	16,000,000-32,000,000

[1] Includes volume beneath the nearshore areas and the adjacent bays.

of this entry depends on the location of the fresh-salt water interface which is not known along much of the perimeter of Long Island.

To obtain the values of "total volume of fresh ground water" in column 3, the entries in column 2 were multiplied by 0.30 (the estimated average porosity), and the result was converted to millions of gallons. This estimate probably is conservative because many of the finer deposits (clays) within the ground-water reservoir probably have a higher porosity.

The storage capacity of the ground-water reservoir is the total volume of water in the ground-water reservoir minus the volume of water that would be retained against the force of gravity if the reservoir were drained—that is, the average porosity minus the average specific retention times the total volume of deposits saturated with water. The average porosity minus the average specific retention is equal to the average specific yield. Previous investigators estimated the average specific yield of deposits in the Long Island ground-water reservoir to be about 5–10 percent (Cohen and others, 1968, p. 26). The specific yield for individual layers in the ground-water reservoir probably ranges fom less than 1 to 25–30 percent. The values in column 4 of table 3 were obtained by multiplying the values in column 2 by 0.05–0.10 (or 5–10 percent) and converting the result to millions of gallons.

As a result of the assumptions that were made, the values of storage capacity in column 4 are probably conservative. However, because of uncertainty about the process of salt-water encroachment and the large volume of fine-grained deposits (silt and clay) in the ground-water reservoir, such conservative estimates are necessary to ensure dependable figures for water-management purposes.

SOURCE OF THE WATER AND INFLOW TO THE HYDROLOGIC SYSTEM

Reference to the accompanying flow diagram (fig. 13) facilitates the following discussion of the hydrologic system under natural conditions. Only flow paths that represent large quantities of water or those that are of special interest or significance are shown. Many other flow paths that commonly represent negligible quantities of water on Long Island, such as infiltration from bodies of surface water to the zone of aeration or direct runoff from the land surface to the ocean, are not discussed in this report.

PRECIPITATION

Under natural conditions, precipitation is the source of all the fresh water on Long Island—that is, it is the total input to the fresh-water hydrologic system. The aspects of the precipitation regimen on Long Island which are especially pertinent to this study are the areal distribution, averages, and ranges of annual, seasonal, and monthly precipitation. Most of the information regarding precipitation considered in the present report is derived from a detailed report that was prepared as part of the present water-budget study of Long Island (Miller and Frederick, 1969).

Information on the distribution by month of the number of days in which specified amounts of precipitation fell and on intensity and frequency of precipitation on Long Island, which was developed in the report by Miller and Frederick, is not considered here. In addition, the drought, which occurred in the Northeastern United States in 1962–66, and its hydrologic consequences on Long Island are evaluated in a separate report (Cohen and others, 1969).

Maps showing average annual, average warm-season (April-September), and average cool-season (October-March) precipitation for water years 1951–65 are shown in figure 14. The period 1951–65 was chosen for these maps because (1) complete or almost complete records were available for that period for the largest number of stations, and (2) data from stations with sufficiently long records showed that averages for the period 1951–65 were close to averages for the so-called normal period, 1931–60.

A significant feature in figure 14*A* is the area of high precipitation in north-central Suffolk County. Miller and Frederick (1969) state that this feature is probably largely related to two factors: (1) The greater distance of the area from the Atlantic Ocean and Long Island Sound and (2) its slightly higher altitude. The map for the average cool-season precipitation (fig. 14*B*) also shows an area of high precipitation in north-central Suffolk County. However, this

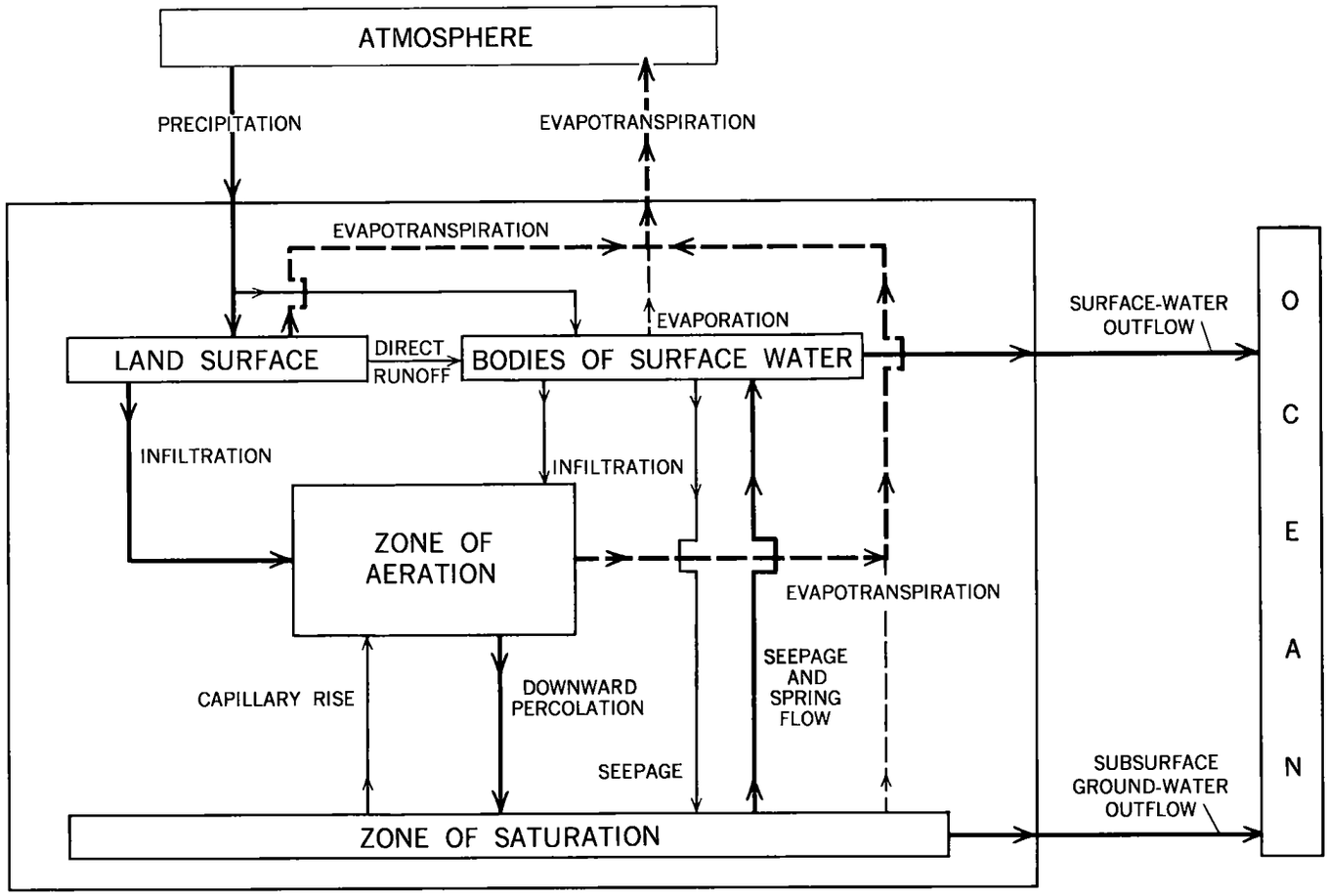


Figure 13.—Flow diagram of the hydrologic system under natural conditions. After Cohen, Franke, and Foxworthy (1968, pl. 64).

feature is less evident in the warm season (fig. 14*C*), presumably because precipitation is more evenly distributed in the warm season than in the cool season.

Mean values of precipitation (derived from fig. 14) for all of Long Island (including the Forks) and for the water-budget area, and ranges in average precipitation are given in table 4. These values show that average warm-season precipitation and cool-season precipitation are almost equal on Long Island.

Composite average monthly precipitation for selected stations for the normal period 1931–60 (fig. 15) indicate that precipitation is distributed fairly evenly throughout the year, and that average monthly precipitation ranges from about 3 to more than 4 inches. During the winter, most of the precipitation on Long Island is derived from regional storms. In the summer, however, most of the precipitation is associated with local thunderstorms. On the average, the lowest monthly precipitation occurs in June—a month of transition between the period when regional storms predominate and the period when local thunderstorms supply most of the precipitation.

Precipitation data from Setauket, the station with the longest period of record (table 5), indicate that precipitation on Long Island ranges widely from month to month and from year to year. For example, although average annual precipitation at Setauket is about 44.5 inches, observed annual precipitation ranged from a low of about 31 inches in 1966 to a high of about 56 inches in 1898.

The values of precipitation described in the previous text are total values—that is, they include snow, snow mixed with rain, and rain alone. The average annual snowfall on Long Island is about 25–30 inches, or about 10–15 percent of the water equivalent of the cool-season precipitation. A tabulation of the number

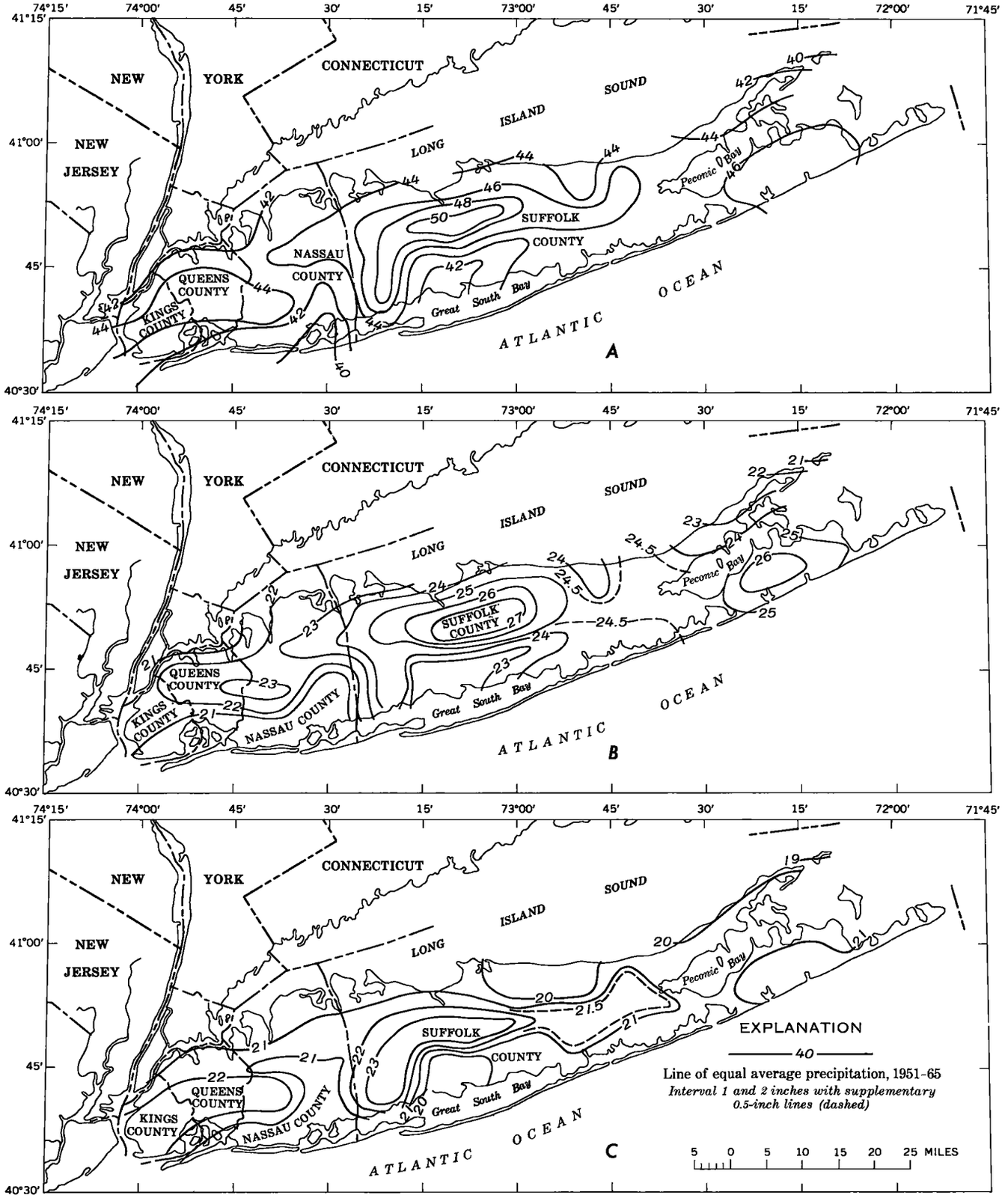


FIGURE 14.—Average annual (*A*), average cool-season (*B*), and average warm-season precipitation (*C*), water years 1951–65. After Miller and Frederick (1969).

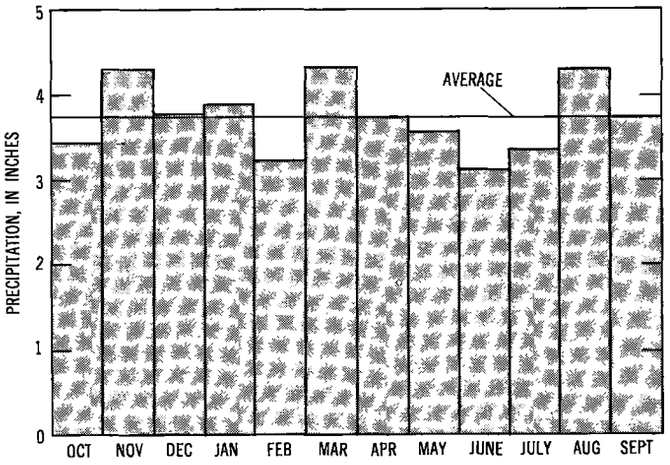


FIGURE 15.—Composite average monthly precipitation for selected stations for the normal period 1931–60.

TABLE 4.—*Average annual and average seasonal precipitation on Long Island, N.Y., and the water-budget area, water years 1951–65*

[In inches]

Area	Precipitation					
	Annual		Cool season		Warm season	
	Mean	Range	Mean	Range	Mean	Range
All of Long Island (including the Forks)	44.3	40–50	23.6	21–27	20.7	19–23
Water-budget area	44.8	41–50	23.8	21–27	21.0	20–23

of snowstorms greater than 6 inches for the New York Weather Bureau Office in Manhattan County for the period 1884–1960 (Miller and Frederick, 1969) showed that most of the large snowstorms were fairly evenly distributed between the first of December and the middle of March. The greatest number of large snowstorms occurred during the first half of February.

DISPOSITION OF PRECIPTATION

Precipitation on the land surface follows three main paths (fig. 13)—direct runoff to bodies of surface water (primarily streams), return to the atmosphere by evapotranspiration, and infiltration into the zone of aeration. Precipitation that infiltrates into the zone of aeration is either transpired by plants or percolates downward to the ground-water reservoir (zone of satuation).

TABLE 5.—*Mean and extreme values of precipitation at Setauket, Long Island, N.Y., water years 1888–1967*

[In inches]

	Precipitation			
	Annual	Warm season	Cool season	Monthly
Mean	44.5	21.7	22.8	3.7
Maximum	56.4	35.4	34.1	13.2
Time of occurrence	1898	1938	1899	Sept. 1938
Minimum	30.8	11.0	12.0	0.1
Time of occurrence	1966	1965	1947	June 1949

DIRECT RUNOFF

Values of direct runoff to selected streams, whose drainage areas have remained virtually unaffected by man, are given in table 6. Data for water years 1958 and 1964 were chosen for comparison because these were years of exceptionally high and low annual precipitation, respectively. On the basis of meager data, it appears that the amount of annual precipitation did not materially affect the percentage of total streamflow that was derived from direct runoff under natural conditions. Furthermore, the figures indicate that the percentage of direct runoff in the discharge of the two northward-flowing streams (Mill Neck Creek and Nissequogue River) was slightly greater than the percentage of direct runoff in the discharge of Carmans River, a southward flowing stream. Two factors probably accounted, at least in part, for this difference: (1) Slightly less permeable soils in areas underlain by glacial till near the north shore as compared to the highly permeable glacial outwash deposits near the south shore and (2) steeper land-surface gradients adjacent to the north-shore streams compared to the south-shore streams.

Because southward flowing streams include most of the streamflow on Long Island (about 75 percent), the data in table 6 suggest that under natural conditions an average of less than 5 percent of total measured streamflow is direct runoff. This quantity of water represents less than 1 percent of the precipitation that fell on the drainage areas of the streams in the water-budget area.

EVAPOTRANSPIRATION

Total evapotranspiration from the hydrologic system of Long Island includes evaporation from the land surface and surface-water bodies, evapotranspiration

TABLE 6.—*Annual direct runoff of selected streams on Long Island, N.Y., whose drainage areas closely approximate natural conditions, water years 1958 and 1964*

Stream	Water year 1958		Water year 1964	
	Average discharge (cubic feet per second)	Direct runoff (percentage of total discharge)	Average discharge (cubic feet per second)	Direct runoff (percentage of total discharge)
Mill Neck Creek	10.7	10	7.2	10
Nissequogue River	47.3	7	37.7	5
Carmans River	30.6	3	20.9	3

from the zone of aeration, and evapotranspiration directly from the ground-water reservoir (fig. 13). Total evapotranspiration excluding evapotranspiration of ground water is briefly discussed in this section of the report. Evapotranspiration of ground water is discussed in the section on "Discharge from the Ground-Water Reservoir."

Annual evapotranspiration constitutes the greatest unknown in the disposition of precipitation on Long Island. Previous investigators estimated average annual evapotranspiration by difference from other quantities in a hydrologic budget. Thus, any errors in the estimates of these other quantities were incorporated in the estimate of evapotranspiration. This procedure resulted in estimates of average annual evapotranspiration that were about one-half of average annual precipitation, or between about 20 and 25 inches. Information is not available to improve upon these estimates in the present investigation.

Average annual values of "potential" evapotranspiration derived by the application of methods developed by Thornthwaite and Mather (1955, 1957) and Meyer (1928) are about 29 and 32 inches, respectively. Thus, the upper limit of annual "potential" evapotranspiration for a specific year is probably on the order of 30–35 inches. Minimum warm-season precipitation for the months April to September for most stations ranges from about 12 to 15 inches. If it is assumed that most of this precipitation is discharged to the atmosphere and that some additional evapotranspiration occurs during the winter months, the minimum values of annual evapotranspiration are probably on the order of 10–15 inches.

Mean annual evaporation from a land pan in central Nassau County for the period 1949–60 was about 48 inches (Pluhowski and Kantrowitz, 1964), of which an average of about 36 inches, or about 75 percent evaporated during the summer months (April-September). This same seasonal distribution of average annual evapotranspiration was indicated by the monthly values of potential evapotranspiration derived from the methods of Thornthwaite and Mather and Meyer.

INFILTRATION TO THE ZONE OF AERATION

No data are presently available to estimate directly the quantity of water that infiltrates into the zone of aeration. However, systematic measurements of soil moisture provide an estimate of evapotranspiration from the zone of aeration and recharge to the water table through the zone of aeration. In addition, such measurements provide valuable information on the storage characteristics of the deposits in the zone of aeration and in the upper part of the zone of saturation.

Studies of soil moisture in glacial outwash deposits using a neutron meter have been underway for several years at the Brookhaven National Laboratory under the direction of G. M. Woodwell. The results of these studies are included in a report by Reiners and Woodwell (1966). Their report included a water budget based on soil moisture measurements for the summer and fall of 1963. Unpublished data from these studies for most of 1966, which include daily precipitation, average water content of the upper 6 feet of the soil profile, and the depth to the water table in a shallow nearby well, are shown in figure 16. The following observations can be made from this figure: (1) When the average water content of the 6-foot soil profile was between about 10 and 11 inches, as in April and late September, ground-water levels slowly declined; (2) when the average water content of the soil profile was greater than about 11 inches as during most of May, ground-water levels rose; and (3) in the extremely dry period of late July and early August, the average water content of the soil was between 5 and 6 inches and ground-water levels declined.

These data and data from Reiner and Woodwell (1966) suggest the following tentative conclusions concerning the soils and uppermost deposits in the Brookhaven area: (1) Field capacity of these soils is about 10–15 percent; and (2) if the total porosity is assumed to be about 30–35 percent, which is indicated by soil-moisture measurements in the capillary fringe, the specific yield of these materials is on the order of 15–25 percent. Although these conclusions are based on very sparse data, they are comparable to conclusions concerning similar deposits elsewhere, and may, therefore, be reasonably representative of the glacial-outwash deposits of Long Island.

Additional observations by Reiner and Woodwell (1966) indicate that the effect of vegetation on soil moisture must occur primarily in the upper 3 feet on Long Island, because the root systems of most indigenous vegetation do not extend below this depth. Probably only the largest trees have any appreciable effect on soil moisture below a depth of 10 feet.

RECHARGE TO THE GROUND-WATER RESERVOIR

Under natural conditions, virtually all ground-water recharge on Long Island resulted from the infiltration of precipitation into the zone of aeration and subsequent downward percolation through the zone of aeration to the water table (fig. 13). As with evapotranspiration, available data do not permit measurement of recharge directly. In the present report, an

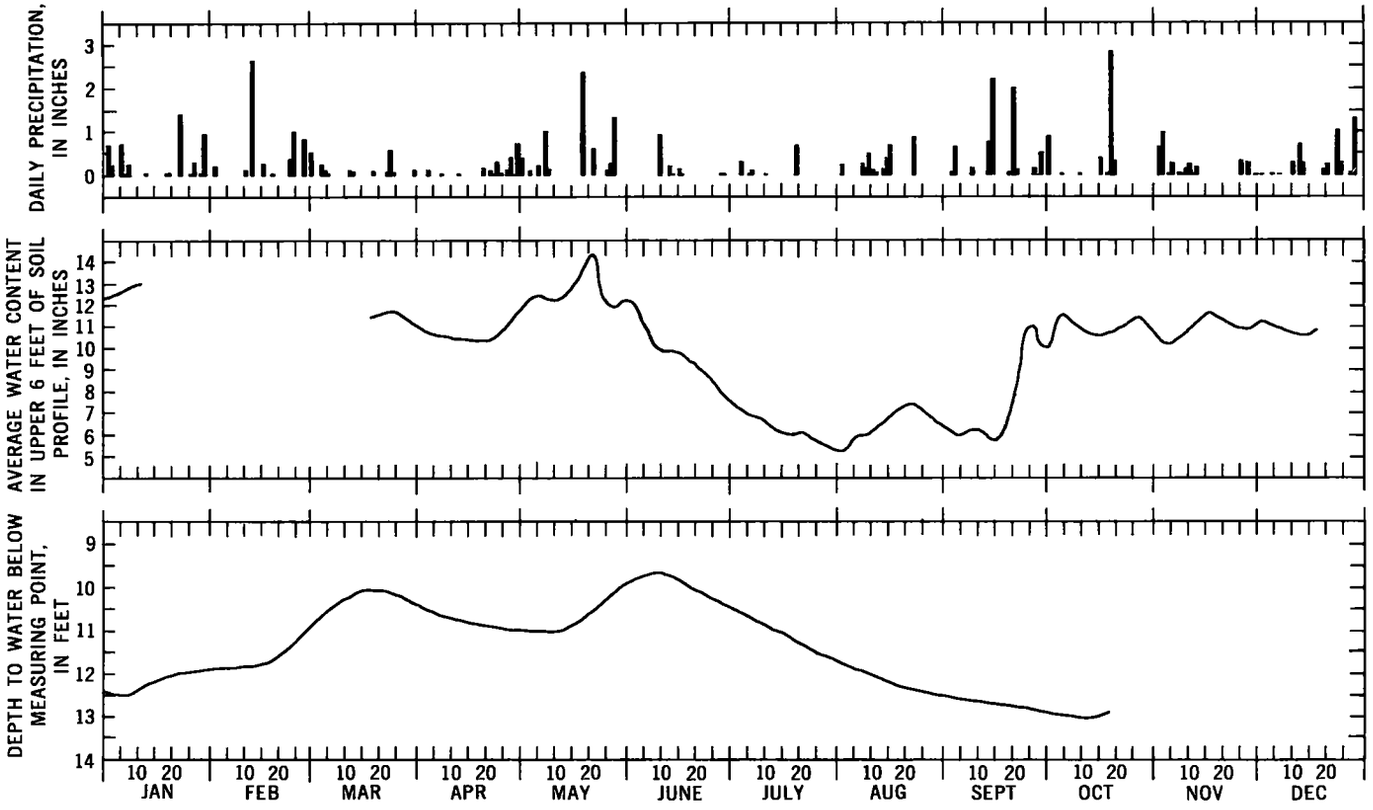


FIGURE 16.—Daily precipitation, average water content in the soil profile at one measuring site, and depth to water in an adjacent well, Brookhaven National Laboratory, in 1966. Data courtesy of G. M. Woodwell, Brookhaven National Laboratory.

estimate of average annual recharge to the ground-water reservoir can be made by first recognizing that under natural conditions long-term average annual recharge to, and discharge from, the ground-water reservoir were equal. An estimate of average annual recharge is obtained, therefore, by summing the estimates of average annual discharge for each element of discharge from the ground-water reservoir. These elements, which include base flow of streams, ground-water evapotranspiration, and subsurface outflow, are evaluated in a subsequent section of this report.

Previous investigators estimated average annual recharge by subtracting estimates of average annual evapotranspiration and other water-budget components from average annual precipitation. These estimates of average annual recharge were equal to about one-half the average annual precipitation (about 22–23 in. of water), or about 1 million gallons per day per square mile (Cohen and others, 1968, p. 44). The data presented subsequently in this report indicate that these previous estimates are in line with the best information presently available. Cohen, Franke, and Foxworthy also estimated that annual recharge ranged from about 10 to 35 inches of water.

Although no direct measurements of the quantity of recharge on Long Island are available, some information is available on the rate of movement of recharge water in the zone of aeration. Average times of travel through the zone of aeration in the till-covered areas of northeastern Nassau County as determined by Isbister (1966) are given in table 7. Isbister equipped several wells having different depths to the water table with water-level recorders. He then observed the time until the water levels in the wells responded to recharge from an identifiable large storm. Wells with progressively smaller depths to water generally showed smaller ranges in lag time. However, the response times in a single well ranged widely. For example, in a well where the depth to water was about 180 feet, the response time ranged from 5 to 16 months as compared to an average of 9–10 months (table 7).

Although the lag times given in table 7 may be considered reasonably representative for the till-covered northern part of Long Island, these times are undoubtedly too large for the more permeable glacial-outwash deposits in the southern part of Long Island. Wells in these deposits with depths to water of 30–40

TABLE 7.—*Relation of depth to the water table and average time lag in response to recharge in till-covered areas of northeastern Nassau County, Long Island, N.Y.*

[After Isbister (1966, table 10)]

Depth to water table (feet)	Average response time (months)	Depth to water table (feet)	Average response time (months)
0–10	0–1	80–100	5–6
10–25	1–2	100–120	6–7
25–40	2–3	120–140	7–8
40–60	3–4	140–160	8–9
60–80	4–5	160–180	9–10

feet often show a marked water-level response within hours or within a day or two after a large storm.

MOVEMENT WITHIN THE GROUND-WATER RESERVOIR

An idealized cross section of part of a ground-water reservoir is shown in figure 17. The dimensions of the cross section are similar to the Long Island ground-water reservoir in a north-south cross section south of the ground-water divide. The potential and flow lines in figure 17 were derived in part from an electric-analog model using graphite paper as the conducting medium (Wyckoff and Reed, 1935). In this model and in figure 17, the vertical exaggeration is about 15 to 1 compared to the Long Island ground-water reservoir. The water table was simulated by 10 discrete potential drops from the maximum potential in the system at the water-table divide (designated arbitrarily as 1000 in figure 17) to base level (zero potential or ground). No attempt was made to model a salt-fresh water interface.

The flow pattern in figure 17 was constructed for the following idealized conditions: (1) The flow was two dimensional, (2) the flow medium was homogeneous, (3) the upper boundary of the flow system (the water table) was a constant source of recharge, and (4) the lower boundary (impermeable bedrock) was a stream surface. Despite the idealized assumptions used to construct this flow net, several significant observations concerning the Long Island flow system can be made from the net. Except for narrow areas near the left- and right-hand margins of figure 17, the predominant directional component of flow is horizontal. In a model without vertical exaggeration the horizontal character of the flow would be even more pronounced. Furthermore, the flow line originating at the water-table divide follows a path nearest the bedrock and discharges farthest from the shoreline. The flow lines originating progressively shoreward of the water-table divide penetrate less deeply into the flow system and discharge nearer the shoreline.

Another significant observation from figure 17 is that, with the particular geometry and potentials fixed in the model, some discharge (electrical output) from the system occurs landward of the shoreline. Because this model is reasonably analogous to the flow system of the Long Island ground-water reservoir, the results suggest that some discharge mechanism may also be acting in this area in the prototype. On Long Island this discharge mechanism is largely associated with the flowing parts of the streams.

Seepage of ground water to the streams is a major factor in modifying the two-dimensional flow pattern in the shallow part of the ground-water reservoir in figure 17. East-west flow components that are perpendicular to the idealized flow section in figure 17 are clearly indicated in figure 18, which is a water-table contour map of the southeastern part of Nassau County. North of the flowing parts of the

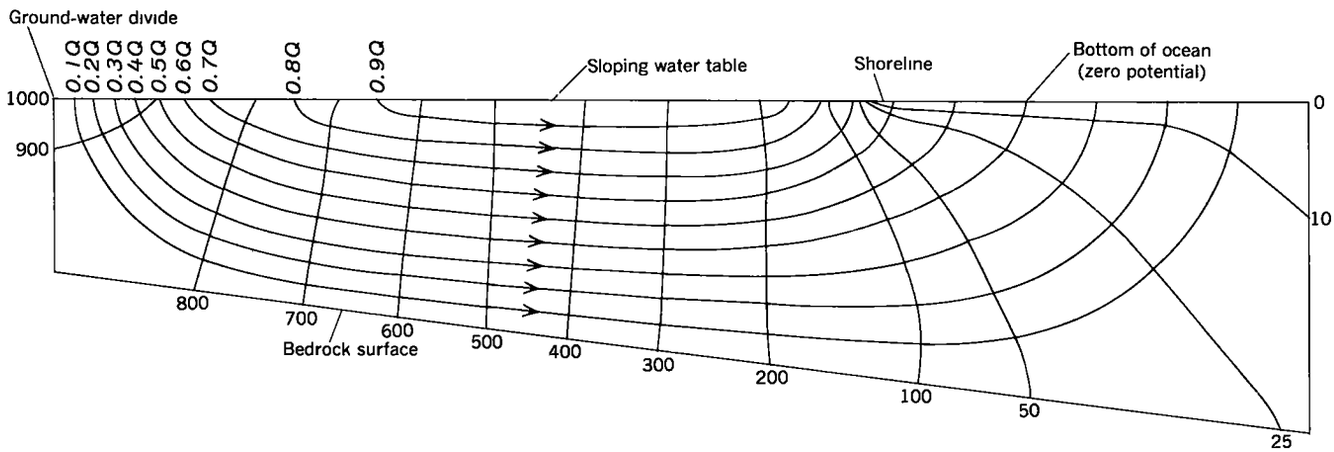


FIGURE 17.—Idealized cross section showing potential and flow lines in part of a homogeneous ground-water reservoir. Q is total discharge through system.

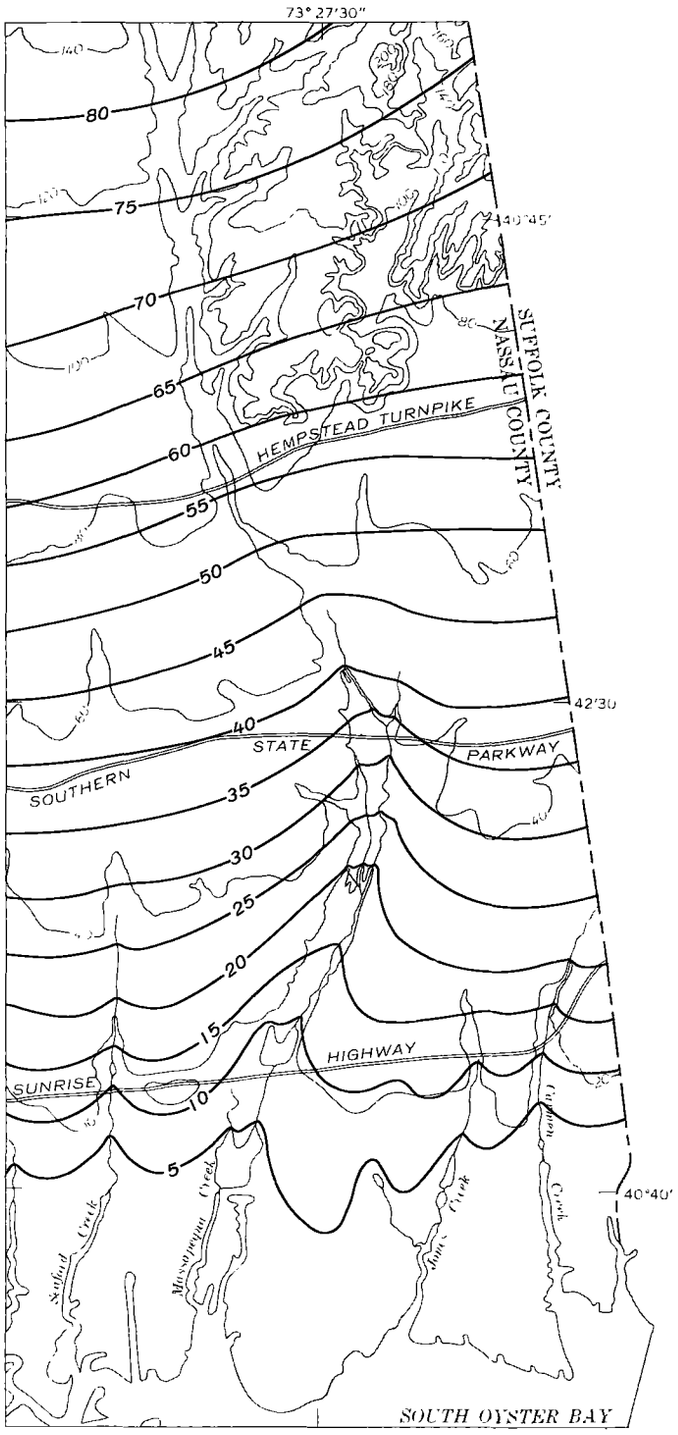


FIGURE 18.—Water-table contours near Massapequa Creek in October 1961.

streams, the water-table contours show relatively even and slight curvatures. In the neighborhood of their flowing parts, however, the water-table contours are bent sharply towards the streams, which clearly indicates that ground water discharges into them.

The ground-water system on Long Island can be divided into two general subsystems—a shallow circulating subsystem and a deep circulating subsystem. Ground water in the shallow subsystem, which is particularly well developed south of the main water-table divide, discharges mainly into the streams; ground water in the deep subsystem discharges into the bays, the Atlantic Ocean, and Long Island Sound. Flow paths in the deep subsystem range in length from one to several miles, and the flow is generally two dimensional (fig. 19). On the other hand, flow paths in the shallow subsystem range from a few feet to several thousand feet, and the flow is generally three dimensional.

Representative geohydrologic sections of the natural flow system in the northern and southern parts of Long Island are shown in figures 20 and 21, respectively. These sections show some of the principal geologic features of the ground-water reservoir that are responsible for modifying the idealized flow pattern shown in figure 17. The presence of almost horizontal and poorly permeable beds in the flow section tends to accentuate the horizontal components of flow, except near the ground-water divide and in discharge areas near the shorelines. Despite the obvious differences in detail, most of the major features of the flow pattern in figures 20 and 21 clearly are similar to those of the flow pattern in figure 17.

Profiles of heads in the major aquifers (fig. 22) show that a relatively small head difference occurs between the water table and the base of the Magothy aquifer as compared to the difference in head between the base of the Magothy aquifer and the Lloyd aquifer. This relatively large difference in head between the base of the Magothy aquifer and the Lloyd aquifer reflects the low hydraulic conductivity of the intervening Raritan clay, the principal confining layer of the Lloyd aquifer. Upward components of flow exist near the bottom of the Magothy aquifer seaward of the intersection of the piezometric surface at the bottom of the Magothy aquifer and the water table. Similarly, upward components of flow exist seaward of the intersection of the piezometric surface of the Lloyd aquifer and the piezometric surface at the bottom of the Magothy aquifer.

Another modification of the idealized flow pattern in figure 17 is caused by the salty ground water that

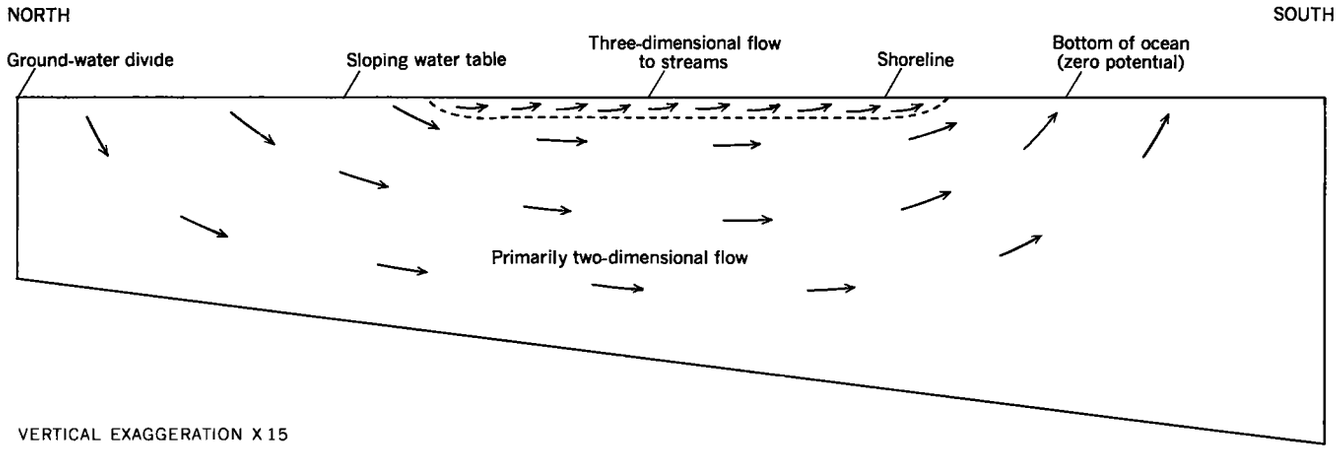


FIGURE 19.—Diagrammatic cross section of the southern half of the ground-water reservoir showing the part of the reservoir with primarily two-dimensional flow and the part of the reservoir with three-dimensional flow to streams.

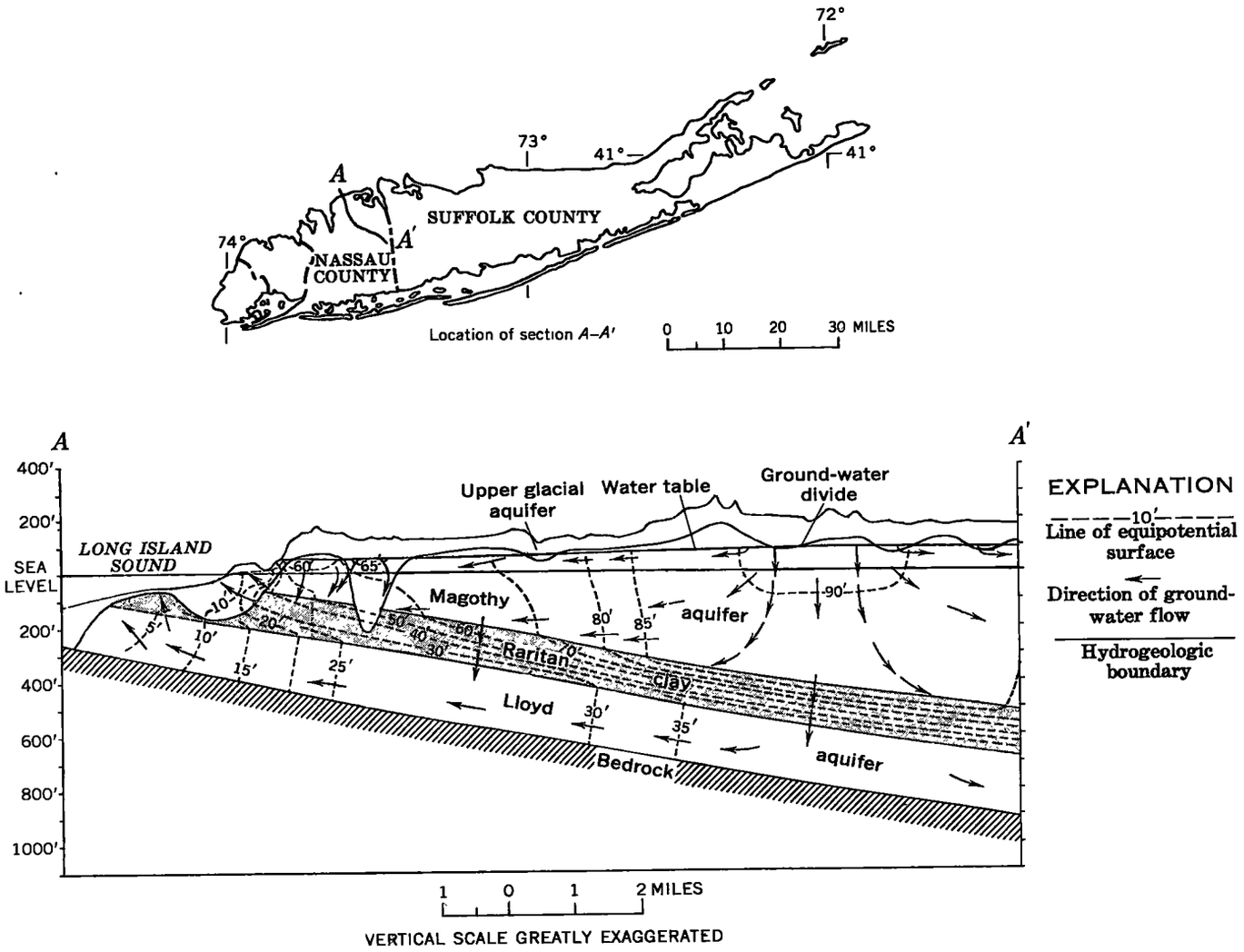


FIGURE 20.—Geohydrologic section of the ground-water reservoir in northeastern Nassau County in March 1961. Adapted from Isbister (1966, fig. 11).

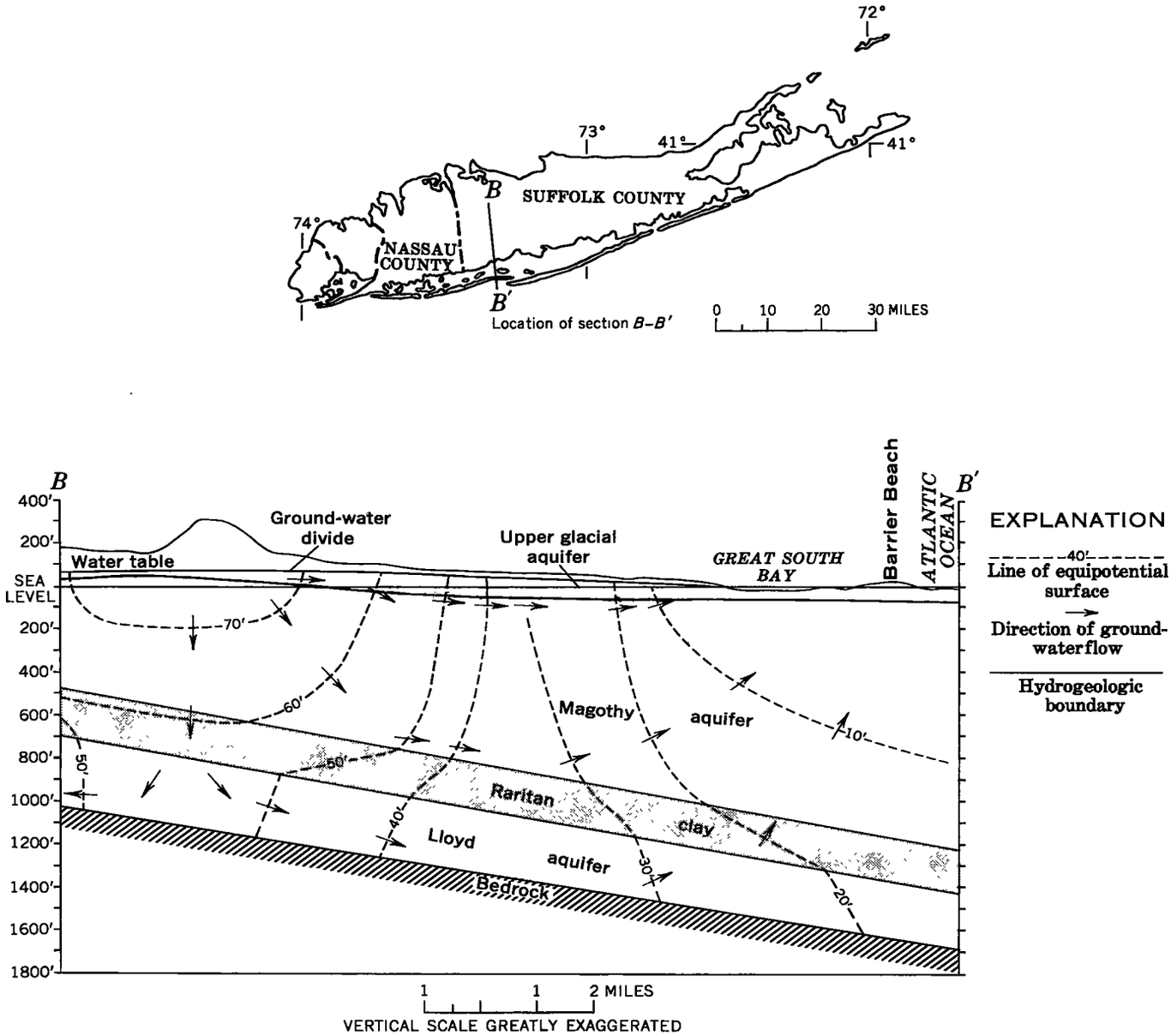


FIGURE 21.—Geohydrologic section of the ground-water reservoir in southwestern Suffolk County in October 1960. Adapted from Pluhowski and Kantrowitz (1964, fig. 13).

bounds the fresh ground-water reservoir of Long Island. The presence of the salty ground water results in several salt-fresh water interfaces at various depths in the Long Island ground-water reservoir. As stated previously, these interfaces are dynamic boundaries that change position in response to changes in head within the ground-water reservoir. The positions of these interfaces are undoubtedly at least partly related to the location of the relatively permeable and impermeable layers in the ground-water reservoir.

DISCHARGE FROM THE GROUND-WATER RESERVOIR

The main elements of discharge from the ground-water reservoir are seepage to streams and springs, ground-water evapotranspiration, and subsurface outflow (fig. 13).

STREAMFLOW AND SPRINGFLOW

Those aspects of streamflow that are emphasized in this report are the annual and daily streamflow from the water-budget area, streamflow in the near-

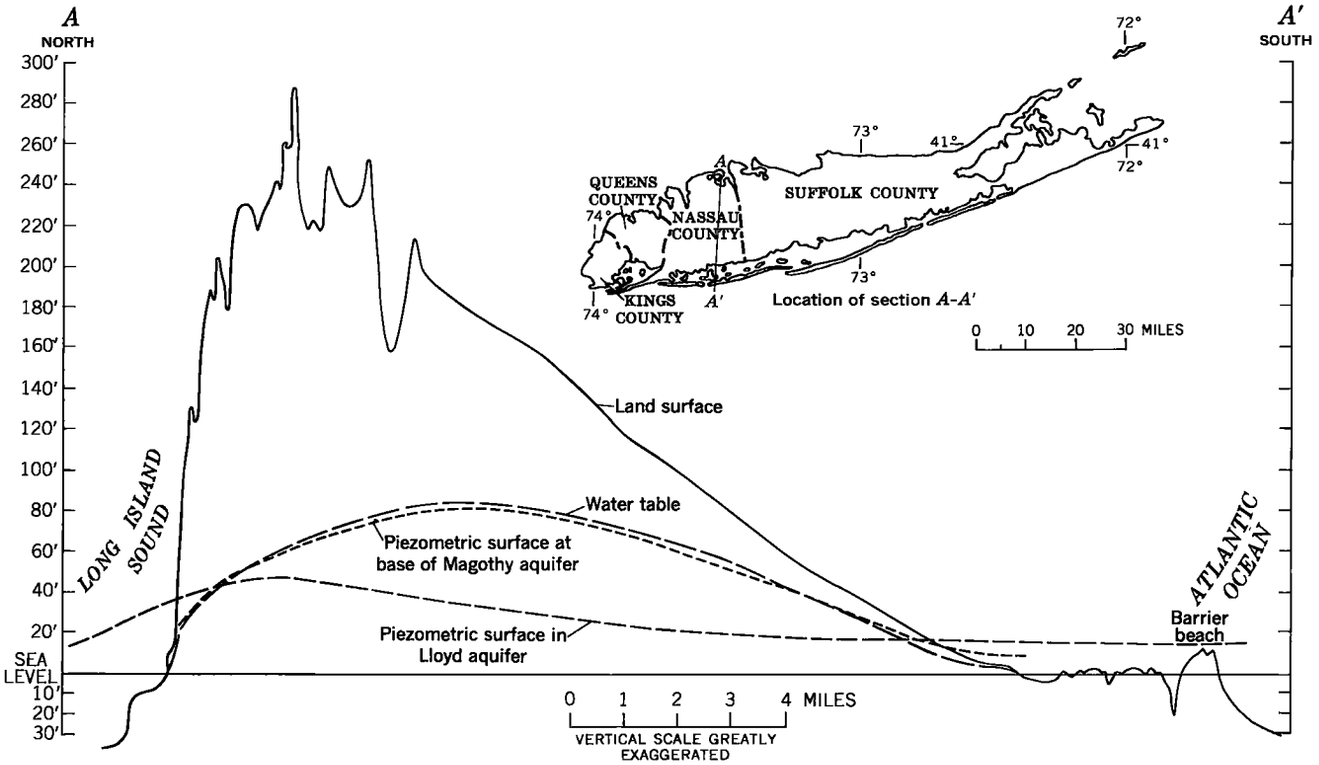


FIGURE 22.—Profiles of the water table and piezometric surfaces at the base of the Magothy aquifer and in the Lloyd aquifer in 1963. Based on unpublished maps prepared by John Isbisher (written commun., 1966).

shore areas, and the relation between ground-water levels and streamflow. Unless otherwise stated, all values of streamflow are for total streamflow and, therefore, include direct runoff. Most of the information presented in this section is derived from a summary of streamflow on Long Island by Vaupel and Spinello (written commun., 1968).

The average base flow of the streams (that is, seepage from the ground-water reservoir) is about 90–95 pecent of total average steamflow at present (1968). The percentage of total average streamflow that is direct runoff presently is somewhat greater than the estimate for natural conditions, because direct runoff to many streams has been materially increased by urban development. (See section on "Disposal of direct runoff to streams.")

In overall aspect, the present locations of Long Island's streams were determined mainly by the ancient drainage pattern that developed during the last ice age. Accordingly, most of the streams flow in broad, shallow valleys that were formed by the much larger streams that existed during melting of the ice sheet. All the southward-flowing streams have gentle gradients that, throughout most of their reaches, average about 10 feet per mile. The northward-flowing streams, especially in the western half of the island, generally have steeper gradients that average about 20–40 feet per mile. The lengths of these streams (distance from gaging station to start of flow along the main channel) range from less than 1 mile to somewhat less than 10 miles (fig. 3). In addition, all the streams are estuarine in their lower reaches.

The names, surface drainage areas, and average flows at the gaging stations of the 19 continuously gaged streams in the water-budget area for the period water years 1940–65 are given in table 8. The gaging stations of these streams were established at points sufficiently upstream from the ocean, bays, and Long Island Sound so that the records would not be affected by tidal fluctuations. The data obtained at these stations, therefore, are not indicative of the total flow of these streams.

The average flows given in table 8 range from less than 5 cfs to slightly more than 40 cfs, and the total average discharge of the 19 streams is about 300 cfs. Moreover, the data in table 8 indicate that there is a very poor correlation between the surface drainage areas of the streams and their average flows.

The average annual discharge of all measured streams (continuously gaged and miscellaneous measuring sites) in the water-budget area for the period 1940–65 was about 475 cfs. A graph of the recurrence

TABLE 8.—*Surface drainage areas and average flows of the 19 continuously gaged streams in the water-budget area of Long Island, N.Y., water years 1940–1965*

Identification number of stream-flow measuring station	Name of stream	Surface drainage area (square miles)	Average flow (cubic feet per second)
1-3025	Cedar Swamp Creek	11	7.2
3030	Mill Neck Creek	12	9.5
3035	Cold Spring Brook	7	4.6
3040	Nissequogue River	27	42.2
3045	Peconic River	75	35.5
3050	Carmans River	71	24.2
3055	Swan River	9	13.0
3060	Patchogue Creek	14	21.2
3065	Connetquot River	24	39.4
3070	Champlin Creek	7	7.5
3075	Penataquit Creek	5	6.2
3080	Sampawams Creek	23	9.8
3085	Carlls River	35	27.7
3090	Santapogue River	7	4.6
3095	Massapequa Creek	38	11.9
3100	Bellmore Creek	17	11.2
3105	East Meadow Brook	31	17.5
3110	Pines Brook	10	5.1
3115	Valley Stream	4	4.8

interval for annual average discharge of all measured streams from the water-budget area based on the period 1940–65 (fig. 23) indicates that the annual average discharge of all measured streams has varied from about 300 cfs to somewhat more than 600 cfs during this period. This variation in annual streamflow by a factor of about 2 over a period of more than 25 years is small compared to corresponding variations in the annual flow of streams in other areas of the humid Northeastern United States.

On the average, an estimated additional 25–50 cfs is discharged from the water-budget area in small unmeasured streams and springs. Thus, the estimated total average discharge of streams and springs from the water-budget area was about 500–525 cfs, or about 340 mgd (million gallons per day) for the 26-year period 1940–65. Of this total, about 50 mgd discharged from the northern part of the water-budget area and 290 mgd from the southern part of the water-budget area, which includes streamflow discharging into Peconic Bay from the water-budget area.

As shown in figure 24, the median of the average daily measured flows from the water-budget area for the period 1940–65 was about 440 cfs, which was slightly less than the average daily flow for this period. Furthermore, the average daily flow ranged from about 250 cfs to more than 1,000 cfs, which was considerably greater than the range in annual average flows.

A large amount of additional water undoubtedly seeps from the ground-water reservoir into the lower tidal reaches of the streams in the nearshore areas—particularly the southern nearshore area. Most of this water is derived from precipitation that recharges the ground-water reservoir in the nearshore areas—that is, it is not part of the deep circulating ground-water subsystem. The estimated average amount of this additional unmeasured streamflow is on the order of 40–80 mgd for the southern nearshore area and 10–15 mgd for the northern nearshore area. These very approximate estimates were developed as follows: The area of the "southern nearshore area" is about 80 square miles. If the average recharge rate in this area is about 1 mgd per sq mi (see section on "Summary of relations

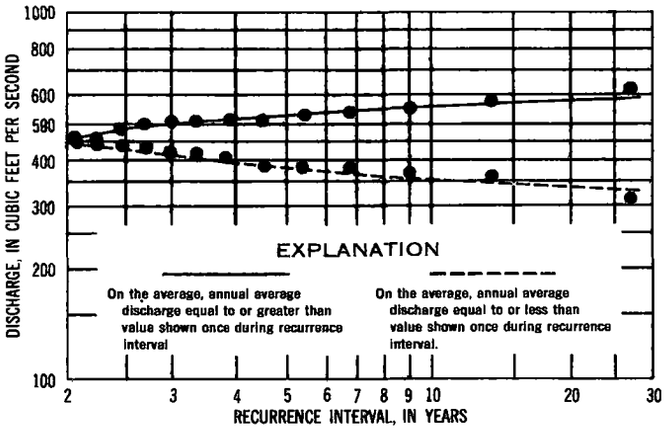


FIGURE 23.—Magnitude and frequency of annual average discharge of streams from the water-budget area D. E. Vaupel and A. G. Spinello (written commun., 1968).

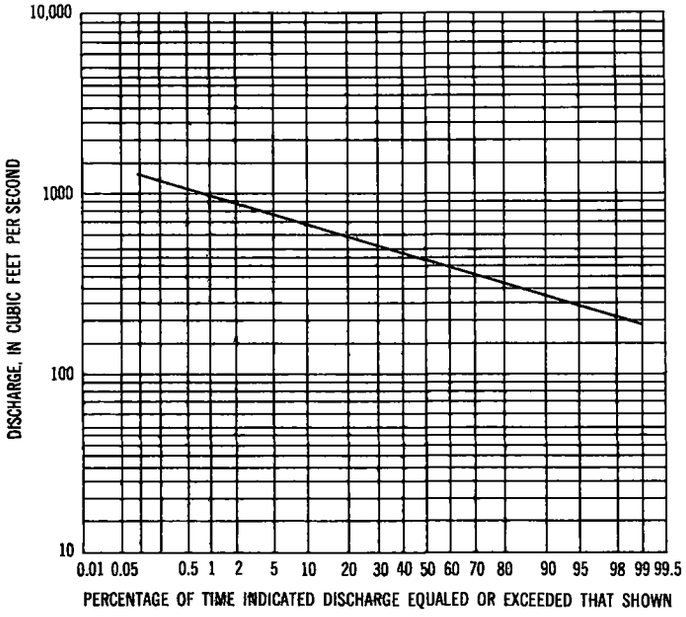


FIGURE 24.—Estimated duration curve of daily streamflow from the water-budget area. D. E. Vaupel and A. G. Spinello (written commun., 1968).

between components of the hydrologic system") and if all the recharge ultimately discharged into nearby tidal reaches of the streams, the resulting average increase in flow in tidal reaches of streams in the "southern nearshore area" would be about 80 mgd. However, a considerable amount of ground water probably is discharged by evapotranspiration (see next section of report) in this area because of the shallow depth to ground water and the high density of vegetation associated with the many swampy areas. Moreover, the average percentage of direct runoff in this area may be higher than the percentage in the water-budget area. Accordingly, an 80 mgd increase in streamflow is considered to be an upper limit, and the correct value is believed to lie between 40 and 80 mgd. The same lines of reasoning were applied to develop estimates of the increase in streamflow in the "northern nearshore area."

The close relation between streamflow and water levels in nearby water-table wells is shown in figures 25–27. The good correlation between the two hydrographs in figure 25 is evident. In figure 26 both sets of data from figure 25 were averaged for each month, which resulted again in two curves of very similar shape. Finally, the relation between the average monthly water-level data and the streamflow data in figure 26 is shown in figure 27. A straight line of best fit was estimated for the points representing October through March, which show an approximately linear relationship between stream discharge and ground-water-level altitude. The obviously different relationship between the two variables during the

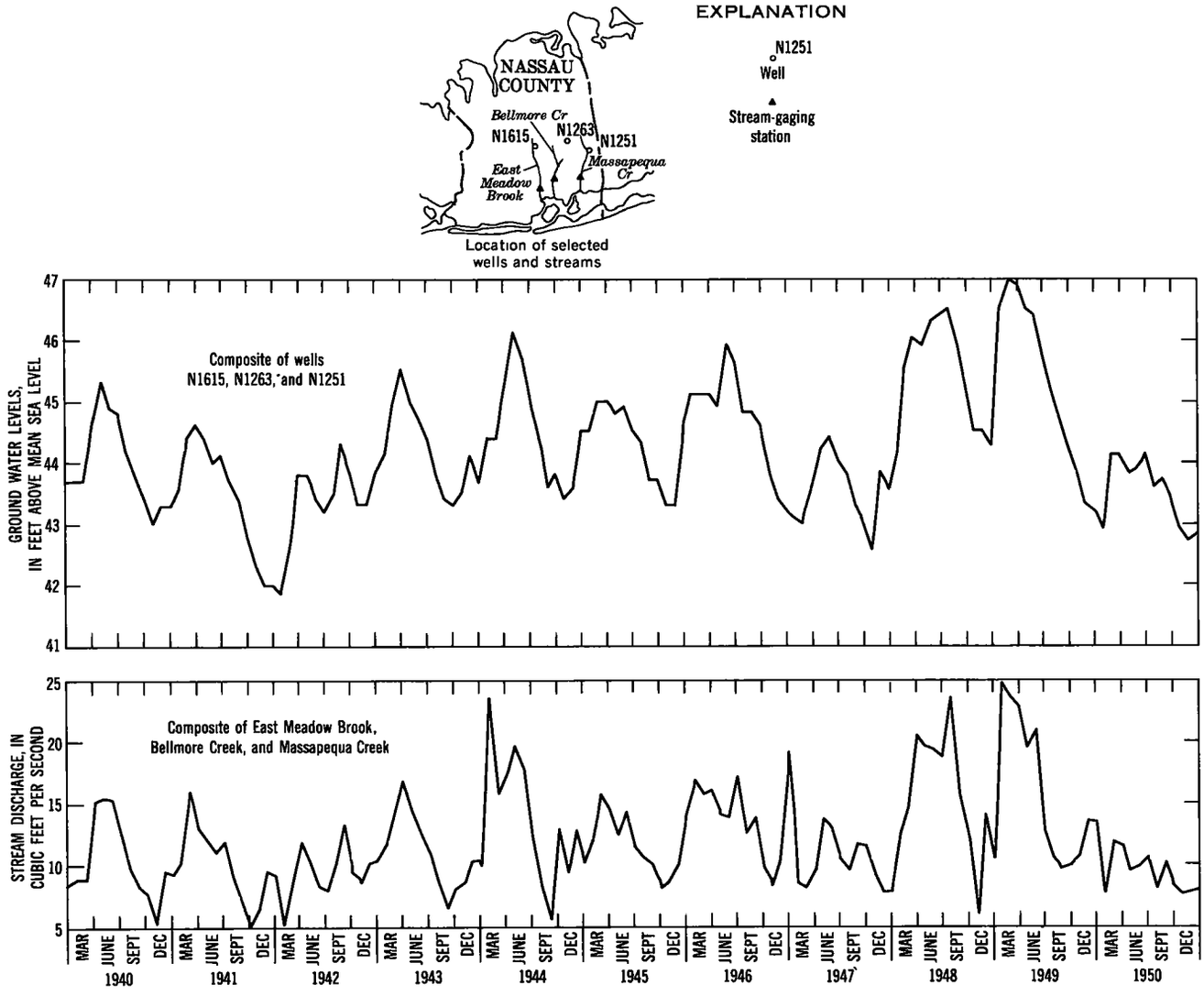


FIGURE 25.—Composite average monthly ground-water levels in selected wells and composite average monthly discharge of selected streams in Nassau County for the period 1940–50.

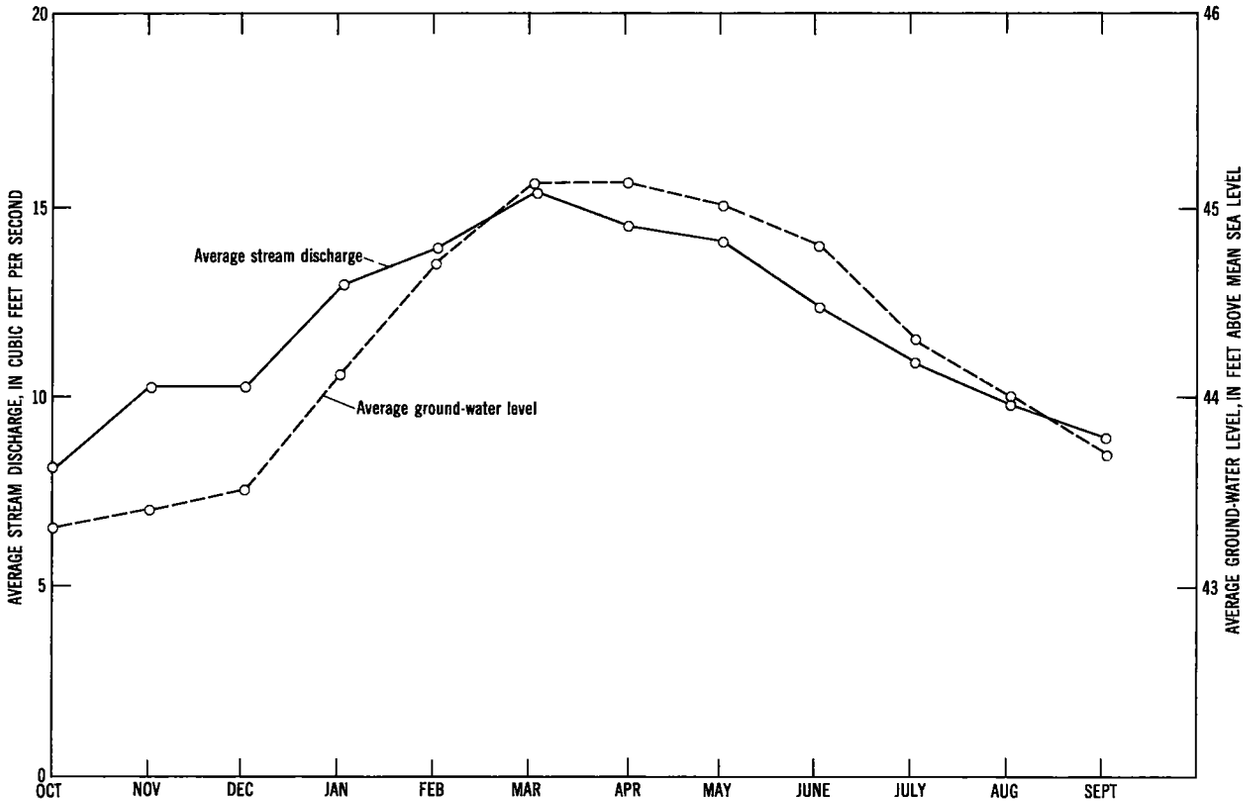


FIGURE 26.—Average monthly discharge of selected streams and average monthly ground-water levels in selected wells in Nassau County for the period 1940–50.

summer months (April–September) is undoubtedly due in part to ground-water evapotranspiration. (See next section of report.)

The regular seasonal variation in ground-water levels and streamflow, which is primarily the result of a seasonal variation in total evapotranspiration and ground-water recharge, is also shown in figures 25 and 26. In figure 26, ground-water levels and streamflow reach their maximums on the average in March or April and their minimums in September or October. The ratio of the maximum to minimum average monthly flows in figure 26 is slightly less than 2 to 1. Although this ratio varies from about 1.2 to 2 for individual streams on Long Island, this variation is small in comparison with many streams elsewhere and reflects the close relationship between the streams and the ground-water reservoir.

GROUND-WATER EVAPOTRANSPIRATION

The separation between the summer and winter recession curves for Carmans River (fig. 28) indicates that some factor that is not operative during the winter months reduces streamflow during the summer months or during periods without precipitation. In an unregulated stream under natural conditions such as Carmans River in the summer months, this factor probably is evapotranspiration of shallow ground water and evapotranspiration of soil moisture which, in turn, results in decreased recharge. In the absence of active evapotranspiration, this ground water would have seeped into the stream channel and increased streamflow. The separation between recession curves of other streams on Long Island (developed by D. E. Vaupel and A. G. Spinello, written commun., 1968) varies widely—some pairs of curves show more separation than Carmans River, and some show virtually no separation. The amount of separation in these curves seems to correlate very roughly with the size of the area adjacent to the stream whose altitude is almost the same as the stream and which is occupied by vegetation.

Pluhowski and Kantrowitz (1964) estimated the quantity of ground-water evapotranspiration in southwestern Suffolk County from observations of daily cyclic fluctuations in ground-water levels of a shallow well during the summer months. The well was located near Sampawams Creek in an area where the depth to ground water was less than 5 feet. From a hydro-

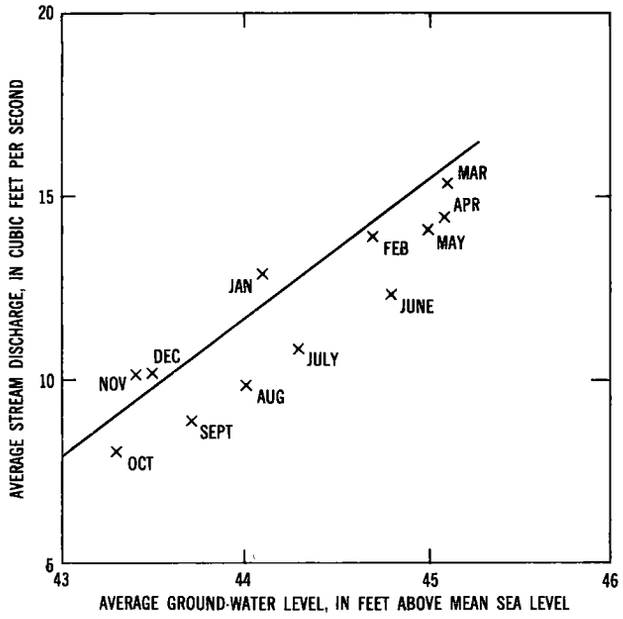


FIGURE 27.—Relation between average monthly discharge of selected streams and average monthly ground-water levels in selected wells in Nassau County for the period 1940–50.

graph of this well and a knowledge of the area in which the depth to ground water was less than 5 feet (about 30 sq mi), they estimated that the average ground-water evapotranspiration within their study area was about 11 mgd.

The depth to the water table is less than 10 feet in about 50 square miles and less than 5 feet in an estimated 30 square miles of the water-budget area. According to the previous estimate, therefore, the estimated average ground-water evapotranspiration from the water-budget area is on the order of 10–15 mgd. Most of the ground-water evapotranspiration on Long Island occurs in the low-lying nearshore areas north and south of the water-budget area—particularly south. No data are presently available to estimate the quantity of water consumed by ground-water evapotranspiration in these areas.

SUBSURFACE OUTFLOW OF GROUND WATER

Subsurface outflow of ground water is the second largest element of discharge from the water-budget area. To help estimate subsurface outflow, maps showing the transmissivity of the principal aquifers of Long Island (fig. 29) were developed in a report by McClymonds and Franke (1971). The Jameco aquifer was not included in figure 29 because it occurs, except for a small area in southwestern Nassau County, outside the water-budget area.

As the starting point in their investigation, McClymonds and Franke estimated the average hydraulic conductivity of the deposits opposite the screened interval of more than 2,000 wells by calculating modified specific-capacity numbers for each well, Q/sL, which is the specific capacity of the well (Q/s, or well discharge divided by drawdown in the well) divided by the screen length (L). The distribution of Q/sL numbers for the principal aquifers of Long Island (fig. 30) clearly differentiates the ability of the screened intervals in the three principal aquifers to transmit water to the wells. The estimated median hydraulic conductivities of the screened intervals in the wells from which data were used to construct the curves in figure 30 are 2,500, 1,000, and 600 gallons per day per square foot in the upper glacial, Magothy, and Lloyd aquifers, respectively.

By correlating the Q/sL numbers with the various observed lithologies in the screened intervals of many wells, estimated values of average hydraulic conductivity were assigned to each lithology in each aquifer. These average hydraulic conductivity values were then applied to each layer in the entire aquifer for individual wells, and the average hydraulic conductivity of the material penetrated by each well for which logs were available was computed. Although considerable variation was found between estimates of average hydraulic conductivity in nearby wells, a reasonable regional pattern of average hydraulic conductivity could be mapped where, on the average, one or more data points were available for every

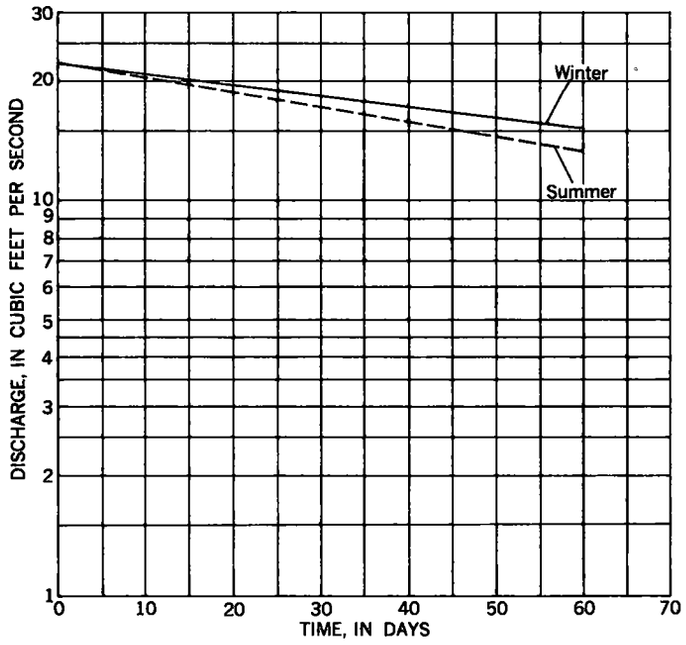


FIGURE 28.—Summer and winter recession curves for Carmans River. D. E. Vaupel and A. G. Spinello (written commun., 1968).

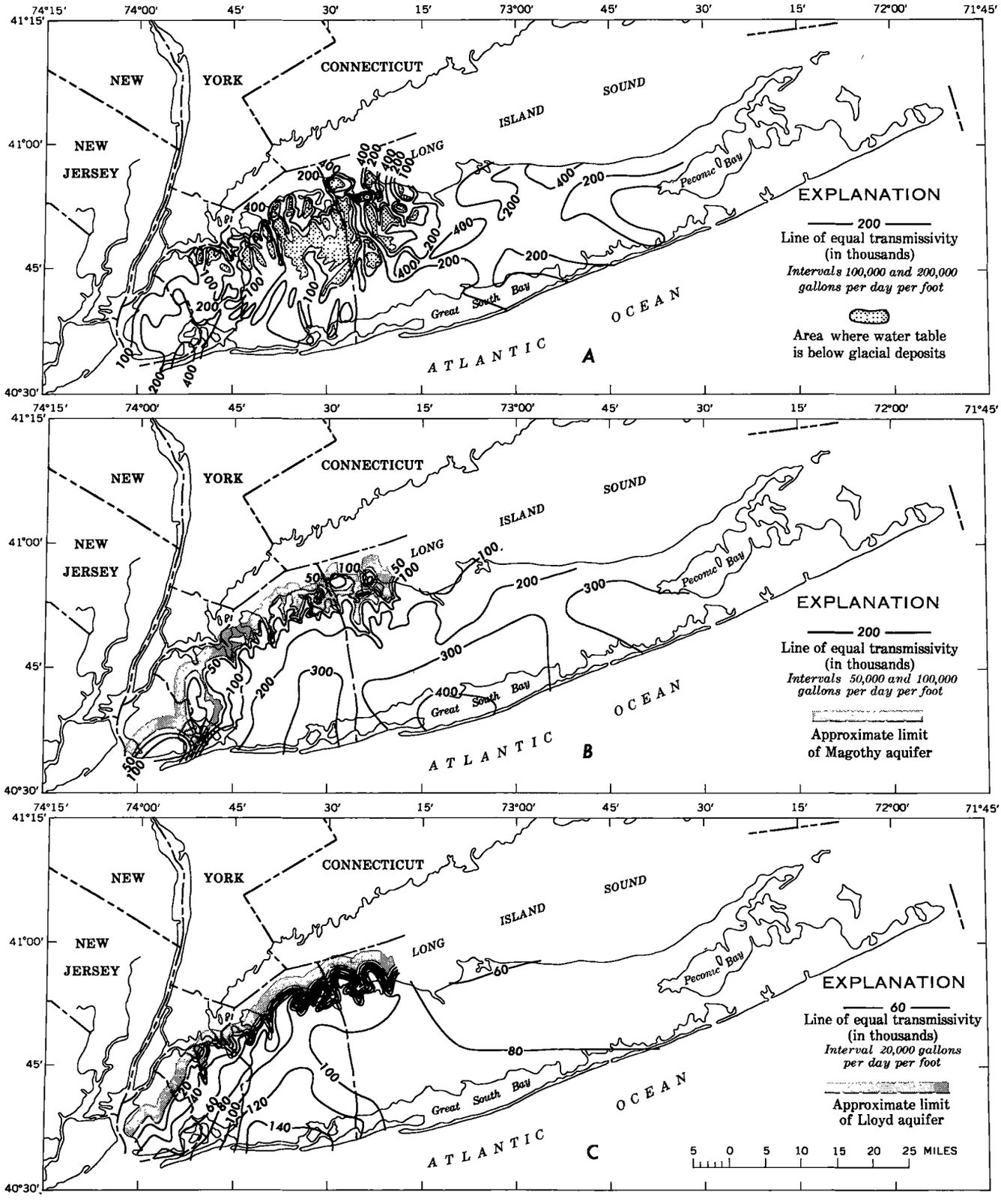


FIGURE 29.—Estimated transmissivity of (*A*) upper glacial aquifer, (*B*) Magothy aquifer, and (*C*) Lloyd aquifer. After McClymonds and Franke (1971). Transmissivity lines on these maps were developed by combining data from aquifer-thickness maps and maps of average hydraulic conductivity for the respective aquifers. (See McClymonds and Franke, 1971.) The high degree of detail shown for the transmissivity lines is not meant to imply a high degree of accuracy for transmissivity at any specific location. Rather, it largely reflects a fairly high degree of accuracy in the information shown on the aquifer-thickness maps and only a moderate degree of accuracy in the information shown on the maps of average hydraulic conductivity.

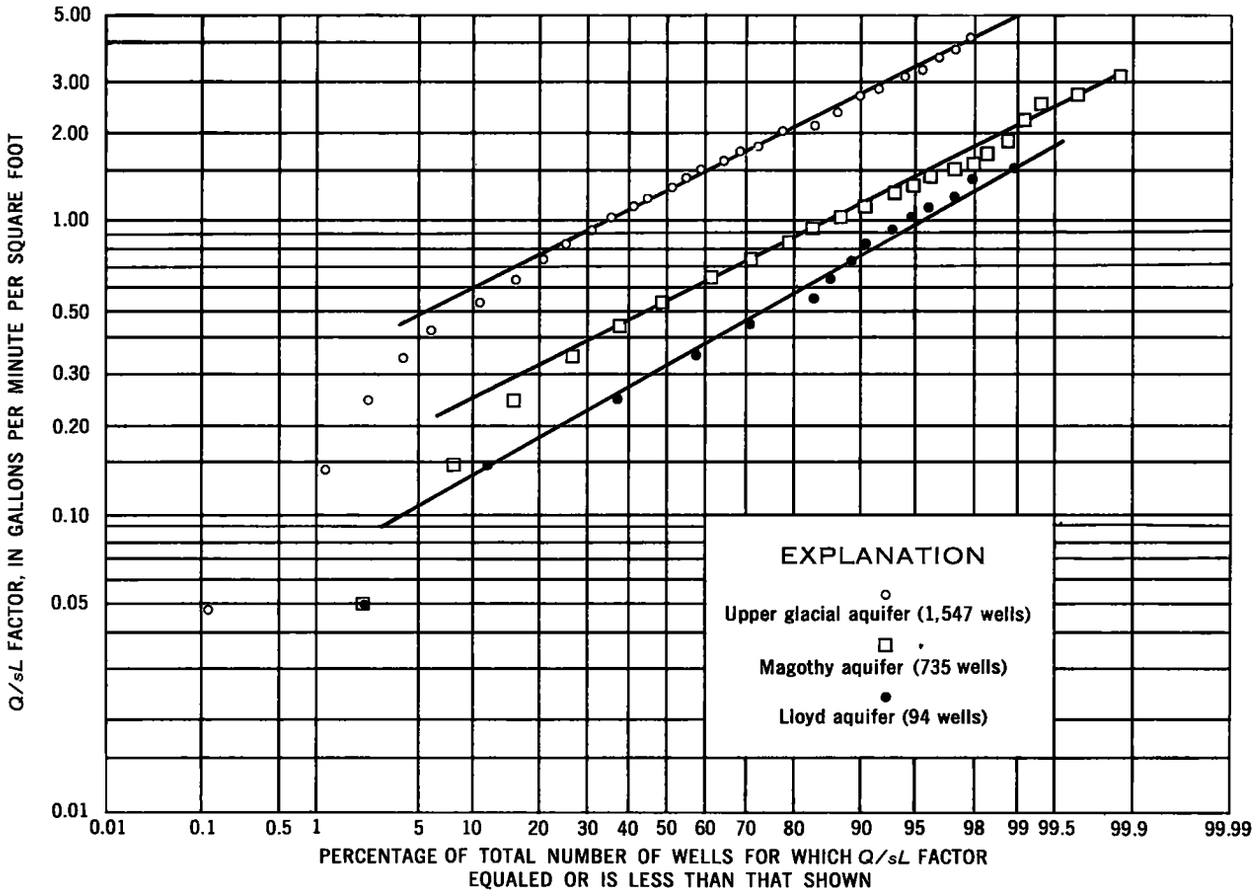


FIGURE 30.—Relation between a modified specific capacity factor (Q/sL) and percentage of total number of wells for the principal aquifers of Long Island, N.Y. After McClymonds and Franke (1971).

2 or 3 square miles. Average-hydraulic conductivity maps were prepared for each aquifer in the manner described above. The average-hydraulic conductivity maps and thickness maps of each aquifer were used to construct the transmissivity maps in figure 29. Average values of thickness, hydraulic conductivity, and transmissivity of the principal aquifers in the water-budget area, which were derived from figure 29 and from additional maps in the report by McClymonds and Franke, are given in table 9.

Estimated rates of subsurface outflow from the water-budget area and for each aquifer are given in table 10. These estimates were computed by applying Darcy's law, $Q=TIL$, to appropriate parts of each aquifer and by summing the flow from each part. In this formula, Q is the flow of ground water, in gallons per day; T is the transmissivity, in gallons per day per foot; I is the hydraulic gradient, in feet per foot; and L is the width, in feet, of the cross section through which the flow occurs. Appropriate T values were obtained from figure 29, and approximate values of the hydraulic gradient I were obtained from water-level contour maps.

TABLE 9.—*Average transmissivity of the principal aquifers for the water-budget area, Long Island, N.Y.*

Aquifer	Average thickness (feet)	Average hydraulic conductivity (gallons per day per square foot)	Average transmissivity (gallons per day per foot)
Upper glacial	120	1,800	210,000
Magothy	620	400	250,000
Lloyd	350	250	85,000

Estimating the quantity of subsurface outflow from the upper glacial aquifer presented special difficulties because much of the water in the upper part of this aquifer discharges into streams. Thus, for the purpose of calculating subsurface outflow, it was assumed that ground water in the upper 40–50 feet of the upper glacial aquifer discharged to streams (see previous discussion on movement through the ground-water reservoir), and calculations of underflow were made only for the material below the upper 40–50 feet. In

addition, the estimates of subsurface outflow from the northern part of the water-budget area were somewhat less certain than those from the southern part because water-level gradients are steeper and subject to wider variation along the north shore compared to the south shore, which makes the selection of average gradients subject to greater error.

TABLE 10.—*Estimated average subsurface outflow of ground water from the principal aquifers and total average subsurface outflow from the northern part, the southern part, and the entire water-budget area of Long Island, N.Y.*

[In millions of gallons per day]

Aquifer	Water-budget area, average subsurface outflow from—		
	Northern part	Southern part	Entire area
Upper glacial	130	40	170
Magothy	120	120	240
Lloyd	20	20	40
Total	270	180	450

Because of possible errors in the estimates of transmissivity and in the selection of average water-level gradients, the possible error in the estimated total subsurface outflow from the water-budget area in table 10 is probably on the order of plus or minus 25 percent. The possible error in the estimate of subsurface outflow from the northern part of the water-budget area and from the individual aquifers may be even larger.

SUMMARY OF RELATIONS BETWEEN COMPONENTS OF THE HYDROLOGIC SYSTEM

Water budgets for the northern and southern parts of the water-budget area and for the entire water-budget area are given in table 11. The values in table 11 are averages, and can be considered valid for the 26-year period water years 1940–65, although not all these averages have been calculated or estimated for exactly this period in this report. Although the amount of fresh ground water in storage locally in the water-budget area has decreased markedly in this period, the average decrease in storage is small. Moreover, in comparison with the total inflow and outflow, the decrease in storage is insignificant and, therefore, is disregarded in the water-budget analysis. If the additional simplifying assumption is made that, during the index period (water years 1940–65), changes in natural ground-water recharge and discharge were roughly compensated for by artificial recharge and discharge, the values in table 11 provide reasonable estimates for water-budget components in the water-budget area under natural conditions.

The most reliable estimates in table 11 are for precipitation and streamflow. The possible error in the budget figures for precipitation is probably not greater than 5–10 percent. The possible error in the estimates of average streamflow, on the other hand, is probably on the order of about plus or minus 15 percent. This possible error is primarily due to the uncertainty in estimating the flow of the ungaged streams from several miscellaneous measurements each year.

An indirect estimate of ground-water recharge under natural conditions can be developed from the data in table 11 if it is assumed that average annual ground-water recharge and discharge were approximately equal for the budget period 1940–65. Accordingly, the estimated average annual natural recharge is equal to the estimated average annual natural discharge—about 800 mgd (table 11). This value is equal to about 1.05 mgd of recharge per square mile for the water-budget area. This figure is very close to previous indirect estimates for average recharge of about 1 mgd per sq mi (Pluhowski and Kantrowitz, 1964, p. 38; Swarzenski, 1963, p. 35).

A comparison of the figures in table 11 shows a marked difference in the ratio of streamflow and subsurface outflow to precipitation in the two parts of the water-budget area. In the southern part, about 30 percent of total precipitation discharges as stream-

TABLE 11.—*Water budgets of the northern and southern parts of the water-budget area and the entire water-budget area of Long Island, N.Y., water years 1940–65* [1]

[In millions of gallons per day]

Type of water-budget element	No.	Water-budget element	Water-budget area		
			Northern part	Southern part	Entire
Inflow	1	Precipitation	650	950	1,600
Internal distribution.	2	Direct runoff	5	15	20
	3	Ground-water recharge [2]	320	465	785
	4	Ground-water discharge to streams.[3]	45	275	320
Outflow	5	Evapotranspiration of precipitation.[4]	325	470	795
	6	Subsurface outflow of ground water.	270	180	450
	7	Streamflow discharging to salt water.	50	290	340
	8	Evapotranspiration of ground water.[5]	5	10	15

[1] The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940–65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less. (See text discussion.) Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow. (See footnotes below.)

[2] The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

[3] The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

[4] The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

[5] These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

flow and 15 percent as subsurface outflow of ground water. The corresponding values for the northern part are about 10 and 35 percent, respectively. As discussed previously, estimates of subsurface outflow may be significantly in error, particularly the estimate from the northern part of the water-budget area. This large possible error may hide real differences in evapotranspiration and recharge in the two parts of the water-budget area, which might be caused by lower infiltration capacities in the surficial soils and greater evapotranspiration in the northern part compared to the southern part of the water-budget area. Unfortunately, however, presently available information is inadequate to evaluate this possibility.

WATER QUALITY

The general paths followed by liquid water through the hydrologic system of Long Island under natural conditions and related water-quality features are shown schematically in figure 31. As air moved across the bodies of salty water bordering Long Island, it picked up small quantities of salts from the ocean spray (fig. 31, item 1). Some of these substances were dissolved in the precipitation that fell on the island

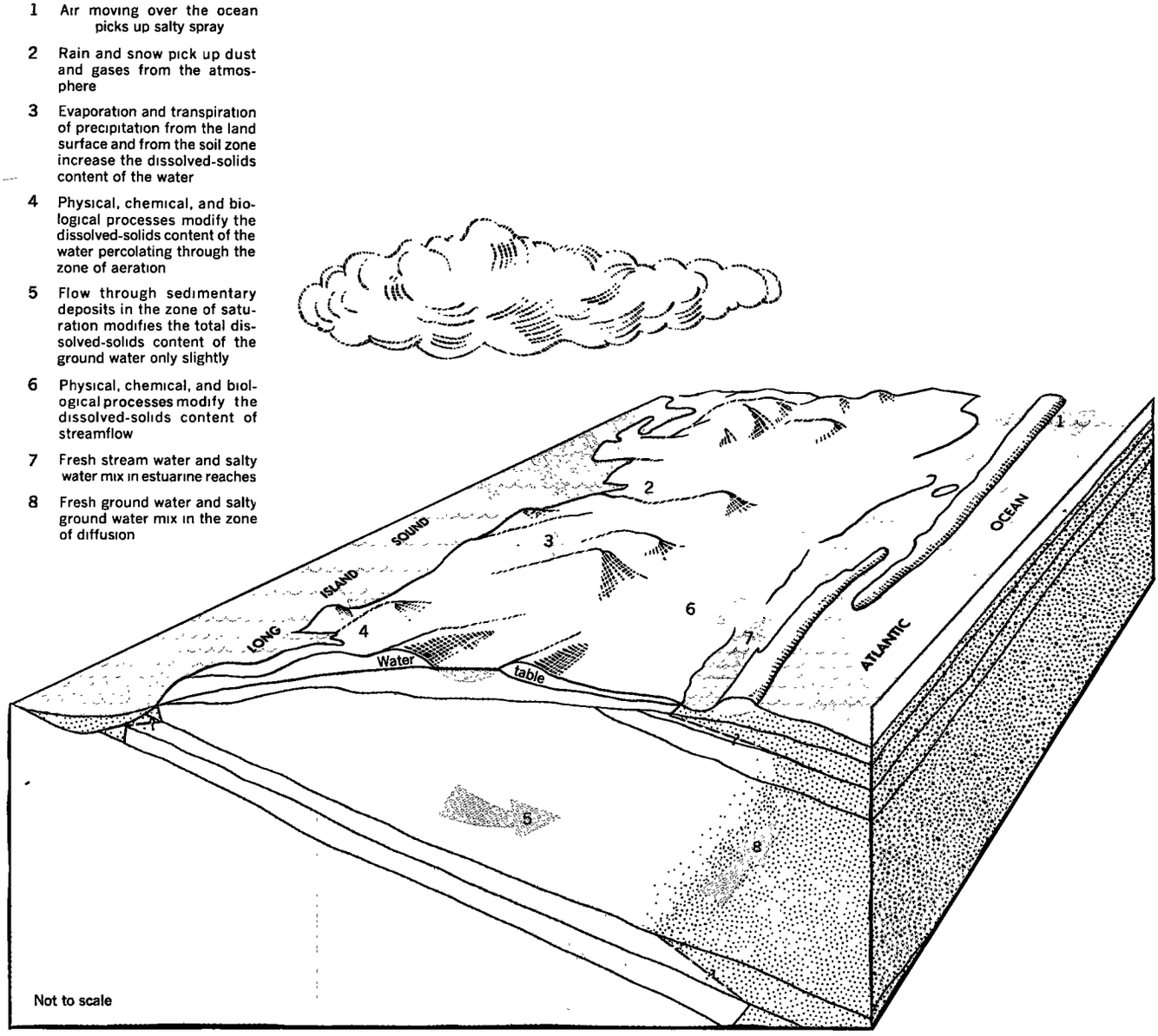


FIGURE 31.—Changes in the chemical quality of the water under natural conditions. After Cohen, Franke, and Foxworthy (1968, pl. 54).

along with particles of dust and gases from the atmosphere (item 2).

Evaporation from the land surface and the soil zone, and transpiration by plants, increased the dissolved-solids content of the precipitation after it reached the ground (item 3). As the water that originated as precipitation moved through the uppermost part of the zone of aeration (item 4), it came into contact with, and partly dissolved, compounds that were formed in the biologically and chemically active soil zone. After passing through the soil zone, the water continued, but at a slower rate, to dissolve additional substances from the remainder of the less chemically active zone of aeration.

Most of the materials in the zone of saturation on Long Island are only slightly soluble in water. Accordingly, the dissolved-solids content of the ground water generally increased only slightly as it moved through this zone (item 5).

Some of the ground water ultimately discharged into the streams where it mixed with direct runoff. The dissolved-solids content of the water flowing in the streams increased, owing to biological activity and the solution of substances in the stream channels (item 6). The stream water underwent a marked further increase in dissolved-solids content (from less than 50 mg/l to hundreds and thousands of milligrams per liter) as the fresh water discharged into, and mixed with, the salty water in the estuarine reaches of the streams (item 7). Similarly, the dissolved-solids content of the ground water increased markedly (to thousands of milligrams per liter) as the fresh ground water mixed with salty ground water in the zone of diffusion (item 8).

Chemical analyses of waters representing various stages in the geochemical cycle shown in figure 31 are given in table 12. These analyses include one of precipitation (analysis 1), two each of samples from the three major aquifers (analyses 2–7), two of ground water near the fresh-salt water interface (analyses 8, 9), two of streams (analyses 10, 11), and two of lakes (analyses 12, 13). The salient features of the analyses in table 12 are summarized as follows:

1. The natural fresh water of Long Island had a remarkably low dissolved-solids content, which was always less than 50 mg/l and in some cases was as little as 20 mg/l.
2. Because the deposits of the Long Island ground-water reservoir were relatively inert chemically, the dissolved-solids content of the ground water changed very little as it moved through the reservoir.
3. Some of the fresh ground water (analyses 3, 4, 6, 7) had a high iron content, which was considerably above the 0.3 mg/l limit recommended for public-supply use (U.S. Public Health Service, 1962, p. 7). The source of the iron in the Magothy aquifer was probably pyrite nodules that occur locally.
4. The pH of Long Island ground water was generally low (commonly less than 6), which made the water very corrosive to metals.

Except for items 3 and 4, which may necessitate minor treatment of the water before use, the natural water of Long Island was suitable for most purposes.

Precipitation has the lowest dissolved-solids content (about 10 mg/l) of the analyses in table 12. Moreover, the surface-water samples have about the same dissolved-solids content as the ground water because most of the surface water is derived directly from the ground-water reservoir. The ground-water analyses in table 12 do not show a progressive increase in dissolved-solids content with increasing time of travel and length of flow path through the ground-water reservoir. On the contrary, the dissolved-solids content seems to decrease with depth, as shown, for example, by the analyses of water from the upper glacial aquifer and from the Magothy aquifer (table 12). Undoubtedly, at least a partial explanation of this apparent anomaly is that virtually no samples of completely uncontaminated water are available from the upper glacial aquifer. Furthermore, the data in table 12 represent a very limited sampling of water within the ground-water reservoir.

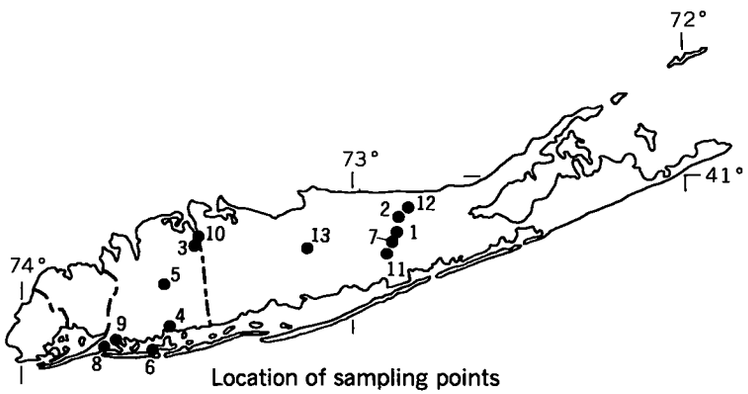
As noted in item 3 of figure 31, evapotranspiration increases the dissolved-solids content of the precipitation water as it moves through the upper part of the zone of aeration en route to the water table. Increases in the chloride content of the shallow ground water are almost entirely the result of this concentrating process because precipitation was virtually the only source of chloride in the waters of Long Island under natural conditions. Therefore, an indication of the ratio of precipitation to evapotranspiration is obtained by comparing the chloride content of rainfall and the shallow ground water. The chloride content of water from both these sources shows considerable variation in space and time. As is evident from analyses 1–3 in table 12, however, evapotranspiration has markedly increased the chloride content of water in the upper glacial aquifer compared to precipitation. These analyses indicate a ratio of precipitation to evapotranspiration ranging between approximately 2 to 1 and 1.5 to 1. This compares with a ratio of about 2 to 1

TABLE 12.—*Selected chemical analyses of natural* [1] *water on Long Island, N.Y.*

[Analyses made by U.S. Geological Survey and reported in milligrams per liter]

Sample	Source of water	Date collected	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids (residue on evaporation at 180° C)	Specific conductance ($K \times 10^3$)	pH	Temperature (° C)	Remarks
1	Precipitation				0.5	0.3	1.6	0.1	----------	3.8	2.7	--------	0.8	10	----------	4.5	----------	Average of 6 composite monthly samples collected from rain gage a Brookhaven National Laboratory for the period Oct. 1965–Mar. 1966.
2	Ground water:																	
	Upper glacial aquifer (well S5518).	Oct. 15, 1948	6.0	0.01	1.5	1.3	3.2	.6	4	6.0	5.0	--------	.1	36	39	6.5	----------	Depth 54 ft; depth to water 32 ft; diameter 6 in. (De Laguna, 1964).
3	Upper glacial aquifer (well N1243).	Dec. 5, 1960	5.4	3.3	4.0	1.0	3.0	1.2	11	6.9	3.9	--------	1.9	35	56	6.1	14	Depth 16 ft; depth to water 6 ft. diameter 1¼ in.
4	Magothy aquifer (well N4149).	Sept. 30, 1953	6.5	.61	.5	.1	2.4	.3	3	1.6	2.5	--------	.1	15	22	5.8	13	Depth 500 ft; diameter 6 in.
5	Magothy aquifer (well N5655).	Mar. 26, 1957	7.5	.01	1.3	.1	2.7	.7	5	1.0	4.3	0.1	1.4	25	24	6.1	11	Depth 255 ft; diameter 12 in.
6	Lloyd aquifer (well N5227).	Nov. 14, 1961	--------	1.5	.9	.5	6.2	.5	4	14	2.0	--------	.1	36	50	5.3	----------	Depth 1,250 ft; diameter 8 in.
7	Lloyd aquifer (well S6409).	Nov. 8, 1948	7.5	1.3	1.5	1.6	4.4	2.2	16	3.5	4.1	.1	.1	32	50	6.4	----------	Sample from screen setting at 1,434 ft; diameter 8 in. (De Laguna, 1964).
8	Salty ground water:																	
	Magothy aquifer (well N4062).	Aug. 1, 1962	20	2.5	10	4.0	18	2.8	50	3.7	29	.1	.1	117	187	6.6	17	Depth 142 ft; diameter 4 in. (Luscyznski and Swarzenski, 1966).
9	Magothy aquifer (well N6707).	July 11, 1960	9.3	39	82	76	520	8.0	----------	76	1,150	.1	.4	2,180	3,760	4.4	16	Depth 506 ft; diameter 4 in. (Luscyznski and Swarzenski, 1966).
	Stream water:																	
10	Cold Spring Brook	May 6, 1966	--------	1.8	3.3	1.3	4.9	.5	14	3.2	7.2	.1	.8	37	56	6.8	14	Sample collected at gaging station; stream discharge 0.40 cfs.
11	Carmans River	Apr. 14, 1948	0	.03	5.2	2.1	4.8	.9	15	8.4	6.6	.0	2.2	49	72	6.5	----------	Sample collected at gaging station; estimated stream discharge 30 cfs (De Laguna, 1964).
12	Lake water:																	
	Lake Panamoka	Jan. 11, 1949	1.6	.01	1.9	1.0	3.8	1.3	5	5.6	5.4	.1	.2	24	46	6.5	----------	De Laguna (1964).
13	Lake Ronkonkoma	Apr. 29, 1948	1.5	.01	2.4	1.1	4.1	.8	5	8.2	5.8	.0	.5	28	47	7.1	----------	Do.

[1] The precipitation sample and the 2 samples of ground water from the upper glacial aquifer may be ghtly contaminated because of the activities of man. However, these samples are among the least contaminated that are presently available. See text for further discussion.



Location of sampling points

which was previously determined indirectly from the water-budget analysis.

HOW MAN HAS MODIFIED THE NATURAL HYDROLOGIC SYSTEM

The following discussion summarizes the effects of man's activities on the hydrologic system of Long Island. For the most part, the discussion is concerned with the effects of man's activities on the ground-water reservoir. An understanding of these effects provides valuable insight into the possible effects of future management alternatives on the hydrologic system.

In this section of the report the calendar year is generally used as the annual period of reference instead of the water year. In addition, succeeding quantitative estimates are generally made for all of Nassau and Suffolk Counties instead of only the water-budget area.

HISTORY AND PRESENT STAGE OF DEVELOPMENT

Ground-water development on Long Island has progressed through three major stages (Heath and others, 1966; Cohen and others, 1968). In the first stage of development, which began with the arrival of the first European settlers, almost every house had a shallow dug well from which water was withdrawn from the upper glacial deposits. Most of the domestic waste water was returned to the glacial deposits through individually owned cesspools. As the population increased, many individually owned wells were abandoned, and public-supply wells were installed in the upper glacial deposits; however, the disposal of waste water through individually owned cesspools continued. Although the quality of the water gradually deteriorated as a result of these practices, the amount of water permanently removed from the ground-water system (the "net withdrawal") was negligible.

Pollution of the shallow part of the ground-water reservoir by water from cesspools eventually forced the abandonment of many wells tapping the upper glacial deposits. In the second stage of development, these wells were replaced by deeper public-supply wells, mainly tapping the artesian Magothy and Jameco aquifers. Most of the domestic and industrial sewage, however, was still returned to the upper glacial deposits through cesspools and septic tanks. Accordingly, the net withdrawals from the entire ground-water reservoir remained negligible.

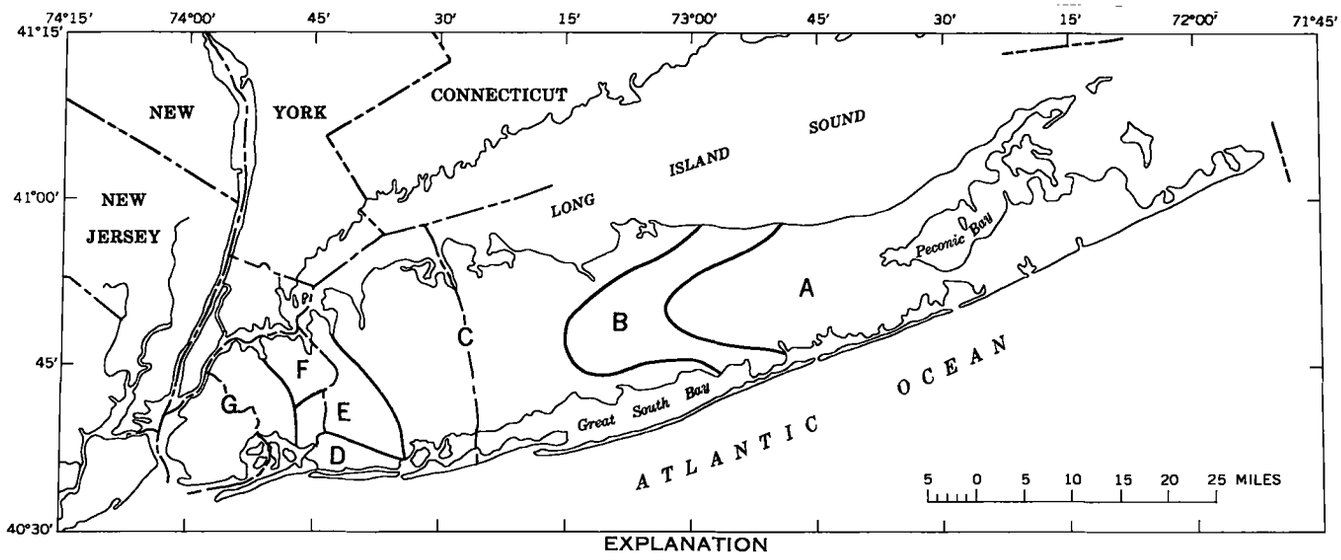
The third major stage of ground-water development was characterized mainly by the introduction of large-scale sewage systems—first in Kings and Queens Counties and then in the western one-third of Nassau County. After the sewers were installed, most of the once-used water that previously had been returned to the ground-water reservoir through cesspools and septic tanks was thereafter discharged to the sea, which represented a permanent loss of water from the system. The resulting disruption of the hydrologic balance caused large-scale salt-water encroachment, first in Kings County, then in Queens County, and most recently in the southwestern part of Nassau County.

The three major stages of development, as well as transitional stages, can presently be observed in different subareas of Long Island (fig. 32). Subarea A is largely rural and has the lowest population density on the island. In general, most of the subarea is in the first major stage of development. Subarea B is mainly in a stage of development intermediate between the first and second stages of development. Farms in this subarea are rapidly being replaced by housing developments, and the new homes are being supplied with water from large-capacity public-supply wells tapping the shallow glacial deposits. Most of the new homes have individual cesspools to dispose of domestic waste water. The ground-water system in this subarea also is still in a virtual state of dynamic equilibrium, although the quality of the shallow ground water undoubtedly is being degraded in the vicinity of the cesspools and septic tanks.

Because it is closer to New York City, subarea C experienced intensive suburban development earlier than subarea B. Most of the subarea is not sewered, and as a result, fairly large parts of the shallow upper glacial deposits have become polluted with cesspool effluent. This pollution, in turn, has forced the abandonment of many of the shallow wells, and most of the water supply for the subarea presently is obtained from deep wells tapping the Magothy aquifer. The subarea, therefore, is in the second stage of ground-water development.

Subarea D is in the third major stage of development. Public-supply water is derived mainly from large-capacity wells tapping the Magothy and Jameco aquifers, and most of the sewage water is discharged to the sea by way of large-capacity sewage-treatment plants. The ground-water system in the Magothy and Jameco deposits is no longer in quantitative equilibrium (inflow is less that outflow), and salty water from the ocean is invading these deposits.

Subarea E also is in the third major stage of development. It differs from subarea D mainly because the salty water has not yet invaded the aquifers in this subarea. If the trend continues, however, subarea D will expand at the expense of subarea E, and the



SUBAREA — CHARACTERISTICS

- A Hydrologic system mainly is in a state of virtual quantitative equilibrium.
- B Transitional in development between subareas A and C.
- C Hydrologic system is locally out of balance; local salt-water intrusion.
- D Hydrologic system is out of balance; widespread salt-water intrusion.
- E Hydrologic system is out of balance; may be subject to salt-water intrusion in the future.
- F Ground-water development is negligible, and the hydrologic system is in balance.
- G Large parts of the subarea are contaminated with salty ground water owing to former intensive ground-water development and related salt-water intrusion.

FIGURE 32.—Status of water development in 1966. After Heath, Foxworthy, and Cohen (1966, fig. 8).

aquifers in subarea E also will be contaminated with salty water.

Almost all the public-supply water for subarea F, which is in northeastern Queens County, is derived from surface-water supplies imported from upstate New York. The subarea is sewered, and because ground-water development is negligible, the ground-water system is still in balance.

All of subarea G, the most highly urbanized part of Long Island, is sewered. Presently, the subarea receives more than 85 percent of its public-supply water from the upstate surface-water reservoirs of the New York City municipal-supply system. As is described in a subsequent part of the report, large parts of the ground-water reservoir in the subarea have been contaminated with salty water because of substantial overdevelopment. Since the mid-1940's, when pumpage in the subarea had to be drastically reduced because of the salt-water contamination, ground-water levels in the subarea have recovered markedly.

EFFECTS OF MAN'S ACTIVITIES ON THE MOVEMENT AND DISCHARGE OF WATER

The following discussion of the effects of man's activities on the movement and discharge of water on Long Island is facilitated by reference to the flow diagram in figure 33. A comparison of this diagram and the diagram showing the flow system under natural conditions (fig. 13) indicates that a number of "boxes" have been added. These new boxes represent manmade structures, including recharge basins, cesspools and septic tanks, water pipes, diffusion and recharge wells, storm drains, and sewer drains. In addition, one of man's activities—namely, pumping of ground water—is also shown diagrammatically. As in figure 13, only flow paths that represent large quantities of water or those that are of particular significance are shown in figure 33.

In addition to the structures mentioned above, man has greatly modified the land surface of Long Island by large-scale construction of streets, parking lots, buildings, and other impervious surfaces. This construction has not only greatly reduced and modified the natural vegetative cover, but it also has necessitated the construction of adequate facilities for storm drainage. The methods of solving the problems of storm drainage on Long Island constitute one of the most important ways in which man's activities have modified the natural hydrologic system. The other major activities of man related to the hydrologic system of Long Island involve the development of ground water and the disposal of used water.

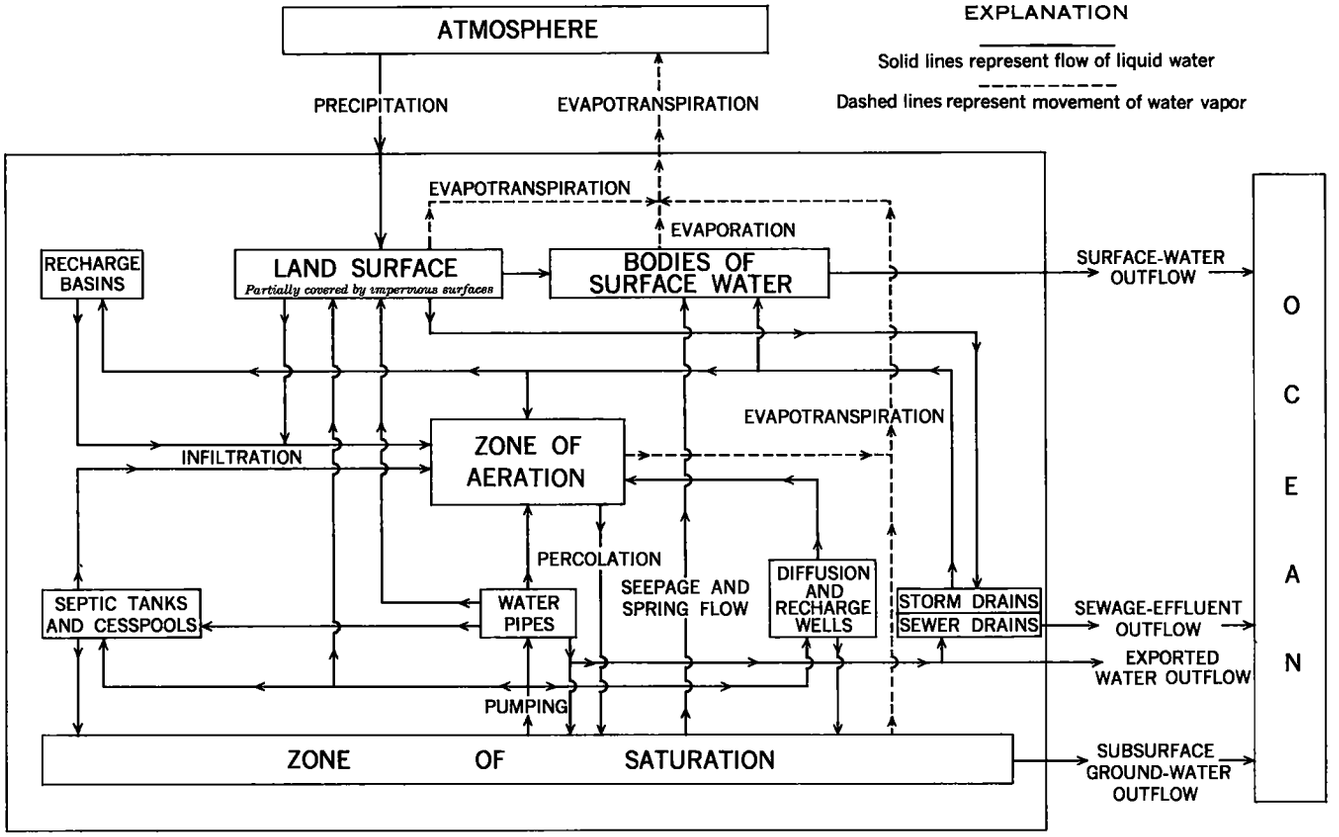


FIGURE 33.—Flow diagram of the hydrologic system, Nassau and Suffolk Counties, in the 1960's.

DISPOSAL OF DIRECT RUNOFF

Direct runoff from urban areas on Long Island flows by gravity through gutters and street inlets to storm sewers. The storm sewers generally transmit the runoff to either recharge basins or nearby streams (fig. 33).

RECHARGE BASINS

Recharge basins are unlined excavations in the glacial deposits; they range from about 10 to 20 feet in depth and from less than 1 to about 30 acres in area. In Nassau and Suffolk Counties there are more than 2,000 recharge basins, most of which are in the water-budget area. In the past two decades, most new housing and industrial developments in these counties have been required to include the construction of one or more basins, the size and number of which were related to the size of the drainage area. Moreover, most of the runoff from highways in these counties is collected in recharge basins. A recharge basin is generally used only where the water table is sufficiently deep to remain below the floor of the basin at least most of the time. Therefore, only a few recharge basins are located in nearshore areas where the water table is within a few feet of the land surface. In addition, on Long Island many street inlets are open bottomed and, therefore, function as small recharge basins.

Seaburn (1970) studied the inflow of two recharge basins in residential developments in Nassau County. From the rainfall-inflow relation for one of these basins (fig. 34), Seaburn estimated that, on the average, about 15 percent of the total precipitation falling on the drainage area of the basin discharged into the basin. In this particular drainage area (15 acres) about 11 percent of the total drainage area was streets, and the total impervious area, including streets, sidewalks, driveways, and roofs was about 32 percent.

The total drainage area of all the recharge basins in Nassau and Suffolk Counties is probably on the order of 250 square miles at present (1968). If it is assumed that 15 percent of total rainfall on this area enters recharge basins and that virtually all this water recharges the ground-water reservoir, average annual recharge to the ground-water reservoir from these basins is on the order of 80 mgd. The assumption that most of the water entering a recharge basin ultimately recharges the ground-water reservoir is based on the observation that water entering most basins percolates into the ground fairly rapidly (commonly within a day or so).

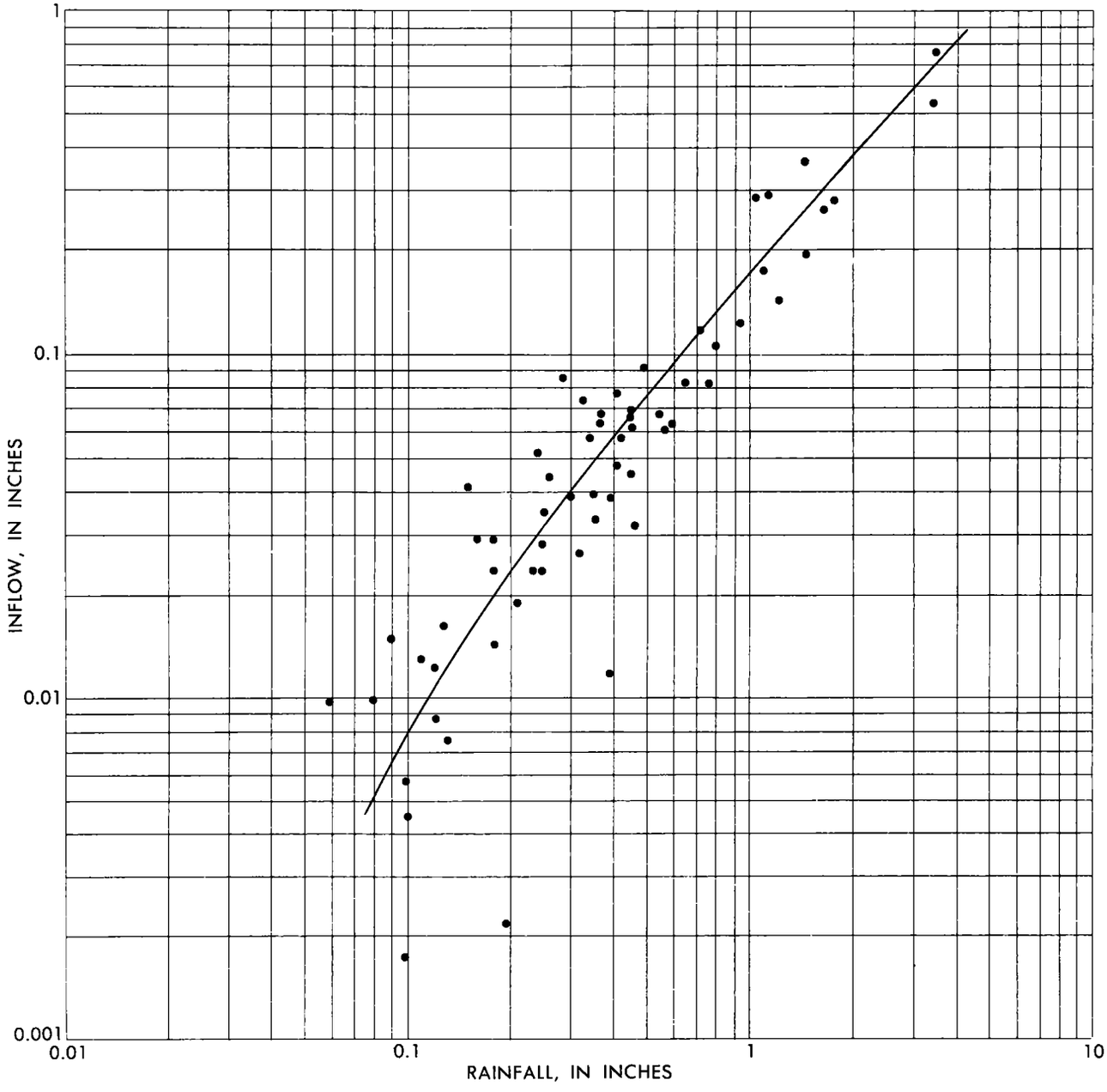


FIGURE 34.—Relation between rainfall and inflow to the Westbury recharge basin, Nassau County, 1966–67. After Seaburn (1970).

Insufficient information is available to determine whether present recharge in the drainage areas of recharge basins has increased, decreased, or remained the same as compared to recharge under natural conditions. According to the previous water-budget analysis, on the average about one-half the precipitation falling on any part of the recharge basin drainage area returned to the atmosphere as evapotranspiration and about one-half recharged the ground-water reservoir under natural conditions. Inflow to a recharge basin probably includes most of the precipitation that fell on the streets and some of the precipitation that fell on areas immediately adjacent to the streets. Thus, a larger proportion of the precipitation falling on this part of the drainage area of a recharge basin probably recharges the ground-water reservoir than under natural conditions. On the other hand, no information is presently available to compare the average recharge through lawns and other uncovered areas, which comprise more than one-half the drainage area of most recharge basins, to the recharge in these areas under natural conditions.

STREAMS

Direct runoff to some streams on Long Island has greatly increased because of increased direct runoff from urban areas. The values of direct runoff to streams as a percentage of total annual streamflow are given in table 13 (D. E. Vaupel and A. G. Spinello, written commun., 1968) for the gaged streams on Long Island in water years 1958 and 1964. These were years of relatively high and low precipitation, respectively. In general, values greater than 6–8 percent in table 13 indicate an increase in direct runoff compared to natural conditions, and these increases are related to urban development.

Seaburn (1969) studied the effects of urban development on direct runoff to East Meadow Brook in Nassau County for the period 1937–62. In 1937 the drainage area of East Meadow Brook was almost completely rural. After a period of intensive development in the 1950's, the southern part of the drainage area was almost completely occupied by housing developments. A cumulative plot of annual direct runoff to East Meadow Brook is shown in figure 35. The marked changes in the slope of the curve coincided with increases in annual direct runoff resulting from the construction of storm sewers draining to East Meadow Brook. The virtually straight curve of cumulative precipitation on the same graph implies that precipitation did not significantly cause the observed increases in direct runoff.

The relation between rainfall and runoff in East Meadow Brook for individual storms in the preurban (1937–43) and urban (1964–66) periods are shown in figure 36. Although the data points show considerable scatter, a marked difference is evident for the two periods—particularly for the larger storms. On the basis of figures 35 and 36 and an accurate delineation of the urbanized areas that were equipped with storm sewers that drain to East Meadow Brook, Seaburn estimated that between 10 and 15 percent of the total rainfall falling on that urbanized area appeared as direct runoff in the stream.

The total area of highly developed land in Nassau and Suffolk Counties from which direct runoff drains directly to streams or into the surrounding bodies of salty water is probably on the order of 200 square miles. If it is assumed that on the average about 15 percent of total rainfall dicharges from this area as

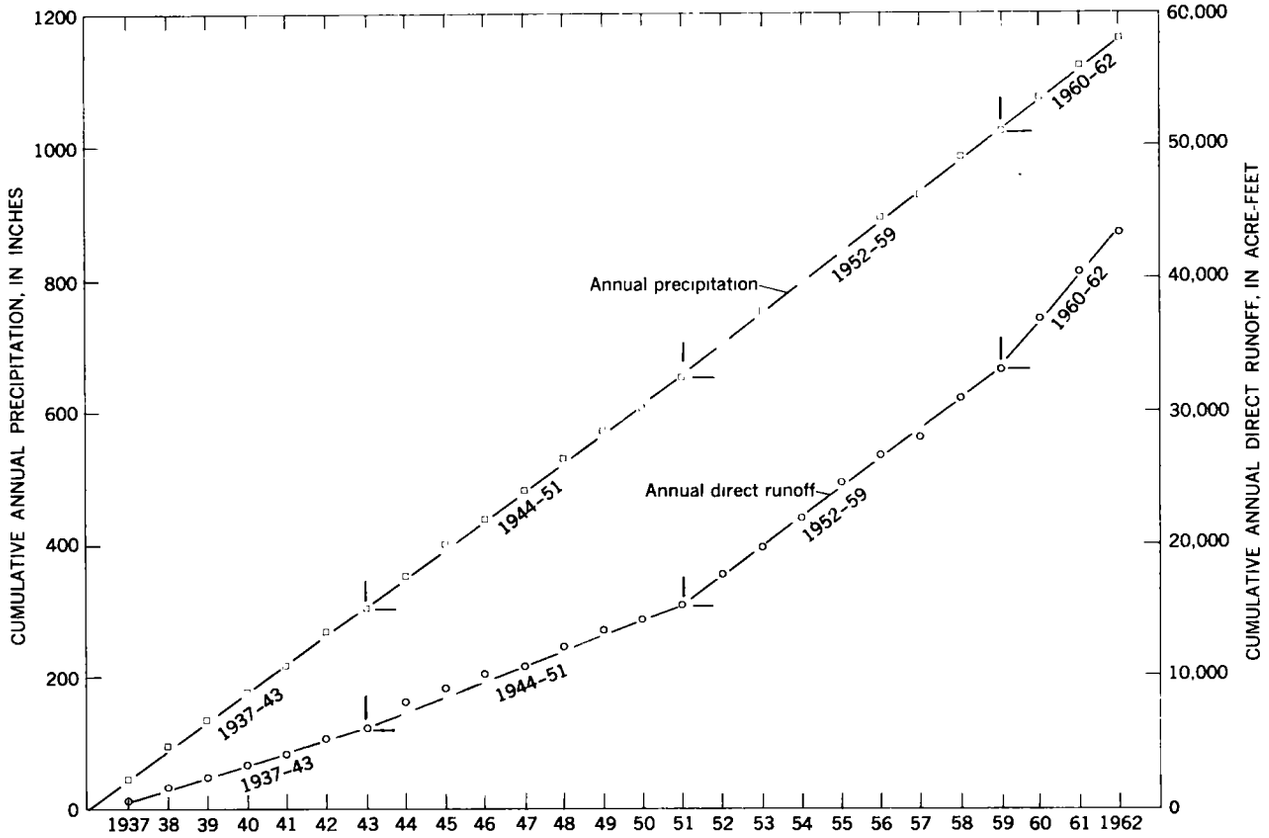


FIGURE 35.—Cumulative curves of annual direct runoff in East Meadow Brook and annual precipitation at Mineola. After Seaburn (1969).

TABLE 13.—*Annual direct runoff of the 19 continuously gaged streams on Long Island, N.Y., for water years 1958 and 1964*

[After D. E. Vaupel and A. G. Spinello, written commun., 1968]

Gaging station	Water year 1958		Water year 1964	
	Total discharge (cubic feet per second-days)	Total direct runoff (percentage of total discharge)	Total discharge (cubic feet per second-days)	Total direct runoff (percentage of total discharge)
Valley Stream	2, 600	32	340	52
Pines Brook	2, 400	26	460	49
East Meadow Brook	7, 700	19	[1] 3, 000	22
Bellmore Creek	5, 500	11	4, 400	11
Massapequa Creek	5, 500	12	3, 100	15
Santapogue Creek	1, 900	12	1, 100	11
Carlls River	11, 000	10	8, 600	8
Sampawams Creek	4, 700	10	3, 100	10
Penataquit Creek	2, 500	10	2, 400	9
Champlin Creek	3, 300	6	2, 200	5
Connetquot River	16, 000	6	12, 000	5
Patchogue Creek	9, 300	12	7, 100	7
Swan River	5, 600	5	4, 400	5
Carmans River	11, 000	3	7, 700	3
Cedar Swamp Creek	3, 200	24	1, 800	23
Mill Neck Creek	3, 900	10	2, 600	10
Cold Spring Brook	1, 800	9	1, 200	6
Nissequogue River	17, 000	7	14, 000	5
Peconic River	20, 000	8	11, 000	7

[1] Total for 9-month period January–September 1964.

direct runoff, the estimated average direct runoff from these areas is on the order of 60 mgd.

The significant feature of the increased direct runoff to streams resulting from urban development is that the direct runoff rapidly discharges into salty water and is therefore lost from the fresh-water system of Long Island. Some of the lost water would probably have been lost by evapotranspiration and direct runoff under natural conditions. However, much of this water undoubtedly represents a loss of recharge to the ground-water reservoir, and this loss causes ground-water levels to decline. In comparing average ground-water levels in urbanized and unurbanized areas by means of double-mass curves, Franke (1968) found evidence that the loss of recharge resulting from increased direct runoff caused average ground-water levels in an urbanized area in southeastern Nassau County to decline about 1–2 feet.

PUMPING AND DISTRIBUTION OF GROUND WATER

Two undesirable effects, both resulting from changes in the position of the two moveable boundaries of the ground-water reservoir (the water table and the salt-fresh water interface) are associated with large-scale pumping of ground water on Long Island. These effects are (1) a regional decline in ground-water levels and (2) an increase in the chloride content of the water in some wells. For these undesirable effects to occur, the pumped ground water must be permanently removed from the ground-water reservoir. Sanitary sewers are the major cause of a permanent loss of water from the ground-water reservoir of Long Island. Instead of returning used water to the ground-water reservoir through cesspools and septic tanks, the sanitary sewers dispose of the used water directly into salty water.

PUMPING OF GROUND WATER

Gross ground-water pumpage in Nassau and Suffolk Counties in selected years is given in table 14. Inasmuch as ground water has been practically the only source of water in these counties, gross pumpage has increased as the population has increased. In Nassau County, gross pumpage increased from about 75 mgd in 1940 to nearly 210 mgd in 1965. Similarly, gross pumpage in Suffolk County increased from about 30 mgd in 1940 to almost 120 mgd in 1965. During the same period, gross ground-water pumpage on all of Long Island increased from about 220 mgd to about 430 mgd. Furthermore, tabulations of pumpage and water use prepared by the New York State Water Resources Commission indicate that the average per capita use of ground water in Nassau and Suffolk Counties was about 140 gallons per day in 1965.

Not all the gross pumpage represents a loss of water from the hydrologic system of Long Island. As is discussed subsequently, much of the pumpage—particularly in Nassau and Suffolk Counties—is returned to the ground-water reservoir following its use. The proportion that actually is lost (net withdrawal) depends upon the type of water use and the method of waste-water disposal.

TABLE 14.—*Gross ground-water pumpage in Nassau and Suffolk Counties, Long Island, N.Y., 1940–65* [1]

[In millions of gallons per day]

Year	Nassau County	Suffolk County	Total (rounded)
1940	75	30	100
1945	63	31	94
1950	110	42	150
1955	130	67	200
1960	150	75	220
1965	210	120	330

[1] Based mainly on data obtained from the New York State Water Resources Commission.

LEAKY WATER PIPES

The two flow paths in figure 33—water pipes to zone of aeration and water pipes to zone of saturation—represent leakage from water-distribution systems. Except in areas of very shallow ground-water levels near the shorelines, most pipelines on Long Island are in the zone of aeration, and most of the leakage from them ultimately recharges the ground-water reservoir.

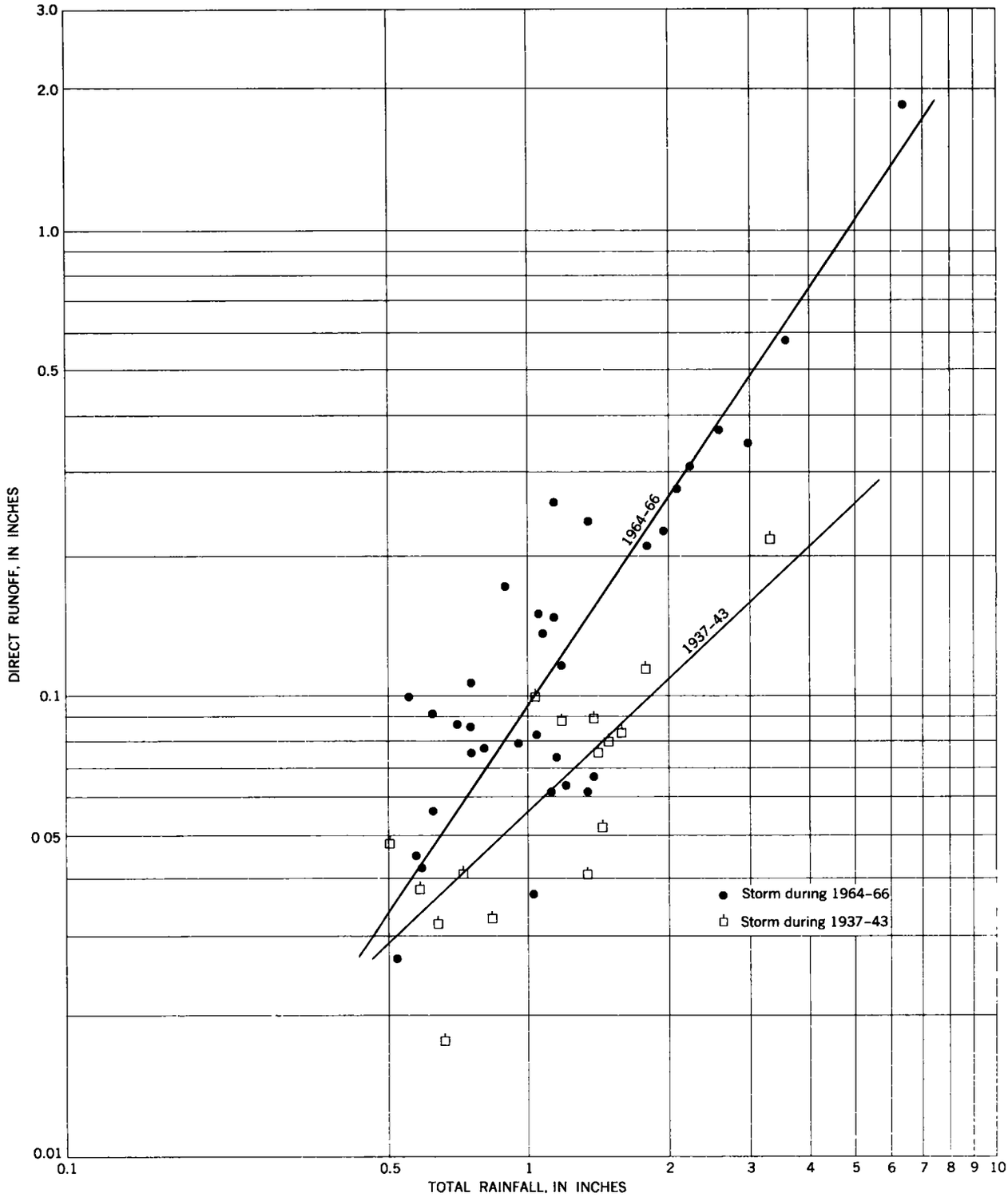


FIGURE 36.—Relation between rainfall and runoff for individual storms in the East Meadow Brook drainage area, Nassau County, for urban (1964–66) and preurban (1937–43) periods. After Seaburn (1969).

Informal discussions with some managers of water-supply companies on Long Island indicate that in well-maintained water-distribution systems the average quantity of leakage is about 10–15 percent of total water input to the systems. If it is assumed that about 15 percent of total public-supply pumpage leaks from the system before use and recharges the ground-water reservoir, the resulting leakage figure for Nassau and Suffolk Counties was about 35 mgd in 1965.

EXPORTED WATER

The flow path designated "exported water outflow" in figure 33 represents an element of discharge from Nassau and Suffolk Counties that is completely controlled by man. Since the beginning of this century, New York City has imported water to Kings and Queens Counties from several well fields near the south shore of Nassau County. Before 1920 the maximum annual-average withdrawals from this system were slightly more than 50 mgd. Since that time, withdrawals have decreased. In the decade 1940–49, the average withdrawal was less than 20 mgd, and since 1950, it was less than 5 mgd. Because the amount of exported water is small compared to natural discharge from the ground-water reservoir, the effect of exporting water on the ground-water reservoir in Nassau and Suffolk Counties is negligible at present.

LAWN SPRINKLING AND IRRIGATION

Two flow paths in figure 33, "water pipes to land surface" and "pumping to land surface," represent lawn sprinkling and other water used for irrigation. The amount of water used in this way is significant because a large part of it is lost from the hydrologic system by evapotranspiration.

A compilation of pumpage by all public water-supply companies in Nassau County for the years 1954–63 showed that, on the average, about 60 percent of the total withdrawals occurred during the summer months (April-September), and that 40 percent occurred in the winter months (October-March). Roughly, three-fourths of the 20 percent difference in seasonal pumpage, or 15 percent of total public-supply pumpage, is assumed to be related to lawn sprinkling. Because most people tend to overirrigate their lawns, it is further assumed that, on the average, about half the water used for lawn sprinkling is lost to evapotranspiration and that the remaining half eventually returns to the ground-water reservoir. Thus, the estimated total quantity of public-supply pumpage lost by evapotranspiration in Nassau and Suffolk Counties in 1965 is on the order of 20 mgd.

The flow path "pumping to land surface" represents several additional situations where ground water is pumped and used locally, including (1) pumping from private wells for lawn sprinkling by owners whose other water-supply needs are supplied by a water-supply company; (2) pumping from "backyard" wells for lawn sprinkling where all the other water supply needs are derived from that well; and (3) pumping for commercial purposes, such as golf-course sprinkling and irrigation of crops. The first two items listed above vary considerably from year to year and are difficult to estimate. There are probably about 60,000 private wells in Nassau and Suffolk Counties, most of which are small-diameter driven wells that extend a few feet into the glacial deposits. The estimated total average pumpage from these wells for lawn sprinkling and related uses is on the order of 10 mgd or less in most years. According to an unpublished estimate by the New York State Water Resources Commission, pumping for commercial purposes, as described above, was about 35 mgd in 1965. This included about 15 mgd for golf-course sprinkling and 20 mgd for farm and nursery irrigation. As is the case with lawn sprinkling, probably 25–50 percent of this water infiltrates into the zone of aeration and ultimately returns to the ground-water reservoir.

DISPOSAL OF USED WATER

Used water on Long Island is disposed of in three major ways—through recharge wells, cesspools and septic tanks, and sanitary sewers. Hydrologically, these methods differ in their effect on both the water balance and the quality of the water in the ground-water reservoir. The effect of these methods of waste-water disposal on the quality of the water is considered in a subsequent section of the report.

RECHARGE WELLS

In 1933 the New York State Legislature enacted a water-conservation law to protect the ground-water resources of Long Island. The law empowered the New York State Water Power and Control Commission (subsequently the New York Water Resources Commission) to regulate the construction of all wells on Long Island that withdraw more than 100,000 gpd (gallons per day) from the ground-water reservoir. In 1954 the law was modified to include all wells having capacities of 45 gpm (gallons per minute) or more (about 65,000 gpd).

The State regulatory agency established a policy in 1933 prohibiting, "the drilling of new industrial wells with capacities in excess of 69.4 gpm (100,000 gpd), unless the water pumped is returned in an

uncontaminated condition into the ground through diffusion wells or other approved structures" (Johnson, 1948, p. 1160–1161). The term "diffusion well" as used on Long Island is virtually identical to the more widely used terms, "artificial-recharge well" or "injection well."

Presently, more than 1,000 recharge or diffusion wells return used ground water to the ground-water reservoir of Long Island. According to unpublished data supplied by the New York Water Resources Commission, an average of about 77 mgd was injected into recharge wells on Long Island in 1965, including about 55 mgd in Nassau and Suffolk Counties. Most of the water was used for air-conditioning (cooling), which caused its temperature to rise markedly before it was returned to the ground-water reservoir. Although the quality of the recharged water is changed, the use of ground water for air conditioning causes virtually no net loss to the ground-water reservoir. Because the pumping and recharge wells are usually very close to one another, the flow path in figure 33 designating this activity is drawn from "pumping" directly to "recharge wells." Although most recharge wells are screened in the zone of saturation (commonly at virtually the same depth as the supply well), some recharge wells are screened in the zone of aeration.

CESSPOOLS AND SEPTIC TANKS

In most of Nassau and Suffolk Counties, used household water is discharged into cesspools and septic tanks (flow paths "water pipes to cesspools and septic tanks" and "pumping to cesspools and septic tanks" in figure 33). Virtually all this water is derived from the ground-water reservoir. Because most cesspools and septic tanks are at least 3 feet below land surface, the used water discharging into them commonly percolates through the zone of aeration or enters the ground-water reservoir directly without appreciable losses by evapotranspiration (see flow paths "cesspools and septic tanks to zone of aeration" and "cesspools and septic tanks to zone of saturation" in figure 33). Therefore, discharge of used water to cesspools and septic tanks, although causing a marked change in the quality of the shallow ground water, does not appreciably disturb the quantitative balance in the ground-water reservoir.

In 1965, total public-supply pumpage in those parts of Nassau and Suffolk Counties where cesspools and septic tanks were used to dispose of used water was about 160 mgd. Based on pumping and sewage discharge tabulations in 1965 and 1966 for the sewered area (see section on "Sanitary Sewers") in southwest Nassau County, the estimated discharge into cesspools and septic tanks was about 70 percent of the total public-supply pumpage, or about 110 mgd. The remaining 30 percent was diverted between the pumping wells and the cesspools and septic tanks by pipe leakage and various uses of water such as lawn sprinkling.

Reportedly, about 260,000 people were not served by a public water-supply system in Suffolk County in 1965, but they obtained their water supply from privately owned wells. If the household use of water (excluding that used for lawn and garden sprinkling) is assumed to be about 50 gallons per day per person, the estimated additional discharge in 1965 to cesspools and septic tanks in Suffolk County from areas served by private wells was about 15 mgd. Therefore, the estimated total discharge in 1965 to cesspools and septic tanks in Nassau and Suffolk Counties was about 125 mgd.

SANITARY SEWERS

The flow paths "water pipes to sewer drains" and "sewer drains to ocean" (fig. 33) represent discharge from the fresh-water system to salty water—usually from a sewage-treatment plant. Some water leaks from the sewers to the zone of aeration where the sewers are above the water table (flow path not shown in fig. 33). If it is assumed that about 10–15 percent of the raw sewage entering the sewer-pipe network leaked from the system before reaching the sewage-treatment plant, the resulting leakage figure for Nassau and Suffolk Counties was about 10 mgd in 1965. In addition, water locally leaks from the sewers to the ground-water reservoir and from the ground-water reservoir into the sewers where the sewers are below the water table (flow paths not shown in fig. 33). However, it is virtually impossible to evaluate quantitatively the amounts of water involved. All the water that discharges to salt water from the sewage-treatment-plant system is ultimately derived, and represents a net loss from, the ground-water reservoir. The sewers are in a sense analogous to the streams in that they "short circuit" the flow of ground water from a point within the ground-water reservoir some distance inland to a point of discharge into salty water.

Total annual average discharge of treated sewage effluent to salty water in Nassau and Suffolk Counties for the period 1950–65 is shown in figure 37. The marked increase from 1950 to 1965 was mainly the result of the completion of the Nassau County Sewer District No. 2 secondary-treatment plant (locally referred to as the Bay Park sewage-treatment plant), which discharged an average of about 50 mgd in 1965. During this period the discharge of treated sewage effluent to salty water in Suffolk County was less than

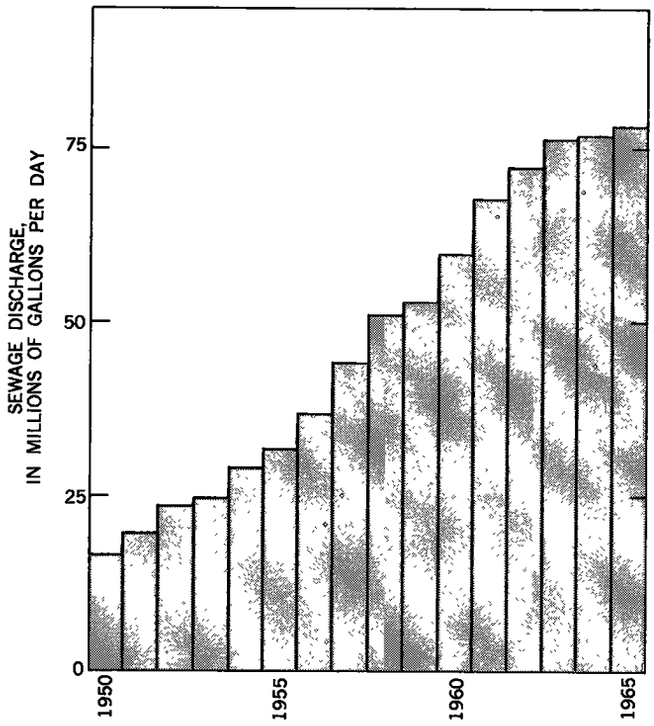


FIGURE 37.—Total treated sewage effluent discharged from Nassau and Suffolk Counties for the period 1950–65. Data from annual reports of the New York, New Jersey, and Connecticut Interstate Sanitation Commission and local agencies.

5 mgd. This low rate of discharge in Suffolk County mainly reflected the fact that most of the sewage in that county was disposed of through individually owned cesspools and septic tanks and the capacity of the sewage-treatment facilities in the county has not increased appreciably in the past 15 years.

The hydrologic consequences of the disposal of used water through sanitary sewers on Long Island are discussed in historical sequence in the following paragraphs.

In the past 60 years, intensive ground-water development accompanied by the disposal of used water through sanitary sewers has caused major changes in the altitude of the water table in Kings and Queens Counties. The 1903 water-table contour map shown in figure 38*A* is based on the earliest available water-level data. Nevertheless, these contours partly reflect the impact of ground-water development because net pumpage at the time already was substantial. In Kings County, for example, net pumpage at that time averaged about 28 mgd (Lusczynski, 1952, p. 4).

By the early 1930's, net ground-water withdrawals for public-supply and industrial use in Kings County exceeded 75 mgd. In addition, natural ground-water recharge had decreased substantially because much of the land surface had been covered with impermeable surfaces such as streets, highways, and buildings. These factors resulted in a marked imbalance in the ground-water system causing a net decrease in the amount of fresh ground water in storage as evidenced by declining ground-water levels.

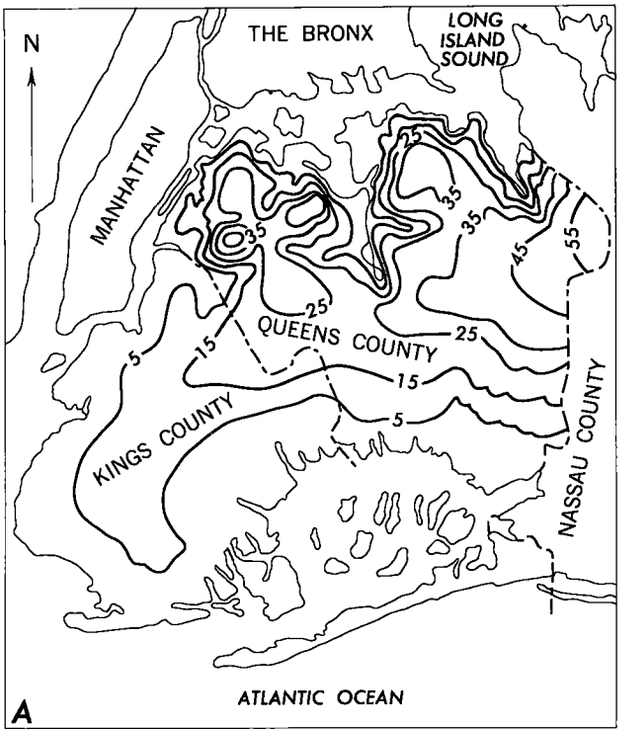
By 1936 the water table in practically all of Kings County had declined below sea level (fig. 38*B*); locally, it had declined about 50 feet to a depth of more than 35 feet below sea level. As a result, a landward hydraulic gradient had developed, and salty ground water invaded the fresh ground-water reservoir.

As wells in Kings County became contaminated with salty water, more and more of the county was supplied with water obtained from upstate New York sources through the New York City public-supply system. In 1946 all pumping of ground water in Kings County for public-supply use was discontinued. In addition, the mandatory use of recharge wells, which returned water used for air conditioning and other purposes to the ground-water reservoir, resulted in the conservation of large amounts of ground water. Accordingly, ground-water levels in Kings County began to recover substantially in the latter 1940's. By 1965, when gross pumpage was about 24 mgd and net pumpage probably was about 10 mgd, the water table in all but the northern part of Kings County had recovered to a position above sea level (fig. 38*C*).

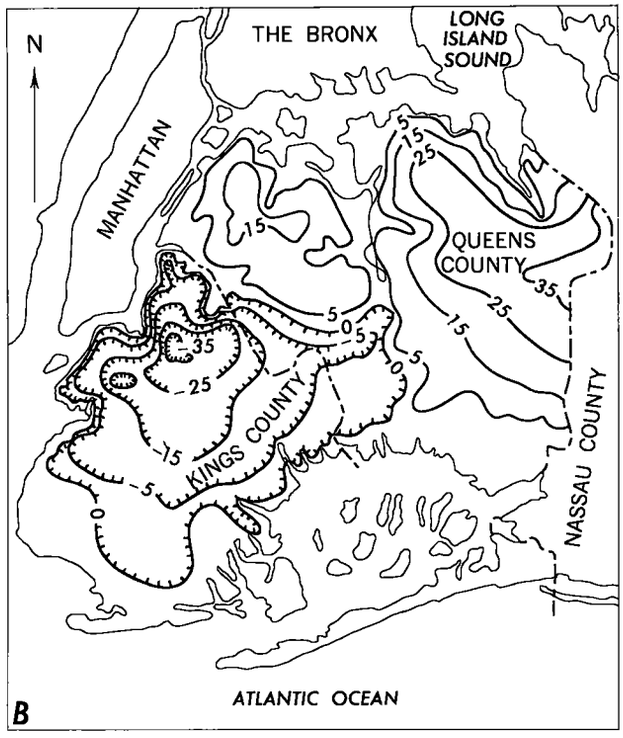
Ground-water pumpage continued to increase in Queens County during the period in which it decreased in Kings County (from the late 1930's to the present). As a result, the water table in Queens County in 1965 locally declined to a level more than 10 feet below sea level (fig. 38*C*), and salty water began to invade the ground-water reservoir in the southwestern part of the county.

Contamination of well water by salty ground water in southwestern Nassau and southeastern Queens Counties has been the cause of considerable concern, and, therefore, the subject of intensive study (Perlmutter and Geraghty, 1963; Lusczynski and Swarzenski, 1966). As noted previously (fig. 10), three major tongues or wedges of salty ground water are found in the area: (1) A shallow unconfined wedge in the upper glacial aquifer, (2) an intermediate confined wedge in the Jameco aquifer and in the upper part of the Magothy aquifer, and (3) a deep confined wedge in the Magothy aquifer and in the Raritan clay.

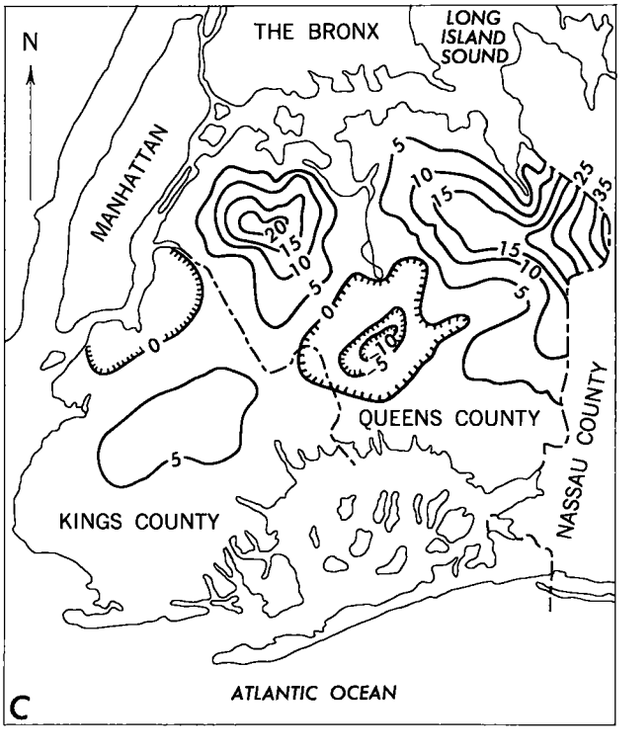
For the most part, the position of the shallow wedge of salty water has not changed significantly during historic time. However, locally, especially in and near



1903
(After Lusczynski, 1952)



1936
(After Suter, 1937)



1965
(Adapted from an unpublished map prepared by the New York State Water Resources Commission, 1966)

1 0 1 2 3 4 MILES

EXPLANATION

10

WATER-LEVEL CONTOUR
Shows altitude of water level.
Contour interval 5 and 10 feet.
Datum is mean sea level

FIGURE 38.—Ground-water levels in Kings and Queens Counties in (*A*) 1903, (*B*) 1936, and (*C*) 1965. After Cohen, Franke, and Foxworthy (1968, pl. 8*B*).

several areas of intensive pumping, the deep body seems to be actively moving landward. Pumpage from the Jameco aquifer and the Magothy aquifer in southwestern Nassau and southeastern Queens Counties is presently more than 100 mgd, and much of this pumpage is ultimately discharged to the sea through sewage-treatment plants. As a result, the amount of fresh ground water in storage in the area is decreasing and thereby causing the salty ground water to move inland.

Lusczynski and Swarzenski (1966, p. 50–52) estimated that the deep salty-water wedge in the Magothy aquifer has moved inland an average of about 1,000 feet (at rates ranging from 10 to 50 ft per yr) since the early 1900's; locally, however, in the vicinity of some well fields, it has moved more than 1 mile inland since 1952, at a rate of about 300–400 feet per year. Lusczynski and Swarzenski (1966, p. 55) also noted that, on the average, the intermediate salty-water wedge in the Jameco aquifer has moved inland less than 1,000 feet since the early 1900's.

Waste water has been disposed of through sewers in southwestern Nassau County since 1951. In 1966 the total sewered area was about 70 square miles, and the annual average discharge of treated-sewage effluent from this area to the sea was about 50 mgd. The estimated average decline of ground-water levels in a 50-square-mile area in southwestern Nassau County due to sewering was about 7 feet in 1966 (Franke, 1968, p. 209).

In summary, although water of relatively poor quality from cesspools and septic tanks is no longer contaminating the ground-water reservoir in sewered areas, the net loss of water to the ground-water reservoir due to sewering can and has caused extensive lowering of ground-water levels, which, in turn, is accelerating the encroachment of salty water into the aquifers of Long Island.

SUMMARY OF EFFECTS OF MAN'S ACTIVITIES ON THE MOVEMENT AND DISCHARGE OF WATER

In this section of the report the effects of man's activities are considered from two points of view—artificial ground-water recharge and losses of water from the hydrologic system.

SUMMARY OF ARTIFICIAL RECHARGE

Most of the artificial ground-water recharge on Long Island results from cesspools and septic tanks, recharge basins, injection wells, and leaking water and sewer pipes. The estimated artificial recharge in Nassau and Suffolk Counties in 1965 from these sources is as follows:

Source	*Million gallons per day*
Cesspools and septic tanks	125
Recharge basins:	
Direct runoff	60
Waste water	25
Injection wells	55
Leaking water and sewer pipes	45
Total	310

The large amount of artificial ground-water recharge in Nassau and Suffolk Counties significantly affects the hydrologic regimen, and a large decrease in this recharge, which, for example, would result from discontinued use of cesspools and septic tanks, would materially alter the quantitative balance of the ground-water system. The imbalance would, as has been discussed previously, cause a decline in ground-water levels and the landward movement of salty ground water, at least locally, into the fresh-water aquifers.

LOSS OF WATER FROM THE HYDROLOGIC SYSTEM AS A RESULT OF MAN'S ACTIVITIES

The activities of man which result in a loss of water from the hydrologic system in Nassau and Suffolk Counties are (1) watering of vegetation (lawn and golf-course sprinkling and irrigation), (2) disposal of direct runoff from urban areas to streams and subsequent outflow to the sea, (3) disposal of sewage effluent to salty water, and (4) export of water to New York City. The estimated total amount of water lost from the hydrologic system of Long Island as a result of these activities for selected years are shown in figure 39. The largest single loss, about 60 percent of the total in 1965 (about 75 mgd), was the discharge of sewage effluent to salty water. In 1940 and 1945, New York City imported about 26 and 10 mgd of ground water, respectively, from Nassau County. These large exports of water from Nassau County caused the trend anomaly that is evident for those years in figure 39.

The estimated total loss from the hydrologic system in Nassau and Suffolk Counties in 1965 resulting from the activities of man, about 125 mgd (fig. 39), is less than 10 percent of the estimated average annual input of water to the hydrologic system within the water-budget area, and less than 20 percent of the estimated total discharge from the ground-water reservoir under natural conditions (table 11). However, much of this loss is concentrated in the 70-square-mile area in southwestern Nassau County that is sewered, and its effect in this area on ground-water levels and streamflow has been marked.

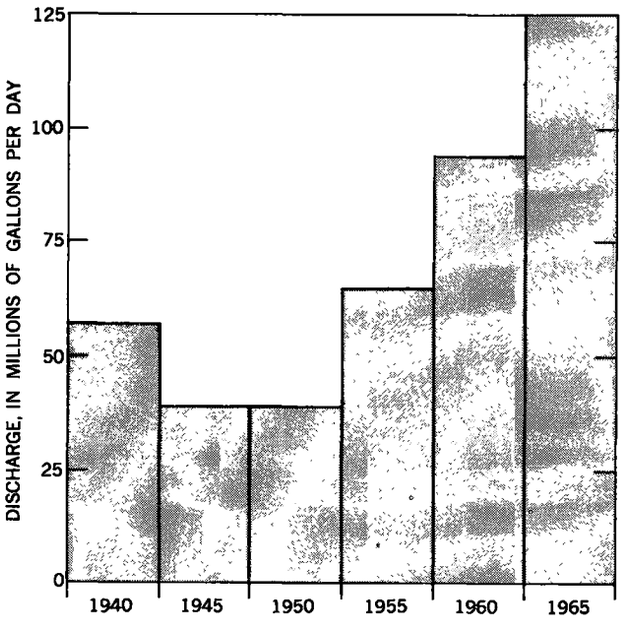


FIGURE 39.—Estimated discharge of water from Nassau and Suffolk Counties, as a result of man's activities, 1940–65.

EFFECTS OF MAN'S ACTIVITIES ON THE QUALITY OF THE WATER

Man has affected the quality of the water on Long Island primarily through the disposal of wastes, including (1) the discharge of smoke and other particulate matter into the atmosphere, (2) the discharge of household waste waters into the ground-water reservoir through cesspools and septic tanks, and (3) the discharge of industrial wastes directly into streams or into the ground-water reservoir through recharge basins. In addition, the dissolved-solids content of the ground water in many areas has increased markedly because of leaching of fertilizers. Selected chemical analyses of water that has been polluted by these various means are given in table 15. In the following discussion the analyses in table 15 are compared to the analyses of natural water in table 12.

Sample 1 of precipitation in table 15 has a high sulfate content (SO_4), which is undoubtedly due in part to contamination of the air as a result of burning fuels. Although in different proportions, samples 2 and 3 of shallow ground water show a particularly high content of calcium, sodium, chloride, sulfate, and nitrate, and the increase in these constituents prob- content of calcium, sodium, chloride, sulfide, and cesspool effluent, respectively (De Laguna, 1964).

Sample 4 represents water that is contaminated with industrial plating wastes (cadmium and hexavalent chromium) and cesspool effluent. This specific occurrence of pollution by industrial wastes has been studied in considerable detail (Davids and Lieber, 1951; Lieber and Welsch, 1954; Welsch, 1955; Perlmutter and others, 1963). The chromium and cadmium content in sample 4 is considerably in excess of the limits recommended by the U.S. Public Health Service (1962) for these metallic ions (0.05 and 0.01 ppm, respectively).

Sample 5 is characterized by a high nitrate content, which results from the disposal of duck-farm wastes directly into the stream. De Laguna (1964) showed a marked contrast in the amount of dissolved nitrate in water from streams located adjacent to duck farms and those distant from duck farms. The introduction of stream water into Great South Bay which is rich in nitrate and phosphate has caused extensive algal blooms and a resulting upset in the chemical and nutrient balance of this brackish-water body; efforts are being made at present to alleviate this source of pollution.

Sample 6 is representative of ground-water seepage to a stream in a highly urbanized area. In this area, household wastes are discharged into the ground-water reservoir through cesspools and septic tanks. Other streams that derive ground-water seepage from similar areas commonly have a total dissolved-solids content ranging between 150 and 200 mg/l. This range is particularly significant because it represents an approximate average dissolved-solids content of the shallow ground water beneath the highly urbanized areas on Long Island which are not sewered. Locally, of course, the shallow ground water may have a considerably higher dissolved-solids content.

Locally, salt-water encroachment has also adversely affected the quality of the ground water. However, this type of contamination of the fresh ground-water reservoir differs from those just mentioned in that man's activities have not added dissolved constituents to the water, but these activities have changed the location of the naturally occurring salty ground water. Selected analyses of salty ground water in the zone of diffusion are given in table 12.

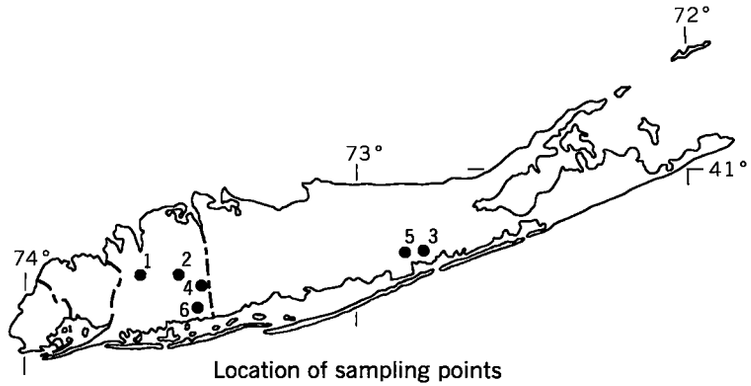
Man has also affected the temperature of the ground water locally. Brashears (1941) described a case history of thermal pollution resulting from recharge of cooling water used in the manufacture of ice in Kings County. Similar situations, although not common, have occurred in other areas where water used for cooling was returned to the ground-water reservoir through recharge wells. In addition, Pluhowski and Kantrowitz (1964, p. 65–66) noted small increases in the temperature of the shallow ground water in the vicinity of housing developments.

TABLE 15.—*Selected chemical analyses of water contaminated by the activities of man on Long Island, N.Y.*

[Analyses made by U.S. Geological Survey and reported in milligrams per liter]

Sample	Source of water	Date collected	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Additional constituents	Total dissolved solids (residue on evaporation at 180° C)	Specific conductance ($K \times 10^5$)	pH	Remarks
1	Precipitation	Feb. 1, 1967	----------		4.4	1.7	3.9	0.4	4	16	3.4	--------	3.6	----------		76	6.4	Partial analysis; composite sample, collected from rain gage at Mineola, N.Y., for period Jan. 3–Feb. 1 1967.
	Ground water, upper glacial aquifer:																	
2	Well N2403	Jan. 21, 1952	9.1	0.04	45	7.3	15	2.6	9	96	22	0.0	46	----------	247	389	6.8	Depth 84 ft; diameter 12 in.; water probably contaminated by fertilizer (De Laguna, 1964).
3	Well S7144	Feb. 13, 1950	8.4	2.0	18	5.7	29	4.4	3	20	50	.1	52	----------	208	360	4.9	Depth 40 ft; depth to water about 20 ft; diameter 2 in.; water probably contaminated by cesspool effluent (De Laguna, 1964).
4	Well N8194	Nov. 7, 1962	13	.22	4.8	1.1	39	5.7	19	57	16	1	16	Hexavalent chromium, 6.2; Cd, 0.4; ABS, 0.26 [1].	173	270	6.2	Water contaminated by metal-plating wastes (hexavalent chromium and cadmium) and cesspool effluent (Perlmutter, and others, 1963).
	Stream water:																	
5	Forge River, West Branch.	Apr. 29, 1948	9.9	.02	8.1	2.6	6.3	4.2	13	7.0	8.8	.3	22	----------	93	114	6.0	Sample collected at Route 27; water probably contaminated by duck-farm wastes (De Luguna, 1964).
6	Massapequa Creek.	May 11, 1966	6.8	.36	13	4.3	16	2.6	12	32	20	.1	12	MBAS, 0.4 [2].	146	211	6.2	Sample collected at gaging station; stream discharge 3.1 cfs.

[1] ABS (alkylbenzensulfonate).
[2] MBAS (methylene blue active substance).



Location of sampling points

WATER-MANAGEMENT IMPLICATIONS OF THE HYDROLOGIC ANALYSIS

The goal of water-resources planning on Long Island is to provide sufficient water of suitable quality to meet the present needs of the residents of Long Island and to meet their needs for a reasonable period of years in the future. This section of the report relates the hydrologic analysis in the previous sections to the planning and development of the local water resources of the area, with special emphasis on Nassau and Suffolk Counties.

THE PRESENT DILEMMA

Future water-resources planning in Nassau and Suffolk Counties must build on the existing state of water-resources development in the area, and it must take into account many complex hydrologic, economic, and political factors. The major features of present water-resources development in the area are (1) withdrawal of ground water from both the shallow unconfined aquifers and from the deeper confined aquifers (2) artificial recharge of polluted waste water through cesspools and septic tanks, (3) injection of relatively uncontaminated waste water through diffusion wells, (4) artificial recharge of direct-runoff water through shallow basins, and (5) discharge of treated sewage water, which was initially derived from the ground-water reservoir, into the sea.

At present (1968), as a result of these water-management practices, total fresh-water outflow from the ground-water reservoir within the water-budget area is greater than total fresh-water inflow, and the amount of fresh ground water in storage is decreasing. This decrease is indicated by declining ground-water levels and the encroachment of salty ground water into the fresh ground-water reservoir. If the present management practices continue, it is likely that, within the water-budget area, (1) the hydrologic imbalance will increase, (2) ground-water levels will continue to decline, and (3) salty ground water will continue to move inland. Accordingly, the present management practices, including particularly the seaward discharge of sanitary sewers, is equivalent to a method of planned overdevelopment.

The complex economic, sociologic, and political factors associated with water-resources development are partly related to the sometimes conflicting interests and desires of the citizens in Nassau and Suffolk Counties. Many citizens are interested in maintaining the size and chemical purity of the lakes and streams for recreation. Others are concerned with maintaining the ecologic balance in the salty bays along the south shore of Long Island to preserve the fauna, flora, and natural beauty of the area. County and State health officials strive to fulfill their responsibilities of assuring a water supply that is completely without hazard to health. All the citizens are, of course, concerned about the cost of future water-resources development.

The present controversy of whether or not to construct sanitary sewers in parts of Nassau and Suffolk Counties is an example of largely valid but conflicting points of view. The present method of disposing of household waste through cesspools and septic tanks in most of Nassau and Suffolk Counties helps maintain the quantity of water in the ground-water reservoir, but causes a deterioration of the quality of the water in the shallow aquifers, which poses a possible health hazard. The construction of sanitary sewers will help preserve the chemical quality of the shallow aquifers, but this construction will result in an increase in the net loss of water from the ground-water reservoir if other conservation procedures are not adopted.

SOME CONCEPTS RELATED TO WATER MANAGEMENT

PRINCIPLE OF CONTINUITY

As a consequence of the principle of continuity, the quantities of water entering and leaving any arbitrary volume (for example, the Long Island ground-water reservoir) within a given time are related by the so-called hydrologic equation:

$$\text{Inflow} = \text{Outflow} \pm \text{Change in storage.}$$

If the change in storage is positive (denoting an increase in the quantity of water in storage), it is added to the right side of the equation; if it is negative (denoting a decrease in the quantity of water in storage), it is subtracted.

The hydrologic system of Long Island must respond to any water-management program in a way that is consistent with the hydrologic equation. If one of the management objectives is to use the water in a way that will not result in a continued decrease in the amount of fresh ground water in storage, it follows from the equation that a balance between total ground-water inflow (recharge) and outflow must be attained. That is, increased consumptive use of ground water must be balanced by increased inflow (such as artificial recharge) or by a reduction of natural outflow (such as ground-water discharge to streams) to avoid a continued decrease in the amount of fresh ground water in storage.

A management program that causes a continual hydrologic imbalance in which the total inflow to the ground-water reservoir is less than the total net outflow (the total quantity permanently lost from the system by evapotranspiration or by discharge to the

sea) necessarily will result in the eventual depletion of the fresh ground water in storage. However, if the concept of temporary overdraft of fresh water from the ground-water reservoir is incorporated into a management program, the number of management choices increases markedly. For example, increased net ground-water withdrawals from the water-budget area could be accomplished if the decision is made to tolerate (1) declining ground-water levels, (2) the landward movement of salty ground water, (3) decreased streamflow, or (4) a combination of these factors.

YIELD OF THE SYSTEM

Discussions on the development of the water resources of Long Island often focus on the "yield" or the "safe yield" of the ground-water system. Probably, the most commonly cited definition of safe yield is that given by Meinzer (1923, p. 55); he defined safe yield as, "the rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible." Todd (1959, p. 200–214) reviewed the concept of safe yield in considerable detail and redefined the term as follows: "The safe yield of a ground-water basin is the amount of ground water which can be withdrawn from it annually without producing an undesired result." Todd's definition is a somewhat more general statement of the concept of safe yield than the definition by Meinzer and, therefore, expands its applicability and enhances its usefulness. Accordingly, the definition of safe yield developed by Todd (1959, p. 200) is adopted in this report.

One of the most significant aspects of the concept of the safe yield of any hydrologic system, including the ground-water system of Long Island, is that a quantitative value for safe yield must be determined within the framework of (1) the hydrologic equation and (2) a precise definition of the extent to which certain undesirable results will be tolerated. Accordingly, the safe yield of any ground-water system is not a single, fixed value, but is a variable that depends upon many complexly interrelated factors.

Safe yield is a useful concept in evaluating the possible alternatives of managing a hydrologic system. However, in practice, the concept has been greatly misused—usually, because an attempt is made to develop a single value for the safe yield of an area. This misuse of the concept of safe yield is detrimental to constructive and intelligent water-resources planning, and under these circumstances effective planning might be facilitated by abandoning the concept altogether.

CONSERVATION OF GROUND WATER

Conservation is usually defined as the careful preservation and protection of a resource—especially the planned management of a natural resource to prevent its exploitation, destruction, or neglect. Management of the water resources of Long Island involves many complex cause-and-effect relationships, particularly within the ground-water reservoir. Therefore, a diversity of opinion exists regarding which factors involve exploitation of the water resources, and what is desirable and undesirable with regard to developing and managing the water resources. Some people believe that it is highly desirable to preserve the present size of the ground-water reservoir—that is, not to decrease the amount of fresh ground water in storage. Others believe that conservation of water involves the most effective use of the available water by man, which may or may not be compatible with preserving the present size of the ground-water reservoir. Despite the fact that they also may share these different points of view, most engineers and scientists would probably agree that the best procedure in planning the water-resources development of Long Island is to evaluate the various water-management alternatives from as many valid points of view as possible and then to select the alternative or combination of alternatives which produces the most desirable, or least undesirable, results in accordance with the wishes of the citizens of Long Island.

WATER-MANAGEMENT ALTERNATIVES

The following alternatives for developing the water resources of Long Island are classified according to the terms of the hydrologic equation which are most affected by the alternatives. Pertinent information developed for each alternative includes (1) changes in the volumes of fresh water flowing into and out of the hydrologic system, (2) changes in storage within the system, (3) changes in internal routing of the water in the hydrologic system (fig. 33), and (4) changes in the quality of the water.

INCREASE INFLOW TO THE HYDROLOGIC SYSTEM

Inasmuch as precipitation was the only source of fresh water on Long Island under natural conditions, increased precipitation and the importation of fresh water from sources other than those on the island are the only methods of increasing the total amount of fresh water on and beneath Long Island. The potential outside sources of fresh water include mainland sources, desalination of sea water or salty ground water, and perhaps the construction of a fresh-water reservoir in Long Island Sound (Gerard, 1966; A. J.

Pansini, written commun., 1967). However, because the present study was concerned mainly with the development of the local water resources, a detailed discussion of these possibilities is beyond the scope of this report.

SALVAGE OUTFLOW FROM THE HYDROLOGIC SYSTEM

The estimated average rate at which ground water discharges into streams and thence into the bodies of salty surface water bordering the island is about 320 mgd in the water-budget area of Long Island (table 11). Much of this water could probably be salvaged by means of a network of carefully spaced shallow wells and pumping galleries adjacent to the streams, particularly near the south shore of Long Island. Such shallow wells are commonly referred to as "skimming wells" because they skim fresh water from very near the top of the ground-water reservoir. With careful spacing of the wells, a large volume of water could probably be withdrawn with only small and local decreases in ground-water levels resulting therefrom. Thus, this method of development would be accompanied by only a minimal decrease in the total volume of ground water in storage.

Salvaging natural ground-water discharge by the use of skimming wells would be largely at the expense of streamflow. The resulting decrease in streamflow to the sea would change the salinity of the bays and estuaries, and thus might alter the plant and animal life therein. The resulting possible harmful effects and the loss of some of the esthetic features associated with the streams would therefore have to be considered carefully when evaluating the possible application of skimming wells.

Because the chemical quality of much of the shallow ground water has been affected adversely by cesspools and septic tanks, the quality of the water withdrawn from the skimming wells might be less than optimum, and, therefore, the water might require some treatment prior to use. Nevertheless, skimming wells, galleries, or collectors seemingly could increase the yield of the Long Island ground-water reservoir substantially compared to the present program of development.

If the total ground-water inflow remains unchanged, the only possibility of significantly decreasing ground-water outflow from the hydrologic system of Long Island without a concurrent decrease of ground water in storage is to decrease evapotranspiration losses. As discussed previously, the quantity of ground water consumed by evapotranspiration in the water-budget area is small. Moreover, the likelihood of salvaging large amounts of precipitation and surface water that are lost by evapotranspiration on Long Island seems remote at present. Accordingly, an attempt to salvage evapotranspiration losses on Long Island does not seem to be a significant water-management alternative at present.

PERMIT A PLANNED DECREASE OF FRESH GROUND WATER IN STORAGE

The ultimate stable positions of the wedges of salty ground water are dependent upon water-level altitudes in the fresh ground-water reservoir. When fresh ground-water levels rise, the wedges of salty ground water move seaward, and, at the same time, subsurface outflow of fresh ground water increases. When ground-water levels decline, the reverse occurs.

Experiments have shown that the landward extent or length of a wedge of salty water in a given aquifer is about inversely proportional to the rate at which ground water is discharging from the aquifer into the ocean (Todd, 1959, p. 281). It follows, therefore, that if a management decision is made to maintain the positions of the interfaces between fresh and salty ground water that existed under natural conditions, then roughly, 400 mgd of fresh ground water (table 11) must be allowed to discharge by subsurface outflow from the water-budget area toward the sea. On the other hand, if the salt-water wedges are permitted to move inland, an additional quantity of fresh ground water could be withdrawn from the aquifers and used consumptively.

If the goal of water-resources planning were to salvage as much outflow from the ground-water reservior as possible and at the same time the decision was made to tolerate a large decrease in the volume of ground water in storage, it might be possible to salvage as much as half the total subsurface outflow of fresh ground water, or about 200 mgd (table 11). Moreover, much of the base flow of the streams that discharges into the sea could be salvaged. It probably would not be feasible to salvage all the base flow of the streams (an average of about 320 mgd), but at least 200 mgd probably could readily be salvaged. Under conditions of intensive development, therefore, extensive and carefully planned lowering of ground-water levels could result in salvaging on the order of 400 mgd—200 mgd of subsurface outflow plus 200 mgd of streamflow.

Ground-water development that results in salvaging large amounts of subsurface outflow and streamflow will result in a decrease of ground water in storage beneath the water-budget area and beneath the bordering bays and the ocean. Sustained regional drawdowns in the ground-water reservoir beneath the

water-budget area on the order of tens of feet would ultimately result in the landward movement of the fresh-salt water interfaces of several thousands of feet or more. The change in storage of fresh ground water beneath the water-budget area would be many times smaller than the change in storage of fresh ground water beneath the bordering bays and ocean.

The amount of fresh ground water in storage beneath the bays and the ocean can only be roughly estimated (table 4). However, even if this quantity of fresh water in storage was accurately known, the amount that could be salvaged as the fresh-salt water interfaces moved landward would be uncertain. Wide variations in hydraulic conductivity in adjacent and overlying layers in the ground-water reservoir could cause an uneven or fingering pattern of salt-water encroachment, which could result in local bodies of fresh ground water being isolated and rendered virtually unrecoverable.

The principle of permitting the salt-water wedges to move inland to new stable positions that require less subsurface outflow of fresh ground water to the sea is, in effect, a method of planned overdevelopment. This method could be employed, to whatever extent deemed desirable, in conjunction with any one of the several other alternative methods of development. In summary, the safe yield of the ground-water reservior of Long Island could be increased substantially if it were deemed tolerable to permit the salt-water wedges to move inland, and thereby allow some of the present wells to become contaminated with salty water.

MAINTAIN APPROXIMATE BALANCE BETWEEN INFLOW AND OUTFLOW BY MEANS OF ARTIFICIAL RECHARGE

According to the principle of continuity, if outflow exceeds inflow the volume of water in storage in the ground-water reservoir must decrease. In the previous section of this report, the advantages of decreasing outflow from the ground-water reservoir accompanied by a planned decrease in the volume of ground water in storage were discussed. At some time in the future, however, the water managers may deem it desirable to maintain the salt-water wedges at approximately constant positions. When this point has been reached, a balance between total fresh ground-water inflow and outflow must be maintained.

Various proposals are now under consideration on Long Island to maintain the balance between fresh ground-water outflow and inflow by artificially recharging treated waste water into the ground-water reservoir. These proposals include (1) injecting renovated water into the deeper aquifers through a line of barrier-injection wells near the south shore (and perhaps also near the north shore at a later date) of Long Island and (2) recharging renovated water into the shallow aquifers through basins that would be located near the center of the island.

Water injected into the deeper aquifers will increase the artesian pressure in the vicinity of each injection well in proportion to the quantity of injected water, and the injected water will move radially away from the well. The seaward hydraulic gradient from the injection well will increase, and a landward hydraulic gradient also will be established. If the wells are properly spaced, the individual mounds of artesian pressure around each well will coalesce, and a pressure ridge will form parallel to the coast. The extent to which the pressure ridge will be effective in preventing the landward movement of salty water will depend upon many complexly interrelated factors, especially (1) the magnitude of the increase in artesian pressure in both the horizontal and vertical directions and (2) the location and magnitude of nearby ground-water withdrawals.

Irrespective of the size and shape of the pressure ridge formed by injecting a given quantity of water into a network of barrier injection wells, theoretically, the yield of the system will be increased by the amount of additional fresh-water recharge to the ground-water system. In practice, however, not all the injected water will be recovered, but a large proportion probably could be salvaged under a careful program of development.

Some of the injected water will move inland toward wells that are withdrawing public-supply water; eventually, diluted treated effluent, and under some circumstances undiluted treated effluent, might be withdrawn from nearby pumping wells. For this reason, the sewage-plant effluent that is injected will receive tertiary treatment to upgrade the quality of the water so that it meets or exceeds virtually all the commonly accepted standards for drinking water.

Shallow basins provide an additional significant option to the water manager as a means of recharging renovated water into the ground-water reservoir—either used alone or in conjunction with injection wells. In Suffolk County a regulation recently established by the Suffolk County Health Department requires that all new housing developments in the county having 100 or more individual homes must be equipped with communal sewage-treatment and disposal facilities. As a result, several housing developments in Suffolk County presently are discharging treated sewage-plant effluent into recharge basins, and the total quantity of such artificial recharge probably will increase markedly in the future.

Shallow basins have the advantage that they are easy to construct and maintain. Furthermore, experience with storm-runoff and disposal basins on Long Island has shown that most such basins can readily dispose of large quantities of treated waste water. A major disadvantage of basins, however, is the large land area that they require.

Theoretically, if after it is used, all the water pumped from the ground-water reservoir is returned by means of injection wells, recharge basins, or other methods, the yield of the system would be almost limitless were it not for water-quality considerations and for the differences between horizontal and vertical hydraulic conductivities. Each time that the water is recirculated (pumped from the ground, used, treated, and returned underground) the quality of the water would deteriorate unless certain demineralizing treatment methods were used. Such methods are possible, but are at present relatively expensive. Even if demineralization is not employed, tertiary treatment of waste water and subsequent recharging of the ground-water reservoir could increase the safe yield of the system manyfold, and might extend the usefulness of the ground-water reservoir of Long Island over hundreds of years.

If most of the future pumpage is from the deeper artesian aquifers and if the pumped water is returned to the shallow aquifers after use, a local imbalance might result in the deeper aquifers. Because vertical hydraulic conductivities ordinarily are much less than horizontal hydraulic conductivities, water returned to the shallow aquifers may not move downward into the deeper aquifers as rapidly as it is pumped from these aquifers, with the result that some water pumped from the deeper aquifers will be replaced instead by laterally encroaching salty water.

CONCLUDING COMMENTS ON WATER-MANAGEMENT ALTERNATIVES

Several major questions must be answered in order to develop a rational and comprehensive plan for managing the water resources of Long Island. Two of the most significant questions that have been considered thus far in the report are (1) should salty ground water be permitted to move inland, and if so, how far inland? and (2) what role should renovated water play in water-resources planning? A third major question and a question that could materially affect the planning process, relates to the length of time for which comprehensive plans should be designed—for 25, 50, or 100 years, or longer. None of these major questions can be answered independently, but each must be answered in the context of the answers to the other questions.

The advantages and disadvantages of permitting planned salt-water encroachment are considered in previous sections of the report. However, an additional word regarding the effect of planned salt-water encroachment on the optimum use of water by man is appropriate. A decrease in the subsurface outflow of ground water from the deeper aquifers on Long Island will be accompanied by a decrease in the volume of water in storage within these aquifers. Over a period of many years the amount of water salvaged as a result of reduced outflow will undoubtedly be greater than the net decrease of ground water removed from storage. Under these circumstances, the argument can be made that, to achieve the optimum use of water by man, some encroachment of salty water would be beneficial.

Several of the apparently most feasible water-management alternatives involve the use of renovated water. From the hydrologic point of view, these alternatives are mainly concerned with achieving the optimum pattern of ground-water withdrawals and artificial recharge of ground water. Another important consideration, however, is the reaction of the citizens of Long Island to the use of renovated water. Instead of recharging renovated water into the ground-water reservoir and allowing it to mix there with unused water before possible withdrawal again by pumping, the same degree of dilution could be obtained by mixing renovated water and unused water in the water mains. This procedure would avoid the cost of recharging much of the renovated water. This course of action, however, may not be acceptable to the citizens of Long Island at present for psychological or other reasons.

The significance of the time factor in water-resources planning cannot be over emphasized. Within the next 25 or 50 years, for example, the technical ability to economically convert salty water to fresh water may be greatly improved. Also, many other water-management alternatives may become technically and economically feasible. In the meantime, the citizens and water planners of Long Island are fortunate because of the large size of the fresh ground-water reservoir. This large volume of high-quality fresh water in storage lends time, which, in turn, provides the opportunity for a careful consideration of the available alternatives and considerable flexibility to the water manager.

This report has shown the close interrelations between the various components of the hydrologic system.

Although the fresh ground-water reservoir of Long Island is very large, the activities of man in one part of the reservoir ultimately will also affect other parts of the reservoir. For this reason, the most efficient planning to utilize and manage the ground-water reservoir can be achieved if the reservoir is developed and managed as a unit without regard for political boundaries.

An adequate evaluation of the various alternatives for developing and managing the water resources of Long Island will require the combined efforts of many specialists including hydrologists, engineers, geologists, ecologists, economists, sociologists, and regional planners. The complexity of the problems involved and the possibly great impact of a final overall plan on the lives of the citizens of Long Island requires such a multidisciplinary approach. Moreover, because of the great cost involved in implementing some of the alternatives, a substantial effort in the planning phase is warranted. As stated previously, because of the great size of the fresh ground-water reservoir, adequate time is available for such careful planning.

A continuing program of hydrologic studies is mandatory to provide the necessary input of hydrologic information to an overall planning effort. The present data-collection activities on Long Island, which provide a continuous record of the state of the hydrologic system, should be continued and further refined. In particular, a more intensive study and monitoring of water quality in various parts of the island would be helpful. Previous efforts to define the shape and areal extent of the various aquifers should also be continued. This is particularly true in eastern Suffolk County where many deep public-supply wells are being drilled in areas where very few deep wells previously existed. The data from these wells will provide much valuable lithologic, water quality, and test information.

As shown in this report, man has already altered both the internal routing within and outflow from the hydrologic system and the quality of the water therein. Man's future role in causing further changes will undoubtedly be even greater. As a result, an increasing amount and intensity of hydrologic study will be necessary to keep abreast of these continual changes.

Finally, the present intensity of water-resources development on Long Island and the projected future development of these resources warrant the use of the most sophisticated tools now available to the hydrologist. An electric-analog model study of most of the Long Island ground-water reservoir is now underway. Studies with this model should help define and evaluate the hydrologic results of some of the management alternatives considered in this report. These studies should be followed by other types of analog studies. Furthermore, it is now possible to simulate at least some problems associated with the Long Island ground-water reservoir on a digital computer. All these tools will aid the water manager in formulating a rational and comprehensive plan for developing the water resources of Long Island.

SELECTED REFERENCES

Baffa, J. J., and others, 1958, Developments in artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 50, no. 7, p. 812–871.

Brashears, M. L., Jr., 1941, Ground-water temperatures on Long Island, New York, as affected by recharge of warm water: Econ. Geology v. 36, no. 8, p. 811–828.

Burr, W. H., Hering, Rudolph, and Freeman, J. R., 1904, Report of the Commission on additional water supply for the City of New York: New York, Martin B. Brown Co., 980 p.

Cohen, Philip, and Durfor, C. N., 1967, Artificial-recharge experiments utilizing renovated sewage-plant effluent—a feasibility study at Bay Park, New York, U.S.A.: Internat. Assoc. Sci. Hydrology Pub. 72, p. 194–199.

Cohen, Philip, Franke, O. L., and Foxworthy, B. L., 1968, An atlas of Long Island's water resources: New York State Water Resources Comm. Bull. 62, 117 p.

Cohen, Philip, Franke, O. L., and McClymonds, N. E., 1969, Hydrologic effects of the 1962–66 drought on Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1879–F, 18 p.

Cooper, H. H., Jr., 1964, A hypothesis concerning the dynamic balance of fresh water and salt water in a coastal aquifer, *in* Sea water in coastal aquifers: U.S. Geol. Survey Water-Supply Paper 1613–C, p. C1–C11.

Davids, H. W., and Lieber, Maxim, 1951, Underground water contamination by chromium wastes: Water and Sewage Works, v. 98, no. 12, p. 528–534.

de Laguna, Wallace, 1963, Geology of Brookhaven National Laboratory and vicinity, Suffolk County, New York: U.S. Geol. Survey Bull. 1156–A, 35 p.

——— 1964, Chemical quality of water, Brookhaven National Laboratory and vicinity, Suffolk County, New York: U.S. Geol. Survey Bull. 1156–D, 73 p.

de Laguna, Wallace, and Brashears, M. L., Jr., 1948, The configuration of the rock floor in western Long Island, New York: New York State Water Power and Control Comm. Bull. GW–13, 32 p.

Faust, G. T., 1963, Physical properties and mineralogy of selected samples of the sediments from the vicinity of the Brookhaven National Laboratory, Long Island, New York: U.S. Geol. Survey Bull. 1156–B, 34 p.

Fleming, W. L., 1935, Glacial geology of central Long Island: Am. Jour. Sci., v. 30, p. 216–238.

Flynn, J. M., and others, 1958, Study of synthetic detergents in ground water: Am. Water Works Assoc. Jour., v. 50, no. 12, p. 1551–1562.

Franke, O. L., 1968, Double-mass-curve analysis of the effects of sewering on ground-water levels on Long Island, New York, *in* Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600–B, p. B205–B209.

Fuller, M. L., 1914, The geology of Long Island, New York: U.S. Geol. Survey Prof. Paper 82, 231 p.

Gerard, R. D., 1966, Potential freshwater reservoir in the New York area: Science, v. 153, no. 3738, p. 870–871.

Harder, J. A., Simpson, T. R., Lau, L. K., Hotes, F. L., and McGawhey, P. H., 1953, Laboratory research on sea-water intrusion into fresh ground-water sources and methods of its prevention—final report: Univ. Calif., Berkeley, Sanitary Eng. Research Lab., 68 p.

Heath, R. C., Foxworthy, B. L., and Cohen, Philip, 1966, The changing pattern of ground-water development on Long Island, New York: U.S. Geol. Survey Circ. 524, 10 p.

Isbister, John, 1966, Geology and hydrology of northeastern Nassau County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1825, 89 p.

Jacob, C. E., 1945a, The water table in the western and central parts of Long Island, New York: New York State Water Power and Control Comm. Bull. GW–12, 24 p.

——— 1945b, Correlation of ground-water levels and precipitation on Long Island, New York: New York State Water Power and Control Comm. Bull. GW–14, 20 p.

Johnson, A. H., 1948, Ground-water recharge on Long Island: Am. Water Works Assoc. Jour., v. 49, no. 11, p. 1159–1166.

——— 1955, Conservation of ground water on Long Island: Am. Water Works Assoc. Jour., v. 47, no. 4, p. 348–354.

Kohout, F. A., 1964, The flow of fresh water and salt water in the Biscayne aquifer of the Miami area, Florida, *in* Sea water in coastal aquifers: U.S. Geol. Survey Water-Supply Paper 1613–C, p. 12–32.

Leggette, R. M., 1936, Long-time records of ground-water levels on Long Island, New York: Am. Geophys. Union Trans., v. 17, p. 341–344.

——— 1937, The mutual interference of artesian wells on Long Island, New York: Am. Geophys. Union Trans., 18th Ann. Mtg., pt. 2, p. 490–494.

Leggette, R. M., and Brashears, M. L., Jr., 1938, Ground water for air-conditioning on Long Island, New York: Am. Geophys. Union Trans., 19th Ann. Mtg., pt. 1, p. 412–418.

Lieber, Maxim, Perlmutter, N. M., and Frauenthal, H. L., 1964, Cadmium and hexavalent chromium in Nassau County ground water: Am. Water Works Assoc. Jour., v. 56, no. 6, p. 739–747.

Lieber, Maxim, and Welsch, F. W., 1954, Contamination of ground water by cadmium: Am. Water Works Assoc. Jour., v. 46, no. 6, p. 541–547.

Lounsbury, Clarence, and others, 1928, Soil survey of Suffolk and Nassau Counties, New York: U.S. Dept. Agriculture, Bur. Chemistry and Soils, ser. 1928, no. 28, 46 p.

Lubke, E. R., 1964, Hydrogeology of the Huntington-Smithtown area, Suffolk County, New York: U.S. Geol. Survey Water-Supply Paper 1669–D, 68 p.

Lusczynski N. J., 1952, The recovery of ground-water levels in Brooklyn, New York, from 1947 to 1950: U.S. Geol. Survey Circ. 167, 29 p.

——— 1961, Head and flow of ground water of variable density: Jour. Geophys. Research, v. 66, no. 12, p. 4247–4256.

Lusczynski, N. J., and Johnson, A. H., 1951, The water table in Long Island, New York, in January 1951: New York State Water Power and Control Comm. Bull. GW–27, 28 p.

Lusczynski, N. J., and Swarzenski, W. V., 1960, Position of the salt-water body in the Magothy(?) Formation in the Cedarhurst-Woodmere area of southwestern Nassau County, Long Island, New York: Econ. Geology v. 55, no. 8, p. 1739–1750.

——— 1962, Fresh and salty ground water in Long Island, New York: Am. Soc. Civil Engineers Proc., v. 88, no. 3207, p. 173–194.

——— 1966, Salt-water encroachment in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–F, 76 p.

McClymonds, N. E., and Franke, O. L., 1971, Water-transmitting properties of Long Island's aquifers: U.S. Geol. Survey Prof. Paper 627–E (in press).

Meinzer, O. E., 1923, Outline of ground-water hydrology with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

Meyer, A. F., 1928, The elements of hydrology: New York, John Wiley & Sons, 522 p.

Miller, J. F., and Frederick, R. H., 1969, The precipitation regime of Long Island, New York: U.S. Geol. Survey Prof. Paper 627–A, 21 p.

Nassau County Planning Commission, 1959, Planning Nassau County—A compilation of land uses: Mineola, Nassau County Planning Comm., 17 p.

New York City Department of Planning, 1962, Land use in New York City: New York, Newsletter Dept. City Planning, April 1962.

New York State Water Pollution Control Board, 1960, Effect of synthetic detergents on the ground waters of Long Island, New York: New York State Water Pollution Control Board Research Rept. 6, 17 p.

Perlmutter, N. M., and Crandell, H. C., 1959, Geology and ground-water supplies of the south-shore beaches of Long Island, New York: New York Acad. Sci. Annals, v. 80, p. 1060–1076.

Perlmutter, N. M., and DeLuca, F. A., 1963, Availability of fresh ground water, Montauk Point area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–B, 39 p.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–A, 205 p.

Perlmutter, N. M., Geraghty, J. J., and Upson, J. E., 1959, The relation between fresh and salty ground water in southern Nassau and southeastern Queens Counties, Long Island, New York: Econ. Geology, v. 54, no. 3, p. 416–435.

Perlmutter, N. M., Lieber, Maxim, and Frauenthal, H. L., 1963, Movement of waterborne cadmium and hexavalent chromium wastes in South Farmingdale, Nassau County, Long Island, New York, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C179–C184.

——— 1964, Contamination of ground water by detergents in a suburban environment—South Farmingdale area, Long Island, New York, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–C, p. C170–C175.

Perlmutter, N. M., and Soren, Julian, 1962, Effects of major water-table changes in Kings and Queens Counties, New York City, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–E, p. E136–E139.

Pluhowski, E. J., 1961, Variation in temperature of two streams on Long Island, New York, *in* Geological Survey research 1961: U.S. Geol. Survey Prof. Paper 424–D, p. D55–D58.

Pluhowski, E. J., and Kantrowitz, I. H., 1962, Source of ground-water runoff at Champlin Creek, Long Island, New York, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–B, p. B95–B97.

——— 1963, Influence of land-surface conditions on ground-water temperatures in southwestern Suffolk County, Long Island, New York, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–B, p. B186–B188.

——— 1964, Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1768, 119 p.

Reiners, W. A., and Woodwell, G. M., 1966, Water budget of a forest damaged by ionizing radiation: Ecology, v. 47, no. 2, p. 303–306.

Sanford, J. H., 1938, Report on the geology and hydrology of Kings and Queens Counties, Long Island: New York State Water Power and Control Comm. Bull. GW–7, 68 p.

Sawyer, R. M., 1963, Effect of urbanization on storm discharge and ground-water recharge in Nassau County, New York, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C185–C187.

Seaburn, G. E., 1969, Effects of urban development on direct runoff to East Meadow Brook, Long Island, New York: U.S. Geol. Survey Prof. Paper 627–B, 14 p.

——— 1970, Preliminary results of hydrologic studies at two recharge basins on Long Island, New York: U.S. Geol. Survey Prof. Paper 627–C, 17 p.

Spear, W. E., 1912, Long Island sources—an additional supply of water for the City of New York: New York City Board Water Supply, 708 p.

Suffolk County Planning Commission, 1962, Existing land use: Hauppauge, Suffolk County Dept. Planning, 42 p.

Suter, Russell, 1937, Engineering report on the water supplies of Long Island, New York: New York State Water Power and Control Comm. Bull. GW–2, 64 p.

Suter, Russell, de Laguna, Wallace, and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers of Long Island, New York: New York State Water Power and Control Comm. Bull. GW–18, 212 p.

Swarzenski, W. V., 1963, Hydrology of northwestern Nassau and northeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1657, 90 p.

Thornthwaite, C. W., and Mather, J. R., 1955, The water balance: Drexel Inst. Technology Pubs. in Climatology, v. 8, no. 1, p. 1–86.

——— 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Inst. Technology Pubs. in Climatology, v. 10, no. 3, p. 185–311.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley & Sons, 336 p.

Upson, J. E., 1955, Ground-water sources on Long Island: Am. Water Works Assoc. Jour., v. 47, no. 4, p. 341–347.

——— 1959a, Relation of Long Island ground-water resources to regional needs: Am. Water Works Assoc. Jour., v. 51, no. 2, p. 286–300.

——— 1959b, Ground-water problems in New York and New England: Am. Soc. Civil Engineers Proc., v. 85, no. HY 6, 12 p.

U.S. Public Health Service, 1962, Public Health Service drinking water standards—1962: Public Health Service Pub. 956, U.S. Govt. Printing Office, 61 p.

Veatch, A. C., and others, 1906, Underground water resources of Long Island, New York: U.S. Geol. Survey Prof. Paper 44, 394 p.

Welsch, F. W., 1955, Ground-water pollution from industrial wastes in Nassau County, New York: Sewage and Industrial Wastes, v. 27, no. 9, p. 1065–1069.

——— 1956, Conservation of ground water practices on Long Island: Water and Sewage Works, v. 103, no. 10, p. 468–473.

——— 1960, Conservation in Nassau County, New York: Am. Water Works Assoc. Jour., v. 52, no. 12, p. 1494–1498.

White, W. N., 1932, A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: U.S. Geol. Survey Water-Supply Paper 659–A, 105 p.

Wyckoff, R. D., and Reed, D. W., 1935, Electrical conduction models for the solution of waste seepage problems: Physics, v. 6, p. 395–401.

TENTATIVE WATER BUDGETS

Tentative water budgets for subareas of the water-budget area are given in tables 16–19. The areas of the subareas are about 100, 210, 125, and 325 square miles, respectively, and the locations of the subareas are shown in figure 2. These water budgets are consistent with the budgets in table 11. For example, the sum of the same budget items in tables 16 and 17 are equal to the corresponding budget item relating to the northern part of the water-budget area in table 11. To achieve this consistency and at the same time subdivide the values in table 11 in proportions most consistent with available hydrologic information, the number of significant figures in many entries in tables 16–19 is greater than the accuracy of these entries warrants.

A possible inconsistency in these data is evident from calculating the recharge per square mile in the four parts of the water-budget area. This inconsistency is due in part to errors in the estimates of individual entries and in part to some deviation from the underlying assumption made in this analysis—especially the assumption that no appreciable change in storage has occurred in these areas during the water-budget period, 1940–65. This assumption is least vaild for southern Nassau County.

TABLE 16.—*Water budget of the northern part of the water-budget area within Nassau County, Long Island, N.Y., water years 1940–65* [1]

Type of water-budget element	No.	Water-budget element	Estimated value of water-budget element (millions of gallons per day)
Inflow	1	Precipitation	210
Internal distribution.	2	Direct runoff	2
	3	Ground water recharge [2]	100
	4	Ground-water discharge to streams [3]	14
Outflow	5	Evapotranspiration of precipitation [4]	108
	6	Subsurface outflow of ground water	85
	7	Streamflow discharging to salt water	16
	8	Evapotranspiration of ground water [5]	1

[1] The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940–65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less. Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow.

[2] The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

[3] The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

[4] The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

[5] These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

TABLE 17.—*Water budget of the northern part of the water-budget area within Suffolk County, Long Island, N.Y., water years 1940–65* [1]

Type of water-budget element	No.	Water-budget element	Estimated value of water-budget element (millions of gallons per day)
Inflow	1	Precipitation	440
Internal distribution.	2	Direct runoff	3
	3	Ground water recharge [2]	220
	4	Ground-water discharge to streams [3]	31
Outflow	5	Evapotranspiration of precipitation [4]	217
	6	Subsurface outflow of ground water	185
	7	Streamflow discharging to salt water	34
	8	Evapotranspiration of ground water [5]	4

[1] The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940–65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less. Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow.

[2] The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

[3] The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

[4] The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

[5] These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

TABLE 18.—*Water budget of the southern part of the water-budget area within Nassau County, Long Island, N.Y., water years 1940–65* [1]

Type of water-budget element	No.	Water-budget element	Estimated value of water-budget element (millions of gallons per day)
Inflow	1	Precipitation	260
Internal distribution.	2	Direct runoff	5
	3	Ground water recharge [2]	113
	4	Ground-water discharge to streams [3]	50
Outflow	5	Evapotranspiration of precipitation [4]	142
	6	Subsurface outflow of ground water	60
	7	Streamflow discharging to salt water	55
	8	Evapotranspiration of ground water [5]	3

[1] The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940–65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less. Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow.

[2] The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

[3] The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

[4] The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

[5] These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

TABLE 19.—*Water budget of the southern part of the water-budget area within Suffolk County, Long Island, N.Y., water years 1940–65* [1]

Type of water-budget element	No.	Water-budget element	Estimated value of water-budget element (millions of gallons per day)
Inflow	1	Precipitation	690
Internal distribution.	2	Direct runoff	10
	3	Ground water recharge [2]	352
	4	Ground-water discharge to streams [3]	225
Outflow	5	Evapotranspiration of precipitation [4]	328
	6	Subsurface outflow of ground water	120
	7	Streamflow discharging to salt water	235
	8	Evapotranspiration of ground water [5]	7

[1] The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940–65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less. Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow.

[2] The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

[3] The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

[4] The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

[5] These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

U. S. GOVERNMENT PRINTING OFFICE : 1971 O - 427-144

STORM WATER
(USGS - '62)

Form 9-014

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

SURFACE WATER BRANCH

Arthur W. Harrington, District Engineer

Albany, N. Y.

A PROGRESS REPORT ON THE DISPOSAL OF STORM WATER AT AN EXPERIMENTAL SEEPAGE BASIN NEAR MINEOLA, N. Y.

BY

H. D. Brice

C. L. Whitaker

R. M. Sawyer

In Cooperation with

NASSAU COUNTY

NEW YORK

U.S. GOVERNMENT PRINTING OFFICE: 1962—O-632210

PROPERTY OF U. S. GEOLOGICAL SURVEY

MINEOLA OFFICE LIBRARY

UNITED STATES GEOLOGICAL SURVEY

SURFACE WATER BRANCH

Arthur W. Harrington, District Engineer

Albany, N. Y.

A PROGRESS REPORT ON THE DISPOSAL OF STORM WATER AT AN EXPERIMENTAL SEEPAGE BASIN NEAR MINEOLA, N. Y.

BY

H. D. BRICE

C. L. WHITAKER

R. M. SAWYER

In Cooperation With

NASSAU COUNTY

NEW YORK

Open-file report. Not reviewed for conformance with stratigraphic nomenclature and editorial standards of the Geological Survey.

Disposal of storm water in urban, and even suburban, populated areas is a problem of major concern to engineer or public-works departments in almost every section of the country. The sites of many cities in river valleys have simplified this problem to one of constructing storm-sewer systems of the usual type, through which surface-water runoff is carried directly into nearby river channels.

Many municipalities and heavily populated suburban communities are not so favorably situated and, especially where a rapidly increasing building program of streets, homes, and commercial buildings has caused an increase in the volume of surface-water runoff, the disposal problem is soon limited to a choice between lengthy and expensive trunk sewers to the nearest natural body of water, or to a system of storage and seepage basins situated within the community and fed by short lines of storm sewers. This latter plan has numerous obvious advantages, if the underlying material is permeable enough that rapid seepage may be expected. Areas such as the interior of Long Island are handicapped by a lack of natural drainage channels but are favored by the presence of coarse sand and gravel of glacial origin. Prior to the large expansion of housing and highway construction in the interior sections of the Island, the need for storm sewers was minimized by the small size of the impervious area and the large infiltration capacity of the surface materials. Surface water from storms of average intensity and duration was absorbed quickly and, from larger storms, was collected in shallow natural depressions from which it seeped within a short time. The movement of large numbers of people to Nassau County resulted in a building program which decreased very rapidly the land-surface area available for seepage

and increased the impervious area from which storm water flows.

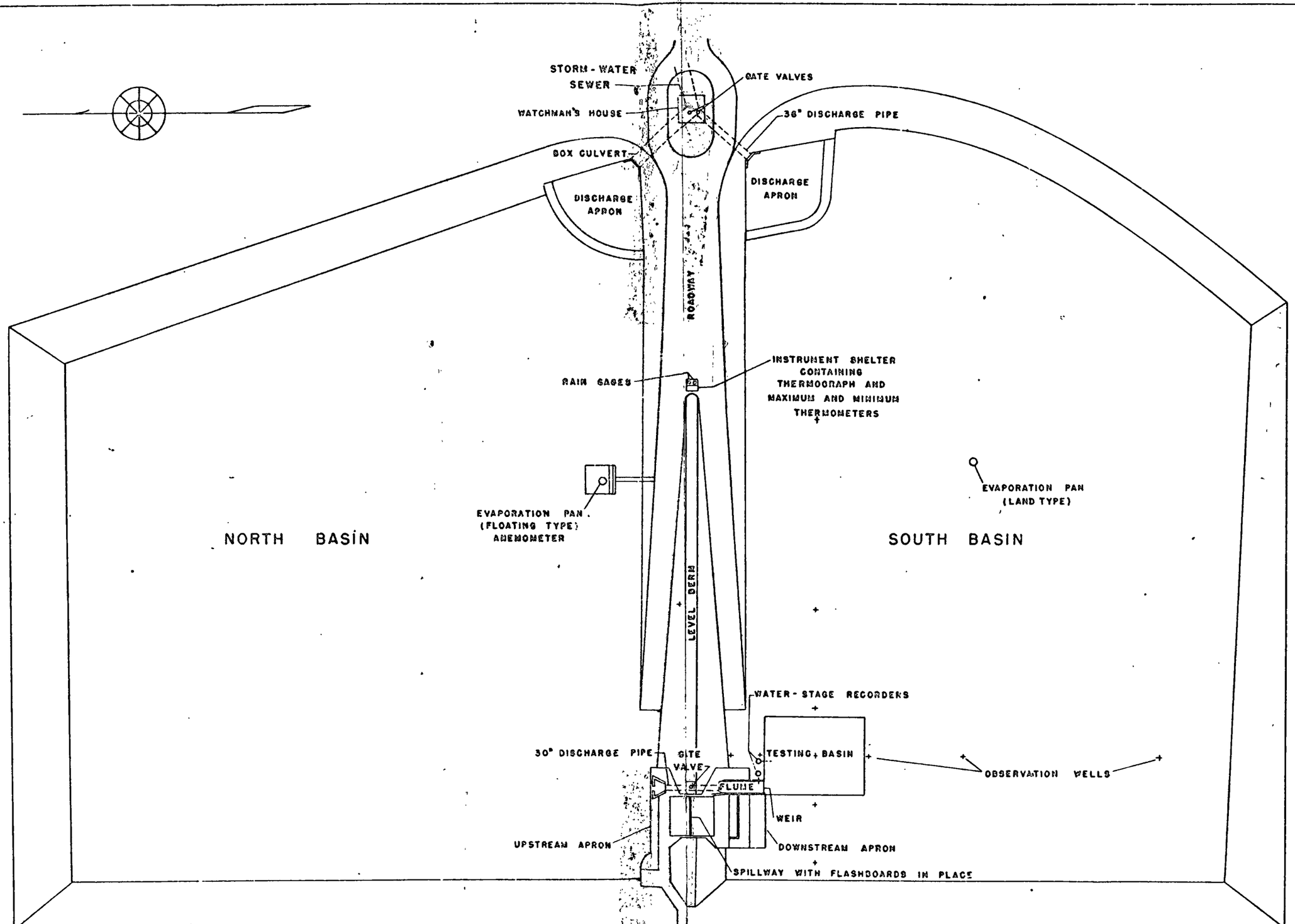
Such a building program of necessity must be accompanied by a program of storm-sewer construction, and Nassau County had to choose between a system of long and costly trunk sewers extending from interior sections of the county to tidewater and the south shore or a system of short sewer lines terminating in seepage basins excavated at strategic interior points. The latter system was selected as part of the long-range drainage plan in 1935, consideration having been given to the need for conservation of the county water supply. The system of long trunk sewers would have carried great quantities of this valuable resource to tidewater and thereby removed it from areas whose water supply it would have replenished. The system of short sewer lines and seepage basins, therefore, in addition to certain economies of construction, provided a means of water conservation comparable in effectiveness to the natural surface conditions of the area. By this system the surface-water runoff during a storm is carried through relatively short sewer lines to artificial collecting basins. From these basins the water seeps through the underlying natural deposits of sand and gravel and thus is returned to the underground reservoir from which most water supplies on Long Island are taken. Because of this replenishment of the water supply, the use of the term "recharge basin" commonly is used to describe these artificial depressions.

Application of this method of surface-water disposal has spread throughout the interior areas of Nassau and Suffolk Counties. It is used by the two counties and their respective towns, and by the State of New York for disposal of water from streets and roadways, by

building contractors in housing projects, and by industries for disposal of treated waste water as well as storm water. Many of the small seepage basins are underground and similar in construction to the common cesspool; other small basins are built as open pits along rural roads and are barricaded by suitable fences. The larger basins are excavated as open pits of a size deemed adequate to contain the surface-water runoff from the surrounding area during a large storm.

Design criteria for such basins were lacking at the time the first group was built by Nassau County and, as the need for more basins increased, it became evident that the performance of those already in use should be studied to determine, if possible, their fundamental characteristics, including performance limitations. The expanding use of this method for disposal of storm water in Nassau County and elsewhere on Long Island may be taken for granted, but the fullest adaptation of the method can be reached only with a better understanding of the factors that control the seepage process under the operating conditions that exist within this immediate area.

For the purpose of such studies, a cooperative agreement was concluded in 1948 between Nassau County and the U. S. Geological Survey, and plans were begun for an experimental project to be located in an existing seepage basin. The use of unfiltered storm water, rather than hydrant water, was considered essential to the success of these experiments, and for best results this water supply should be available at all times and ample in quantity. Only the Rockaway Road basin, near Mineola and Garden City, was found to meet this requirement. The layout here is shown in Plate 1. These basins are separated by an earthen dike, with



ROCKAWAY ROAD EXPERIMENTAL SEEPAGE BASIN PROJECT

DR. E.S.C. CK. R.J.S. TR. E.J.R.

masonry spillway equipped with timber flashboards. Near the spillway a 24-inch hand-operated sluice gate is set in a 30-inch concrete pipe discharge line connecting the two basins at the floor elevation. The floor of each basin is nearly level, and the minimum height of the banks surrounding the basins is about 12 feet. Surface-water runoff, from storm rainfall or melting snow, enters the north, or desilting, basin through the system of collecting sewers. If and when the duration and intensity of the storm rainfall, or the runoff from melting snow, results in a greater volume of inflow than the capacity of this basin at that time, the excess volume flows over the spillway into the south, or seepage basin. During the period of detention in the desilting basin the heavier particles of silt settle to the bottom, and during periods of overflow only the lighter particles are carried over the spillway to the seepage basin. Over the years the accumulation of silt on the bottom and sides of the desilting basin had reduced the rate of seepage from that basin to such an extent that water was impounded to a depth of several feet between storms. This impoundment would provide a constant supply of unfiltered storm water with sufficient head for flooding a small (40 ft. x 50 ft.) experimental seepage basin to a depth of several feet and with sufficient volume for maintaining a suitable rate of inflow to the experimental basin for ample testing periods, or for repeated floodings of the plot at regular or irregular intervals of time.

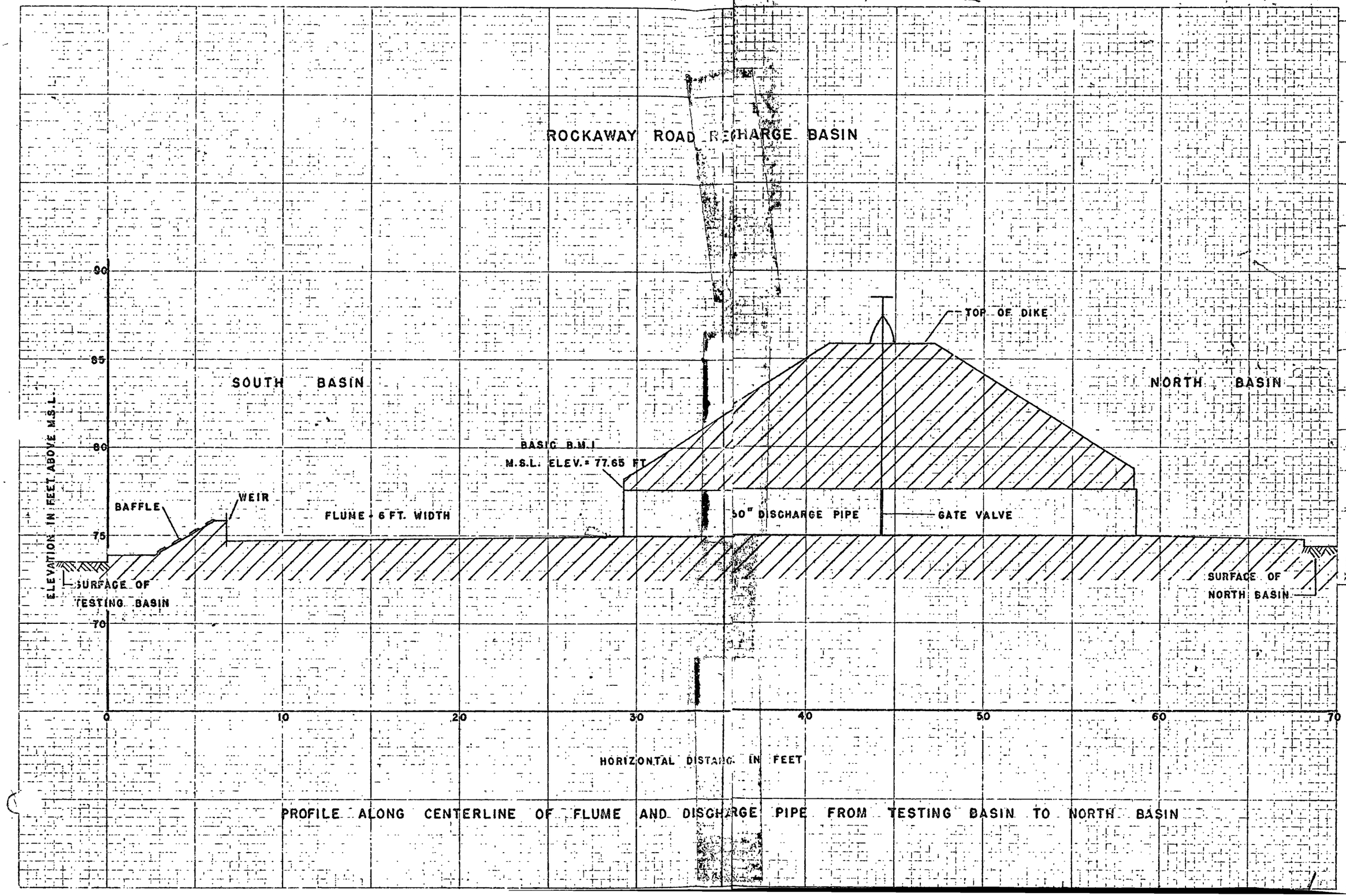
Careful consideration was given to the design and layout of the project in order to make the best use of the original features, and in final form the experimental apparatus consisted of a measuring flume 6 ft. wide and 22 ft. long with a sharp-edged steel weir plate at the

discharge end, a testing basin 40 ft. x 50 ft., constructed of tongue-and-grooved timber, a water-stage recorder with concrete stilling well and timber shelter for recording head on the weir, and a similar recorder installation for recording depth of water in the testing basin. The stilling wells consisted of 30-inch concrete pipe sections set vertically on concrete foundations. Timber recorder-shelters were bolted to these concrete stilling wells.

All structures of the project which were to be located on the floor of the south, or seepage, basin were designed for complete submergence. Records of water level previously collected by the County of Nassau showed that this basin would be flooded to a considerable depth during periods of unusually high runoff. Plans were made for removal of the recorders from their shelters when not in use. All testing apparatus was located and constructed so that it would not interfere in any way with the regular operation of the south seepage basin. Plate 1 illustrates the relative size and location of the north (desilting) and south (seepage) basins, the flume, weir, testing basin, recorder wells, sluice gate, and spillway. Plate 2 shows a profile of the flume and discharge pipe between the north and south basins.

The rate of inflow to the testing basin was to be measured by means of the calibrated weir, and the rate of seepage from the testing basin would be measured on the basis of the observed changes in volume of water stored in that basin, and the rate of inflow to the basin, during any selected interval of time. During periods when seepage from this basin exceeded inflow, the volume of water in storage would decrease, and vice versa. (see example in Table 1). By means of the 10:12

PLATE 2



PROFILE ALONG CENTERLINE OF FLUME AND DISCHARGE PIPE FROM TESTING BASIN TO NORTH BASIN

Year,
Meas. Nos.,
Max. G. H.,
Min. G. H.,
Plotted by
Checked by

Curve approved by:

Office Engineer.

District Engineer.

Date

gage-height scale of the testing-basin water-stage recorder it was possible to determine relatively small changes in volume in storage.

Other instruments and apparatus installed in the immediate vicinity and used in connection with the seepage tests included the following: A floating evaporation pan in the desilting basin, an anemometer on the raft surrounding this pan, a land-type evaporation pan on the floor of the large seepage basin, maximum and minimum air-temperature thermometers, recording and nonrecording precipitation gages, a water-temperature thermometer, and two water-stage recorders, one on the desilting basin and the other on the main seepage basin. The observations of water loss from the so-called evaporation pans were intended to serve the twofold purpose of collecting the first data of this type in the area and of providing a record of the approximate amount of water lost from the testing basin during periods of operation. Daily observations were made at both pans during the months when the water in the pans was not frozen. The data thus collected provide a good record of the water loss from such pans at this location and under the conditions existing here. Observations of water-table fluctuations under and around the test basin, caused by the testing operations, were considered desirable, and several observation wells were installed. The relative location of these and the other instruments and apparatus also is shown in Plate 1.

Following construction of the flume, weir, testing basin, water-stage recorder wells and shelters, evaporation pans, and thermometer shelter, and the installation of the required instruments, the weir was calibrated and all equipment tested to insure satisfactory operation. Certain assumptions relating to actual operation that had been incorporated

into the original plans were verified by actual test runs.

Before establishing a schedule of the experiments to be conducted, a careful study was made of the so-called infiltration phenomena to be expected under conditions such as those to be found in the average Nassau County seepage basin. In hydrologic literature infiltration is the term commonly used to describe the movement of water through the surface zone of a natural soil profile. However, because the natural soil profile in this area of Long Island is normally only a few inches in depth this material was removed during construction of the large desilting and storage basins, and the term infiltration is used herein to describe the movement of water through an artificially-created surface zone, or layer, composed of various organic and inorganic sediments deposited by storm water. It was anticipated, therefore, that the most critical conditions governing infiltration here would be those that exist in this surface zone, and that the size and arrangement of the particles of sediment and the changes which these particles undergo when wetted, dried, frozen and thawed would determine, to a great extent, the rate of movement of water through this critical zone.

Some other factors affecting infiltration relate to subsurface conditions and include soil moisture, the amount, distribution and types of colloids present, depth to the water table, the location of less permeable zones, surface tension and film forces, chemical composition of the water, and temperature of both the soil and the water. It was expected that the probable influence on infiltration of some of these factors could not be determined by the experiments to be conducted here, but other conditions such as freezing and thawing of the surface

zone were expected to show a pronounced influence and plans were made to study this influence during the course of the project.

The depth, or distance, from the basin surface to the water table was expected to remain sufficient in magnitude during the testing operations to insure that seepage rates were not being influenced by the water-table position. Only on rare occasions when the south basin might be flooded to a depth of 10 feet or more was it expected that seepage from that basin would exceed the lateral seepage capacity of the surrounding materials. Only by submerging a considerable portion of the sodded and highly permeable basin walls would this be possible, but under such conditions it was expected that the water table might rise to a level equal to or higher than that of the south basin bottom. This would be a temporary condition, would occur infrequently, and would not be representative of the conditions that had been observed during the major portion of the period of operation of the Rockaway Road basin installation. The entire testing program was planned for those flooding conditions known to occur most frequently rather than unusual conditions.

Of primary interest, however, was the question of similarity of the materials underlying the area in which new seepage basins might be built to those underlying the Rockaway Road basin. As stated above, it was anticipated that the surface zone would control seepage rates because the accumulation of fine silt, etc., had reduced the permeability of that zone below that of the underlying material, but it was recognized that this condition could be modified readily by removing either the entire surface zone or the fine material therein. By thus increasing the permeability of the surface, the control zone might become any

zone of lower permeability at a lower elevation and above the water table. In other words, the critical zone is believed to be the zone of lowest permeability between the surface and the water table, and only if general similarity of the underlying materials throughout the area does exist would it be possible to use at other sites within that area the results of the tests to be conducted at the Rockaway Road basin.

Most of the existing basins were excavated to depths of 10 to 15 feet and the materials exposed in these excavations were found by inspection to be more or less similar. To extend this inspection to greater depths, and include the material underlying the existing basins, a testing program was carried on by Bernard L. Rolfe, Soil Scientist, U. S. Geological Survey. By means of small excavations in seepage basins situated southeast and north of the Rockaway Road basin, Mr. Rolfe collected samples of the underlying material at various levels and reported, in part, as follows: "The stratigraphy of the basins is quite similar. They are located in sandy, gravelly outwash plain, product of Wisconsin glacial action. The material is coarse textured and extremely permeable. The direction of deposition was from north to south and occasional lenses of clay will be distributed along this axis, which lenses cause slow, restricted percolation, and may result in ponding." Descriptions of profiles for the basins at Rockaway Road, Herrick Road, and Stewart Avenue, as written by Mr. Rolfe, are as follows:

<u>Basin</u>

Site - Rockaway Road Recharge Basin (M-1).

Location - N. W. corner of main seepage basin.

Profile Description

(1) 0"-4" Dark gray, fine gravel to coarse sand containing rounded quartz gravels and scattered mica fragments. Gravel forms a surface cap and is underlain immediately by coarse sand. Structureless - single grain aggregation.

(2) 4"-13" Yellow-brown coarse to medium sand, subangular, clean quartz. Structureless. More moist than material above. (Presence of more fines than above).

(3) 13"-25" Coarser subangular quartz fragments, Muscovite (white) mica abundant. Structureless. Whitish-yellow color. Drier than preceding.

(4) 25"-30" Brown, coarse, more moist than material above, subangular, fine gravel fragments. Iron stains on quartz and other indications of slight presence of iron oxides.

(5) 39"-48" Dark, rich brown, moist, subangular coarse sand and fine gravel. Iron-stained and moist. Structureless. Presence of a few larger particles.

Note.- The dark, organic layer of fine sludge on the surface is the deposit of storm waters. These fines present a tightly-curled appearance when dry. Average soil T. = 76°F.

Basin

Site - Rockaway Road Recharge Basin (M-2).

Location - S. E. corner of seepage basin slightly higher elevation than M-1.

Profile Description

(1) 0"-4" Gravel cap evident (seems common to entire basin). Coarse sand darkened by organic material interspersed with pebbles. Structureless, brown color.

(2) 4"-13" Rich reddish-brown coarse sand. Pebbles are rounded, coarse sand fragments are angular. Structureless (but resistant to shovel).

(3) 13"-25" Same as above.

(4) 25"-39" Similar to above. Greater % fines, more moist than material above.

(5) 39"-48" More moist than material above. Color (purple) dominated by Mn-bearing pebbles.

Few gravels as large as 3" diameter. Larger ones rounded, smaller angular (a characteristic of glacially moved quartz particles.)

Structureless. Rather moist.

Note.- Profile is characterized by resistance to shovel, in contrast to M-1. Many pebbles (rounded) of size 2½"-3" diameter. Slight increase in fines appears sufficient to cause higher moister content along with cementing influence. Slight pressure with fingers is sufficient to rupture aggregation.

Basin

Site - Rockaway Road Recharge Basin (M-3)

Location - N. W. corner of seepage basin.

Description

No pit dug for samples. Digging was easy - bulk of material is coarse sand with few large pebbles. Most lie within 1"-2" diameter range. Directly beneath surface 4" of organically darkened material lies 4" of grayish white coarse sand. This is in turn underlain by a layer of pebbles of schistose rock.

Basin

Site - Rockaway Road Recharge Basin (M-4).

Location - Directly beside test plot.

Description

Generally similar to M-1. Dark organic layer on surface is underlain by thin white coarse sandy layer; followed by a foot of decomposed granitic sand and gravel, most of which is leached; no ferruginous material.

Basin

Site - Herrick Road Basin (M-6).

Location - Near center of upper and lower levels of basin.

Profile Description

Upper Seep Area (1) Gravel cap (darkened by organic silting). This layer is 4" deep - sharply underlain by band of deep red, iron-stained sand and gravel-sized quartz fragments. Coarser fragments are sub-rounded while sand size is angular. From 6" down, similar to above. Yellow-brown coarse sand-size quartz interspersed with gravel of varying size up to 3" diameter.

Lower Seep Area (2) Similar to above. Gravel interspersed with sand size through profile. Moist at 2 ft. The finer sand extends to depth of 1 foot, contains numerous mica particles. The coarser sand is at 2 feet, moist, contains dark and light quartz particles.

Basin

Site - Stewart Avenue Basin.

Location - No pit dug.

Description

Undisturbed cover of silting has resulted in dark layer of fine material. Subsurface is similar to other basins; a coarse porous profile.

His summary states "The descriptions are those of a glacial outwash plain, little modified by cultural practices. Any variation will be caused by randomness in deposition. Generally, the basin profiles show similarity as to coarseness of texture, absence of fines, and extreme porosity".

Although the natural soil mantle covering the outwash plain is usually not more than a few inches in depth, it must be remembered that the seepage basins under study are merely large excavations with depths of 10 to 15 feet and hence do not have natural soil-surface horizons. Every profile described by Mr. Rolfe is characterized by coarse sand, rounded pebbles, and gravel of varying size up to 3 inches in diameter.

The absence of clay and colloid is noticeable and little or no swelling is expected.

Test holes were not dug inside the testing basin because the underlying materials had been examined while excavating the trench for the timber wall of the basin. This trench was 3 feet deep and surrounded completely the area to be tested. This examination showed that these materials, and their arrangement, were similar in all respects to those at surrounding basins. There were two reasons for not disturbing the surface of the testing basin. First, it was desired to eliminate from the study the unknown, and perhaps variable, effect of scarifying, and second, if the capacity of the testing basin without scarifying was found to be equal to that of the large seepage basin with scarifying, some economy could be effected by eliminating this practice as a feature of basin maintenance.

Thus, on the basis of Mr. Rolfe's observations it can be stated that the materials underlying the area in which basins are now being operated are similar in all pertinent aspects, and it may reasonably be assumed that the seepage characteristics observed at the Rockaway Road basin will not differ greatly from those of other basins in the area insofar as the subsurface materials are concerned.

Because of the greater percentage of fine silt and organic material in the surface zone of all basins examined than in the underlying material, it was assumed that the permeability of the underlying material is greater than that of the surface material. Also, as mentioned on p. 8, because of the usual 8 to 10 feet distance between the surface zone of the testing basin and the water table, and because of

the lower permeability of the surface zone than that of the subsurface zone, it was assumed that the water table under the testing basin would not rise sufficiently during testing operations to interfere with or influence the seepage from the testing basin.

Further, it was recognized that the testing apparatus had certain physical limitations with respect to size and that extreme conditions such as those resulting from large, infrequent storms, could not be tested. These limitations were not believed to be serious, however, because of the relatively few flooding events that would fall outside the range of testing that would be possible and because that range was believed to cover the majority of storm events occurring in any one year. Design criteria for seepage basins are subject to certain flexibilities dictated by local conditions and it was expected that the results of testing in the experimental basin would provide a more adequate basis for adjusting design to site conditions.

With further regard to the infiltration phenomena, consideration was given to the probable accumulation of silt on the surface of the testing basin as compared with the probable accumulation on the large seepage basin. Water for the testing basin was to be drawn from the bottom of the desilting basin and was expected to have a higher sediment concentration than that of the water that flows from the top of the desilting basin into the large seepage basin during storms. However, the sediment load of this overflow was expected to vary as a result of differences in the detention period, and at times the load might be equal to the usual concentration of the water drawn from the bottom for testing in the small basin. Thus the rates of accumulation

of sediment in the two basins on an annual or long-term basis might be nearly equal and it was concluded that any small differences that did exist would be impracticable to measure.

Another factor that required study in relation to the expected infiltration characteristics of the test basin was the development of what is sometimes called a saturated front in the profile between the surface of the testing basin and the water table. It was desired to learn whether or not the sub-surface material became saturated during periods of flooding of the testing basin and to establish a relationship between the depth of water in the basin and the depth of the saturation zone, if such a zone was developed. The necessary testing for this study was done by placing tensiometer cups at depths of 6, 12, 24 and 48 inches below the surface at points about 10 ft. apart across the test basin from north to south. Each was calibrated to zero, in saturated material taken from the profile, and carefully sealed with a watertight collar just under the ground surface to prevent water from running down the tube. The testing basin then was flooded to a depth of about 0.5 ft., tensiometer readings were made at brief intervals until all readings had reached equilibrium. A relatively uniform depth of water was maintained over the basin surface during the period required for this test, and the rise in the water table under the basin during the test was observed to be rather small. Readings of the tensiometers were continued until it became evident that the readings were not going to change. The flow into the testing basin then was shut off, the basin was dewatered, and the tensiometer readings were allowed to rise to their highest point, indicating that all of the water that could pass downward through

the sand and gravel under the force of gravity had passed the depth of the lowest tensiometer cup. The test was repeated several times using successively greater depths of water in the testing basin. The tensiometers were left in place following these tests and additional readings were made during other types of tests such as those illustrated on Figures 15, 16, and 17. The tests illustrated by those figures were started November 5, 1951 and the testing basin was flooded continuously for several weeks thereafter, and the depth in the basin was varied from 2.8 ft. (water level at top of testing basin wall) to less than 0.5 ft. Tensiometer readings made on November 15, 1951 did not show saturation at either the 6 inch, 12 inch, 24 inch, or 48 inch depths (48 inch was maximum depth tested) although the basin had been flooded continuously since November 5, and to depths as great as 2.8 ft. November 9. The temperature of the water in the large (south) seepage basin was 54°F and in the testing basin, 53°F, at the time of the tensiometer readings November 15. During the tensiometer tests previous to those of November 15 saturation was not shown at any of the depths tested (6, 12, 24, and 48 inch), but some of the readings for the 6-inch depth indicated a greater moisture content at that level than at the lower levels. This may have resulted from a slight leakage around the seal but it is very doubtful that complete saturation was developed at that level over the entire area of testing basin, and it is certain that complete saturation did not develop at any of the lower depths. These results are believed to have verified the assumption made earlier, that the rate at which water will move downward to the water table through the material beneath the surface zone and then laterally through the surrounding material, is

greater than the rate at which water will pass through the surface zone of either the testing or the south seepage basin, and, that the development of a saturated front appreciably greater than that of the surface zone is not possible. An attempt to saturate the highly permeable subsurface material with water passing through the material of low permeability at the surface would be similar to an attempt to fill a coarse sieve with water passing through a fine sieve.

The water temperatures observed November 15 indicate that the low air temperature of the preceding night had a greater effect on the smaller volume of water in the testing basin than on the larger volume in the south seepage basin, resulting in a differential of 1°F. During other simultaneous tests of the two basins the average water temperature in each basin was the same, or so nearly the same as to rule out the possibility of explaining the difference in seepage rates as the result of different water temperatures in the basins.

In addition to these preliminary studies of the factors that were expected to influence infiltration in the testing basin as well as in existing and possible future seepage basins in this area, considerable study was given during the planning of the project to the types of tests that would be most suitable.

As a result of these studies plans were made to conduct all tests for a period of several growing seasons without removing the silt or weeds and without scarifying the surface of the testing basin. The south, or seepage basin, was kept clear of weeds and was scarified occasionally by Nassau County maintenance crews.

Repeated-flooding tests and tests of continuous flooding at

constant head and continuous flooding at variable head were planned for all seasons of the year. Simultaneous tests of the south seepage basin and the testing basin were planned for periods when conditions were suitable. Such conditions would exist after both basins had been flooded during a large storm and when the water level had receded to the top of the testing-basin wall and when there was no more inflow from the north basin. Below that point the two basins are separate units and their respective water-surface elevations would be recorded by the water-stage recorders installed on each. Water temperatures in the two basins would be equal or nearly equal, and both would have been flooded for about the same period of time prior to the tests, thereby eliminating these two factors from consideration in studying the results of the tests. (The possibility of making these simultaneous tests of the two basins by attempting to measure the inflow into the south seepage basin during periods of overflow of the north, or desilting basin, was given careful consideration and abandoned because of the impracticability of constructing and rating a weir on the spillway between the north and south basins by means of current-meter discharge measurements. The use of a theoretical rating for such a weir would have introduced an error of unknown magnitude into the comparative data, making the results unreliable and possibly misleading). The repeated-flooding tests were expected to show the effects on infiltration of alternate wetting and drying of the surface, and during the winter to show the effects on infiltration of freezing and thawing of the surface zone. The continuous-flooding tests were expected to develop relationships between seepage capacity and period of flooding for various periods throughout the year. The effect on

infiltration of the root channels of the plants that were allowed to grow could best be determined by means of two identical testing basins operated concurrently, one with growing plants and one without. Such a plan was not feasible here and a decision was reached whereby the plants would be allowed to grow for several seasons, during which various types of tests would be conducted and after which the plants would be removed and a similar testing program repeated. The results of the two series of tests would be expected to show the approximate effect on infiltration of the plant roots at different times of the year. An exact determination of this effect of the roots would not be possible because of other factors that could not be held constant.

It was expected that tests other than those planned might be made during the course of the project as experience was gained and as the need for such tests became evident.

After calibration of the weir was completed and the instrumentation of the project had been tested under operating conditions, actual testing was begun in February 1949. In the following pages the results of most of the testing that was done between that date and October 1953 will be illustrated graphically and described. These results cover the types of tests mentioned above.

Four consecutive floodings of the testing basin were made Feb. 11, 1949. The first recession was not completed when the second flooding was made, hence the first test has not been included in Figure 1. Tests 2, 3, and 4 are shown in Figure 1 with seepage rate in gallons per square foot per day plotted against depth of water in basin in feet. The same units were used in later tests of similar nature. The surface

of the testing basin had been frozen and thawed several times prior to these tests and the seepage capacity was very high. Some reduction in capacity resulted from the repeated floodings, as shown between tests 3 and 2, but the higher head used for test 4 appears to have increased the seepage rate somewhat more than the reducing effect of the repeated floodings. The difference in rates between tests 3 and 4 is negligible.

Another type of test is illustrated in Figure 2. This test was started August 15, 1949, at 11 a.m., with a rate of inflow to the testing basin of 129 gallons per square foot per day. This inflow rate represented the seepage capacity for a depth of 0.08 foot of water in the basin and that depth was maintained until August 16, 9:45 a.m. At that time the inflow rate was increased to 234 gallons per square foot per day and the depth increased gradually to 1.20 feet August 17, 3 a.m. Inflow was next increased to 279 gallons per square foot per day and the depth increased gradually to 1.54 feet August 17, 9:30 p.m. Inflow was then decreased gradually to 144 gallons per square foot per day and the depth fluctuated slightly but did not change appreciably. During the period August 19, 1 p.m., to August 22, 8:45 a.m., the depth increased slowly and reached equilibrium at 2.15 feet when the inflow rate was about 149 gallons per square foot per day. Between 8:45 a.m. and 1 p.m. August 22, the inflow decreased to 127 gallons per square foot per day and the depth decreased to 2.11 feet. The test was ended there. One of the most significant things demonstrated by this test is the final seepage capacity of the testing basin of more than 127 gallons per square foot per day for a depth of just over 2 feet, after continuous flooding for 170 hours at variable rates and heads.

Two consecutive floodings were made October 11, 1949, results of which are shown in Figures 3 and 4. Figure 3 shows a rather complete picture of the relationship between the two tests. These graphs were drawn on the basis of depth and seepage rate data taken directly from the field data for half-hour intervals. Seepage rates are compared at identical depths and it is noted that for depths down to 0.6 foot the capacity of the basin during test 10 was about 32 per cent of the capacity during test 9. At the smaller depths the relative capacities approach each other. Test 10 was started immediately after test 9 was completed, and although the initial depth for test 10 was less than that for test 9, $3\frac{1}{2}$ hours more time was needed to dewater the basin for test 10 than for test 9. Figure 4 shows the average seepage rates for the two tests in relation to the midpoint of each test. The average rate for the second test is equal to 51 per cent of the average rate for the first.

Figure 5 illustrates the results of a continuous inflow test October 26-28, 1949, during which the rate of inflow to the testing basin decreased very slowly from 168 to 124 gallons per square foot per day. At the beginning of the test run, a large proportion of the inflow went into storage, but, as the depth increased, the seepage rate increased also, and the storage rate declined. The effect of continued submergence became apparent early on October 27 when the seepage rate began to decline without a consequent decline in depth. The depth increased slowly until the inflow was shut off October 27, 1:45 p.m., at which time the seepage rate was 122 gallons per square foot per day and the depth was 2.15 feet.

Figure 6 shows the results of a pair of tests (12 and 13) with

an elapsed time interval of 145 hours between the first and second. It is noted from the table on Figure 6 that although the second test had an initial depth 0.34 foot greater than the first, the time consumed in emptying the basin for the second test was $3\frac{1}{2}$ hours less than that for the first. It is observed, also, that the seepage rate for the second test is about 134 per cent of that for the first test for any depth.

Figure 7 shows the results of test 14, a single flooding December 15, 1949, soon after the basin surface had been frozen and thawed. The initial seepage rate was more than 400 gallons per square foot per day, and at the end of the dewatering period, as the basin was emptied, the rate was about half the initial rate. The initial depth was 1.39 feet and the time consumed in dewatering the basin was about 0.7 hour, as compared with 1.86 feet and 13 hours, the initial depth and time for dewatering for test 12 made Nov. 2, 1949, prior to the freezing and thawing.

Figure 8 was prepared from the results of test 15, January 5-7, 1950 during which inflow to and seepage from the testing basin were equalized at a depth of about 2 feet in the basin. This condition of equillibrium was maintained until the water table at the observation well at the center of the testing basin was observed to be approaching a constant level, about 2.8 feet higher than at the beginning of the seepage test. The observed rise in the observation well 150 feet south of the testing basin was about 0.4 foot.

Figure 9 shows the relationship between seepage rate and depth of water in the testing basin during the dewatering period of test 15. The basin had been flooded $6\frac{1}{2}$ hours to a depth of about 2 feet but was

dewatered in 1¼ hours after inflow was stopped.

Table 1 is a tabulation of the pertinent data observed during test 15, with an accounting for the total inflow and the total seepage.

The rate of inflow was determined by means of the weir (calibrated by current-meter measurements), and the total inflow during each interval was computed on the basis of this rate of inflow per minute and the length of the interval in minutes. The total possible rise of the water level in this basin during each interval also was computed from the total inflow figures. The summation of this column shows the height in feet of the column of water, 40 ft. x 50 ft. in plan, that passed through the bottom of the testing basin as seepage between 10:10 a.m. and 5:40 p.m. January 5, 1950. The amount of rise or fall of the water level in the basin during each interval was determined from the graph produced by the water-stage recorder connected to this basin, and the changes in storage during each interval were computed on the basis of this record and the known area of the basin. Total seepage from the basin for each interval was computed on the basis of the total inflow and the storage changes. Each of these components was computed independently, hence the difference of 1.1% between the computed values of total net inflow and total seepage indicates a relatively high order of accuracy of the observed data.

Observations of water loss from the floating evaporation pan indicated a total loss of about 20 gallons of water from the testing basin by evaporation during the testing period. This amount was subtracted from the total inflow before comparison of the inflow and seepage figures.

Test 15, Jan. 5, 1950

Time intervals 10:10 a.m. to 5:40 p.m.	Number of minutes in interval	Measured inflow to testing basin: Rate, gals.per minute	Measured inflow to testing basin: Total gals.	Total possible rise of water level in basin w/o seepage, feet	Measured rise or fall in water level in basin during interval, feet	Gain or loss in storage in basin during intervals, gals.	Total seepage from basin during interval, gals.	Average seepage rate during interval, gals.per sq.ft. per day
10:10-10:32	22	1,343	29,546	1.975	+1.760	+26,331	3,215	105
10:32-11:32	60	480	28,800	1.925	- .237	- 3,546	32,346	388
11:32-12:15	43	674	28,982	1.937	+ .504	+ 7,540	21,442	359
12:15- 1:00	45	525	23,625	1.579	+ .035	+ 524	23,101	370
1:00- 1:17	17	466	7,922	.530	- .035	- 524	8,446	358
1:17- 3:52	155	471	73,005	4.880	(- .010 (+ .010	0	73,005	339
3:52- 4:26	34	430	14,620	.977	- .063	- 943	15,563	330
Inflow shut off at 4:26								
4:26- 5:40	74	-	-	-	-1.809	-27,064	27,064	263
Totals	450	-	206,500	13.803	-	+ 2,318	204,182	-

	Gallons
Total gross inflow	206,500
Evaporation loss	20
Total net inflow	206,480
Total seepage	204,182
Difference	2,298 = 1.1%

Figure 10 shows the results of another continuous-flooding test. Inflow was started at 9:15 a.m. April 4, 1950, at a rate sufficient to cause the depth to increase in the testing basin. About 11:15 a.m. the inflow rate was decreased to 171 gallons per square foot per day and the depth became stable at about 0.82 foot. At 12:08 p.m., inflow was increased and the depth again was allowed to increase. About 2:10 p.m., the inflow was decreased to 164 gallons per square foot per day and the depth became stable at about 1.12 feet. Inflow was increased again and the depth allowed to increase until 7:15 p.m., when inflow was reduced to 138 gallons per square foot per day and the depth became stable at 1.57 feet.

Figure 11 has been prepared to show the results of another continuous-flooding test, starting first with a high inflow rate and maximum depth. Inflow was started at 9:45 a.m. April 7, 1950, and at 5 p.m. the inflow and seepage rates had reached a state of equilibrium at depth 1.84 feet. Inflow was reduced further and equilibrium was reached again at depth 0.81 foot at 7:30 a.m. April 8, 22 hours after flooding began. Inflow was increased at this point but the effect of the continued flooding resulted in equilibrium between depth, inflow and seepage being reached at a smaller seepage rate than formerly obtained for the new depth. Thus at the point marked 36 hours on Figure 11 it is observed that the seepage rate is less than 150 gallons per square foot per day at a depth of 1.05 feet, while prior to the 22-hour point the seepage rate for 1.05 feet depth was about 170 gallons per square foot per day. The next phase of this test was the reduction of inflow to 88 gallons per square foot per day. This inflow rate reached

equilibrium with seepage at depth 0.51 foot at about 12 m. April 9, 51 hours after flooding began. The next lower point of equilibrium was reached at 5 a.m. April 10, with inflow equal to seepage at about 50 gallons per square foot per day at depth 0.39 foot. A further reduction in inflow resulted in an extreme low point on the graph. After 97 hours of continuous flooding, inflow and seepage rates were equalized at about 21 gallons per square foot per day at depth 0.08 foot. Thereafter the inflow rate was increased and the depth increased, but not in the same relationship as existed earlier in the test. With inflow rate at about 48 gallons per square foot per day, the depth finally became stable at 0.70 foot as compared with 50 gallons per square foot per day at depth 0.39 feet after 67 hours of flooding. The last phase of this five-day test was the reduction of inflow to about 32 gallons per square foot per day. Equilibrium at this rate was reached about 12:30 p.m. April 21 at depth 0.43 foot, 123 hours after flooding began April 7. This is more than twice the depth at which equilibrium would have been reached for the inflow rate prior to the 97-hour point in the test.

It was stated earlier in this report that plans were made for conducting simultaneous tests on the main seepage basin and on the testing basin when the main basin was flooded to a depth at or below the top of the testing basin wall. The first such test was made May 29, 1951, and is illustrated in Figure 12. About 8:15 a.m. the testing basin was flooded to a depth somewhat greater than that in the main basin and inflow was shut off. The water level in the testing basin fell rapidly, and at about 11:45 a.m. the basin was refilled. This

time the rate of recession of water level in the testing basin was slightly less than that during the first recession but appreciably greater than the recession in progress on the main basin. The test was stopped shortly after 7 p.m., at which time the water level in the testing basin was lower than that in the main seepage basin.

Figures 13 and 14 are presented to show several relationships that were illustrated by the results of three floodings July 3, 1951. The first, Figure 13, is similar in character to several others preceding it and shows the effective reduction in basin capacity with successive floodings. The largest reduction between the first and second tests was in the medium depths where the seepage rate for the second test was only about 25 per cent of that for the first test at any depth. In the second and third tests, it was observed that as the depth decreases the ratio of seepage rates approached unity and at the larger depths the rate for the third test was about 33 per cent of that for the first. A similar relationship was observed between tests 9 and 10, as shown in Figure 3, in which instance the greatest reduction in seepage capacity was effected also at the larger depths, and at the smaller depths the ratios approached unity.

Figure 14 is based on the same three floodings of July 3, 1951, (tests 22, 23 and 24) and shows graphically the relationship of the depth and time elements of the three, as well as the approximate rise in the water table during each test. It was stated earlier in this report that repeated floodings resulted in a reduction in seepage rates and this in turn resulted in smaller increases in water-table elevations. This point is illustrated by the graphs of observation-well

readings related to each testing-basin-flooding in Figure 14.

Additional opportunities for simultaneous testing of the main basin and the testing basin were presented beginning November 5, 1951. Figures 15, 16, 17 and 18 have been prepared from data collected November 5 to December 4, 1951, in a series of simultaneous tests on the two basins. The first test was begun November 5 by flooding the testing basin to the same level as that of the water in the main basin and then shutting off the inflow, as shown in Figure 15. The water level in the testing basin receded more rapidly than that in the main basin, and on November 7 both basins were flooded by runoff from another storm. As soon as the water level had receded to the top of the testing basin wall, the records of water level on both basins were collected independently and it was observed again that the testing basin water level receded more rapidly than that of the south seepage basin. This part of the test is illustrated in Figure 16. More storm-water runoff flowed into the south basin November 17 and 18, and the water level in the two basins was made to coincide again in the afternoon of November 18. The recession of the water level in the testing basin was again observed to be much more rapid than that of the main basin. This test is shown in Figure 17. Just prior to November 29, while the testing basin was empty, the air temperature fell sharply and the basin surface froze. The capacity of the testing basin was increased materially, and during the six floodings made November 29 to December 3 more than 6 feet of water was disposed of in the testing basin while about 0.4 foot of seepage was taking place in the main basin. The effect of this freezing is shown in Figure 18. Additional water could have been disposed of through

the testing basin, but the results of the six floodings were considered sufficient to illustrate the beneficial effect of freezing and thawing.

Figure 19 shows the results of a series of repeated floodings made February 23-25, 1952. The first pair shows a reduction in seepage rate of about 60 per cent at all depths but the second pair shows a smaller reduction at the larger depths than at the smaller depths. In comparing these results with those of the three tests of July 3, 1951, it is observed that the ratios of seepage rates for the first pair of tests in each series follow a similar pattern but the ratios of the rates for the second pair in the two series are directly opposite in pattern, those for the second series decreasing and those for the first series increasing with decreasing depth. It is observed also that the shape of the curves for tests 40 and 41 indicates a smaller rate of change in seepage rates at lower depths than for tests 38 and 39.

Figure 20 is another example of the effect of elapsed time and seepage rates. Test 54 was made September 6, 1952, and shows seepage rates equal to about one-half of the rates for test 55, made 544 hours later, on September 20. By contrast, test 56 was started 9 hours after test 55 was completed and the rates for test 56 vary from 25 per cent to 54 per cent of those for test 55 at depths between 0.8 foot and 0.3 foot. Test 57 was started 94 hours after completion of test 56 and during that interval of time the capacity of the testing basin increased almost 200 per cent at depth 0.8 foot but only about 8 per cent at depth 0.3 foot.

Figure 21 illustrates another series of flooding tests made during the period October 6-25, 1952. In contrast to the results of tests 54 and 55 in the series of September 6-26, 1952, the first two

tests of the October series (58 and 59) show a reduction in seepage capacity although a period of 214 hours elapsed between these tests. Test 59 shows a rate equal to about 48 per cent of that for test 58 at depth 0.9 foot and a reduction in ratio of seepage rates with decrease in depth. Further reduction in seepage capacity was observed between succeeding tests 60 and 61. Test 60 was made 61 hours after test 59, and test 61 was made 37 hours after test 60. An interval of 116 hours elapsed between tests 61 and 62, resulting in a small increase in capacity, but this increase was trivial as compared to the large increase observed between tests 56 and 57 in the September 1952 series. It should be emphasized, however, that the seepage rates observed during the October series were much larger than those of the September series.

Figure 22 has been prepared to show the results of the observations of water loss and precipitation at the Rockaway Road site. Both the water-loss and precipitation data have been used in the computation of results of the seepage experiments where such use was required. During a continuous-flooding test covering a period of several days, the water loss from the testing basin was taken into account in balancing inflow with seepage. For the single-flooding tests, the water loss was negligible.

The seasonal data for adjusted water loss from the floating pan and for precipitation are as follows:

Year	Adjusted Water Loss, Inches	Precipitation, Inches
1949 (April through November)	29.78	27.91
1950 (do. do. do.)	26.45	24.47

Year	Adjusted Water Loss, Inches	Precipitation, Inches
1951 (March through December)	27.94	42.55
1951 (April through November)	26.01	31.27
1949 (April through October)	28.08	26.40
1950 (do. do. do.)	24.53	20.59
1951 (do. do. do.)	24.73	23.93

A comparison of the data for the period April through October shows that the adjusted water loss during the growing season was slightly greater than the precipitation.

The water-loss data plotted in Figure 22 are observed floating-pan data unadjusted. The seasonal data for water loss tabulated above are the sums of the adjusted monthly totals for the periods listed. The observed monthly water-loss data consist of a summation of the observed water-loss for each day of the month. During periods of precipitation the observed catch at the standard rain gage nearby was used in the computation of net gain or loss from the floating pan. In most instances the precipitation exceeded the observed water loss between observations and the net loss from the pan was considered to be zero. The coefficient used in adjusting the observed monthly data to represent water losses from natural bodies of water was 0.80, as recommended by a Special Committee of the American Society of Civil Engineers.

Wind-movement and air-temperature data have been collected, as well as water temperatures for both floating and land pans and for the large storage basin. Temperature of the water used in the seepage tests was observed to vary from a low of $39\frac{1}{2}$°F in December to a high of 78°F in July. The effect of this difference in temperature on the

seepage rates cannot be evaluated because of other more significant factors. Examination of the test data shows that some of the highest seepage rates were observed when the water temperature was the lowest, and, conversely, some low rates were observed during months when water temperatures were high. This is but one example of the counterbalancing of the many factors that influence seepage rates and serves to illustrate the difficulty with which these factors are isolated and evaluated.

The tests made to date show minimum and maximum seepage rates of about 20 and 400 gallons per square foot per day, respectively, at a testing depth of 1 foot, emphasizing the large effect of factors other than depth on the seepage capacity of such basins. Seepage rates between these minimum and maximum values were observed under a wide variety of conditions, as illustrated by the following graphs, but because of the great variation in the conditions that prevailed during the many tests it is not possible to combine the observed results into one graph for comparative purposes. Neither is it possible, at this stage in the program, to draw conclusions regarding the relationships between the observed results and the prevailing conditions for all of the tests conducted to date.

It was recognized at the beginning of the project that experimental work of this type under field conditions is always handicapped by lack of control of the many factors and variables involved and that a considerable period of time would be needed to collect data that might be considered representative of any one period of the year. Certain important phases of the study, such as the determination of the

similarity of the materials underlying this and other seepage basins in this part of the county, the tests showing that the seepage capacity of the testing basin continues to be equal to or greater than that of the main seepage basin without having been scarified and after having been flooded much more frequently than the main basin since the beginning of the project, the tensiometer tests that show the absence of an appreciable depth of saturation of the sand and gravel profile during testing of the basin, and the tests that show that repeated floodings at short time intervals result in reduced seepage rates and smaller successive rises in water-table elevations, have been substantiated.

As the program is continued some of the tests described above should be repeated within the same period of the year and under climatic conditions similar to those existing when the first tests were made, to determine, if possible, the seasonal seepage characteristics of the basin with the basin surface unchanged except for the natural changes produced by the elements.

When these tests have been completed the weeds and roots should be removed and the testing basin scarified to a depth sufficient to break up the surface zone. Continuous and repeated-flooding tests then will be repeated and the results compared with those obtained with the basin floor undisturbed.

Following this series of tests the entire surface zone should be removed from the testing basin and the same type tests repeated until the number of floodings equals the number of floodings of the south basin, as indicated on the recorder charts for that basin, during a

period of several years. The testing-basin surface should not be disturbed during this series and any observed decrease in seepage capacity then may be attributed to the development of a new surface zone of silt, etc. Whenever possible, during the period covered by this series the south basin and the testing basin should be operated simultaneously for comparison of respective capacities.

Subsequent progress reports are to be prepared as the program is continued.

The cooperation of John C. Guibert, Commissioner of Public Works, and of W. Fred Welsch, Senior Engineer, in charge of Division of Sanitation and Water Supply, Department of Public Works, Nassau County, as well as that of other county employees who have aided materially in the collection of data for this project, is gratefully acknowledged.

U. S. Geological Survey engineers who have been responsible for the design and operation of the project, under the supervision of Arthur W. Harrington, District Engineer, Albany District, are H. D. Brice, C. L. Whitaker, and R. M. Sawyer, engineers in charge of the Jamaica and Mineola offices. Survey engineers who have assisted in the operation of the project are E. J. Pluhowski and G. S. Craig, Jr.

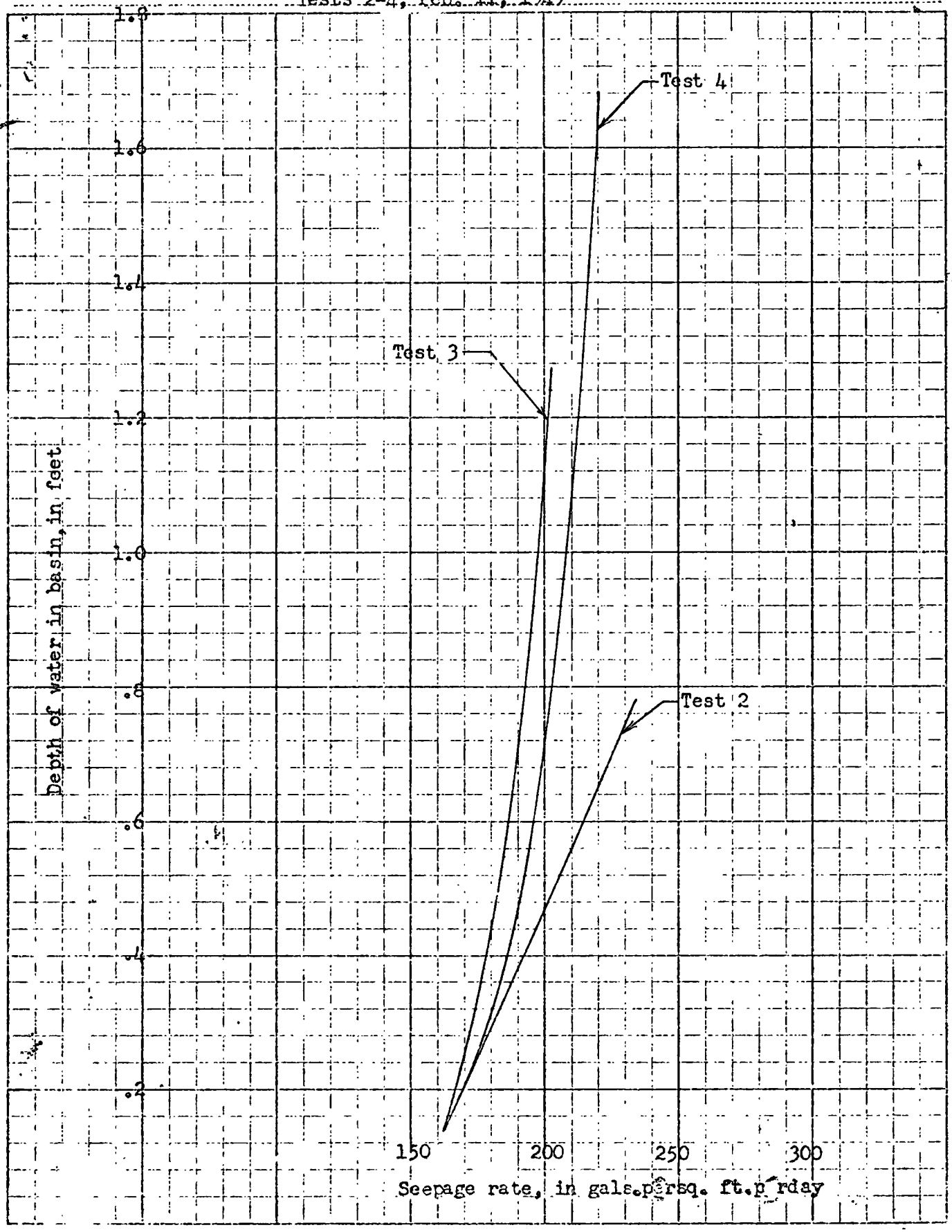
0-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 1

ROCKAWAY ROAD PROJECT

Tests 2-4, Feb. 11, 1949



Sheet No. ... of ... Sheets. Prepared by HDB ... Date ... Checked by ... Date ...

16—61235-1 U. S. GOVERNMENT PRINTING OFFICE

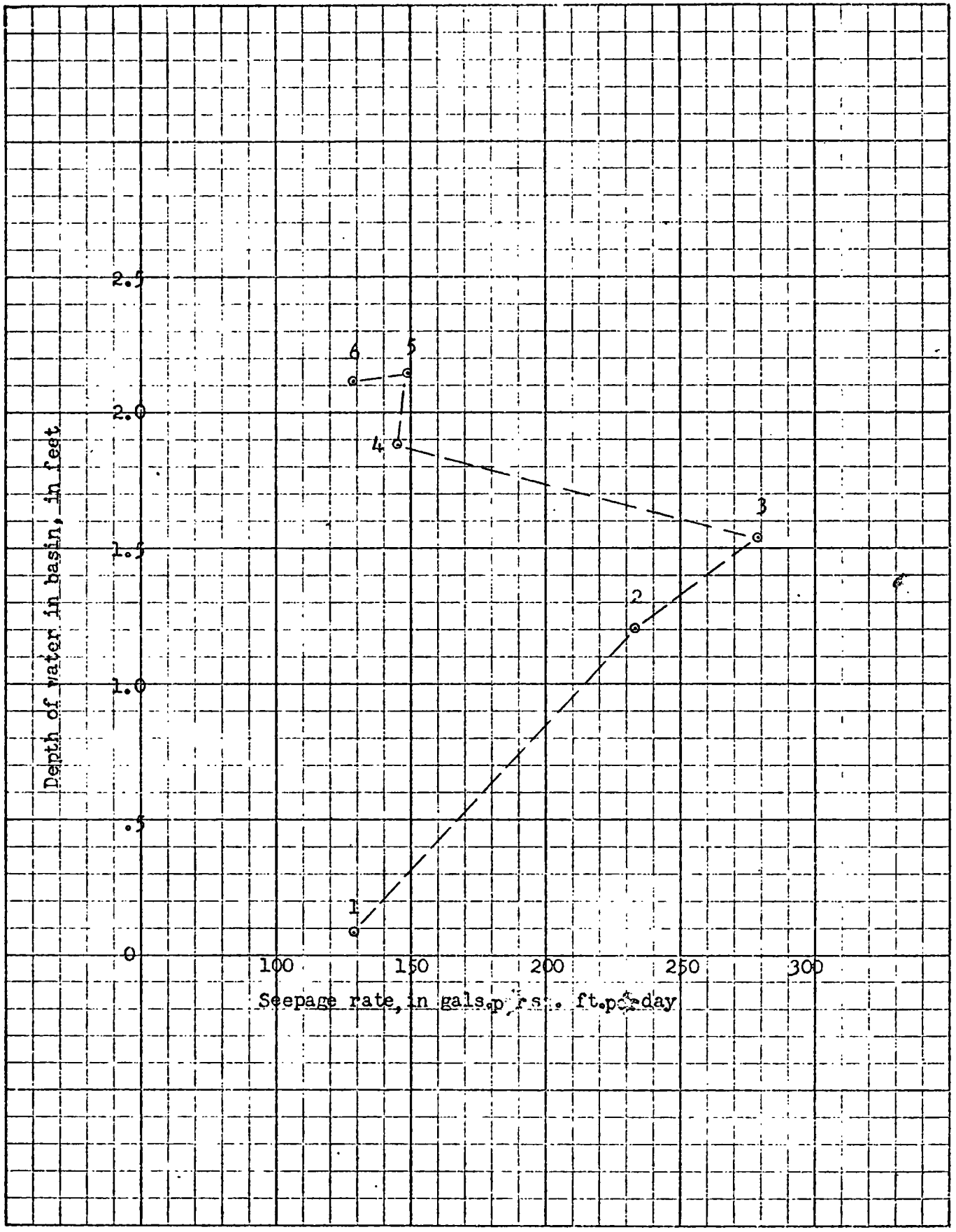
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 2

ROCKAWAY ROAD PROJECT

Continuous inflow test, Aug. 15-22, 1949



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

16—54235-1 U. S. GOVERNMENT PRINTING OFFICE

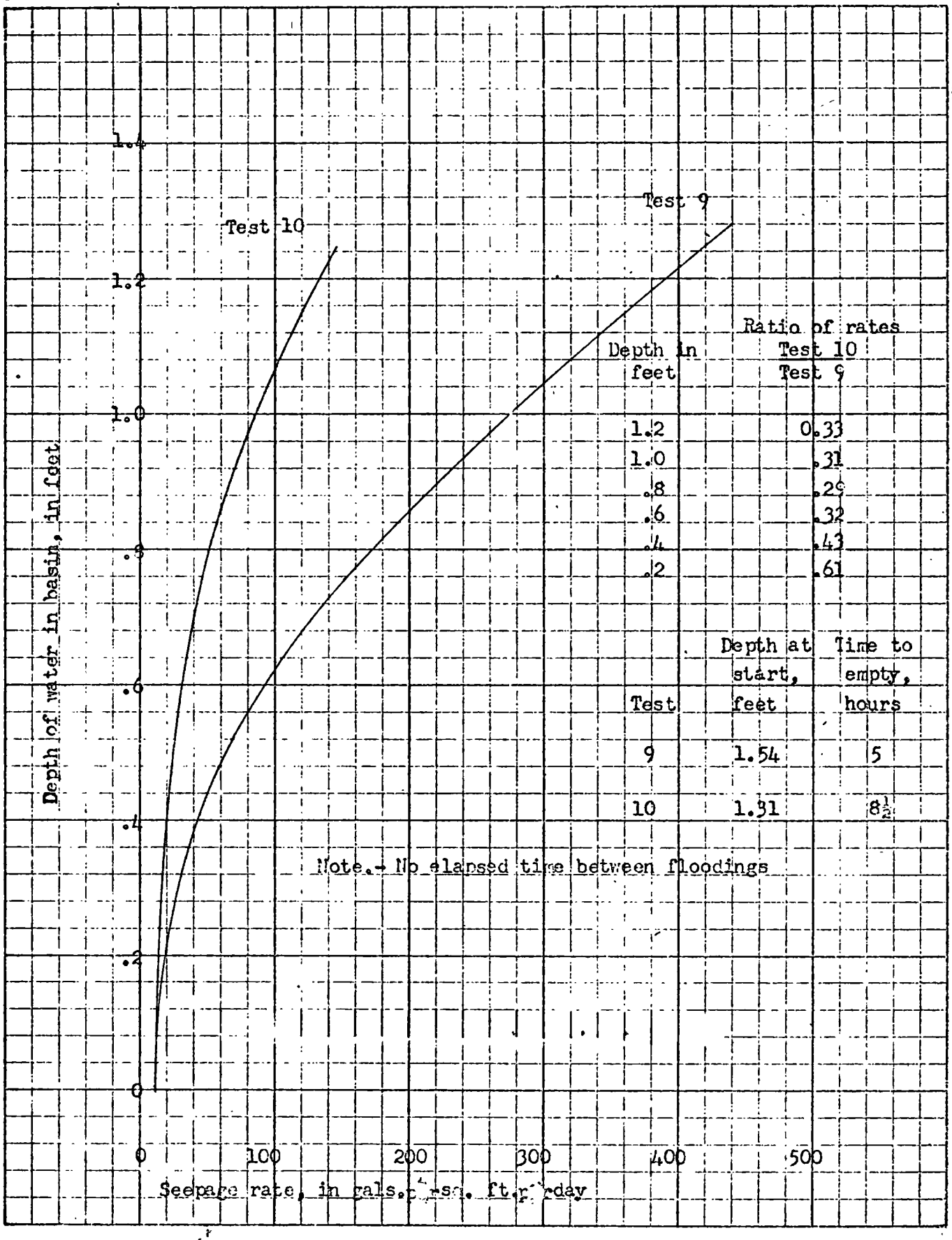
9-213-B
(March 1959)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 3

ROCKAWAY ROAD PROJECT

Tests 9, 10, Oct. 11, 1949



Depth in feet	Ratio of rates Test 10 / Test 9
1.2	0.33
1.0	.31
.8	.29
.6	.32
.4	.43
.2	.61

Test	Depth at start, feet	Time to empty, hours
9	1.54	5
10	1.31	8½

Note.- No elapsed time between floodings

Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

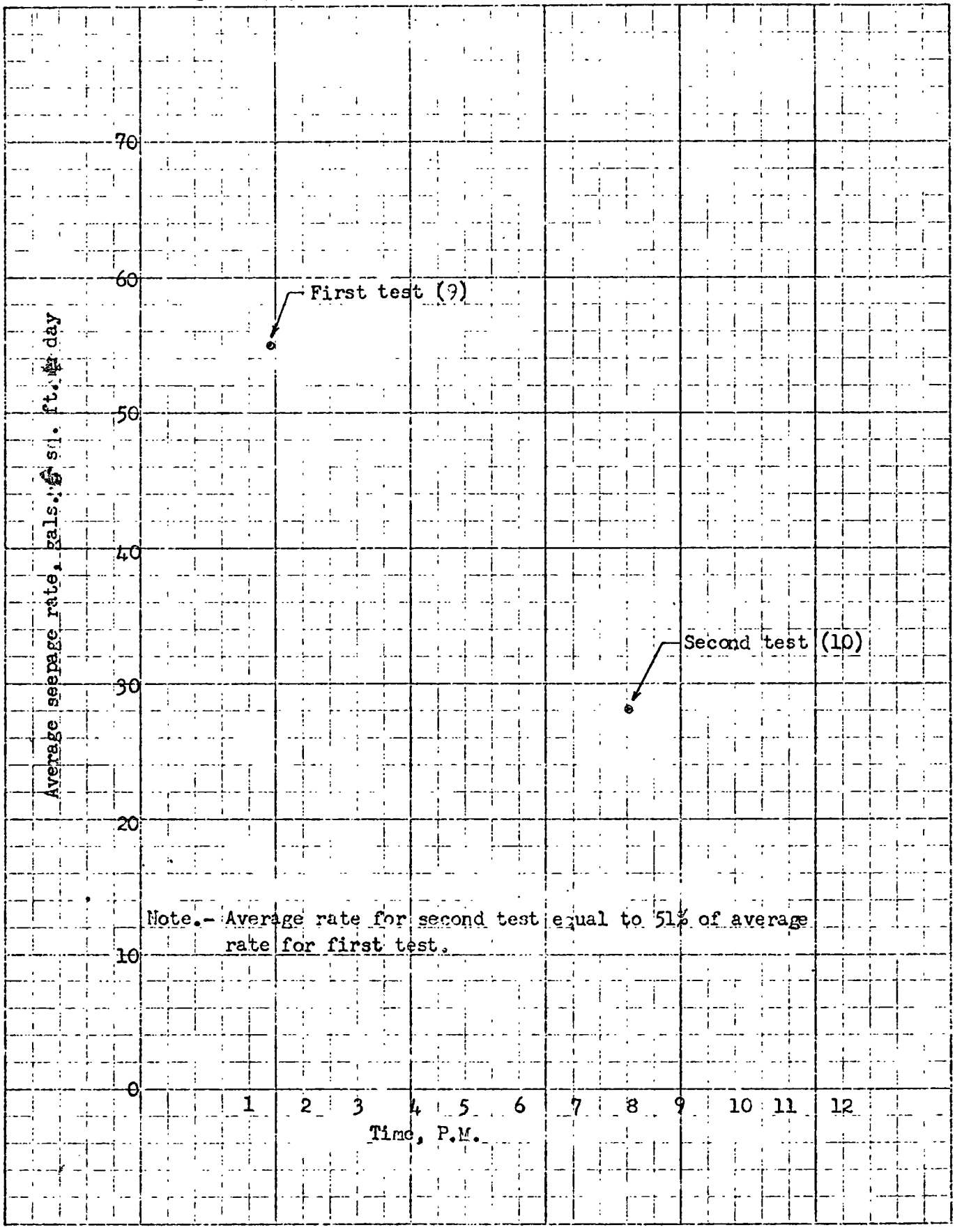
16- 54235 1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 4

ROCKAWAY ROAD PROJECT

Reduction in average seepage capacity resulting from repeated floodings, Oct.11,1949.



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

16—84235-1 U. S. GOVERNMENT PRINTING OFFICE

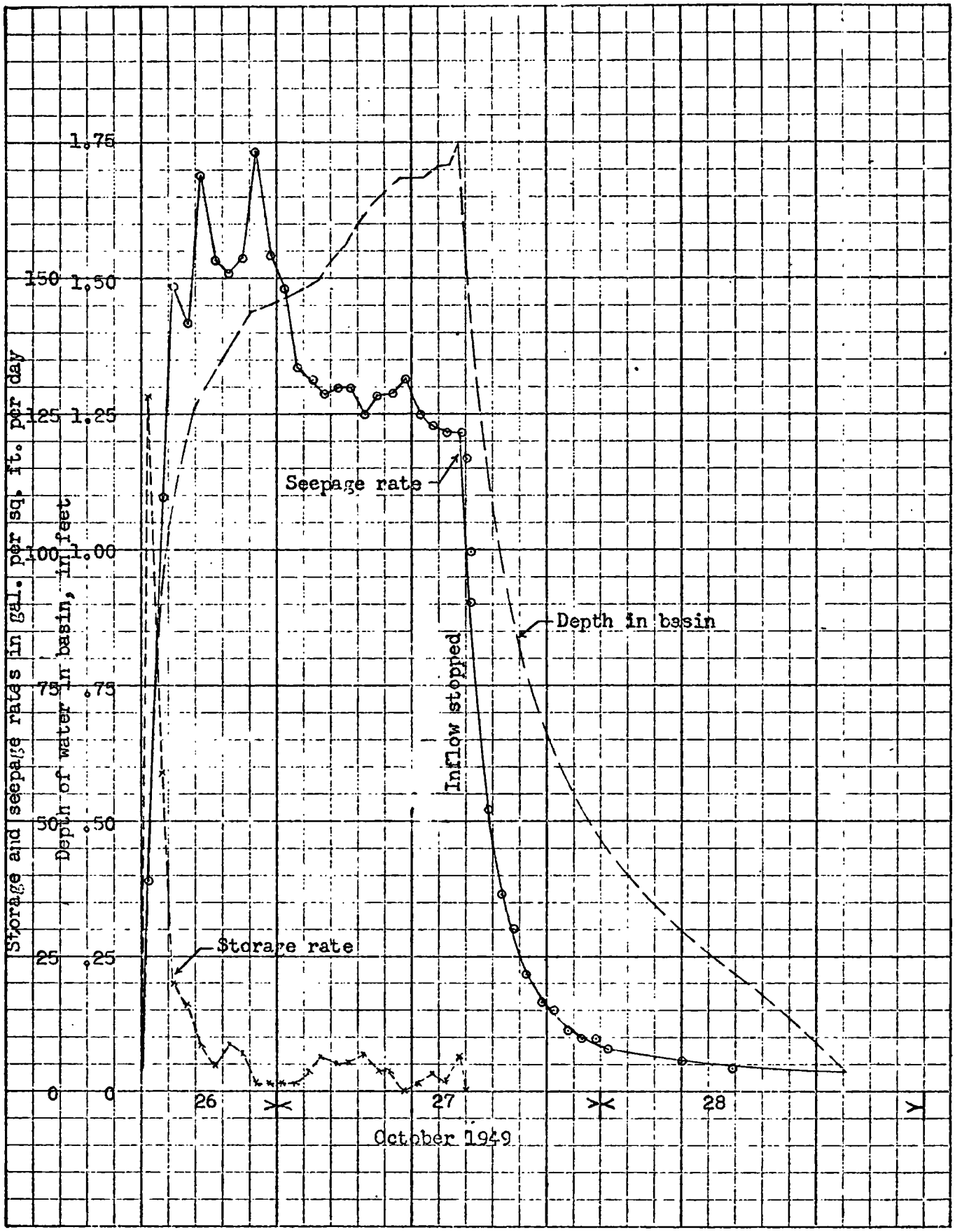
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 5

ROCKAWAY ROAD PROJECT

Continuous inflow test, Oct. 26-28, 1949



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

16—34235-1 U. S. GOVERNMENT PRINTING OFFICE

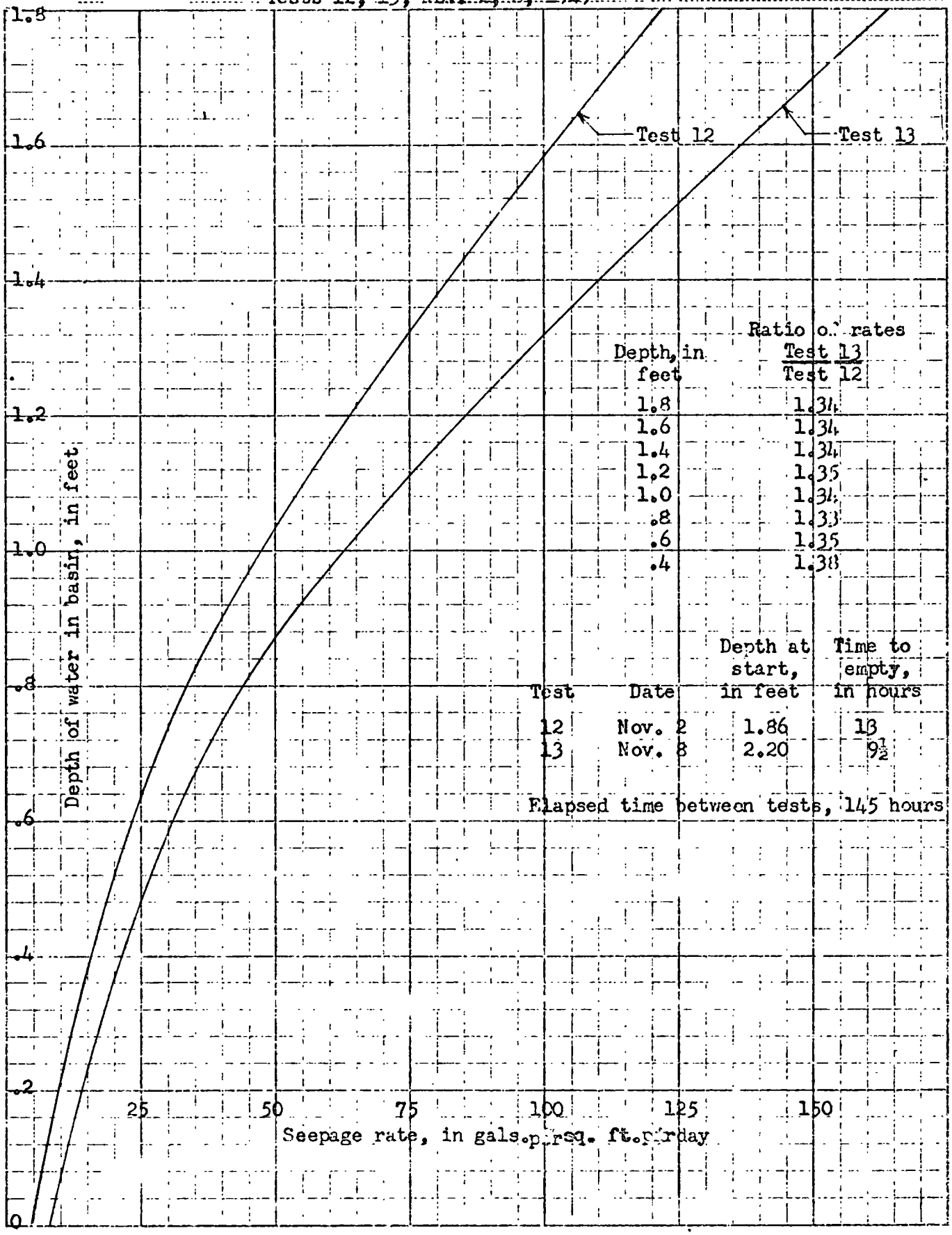
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 6

ROCKAWAY ROAD PROJECT

Tests 12, 13, Nov. 2, 8, 1949



Depth, in feet	Ratio of rates Test 13 / Test 12
1.8	1.34
1.6	1.34
1.4	1.34
1.2	1.35
1.0	1.34
.8	1.33
.6	1.35
.4	1.38

Test	Date	Depth at start, in feet	Time to empty, in hours
12	Nov. 2	1.86	13
13	Nov. 8	2.20	9½

Elapsed time between tests, 145 hours

Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

16—84235-1 U. S. GOVERNMENT PRINTING OFFICE

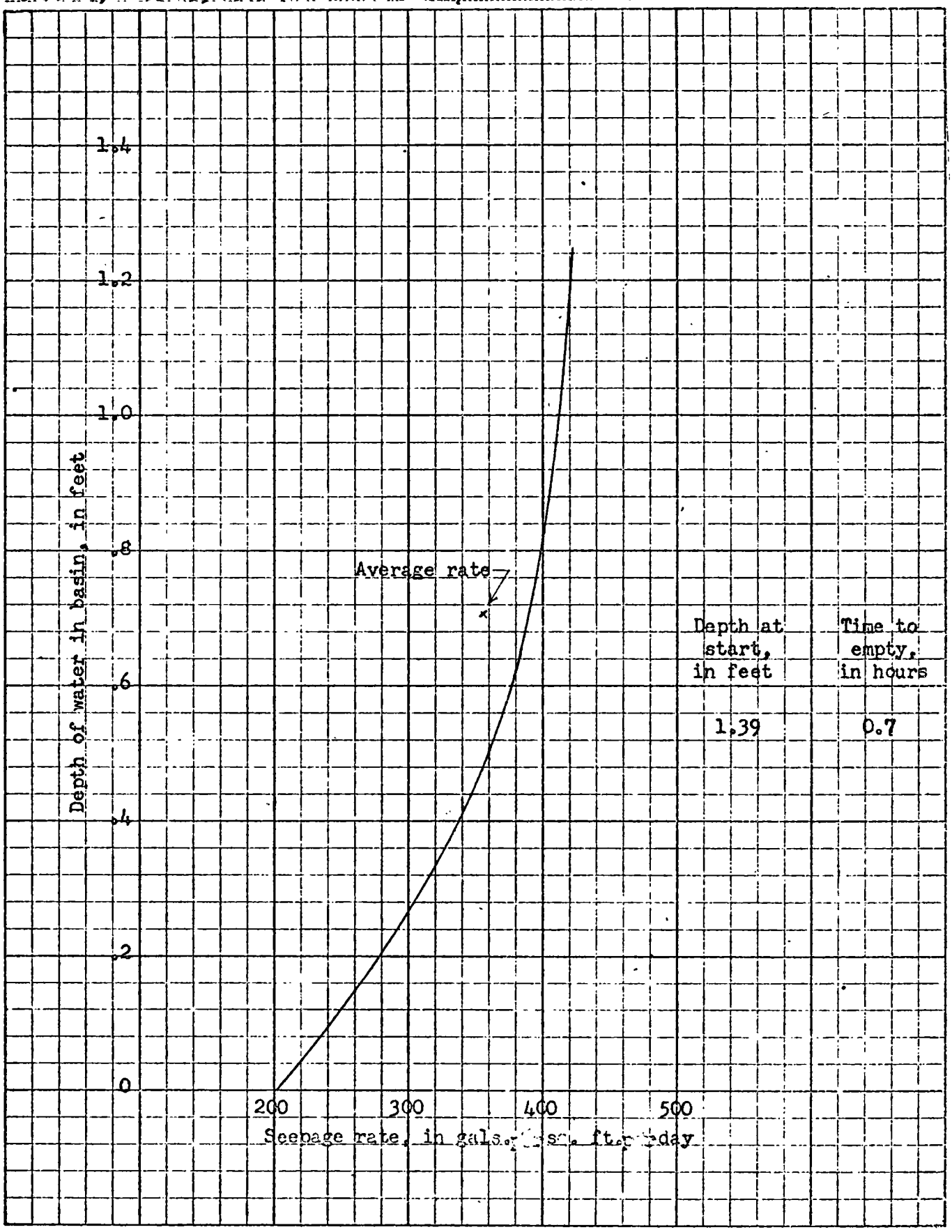
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 7

ROCKAWAY ROAD PROJECT

Test 14, Dec. 15, 1949 (after basin surface was frozen)



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

16-54236-1 U. S. GOVERNMENT PRINTING OFFICE

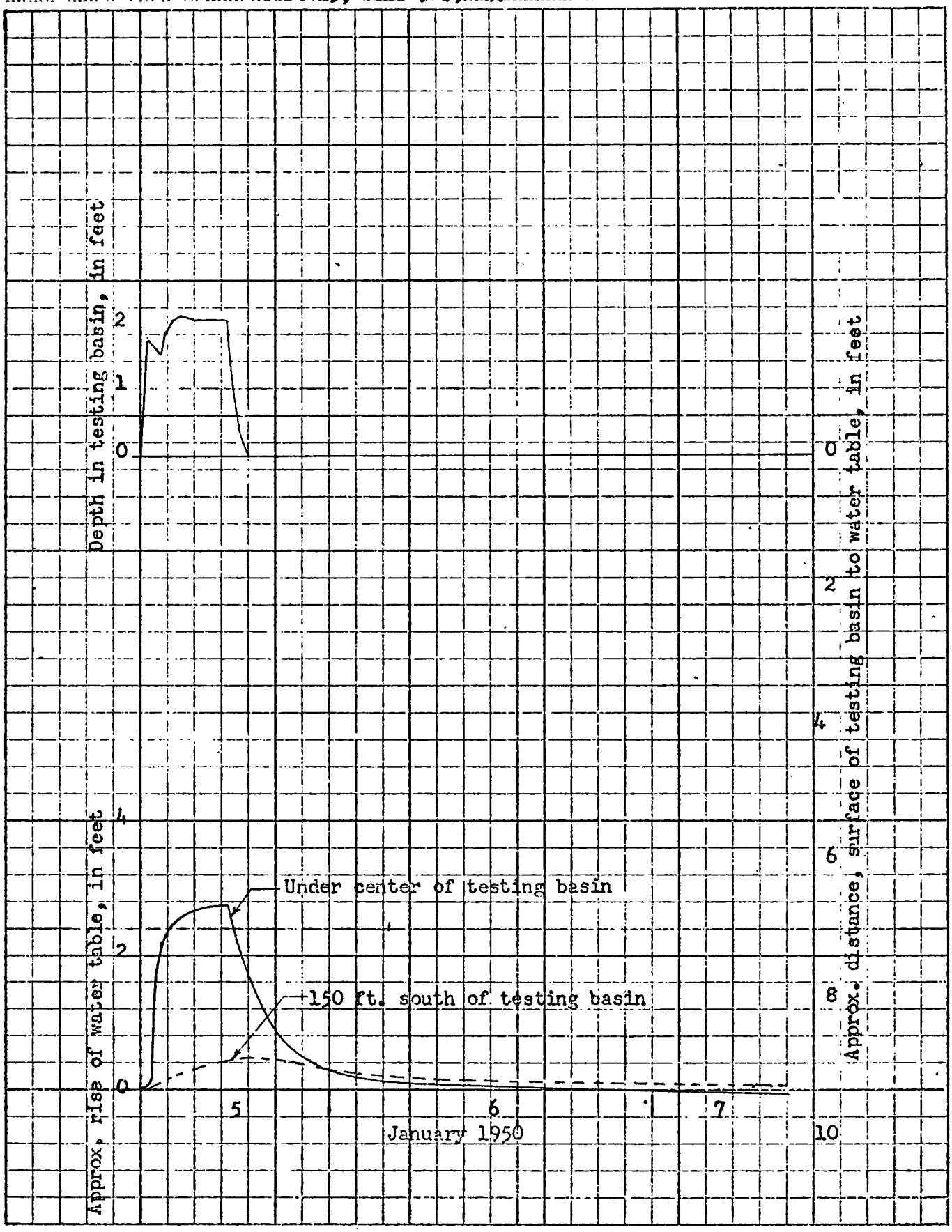
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 8

ROCKAWAY ROAD PROJECT

Test 15, Jan. 5-7, 1950



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

16—54235-1 U. S. GOVERNMENT PRINTING OFFICE

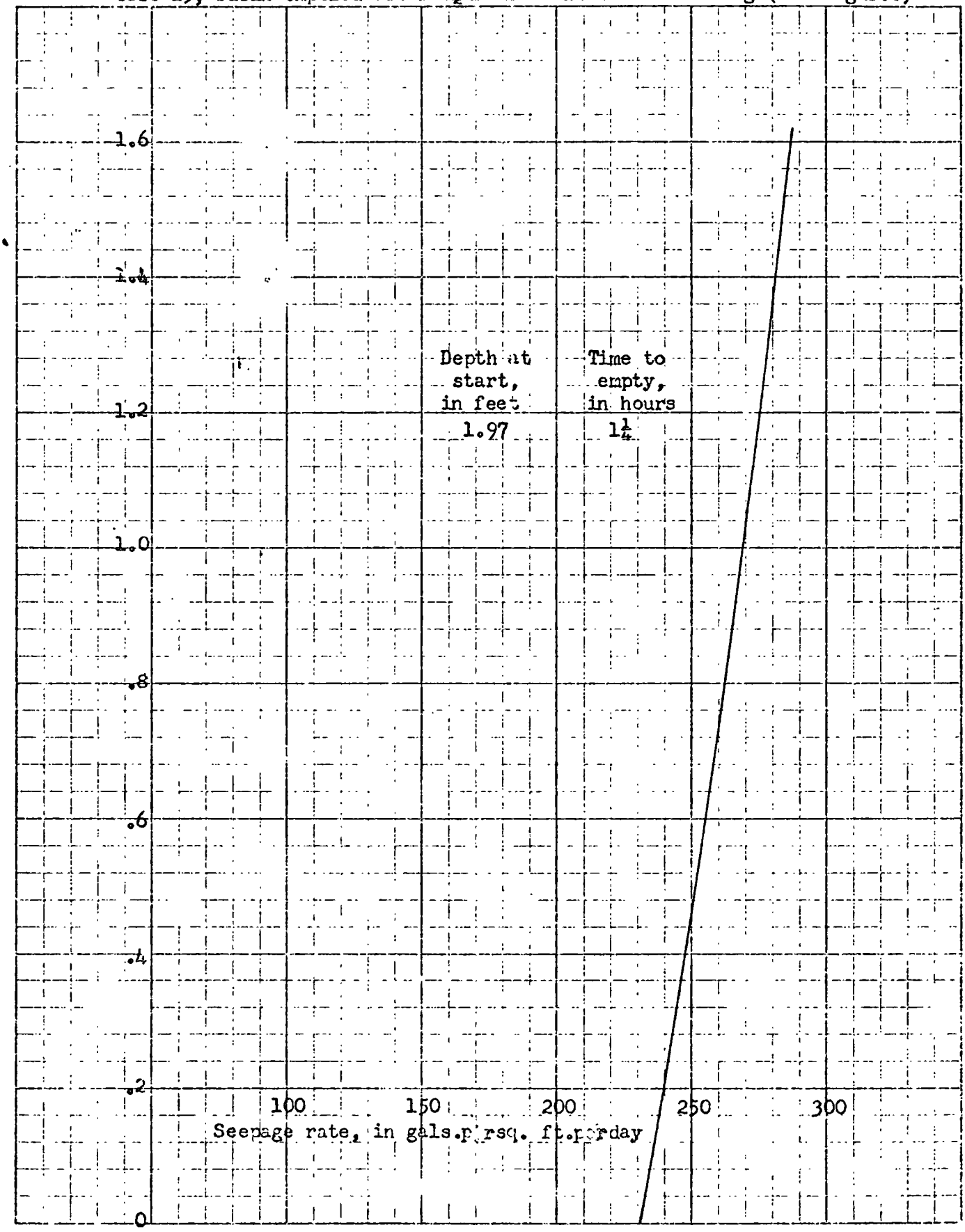
9-213-16
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 9

ROCKAWAY ROAD PROJECT

Test 15; basin emptied after 6½ hours continuous flooding (see Figure8)



Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

16—64235-1 U. S. GOVERNMENT PRINTING OFFICE

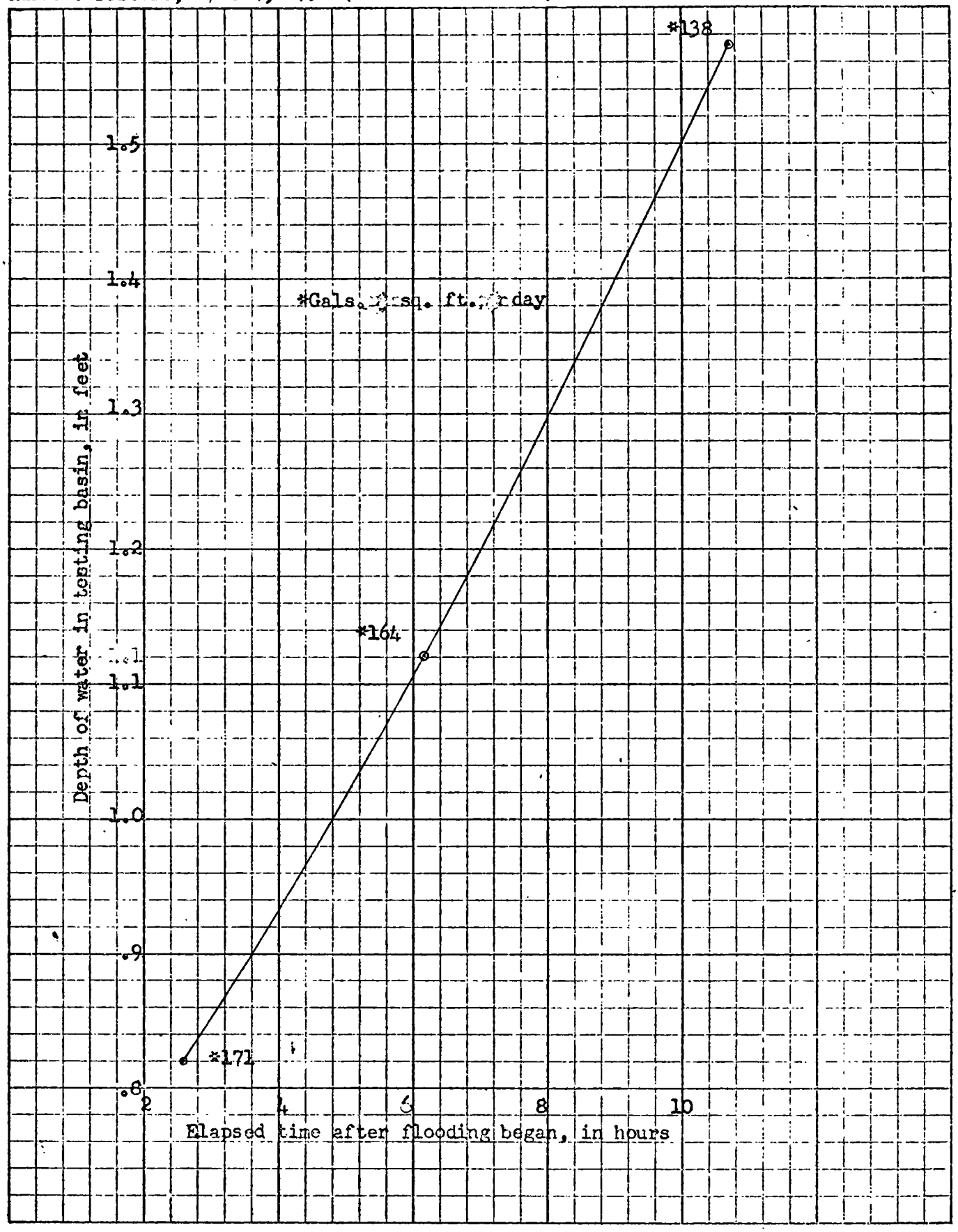
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 10

ROCKAWAY ROAD PROJECT

Test 16, Apr. 4, 1950 (continuous inflow; inflow and seepage balanced)



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

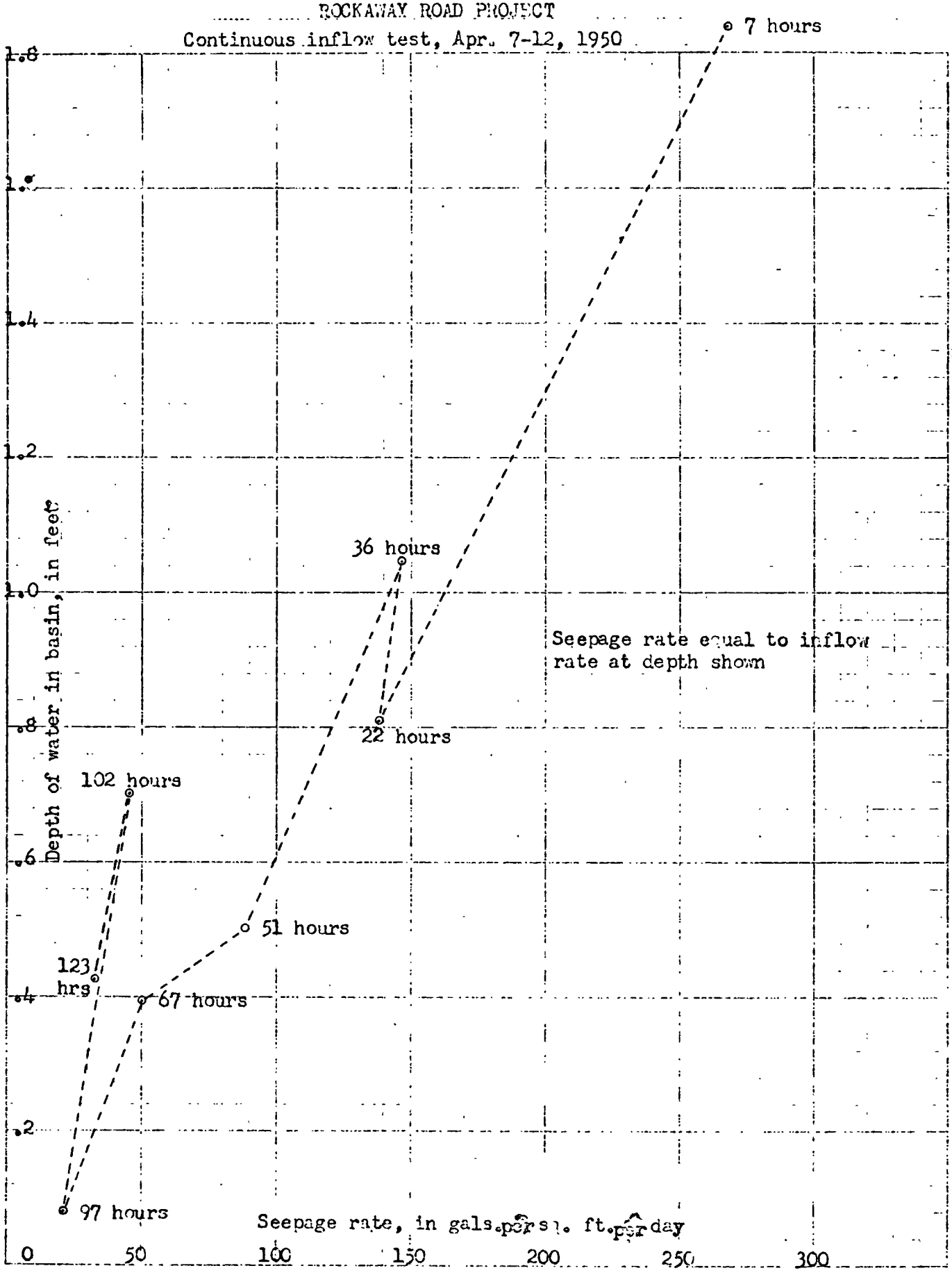
16—54235-1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 11

ROCKAWAY ROAD PROJECT

Continuous inflow test, Apr. 7-12, 1950



No. of Sheets. Prepared by HDB Date Checked by Date

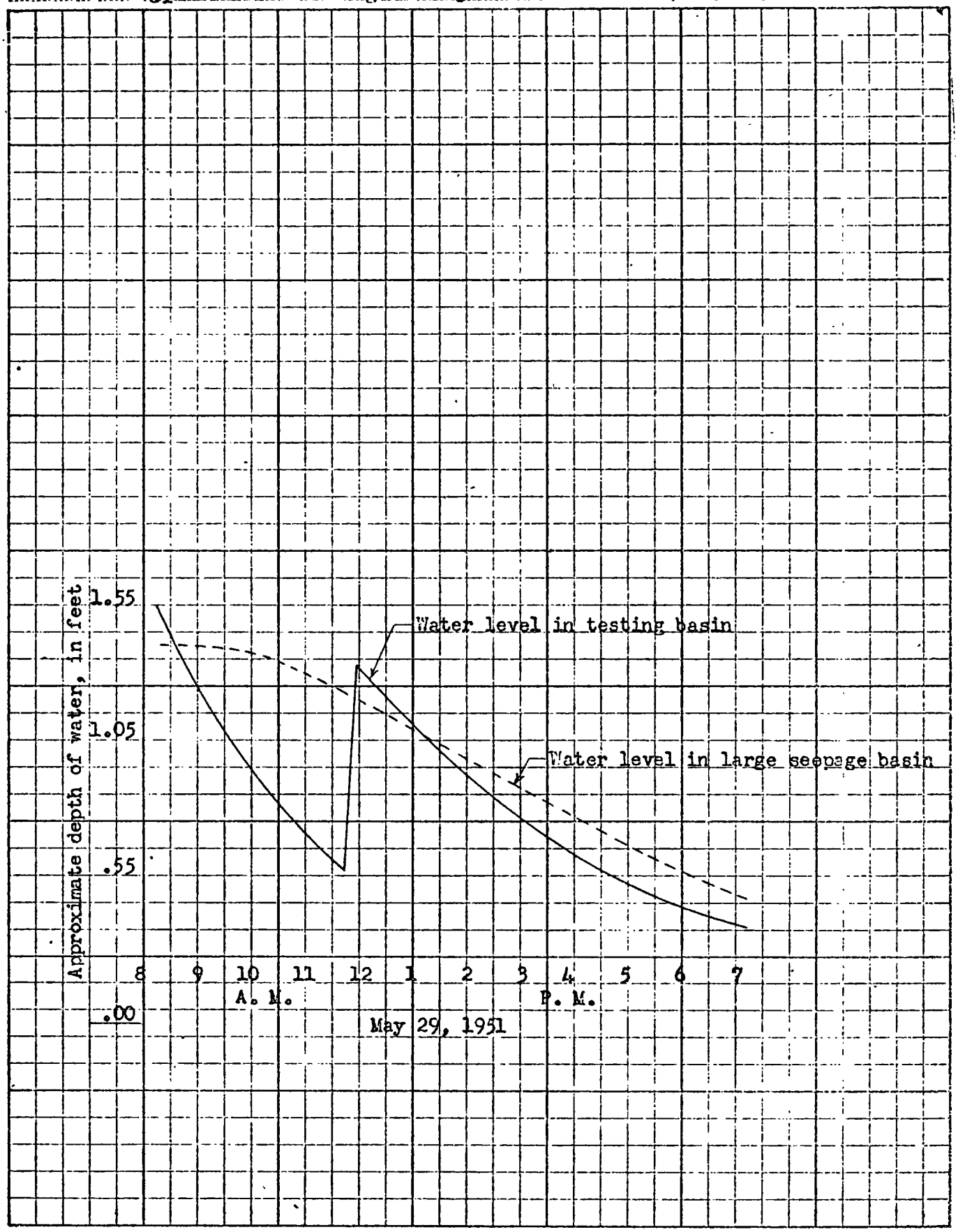
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 12

ROCKAWAY ROAD PROJECT

Simultaneous testing of large and small basins, May 29, 1951



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

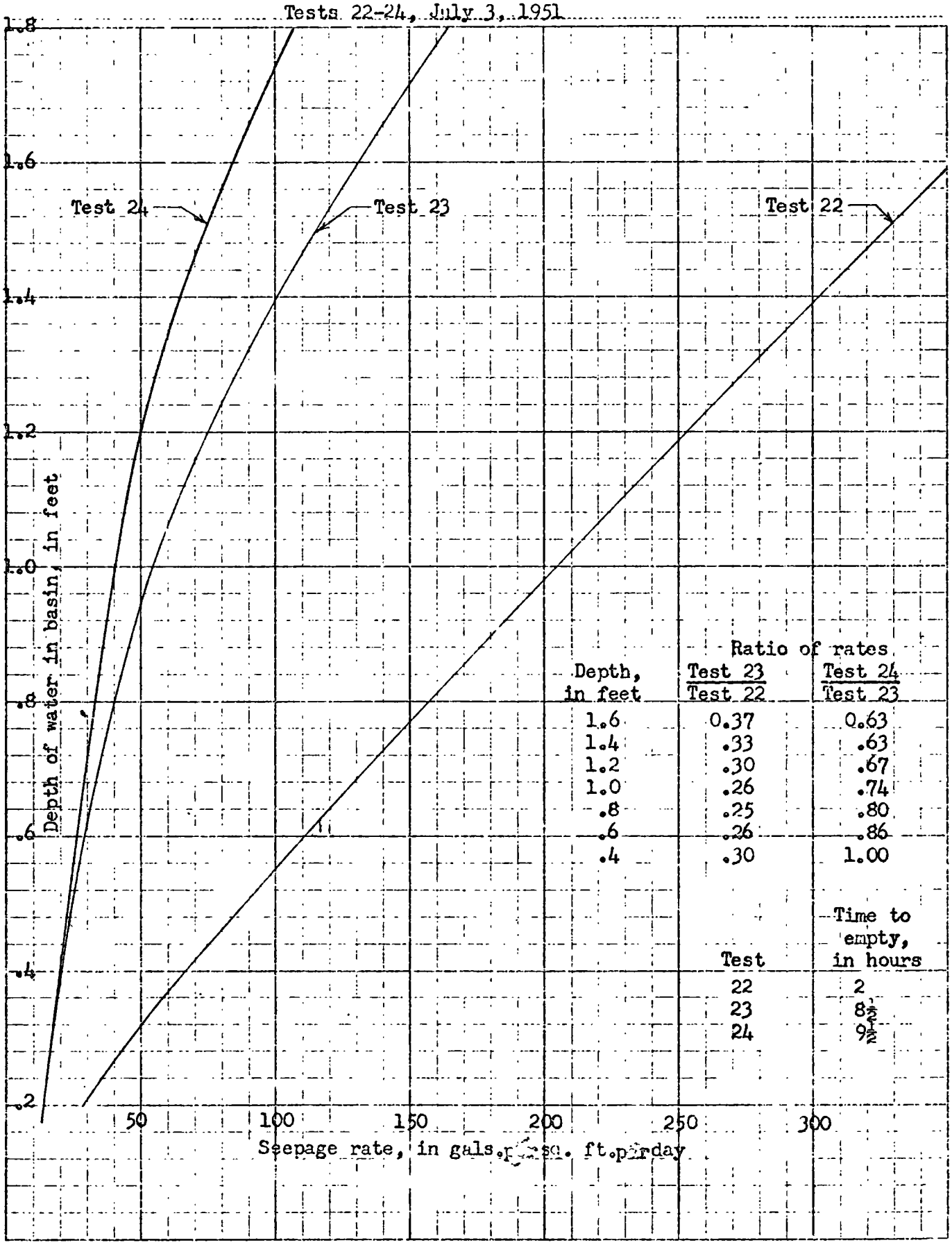
16—51235-1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 13

ROCKAWAY ROAD PROJECT

Tests 22-24, July 3, 1951



Depth, in feet	Ratio of rates: Test 23 / Test 22	Ratio of rates: Test 24 / Test 23
1.6	0.37	0.63
1.4	.33	.63
1.2	.30	.67
1.0	.26	.74
.8	.25	.80
.6	.26	.86
.4	.30	1.00

Test	Time to empty, in hours
22	2
23	8½
24	9½

Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

16—64233-1 U. S. GOVERNMENT PRINTING OFFICE

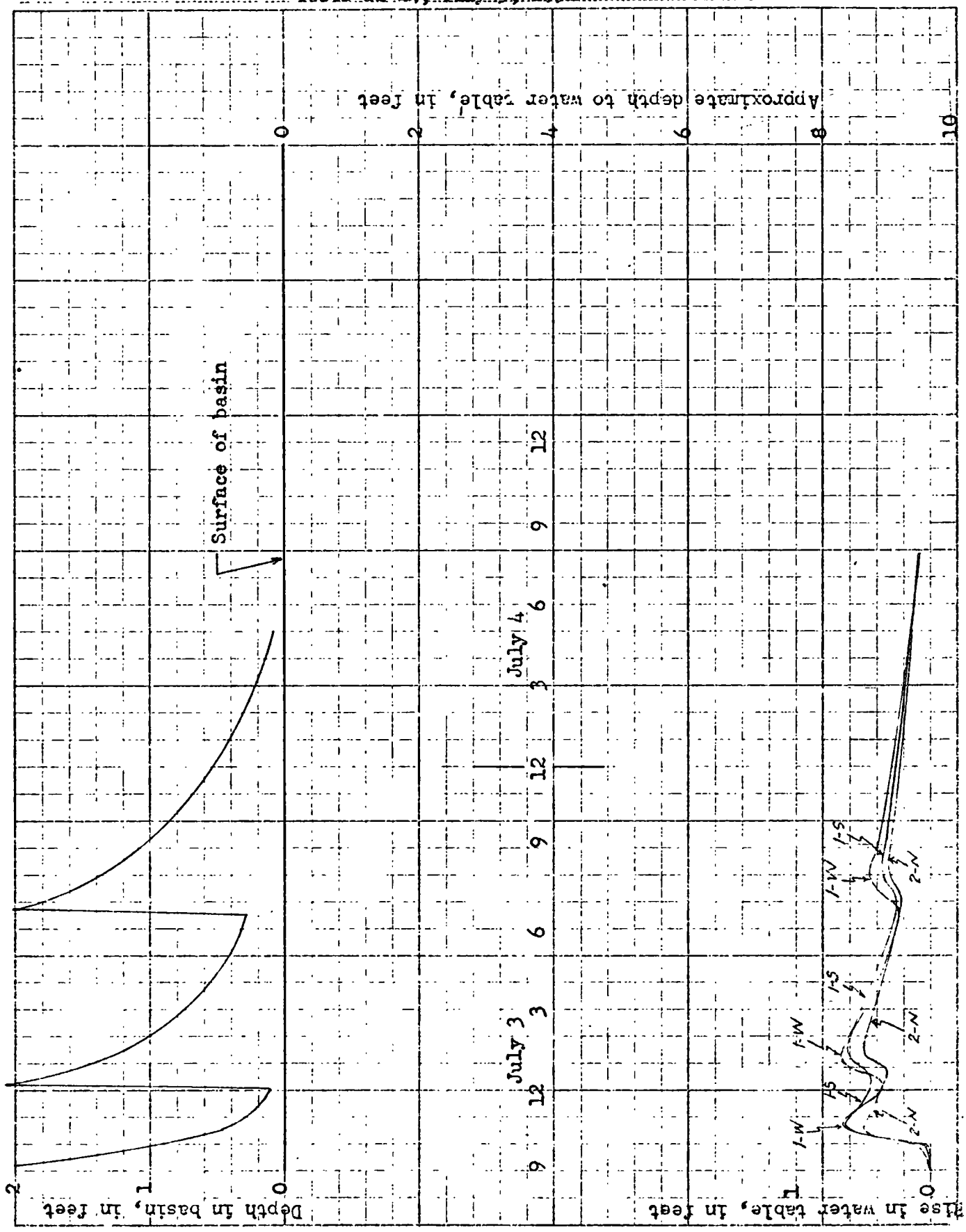
9-215-4
March 1939

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 14

ROCKAWAY ROAD PROJECT

Tests 22-24, July 3, 1951



Sheet No. ..... of ..... Sheets. Prepared by HDB Date ..... Checked by ..... Date .....

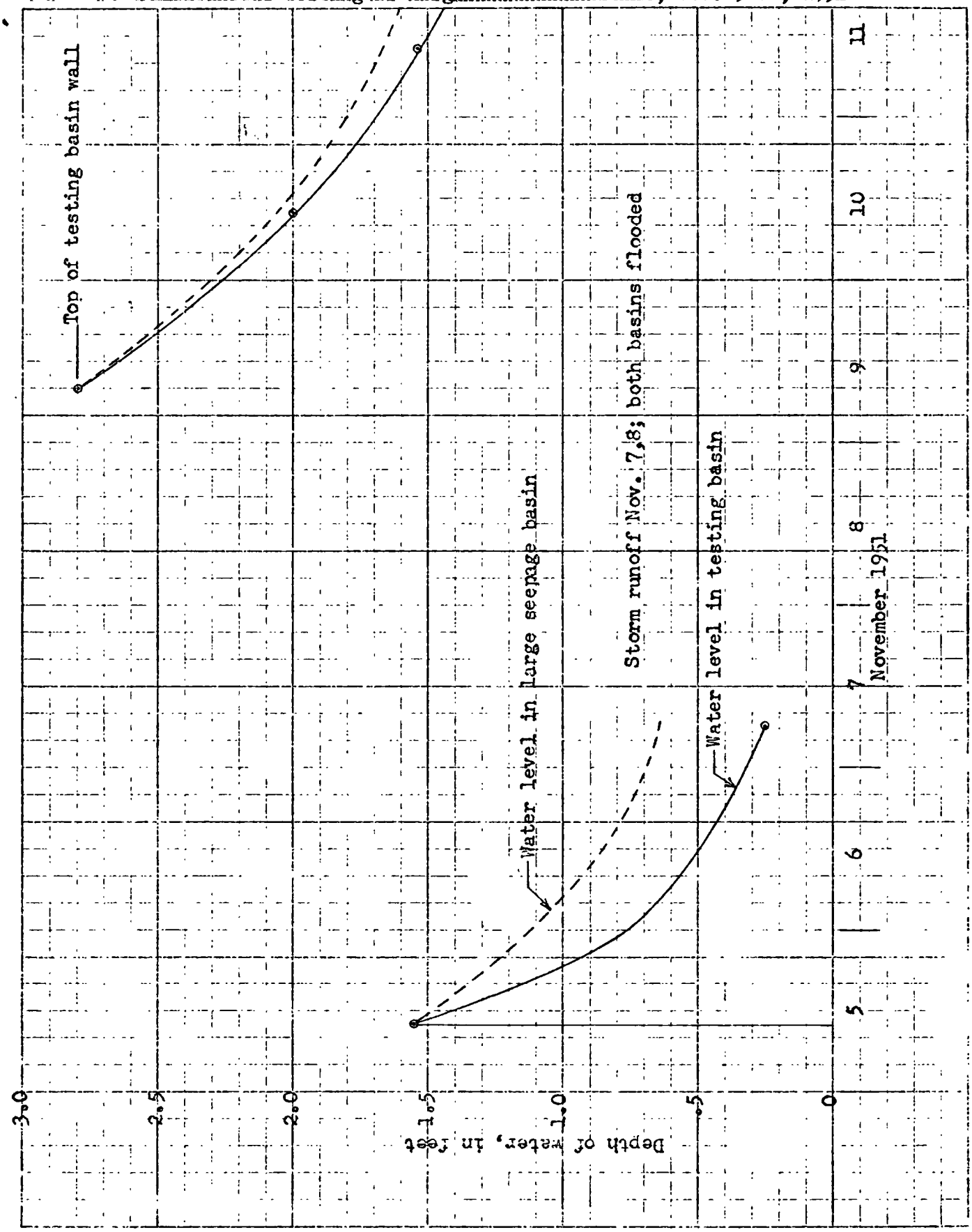
16—81235-1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 15

ROCKAWAY ROAD PROJECT

Simultaneous testing of large and small basins, Nov. 5-11, 1951



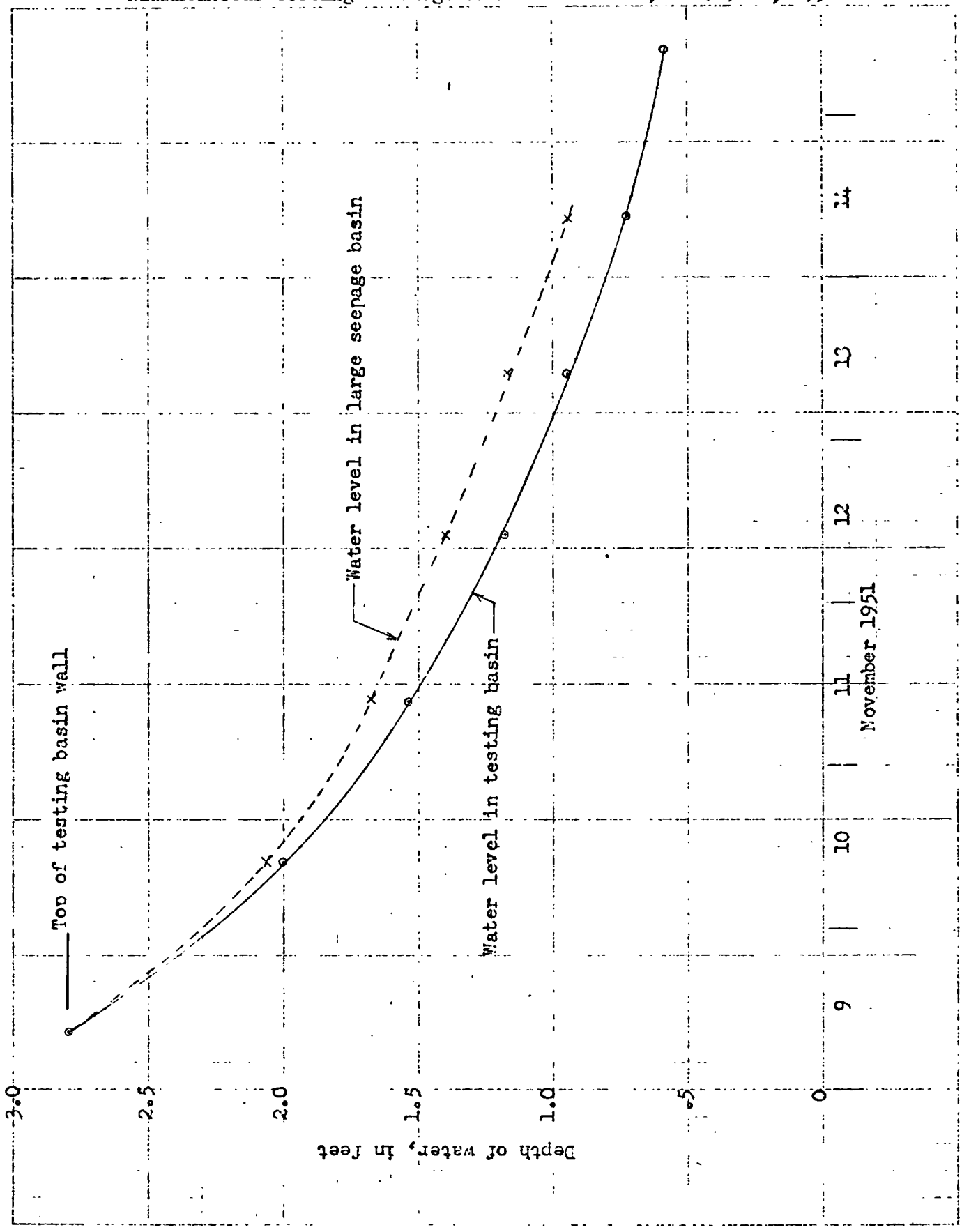
Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 16

ROCKAWAY ROAD PROJECT

Simultaneous testing of large and small basins, Nov. 9-14, 1951



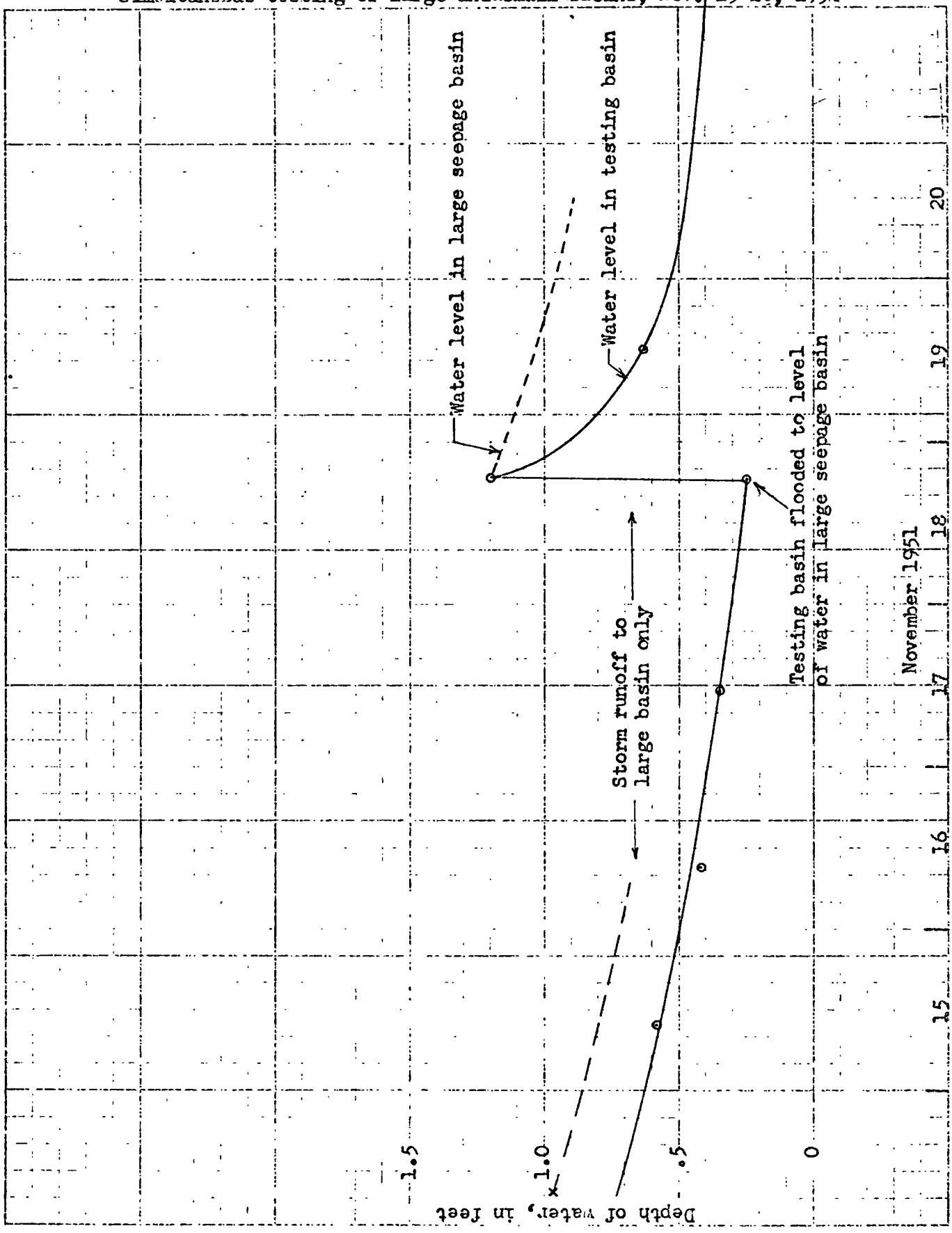
Sheet No. of Sheets. Prepared by HDB Date Checked by Date

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 17

ROCKAWAY ROAD PROJECT

Simultaneous testing of large and small basins, Nov. 15-20, 1951



Sheet No ... of ... Sheets. Prepared by HDB. Date ... Checked by ..... Date ...

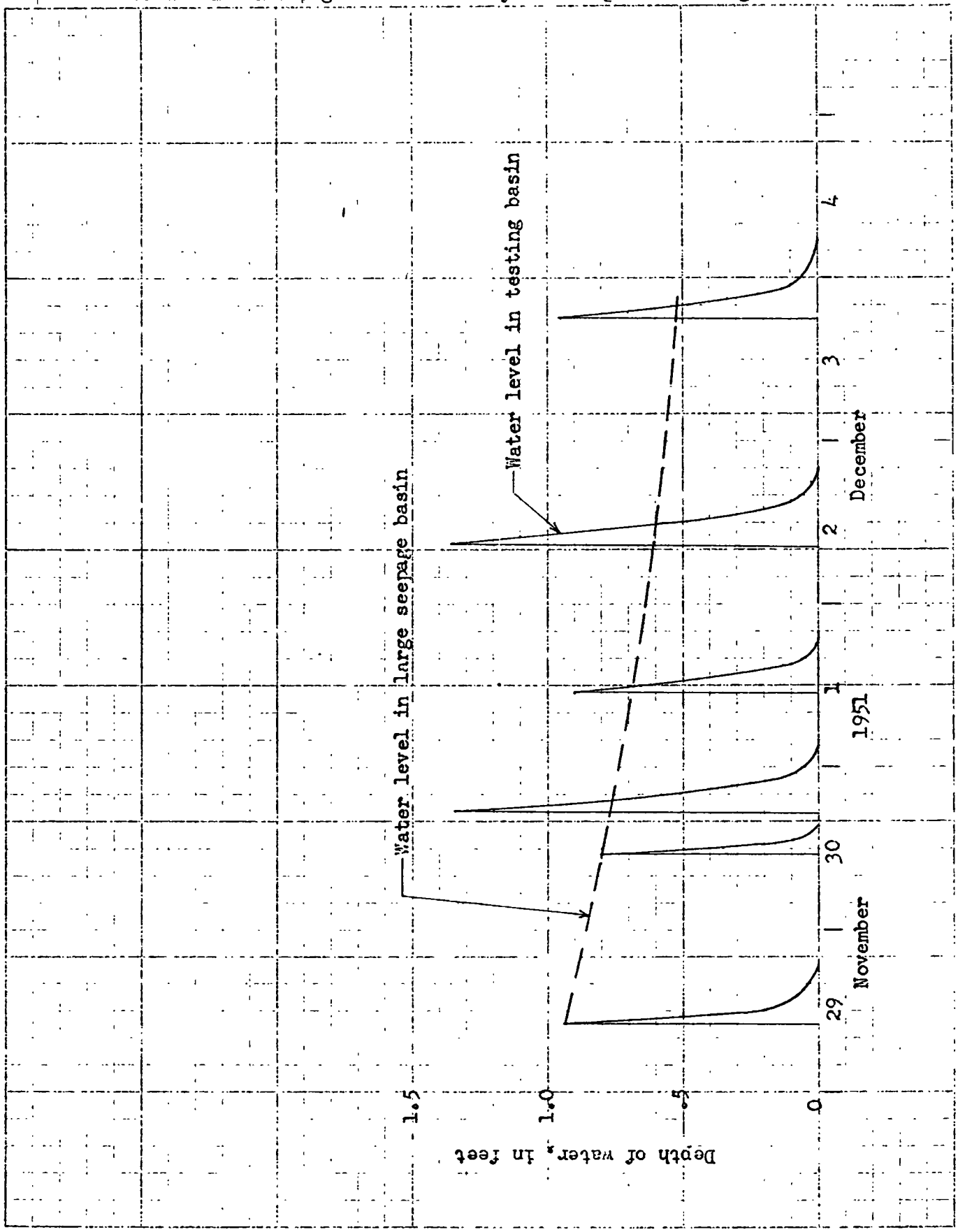
16—51235-1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 18

ROCKAWAY ROAD PROJECT

Increase in seepage rate caused by freezing and thawing of basin surface



Sheet No. . . of . Sheets. Prepared by HDB Date . . Checked by . . . . . Date .

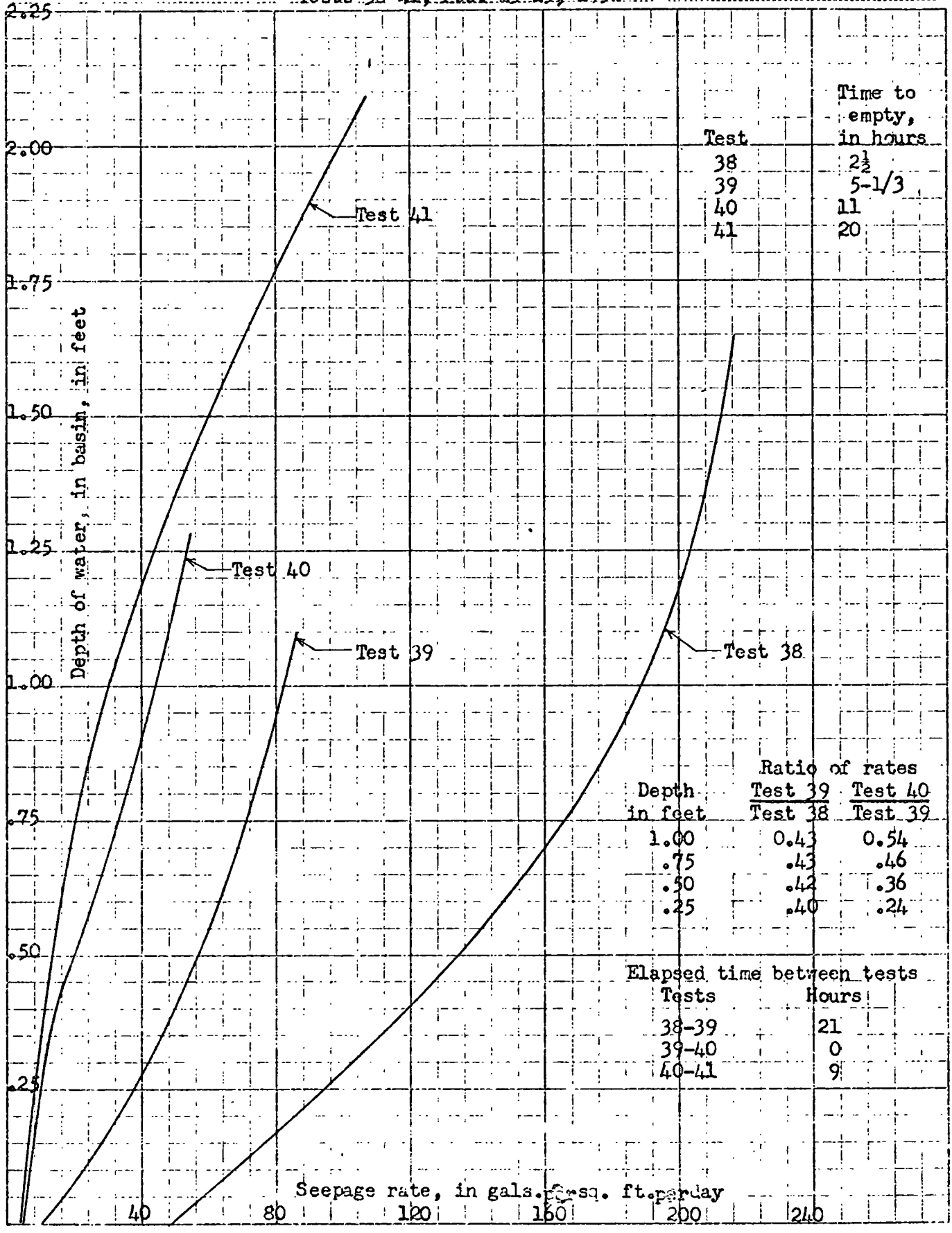
9-214-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 19

ROCKAWAY ROAD PROJECT

Tests 38-41, Feb. 23-25, 1952



Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

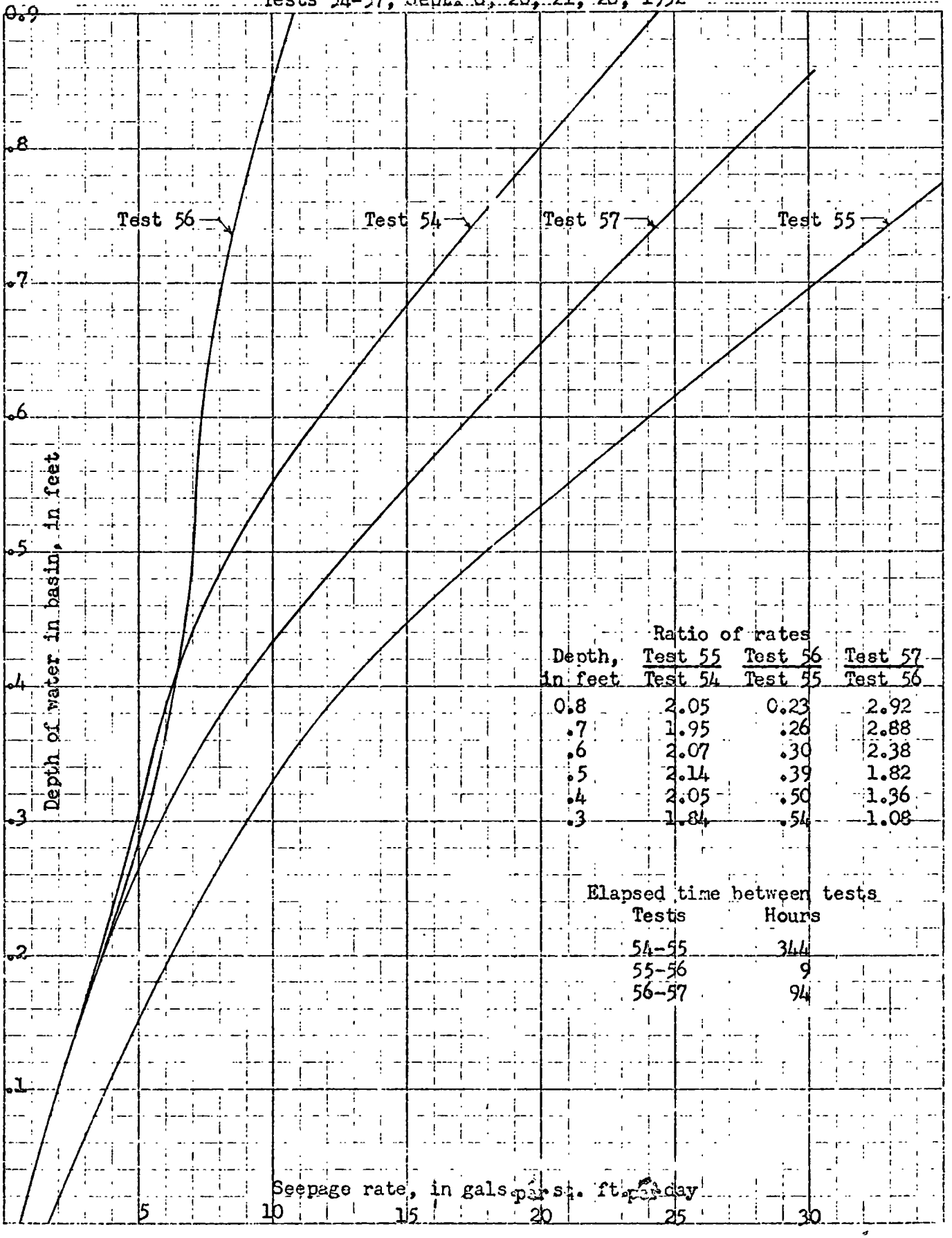
16—31235-1 U. S. GOVERNMENT PRINTING OFFICE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 20

ROCKAWAY ROAD PROJECT

Tests 54-57, Sept. 6, 20, 21, 26, 1952



Ratio of rates

Depth, in feet	Test 55 / Test 54	Test 56 / Test 55	Test 57 / Test 56
0.8	2.05	0.23	2.92
.7	1.95	.26	2.88
.6	2.07	.30	2.38
.5	2.14	.39	1.82
.4	2.05	.50	1.36
.3	1.84	.54	1.08

Elapsed time between tests

Tests	Hours
54-55	344
55-56	9
56-57	94

Sheet No. ... of ... Sheets. Prepared by HDB Date ... Checked by ... Date ...

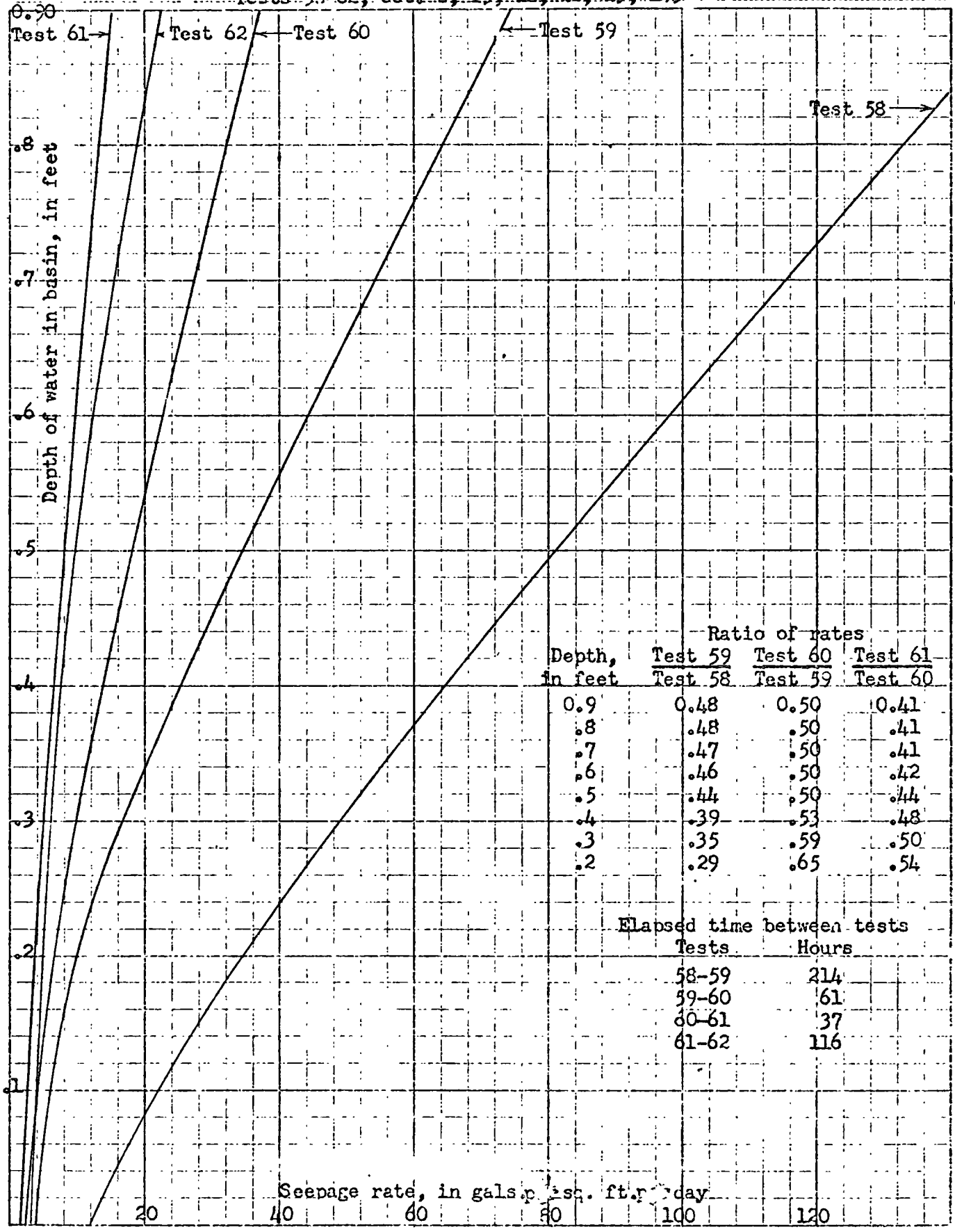
9-213-B
(March 1950)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 21

ROCKAWAY ROAD PROJECT

Tests 58-62, Oct. 6, 15, 18, 20, 25, 1952



Depth, in feet	Ratio of rates: Test 59 / Test 58	Test 60 / Test 59	Test 61 / Test 60
0.9	0.48	0.50	0.41
.8	.48	.50	.41
.7	.47	.50	.41
.6	.46	.50	.42
.5	.44	.50	.44
.4	.39	.53	.48
.3	.35	.59	.50
.2	.29	.65	.54

Elapsed time between tests

Tests	Hours
58-59	214
59-60	61
60-61	37
61-62	116

Sheet No. .... of .... Sheets. Prepared by HDB Date .... Checked by .... Date ....

16—64235-1 U. S. GOVERNMENT PRINTING OFFICE

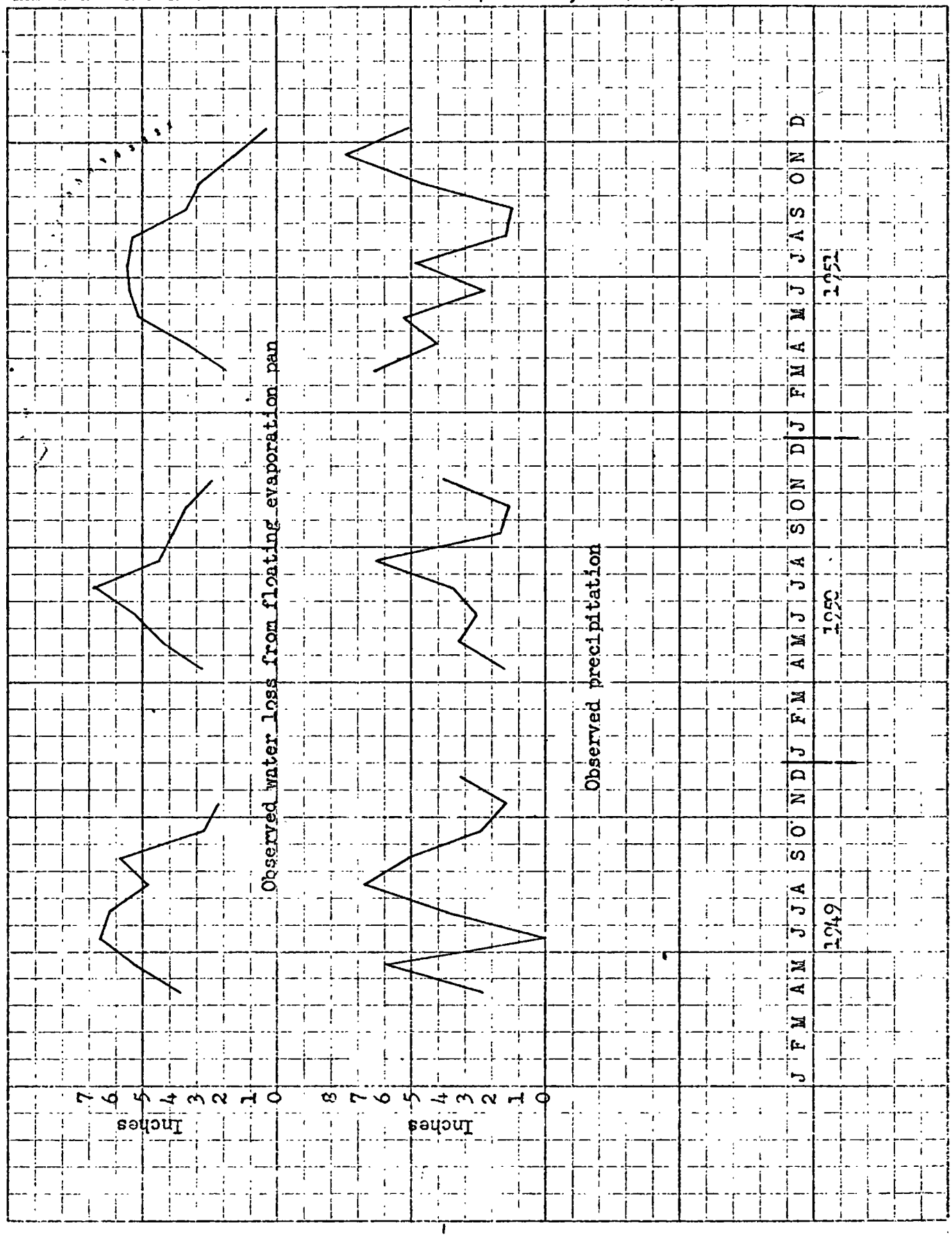
9-213-B
(March 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Figure 22

ROCKAWAY ROAD PROJECT

Water loss and precipitation, 1949-1951



Sheet No. . . . . of . . . . Sheets. Prepared by HDB . . . . Date . . . . . Checked by . . . . . Date . . . . . .

16—54235-1 U. S. GOVERNMENT PRINTING OFFICE

WS-NASSAU (G&H-63)

NASSAU COUNTY, NEW YORK

Summary of

Report on Water Supply

June, 1963

Greeley and Hansen
Engineers
New York Chicago

ACKNOWLEDGEMENTS

Many individuals and organizations have cooperated and assisted in furnishing information and data used in the studies leading to this report. The sources are too numerous to be cited individually and are collectively gratefully acknowledged. Special note is made of the assistance of various personnel of the Department of Public Works, of the Nassau County Planning Commission and of the following other persons and organizations:

United States Geological Survey
Mineola Office
Mr. N. M. Perlmutter, et al.

State of New York
Water Resources Commission
Westbury Office
Mr. A. H. Johnson, et al.

City of New York
Department of Water Supply, Gas and Electricity
Mr. E. C. Clarke, et al.

Long Island Lighting Company
Mr. John J. O'Connor, Rate Department.

SYNOPSIS

Nassau County is estimated to have a population of 2,250,000 persons in 2010. The increased demands for water and the construction of sewers discharging used water directly to sea require a comprehensive plan to avoid a critical water supply problem.

Pumpage is estimated to increase to 298.0 mgd in 2010. Part of the pumpage is returned to the ground. Discharge to sea, which represents the required yield, is estimated to increase to 239.0 mgd.

The natural yield of the ground water supplies is estimated to be 154.0 mgd. Waste water injected as a salt water barrier along the south shore is recommended to permit increasing the developable yield to 181.0 mgd. This is expected to be adequate until about 1987. Thereafter, supplementary water will be required, reaching 58.0 mgd in 2010.

Supplementary water might be purchased and imported from New York City or Suffolk County by desalting sea water or recharging waste water. Recharging purified waste water in the central part of the County is recommended.

The recommended project includes additions to the supply system, including scattered wells, storage tanks, transmission mains, and waste water treatment and recharge

works. Inclusion of the two infiltration galleries, the Milburn Pumping Station, and the 72-inch steel main of the New York City Ridgewood system in the proposed system is recommended as soon as they are available and can be acquired, probably not until 1975. A four stage program of construction of new works is outlined at a total cost of $76,363,000.

Pilot studies preparatory to design of waste water reclamation facilities are recommended covering five years at a cost of $600,000.

Acquisition of all supply works and operation of these and the proposed works as a wholesale supply system under a Division of Water in the Department of Public Works is recommended. Retail distribution services can remain with present agencies or can be consolidated in the Water Division or expanded town water districts.

Privately owned and New York City facilities are expected to be purchased. Based principally on reported book values, the purchase costs may be in the order of $52,000,000. Individual evaluation studies will be necessary to determine offering prices. Transfer of publicly owned supply facilities is recommended by appropriate agreements, with assumption of related debt by the County.

Wholesale supply activities of the Water Division are proposed to be financed by a wholesale service charge to the retailing agency of 7½ cents per 1,000 gallons plus an ad valorem tax for necessary additional revenue.

Exclusive of debt service on acquisition costs, the total annual costs in 1980 are estimated at $8,926,000. Wholesale water charges are expected to produce $5,205,000. The remainder, $3,721,000, requires a property tax of about 10 cents per $100 of value. Debt service for acquisition costs, using $52,000,000 for illustration purposes, would add about 7 cents to the property tax.

SAMUEL A. GREELEY
PAUL HANSEN (1920-1944)
PAUL E. LANGDON
THOMAS M. NILES
KENNETH V. HILL
SAMUEL M. CLARKE
GEORGE M. HITE
DONALD NEWTON
CARL W. REH
M. D. R. RIDDELL
RICHARD H. GOULD

GREELEY AND HANSEN
ENGINEERS
14 E JACKSON BLVD • CHICAGO 4, ILL. • TELEPHONE WEBSTER 9-5850

June 20, 1963

Mr. Eugene F. Gibbons
Commissioner of Public Works
County of Nassau
Executive Building
Mineola, New York

Dear Mr. Gibbons:

We are pleased to transmit our "Summary of Report on Water Supply" for Nassau County. This volume contains a summary of the more fully detailed "Report on Water Supply" prepared in conformance with the agreement for engineering services, dated June 21, 1962.

Yours very truly,

GREELEY AND HANSEN

Donald Newton

Donald Newton

DN:MG

NASSAU COUNTY, NEW YORK

Summary of

Report on Water Supply

TABLE OF CONTENTS

Number	Description	Page
1.	General Statement	1
	PART I - WATER REQUIREMENTS	
1.	Population and Water Use.	1
2.	Consumptive Use of Water.	3
3.	Supplemental Water Requirements	4
	PART II - WATER RESOURCES	
1.	General	6
2.	The Natural Yield	7
	PART III - DEVELOPMENT OF RESOURCES	
1.	General	9
2.	Procedures for Future Ground Water Developments.	9
3.	Supplement Water.	17
4.	Bases of Design	25
5.	Projects.	27
6.	Suggested Construction Schedule	35

TABLE OF CONTENTS (Continued)

Number	Description	Page
	PART IV - ADMINISTRATIVE AND FINANCIAL CONSIDERATIONS	
1.	General	41
2.	Legislation	46
3.	Form of Water Agency.	47
4.	Acquisition of Existing Facilities. . . .	51
5.	Costs of Water and Suggested Charges. . .	56
6.	Summary	62

NASSAU COUNTY, NEW YORK

Summary of

Report on Water Supply

LIST OF TABLES

Number	Title	Following Page
I-1	Land Use	2
I-2	Estimated Future Population in Water Districts	2
I-5	Estimated Annual Average Pumpage	2
IV-1	Recommended Project Annual Costs	57

LIST OF FIGURES

I-2	Population	2
I-7	Water Pumpage, Consumptive Use and Recharge	3
II-15	Yield vs. Consumptive Use	5
III-2	Pressure Distribution Zones	25
IV-1	Organization Chart	50
Plate A	Recommended Project	Rear Cover Map Pocket

NASSAU COUNTY, NEW YORK

Summary of

Report on Water Supply

1. General Statement

The detailed report comprises four parts, as follows:

Part I - Water Requirements

Part II - Water Resources

Part III - Development of Resources

Part IV - Administrative and Financial Considerations

It is the intent here to summarize the data and recommendations for a comprehensive water supply program for Nassau County to the year 2010.

PART I - WATER REQUIREMENTS

1. Population and Water Use

Part I of the Report includes the studies and estimates of water supply needs related to land use, population and industrial and commercial development.

Based on surveys and reports by the Nassau County Planning Commission and other data, significant increases are included in the forecast for apartment and industrial areas in the County. Other land use categories have been adjusted to fit anticipated changes. The apartment area is estimated to increase from 0.36 per cent of the total area

in 1960 to 5.67 per cent in 2010. The industrial area is estimated to increase from 3.00 per cent in 1960 to 4.75 per cent in 2010. Vacant area decreases from 17.80 per cent in 1960 to zero per cent in 2010. The increase in apartment area is particularly significant because the high population density of apartment areas (75 persons per acre in 2010) greatly affects population estimates and, therefore, public water supply estimates. The estimates of land use are shown in Table I-1.

It is estimated that the population of Nassau County will increase from 1.3 millions in 1960 to 2.25 millions in 2010, as shown on Figure I-2. The population distribution by water districts is shown in Table I-2.

Coupled with the population increase, the unit quantity of water pumped by public supplies is estimated to increase from 95 gallons per capita daily to 115 gallons per capita per day. Data relating to water requirements are given in Table I-5 and are briefly summarized as follows:

	1960	1980	2010
Population (millions)	1.30	1.80	2.25
Domestic Pumpage			
Per Capita (gcd)	94.90	105.50	115.00
Total (mgd)	123.40	190.00	258.80
Commercial and Industrial Pumpage (mgd)	21.60	33.00	39.20
Total Pumpage (mgd)	145.00	223.00	298.00

TABLE I-1

NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY

Land Use

Classification	1960 Ac.	1960 %	1975 Ac.	1975 %	2010 Ac.	2010 %
Apartment	630(4)	0.36	5800	3.28	10000	5.67
Other Residential	81847(4)	46.30	86000	48.58	94100	53.30
Business	4836(4)	2.74	5100	2.98	5500	3.11
Industry	5291(3)	3.00	6200	3.51	8400	4.75
Recreation	11808(4)	6.70	12400	7.02	13000	7.35
Public	11588(4)	6.55	12200	6.90	13500	7.64
Streets and Parkways	27607(4)	15.62	28380	16.10	30480	17.25
Inland Water	1646(1)	0.93	1646	0.93	1646	0.93
Vacant	31373(5)	17.80	18900	10.70	0	0
Total	176626(3)	100.00	176626	100.00	176626	100.00

(1) From 1955 Nassau County Land Uses Report.

(3) From Data supplied by Nassau County Planning Commission.

(4) From 1959 Nassau County Land Uses Report.

(5) Total Areas less all other land use areas except "Vacant" Areas.

(6) From 1959 Nassau County Planning Commission Population Report.

TABLE I-2

NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY

Estimated Future Population in Water Districts

	Area (Acres)	1960 (1) Total	1960 (1) Per Acre	1975 Total	1975 Per Acre	2010 Total	2010 Per Acre
Municipalities							
1 Bayville Village	1000	4170	4.2	10400	10.4	12500	12.5
2 East Williston Village	350	2940	8.4	3740	10.7	5260	15.0
3 Farmingdale Village	750	6128	8.2	8170	10.9	9300	12.4
4 Freeport Village	3210	34419	10.7	40110	12.5	49120	15.3
5 Garden City Village	3480	23948	6.9	30250	8.7	37520	11.8
6 Hempstead Village	2400	34641	14.4	43190	18.0	49960	20.8
7 Long Beach City	1470	26473	18.0	36200	24.8	42380	28.8
8 Mineola Village	1210	20519	16.9	25350	21.0	36110	25.8
9 Old Westbury Village	6450	5831	0.9	19300	3.0	35000	6.0
10 Plandome Village	310	1222	3.9	2790	9.0	3770	12.1
11 Rockville Center Village	2240	26355	11.8	30020	13.4	36670	16.4
12 Sands Point Village	2720	2161	0.8	5400	2.0	10000	3.7
13 Williston Park Village	370	8255	22.3	8900	24.0	9300	25.0
Water Districts							
14 Albertson W.D.	1620	10279	6.3	14700	9.1	19700	12.2
15 Bethpage W.D.	3350	26057	7.8	34470	10.3	42680	12.7
16 Bowling Green W.D.	890	11977	13.5	12880	14.5	14590	16.4
17 Carle Place W.D.	880	9314	10.6	12120	13.8	16490	18.7
18 East Meadow W.D.	3610	51792	14.3	54200	15.0	56000	15.5
19 Franklin Square W.D.	1040	17396	16.8	20070	19.2	25300	24.3
20 Garden City Park W.D.	1960	19580	10.0	23510	12.0	28730	14.6
21 Garden City South W.D.	50	644	12.9	700	14.0	730	14.6
22 Glenwood W.D.	260	580	2.2	1440	5.5	2290	8.8
23 Hicksville W.D.	5050	55497	11.0	62300	12.3	71650	14.2
24 Island Trees W.D.	410	5744	14.0	5900	14.0	6150	15.0
25 Jericho W.D.	23600	44764	1.9	118320	5.0	202480	8.6
26 Levittown W.D.	2750	39818	14.5	40400	14.7	41200	15.0
27 Lido Point Lookout W.D.	1270	2385	1.9	11190	8.8	16320	12.8
28 Locust Valley W.D.	5630	5794	1.0	13030	2.3	24850	4.4
29 Manhasset-Lakeville W.D.	6370	32409	5.1	55550	8.7	85920	13.5
30 Massapequa Park W.D.	3950	43658	11.0	46300	11.7	50550	12.8
31 Oyster Bay W.D.	2680	6141	2.3	11310	4.2	19770	7.4
32 Plainview W.D.	4680	32424	6.9	39200	8.4	51500	11.0
33 Port Washington W.D.	4180	25382	6.1	40980	9.8	57120	13.7
34 Roslyn W.D.	3260	19123	5.9	26260	8.0	35830	11.0
35 South Farmingdale W.D.	3750	41839	11.1	45000	12.0	50000	13.3
36 Uniondale W.D.	1610	20041	12.4	24100	15.0	25800	16.0
37 Westbury W.D.	2160	18754	8.7	23780	11.0	35590	16.5
38 West Hampstead - Hempstead Gardens W.D.	1700	25306	14.9	27380	16.1	32030	18.8
Water Companies							
39 Citizens W.S. Co.	4320	27523	6.4	37740	8.7	52770	12.2
40 Jamaica W.S. Co.	6470	101065	15.6	114930	17.7	147500	22.8
41 Long Island Water Corp.	22450(2)	234459	10.4	302870	13.5	395830	17.6
42 New York Water Service							
Glen Cove	4380	23817	5.4	41250	9.4	54630	12.5
Merrick Div.							
East Section	2050(3)	17647	8.6	18870	9.2	26640	13.0
West Section	12820(3)	118963	9.3	133820	10.4	184670	14.4
43 Sea Cliff W. Co.	2250	11618	5.2	13500	6.0	15800	7.0
Non Franchised Areas							
C	720	270	0.4	1440	2.0	3600	5.0
D	1600	701	0.4	3200	2.0	8000	5.0
E	880	342	0.4	1760	2.0	4400	5.0
Total	170610	1300165		1698290		2244000	
Mitchel Field Area	1260)			1710		6000	
Roosevelt Raceway Area	830)						
Bethpage State Park	1190						
Nassau Co. Park (4)	980						
Hempstead Lake State Park	630						
Misc. Parkways	1120						
Total	176620(5)			1700000		2250000	

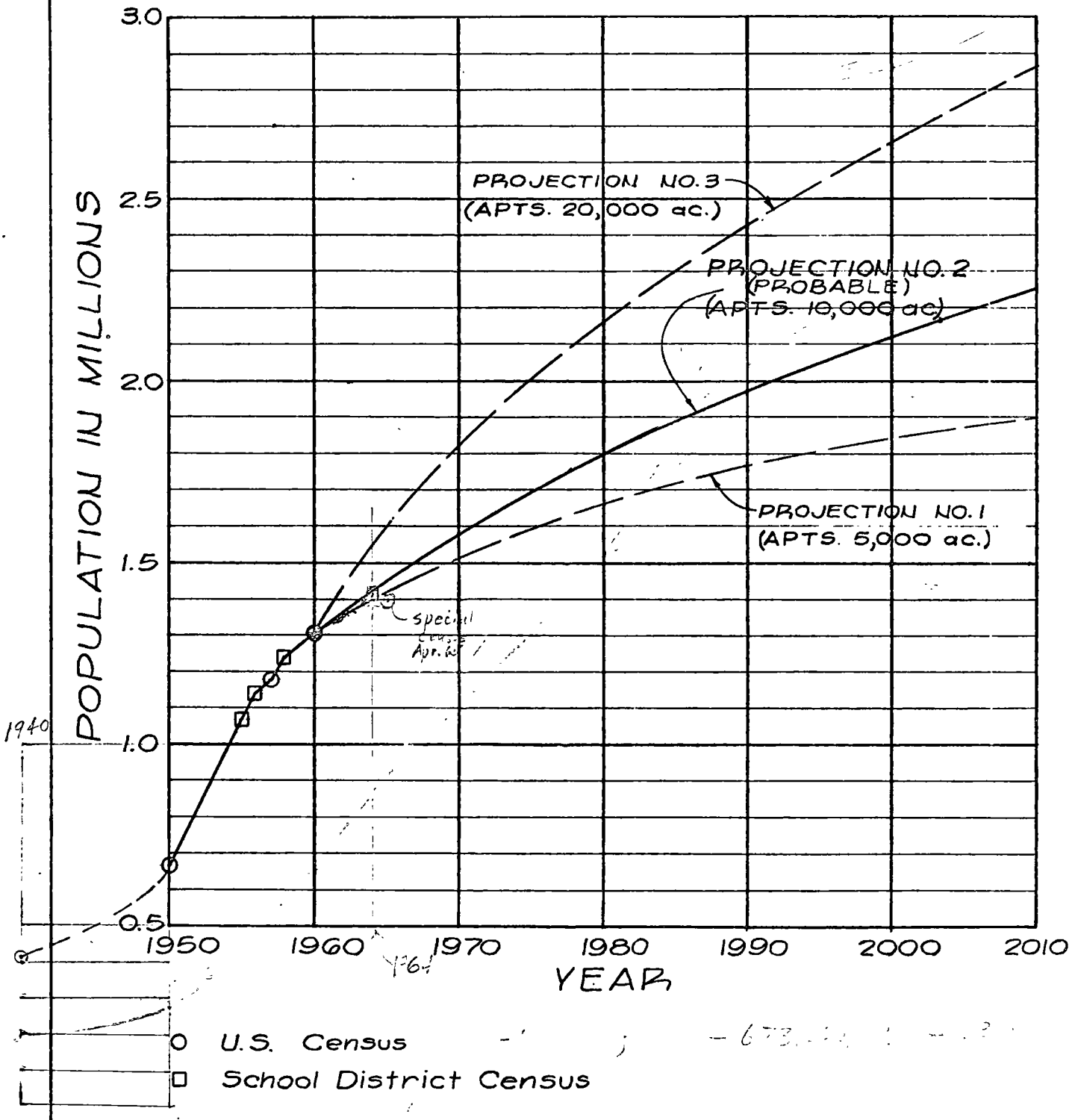
(1) From Census Data.
(2) Mainland plus Island Park Islands and islands in Lawrence corporate limits.
(3) Mainland total area and two islands adjacent to mainland southeast of Freeport.
(4) Including County-owned land east of Carmen Ave. 14.7 ± acres.
(5) Includes islands only as shown on Figure I-1.

TABLE I-5
NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
Estimated Annual Average Pumpage

Water Supply Area	Sq.Mi.	Annual Average Pumpage in MGD 1960 Public Supplies	1960 Ind. & Com.	1960 Total	1975 Public Supplies	1975 Ind. & Com.	1975 Total	(1) 2010 Public Supplies	2010 Ind. & Com.	2010 Total
Sands Point Village	4.25	0.39	0.003	0.402	1.05	0.003	1.05	2.13	0.003	2.133
Port Washington W.D.	6.53	2.46	0 342	2.802	4.22	0.612	4.83	6.45	0.854	7.304
Plandome Village	0.48	0.20	-	0.200	0.38	-	0.38	0.57	-	0.570
Citizens W.S. Co.	6.75	3.06	0.263	3.323	4.48	0.323	4.80	6.86	0.331	7.191
Manhasset-Lakeville W.D.	9.95	4.98	2.308	7.282	9.10	2.863	11.96	15.45	2.962	18.412
Sea Cliff Water Co.	3.52	0.79	0.536	1.326	1.00	0.700	1.70	1.26	0.762	2.022
New York W.S. Corp. Glen Cove Division	6.85	2.46	0.899	3.359	4.54	1.378	5.918	6.60	1.731	8.331
Locust Valley W.D. & Bayville W.D.	10.35	1.37	0.204	1.574	3.42	0.246	3.66	5.97	0.246	6.216
Oyster Bay W.D.	4.19	0.60	0.235	0.835	1.15	0.322	1.47	2.21	0.369	2.579
Roslyn W.D. & Glenwood W.D.	5.50	2.44	0.260	2.700	3.82	0.391	4.211	5.75	0.484	6.234
Old Westbury Village	10.08	0.46	0.005	0.465	1.72	0.006	1.726	3.43	0.006	3.436
Westbury W.D. & Bowling Green W.D.	4.77	3.18	0.505	3.685	4.03	0.663	4.69	6.07	0.729	6.799
Williston Park Village & East Williston Village	1.12	0.94	0.029	0.969	1.11	0.036	1.146	1.41	0.038	1.448
Jericho W.D. & Plainview W.D.	44.20	7.66	2.839	10.499	16.85	4.171	21.021	29.70	5.079	34.779
Jamaica W.S. Co.	10.11	12.09	0.391	12.481	14.70	0.476	15.176	20.60	0.481	21.081
Garden City Park W.D.	3.06	1.85	0.248	2.098	2.35	0.329	2.679	3.13	0.367	3.497
Garden City South W.D. & West Hempstead - Hempstead Gardens W.D.	2.73	2.27	0.056	2.326	2.64	0.067	2.707	3.34	0.067	3.407
Hempstead Village & Uniondale W.D.	6.25	5.22	0.328	5.548	6.73	0.405	7.135	8.25	0.416	8.666
Mineola Village	1.89	2.37	0.274	2.644	3.12	0.339	3.459	4.87	0.350	5.220
Albertson W.D.	2.53	1.11	0.035	1.145	1.73	0.044	1.774	2.54	0.046	2.586
Carle Place W.D.	1.37	0.87	0.543	1.413	1.22	0.807	2.027	1.81	0.992	2.802
Garden City Village	5.43	4.01	0.332	4.342	5.36	0.408	5.768	7.31	0.418	7.728
Franklin Square W.D.	1.62	1.53	0.008	1.538	1.82	0.009	1.829	2.53	0.009	2.539
Hicksville W.D.	7.89	5.40	1.478	6.878	6.35	1.959	8.309	8.02	2.177	10.197
Bethpage W.D.	5.23	2.19	4.816	7.006	3.10	7.250	10.350	4.22	9.010	13.230
Farmingdale Village & So. Farmingdale W.D.	7.02	3.76	0.160	3.920	4.41	0.229	4.639	5.40	0.273	5.673
East Meadow W.D.	5.63	3.25	0.121	3.371	3.69	0.146	3.836	4.20	0.146	4.346
Levittown W.D. & Island Trees W.D.	4.93	4.35	0.504	4.854	4.63	0.606	5.236	5.16	0.606	5.766
Long Island Water Corp.	35.10	19.50	1.326	20.826	26.65	2.103	28.753	38.40	2.709	41.109
Rockville Centre Village	3.50	3.22	0.050	3.270	3.84	0.060	3.900	5.13	0.060	5.190
Freeport Village	5.02	3.03	0.211	3.241	3.81	0.584	4.394	5.11	0.982	6.092
New York Water Service Merrick Division & Massapequa Park W.D.	29.40	10.22	0.354	10.574	12.13	0.928	13.058	17.54	1.529	19.069
Long Beach City	2.30	4.70	0.022	4.722	6.84	0.032	6.872	8.77	0.037	8.807
Lido-Point Lookout W.D.	1.98	0.65	0.012	0.662	3.29	0.014	3.304	5.25	0.014	5.264
Non-Franchised Areas										
C	1.13	-	-	-	0.14	-	0.140	0.40	-	0.400
D	2.50	-	-	-	0.32	-	0.320	0.88	-	0.880
E	1.38	-	-	-	0.18	-	0.180	0.48	-	0.480
Mitchel Field Area & Roosevelt Raceway Area	3.27	0.44	1.650	2.090	0.57	3.200	3.770	1.12	4.658	5.778
Nassau Co. Park	1.53	-	0.253	0.253	-	0.304	0.304	-	0.304	0.304
Bethpage State Park	1.86	0.19	-	0.190	0.21	-	0.210	0.23	-	0.230
Jones Beach State Park	-	0.21	-	0.210	0.25	-	0.250	0.28	-	0.280
Total	273.20	123.42	21.60	145.02	176.95	32.01	208.96	258.83	39.24	298.07

(1) Gross pumpage without deductions for returned water.

FIGURE I-2



NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
POPULATION

GREELEY AND HANSEN

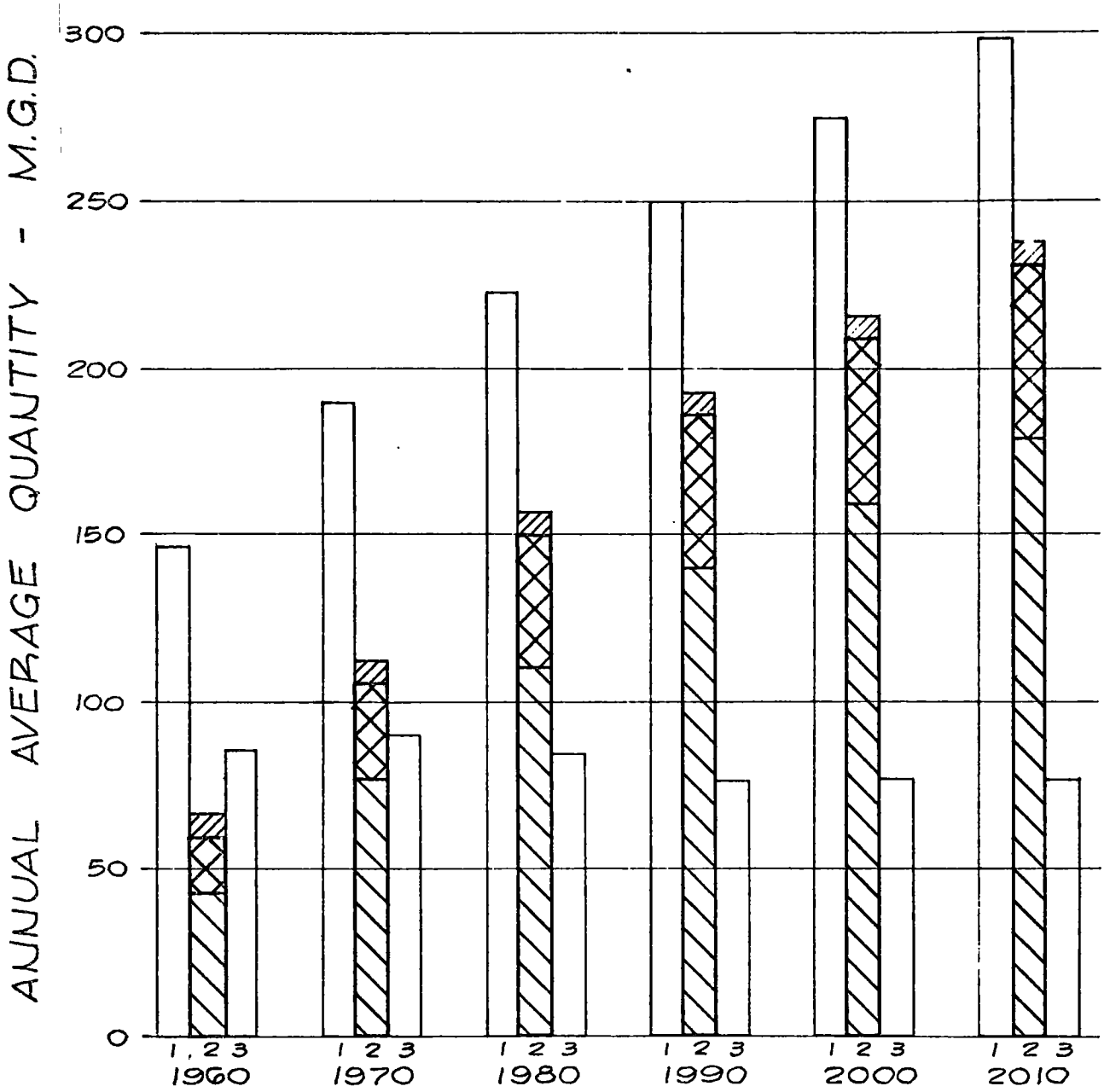
2. Consumptive Use of Water

In order to evaluate the relationship between total pumpage and the water effectively discharged from the underground supply, a use inventory of the total pumpage was made. The several uses were classified into three categories, namely, (1) water returned to ground by cesspools, industrial recharge and leakage from the water mains, (2) water used and lost by sprinkling, and (3) water consumed and discharged to sea, including the accretion by infiltration into the sewers, referred to herein as the required yield.

The water use inventories are shown on Figure I-7 and are summarized as follows:

	Annual Average Quantity (mgd)		
	1960	1980	2010
Total Pumpage	145.0	223.0	298.0
Pumpage Returned to Ground	83.5	84.0	78.0
Loss by Sprinkling	13.0	21.6	33.5
Consumptive Use and Infiltration Discharged to Sea	65.7	156.6	239.0

FIGURE I-7



1 Total Pumped
2 Consumptive Use Discharged to Sea
3 Returned to Ground Water
Domestic Sewage
Infiltration
Industrial Waste

NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
WATER PUMPAGE
CONSUMPTIVE USE
AND RECHARGE

GREELEY AND HANSEN

3. Supplemental Water Requirements

The natural yield, developable without special protective measures against salt water intrusion, is estimated to be about 154.0 mgd and is expected to be adequate until about 1980.

Along the south shore, conditions are suitable for the formation of a barrier to salt water intrusion by injecting reclaimed waste water from the Bay Park and the proposed Seaford sewage treatment works. Such a procedure will permit developing practically all of the fresh water underflow in the Magothy and Glacial strata. Waste water reclamation and recharge in such a line development is recommended and is estimated to add 27.0 mgd to the developable yield. The gross yield with such protective measures is about 181.0 mgd and is expected to be adequate until about 1987.

The approximate areal distribution of the gross yield is summarized as follows:

	Average Gross Yield in mgd
North Slope	55.0
South Slope	126.0(1)
Total	181.0

(1) Including 27.0 mgd recovered by barrier recharge.

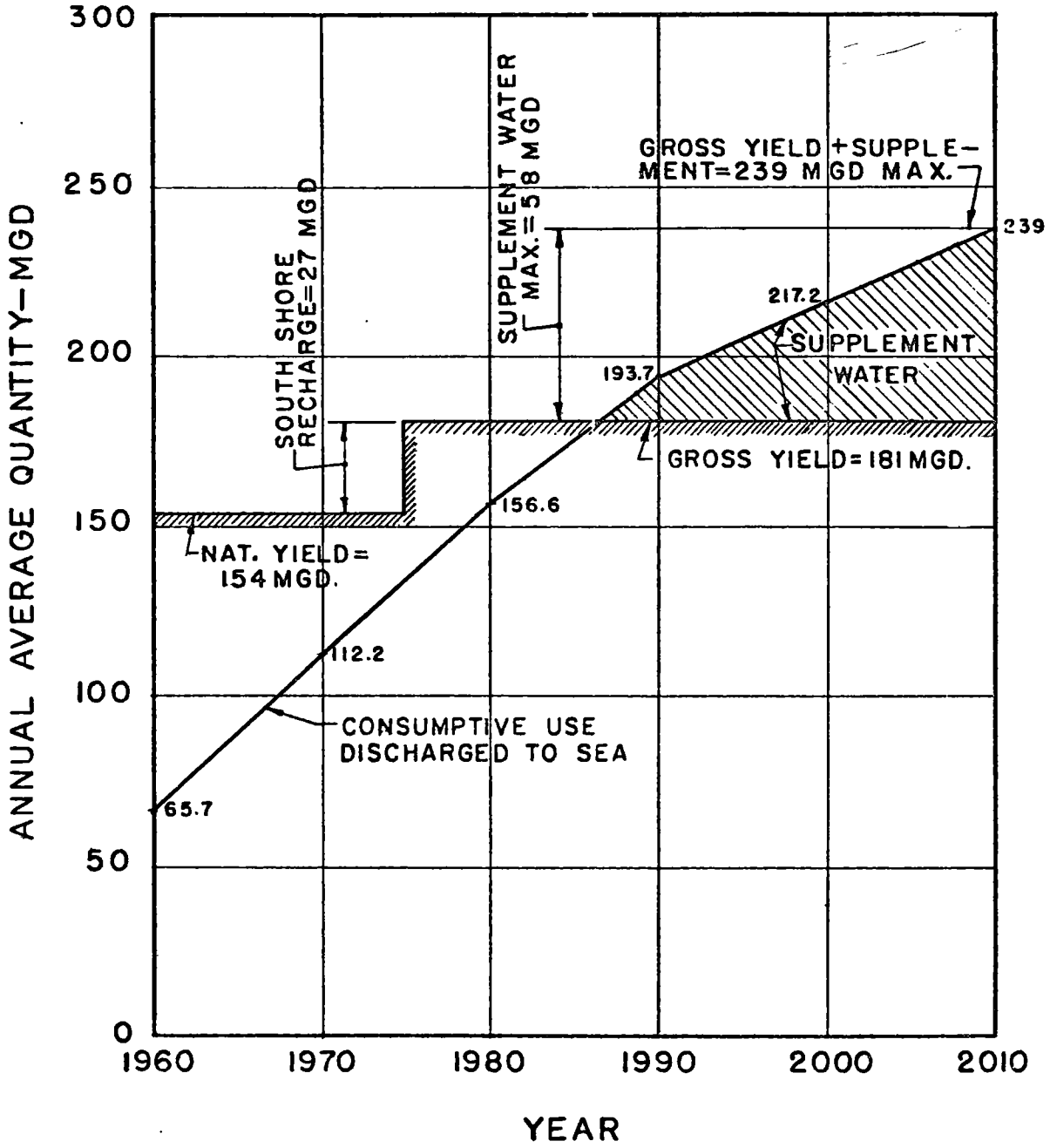
About 1987 a means of supplementing the gross yield is expected to be necessary. The supplement needed, and available by import, waste water reclamation or desalination, increases to an estimated 58.0 mgd, as shown on Figure II-15 and as follows:

	Estimated Annual Average Quantities (mgd)				
Year	Req'd. Total Pumpage	Public Supply Pumpage	Req'd. Yield	Available Yield	Req'd. Supplemental Water (1)
1960	145.0	123.4	65.7	154.0	0
1970	190.0	142.0	112.2	154.0	0
1980	223.0	160.5	156.6	181.0(2)	0
1990	250.0	177.0	193.7	181.0	12.7
2000	274.0	237.5	217.2	181.0	36.2
2010	298.0	258.8	239.0	181.0	58.0

(1) Required yield less available yield.
(2) Includes 27.0 mgd south shore waste water recharge.

A three-year period of deficient precipitations likely to occur once in twenty years averages 35 inches per year. Towards the end of the century, such drought would result in lowering the water table an average of about 8 feet. It is believed that such a temporary lowering can be tolerated, although some near-shore wells may produce water with increased chloride concentrations. A five-year drought of the same magnitude would lower the water table about 13 feet and

FIGURE II-15



NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
YIELD VS CONSUMPTIVE USE

GREELEY AND HANSEN

probably cause material problems with salt intrusion. It is probable that severe restrictions on water use would then be required and should be placed in effect in the third summer of any drought period and maintained through at least one year of excess precipitation.

No drought deficiency of less than 8 inches for three years or less than about 5 inches for five years is estimated to require any curtailment in water use. Such droughts do not affect the period of adequacy of the average yield.

PART II - WATER RESOURCES

1. General

In this section of the Report, the ground water system is analyzed to provide the basis for estimating the available natural yield, or that part of the outflow of ground water which can be developed and used, without return to the ground, without causing detrimental salt water intrusion.

Primary factors in the analysis are the water entering the ground as precipitation, water main leakage and sewage and industrial waste recharge and the water leaving the ground by evaporation, transpiration, runoff and sewage discharged to sea. The method employed includes artificial

sprinkling in the total water loss by evaporation and transpiration. As a result, the term "natural yield" is synonomous with the water consumptively used and discharged to sea, up to that quantity which, if exceeded, will result in detrimental salt water intrusion. When the continued development produces water use and discharge as sewage in excess of this quantity, means of supplementing the natural yield by import from outside sources or by water reclamation procedures must be available.

2. The Natural Yield

The natural yield estimates are based on a water balance analysis of the disposition of the precipitation in the County in recent years and estimates of the proportions of the outflows to salt water which may be reasonably recovered for human use with final discharge to sea via the sewer systems.

Estimates of the present underground outflow to sea employing available geologic data and hydraulic principles are used as a guide in estimating the amount and direction of the outflows in the several water bearing formations. These provide the basis for the estimates of the recoverable fraction of the outflow in each aquifer and the magnitude of future developments on the north and south slopes of the ground water table.

The main catchment area is estimated to comprise 189 square miles. At present, the natural outflows are estimated to be about 20 inches per year, or 180.0 mgd. The underground outflows are estimated to amount to about 11.5 inches per year, or 104.0 mgd, with balance occurring as stream discharge. An additional amount, averaging about 57.0 mgd for 1956 through 1960, inclusive, is discharged as sewage.

The developable natural yield of the 189 square mile main catchment area is estimated to be about 16.6 inches per year, or 150.0 mgd, as indicated in the following water balance summary.

	Annual Amounts in Inches (1)			
	Present Conditions (1956-1960)		Estimate of Natural Yield	
Average Precipitation at Mineola		44.9		43.0
Evapo-transpiration (2)		19.4		20.0
Recharge to Ground Water (Difference)		25.5		23.0
Change in Storage		+ 0.8(3)		0
Subtotal		26.3		23.0
Natural Outflow				
Streams	8.5		0.9	
Deep Underflow	11.5		5.5	
Total		20.0		6.4
Yield (Water used and discharged to salt water)		6.3		16.6

(1) For probable catchment area of 189 square miles one inch per year equals 9.0 mgd.
(2) Including sprinkling loss.
(3) Water level drop.

The Manhasset and Great Neck necks lie outside of the main catchment area. The estimated yield from these minor catchment areas is about 4.0 mgd, which increases the natural yield to a total of about 154.0 mgd.

PART III

DEVELOPMENT OF RESOURCES

1. General

Part III of the Report deals with possible methods of developing the resources, procuring the required supplementary water, and economic comparisons of practical projects for development and distribution of the available resources and the supplementary water.

The bases of design and estimates of costs are given. Costs are related to present day levels and are based on preliminary designs to meet requirements to the year 2010. The estimates of costs of construction and operation of the proposed water supply and transmission facilities are adequate for preliminary financing considerations.

2. Procedures for Future Ground Water Developments

Procedures for increased development of ground water supplies have been discussed and under the following headings:

A. Surface Water Supplies
B. Glacial Supplies
C. Magothy Formation Supplies
D. Lloyd Sand Supplies
E. Existing New York City Supply Works

A. Surface Water Supplies

Less than 10 per cent of the stream flow in Nassau County is surface runoff. The balance is ground water outflow appearing in the streams near the shore. The anticipated depressing of the ground water levels, as export to sea as sewage increases, will decrease the stream flows. Even at present there are only six streams of sufficient size for economical sources of water. Stream flow records indicate that monthly periods of as little as 45 per cent of the average may be expected to occur, on the average, every two years and considerable storage would be necessary to permit developing a yield approximating the average stream flow.

The south slope contains the main streams, but land is highly developed and the topography is unsuitable for large reservoirs. Reservoirs would be shallow with large evaporation and seepage losses.

Nassau County surface waters will continue to be suspect because of pollution, and filtration and chlorination would be necessary to insure bacteriologically safe water from the streams.

Although water can be obtained from the existing Ridgewood System ponds, this is not considered desirable, except as a temporary procedure. Surface water supplies are not recommended.

B. Glacial Supplies

The Upper Pleistoscene formations have been subject to heavy pollution from cesspools. Only about 13 per cent of the total pumpage is from wells in these formations. The construction of sewers eliminates the principal source of pollution, and the quality of the glacial supplies is expected to improve slowly. Complete recovery is unlikely.

Water from the glacial strata is the major contributor to stream flows. The principal works tapping the glacial supplies are the ponds, shallow wells and infiltration galleries of the Ridgewood System owned by New York City.

It is believed that the construction of sewer systems will restore this water horizon to increased importance. The infiltration galleries are considered most effective for developing the shallow horizons. Because of their relatively small effect on ground water levels, galleries are particularly suited to near shore developments recapturing water from the streams and intercepting shallow horizon waters which might otherwise be lost by subsurface

outflow to the bays. The topography of the north shore is not well suited to galleries, although further subsurface exploration might indicate their use in lieu of some near shore wells. It is recommended that the existing Wantagh and Messapequa infiltration galleries, capable of producing about 30.0 mgd, be included in the plans for the ultimate future supply development. Construction of additional galleries is considered in the western portion of the south slope in certain alternates involving maximum development near the shore lines.

Including recaptured stream flows, it is estimated that about 51 per cent, 78.0 mgd, of the natural yield of about 154.0 mgd can be developed from the glacial horizon.

C. Magothy Formation Supplies

The Magothy formation is the present largest producing water horizon. Wells in this formation are generally good producers, and with proper pump and screen settings can be relied on for increased use during peak demands, including some "mining" from the underground storage during periods of deficient precipitation.

Theoretically, all of the 154.0 mgd natural yield could be developed by Magothy wells, accompanied by water table lowering to reduce upper formation outflows to sea.

However, it is estimated that about 47 per cent, 72.0 mgd, of the estimated 154.0 mgd natural yield, will be developed from the Magothy formation. An additional 27.0 mgd is expected to be recoverable by practicing waste water recharge to form a salt water barrier along the south shore.

D. Lloyd Sand Supplies

Water from the Lloyd sand is pumped near the shores, in particular on Long Beach. Available data appear to indicate a present overdraft on this aquifer, accompanied by an as yet undetected salt water intrusion from the south.

It is expected that future anticipated lowering of the water table will decrease recharge to the Lloyd sand.

Recognizing the probable future "salting" of Lloyd wells on Long Beach, the presence of iron in the water there in substantial quantities, and the distribution and intensity of future water needs, it is recommended that the Lloyd sand use be limited to the existing facilities in the northwest and on Jones Beach along the south shore, and a limited number of new wells along the north shore. All development alternates include provisions for supplying Long Beach island with water from the mainland.

The Lloyd sand is expected to produce only about 2 per cent, about 4.0 mgd, of the estimated natural yield of about 154.0 mgd.

E. Existing New York City Supply Works

The City of New York maintains supply works in Nassau County, generally located along Sunrise Highway and comprising Ridgewood Water Supply System. This system formerly supplied about 50.0 mgd from Nassau County to Brooklyn. Modernization and electrification of the works was carried out in the 1930s and 1940s. Since 1950, the works have been used only in 1953 and 1954, and again in the fall and winter of 1957-58 when the Catskill Aqueduct was out of service for cleaning and inspection.

At present, the "East Watershed" works are maintained in a ready reserve status. The works west of Freeport, with the exception of a 72-inch diameter steel main, have been declared surplus. It is understood that New York City proposes to maintain the East Watershed works on reserve status until improvements to their main city supply tunnels are completed in about 1975. Certain improvements now under way might make the Nassau works unnecessary after about 1965, but we are advised there is no means of determining this in advance.

The West Watershed works in Nassau County, now declared surplus, comprise the following principal facilities:

1. The Clear Stream and Watts shallow well field stations with a total capacity of 8.0 mgd.

2. A brick horseshoe section, gravity conduit, from the Hempstead Storage to the Queens County line.

3. Two 48-inch diameter cast-iron low pressure mains extending from the Milburn Pumping Station in Freeport to the County line, and a 36-inch cast-iron main extending from Freeport to the brick conduit near Smith's Pond.

4. An abandoned steam powered pumping station at Smith's Pond.

5. The Hempstead Storage Reservoir and Hempstead Pond formerly yielding about 8.0 mgd by gravity flow through the brick conduit. It is understood that most of the lands surrounding these two ponds have been transferred to the Long Island State Park Commission and Nassau County for recreational uses.

The East Watershed works, which are maintained in a "ready reserve" status, comprise the following:

1. The Massapequa and Wantagh infiltration galleries with a total rated output of 30.0 mgd.

2. Five shallow well stations, Massapequa, Wantagh, Matowa, Merrick and Agawam, with a total rated capacity of 31.0 mgd.

3. The East Meadow Pond, Wantagh Ponds and Massapequa Pond, with a reported total yield of about 14.0 mgd.

4. A brick gravity conduit from the Massapequa Pond to the Milburn Pumping Station.

5. A 72-inch steel main extending across the County. East of the Milburn Pumping Station this is operated as a low pressure collector. West of the pumping station the main is under the Brooklyn distribution system pressure.

6. The Milburn Pumping Station in Freeport, including four pumps with a rated capacity of 35.0 mgd, discharging directly to the Brooklyn distribution system. Three additional pumps with a rated capacity of 70.0 mgd, formerly discharged to the low pressure system, now inactive.

Based on examination of general information relating to the Ridgewood Water Supply System, the following conclusions can be stated with respect to the applicability of these works in plans for additional water supply development in Nassau County:

1. The pond supplies are not considered to have future use.

2. The driven wells are considered to have indeterminate additional life, and to be of potential use only as interim, additional capacity facilities. They are not included in development alternates.

3. The infiltration galleries are considered to be well adapted to future supply use and are included in development alternates.

4. The brick gravity conduits are considered to be of no potential use in any development scheme.

5. The two 48-inch cast-iron mains from Milburn Pumping Station to the County line can be utilized, in part, in transmission works in the southwest part of the County, but are subject to further verification of safe operating pressures.

6. The retention of the East Watershed facilities and the 72-inch diameter steel main by New York City until about 1975 may prevent early acquisition and use by Nassau County of the most valuable elements of the Ridgewood System.

7. Temporary use of the two driven well stations in the West Watershed in the County would be possible, and the additional pumpage, about 8.0 mgd, could be of some temporary help in meeting increased needs in the southwestern section of the County. This would not be necessary if the East Watershed works were available immediately.

8. The ability of the East Watershed works to develop and export 35.0 mgd or more is not expected to present any difficulties until construction of sewers is advanced in proposed Sewer District No. 3. At such time a continued draft by New York City may cause an undesirable water table recession in the southeast part of the County.

3. Supplement Water

Procedures considered for supplementing the 181.0 mgd gross yield included the following:

A. Purchase of water from New York City or Suffolk County.

B. Reclamation of waste water.

C. Saline water conversion.

The possibility of operation of supply works outside of the County has been considered. Such supply works might be in Queens County, Suffolk County, or on the mainland. This possibility is considered to be quite remote and much involved in legal complications. A more practical approach appears to lie in the negotiating of long term water purchase agreements. The purposes of this study are served by consideration of outside supplement water as a possibility and considering the cost of outside supply or purchase to

be equal in comparisons with other means of making available the additional amounts of water entirely within the County.

The following paragraphs summarize the general features of these procedures for supplementing natural yield and the consideration given to them in the studies of supply project alternates.

A. Purchase of Water

Purchase of water from New York City is a possibility if the City's planning provides capacity for Nassau County's needs for supplement water and the price provides a reasonable return on the additional capital investment. This has not been included in the City's plans up to the present. Present plans for improvement of the distribution system in the City are understood to include a third tunnel by about 1975, extending from the Bronx into eastern Queens. Having in mind that capacity could readily be provided in such a tunnel, it is suggested that negotiations be undertaken to ascertain the possible terms of such an agreement to supply Catskill water to the County when this tunnel is completed, about 1975.

Delivery of purchased water has been considered at two locations, a connection through the 72-inch steel main of the Ridgewood System in the south, and a second connection

to a new transmission system near North Hempstead Turnpike in the north. Alternates have been studied where the purchased water is all taken in the south and also when divided between the foregoing points, as follows:

	Annual Average Quantity in 2010 mgd
One delivery point near Sunrise Highway	58
Two delivery points	
near North Hempstead Turnpike	7 to 13
near Sunrise Highway	51 to 45
Total	58

It is assumed that the delivery pressure would be about the same as now present in the 72-inch main near the County line. Purchased water would be taken at approximately the annual average rate. A purchase agreement might provide an annual payment related to the proportional fixed costs of the capacity used by Nassau County, and a charge for water actually taken. Such charges cannot now be estimated. A preliminary estimate of $150 per million gallons has been used.

Purchase of water from Suffolk County has also been considered, with delivery at the end of the 72-inch steel main of the Ridgewood System near Sunrise Highway and the County line. This alternate has not been discussed with

Suffolk County authorities. The availability of as much as 58.0 mgd is based on the reported yield of the Suffolk County sources as being at least 400.0 mgd and an estimate that the requirements would not exceed 300.0 mgd until the Suffolk County population increased to four times that in 1960. A cost of $150 per million gallons has been used in preliminary considerations. It is not entirely clear as to how the existing law which blocked the extension of the Ridgewood System into Suffolk County would affect such a sale of water and such purchases could not start until after 1975, when the 72-inch steel main of the Ridgewood System is presumed to be available.

Water might also be taken simultaneously from New York City and Suffolk County without significant changes in the transmission systems, since the existing 72-inch main of the Ridgewood System would be the primary distributor.

B. Reclamation of Waste Water

Waste water from the sewage treatment plants can be reclaimed by supplementary treatment and re-used to permit an effective increase in the natural yield. The two basic procedures can be summarized as follows:

1. Injection into the ground to maintain subsurface outflow while permitting increased withdrawal of fresh water further inland, or spreading or injection as direct recharge of the underground water body.

2. Direct introduction into the mains for re-use, used to date only for irrigation systems and industrial water supplies.

Underground injection of reclaimed sewage treatment plant effluent has been accomplished in pilot scale operations in California, which show that the effluent from an activated sludge plant can be injected into an aquifer with minimal operating difficulties if chlorinated and filtered. Such a treated waste water can be injected near the shore lines to maintain the outflow and prevent salt water intrusion at specific locations. It can also be injected at some distance from the shores where it will mix more generally with the fresh water recharge.

The first procedure is most effective in artesian aquifers and can be used in unconfined aquifers, although the absence of an impervious overburden reduces the effective capacity of each well. Clay lenses are present in the Magothy formation, and it is believed that careful well location would permit these lenses to act as localized pressure caps, permitting an approach to artesian conditions. This barrier procedure minimizes introduction of injected water into pumping wells. In Nassau County, it is well suited to the south shore and can be used to permit practically full development of the outflow to the south in the Magothy. An estimated additional 27.0 mgd of

fresh water can then be pumped without concern about salt water intrusion. This procedure is incorporated in all supply development alternates. The preliminary design includes rapid sand filtration plants at Bay Park and the proposed Seaford plant for post-treatment of the activated sludge plant effluent. The chlorinated, filtered water will be conveyed in pressure mains to injection wells across the County about one mile south of Sunrise Highway.

The effects of such injection will be most readily observed in the Woodmere-Hewlett area, where salt water has already been noted beneath the Gardiners clay under artesian conditions.

A pilot program at the Bay Park sewage treatment plant is recommended to establish final design criteria for the wells and waste water treatment facilities. An exploratory drilling program is recommended along the proposed injection well line to define the formations for final siting of wells.

The second procedure is inland recharge, either by wells or by recharge basins. In this procedure, waste water is recycled, continuously diluted by fresh precipitation recharge, and largely recovered by the pumping wells. Properly designed and operated works, combined with final chlorination at the pumping wells, will permit maintaining safe water supplies. Using this procedure to obtain the

58.0 mgd supplement to the gross yield of about 181.0 mgd, obtained with barrier recharge, results in about 25 per cent of the water consumed being re-used. Theoretical continuous recycling in the ratio of 1 to 3 would produce an equilibrium at about 50 per cent of the concentration of dissolved materials present in the injected water. In practice, the concentrations would vary considerably at the pumping wells.

The characteristics of the Bay Park treatment plant effluent indicate that post-treatment by filtration and chlorination will produce a high quality reclaimed water meeting or bettering all drinking water standards of the United States Public Health Service. No analyses are available for detergents, but it is expected that there would be less than 1.0 mg/l as ABS in the reclaimed water and would cause no difficulties. Experimental work with the Hyperion Plant effluent, in reclamation and injection work by the Los Angeles Flood Control District, substantiates these conclusions.

The alternate inland recharge procedure is by recharge basins. These would be similar to the highly successful storm water recharge basins and located in the same general area. The waste waters would be pretreated by filtration and chlorination, as for injection wells. Basins would be

in duplicate, with each unit designed for the expected average rate of application, and the second unit permits cleaning, intermittent application and reserve capacity for drought periods. Each unit is designed for a percolation rate of 75 gsfd. The basin procedure is likely to result in greater mixing of recharged waste water in the general ground water body.

Re-use of waste water directly to maintain stream flows and pond levels has been considered. The procedure is not as suitable as recharge for water supplement purposes and has not been included in alternate procedures in the detail studies. It should be noted that the injection and recharge basins procedures for reclamation will also assist in maintaining water levels and stream flows.

Provision should be made for mandatory use of reclaimed water for sprinkling where transmission mains are near to parks, golf courses and public buildings with large landscaped grounds at a nominal charge for water used.

Waste waters have been reclaimed and returned directly to mains for direct re-use in industrial processes. No direct re-use for domestic purposes has been regularly practiced in the United States, and this is not recommended at this time in Nassau County.

C. Salt Water Conversion

Saline water conversion procedures have been reviewed. This study is limited to the next fifty years and at present relative cost levels, desalination offers no economic advantage over other available procedures. Desalination may become necessary in Barrow Creek in the future, but is not included in the proposed procedures.

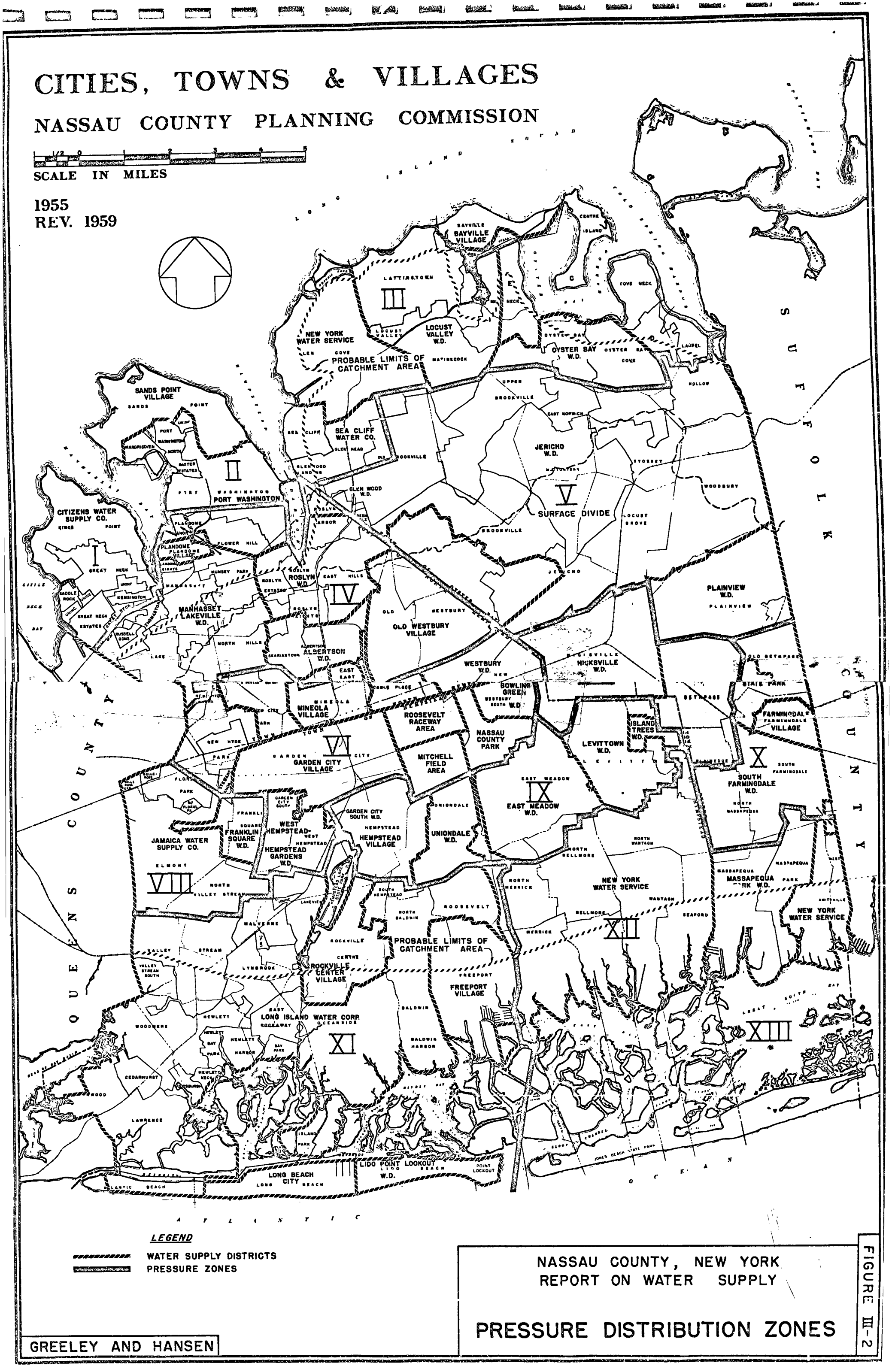
4. Bases of Design

A. Pressure Distribution Zones

The various water districts operate with system pressures adopted locally and not necessarily compatible to joint-use works and system interconnections. It is proposed to co-ordinate existing distribution pressures into thirteen zones, as shown on Figure III-2. Zone boundaries are based on existing water district boundaries, ground elevations, and minimal changes from present pressures.

B. Design Capacities

The estimates of required well capacity are based on maximum day rates with a ten per cent allowance for reserve capacity. Maximum day rates are estimated to vary with population from 300 per cent of the annual average for less than 10,000 persons to 200 per cent for populations of 50,000 or more.


CITIES, TOWNS & VILLAGES
NASSAU COUNTY PLANNING COMMISSION
SCALE IN MILES
1955
REV. 1959
BAYVILLE VILLAGE
LATTINGTOWN
NEW YORK WATER SERVICE
LOCUST VALLEY W.D.
PROBABLE LIMITS OF CATCHMENT AREA
OYSTER BAY W.D.
SANDS POINT VILLAGE
SEA CLIFF WATER CO.
JERICHO W.D.
PORT WASHINGTON
GLEN WOOD W.D.
SURFACE DIVIDE
CITIZENS WATER SUPPLY CO.
PLANDOME VILLAGE
ROSLYN W.D.
PLAINVIEW W.D.
MANHASSET LAKEVILLE W.D.
OLD WESTBURY VILLAGE
ALBERTSON W.D.
WESTBURY W.D.
HICKSVILLE W.D.
BOWLING GREEN W.D.
MINEOLA VILLAGE
ROOSEVELT RACEWAY AREA
NASSAU COUNTY PARK
FARMINGDALE VILLAGE
LEVITTOWN W.D.
GARDEN CITY VILLAGE
MITCHELL FIELD AREA
SOUTH FARMINGDALE W.D.
EAST MEADOW W.D.
JAMAICA WATER SUPPLY CO.
FRANKLIN SQUARE W.D.
WEST HEMPSTEAD-HEMPSTEAD GARDENS W.D.
GARDEN CITY SOUTH W.D.
HEMPSTEAD VILLAGE
UNIONDALE W.D.
NEW YORK WATER SERVICE
MASSAPEQUA PARK W.D.
PROBABLE LIMITS OF CATCHMENT AREA
ROCKVILLE CENTER VILLAGE
FREEPORT VILLAGE
EAST LONG ISLAND WATER CORP.
LIDO POINT LOOKOUT W.D.
LONG BEACH CITY
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
LONG ISLAND SOUND
ATLANTIC OCEAN
NASSAU COUNTY
QUEENS COUNTY
SUFFOLK COUNTY
LEGEND
WATER SUPPLY DISTRICTS
PRESSURE ZONES
NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
PRESSURE DISTRIBUTION ZONES
FIGURE III-2
GREELEY AND HANSEN

Proposed transmission mains are designed for about 160 per cent of annual average requirements. However, in localized areas, larger transmission mains providing capacity equal to the maximum day needs are provided. Storage requirements are estimated at 20 per cent of the maximum day demand, based to meeting future hour requirements with supply system deliveries and local pumping supplying water at the maximum day rate. Ground storage tanks are used in these preliminary designs, with booster pumps delivering the stored volume in 4.8 hours.

New supply works are to include facilities for corrosion control and chlorination using lime, polyphosphates and liquid chlorine, automatically fed proportional to the metered rates of flow.

Construction and operation cost estimates are based on present Nassau County cost levels. Debt service charges are based on a simplified assumption that principal and interest payments would be uniform at 5.44 per cent per year for 3-1/2 per cent 30-year bonds. Imported water is assumed to be purchased at the County line at the rate of $150 per million gallons.

5. Projects

The alternate projects analyzed recognize several sources of supplements to the natural yield:

a. Import from New York City

b. Import from Suffolk County

c. Reclamation of treated sewage or salt water desalination

and two basic procedures for location of new internal supply works:

a. A spread development with wells located near the points of use.

b. A linear development near the shores for base production, the annual average pumpage, plus peak period supply for wells located near the points of use.

Preliminary consideration of various problems has resulted in certain assumptions which are uniform to all alternate projects, as follows:

a. Purchased supplement water will be taken at approximately the annual average rate. In all alternates involving purchased water, it is expected to be received at either the east or west end of the 72-inch main of the New York City Ridgewood Water Supply System. In certain alternates, an additional point of taking is considered in the northwest corner of the County.

b. Works developed to supply water to remote areas are conceived as base load facilities, with maximum capacities equal to the maximum month rate, about 160 per cent of the annual average rate, except as specifically noted.

c. Peak demands exceeding 160 per cent of the annual average rate are to be met by wells and tanks located within the district experiencing the demand, except for the following cases:

   (1) All demands on Long Beach island are to be met ultimately by mainland facilities, with the Lloyd sand wells expected to be salted at some time in the future.

   (2) The recharge of the Manhasset and Great Neck necks is estimated to be capable of supporting continued pumping at approximately the present annual average rate. All increases in total requirements and peak demand rates on the necks are assumed to be met by works within the main catchment area.

d. It is proposed that pumping from the Lloyd sand be ultimately limited to Jones Beach and portions of the north shore, including Manhasset, Great Neck, Bayville and Centre Island.

e. Existing wells, tanks and booster pumping stations, and replacements thereto, are assumed to be a continued part of the supply works without capital expense, except for modifications for different operating pressures and extensions to existing control systems.

f. Portions of the New York City Ridgewood Water Supply System are assumed to be ultimately incorporated into the supply system. These elements comprise the 72-inch steel main across the County, the Milburn Pumping Station, and the Massapequa and Wantagh infiltration galleries. The driven well stations and the two 48-inch cast-iron mains across the western half of the County to about Freeport are considered to be interim facilities which would be replaced by other works.

g. Annual cost comparisons are based on the year 2000, approximating the average of the period of supplement water needs, about 1987 to 2010.

Thirteen alternate plans for well development, providing supplement water, and transmission facilities, were analyzed without detailed cost analyses. Eight alternates were selected for full studies, with preliminary design of facilities and cost estimates.

Outline descriptions of these alternates are as follows:

Alternate 1-A

1. Spread plan for location of wells.
2. Import up to 58.0 mgd in 2010 from New York City at existing 72-inch main near Sunrise Highway.
3. Acquire and operate the Massapequa and Wantagh infiltration galleries, the 72-inch steel mains, and the Milburn Pumping Station from New York City.
4. Necessary transmission system, booster pump stations and storage tanks.
5. Reclaimed water injection well system along the south shore to inject an average of 27.0 mgd.

Alternate 2-A

1. About one-half of the total yield to be developed along the north and south shores, and balance from inland area.
2. Import up to 58.0 mgd in 2010 from New York City at existing 72-inch main near Sunrise Highway.
3. Balance of yield to be developed by wells over entire catchment area.
4. Massapequa and Wantagh infiltration galleries, 72-inch main, and the Milburn Pumping Station of the New York City Ridgewood System to be acquired and incorporated into the system.

5. Transmission system and appurtenances.

6. The 27.0 mgd south shore reclaimed water injection system.

Alternate 2-B

1. Same as Alternate 2-A, except that the import from New York City is assumed to be split with 13.0 mgd taken in the northwest and 45.0 mgd taken in the southwest parts of the County.

Alternate 3-B

1. Estimated 2010 requirements to be developed near the shores.

2. Import 58.0 mgd from New York City with 13.0 mgd taken in the northwest and 45.0 mgd taken in the southwest parts of the County.

3. Massapequa and Wantagh infiltration galleries, 72-inch main, and the Milburn Pumping Station of the New York City Ridgewood System to be acquired and incorporated into the system.

4. Besides wells, the shore line development is to include two new infiltration galleries along Sunrise Highway.

5. Transmission system and appurtenances.

6. The 27.0 mgd south shore reclaimed water injection system.

Alternate 4-A

1. This alternate is similar to Alternate 1-A, except that the 58.0 mgd imported from New York City is replaced by an addition to the yield accomplished by mid-County injection wells to permit return of reclaimed waste water. A like capacity in pumping wells is provided along with transmission mains principally to the southwest and northwest sections of the County.

Alternate 4-B

1. This alternate is similar to Alternate 4-A, except that the 58.0 mgd recharge in the center of the County is accomplished by recharge basins instead of by injection wells.

Alternate 5-A

1. This alternate differs from Alternates 2-A and 2-B, in that the estimated yield from within the County is increased by 58.0 mgd by waste water recharge in the middle of the County and no import from outside is required. The amount to be developed along the north and south shores will increase to 57.0 mgd and 46.0 mgd, respectively. The balance of pumpage has been distributed approximately uniformly throughout the catchment area.

Alternate 5-B

1. This alternate is similar in all respects to Alternate 5-A, except that the recharge of 58.0 mgd in the center of the County is accomplished by recharge basins instead of injection wells.

The estimates of total cost for construction and annual costs for operation, maintenance and debt service in 2000 are summarized as follows:

Alternate	Estimated Amount in $1,000's Total Cost of Proposed Works	Total Annual Cost in 2000	Cost per 1000 gallons in 2000
Supplement Water Purchased			
1-A Spread Development	$58,880	$13,302	$0.154
2-A Partial Line Development	60,810	13,100	0.152
2-B Partial Line Development with Purchased Water Delivered at Two Locations	58,750	12,971	0.150
3-B Full Line Development with Purchased Water Delivered at Two Locations	72,600	14,215	0.165
Supplement Water By Recharge Of Reclaimed Waste Water			
4-A Spread Development with Recharge By Injection Wells	$83,300	$14,187	$0.164
4-B Spread Development with Recharge By Basins	76,143	13,797	0.159
5-A Partial Line Development with Recharge By Injection Wells	89,850	14,699	0.170
5-B Partial Line Development with Recharge By Basins	83,215	14,228	0.165

All of the above estimates are based on present cost levels for construction and operation and maintenance of the works and do not reflect the effect of future increase in costs on

the actual fund requirements at any given time. They also do not include allowances for acquisition of existing facilities which would be the same for all alternates.

Total annual costs for Alternates 1-A, 2-A and 2-B in 1994 are somewhat lower than the annual cost for Alternate 4-B. In 2010, the annual cost for Alternate 4-B becomes the lowest.

An analysis has been made of the intangible factors affecting the selection of the most desirable alternate. Based on the relative merits of the several projects on all factors, and giving material weight to the adaptability of the projects to meeting the early needs for local deficiencies, particularly in the northwestern part of the County, and the ability to be modified by deferring construction of any part in favor of another source of supplement water, it appears that Alternate 4-B presents the greatest capabilities and flexibility.

An additional factor, not within the scope of this water supply study, but affecting the inland recharge alternates, such as Alternate 4-B, is the possibility of locating sewage treatment works inland and near the waste water recharge areas. In these studies, it has been assumed that all recharged waste water in the eastern portion of the County would be obtained from the proposed site

of the single plant for SDD No. 3 in Seaford. If a portion of the necessary sewage treatment works were to be located inland in the approximate latitude of Hicksville, reclaimed waste water could be returned to the ground in this area with little or no pumping cost and with commensurate reduction in transmission main costs. Based on the preliminary designs, the capacity of the recharge basins which could be served from such a plant is estimated to be about 33.0 mgd. In addition, such inland treatment works might be arranged to receive sewage from inland portions of the SDD No. 2 sewer system.

Inland treatment and recharge works may also permit early inland sewer service, while deferring construction of some major interceptors and portions of the proposed Seaford plant. Such a situation may now exist in the vicinity of Mitchel Field and the existing Air Force treatment plant, for this base might be used as an interim disposal works for a part of SDD No. 3 and as a pilot installation to fully refine the operating results and design parameters for future recharge basins.

The recommended project is Alternate 4-B, comprising a spread location of wells, mid-County waste water recharge by basins, and includes a line injection system along the south shore and the acquisition of the existing Wantagh

and Massapequa infiltration galleries and appurtenances from New York City. The recommended project is shown on Plate A.

6. Suggested Construction Schedule

The construction program is based on present considerations of areas and times of need and must be reviewed periodically to suit developments. The program for the recommended project is indicated on Plate A and summarized in the following paragraphs:

Stage 1 - Prior to 1970

The first stage of the construction program is designed to provide capacities adequate until about 1975. The principal elements, having an estimated total cost of $15,200,000, comprise the following:

1. The first stage of the wells and transmission mains serving the Manhasset and Great Neck necks.

2. The connecting main from Sunrise Highway to Long Beach and Lido-Point Lookout, including an interim connection to one of the existing 48-inch cast-iron mains of the New York City Ridgewood System and interim activation of the Clear Stream and Watt's Pond driven well stations. The expense of preparing for the interim use of these wells is estimated to be $220,000.

3. Additional wells and storage tanks at various locations.

Stage 2 - 1970 to 1980

The additional works in this stage provide capacity until about the year 1985. It is assumed that the East Watershed works of the New York City Ridgewood system will be acquired during the latter part of this decade. The line recharge system along the south shore will be constructed. The principal elements, having an estimated total cost of $19,550,000, comprise the following:

1. The acquisition and integration of the Massapequa and Wantagh infiltration galleries, the Milburn Pumping Station, and the 72-inch steel main of the New York City Ridgewood System.

2. The waste water treatment facilities at the Bay Park Treatment Plant and the related injection well system. These are included in the first half of this decade.

3. The waste water treatment works at the proposed Seaford plant of SDD No. 3 and the related injection well facilities. These are included in the second half of this decade.

4. Additional wells, tanks and minor connecting mains at various locations.

Stage 3 - 1980 to 1990

The additional works in this stage provide capacity until about 1995. The principal elements, having an estimated total cost of $20,590,000, comprise the following:

1. The initial stage of a transmission main from the Westbury-Jericho area to the southwest section and related wells.

2. The enlargement of the waste water treatment works at Bay Park and the construction of the mid-County recharge basin system related thereto.

3. Further extension of the transmission mains and well facilities serving the northwest area and the necks.

4. Additional wells, tanks and connecting mains at various locations.

Stage 4 - 1990 to 2010

The additional works in this stage provide capacity to the end of the design period, 2010. The principal elements, having an estimated total cost of $21,023,000, comprise the following:

1. The enlargement of the waste water treatment facilities at the Seaford plant and the construction of the related mid-County recharge basin facilities. (It should be noted that upsewer treatment works may possibly eliminate the need for expansion of treatment facilities for reclaimed water at Seaford and the major north-south transmission main.)

2. Further extension of the transmission mains and wells into the Jericho area to serve the northwest and southwest sections.

3. Additional wells, mains, tanks and booster pumping stations at various locations.

The estimate of cost for the staged construction amounts to $76,363,000, and includes interim facilities at a cost of about $220,000 more than if constructed at one time. These interim facilities are included to provide readiness to serve Long Beach in the event of early salting of the Lloyd wells, because it is understood that New York City plans to retain the eastern part of its Ridgewood system until about 1975, including the 72-inch steel main and the infiltration galleries included as permanent elements of the recommended project.

The preliminary designs of facilities for additional treatment of waste water from the sewage treatment plants and of the injection and recharge facilities, are based on established procedures in water treatment, modified by data from water reclamation and injection studies, principally in California. It is recommended that a pilot program be instituted at the earliest practical date in order to permit development of final designs for the waste water treatment and recharge works well in advance of the need. The principal components of the pilot program would comprise:

a. Studies at the Bay Park Treatment Works comprising operation of a pilot waste water treatment plant incorporating various processes and equipment, together with a pilot injection well and observation wells.

b. Pilot studies related to the recharge basins at the existing Mitchel Field Treatment Plant, if possible, comprising the operation of a pilot water treatment plant using procedures developed in the program at Bay Park, and the operation of a pilot recharge basin and observation wells. This program would also have the objective of determining the extent of mixing of the reclaimed water with the underground supply and its effect on water quality.

c. A test drilling program to precede the construction of line recharge system along the south shore. This would comprise drilling to determine relatively shallow subsurface geology, particularly the location and probable extent of clay strata and drilling a limited number of wells to the bottom of the Magothy formation. The deep wells would be logged and pumped for determination of formation constants and equipped as observation wells for deep strata piezometric heads and possible salt water intrusion.

These pilot studies are estimated to require a total of $600,000, allocated as follows:

Year	Amount
1964	$ 70,000
1965	125,000
1966	170,000
1967	120,000
1968	115,000
Total	$600,000

It is recommended that the pilot program be included in the annual County budgets for 1964 through 1968, inclusive.

The total estimated fund requirements for the proposed construction, including the recommended pilot testing program and interim facilities, are summarized as follows:

Stage		Estimated Total Cost(1)
No. 1 - Before 1970		
	Permanent Facilities	$14,980,000
	Interim Facilities	220,000
	Pilot Study Allocation	600,000
	Subtotal	$15,800,000
No. 2 - 1970 to 1980		19,550,000
No. 3 - 1980 to 1990		20,590,000
No. 4 - 1990 to 2010		21,023,000
Subtotal	Permanent Facilities	$76,143,000
	Interim Facilities	220,000
	Pilot Study Allocation	600,000
Total		$76,963,000

(1) Related to national average Engineering News-Record Construction Cost Index = 900. Includes land and 20% for contingencies, engineering and miscellaneous.

PART IV

Administrative and Financial Considerations

IV-1. General

At present, the water supply activities of the County Department of Public Works are limited, in general, to advisory functions with respect to the regulation of water resource use by the Water Resources Commission, the fostering and development of cooperation between existing water supplying agencies, and the development of water resource and use data and information, including cooperative work with State and Federal agencies.

Water service is now furnished to the largest part of the present population of the County by the five water companies. The balance is served by 38 separate municipal water departments and water districts, including the town districts such as Levittown, East Meadow and Uniondale.

The water needs and the areas where additional supply developments can be made contravene existing political boundaries. Existing laws permit the formation of town water districts embracing the whole town, and the scope of town water supply and distribution activities could be so extended. Consolidation of water supply responsibilities in the towns would simplify the control problems. It would still leave the need for co-ordinating authority and

for an agency to develop and operate recharge works benefiting all users. It can in fact be argued that the best ultimate solution to the water supply problem may lie in an island-wide approach, with one agency either carrying out all supply activities or acting as an authoritative co-ordinator of operations and financing activities. Considering all factors, it appears inevitable that the County's role must be materially increased to meet the challenge imposed by present and future geographic maldistributions of the needs and resources.

Three alternate definitions of broadened County activities are as follows:

Plan A. Regulation and supervision.

Plan B. Wholesale water supply.

Plan C. Retail water supply.

The responsibilities of a County agency under these three plans are outlined as follows:

Plan A - Regulation and Supervision

Under this plan, a County agency would regulate and control the construction of wells and major transmission system works to conform to a comprehensive plan. Actual operation of the supply works might gradually be consolidated under three town water districts. This program requires power to

(1) Enforce inter-district cooperative agreements for sale and transmission of water.

(2) Assist in financing works required in one franchised area or district for the benefit of another franchised area or district and to levy County-wide taxes and sell bonds for this purpose.

(3) Finance and construct water conservation or recharge works and to enter into contracts with other County agencies, districts or companies for the operation and maintenance thereof.

(4) Carry on research and investigations beneficial to water resource development, conservation or protection on a County-wide basis.

Plan B - Wholesale Water Supply

Under this plan, a County agency would supply water wholesale to existing districts, companies or municipalities. The County agency would construct and own all new public supply works and acquire existing works. This program requires power to

(1) Establish a County-wide, or other comprehensive districts or water service areas.

(2) Construct and acquire wells, transmission mains, storage and pumping facilities, treatment facilities and other appurtenances.

(3) Operate and maintain such works or to lease them or to contract for their operation and maintenance by others.

(4) Assist in the financing of works conforming to the comprehensive plan, but having limited benefits to the district, company or municipality in whose service area they are constructed.

(5) Construct and operate and maintain water conservation or recharge works, or contract for their operation by others.

(6) Negotiate with other public bodies or agencies and to contract for purchase of water or acquisition of water rights and enter into cooperative arrangements for supply developments outside of Nassau County.

(7) Conduct research and investigations beneficial to water resource development, conservation or protection on a County-wide basis.

(8) Enter into contracts and establish charges for wholesale sale of water to other agencies.

(9) Finance construction by taxes or charges applied uniformly to the district or service area without regard to local or immediate benefit, or levy taxes or establish charges to defray debt service on a uniform basis for bonds used to finance construction.

Plan C - Retail Water Supply

Under this plan, the County agency would perform all water supply functions now provided by many separate agencies, including the town water districts. All of the powers included under "B - Wholesale Water Supply" would be required and extended to the distribution of water for retail sale to individual consumers.

Plan A, Regulation and Supervision, appears to complicate maintaining effective control, constructing joint use works and equalizing financial burdens on districts not favorably situated for well development. The current

construction by the Great Neck Water District of a remote well in the Manhasset-Lakeville District is an instant case. It is evident that supplements to the natural yield will ultimately be needed, and development and distribution of such water will require some agency to be capable of wholesale supply and distribution.

The delivery of water to retail customers is an accepted municipal function. It is now capably performed by a number of autonomous municipalities and districts, including town districts and several private companies in Nassau County. It would be practical to continue this practice through established facilities and agencies with respect to all retail customer relationships and practices.

It is recommended that Plan B be adopted, under which the County assumes the responsibility for all supply works and wholesale water to existing agencies. This recommendation constitutes the goal to be achieved by progressive extension of actual operation of existing supply works for the County-wide benefit, by contracts or other agreement forms, and construction of all new supply works. The recommendation does not preclude the inclusion of distribution and retail services, where desired. However, their performance by a County agency is not essential to effective control of development of the water resources, and ultimate consolidation of retail services in enlarged town districts would be appropriate.

IV-2. Legislation

The present Nassau County charter is believed to contain all of the fundamental powers necessary for a County water agency. The principal deficiency in the present charter provisions appears to be in their scattered arrangement.

There appear to be two State law provisions pertinent to revisions in the present charter relating to water supply. One of these is affirmation of the right to amend County charters locally. Similar statements are included in Article 6-A of the County Charter Law, added by the Laws of 1959, County Law, and Article 6 of the County Law, added by the Laws of 1960.

The second provision is Article 5-A - County Water Districts, added by the Laws of 1953. This article contains a complete statement of the powers and duties of a County water agency. In general, the provisions are comparable to the present scattered provisions of the existing charter. They are, however, more complete and up to date with respect to procedures and other details pertinent to formation and operation of such an agency.

The review of present legislation as related to a County water agency leads to the following conclusions with respect to legislative needs:

a. No additional legislation is required at the State level.

b. It is recommended that the existing scattered definitions of water supply powers in the present charter be repealed and that the charter be amended by the adoption in toto of Article 5-A - County Water Districts of the County Law.

IV-3. Form of Water Agency

The fundamental powers required by a County agency for effective operation and control of the water resources have been stated in Section IV-1. These powers and the performance of wholesale supply activities, and retail supply as well, could be placed in three common administrative forms as follows:

a. An authority of semi-autonomous nature, governed by an appointed Board of Trustees operating under an appropriate charter or enabling act.

b. A new County Board, agency, district or department established as a regular unit of County government.

c. An existing regular County department, commonly the Department of Public Works.

All of these can provide effective operation and administration of water supply activities. A basic difference lies in the permissible financing procedures.

A County government unit is limited to general obligation, serial bond financing. Under the State

Constitution, Article VIII, indebtedness for water supply is exempt from the constitutional debt limits. In addition, under the Local Finance Law, a referendum is not required for the County to issue water supply bonds. Excellent interest rates can generally be expected with such full faith and credit bonds. It is not required that debt service and other costs be met solely by taxes on property. Revenues from use charges may be used in whole or in part. Short term capital financing is available through capital notes or bond anticipation notes to allow greater flexibility in financing improvements. In general, municipal waterworks enjoy a favored position under existing laws.

A water authority, under present New York State Law as in other States, is limited to financing operation and construction out of revenues from service charges and revenue bond sales. It has no power to levy taxes and must maintain a substantial excess of income over all operation and debt service charges to insure its ability to market the revenue bonds for capital improvements. However, the accumulation of reserves is limited. There are numerous examples of successful water authorities throughout the country. Two well known examples in New York are the Suffolk County Water Authority and the

Onondaga County Water Authority. The latter is not to be confused with the recently formed Onondaga County Water District which is a County-wide wholesale supply agency. Primary considerations in establishing an authority form of organization include the following:

a. Is it desirable to establish an additional autonomous governmental agency?

b. Is there a ready market for sufficient water to provide adequate revenues at reasonable charges?

c. Can the sale of this water be assured by contracts or exclusive distribution rights?

d. Is it desirable to place all of the costs for works which provide future benefits to properties not now fully developed, on present users?

e. Can the authority be provided with tax revenues by the County for performing services benefiting other than authority customers, such as research, pilot programs and waste water recharge works?

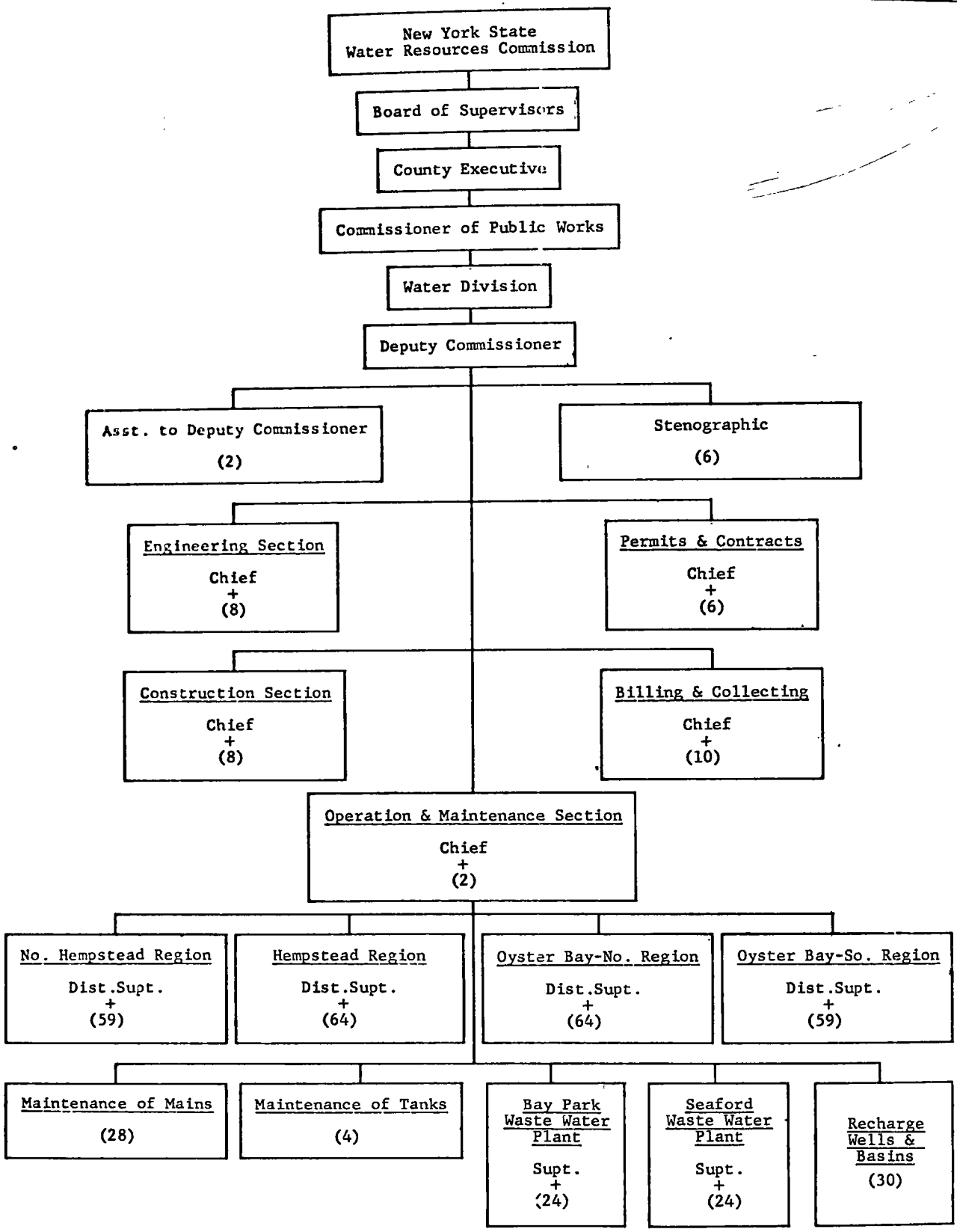
These points can be effectively argued and supported pro and con for Nassau County. In our experience with various forms of organizations and financing, one of the most troublesome problems of authority operation, and revenue bond financing in general, has been the limitation imposed on the scope of projects which anticipate future needs. This arises from the necessity of maintaining reasonable use charges on one hand, and the revenue bond indenture provisions that net revenues, after operation

and maintenance costs, be as much as 60 per cent in excess of the annual debt service requirements. The cost of borrowing by revenue bonds is normally greater than general obligation bond financing and is materially affected by the operating experience record and the size of the program to be financed as compared to the existing system. Frequently the bond issue is increased by several years of interest to allow revenues to build up sufficiently to meet operating expenses, establish the reserve fund and also meet the annual debt service requirements.

Considering such factors, it appears that an authority with its limitations on financing, has no significant advantage over a regular County agency. It is believed more desirable that the water agency be constituted as a regular unit or department of County government and we advise and recommend that this be in the form of a separate Water Division in the Department of Public Works under a Deputy Commissioner.

Various organization charts have been studied, including the possible role of the towns in broadened functions. The suggested organization for wholesale water supply under the Water Division of the Department of Public Works is indicated on Figure IV-1. The principal operating functions are decentralized into four regions, each comprising one or

FIGURE IV-1



TOTAL PERSONNEL = 410

GREELEY AND HANSEN

NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY
ORGANIZATION CHART

more of the proposed pressure service zones. The proposed telemetered control for the wells and booster pumping stations would be centralized at these regional headquarters. The scope of the system to be operated indicates that the organization may ultimately comprise about 410 persons, in the following general categories:

	Number
Administration, Engineering and Clerical	62
Supervision and Operation	348
Total	410

IV-4. Acquisition of Existing Facilities

In prior sections, the operation of all supply works by a County agency has been discussed as a basic premise to the development of County-wide wholesale water responsibilities. At present, all of such works, including wells, storage tanks, booster stations and transmission mains, to the extent that such now exist, are owned and operated by districts, municipalities and water companies. The transfer of the actual operation and of ownership of these facilities is expected to be accomplished by separate negotiations gradually effectuating the transfer to the proposed Water Division.

The presence of privately owned water companies complicates the establishment of the recommended supply procedures, and full effectiveness may not be possible until the privately owned supply works have been acquired by purchase. Acquisition of the complete distribution systems would not be essential, but may be the most practical approach. The company-owned facilities appear to require the following special considerations:

a. Include the company areas within the County water district as defined subdistricts.

b. Initially exempt such subdistricts from any charges or taxes related to operation of supply works in the balance of the district.

c. Assess proportionally to such subdistricts only those costs related to general benefits, including debt service on new construction, administration and research and development costs and if private ownership continues until such time, the proportionate shares of operation and maintenance for waste water recharge works.

d. When the company facilities have been acquired, distribute the debt service related to acquisition between supply and distribution, with the former being proportioned on a County-wide basis and the latter assessed to the subdistrict.

e. Operate all the supply works under the proposed Water Division with wholesale charges for water being made on the uniform County-wide basis to the subdistrict.

f. Operate the distribution system as a Water Division function, or as a town district, with the retail charges being adequate to meet all costs, including operation and maintenance costs and debt service charges on the distribution works. The former customers of private water companies would then be on a comparable basis with the water districts, with the user paying for all of the local retail service costs, plus the wholesale charges and taxes related to the Water Division operations.

It is assumed as a basic concept that publicly owned facilities cannot be "sold" to another group of residents of the County. With respect to the publicly owned works of municipalities and water districts, the transfer of ownership is assumed to be without compensation other than the transfer of outstanding debt to the entire County. This debt service transfer may be in a variety of forms, including rebates of wholesale charges, direct fund transfers to the local agency for the annual payments or by refunding local bonds with the County bonds. The procedure should be flexible, since the works may have been financed by bonds used in part for purposes other than the supply works and the local may not be refundable.

The steps in the implementation of County ownership and operation of publicly owned facilities are visualized in the following manner, being activated upon an established date for the start of Water Division operation:

1. The Water Division assumes the duty of constructing all new supply works.

2. The Water Division assumes supervision of the operation of all wells, which includes the authority to direct the transfer of water through existing connections from adjacent districts in order to permit control of pumping within any area.

3. The Water Division assumes the financial burden of operation of all of the existing supply works, with reimbursement to the operating district in cash derived from County-wide water revenues or by crediting the operating costs against the Water Division charges for wholesale supply services to the district.

4. The initiation of negotiations for transfer of the ownership of the supply facilities to the Water Division.

5. The ultimate assumption of actual operation by the Water Division, including the transfer of personnel to the County payroll where desired and proper to avoid job dislocations.

Certain of the New York City facilities in Nassau County are expected to be permanent parts of the County supply system. The acquisition of these works must also be negotiated. The present studies do not include detailed analyses of the facilities owned by the companies and New York City necessary for determination of the present fair value of the works as a basis for such negotiations. Detailed valuation studies will be necessary in each acquisition. The present reported book

values of the private utility company facilities have been used to provide a preliminary indication of the possible magnitude of purchase costs.

Book values are not available for the publicly owned facilities of the New York City Ridgewood Water Supply System. In lieu thereof, preliminary costs for replacement at present prices have been estimated for those facilities considered to be suitable as permanent parts of the County system. These data are summarized as follows:

	Amount	
Water Companies		
Reported Book Value in 1961		
Total	$72,557,000(1)	
Outside of Nassau Co.	34,000,000(2)	
In Nassau Co.		$38,557,000
New York City		
Replacement Cost for Part of Ridgewood Water Supply System(3)		13,570,000
Total in Nassau Co.		$52,127,000

(1) From 1961 reports to Public Service Commission rounded to nearest $1,000. Includes Citizens W.S. Co., Sea Cliff W. Co., Long Island W. Corp., Jamaica W.S. Co., and Utilities and Industrial Corp.

(2) Parts of Jamaica W.S. Co. and Utilities and Industrial Corp. Value approximated in ratio of 1961 annual average pumpages.

(3) Preliminary estimate without depreciation for Wantagh and Massapequa galleries, Milburn Pumping Station and the 72-inch steel main.

It should also be noted that the reported values in 1961 include the Citizens Water Supply Company and the Glen Cove Division of the Utilities and Industrial Corporation, which are now in process of transfer to public ownership.

The indicated total of the book values and replacement costs of facilities in Nassau County, about $52,000,000, indicates the possible order of magnitude of the acquisition costs for the remaining water supply and distribution facilities not now owned by Nassau County public bodies. The distribution systems represent about 70 per cent of the reported book values, and where acquisition of only the supply facilities can be accomplished, the acquisition costs may be materially reduced. The estimates of cost for the proposed construction include no allowance for existing facility acquisition. An allowance is included in the subsequent general summary of total fund requirements.

IV-5. Costs of Water and Suggested Charges

In Part III, estimates of the annual costs for the recommended project have been presented. These included the annual debt service charges on the proposed construction, and operation and maintenance of all wells, plus

the proposed transmission mains, tanks and booster pumping stations and the recharge works for waste water. These prior estimates, adjusted to reflect the debt outstanding from bond sales related to the suggested construction program, together with a similar estimate for 1980, are shown in Table IV-1. These costs, reduced to the equivalent cost per 1,000 gallons, are summarized as follows:

Year	Estimated Total Wholesale Cost of Water per 1,000 Gallons
1980	$0.128
2000	0.151
2010	0.132

The unit costs in 2000 and 2010 reflect the retirement of the bonds issued for the first two stages of construction, assumed to be sold in 1967 and 1975.

The annual reports for the several water companies providing supply and distribution services wholly or partially in Nassau County have been reviewed to obtain representative costs at present. These data cover only operation and maintenance costs. The range is from about $0.12 to $0.25 per 1,000 gallons. The average is about $0.14 per 1,000 gallons, distributed as follows:

TABLE IV-1

NASSAU COUNTY, NEW YORK
REPORT ON WATER SUPPLY

Recommended Project
Estimated Total Annual Costs

Item	Year 1980	2000	2010
Annual Average Quantity - mgd			
Pumped	190	201	201
Mid-County Recharge	0	36	58
Total Public Supplies	190	237	259
Industrial Supplies	33	37	39
Total	223	274	298
Construction Debt Outstanding (in $1,000's)	$34,750	$61,163	$41,613
Total Annual Costs (in $1,000's)			
Operation & Maintenance			
Supply Works	$5,085	$6,293	$6,505
Recharge Works	577	1,632	1,779
Subtotal	$5,662	$7,925	$8,284
Administrative	1,390	1,730	1,890
Debt Service @ 5.44% per year	1,876	3,327	2,264
Total	$8,926	$12,982	$12,438
Costs per 1,000 gallons(1)			
Operation & Maintenance			
Supply Works	$0.073	$0.073	$0.069
Recharge Works	0.008	0.019	0.019
Subtotal	0.081	0.092	0.088
Administrative	0.020	0.020	0.020
Debt Service	0.027	0.039	0.024
Total	$0.128	$0.151	$0.132

(1) Based on total public supply pumpage as follows:
1980 @ 190 mgd = 69,400 mg per year
2000 @ 237 mgd = 86,500 mg per year
2010 @ 259 mgd = 94,500 mg per year

Item	Average Operation and Maintenance Cost per 1,000 Gallons
Source of Supply	$0.009
Power and Pumping	.040
Transmission and Distribution	.029
Accounting and Billing	.018
Administration and General	.040
Total	$0.136

Debt service on the book values, on the basis used in these studies, would add an average of about $0.11 per 1,000 gallons to these reported costs.

Based on the foregoing data, an illustrative estimate of the cost of water at present cost levels, with wholesale supply services by the proposed Water Division and retail services by existing agencies, is summarized as follows:

	Illustrative Cost per 1,000 Gallons
Operation and Maintenance	
Wholesale Services	$0.103
Retail Services	0.080
Debt Service	
Existing Facilities	0.110
Proposed Works (including allowance for acquiring essential parts of Ridgewood System)	0.037
Total	$0.330

Various methods of charging for wholesale supply activities have been considered. Considering the nature of the services of the County system and the provisions for capacity to serve considerable future increases in population in the proposed works, it is considered proper that a material portion of the revenues be obtained from charges to property and the balance by a service charge.

The distribution of charges to property and use is often based on a detailed analysis of the proportions of the cost of the various elements which are caused to be made for the immediate users and those caused by benefits to property. The latter include such factors as capacity for future growth and fire protection. This type of detailed analysis is not considered necessary for the present purposes of determining a suggested schedule of wholesale charges.

The suggested schedule of charges for wholesale water service is based on the following distribution:

<u>To Use</u>

1. The cost of operation and maintenance of all County operated supply works, excluding the facilities for recharging waste water.

To Property

2. The cost of operation and maintenance of facilities for recharging waste water.

3. The cost of administration of the County system.

4. The cost of debt service.

Based on this and the estimates of annual cost for 1980, we recommend a uniform wholesale charge of 7-1/2 cents per 1000 gallons. This charge would be applied to the water metered and delivered into the mains of the agency performing the retail distribution services. It is further recommended that the balance of the needed annual revenues be derived from an ad valorem tax on all properties in the County, or within the County water district, if such does not include the whole of the County.

A computation of the annual revenues, showing about 59 per cent obtained from users and about 41 per cent from property in 1980, under the proposed bases of charges, is as follows:

Item		Estimated Annual Revenue in 1980	%
Use Charge			
Average public supply pumpage - 190 mgd			
190 mgd x 365 x $\frac{\$0.075}{1,000 \text{ gallons}}$	-	$5,205,000	58.5
Property Charge (excluding costs of acquisition)			
Assessed value			
$3,800,000,000[1] x $\frac{\$0.098}{\$100}$	-	3,721,000	41.5
	Total	$8,926,000	100.0

(1) August 1,1962, nonexempt assessment of $2,833,838,461 increased in proportion to estimated population increase.

The above computation does not include debt service on the cost of supply facilities purchased by the County. The amount of such additional debt service cannot be determined until evaluation studies and purchase negotiations have been undertaken. For example, if purchase costs amounted to $52,000,000, additional revenue from property charges in the amount of about $2,830,000 per year would be necessary, increasing such charges about 76 per cent to about $0.17 per $100.

IV-6. Summary

In preceding sections of the report various elements pertinent to the recommended project and the financing are discussed. These are summarized as follows:

1. The population of Nassau County is estimated to be 2,250,000 in the year 2010.

2. It is estimated that the quantity of water required to be pumped will increase to an average of 298.0 mgd in 2010, including industrial pumpage, and that the water lost by direct discharge to sea, the required yield, will increase to 239.0 mgd.

3. The yield of the ground water supply is estimated at 181.0 mgd, including 27.0 mgd made recoverable by formation of a barrier to salt water along the south shore by injection through wells of reclaimed waste water.

4. The estimated yield of 181.0 mgd is expected to be adequate for all needs until about 1987.

5. An additional 58.0 mgd will be required by 2010, which must be imported or made available by inland recharge of reclaimed waste water.

6. The recommended project (Alternate 4-B) includes a 58.0 mgd supplement to the yield by inland basins recharging reclaimed waste water, additional supply wells distributed to provide relative uniformity of pumpage throughout a main island catchment area of 189 square miles, transmission mains and storage facilities and appurtenances, waste water treatment works and a salt water barrier system of injection wells south of Sunrise Highway, and includes the earliest possible acquisition and use of parts of the New York City Ridgewood System, including the two infiltration galleries, the Milburn Pumping Station and the 72-inch steel main across the County. The proposed new construction is estimated to cost $76,363,000 at present price levels.

7. A construction program in four stages is outlined.

8. A program of pilot studies and field investigations to precede detailed design and construction of the waste water recharge works is recommended, amounting to $600,000, tentatively scheduled over five years.

9. It is recommended that the operation and maintenance of all supply works be transferred by suitable agreements with other agencies to a proposed Water Division in the Department of Public Works, with this Division also constructing all new supply facilities.

10. Estimates of total annual costs for the supply system have been made for operation under the recommended procedure and construction program, which indicate an annual cost in 1980 of $8,926,000, exclusive of debt service for acquisition of existing works and retail distribution costs.

11. It is recommended that the needed annual revenues be derived from a wholesale charge of 7-1/2 cents per 1000 gallons for water delivered at connections to the retail distribution systems, and a property tax to cover the balance, including administration debt service and operation and maintenance of waste water recharge works.

    The Water Division is proposed as the wholesale water supply agency. Retail distribution services are proposed to be left with existing agencies or consolidated into expanded town districts.

12. Acquisition of existing supply facilities is discussed. Municipal supply facilities are presumed to be transferred to County control without compensation, except assumption of related debt. Privately owned supply facilities are presumed integrated into the County system by purchase. The related distribution facilities, if also acquired, are assumed to be operated either by the proposed Water Division or by the towns.

13. Acquisition costs cannot be determined without individual evaluation of each company's facilities as a basis for offering prices. Reported book values in 1961 have been adjusted in two cases for value outside of Nassau County in proportion to 1961 pumpage, and preliminary estimates made of replacement cost, without depreciation, of part of the New York City Ridgewood System. These preliminary data appear to indicate a worth subject to verification later, including company owned distribution facilities in Nassau County, in the order of $52,000,000.

It is presumed under existing New York State law that construction and acquisition will be financed primarily by issuing general obligation bonds which will be excluded from the normal debt limits. Bonds are assumed to be issued from time to time as required under the four-stage construction program.

Recognizing the preliminary approximate nature of information relating to acquisition costs and using $52,000,000 as an illustrative amount, and assuming completion of acquisition by about 1975, the total fund requirements would be about $128,963,000, as follows:

Period	Amount in $1,000's Estimate for Construction of New Works (1)	Illustrative Estimate for Acquisition of Existing Works (2)	Total
Before 1970	$15,800 (3)	$17,000	$ 32,800
1970 to 1980	19,550	35,000	54,550
1980 to 1990	20,590	-	20,590
1990 to 2010	21,023		21,023
Total	$76,963	$52,000	$128,963

(1) Based on a national average Engineering News-Record Construction Cost Index of 900.

(2) Based principally on reported book values of company facilities in 1961.

(3) Includes pilot study program estimated at $600,000 over five years.

WS-SUFFOLK
(WIGGIN-'57)

Report on a Comprehensive Plan For The Development and Distribution of the Available Water Supply of Suffolk County, Long Island, New York

Prepared for The Suffolk County Water Authority

By

Thomas H. Wiggin,
Consulting Engineer

January 1957

Suffolk County Water Authority

BRIGHTWATERS, N. Y.

AUTHORITY MEMBERS

FRANKLIN S. KOONS, *Chairman*
HARRY PAUL FISHEL, *Secretary*
CHARLES W. FRIEMAN, *Assistant Secretary*
CARLL S. BURR, JR., *Treasurer*
T. BAYLES MINUSE

N. F. FENN ..... *General Manager*
HOMER F. GARDNER ..... *Assistant General Manager and Chief Engineer*
LOUIS W. WEINFURT ..... *Assistant General Manager, Distribution*
DAVID L. GLICKMAN ..... *Counsel*
J. LEONARD NEWMAN ..... *Chief Accountant*
EUGENE SIDOTI ..... *Assistant Chief Accountant*
WILLIAM V. BURNELL ..... *Consulting Engineer*
STONE & WEBSTER ENGINEERING CORPORATION, NEW YORK ..... *Advisory Engineers*
UNITED STATES TRUST COMPANY OF NEW YORK ..... *Fiscal Agent*
PRICE WATERHOUSE & COMPANY ..... *Independent Accountants*
R. W. PRESSPRICH & COMPANY ..... *Financial Consultants*

FACTS ABOUT THE AUTHORITY

The Suffolk County Water Authority is a public benefit corporation. It operates by virtue of the provisions of the Public Authorities Law of the State of New York. The Authority is empowered to survey the water resources of the County and prepare plans for their development, subject to the approval of the State Water Power and Control Commission. It can acquire, construct, develop, and operate a public water supply system in Suffolk County.

The Authority has no power to levy taxes. In this respect it differs from municipal corporations which have taxing powers. It is permitted to issue Revenue Bonds pledging the revenues received by the Authority to secure payment of the bonds. Neither the State, County, or municipalities are liable on the bonds which are only payable out of funds of the Authority.

REPORT on a COMPREHENSIVE PLAN for the DEVELOPMENT and DISTRIBUTION of the AVAILABLE WATER SUPPLY of SUFFOLK COUNTY

By Thomas H. Wiggin, Consulting Engineer

January 1957

TABLE OF CONTENTS

	Section Numbers	Pages
COMMISSION to UNDERTAKE the WORK		1
ORGANIZATION EMPLOYED	1	1
GENERAL DESCRIPTION of SUFFOLK COUNTY	2.1 & 2.2	3-5
Quality of Suffolk County ground water	2.2	4
ESTIMATES of SAFE GROUND and SURFACE WATER YIELD of LONG ISLAND:	3.1 3.5-7	6-10
Need for limiting development of Suffolk County to what ground water supply will serve	3.1	6
Salt water intrusion	3.2	6
Source of the water not Connecticut	3.3	6
Rain and snow as the source	3.4	7
Basic facts and questions regarding ground water yield of Suffolk and Nassau counties	3.5-1	7
Geological uncertainties in connection with formation in which to place well screens	3.5-2	7
Loss of water into sea generally indeterminate	3.5-3	8
Estimates of yield where water table is low	3.5-4	9
Increasing care required as use approaches ultimate yield	3.5-5	9
Data on yield from N.Y. City's Plants in Nassau County	3.5-6	10
Data on yield from the exhausted supplies of Kings and Queens counties	3.5-7	10
VARIOUS ESTIMATES of POTABLE WATER YIELD APPLICABLE to SUFFOLK COUNTY:	3.6-1 to 3.6-6	11-14
Yield estimate of John R. Freeman, 1900	3.6-2	11
Yield estimate of Walter E. Spear, 1903	3.6-3	11
Yield estimate of Walter E. Spear, 1908	3.6-4	11

	Section Numbers	Pages
Author's estimate of actual historical yield of ground water of Kings and Queens counties from 1903 to 1932	3.6-5	12
1937 Estimate of yield by late Russell Suter	3.6-6	13
Author's 1956 estimate of yield	3.6-7	14 to 16
DISCUSSION of the VARIOUS FIGURES for YIELD:	3.7-1 to 3.7-9	17 to 22
No mathematical proof available	3.7-1	17
Mr. Suter's conception that improved geological knowledge and well drilling technique could increase yield	3.7-2	17
Mr. Spear's plan included reservoirs	3.7-3	17
Influence of methods of sewage disposal	3.7-4	17
Purified sewage effluent excluded from author's estimate of yield	3.7-5	18
Influence of methods of surface drainage disposal	3.7-6	18
Need for reliable estimates of yield	3.7-7	19
An informative estimate of yield possible in Nassau county	3.7-8	19
Examination as to the effect of seasonal demand and of low rainfall on yield	3.7-9	19 to 22
DENSITY ZONING for LIMITING the POPULATION of SUFFOLK COUNTY:	4.1 to 4.4	23 to 24
General - Factors in problem stated	4.1	23
Safe yield and per capita consumption factors	4.2	23
Factor of land area available for housing	4.3	23
Preliminary estimate of permissible size of building lots	4.4	24
Comments on density zoning	4.4	24
MARGINAL LAND and DEPTH PROTECTION for PURITY of WELL WATER:	5.1 to 5.7	25 to 28
Past practice on Long Island	5.1	25
Present practice in Nassau & Suffolk counties	5.2	25
More yield seems probable with both shallow and deep wells; also economy in cost of well sites.	5.3	26
Evidence as to sanitary danger to well water from adjacent pollution	5.4	26
Experiments on travel of pollution at Fort Caswell	5.4-1	26
Experiments on travel of pollution at Lodi, Cal.	5.4-2	27

	Section Numbers	Pages
Dissolved or Fluid Chemicals May Travel Great Distances in Aquifers.	5.4-3	27
Recommendations as to marginal land and depth protection for well water	5.5	27
Sanitarily safe construction of wells necessary	5.6	28
Bacteriological analyses necessary	5.7	28
COMPREHENSIVE PLAN:	6.1 to 18	29 to 52
General	6.1	29
Restatement of estimated yield per sq. mi. in various parts of County. Necessary well capacity directly related thereto	7.1	30
Peak rates of use, general statement	7.2	30
Statistical data on average & peak uses from plants of the Authority	7.3	31
Storage required as ratio to peak day use	7.3	31
Illustrative estimate of well and infiltration gallery capacity required per sq. mile in various parts of County	7.4	32
LOCATION and SPACING to WELLS and INFILTRATION GALLERIES		33
General	8.1	33
Wells in glacial outwash near shore	8.2	33
Infiltration galleries - early installation of some recommended	8.3	33
Wells farther inland	8.4	33
Wells in all formations needed ultimately	8.5	34
Possibility of deep wells nearer south shore	8.6	34
Types of wells: Tubular, Layne gravelled type, reverse rotary & Kelly	8.7	35
Small well near main well to obtain true draw-down recommended for wells near shores	8.8	35
MARGINAL LAND and WELL DEPTH PROTECTION FOR PURITY of WELL WATER; also QUESTION of ADVANCE PURCHASE of SITES:	9.1-9.2	36-37
100-foot margin deemed sufficient; in later years may be reduced	9.1	36
Zoning restrictions troublesome in obtaining sites	9.1	36
Water tightness of well casings and well tops necessary	9.1	36
Bacteriological analyses necessary; chlorine seldom	9.1	36
Advance purchase of sites probably uneconomic, but purchase by housing developers an economic aid	9.2	36

	Section Numbers	Pages
Possible use for well sites, etc. of park land along streams and ponds and perhaps on parkway land and land taken for taxes	9.2	
SUPPLIES to ISLANDS and BARRIER BEACHES	10.1	37
OUTPOST and WATER LEVEL WELLS	11.1	37
HYDRAULIC GRADES and PRESSURES	11.2	38
HYDRAULIC GRADES and PRESSURES		39
General	12.1	39
Minimum Pressures	12.2	39
PIPE LINES:		40
General	13.1	40
Distribution pipe lines	13.2	40
Interconnecting pipe lines	13.3	40
Materials and specifications for pipe lines	13.4	41
Cast Iron Pipe	13.4-1	41
Joints for Cast Iron Pipe	13.4-2	41
Cement-Asbestos Pipe	13.4-3	42
Reinforced Cement Pipe	13.4-4	42
STORAGE in GROUND and in TANKS:		42
General	14.1	42
Elevated tanks vs. tanks at ground level	14.2	43
Conclusions and recommendations of the author as to storage	14.3	43
Economic comparisons needed	14.3	44
Suitable types of reservoir & tank storage	14.4	44
SUGGESTIONS for IMPROVED LAWS, REGULATIONS or PRACTICES:	15.1	45
Explanation of need for improved regulations	15.1	45
Lack of centralized planning authority and suggestions for correcting this omission	15.2	45
Water supply data needs to be made more available	15.3	46
Need for additional data and suggestions for additional powers needed by Water Power & Control Commission to permit obtaining it	15.4	47-49
Some exploration wells seem to be needed now	15.5-1	49
List of deeper wells in Suffolk County	15.5-2	49
Description of Spear stove-pipe wells	15.5-3	50
Spear's water level wells placed close to stove-pipe wells	15.5-3	50
Conclusions as to need for some exploratory wells	15.5-4	50

	Section	Pages
Need for contour maps of Suffolk County	16.	50
Importance of water supply requiring cooperation of all governmental agencies and of citizens	17.	51
Concluding statements re. this report	18.	51-52

TABLE OF CONTENTS

APPENDICES

			Pages
Appendix	A -	Geology of Suffolk County, N.Y. by R.M. Leggette	A1-A18
"	B -	Statistics and Forecast of Population of Suffolk County by T.H. Wiggin	B1-B1
"	C -	Report on the Quality of the Water Supplies of Suffolk County, Long Island, N.Y. by George D. Norcom	C1-C13
"	D -	Report on the Possibility of Recovering Sewage to Augment the Underground Waters of Suffolk County, Long Island, N.Y. by George D. Norcom	D1-D10
"	E -	Statistics of Suffolk County Water Supply Plants by Charles A. Niles	
"	F -	Statistics of Precipitation on Long Island by T.H. Wiggin	F1-F4
"	G -	Ghijben-Herzberg and Hubbert Theories of Fresh Water-Salt Water Balance in Permeable Sands and Gravels by T.H. Wiggin	G1-G4
"	H -	Infiltration Galleries. Data from Augus D. Henderson; Compiled by T.H. Wiggin	H1-H5
"	J -	Recharge Basins, Outpost & Water Level Wells by W.F. Welsch	J1-J19
"	K -	Diffusion Wells. Data from A.H. Johnson; compiled by T.H. Wiggin	K1-K6

Maps

Plate No. 1 -	Profiles of Water Table Elevations in Suffolk County on July 1, 1903, on January 1, 1951 and January 1, 1956	
Plate No. 2 -	General Map of Suffolk County showing location of Existing Water Supplies and other details	

---

* 1 Page of description matter and an 8 page table.

Report on a Comprehensive Plan for the Development and Distribution of the Available Water Supply of Suffolk County

By Thomas H. Wiggin, Consulting Engineer

In August 1955 the Suffolk County Water Authority commissioned the author to make a study and report for a comprehensive plan of development of the potable water supply of Suffolk County, looking far into the future. The plan was to be such that it would result in the orderly and efficient utilization of the total water resources of the County.

The need of a comprehensive plan was recognized not only by the Suffolk County Water Authority but also by the executive department of the State Water Power and Control Commission, which has the duty of passing upon all plans for proposed water wells of capacities 45 gallons per minute and over and plans for utilizing these wells. Agricultural wells and fire wells without permanent pumps are excepted from this law.

The author recognizes that a comprehensive plan cannot be final, or static, but must grow with the accumulation of geological information and experience. This is particularly true of Suffolk County because there have not been as yet enough wells, particularly deep ones, to permit assured plotting of the deeper geological formations or to know their nature as regards the quantity and quality of their yield of potable water and their liability to salt water intrusion.

ORGANIZATION FOR THE SUFFOLK COUNTY WATER SUPPLY STUDY

Section 1. On undertaking this study, the writer immediately engaged the assistance of the following personnel, all having many years of experience, as had the writer, in the problems of developing and distributing ground water in all parts of Long Island:-

Mr. George D. Norcom, sanitary consultant, who has been consultant since about 1930 to many of the water plants on Long Island, New Jersey and elsewhere in the United States.

Major R.M. Leggette, consulting geologist, who has had many years of experience in ground water supplies on Long Island as well as elsewhere in the world, both as a member of the U.S. Geological Survey Water Resources Branch, and in recent years, as consultant in private practice. For some years he has been a consultant to the Suffolk County Water Authority.

Mr. Charles A. Niles, Civil Engineer, who has had a part, as engineer and superintendent for a contracotr for many years, in constructing water supplies on Long Island, was Director of Environmental Sanitation in the Suffolk County Department of Health for about ten years, and in recent years has been engineer for many of the new water supply developments in Suffolk County.

These key members of the organization which has assisted the writer in the collection of data and studies for this report were present at a conference early in Sept. 1955 with Chairman Franklin S. Koons, General

Manager N.F. Fenn and Assistant General Manager and Chief Engineer Homer F. Gardner of the Suffolk County Water Authority, at which time the preliminary plans for proceeding with the study were outlined. The same officals of the Water Authority have been consulted from time to time and have given the writer full cooperation. Messrs. Norcom and Leggette have, as planned, written appendices to this report which are bound herein. An appendix containing existing plant data by Mr. Niles has also been added.

The writer has also had the generous cooperation of the engineering organizations of the Water Power and Control Commission and the United States Geological Survey. In the former organization should be mentioned Executive Engineer John C. Thompson at Albany and Arthur H. Johnson, Associate Engineer in charge of the Commission's Long Island Office at Jamaica. In the U.S. Gelogical Survey organization at Mineola, Nassau County, L.I., Messers. N.J. Lusczynski of the Ground Water Division and Richard M. Sawyer of the Surface Water Branch should be mentioned with gratitude for their cooperation in supplying data.

The Suffolk County Department of Health has also given generous aid in supplying results of the water analyses made by its laboratory.

Mr. W. Fred Welsch, Senior Civil Engineer of Nassau County, and Mr. Henry L. Frauenthal, his assistant, have also aided with data relating to the ground water of that county, experience with which is of great value because it is the best available evidence of the experience which Suffolk County may be expected to have as its population grows. Mr. Welsch's valuable contribution in devising the water-saving recharge basins is noted elsewhere. (See Appendix J)

The writer has also obtained help from Mr. Angus D. Henderson, Consulting Engineer, in assembling exact details of New York City's ingenious and valuable infiltration galleries at Massapequa and Wantagh, Nassau County. (See Appendix H). Mr. Henderson had a long connection with New York City's ground water system in Nassau County and has had wide experience as a consultant in ground water and other water supplies.

GENERAL DESCRIPTION OF SUFFOLK COUNTY

Section 2.1 - Suffolk County comprises the eastern approximately 2/3 of Long Island and includes, as well, Shelter, Fishers, Plum and Gardiner's Islands, also outlying dunes, or "barrier beaches" totaling about 50 miles in length, lying south of the south shore and separated from the mainland by the huge South Bay and, farther east, by the smaller Moriches Bay and Shinnecock Bay.

Shelter Island, the smallest of the ten towns of Suffolk County, comprising approximately 8,000 acres, has two water supply systems, one a municipal plant serving the Incorporated Village of Dering Harbor and the other a privately-owned system supplying the unincorporated area of Shelter Island Heights. Individual wells are used throughout the balance of the Island.

Fishers Island, a part of the Town of Southold, is partially served by a privately-owned water company. The supply is obtained from ponds, a series of small wells and an infiltration gallery. There is a gravity, rapid-sand filter plant.

Plum Island is the seat of a United States government laboratory for the study of certain diseasrs of cattle and is wholly restricted.

Gardiner's Island, with an area of about 3,000 acres and in the Town of East Hampton, has remained in possession of the same family since 1639 and still is maintained as a private estate.

On the "barrier beaches", along the south shore, are a number of public water supply systems. The ocean frontage at Westhampton Beach and Quogue are supplied from the mainland by the Suffolk County Water Authority. The incorporated villages of Saltair and Ocean Beach have their own municipal water supplies and many of the other communities along the beach are served by privately or community owned water plants. Scattered and separated summer homes use individual wells.

The geology of Suffolk County is described in Appendix A by Mr. R.M Leggette. Owing to the relatively few deep wells in the County, it is necessary to infer its geology to a considerable extent from that of Kings, Queens and Nassau counties, particularly the latter.

Topographically the County is characterized by a high ridge of glacial origin, reaching an elevation of about 300 feet, running approximately east and west at roughly 1/3 of the width of the County from its north shore, and separating into two ridges in the east, where the Peconic bays divide the island into two prongs, sometimes called the North & South "flukes". The northerly of these flukes terminates at Orient Point, east of Greenport, and the southerly one at Montauk point.

North of the ridge and west of the Peconic bays, the slope to Long Island sound is generally abrupt, though with some indented estuaries and marshes, while south of the ridge is a long gentle slope terminating at the northern shores of Great South, Moriches and Shinnecock Bays.

A number of surface streams, mostly on the southerly slope, flow to Great South Bay, Moriches Bay, Shinnecock Bay and Peconic Bays. Some of these terminate in ponds near the south shore and there are a number of

other ponds in the interior of the county, including Lake Ronkonkoma which has an area of about a square mile and is surrounded by many houses mostly for summer occupancy.

The sub-soil of Suffolk County is generally sandy, yellow in color except on the ocean side of the south shore dunes which are of sea sand of the usual light gray color. The top soil sustains many farms. Elsewhere the ground is generally covered with scrub growth, mostly oak and pine, with considerable wild grass also.

As the use of water in Suffolk County is now small, compared with the available yield, ground water levels are high, reaching a maximum of about 70 feet above sea level under the ridge. This results in a copious flow in the streams, which was estimated for the calendar year 1955 at the very large average total of about 230 million gallons daily, about 90 per cent of which is thought to have been ground water derived from the rains soaking into the soil but which has emerged from the ground in the lower reaches of the streams because the ground water level there is above the levels of the streams. This 1955 flow was believed to have been a fair average for other years. The author believes these stream flows will gradually diminish as the use of ground water increases. This belief was originally based on theoretical grounds but has been confirmed by observations in southern Nassau County.

The population of Suffolk County was estimated by the Long Island Lighting Co. for Jan. 1, 1956, as about 452,000, as compared with about 1,087,000 for Nassau County. The approximate areas are respectively 920 and 274 sq. miles, which gives an average population per sq. mile for Suffolk County of about 492 and for Nassau of about 3,970, i.e. 8 times the density of Suffolk County. The denser part of the Suffolk County population is near the boundary between it and Nassau County. The estimated growth in population of Suffolk County is about 35,000 per year at present as compared with about 60,000 in Nassau County. Appendix B gives a more detailed account of the present and expected population growth of Suffolk County.

Section 2.2 - Quality of Water. This important matter is the subject of Appendix C. by Mr. Geo. D. Norcom. It is bound with this report. Additional chemical analyses of water from various Suffolk County plants are contained in the tables by Mr. Charles A. Niles in Appendix E. The water obtainable nearly everywhere from the sands and gravels which inderlie the surface soil of Suffolk County is generally of excellent quality, palatable, soft, sterile and generally free from troublesome elements such as iron and manganese. It contains some carbonic acid gas (CO_2), which renders it somewhat corrosive, but this is easily neutralized - and in public supplies generally is - by the addition of lime or caustic soda.

Iron is found in somewhat excess quantities in the well water of the barrier beaches and of islands at the easterly end of the County. Also the Sag Harbor plant of the Suffolk County Water Authority has for many years required and possessed an iron removal plant. No other plant of the Authority is so troubled.

Manganese, which, when present in objectionable quantities in water, causes stains in laundry and accumulation of a black coating in pipe lines, caused trouble only in the Amityville and Babylon plants of the Authority,

but has been kept under reasonable control by generally moderating the output of the plants. Manganese, however, is a potential trouble-maker, since a number of wells in Nassau County, which had for several decades yielded excellent water, have recently begun to yield very objectionable quantities of manganese and similar troubles have appeared recently in west Suffolk County. So far no explanation has been found.

The greatest hazard to the water, however, is believed by the author to be chemicals, such as detergents and fluids containing chromium or other plating material and many others. These, being fluid, travel with the facility of water in the aquifers and in some cases have been found in well water. This is a matter which is being watched by local and state health officials. It is also a proper subject for zoning boards in the matter of control of location of industries.

Danger from radio-active nuclear refuse needs to be mentioned for completeness, but it is so highly technical that only the nuclear laboratories can deal with it. They are doing so but it is obvious that the increasing use of nuclear forces will call for the utmost vigilance by nuclear experts; also by others charged with matters of public health in order to be always assured that the necessary vigilance exists.

ESTIMATES OF SAFE GROUND AND SURFACE WATER YIELD OF LONG ISLAND

GENERAL

Section 3.1 - Need for Limiting Development of Suffolk County. It is the author's opinion that the development of Suffolk County as a place of residence and manufacture should be limited to what can be supplied by the available water supply yield, i.e. the yield which will be available year after year without exhaustion. To import water to Suffolk County either from New England across Long Island sound or from upland in New York State, as is done for the City of New York, would be very expensive and the writer sees no gain to the future population in Suffolk County from crowding them in so that water would need to be imported.

It is true that some progress is being made in reducing the cost of purifying sea water but all processes tried are still very expensive and it will be time enough to start squeezing in more population after purified sea water at reasonable cost becomes an accomplished fact.

Section 3.2 - Salt Water Intrusion. The older Long Island supplies, as in Kings County and parts of Queens County, were used increasingly nearly to exhaustion so far as potable water is concerned, that is, pumped until the ground water table was lowered so far that the supplies in those areas were spoiled by infiltration of sea water. The danger of similar occurrences in Nassau county has long been recognized and county, state and national authorities, charged with the care of the water supply, are continually studying and making observations regarding salt water intrusion and taking the best steps to avoid it. In the case of Nassau county, the long-continued practice of the export of 50 or more million gallons of water daily by and to the City of New York is expected to be gradually discontinued, beginning next year. This will help the situation in Nassau County somwhat.

Some other parts of the U.S. have ground water exhaustion to contend with and some districts are working hard to rebuild exhausted sources by recharging with water applied by seepage beds, recharge wells or even by purified sewage though the latter method has been applied only to irrigation water. It is the writer's hope to indicate how this problem of exhaustion can be avoided in Suffolk County. As an indication of the importance of this salt water intrusion hazard, not only in the United States but also in many other quarters of the world, just one of the many technical publications on this subject, viz., Technical Bulletin No. 10, entitled "An Abstract of Literature Pertaining to Sea Water Intrusion and Its Control", issued by the Sanitary Engineering Research Project of the University of California, Richmond, California, in July 1953, contains 74 pages with over 230 summaries of technical papers on this subject, going back to the clebrated original Ghijben notes in 1888-1889 on the principles governing intrusion of sea water. (See Appendix G)

Section 3.3 - Source of The Water is Not Flow Under Long Island Sound from Connecticut. There is still a lingering superstition on the part of a few non-technical inhabitants of Long Island that the main ground water supply of Long Island is derived from underground streams originating on the mainland, i.e., Connecticut, and passing under the salt water of Long Island Sound. The generally rocky shores and rocky upland country of

Connecticut, and the fact that the rock is generally of an insoluble nature without caves and underground channels, would in themselves make such a theory untenable even without the additional evidence of deep wells on Long Island which have revealed the nature of the ground down to the base rock. There is no stratum of earth or of rock through which water could pass from Connecticut under the Sound and rise up into the sand layers in which the wells from which the water supply of Long Island is largely obtained.

Section 3.4 - Rain as the Source. On the other hand, there is every evidence that rain (or melted snow), percolating through the porous soil of Long Island, is the source of the supply. The average yearly precipitation on Long Island is about 42 inches of depth. The precipitation varies greatly from year to year, the minimum being about 35 inches and the maximum about 55 inches. Precipitation over about 50 inches occurs very seldom and is attributable to hurricane storms during which direct run-off into the sea is large. Statistical records of precipitation are given in Appendix F.

If all the rain and snow which falls on Suffolk County actually did soak into the ground and not any were lost by surface stream flow into the ocean and into the air through evaporation and through transpiration from vegetation, an average precipitation of 42" would make available each year from each square mile of territory about 730 million gallons of water, giving an average for each day of 2 million gallons per sq. mile. If only 1/2 of the rain soaked into the ground, the available yield would be cut to 1 million gallons per sq. mile which is the highest yield per sq. mile that has been seriously considered as ultimately possible for Long Island. To get this yield, more than one half of the rainfall would have to soak into the ground, as there are unescapable losses of percolation water by evaporation, transpiration, stream flow of water which comes back from the ground into the streams and underground flow into the sea, as will be explained in paragraph 3.5-3.

Section 3.5-1 - Basic Facts and Questions Regarding Ground Water Yield of Suffolk and Nassau Counties. Considering the importance of knowing the safe ground water yield of Suffolk and Nassau Counties, it is surprising how little is really known about it. In what follows a few basic facts which seem to be axiomatic, also a number of uncertainties are stated, but there are not enough facts to permit an unquestionable estimate of yield.

Section 3.5-2 - Geological Uncertainties in Connection with Formation in which to Place Well Screens. One of the uncertain factors in estimating and in developing the safe yield is the complicated geology of Long Island, in general, which is shared by Suffolk County in greater degree because there have been fewer wells from which to learn its geology. The top formation, glacial outwash, is comparatively simple, though recently found to be less simple than previously thought. The glacial outwash generally abuts on salt water and cannot be drawn upon to the extent of lowering its water-table to or nearly to sea level without intrusion of salt water.

Next below is the Magothy formation, with a disorderly interbedding of sand and clay. Here every well is a new exploration to discover at what depth lie the beds which carry water in quantity sufficient to justify placing the whole or a part of the screen of that well in them. There is a tendency on the part of health officials to insist on well screens being placed in the Magothy, rather than in the glacial outwash in order to get

greater depth protection against possible pollution. This in Nassau County in 1955 caused about 72 per cent of the potable water to be taken from Magothy as against about 15 percent from the glacial outwash. The corresponding figures for the Jameco and the Lloyd formations were about 3 and 10%, respectively. The greater share of the available ground water supply is nevertheless in the glacial outwash.

The Magothy clay beds extend out under the bays south of Long Island - perhaps many miles out to sea - and explorations may show that wells may be placed in the Magothy near the shore or even on the barrier beaches - some wells exist there already (1) - without intrusion of salt water.

But if many wells are placed in the glacial outwash, will they rob the ground water recharge into the Magothy; and vice versa, if most of the wells are carried into the Magothy, will the recharge into that formation, through the many layers of clay, be sufficient to prevent a large and unnecessary waste of water into the sea from the glacial outwash? Only time and intelligent and continuous, well-financed study will answer these questions (2).

The Lloyd sand, which overlies the base rock and, like the Magothy, probably extends well to the south of Long Island, has as yet been only very slightly explored in Suffolk County and in times past there was much speculation as to where the water in it comes from. Geologists have now concluded that it must come by slow percolation through the vast areas of clay covering. Observations in Nassau County have shown that the static water level of the Lloyds formation is sensitive to the rate of pumping from it so that pumping from it has to be controlled. Experience with some sixteen wells, six of which were bad, has shown that the Lloyd formation is liable to salt water intrusion if wells are sunk into it along the north shore where its elevation is relatively high. Near the south shore of Suffolk County, Lloyd gravel is very deep, viz. roughly 1500 feet at the Nassau County easterly border and estimated at about 1600 ft. at Southampton. Water from Lloyd formation has not been definitely included in the writer's figures of yield.

There is also the question of iron and manganese, the former occurring at times in waters east of Riverhead and in waters from the barrier beaches. (See Appendix C)

It will be noted in the writer's conservative estimate (See Section 3.6-7) that the estimated yields per sq. mile along the north shore and from the two "flukes" east of Southold Bay and Cherry Point are assumed at the low figures of 0.35 Mgd and 0.30 Mgd per sq. mile. These estimates are of course only approximate but conservatism seems indicated at present.

Section 3.5-3. Loss of Water Into The Sea Generally Indeterminate. The systematic observation of the elevation of the ground water table in

---

(1) They take water from under deep beds of clay but, as is usual for barrier beach wells, the water is high in iron, in these cases generally 2 to 3 times the maximum quantity for satisfactory water.

(2) Mr. Russell Suter wrote of the general insufficiency of geological knowledge. See Section 3.6-6.

Nassau and Suffolk Counties, while of great assistance in estimating whether the ground water supply is holding its own, does not indicate the potential yield but merely shows the particular pattern of elevation of the ground water table at which a temporary balance - always slowly changing - has been reached between the supply of rain water which has percolated into the ground and the water consumption and losses of all kinds, viz.,

(a) by flow of that part of sewage which is piped into the sea, rather than being disposed of into the ground,

(b) by evaporation of percolated water which has been returned to the surface by capillary action or by transpiration from vegetation,

(c) by evaporation of most of the water which has been pumped from the ground and used in irrigation of lawns or crops,

(d) by that part of stream flow which comes from ground water seeping back into the streams (estimated roughly as perhaps 90% of the stream flow, and finally

(e) by the underground seepage into the sea.

Of the above items of ultimate consumption of percolated water, items (d) and (e) must vary with the elevation of the ground water table since they are energized by the slope of the ground water table toward the streams and toward the sea. It must follow that the available yield would increase with lowering of the ground water table, because items (d) and (e) above would then be reduced. Furthermore losses (d) and (e) must be up to the present period the major part of the ultimate consumption of percolated water because the elevations of the water table in general have not changed to an important degree in Nassau County, except in the westerly part, or in Suffolk County, since the time when they were carefully measured at many places by Walter E. Spear in 1903, though uses have increased greatly in Nassau County. The comparative smallness of the change in water table elevation is shown as regards Suffolk County and the adjacent part of Nassau County by the cross sections of the ground water table on Plate 1 bound herewith. Additional data as regards Nassau County is shown in Water Power and Control Commission Bulletin GW-27, dated 1951, Plate 4, Sections C-C' to G-G' inclusive. A drop in the water table is to be expected in Nassau County - has already been reported by one observer - as the discharge of sewage into the sea is increased.

Section 3.5-4. Estimates of Yield Where Water Table is low. Where there is exhaustion of the ground water yield, as was produced by excessive pumping in Kings and much of Queens County, the escape of water into the sea no longer occurs - in fact the flow is reversed to the extent that salt water intrusion occurs - and a measure of ultimate usable yield would be possible if all the factors of consumption, including flow of sewage into the sea, were recorded for a period of years sufficient to practically equalize the variations in rainfall. Measurements of this kind are approached on some of the smaller islands where water is at a premium and ground water tables become low. The author made an approximate estimate for Kings and Queens Counties in 1934 as is described further on in Section 3.6-5. This was a case of low ground water, which for years was below sea level.

Section 3.5-5. Increasing Care Required as Use Approaches Ultimate Yield. It is evident from the above paragraphs that, as the use approaches

the ultimate yield. the measurement and study of water table elevations becomes more and more important, particularly in areas where conditions favor sea water intrusion and consumption becomes high relative to local yield. Such is already the case in the North Western part of Nassau County where pumpage from the Lloyd formation exceeded for a time the fresh water yield and had to be curtailed. Constant care in the collecting and study of ground water levels and chloride content of the water will be the price of the successful development and operation of the Suffolk County water supply.

Section 3.5-6. Data on Yield from New York City's Plants in Nassau County. In Nassau County, during the period when the draft by New York City was practically the only draft of importance in the southern part of the County, and that draft was exported to New York City, there was a chance to make some sort of an estimate of the ground water yield. Such estimates of this yield as were made by Walter E. Spear in 1903 and 1908 are noted among the various estimates of yield given in pages which follow. In the absence of better data, the author's estimates of yield for this report are greatly influenced by these New York City figures.

Section 3.5-7. Data on Yield from the Exhausted Supplies of King's and Queens Counties. In 1933 and 1934, after the water supplies of Kings County and the western part of Queens County had been practically ruined by over-pumping, and the water tables were at or much below sea level, the writer originated and supervised the making of an estimate of the water yield of the two counties between the years 1903 and 1932. That estimate also is included among those given in the following pages. It was dated Feb. 26, 1934 and was submitted in evidence in Application No. 681 before the Water Power and Control Commission. It has the weaknesses that the water table in 1903 was not of record in Kings and Queens Counties and had to be derived from various subway and sewer construction records; also the industrial pumping over the years was to too great an extent estimated. However it is the only estimate of Long Island ground water yield known to the author which has sought to take account of all factors and which had the opportunity to do so because the water table was either below or not far above sea level so that underground loss of water to the sea was negative or of little importance.

VARIOUS ESTIMATES OF POTABLE WATER YIELD APPLICABLE TO SUFFOLK COUNTY

Section 3.6-1. In what follows the writer has collected the data or safe yield of Long Island which has come to his attention in a study which has been rather intensive at various times since about 1932.

Section 3.6-2. Yield Estimate of John R. Freeman, 1900. The late John R. Freeman, who was sometimes called "The Dean of American Engineers", gave some attention to the possiblility of obtaining additional water for the City of New York from the southern part of Suffolk County east of Massapequa. His conclusions in his earliest consideration of this subject are given on page 100 of his report made to Bird S. Coler, Comptroller of the City of New York, dated March 23, 1900. Mr. Freeman's estimates of the water which could thus be obtained were from 60 to 120 million gallons per day. The exact area of land contemplated in this statement is not given but the description would include at least 400 sq. miles. If the mean of Mr. Freeman's figures of yield were taken, viz., 1/2 (60 + 120) or 90 million gallons daily, (mgd), his yield per sq. mile would compute 90/400 = 0.225 Mgd per sq. mile, a very conservative figure.

Section 3.6-3. Yield Estimate of Walter E. Spear, 1903. See Report of the Commission on Additional Water Supply of the City of New York, pages 842 and 843. Mr Spear was a division engineer of that Commission in charge of ground water studies on Long Island. These studies took only about 10 months but there was a considerable force engaged in systematic work which included not only complete statistics of the extensive ground and surface water yield of New York City's so-called Ridgewood system in Nassau County, operated for the supply of Brooklyn, but also extensive observations on ground water levels all over Long Island. The summary statement by Mr. Spear for the yield of Suffolk County was as follows:

"During a series of dry years the seepage into the streams accounts for about 1/3 of the annual percolation of 15 inches, or 5 inches of water, and the underflow to the sea makes up the remaining 2/3, or 10 inches, which is 28% of the minimum rainfall of 35 inches.

"From the maximum underflow of 10 inches from each sq. mile of ground water catchment area, which is considered to be the lowest reasonable value during a period of dry years, probably 450,000 gals. per day sq. mile can be developed. This amount is the natural flow of the underground waters, and may be obtained without materially lowering the water table. By drawing upon the ground water storage and supplementing the supply from the underflow and by properly filtering the flow of the surface streams, a total minimum supply of fully 800,000 gallons per day per sq. mile may be developed.....

"If legal restrictions were removed, an additional supply or..... fully 75 million gals. of surface water may readily be obtained from the 220 sq. miles of ground water catchment area in Suffolk County from the Nassau County line to Moriches,....."

Section 3.6-4. Yield Estimate of Walter E. Spear, 1908. See Two Vol. Report, dated 1912, "Long Island Sources.....Manner of Obtaining from Suffolk County, Long Island, An Additional Supply of Water for The

City of New York." Mr. Spear, aided by a large organization, continued and broadened his 1903 studies of Long Island sources and devised a plan for an aqueduct, wells, surface water reservoirs and purification plants for taking about 150 Mgd of water from Suffolk County for New York City. The Spear 1908 study included a further study of the record of yield of New York City's Nassau County Sources; also test wells, stream gagings, rainfall observations, ground water level measurements at many new small test wells; also a study of European ground water methods and experience.

Mr. Spear's plan assumed the taking of water from Suffolk County from the area between the ridge of the island formed by glacial moraines and the south shore of Long Island, bounded on the west side by Nassau county and on the east side by a north and south line about 3 miles east of Riverhead. The supply was to be transported to the vicinity of the City's Ridgewood pumping station in Queens County by an aqueduct along the southerly part of Suffolk and Nassau Counties. The wells were to be located partly along the easterly approximately 15 miles of the main aqueduct and along 4 approximately north and south collecting aqueducts located in the approximate longitude of Riverhead, Brookhaven, Central Islip and Babylon. These north and south aqueducts had their north ends nearly as far north as the morainal ridge of the island. The wells were to be located at the center of a continuous taking preferably 1,000 ft. wide - possibly less where land was expensive. The collecting aqueducts would be placed 25 feet away from the line of wells and the maintenance highway would be placed on the opposite side of the wells.

The wells were to be spaced at "short intervals" and to be 100 and 200 ft. in depth, the latter penetrating at full depth of the yellow gravel. Mr. Spear was leaning toward the California stove-pipe type of well with screens in all coarse strata encountered. This type of well consisted of a double thickness steel casing sunk by bucketing out the sand and jacking the casing down and then perforating the casing opposite each water bearing stratum by expanding rings of sharp tools.

It was proposed to locate the main aqueduct considerably north of the then existing developments along the south shore of Suffolk County in order to keep the bottom of the cones of depression above sea level and also to avoid depleting such wells as there might be in the developed sections.

Based on the gagings of the surface streams and on the experience in New York City's Ridgewood system in Nassau County, there were included in the plan a number of storage reservoirs which it was estimated would have to have a capacity of at least 50 million gallons per sq. mile of watershed in order to maintain a yield of 800,000 gals. per day per sq. mile or 266 Mgd from the 332 sq. miles which the plan assumed would be used.

Section 3.6-5. The Author's Estimate of Actual Historical Yield of Ground Water of Kings & Queens Counties from 1903 to 1932.** This study was based on the following data:

(a) Records of pumpage at public supplies from ground water sources in Kings & Queens Counties for each year 1903 to 1932.

(b) Records and estimates of industrial pumpage in Kings & Queens Counties in the same years.

(c) Estimated contours of static water levels in Kings & Queens Counties in 1903, based on data from sewer, subway and other construction in

** See also Section 3.5-6.

Kings & Queens Counties, made to coincide with the Spear 1903 ground water contours of Nassau County at the boundaries between Nassau County and Queens County which is where the Spear 1903 contours terminated in the West.

(d) Contours of static water levels in the 2 counties in 1932, based on many careful observations in 1932, made under the direction of the writer and also static levels observed by the Bureau of Water of New York City and by the Jamaica Water Supply Co.

The above data was applied as follows: The total yield in the 29 years 1903 to 1932 was equal to the total pumpage, (a) + (b) above, minus the total of the "mined" water between 1903 and 1932 ground water contours, assumed to be 30% (= assumed % of voids in the sand) of the gross volume between the two sets of contours, (c) and (d) above.

The result was close to 0.85 Mgd per sq. mile of total area of the 2 counties i.e. Kings & Queens, and about 1.0 Mgd per sq. mile based on the estimated pervious area, i.e., total area of the 2 counties less area of buildings, pavements and other impervious surfaces.

It should be stated that an assumption is required that the relatively small loss of water by underground flow into the sea during the early years of the period, when the ground water was a little above sea level, was practically balanced by infiltration of salt water and fresh water flow into Kings and Queens Counties from Nassau County during the latter years of the period.

Section 3.6-3. 1937 Estimate of Yield by the late Mr. Russell Suter, former Executive Engineer of the Water Power and Control Commission of the State of New York. See pp. 32 to 34 of Bulletin GW-2, entitled Engineering Report on the Water Supplies of Long Island.

		Nassau County	Suffolk County
1.	Area in Square miles	274	920
2.	Ave. Rainfall in inches per year	42	42
3.	Ave. Yield, if all rainfall could be utilized (Mgd)	548	1840
4.	Maximum natural yield (Mgd)	342	1150
5.	Minimum natural yield (Mgd)	274	920
6.	Yield reduced by sewers (Mgd)	270	920
7.	Safe present development (Mgd)	130	460

(Table above was copied from Mr. Suter's Table on page 32 of Bul. GW-2 with insertion of line 2 by author of this report)

Notes by author of this report.

(a) Mgd means million gallons daily

(b) Rainfall (line 2) computed by author of this report, using Mr. Suter's figures in lines 1 and 3

(c) Maximum natural yield, line 4, is based on 1.25 Mgd per sq. mile.

(d) Minimum natural yield, line 5, is based on 1.00 Mgd per sq. mile.

(e) Yield reduced by sewers, line 6, is slightly reduced from line 5 for Nassau County and not at all for Suffolk County. At the time of Mr. Suter's estimate, 1937, there were few sewers in Nassau and practically none in Suffolk County.

Mr. Suter in the report GW-2, following the table from which the figures above were taken, commented on his table. Certain of these comments are paraphrased below.

The yields of 1.25 Mgd per sq. mile, used in line 4 above, was characterized as beyond hope of ever being reached. The yield of about 1 Mgd per sq. mile in line 6 above was characterized as possible only if the area had not been previously overpumped, all wells systematically placed as part of a single system, precise knowledge of underground conditions available and great advances made in the art of developing ground water. Such results were said to be impossible today and perhaps would never be possible. The last line, 7, in the table above is charcterized as what could be aimed at today (1937).

At the time of present writing, 1956, 19 years have elapsed since Mr. Suter made his estimate. So far as the writer knows, no official estimate has been published since.

Section 3.6-7. The Author's 1956 Estimate of Fresh Water Yield. The author's also estimate the potential fresh water yield of Suffolk County was derived largely from a study of the records of New York City's Ridgewood Supply in Nassau County and Eastern Queens County for the years 1897 to 1904, inclusive, as contained in Walter E. Spear's Report to the Board of Water Supply of the City of New York in 2 printed volumes dated 1912, which include elaborate records of the 1907-1908 studies for a supplementary supply from Suffolk County for the City of New York.

The figures given below are million gallons daily (Mgd) per sq. mile from the 159 sq. miles of territory assumed by Mr. Spear to be tributary to New York City's water supply system in Nassau County and Eastern Queens. See Spear 1912 report, Vol. 1, Table 6, following page 114.

(a)	Actual average rate of delivery to the Brooklyn system in years 1897 to 1904, incl.	0.617 Mgd per sq. mile
(b)	Measured wastage over the spillways of the several reservoirs	0.084 Mgd per sq. mile
	Total measured use plus measured wastage to the sea over spillways of reservoirs. (Wastage to sea by underflow in ground not measurable).	0.701 Mgd per sq. mile

There were many considerations which prevented the direct adoption of the above figures as the yield in Suffolk County:

1. The figures contain a measured wastage averaging 0.084 Mgd per sq. mile over the weirs of the various ponds and reservoirs which were a part of the Ridgewood system. There is no definite knowledge as to what part of this is preventable.
2. The average total yearly rainfall for the period was high, viz. 46.86 inches as compared with 42.88 for the average of the years 1879 to 1928 inclusive, and 37.13 for the driest period, viz. 1928 to 1931. (See Appendix F, Table 1)
3. It was known, and clearly stated in the Spear report, that the easterly part of the 159 square miles had not been developed to the extent of its full quota of wells. The above table combines the yield of 67 square miles of well-developed westerly part of the 159 sq. miles with 92 sq. miles of incompletely developed easterly part, and Mr. Spear estimated their potential yields as about 0.900 Mgd per sq. mile for the westerly part and 0.700 Mgd per sq. mile for the Easterly part, or roughly 0.800 Mgd for the average of the 159 sq. miles, but thought that a yield of nearly 1.00 Mgd per sq. mile might be attained in years of normal rainfall, assuming full development of collecting works.
4. Mr. Spear included the ponds and reservoirs as a part of a permanent system. There is not the same chance of doing so in Suffolk county. At the same time Mr. Spear noted as a matter of observation that the ponds tended to shrink in the regions where there were more complete well developments. The writer has elsewhere stated his belief that this will occur in Suffolk county with the full development of later years and will tend to decrease the loss of water to the sea.

After considering all the above data from the Spear report, and his own experience in the development of ground water supplies in all four counties of Long Island, the writer arrived at the following figures for what he considers the conservative safe ground water yield of Suffolk County.

	MGD
A. For area north of the topographical divide and west of Southold bay, not including some marginal land at and near the shores, 131 sq. miles at a yield of 0.35 Mgd	46.
B. For area from Southold Bay East to Orient Point, not including some marginal land at and near the shores, 7 sq. miles at a yield of 0.30 Mgd	2.
C. For area south of the topographical divide, not including area of a strip along the south shore and the shores of the Peconic bays about 1 mile wide and not including the area between Montauk Point and Cherry Point (a little East of Amagansett) nor areas east of Southold, 640 sq. miles at a yield of 0.70 Mgd	448.
D. For area between Montauk Point and Cherry Point, not including a strip along the shores about 1/4 mile wide, 16 sq. miles at a yield of 0.3 Mgd	5.
Total Safe Yield	501 Mgd.
Total effective area	794 sq. mi

Note 1. Areas used above were obtained by planimetering areas on a map of the Water Power & Control Commission to a scale of 1 to 125,000, or about 2 miles to the inch, using limiting boundaries added by the writer to indicate marginal areas along the salt water excluded as useless for a permanent water supply.

Note 2. The computed conservative safe yield of Suffolk County, 501 Mgd, compares with the 460 Mgd estimated by Mr. Suter in 1937, as shown in Section 3.6-6 above.

Note 3. Since the recorded yield in the 159 sq. miles assumed by Mr. Spear to have been tributary to this watershed in Nassau and Eastern Queens County system owned by New York City was exported to New York and not run in part back into the ground as sanitary sewage, the yield should be equal to that after a sanitary sewer system is in operation discharging its purified effluent into the sea. The writer agrees with the views of Mr. Geo. D. Norcom (see his Appendix D) that the County should have a sewerage system ultimately and should not plan to augment the potable water supply by the use of seepage into the ground of the effluent of sewage plants, however purified. Some factor of safety would be afforded by the construction and operation of "recharge basins", i.e. small reservoir-like basins into which surface drainage is led from catch basins through pipe systems, so that the drainage water may seep into the ground and be added to the water supply instead of finding its way for the most part into salt water by way of natural streams or surface water drainage systems. It should be noted however that a considerable part of the surface drainage must have been caught in the several streams and reservoirs which were part of the New York City Ridgewood system, data from which was considered in estimating safe yield of Suffolk County.

Note 4. It is necessary to define what relation this estimated yield has to metered consumption of customers. All existing water distribution systems leak. The sum of customers meter readings will generally lack 10 to 15 per cent of the sum of supply pumping station meter readings, i.e. the pumping stations which in this case take the water from the ground, not including those which pump the water a second time to raise its pressure. This 10 to 15 per cent of leakage would on Long Island return to the ground water supply. Since the data on which the author's 1956 estimate of yield described above was on water taken from reservoirs, ponds and wells and exported to Brooklyn through large, direct line conduits and not through the grillage of a distribution system, the estimated 501 Mgd yield would correspond with net use and not with the primary quantity pumped from the ground in systems situated where the water is to be consumed.

Hence, when supplying customers in Suffolk County through a distribution system, there would be a return to the ground, through pipe leakage, of a considerable part of the original pumpage from the ground. As modern pipe line joints generally have less leakage, this 10 to 15% tends to become reduced; furthermore, some of this leakage gets into sewers and some, viz. that occurring near the shores, joins the underground flow into the sea. Later in the report I have credited 7.5 per cent as returned water.

DISCUSSION OF THE VARIOUS FIGURES GIVEN ABOVE FOR SAFE WATER YIELD PER SQUARE MILE FOR LONG ISLAND

Section 3.7-1. As previously stated there is as yet no mathematical proof of the ultimate safe yield per sq. mile of Long Island, i.e. the yield which could be obtained with the water table drawn down to the level which would reduce wastage into the sea by stream and underground flow, but not drawn below the level which would cause salt water intrusion.

Section 3.7-2. Mr. Suter (see Section 3.6-6 above) visualized better geological knowledge and better methods of withdrawing the water which in time might permit a take of 1 Mgd per sq. mile without ruination. It may be noted, however, that the author's computation of the yield of Kings and Queens Counties between 1903 and 1932 did not reach 1 Mgd per sq. mile of gross land area. See Section 3.6-5. Data was known to be imperfect in this case but the water table was drawn below sea level which could not be done safely for a permanent supply.

Section 3.7-3. Mr. Spear used 0.800 Mgd per sq. mile on the supposition that large reservoirs could be built in Suffolk County (see last paragraph of Section 3.6-4) and the surface water from them filtered and added to the ground water. This would have been practicable in 1910 but does not seem so at present. The writer thinks of the County or park system owning the existing ponds and pond sites on the streams, but with ponds of smaller areas than at present, used for recreation and scenic beauty, and with well pumpage from their vicinity limited to the amount which would keep the water table high enough to maintain these smaller ponds. This is thought to be in harmony with the necessity of preventing intrusion of sea water. Such smaller reservoirs, however, would not store, for dry weather use, the larger surface water flows from heavy rain storms as was visualized by Walter Spear in his studies of 1908.

Section 3.7-4. Influence of Methods of Sewage Disposal. Previous to the installation of a sewerage system, disposal is generally into the ground by cesspools and septic tanks with underground outlet piping having perforations or open joints. The six estimates of yield described previously were affected variously by sewerage. The first, that of John R. Freeman, (See Section 3.6-2), doubtless took no account of sewage disposal. Those of Walter E. Spear, Sections 3.6-3 and 3.6-4, were really based on the records of the New York City's Ridgewood system in Nassau and Eastern Queens counties, but this water was exported to Brooklyn, so that in effect the water used was lost to Nassau County and not recirculated as sewage.

The writer's estimate of the average 1903-1932 yield of Kings & Queens Counties, Section 3.6-5 above, had a very varied sewage influence. In the early years, ground water was high and sewers received not only household waste but also roof and street drainage as well as leakage into the sewers, which was very considerable. The sewerage systems were not complete, however, so that in some districts the sewage went back into the ground.

Later the ground water became very low - lower than the sewers because of overpumpage - and, as sewers, unless perhaps of very recent construction, have always shown considerable leakage, there must have been much seepage

of sewage into the ground. This seems to be evident in the increased nitrates found in the water, probably derived from sewage purified by natural nitrification in the porous sands. (See Appendix D on sewage).

There are of course no records by the use of which a computation could be made of these influences, but in a rough way the plus and minus influences may perhaps be considered as being about balanced over the 29 years.

Mr. Suter's estimates of yield, Section 3.6-6, show by notes that some consideration was given to the influence of sewage on yield. There is no detailed explanation as to how he figured his allowance for sewage.

The author's conservative estimate, Section 3.6-7 above, was also based on Mr. Spear's Ridgewood records, and as this water was exported to Brooklyn, the author's estimate should provide for the ultimate loss into the sea of 100% of the water use, not including water pumped for irrigation, though that applied by spray is probably nearly all lost by evaporation and transpiration from vegetation.

Section 3.7-5. Purified Sewage Effluent Excluded from Estimate of Yield. The sanitary question as to the ultimate future use of sewage effluent from modern sewage purification plants is treated in Appendix D by George D. Norcom. The writer's estimate Section 3.6-7, assumes the ultimate disposal of purified sanitary sewage into the sea.

Section 3.7-6. Influence of Methods of Surface Drainage Disposal. Modern impervious highways, sidewalks, court yards and house-tops interfere with and reduce the seepage of rainfall and snowfall into the ground. In some municipalities, New York City, for example, such drainage from pavements and roofs goes into the sewers and thence into the sea. In some other municipalities, two sewerage systems are provided, one for sanitary sewage and the other for surface water drainage, but where possible, the surface water drainage is generally wasted into water courses, though in some cases parts of it get into storage water supply reservoirs.

In Nassau County, and somewhat in Suffolk County, the practice has grown up, and become compulsory, of providing seepage basins in which surface water soaks into the ground to augment the ground water supply. This is taken up in Appendix J. The results have been found very promising as regards salvaging surface drainage. When Suffolk County is fully developed and the maximum of impervious area is reached, the saving in water by the use of recharge basins might reach 15 per cent or more in available water supply, based on rough preliminary estimates made by the Engineering Dept. of Nassau county for that county.

Recharge basins at present are being installed at the initial expense of housing developers in cost of land and construction of basins, with their care at the expense of the public at large. Practically the whole expense comes finally on house owners and the general public as one of the uncomputed costs of water supply. The recompense for this expense comes immediately in freedom from flooded streets and the saving of the expense of an extensive trunk drainage system. Additional recompense will come at the time when the population has so increased that the additional water capacity is needed.

Section 3.7-7. Need for Reliable Estimates of Water Yield. In the foregoing pages the various estimates of yield per unit of area of Long Island have been explained and the attempt has been made to show the uncertainties in these estimates. The problem is the same for any part of the Island except that the ground waters of Kings and parts of Queens Counties have been so overpumped that they have had to be largely abandoned on account of intrusion of salt water. Cessation of pumpage in 1947 in Flatbush, where for many years about 25 Mgd was pumped from wells on about 6 sq. miles of territory has caused a pronounced rise of ground water level (which at one place had been about 35 feet below sea level) but no one thinks of trying to renew the use of ground water there as a public supply of potable water. New York City has taken over the supply of Kings County entirely, and of the western parts of Queens County, using upland sources plus small quantities of ground water from Queens County and at times ground water from its Nassau county system.

Section 3.7-8. An Informative Estimate Possible in Nassau County. For knowledge of the probable water yield of Suffolk County one has still, as in the 1903 and 1908 studies of Walter Spear previously described, to look to the records of Nassau County. A direct arithmetical estimate of yield of Nassau County could apparently be made like that made by the writer for Kings and Queens Counties for the period 1903 to 1932. (See Section 3.6-5 above). A period of say 6 years might perhaps be sufficient to eliminate for the most part the differences in rainfall, which have a great effect in the elevation of the ground water table, i.e. in the quantity of water stored in the ground water reservoir; but the estimate should be a continuing one. Such an estimate would determine the yield for the elevations of ground water as existing for the period studied. Some increase in yield would occur with reduced water levels due to increased use of water, because there would be less waste into the sea through underflow in the ground and in surface streams. No matter how carefully such an estimate is made, there is always the question as to how much water is escaping into the sea, between and beneath the wells. There must always be some loss and the problem is to so arrange the spacing and depth of wells near the shores that this loss will be a minimum consistent with avoiding the intrusion of salt water. The lower the ground water can be maintained without salt water intrusion, the greater will be the yield available for use.

In such a study of Nassau County yield made under present conditions there would not be the same necessity, as was the case in the author's 1934 estimate, of approximating by various devices the initial water table elevations and pumpage quantities which are needed for the reckoning.

Section 3.7-9. Examination as to the Effect of Seasonal Peak Demand and of Low Rainfall on Yield. As is known to all, the summer months in the northern part of the country produce greatly increased rates of water use. and on certain extraordinarily hot days the use may be twice or more times that during cooler parts of the year. It is necessary to examine whether this high seasonal use requires any diminution in the estimates of safe yield per square mile, which in the foregoing computations, have been based on average rates of use for a year and have taken no account of the high summer rates of use.

It will be stated without present proof that the effect of a very high rate of consumption for a day or for serveral consecutive days has in general no considerable effect on the level of the ground water table, because

the interstices in the sands and gravels of Long Island form a huge reservoir of fresh water. However, the cumulative effects of a long hot summer season cannot be dismissed without proof as to its effect on the safety of the figures for estimated safe yield. An example will be given below.

After examination of the statistics of monthly consumption in the Suffolk County Water Authority plants combined for the year 1953, a year of high summer uses, and of similar statistics for a Nassau County plant known for its relatively high summer rates of use, the author chose the latter plant to illustrate the problem. At that plant in 1953 the total consumptions in the summer months were much above the average monthly consumption as is shown in the table below, which shows also the effect of these variations in draft on a square mile of the south slope of Suffolk County, assumed in the foregoing estimate of yield to have a safe yield of 0.700 million gallons daily.

EFFECT OF SEASONAL DEMAND ON WATER LEVELS
EXAMPLE FROM TYPICAL L.I. PLANT FOR 1953

Month in 1953	Water Consumption Expressed as Ratio to Average for year taken as Unity	Deficiency in Draft		Excess of Draft	
		Expressed as Ratio to Average	Expressed as Mgd. for Month (1)	Expressed as Ratio to Average	Expressed as Mgd. for Month (1)
1.	2.	3.	4.	5.	6.
January	0.597	0.403	8.75		
February	0.675	0.325	6.37		
March	0.691	0.309	6.70		
April	0.721	0.279	5.86		
May	0.790	0.210	4.55		
June	1.382			0.382	8.02
July	1.756			0.756	16.41
August	1.260			0.260	5.64
September	1.300			0.300	6.30
October	1.116			0.116	2.52
November	0.908	0.092	1.93		
December	0.804	0.196	4.25		
	12.000	1.814	38.41 (2)	1.814	38.89 (2)

(1) Note - Figures in Columns 4 and 6 are on basis of an average daily draft for year from 1 sq. mile equal to the estimated safe yield of 0.700 Mgd per sq. mile for the Southern slope of Suffolk County, as given in Section 3.6-7. Quantities in Columns 4 and 6 therefore = figures in columns 3 and 5, respectively, multiplied by days in month and by 0.700.

(2) Note - These totals should be the same but differ slightly because of use of actual number of days in months instead of average number.

Arithmetically considered, excesses of yield over draft (Col. 4 above) would accumulate in the ground during the previous fall and spring (there is a time lag in its reaching the ground water table) and would be removed in the summer by equal excesses of draft over yield (Col 6 above). The extent of the rise and depression of the water table could be approximated as follows:

1" depth of water on 1 sq. mile of area = 17.4 million gals. In sand and gravel having 30% of voids, 17.4 MG would fill voids in 1 sq. mile to a depth of 1/0.30 = 3.33 inches. The excesses of yield and of draft averaging about 38.65 MG in columns 4 and 6 would be sufficient to cause a rise and fall of water table on 1 sq. mile of 38.65/17.4 x 3.33 = 7.4 inches. Unknown variations in wastage into the sea prevent accuracy in such a computation but the conclusions stated below seem justified.

It is evident that the elevation of ground water table would not be markedly affected by the monthly variations in consumption and much less by even the maximum hourly variations that may occur on peak days.

Cycles of low rainfall are much more important influences on ground water levels but the estimate of yield, 0.700 Mgd for the area under consideration, was intended to be safe even in cycles of low rainfall. A yield of 0.700 Mgd per square mile would correspond to (365 x 0.7) divided by 17.4 = 14.7 inches of percolated rainfall per year, which is about one-third of the usual rainfall.

Scrutiny of the long rainfall record of Western Long Island (1879 - 1931 incl.)* compiled by the late I. M. de Varona, then Engineer of Water Supply of Brooklyn, later Chief Engineer of Water Supply of greater New York City, showed three periods of very low rainfall as follows:

1879 to 1883 incl., 5 years, average 39.39", total deficiency 15.3 in.
1891 to 1896 incl., 6 years, average 37.98", total deficiency 26.8 in.
1928 to 1931 incl., 4 years, average 37.13", total deficiency 21.2 in.

The deficiency stated above is reckoned as the deficiency below 42.44 inches per year which was the average rainfall for the whole period, 1879 to 1931 inclusive.

The longest rainfall record in Suffolk County appears to be that at Setauket in the northern part of Suffolk County, on the Sound. That record extends from 1885 to the present time. A scanning of the Setauket record indicates no period of deficiency as bad as those listed above for Western Long Island. The Setauket average for the years 1885 to 1955 inclusive is 45.27 inches, about 3 inches higher than the de Verona average for Western Long Island. Walter E. Spear wrote of a probable excess of rain in Suffolk County over that of Nassau County.

The deficiency of 26.8 inches of rain in 6 years in the Western Long Island record, assuming an average percolation, less wastage of ground water into the sea, of say 1/3, would correspond with a lowering of the ground water table of (26.8/3) divided by a void ratio of about 0.30. The result is an average drop of 30 inches, which what is known of the history of Long Island ground water fluctuations does not indicate to be improbable. Wastage into the sea would be somewhat reduced by the lowering of the water table.

* See Appendix F, Table 1.

The above study is of course only a crude approximation since evaporation from the ground and from vegetation are an important element in the result and they are larger in dry periods, so that the effect of such periods in reducing ground water levels would be accentuated. Mr. C. E. Jacob made a study relating to this matter. It is entitled "Correlation of Ground-water Levels and Precipitation on Long Island, New York" and was published in Bulletin G.W-14 of the New York Water Power & Control Commission series. Recently the author attempted to have another study of this kind made but there proved to be too many uncertainties in the available data. Ultimately, with sufficient records available, a reasonably accurate arithermetical accounting for the precipitation should be possible and is desirable for such an invaluable asset as the water supply of Long Island.

DENSITY ZONING FOR LIMITING THE POPULATION OF SUFFOLK COUNTY

Section 4.1 - General. Previously in this report (See Section 3.1) the writer has expressed his belief that the population of Suffolk County should be presently limited by density zoning to the number which it is estimated can be supplied by the full development of its ground water resources, leaving to the future the possibility of modifying the zoning if and when the purification of sea water on a large scale becomes economically practicable, provided the people of the County then wish to give up their uncrowded condition of living.

The planning for such density zoning would involve not only the estimate of the safe water yield of the County but also estimates of the future per capita consumption for all purposes and the area of land which will finally be available for residential purposes. In what follows the the author has suggested figures for all these factors and drawn some tentative conclusions, subject to modification when better figures for these factors become available.

Section 4.2 - Safe Yield and Per Capita Consumption. The present estimate of safe water yield has been stated at length as 501 Mgd (See Section 3.6-7). The estimate of future consumption will be stated in the commonly used terms of per capita consumption, in which is summarized consumption for all purposes, including air-conditioning and irrigation as well as household use both by permanent residents and by transients, but all expressed as an average daily consumption by the permanently-residential population. This future per capita consumption the author has assumed to be 150 gallons per capita which is roughly fifty per cent more than that of Nassau County at present and somewhat more than double that of Suffolk County at present. The per capita figures here meant are all somewhat less than the required pumpage, because they do not include water "diffused" back into the ground by industrial plants and air-conditioning plants, nor the estimated return back into the ground by unavoidable leakage from the water distribution pipes.

Section 4.3 - Land Available for Housing. The third factor, viz. area of land ultimately available for residence lots, involved an estimate of the area required for the many public purposes, such as sub-division streets, main highways, park ways, parks, golf grounds and beach resorts, ponds, recharge basins, public airfields, cemeteries, railroads, hospitals, school grounds, pumping stations and well fields, shopping centers, manufacturing and commercial buildings and their parking areas, and airfields, including approximately 8 square miles of the Brookhaven National Nuclear Laboratories and about 10 square miles of sea-side land not available for housing. For these various public and other purposes, an area equal to about 45 per cent of the total County land area of 920 square miles was listed, which would have left 55 per cent for residence lots.

A Conference with Mr. John M. Muddeman, Consultant to the Suffolk County and other planning boards, indicated that this 45 per cent was an underestimate. Reference was recommended to a treatise by an authority on this subject * wherein statistics were given showing that the percentage

*See 1953 Edition of "Land Uses in American Cities", by the distinguished planning consultant, Harland Bartholomew.

of land used for residential purposes in cities averages around 40 per cent of the "developed" area and the developed area even in cities of 25,000 population and over may not be quite 80 per cent of the whole area. As it is hard to imagine anything like 20 per cent of such attractive country as Suffolk County as to be permanently undeveloped, the author is cutting this to 10%. These latter proportions would make 40 per cent of about 90 per cent or 36 per cent of the total 920 square miles i.e., 331 square miles, available for residence lots.

Section 4.4 - Estimate of Average Size of Building Lots. Using the estimates given in Sections 4.2 and 4.3 above for the three factors, the average size of building lots which, assuming single family dwellings, would house the maximum population for which the estimated safe water yield of the County would suffice figures out as follows:

501 Mgd at 150 gallons daily per capita would serve 3,340,000 people.

3,340,000 people at an average of say 3.6 per dwelling would require 928,000 houses.

928,000 houses occupying 331 square miles or 211,840 acres of house lots would require on the average 0.228 of an acre or about 9,900 square feet per lot.

Density zoning has been generally accepted as proper and reasonable. Recently some excesses have been committed in zoning ordinances because of inundations of new population in desirable localities. No such excess would be involved here. A reasonable range of lot sizes from a maximum of not less than an acre for more sightly regions, 1/2 acre for others and down to 60' x 110', or 0.151 acre for smallest lots, would appear to solve the water supply conservation problem. However, study by the best informed persons available to the County regarding land uses, parks, highways etc., is necessary before any final figures can be obtained.

MARGINAL LAND AND DEPTH PROTECTION FOR PURITY OF WELL WATER

Section 5.1 - Past Practice on Long Island. Though the quality of public water supplies of New York City have been since a few years before 1900 under the most expert laboratory protection of skilled sanitary chemists and bacteriologists, trained in the knowledge developed during about a decade around and previous to 1890 by the Lawrence, Massachusetts, State Board of Health experimental research work, the location of new well sites in Kings and Queens counties never, so far as the author knows, became a matter of definite enforced rules as to marginal land protection. Many wells with the engineering of which the author was connected were placed on lots 25 feet or so by 100 feet, with buildings adjacent and sewers in the streets. Old cesspools were located where possible and avoided. Some of these wells were 400 to 430 feet deep but most of them were about 150 feet.

The New York City water laboratory was very careful in its bacteriological examinations of the water but chlorination was seldom necessary, though always available either from installations at the wells or ready in storage. Chlorination was done at a few wells, where not necessary for bacteriological reasons, to destroy slight hydrogen sulphide tastes and odors and was done as a precautionary measure at a number of shallow wells. That some sewage, purified by the ground, reached the wells seems to the writer to be indubitable and the fact that the nitrates were relatively high seems to be corroborative.*

The New York State authorities have required larger lots in Nassau and Suffolk counties and water companies have been glad to comply since land was generally available without excessive cost. However, margins of protection have been sometimes as small as 100 feet and even less for existing wells.

Section 5.2 - Present Practice in Nassau & Suffolk Counties. The general practice of the New York State Water Power & Control Commission is to require a margin nowhere less than 100 feet from well to property line of a well site, unless there is some potential sanitary hazard which in their judgment requires more in which cases margins of 200 feet or even 300 feet may be required. No stated distinction in marginal protection is made between wells in the upper, or glacial outwash, formation and deeper wells with screens in other geological formations. However, greater depth of well does apparently cause greater leniency in cases where the conventional margin is difficult to get.

The local county health officials generally try to have not less than a 200 ft. margin and urge the placing of the screens in the deeper formations, but will make some concession to marginal protection in cases of deeper wells where margins are difficult to obtain. This in Nassau county has resulted in about 72 per cent of the water being taken from the Magothy formation in 1955, the latest year of record, as against about 15 per cent from the Glacial outwash, 3 per cent from the Jameco and 10 per cent from the Lloyd sand, whereas the potential supply from the Glacial is greater than that of the deeper strata combined.

*See Appendix D by George D. Norcom, part relating to the former supply for Flatbush, Brooklyn, N.Y.

The rules of the New York State Water Pollution Board forbid the presence of polluting matter within distances specified in decisions by the State Water Power & Control Commission, or if no limiting distances have been specified, within 200 feet of well, spring or infiltration gallery used as a source of public water supply and none within 100 feet of well, spring or infiltration gallery used as a source for any other kind of drinking water supply, unless a lesser or greater distance is approved, permitted or required by local health authorities or the State Department of Health; otherwise, none in such a way or in sufficient amounts to impair the waters for use as a source of water supply for drinking, culinary or food processing purposes. Nothing in their specifications "shall be construed as preventing the location of new wells under the jurisdiction of the Water Power and Control Commission".

Section 5.3 - More Yield Seems Probable with Both Shallow and Deep Wells; also Economy in Cost of Well Sites. The observations of the Nassau county engineering department indicate that in a period of generous rainfall the upper ground water-table rises faster than that in the Magothy and the latter faster than that in the Lloyd formation. No statistical data on this is available to the author, but it is his opinion that when the full potential supply becomes necessary, more water would be wasted into the sea then would be the case if the draft were divided properly between all available formations. This view has met with no contrary opinions in the author's discussion of it with those who are best informed on Long Island ground water conditions.

The author has had successful experience, and no unsuccessful experience with placing deep and shallower wells on the same lot, where the sand formations are separated by even thin clay beds. This arrangement has made for economy in cost of well sites and in other ways.

Section 5.4 - Evidence as to Sanitary Danger to Well Water from Adjacent Pollution. Bearing on this question the author has his long experience with Long Island wells and with those in many other plants in various states. He also has read reports of special investigations on this subject and has had the benefit of Mr. Norcom's comments and of his report included as Appendix D.

Some experience known to the author indicates that, with exceedingly few exceptions, bacterial pollution does not get into the ground water with even as little as four feet of sand as a barrier between cesspools, for example, and an adjacent shallow well. Opposed to this view is a classic example in which B. coli is reported to have traveled a maximum distance of 232 feet. This case is referred to below. Coarse sand or gravel between the source of pollution and the aquifer would make a potentially dangerous condition.

Section 5.4-1 - Experiments at Fort Caswell. See Hygienic Laboratory Bulletin No. 147, 1927, U.S. Public Health Service. A trench was polluted with excreta and uranin. Tests of 423 ground water samples taken at 41 distances from the source of pollution up to a maximum distance of 424 feet, apparently in the direction of ground water flow, showed B. coli present in 2 out of 24 samples taken at a distance of 232 feet. B. coli were found in a few of the several samples taken at each of the distances of 35', 45', 50', 60', 65', 95', 115', 116', 170', 180', 190', 195', 210',

228', but in one of the samples taken at 3', 15', 70', 75', 80', 85', 90', 100', 110', 125', 184', 203'. No. B. coli were found at the 14 points tested beyond 232' up to the last point 424' away. The tests were made between June 1, 1923 and June 22, 1925. The test at the 232 foot point was made on July 17, 1924. The ground material was described as fine with a ground water movement of only a few inches a day. (Note - 232' travel between June 1, 1923 and July 17, 1924, would be 232 x 12 = 2784" travel in 412 days, or 6.8 inches per day. It might be questioned if the B. coli could live that long. Author)

Section 5.4-2 - Experiments at Lodi, California. See California State Water Pollution Control Board, Sacramento, Calif., S.W.P.C.B. Publication No. 6, 1953, entitled "Field Investigation of Waste Water Reclamation in Relation to Ground Water Pollution." The first of 7 conclusions stated on page 16 of this report was worded as follows:

> "1. A bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid passes through at least four feet of soil."

This conclusion was qualified by the authors in their 7th conclusion, calling attention to the fact that their study was with Hanford, fine, sandy loam and that further investigations with different soils were necessary "in order to generalize the foregoing conclusions." This author recalls hearing of some very early experiments by the Brooklyn water works department in which cesspool pollution was found absent at a distance of 4 feet. In the comments on tests noted in Bulletin No. 147 relating to the Fort Caswell investigations, conclusions were stated that the soil above the water table was the best sanitary protection and that rise and fall of the water table due to variations in the rainfall were potent aids in limiting travel of the pollution.

There is clear experimental evidence that sewage forced into an aquifer will travel with the ground water to much greater distances than if allowed to percolate by gravity. Doubtless under all conditions a formation of coarser particles will permit greater travel than one with finer particles.

Section 5.4-3 - Dissolved or Fluid Chemicals May Travel Great Distances in Aquifers. The author has had personal knowledge of at least five cases where chemicals have traveled some hundreds or a few thousands of feet between points of entrance in the direction of ground water flow. The fact of such travel of fluids is well established and has no direct bearing on the question of pollution by disease germs or viruses.

Section 5.5 - Recommendations as to Marginal Land and Depth Protection for Well Water. The author believes that there is very little danger of bacteriological pollution of well water from the ground surrounding a well. Experience with wells in Kings and Queens counties over many years, as described in Section 5.1 above, is more convincing than for example the classic example at Fort Caswell, Virginia, described briefly in Section 5.4-1 above. The travel time there, 412 days to the point 232' distant from the source of pollution, seems too long to suspect the same source of pollution. The author believes that a 100 foot margin all around the well

is ample and is of the opinion that as Suffolk county becomes more settled, a lesser distance will finally be accepted where larger lots are not available without removing buildings.

Within the 100 ft. margin there should be no known sources of pollution, such as cesspools. Abandoned cesspools, if necessarily included within the marginal distance, should be sterilized after removing any residual contents. Sewer connections should be located so as to be sure they are not within the marginal area.

Since gas house and other chemical wastes, fluid or in solution, travel an indefinite distance with the ground water flow, that possibility should be investigated for past or existing possibilities of phenolic or other chemical pollution since these pollutants cannot generally be removed by any treatment practicable at a well installation. It should be the duty of the zoning board and the local health officials to prevent such pollution.

As for depth of wells, the author would not sacrifice the ultimate ground water yield by forbidding the placing of well screens in any of the aquifers - glacial, Magothy or Lloyd, nor would he prescribe minimum depth to the well screen or to the infiltration gallery pipe line, since in many places in the Eastern part of Suffolk county and near the shores, shallow wells or infiltration galleries are likely to be the only available source, as on the north and south flukes. A band of 100 feet on each side of an infiltration gallery should be sufficient protection where the ground is soil or sand, or sandy gravel.

Section 5.6 - Sanitarily Safe Construction of Wells Necessary It is of course of paramount importance, as has long been recognized by sanitarians and by water engineers in their designs and specifications, to so construct the wells that there shall be no direct leakage into them. This involves well casings of substantial thickness with tight joints, sealed into the ground in their upper parts, wide concrete foundations connected in a water-tight manner to the top of the casings, and water-tight joints between pump bases and casings.

Section 5.7 - Bacteriological Analyses should of course be made with sufficient frequency for water from any source, and chlorine should be used when necessary. At many, perhaps most, well sites the author believes both shallow and deep wells may be placed to advantage.

COMPREHENSIVE PLAN

Section 6.1 - General. There are now in Suffolk County water plants under various ownerships to the number indicated below.

15 Municipally owned plants, mostly those of water districts.

12 Suffolk County Authority plants

71+ Privately owned plants.

These plants are in general without connections to each other except in the case of Water Authority plants, four of which, viz: Amityville, Babylon, Bay Shore and Patchogue, are inter-connected lightly, but sufficiently for the present density of population.

The general map bound at the end of this report shows the location of these public supplies and of their wells, pumping stations and principal pipe lines. It also shows the elevation of the ground at many points and by blue contours the elevation of the ground water table as plotted by taking the average of the maximum and minimum elevations at each of the many test wells during the year 1955.*

Appendix E contains tables giving the main facts regarding the wells, pumping equipment, tanks and quality of water of these plants. An examination of the general map, attached at the end of this report will show that these public water supplies in Suffolk County, whether those of the Water Authority, of water districts or of other municipal agencies, or privately owned, are in general spread widely apart, except in the westerly part of the County. The areas between them are in general supplied by small individually-owned wells, having for the most part automatically-controlled pumps and pressure tanks, serving single houses, stores, manufacturing plants, etc.

The author hence has found it impracticable to show by a drawing a general plan of future development as can be done, for example, in the case where the water is to come from a distance and be transported by an aqueduct or pipe line.

Here we have a potential water supply under almost all the land and the order of occupancy of the land, in sufficient density to create a demand for a public water supply or support it financially, is determined not by local or County government but by developers operating under the American free-enterprise system. The activity of public authority, as represented by the State Water Power and Control Commission and the State and County departments of health, is limited to advice and finally approval or disapproval of proposed water supply installations.

This report therefore concerns itself mainly with

(a) Estimates of the safe water yield of the County,

*For a detailed explanation of these wells and the water table contours derived from them see Bulletin GW-27 of the New York State Water Power & Control Commission, dated 1951.

(b) Study of the geology as affecting the proper location, spacing, capacity and depth of wells in order to obtain ultimately the maximum practicable water yield while avoiding the induction of backish water,

(c) Standards of construction for wells, pumps, tanks and pipe lines,

(d) Problems of preserving from pollution the fine quality of the water, and finally

(e) Suggestions aimed at improving the knowledge relating to the water supply and as to the regulations under which the development of the water supply must proceed.

The report assumes that in time, as population increases, wells and some infiltration galleries will be rather closely spaced over the whole County, because only in that manner can the full supply be obtained and the peculiar economic advantages of "short haul" water be realized.

The bases for the conclusions stated in the following description of the plan have been derived in general from the studies described in the preceding sections of the report or from the appendices.

Section 7.1 re-statement of Estimated Yields per Square Mile in Various Parts of County. Necessary Well Capacities are Directly Related Thereto. In the author's estimates of the total safe yield of Suffolk County (See Section 3.6-7), certain estimates were made of the safe yield of various parts of Suffolk County. A summary of those assumptions follows:

A.	For area north of the topographical divide and West of Southold Bay, 131 sq. miles at 0.35 Mgd per square mile	46 Mgd
B.	For area on North fluke East of Southold Bay, 7 sq. miles at 0.30 Mgd.	2 Mgd
C.	For area South of the topographical divide, West of Southold Bay and West of Cherry Point near Amagansett, 640 sq. miles at 0.70 Mgd.	448 Mgd
D.	For area on South fluke, East of Cherry Point, 16 sq. miles at 0.30	5 Mgd
	Totals 794 Sq. Miles and	501 Mgd

These estimates of yield are of course approximate but are the best the author has been able to arrive at with the data available at present. The plan as to ultimate capacity of the wells will necessarily be related to these estimates of ultimate yield.

Section 7.2 Peak Rates of Use. The above figure of yield relates to average daily yield and use for a year in the period after the County has reached full development. Peak day demands must also be met by wells, and excess of peak hour rates of demand over peak day demand may be met either by more well capacity (which means drawing on storage in the ground, thus

increasing the maximum rate of draft but not the total draft for the day) or by storage in tanks or by a combination of storage in the ground and storage in tanks.

Peak day and peak hour demands are so variable, as between different plants, and in recent years so increasing and so unpredictable that each future period and plant must ascertain its own requirements. What follows below is intended to illustrate the principles involved.

Section 7.3 - Statistical Data on Average and Peak Uses from Plants of the Authority. Statistics for the calendar year 1955, compiled by Mr. H.F. Gardner, Asst. General Manager and Chief Engineer of the Suffolk County Water Authority, indicate the following peak consumption figures:

(a)	Ave. yearly rate of consumption per service, for all Water Authority plants combined, including water pumped and water withdrawn from storage	0.170 gals.per min.
(b)	Ave. peak day consumption per service of same plants combined	0.376 " " "
	Ratio of (b) to (a) = 0.376/0.170 =	2.21
(c)	Ave. maximum or peak rate of consumption per service of same plants combined, including water pumped and water from storage =	0.716 " " "
	Ratio of (c) to (a) = 0.716/0.170 =	4.21
(d)	Ave. rate of consumption per service of same plants combined, for maximum 5 hours of peak day	0.659 " " "
(e)	Approximate storage required, expressed in per cent of peak day, if well and well pump capacity is equal to, but not more than, the average rate of consumption on the peak day, is as follows:-	

$$\frac{(0.659 - 0.376) \times 5 \times 60}{0.376 \times 24 \times 60} = 15.7\% \text{ of peak day consumption*}$$

It will be noted that the above figures are based on averages of all 11 plants of the Authority. Individual plants vary. For example the peak rate, 0.716 as an average above, varied for the different plants from 0.60 to 1.16. A common pumping capacity for small new plants with no considerable storage is 1.00 g.p.m., which is admittedly quite liberal.

In what follows it will be assumed, to illustrate certain principles, that the peak day consumption will be 2.2 times the average daily consumption for the year and that the maximum excess of consumption over the average rate for the peak day which occurs during 4 or 5 hours of the peak

*Note - Data for an exact estimate of the average percent of storage used is not available as the rate of consumption on the peak day may have exceeded the average rate for the day during other than the 5 peak hours. A storage of 25 per cent of the peak day use has been found by the Authority's engineers and in other cases over the years by the author to be a reasonable provision.

day will be provided for by storage to the extent of 25 per cent of the total peak day use; further that 20 per cent of this storage, i.e. 20% of 25% of the total peak day use, will be from the ground, i.e. storage obtained by extra pump capacity.**

The required pump and well capacity will therefore be the sum of two rates as follows:

(1) 2.2 x (average daily consumption for the year)

(2) 5% of (1) to provide for the use of the ground storage.

Total = 1.05 x 2.2 x (average daily consumption for year,)
= 2.31 x (" " " " ")

A factor of say 25% - not large because at the time of full development of the County, interconnections would have been installed - should be added to care in part for breakdowns. This factor would increase the total to 2.31 X 1.25 = 2.89 X (average daily consumption for the year.)

Since, at the time of full development of the County, the average pumpage from various parts of the County is assumed to be equal to the safe yield of those parts, the above computations would mean that the factor of 2.89 would be applicable to the estimated safe yield of the various parts as summarized in Section 7.1 above. The results would be as tabulated below.

Sect. 7-4 - Estimated Well and/or Infiltration Capacity and Pump Capacity per square Mile.

For 131 sq. miles along north slope,	0.35 Mgd	X 2.89	= 1.01
For 7 sq miles of north fluke,	0.30 "	X 2.89	= 0.87 Mgd
For 640 sq. miles of south slope,	0.70 "	X 2.89	= 2.02 Mgd
For 16 sq. miles of south fluke,	0.30 "	X 2.89	= 0.87 Mgd

It is of course to be understood that the above figures are mainly for the purpose of showing concretely the relationship between estimated safe yield and the ultimate well and/or infiltration gallery capacity required to produce it when needed, even during days of greatest consumption. In using the factor 2.89, derived above, it was assumed that the relationship between average and peak consumption would remain the same as it was in 1955, though the per capita consumption assumed for the future period of full development of the County is about double that at present and the relationship might be considerably different. However, the method of approach to an answer could apparently be the same.

**It should be emphasized that the percentage of storage assumed to be in the ground does not affect the total pumpage for the peak days, though it does increase the maximum rate and the variations in the necessary rate of pumping from hour to hour. It is always an economic question whether to provide a greater or less percentage of storage in the ground with corresponding extra pump capacity or to provide the storage in tanks at ground level or in elevated tanks.

Well capacity will of course not be uniformly distributed over any considerable area of the County, but experience with older plants indicates that it will tend to become more evenly distributed as consumption approaches the ultimate safe yield.

LOCATION AND SPACING OF WELLS AND INFILTRATION GALLERIES

Section 8.1 - In the foregoing pages estimates have been given of the amount of installed well and infiltration gallery capacity, about 2 Mgd per sq. mile which the author estimates should be available in the 640 square miles of area south of the superficial divide and west of Southold Bay and Cherry Point; also the conclusion that areas of less yield per square mile would by the same method require proportionately less well and infiltration gallery capacity. The ultimate pattern for wells and infiltration galleries which is indicated for Suffolk County from past experience and the present geological knowledge is as follows:

Section 8.2 - Wells in the Glacial Outwash near Shores. Along the shores of salt water no public water supply well with screens in the glacial outwash should be located in a strip varying from about 1/2 mile to 2 miles wide according to elevations of the ground and the water table. Wells with screens in the glacial outwash, located nearest the shores should be of relatively small capacity and relatively closely spaced. A spacing of 200 to 500 feet and capacity of 200 to 500 g.p.m. is in mind, but each location requires study to avoid cones of depression which will tap salty water. Though such closely-spaced wells near the coast are necessary finally to get the full yield, it will be a question, in each general location, at what stage in the population growth it will be economic to install them. Infiltration galleries would better serve the same purpose if land could be had. And it would pay to install infiltration galleries at an early date in order to secure the land. Outpost wells should be used to give warning of salt water intrusion.

Section 8.3 - Infiltration Galleries. It is recommended that infiltration galleries, similar to those of New York City's system, in Massapequa and Wantagh, be tried as soon as practicable where land is available, near the shore but not nearer than for wells as above described. These seem likely to be better than wells near the shore and may be found successful in the matter of reasonable yield and freedom from salt water intrusion. In narrow parts of the "flukes", infiltration galleries seem to be the only chance of obtaining water without an objectionable admixture of salt water. (See Appendix H for information on infiltration galleries.)

Section 8.4 - Wells Farther Inland. These may be more widely spaced and of greater capacity, though it will be necessary to compare the cost of having the wells near the points of use with wells more widely spaced requiring greater cost of transportation; also ultimately to investigate whether closer spacing will be needed to prevent wastage of water into the sea. This latter consideration has generally caused a gradual filling-in of wells in spaces originally left without wells. In Flatbush and Woodhaven, wells about 150 feet deep and of about 500 to 600 g.p.m. capacity were found not to interfere with each other when spaced about 1200 to 1500 feet apart. Well fields in the present plants of the Authority are

of course much farther apart, generally several miles. Two or more wells may be placed on the same plot, as near together as 100 feet or even less. Although there will be some interference in their cones of depression and some reduction in their yield, they would be run simultaneously only in hours of high rates of consumption.

Section 8.5 - Wells in All Formations. The author recommends making use of both the glacial outwash and the Magothy formations, also ultimately the Lloyd formation, if found useful after explorations made so far only to a limited extent except near the North Shore,* doubtless because of its great depth elsewhere.

The author sees no reason why the Authority should not continue to take full advantage of the economy of early use of the glacial outwash. It is to be hoped, however, that it will be generally practicable as regards vertical interference to place wells in Magothy on the same lots at such time as will be required to provide for seasonal peak consumption and increasing population. It would be well to extend the test wells of some at least of the wells placed in the early years into the Magothy to test such interference.

There is evidence in Nassau County in an observed lag in the rise of the water table in the Magothy and a greater lag in the Lloyd, after a period of copious rain, as compared with the prompter rise in the glacial outwash, also in the fact that about 72% of all the water from wells in Nassau County comes from the Magothy, that the water does get through the clay beds existing in the Magothy and above the Lloyd. It seems more than probable, however, that the use of the glacial outwash is necessary to prevent unnecessary wastage of water by underground flow into the sea.

Section 8.6 - Possibility of Deep Wells Nearer South Shore. Deep wells on the barrier beaches both in Nassau County and in Suffolk County penetrated thick strata of clay and yielded water of acceptable quality, except that in a number of cases the iron content was high These wells include those in the Lloyd formation at Long Beach in Nassau County and those in the Magothy formation supplying Jones Beach, in Nassau County, also those supplying Fire Island, Ocean Beach, Saltair, and other places in Suffolk County. In these wells the static levels are generally 8 or 10 feet above sea level. Geologists visualize these so-called Cretaceous formations as extending far out to sea but doubt the continuity of the clay beds, thinking of them rather as lenticular. Since deep wells have been successful on the barrier beaches, it would seem probable that fresh water could be obtained from deep wells on the mainland at or near the south shore of Suffolk County.** Whether the water would shown the characteristically high iron or similar wells on the barrier beaches is of course unknown.

*Here ten wells in Lloyd near the North Shore are in successful use, but six others in Lloyd, three of which were on the northern fluke, did not yield acceptable water. Also two very deep wells, 1562' and 1498' respectively, to rock, at the Brookhaven National Laboratory, were not found worth developing for water.

**If the clay beds are discontinuous, e.g. lenticular, salt water might enter in the future when full development has lowered the water table and reduced the underflow to the sea.

Walter E. Spear supervised the drilling of a great number of test wells in Suffolk County for the Board of Water Supply of the City of New York in 1907 and 1908 and wells pertinent to this present subject are shown in Volume 1, pages 226 to 252 and drawings sheets 47-49, in the Board of Water Supply Report on Long Island sources in two volumes dated 1912. The California stovepipe wells there reported were sunk to various depths up to a maximum of 931 feet for Well No. 8. They show various beds of clay which could protect the deeper formations from salt intrusion. This possible source of water should doubtless be considered at a later date in the development of Suffolk county.

Section 8.7 - Types of Well. These are so well known that only identifying description will be included here. The simplest type is the tubular well in which a steel casing is sunk by bailing and driving and a screen is placed in the formation below the casing. This has had extensive use in times past but its use is now less common except in smaller sizes.

The so called Layne Gravel-Packed well, sunk by rotary methods, the sides of the well being temporarily supported by a mixture of clay and water, circulated so as to bring up the material dislodged by the rotating tool, has had a long vogue for larger wells but is now being displaced generally by the so called "Reverse Rotary Method" which accomplishes the same purpose, including gravel packing, and can be constructed more rapidly.

The Kelly well, which is sunk inside removable telescoping steel casing by the use of an orange-peel bucket above the water table and by methods similar to the Layne well below the water table, had originally a concrete screen and casing strung on cables and extending to the top of the well. It has been used for many years in the Midwest and to a lesser extent in the East. It originated the use of coarse sand as a pack around the screen which was superior in keeping out sand from the finer formation to the coarser gravel used in the other types of so called gravel-packed wells. The author has been informed that some recent Kelly wells have been constructed with non-corrosive, metal screens instead of concrete screens. The author's experience with Kelly wells has been favorable as is true also of the other types.

Any of these types of wells are suitable for use, but, in comparison with tubular wells, the greater capacity or the lesser drawdown, which can be obtained economically by the reverse-rotary type of well, and in comparison with the older type of gravel-packed well, the lesser cost, has made it generally the first choice in the past few years.

Section 8.8 - Small Well Near Main Well to Obtain True Drawdown. The author has for some years believed that it would be worth while to include in the contract requirements for a considerable number of wells the construction of a small well as near as practicable - perhaps at the outer edge of the gravel pack of the main well - in order to get the true drawdown which is necessary to intelligently consider the danger from the intrusion of salt water. Drawdowns taken within the well include screen and gravel losses which may be considerable. In wells near the seashore, particularly where in accordance with the evidence in tests of the Ghijben-

Herzberg principle* a pinnacle of salt water will be formed under a well and may actually admit salt water, it is particularly necessary to know what the real water level in the formation is rather than the water level inside the casing.

Section 9.1 - Marginal Land and Well-Depth Protection for Purity of Well Water; also the Related Question of Advance Purchase of Well and Infiltration Gallery Sites. The subject of marginal and depth protection is treated at some length in the earlier part of this report, viz., in Sections 5.1 to 5.7. The author's conclusions in brief are as follows:

1. Though in some tests wells did not receive bacteriological pollution from sources of pollution which were even less than 10 feet from the well, and freedom from bacterial pollution has been general in wells located on small lots in well populated regions, a margin of about 100 feet for such an important matter as purity of the water supply is not unreasonable. Often other facilities such as tanks and booster pumping stations may be placed on the sites with wells. This will justify and sometimes require larger lots.
2. As the County grows more populated, it will be more and more difficult to secure large lots unless resort is had to condemnation and demolition of buildings. Zoning, though a help in many respects, has been a source of great delay and exasperation to those responsible for seeing that the population is properly served with water. All want water in plenty but do not want the facilities - wells, pumping stations and tanks - within sight of their homes. In a long practice the author has known of only one case where a group of owners of fine homes cooperated in allowing a water stand pipe, surrounded by a stone tower, to be built in their midst. Long ago trees grew around it and no one now thinks of it. The modern practice of giving much attention to the architecture, land-scaping and maintenance of service buildings, together with the education of the public and zoning authorities in the importance of having water supply facilities in their correct locations, would seem to be the only possible answer.
3. It is of paramount importance, as has long been recognized and generally provided for by sanitarians and water engineers, that wells and well heads be so constructed that there will be no direct leakage into them either from the surface or through the upper parts of the casing. Bacteriological analyses at proper frequency and the use of chlorine, if found necessary, are of course to be assumed, though well water from sand and gravel formations is generally found to be sterile. See Section 5.6 and 5.7.

Section 9.2 - Question of Advance Purchase of Sites. The author has elsewhere advocated ownership by the public of the banks of streams and ponds, but with the legal right clearly stipulated to have public water supply wells placed thereon as these locations are proper ones not only for open spaces but also for wells. As to advance purchase of sites for wells with their buildings for electric controls and chemical treatment of the water, and for other water supply facilities such as tanks, booster

*See Appendix G; also Section 15.5-3, second paragraph.

pumping stations and material storage, this can be done in a few cases for a few years ahead but seems generally to be economically impracticable for the decades that will follow.

Even assuming as few sites as one per square mile and making the relatively slight allowance for the sites already in use for existing water supplies, the property cost of say 750 sites would probably run over $10,000,000 unless the size of the sites were reduced below the approximately 4 acres or more now required. There is also not infrequently the problem caused by the fact that not every area of land proves to be favorable in the underground formation for a well of proper yield. It has been found wise to option property and try its suitability by a test well before closing its purchase. It may be that land for infiltration galleries involving long strips could be purchased to advantage further in advance of needs.

Land developers will be obliged to reserve well sites for the water supply of new housing which is too far separated from an existing water supply to be immediately served by one. The cost of such sites will fall justly on the new population immediately benefited.

The County has a large and increasing mileage of wide highways and parkways. There is much vacant land in their rights-of-way, particularly at access points. The author has observed areas suitable for well sites and wondered if they could not be so utilized.

Another possibility has been suggested, viz., use, where suitable, of land taken by the County for taxes. This would require the clearing of titles as provided by law.

It would be wise for the Authority to make further study of the problem of securing land for water supply purposes and to invoke the aid of other agencies in the towns and County.

Section 10.1 - Supplies for Islands and Barrier Beaches. In Sections 2.1 and 2.2 are brief descriptions of the nature of the supplies on the islands and barrier beaches and the quality of their water. Their problems are local and may apparently be solved by a continuation of the same methods as may be required by increase in permanent or temporary summer population. This summer population is generally more important as to water facilities required. Supplies of Gardiners and Plum Island are apparently matters for the owners and the Federal government respectively.

OUTPOST AND WATER LEVEL WELLS

Section 11.1 Outpost wells are like sentinels to give warning of the approach of the enemy - in this case salt water. Information on a Nassau county map, kindly supplied to the author, shows 27 outpost observation wells in various parts of Nassau county, in various of the geological formations, viz., in glacial deposits, Magothy and Lloyd. A number in Lloyd are located in the Port Washington region where the rate of draft from wells has to be regulated to avoid salt water intrusion. There are a few observation wells in the interior of the County but the greatest concentration is near the south shore. A few selected wells in the westerly part of

Suffolk county are shown. Water from these wells is analyzed from time to time to note increase, if any, in the salt content.

The author had a part of initiating outpost wells in Nassau county and they are believed by him and by others connected with the problem of salt water intrusion to be an essential part of the study and care of any ground water supply which is located near salt water. It was planned that their cost in Nassau county should be shared by the interested water supply ownerships and the various government agencies engaged in the study and care of the Long Island ground water supply.

A comprehensive plan for Suffolk county should include a plan for outpost wells and the systematic chemical analysis of their water. Their screens should be placed in each of the geological formations used for water supply. Systematic analyses of water from existing water supply wells are of course of great use but generally do not give advance warning of salt water intrusion. At present there is not enough information about the geologic formations of Suffolk county to permit a completely intelligent layout of outpost wells. With the present moderate use of water the problem is not immediate but should not be lost sight of.

Section 11.2 - Water Level Wells. Water Spear in 1903 and again in 1907-8 placed many small wells for measuring elevations of the water-table, both in Nassau and in Suffolk counties. The author has been informed that many of these have been recovered in recent years and are still in use. Many others have been added. Bulletin GW-12, dated 1945, of the N.Y. Water Power & Control Commission, by C.E. Jacob, made in cooperation with the U.S. Geological Survey, gives a history of water level investigations on Long Island, going back to the year 1851. The Water Power and Control Commission, the United States Geological Survey and the Nassau County Engineering Department have all been alive to the importance of the fluctuations in the levels of the water table, at least since 1932, and in recent years observations have been systematic and officially recorded and studied.

Walter Spear made the first general survey of water table elevations in 1903 and again in 1907-8. The author supervised a systematic survey of water levels in Kings and Queens counties and the southern part of Nassau county in 1932 and 1933, which revealed the near exhaustion of Kings and parts of Queens county supplies, proved by simultaneous determinations of salt water intrusion.*

Some joint reports of the Water Power and Control Commission in the U.S. Geological Survey show the ground water levels. The last report, Bulletin G.W. 27, was in 1951 but current elevations can be obtained on request to either the Commission or the U.S.G.S. Survey. The general map at the end of the author's present report shows ground water table contours in Suffolk county at the beginning of 1956 and a drawing next before the map shows for each of four profiles across the county, water table levels

---

*At the suggestion of Mr. W.W. Brush, then Chief Engineer of New York City's Department of Water Supply, the author's original observations were extended by including data from additional wells belonging to the City and the Jamaica Water Supply Co., and revised maps of water levels and chloride in Kings and Queens counties were made, dated 1933, and became exhibits in Water Supply Application Case No. 681.

in years 1903, 1951 and 1956. Changes in water table elevations since 1903 are not very marked, even in Nassau county except in its westerly part, as would be expected, since much of the used water has been returned to the ground. Water exported by New York City has been the principal ultimate use until the last few years when the County's sewage system has added materially to the sewage discharged into the sea.

The only recommendation which the author has on this subject of water level wells is for more frequent bulletins, the last being in 1951. Probably the water tables in the "flukes" will require more intensive water level study. Salt water intrusion in them seems to be rather common. As elsewhere stated, infiltration galleries here may aid.

HYDRAULIC GRADES AND PRESSURES

Section 12.1 - General. Since the land of Suffolk county varies in elevation from sea level to a maximum of over 400 feet, it will of course be necessary to continue to establish zones of higher pressure such as those existing in Huntington and the town of Islip. This will involve the establishing of boundaries of so-called zones within which a general ceiling of pressure is derived from the same source. It will of course be necessary to carry higher pressures at the portion of a zone having lower ground elevations in order to have sufficient pressure in the parts having higher ground elevations. The real question then becomes one of fixing the lowest hydraulic grade in a zone which will properly serve the customers, considering friction losses in the piping as well as the high ground.

Section 12.2 - Minimum Pressures. Considering both the necessity of domestic use and reasonable provisions for an adequate supply to fire protection pumpers, the author recommends the following as a general guide to a satisfactory system.

1. Hydraulic gradients at the sources should be set so that, with the distribution system as existing or, as to be presently improved, pressures will meet the reasonable requirements of the underwriters at all hydrants which the Authority intends to authorize. In computing hydraulic gradients at a hydrant, it is not reasonable to consider peak hour loads from lawn sprinkling in the immediate vicinity of the hydrant - say within 500 feet.

2. As a second criterion, the pressures at the outskirts of the system in a zone of supply should not fall below 25 p.s.i. under peak hour conditions without fire flow.

3. Pressures during off-peak hours of summer months should not in general fall below 45 p.s.i. in areas served directly by the Authority.

4. Where districts are served at wholesale, a pressure of at least 60 lbs. on the downstream side of the meter will generally be required to give satisfaction. A supply system which has such a load, in addition to its own load directly-served, may have to carry a higher pressure than would otherwise be the case. In some cases a booster on the line to the outside district is necessary.

PIPE LINES

Section 13.1 - General. Pipe lines may be divided into two classes, viz., those serving as the distribution system of a more or less self-contained water service district and those of which the main, or at least original function, is as inter-connections between such districts. The 12-inch connection along the south shore between Amityville and Bellport is an example of such interconnecting pipe lines.

Section 13.2 - Distribution Pipe Lines. Unless under very unusual circumstances, these should be not smaller than 6" in diameter and, with the multiplicity of wells required to develop the ground water supply, will seldom need to be larger than 12", or at most 16" in diameter to provide the proper hydraulic gradient. It is highly desirable to avoid permanent dead ends such as may be caused by dead-end streets, sometimes called cul de sacs. These are objectionable as a matter of street planning, but are popular with growing families and cannot always be avoided topographically. The main drawback to short dead-end pipe lines is in their liability to produce tastes and odors in the water because of deficient circulation. If land ownership permits an end connection to an adjacent part of the distribution system, that is generally the best solution; otherwise a blow-off for occasional bleeding may serve for a short dead end, while a complete loop may be found necessary for a long one. In the latter case it may be found that one side of the loop may be of smaller pipe. This whole problem is not one for a rigid rule but requires experience with the particular water.

As to the occasional justification for use of smaller than 6" pipe in a distribution system, an example will illustrate. The author once designed a system which proved to be perfectly satisfactory where there happened to be two parallel streets with short cross streets. In this case mains of 6" and 8" size were placed in the main parallel streets and 2" pipe were used in the short cross streets, hydrants being placed only on the 8" main.

Section 13.3 - Interconnecting Pipe Lines. Such pipe lines may have one or several of the following purposes:

(a) To carry water to a new settlement which can be thus more economically served than by immediately constructing its own well supply.

(b) To augment the supply of a district having deficient ground water resources.

(c) To completely supply a district having only water of unsatisfactory quality.

(d) As a mutual safeguard against failure of either supply or to reinforce either supply in case of fire.

Such interconnecting pipe lines are likely to become main arteries in the distribution system as the population fills in between districts.

The sizes of these interconnecting pipe lines will of course be determined by hydraulic computations but there will doubtless be few cases where their diameters will be less than 12" and there may be cases where they should be 16" or even 20" or 24" in diameter.

Section 13.4 - Materials and Specifications for Pipe Lines. Internally, pipe should have the best of protection against corrosion because the value of a pipe line is in its carrying capacity and corrosion can and often in the past has reduced capacity and hence real value by 50% or even 75%. Information on various kinds of pipe follows.

Section 13.4-1 - Cast iron pipe has a very long history of satisfactory service - well over 100 years and still satisfactory. In recent years cast iron pipe have been the subject of much research and laboratory testing by a committee of consumers and producers.* This committee is sponsored by the American Water Works Association, American Gas Association, New England Water Works Association and the American Society for Testing Materials. The author is chairman. The work of this committee has resulted in the modernizing of specifications under which cast iron pipes are now manufactured and sold. A list of those specifications which relate to water pipe is given below. They may be obtained from the American Water Works Association in whose standards they are included.

A.S.A. A21.1-1957, Manual for the Computation of Strength and Thickness of Cast Iron Pipe

A.S.A. A21.2-1953, Cast Iron Pit Cast Pipe for Water or Other Liquids

A.S.A. A21.4-1953, Cement Mortar Lining for Cast Iron Pipe and Fittings

A.S.A. A21.6-1953, Cast Iron Pipe Centrifugally Cast in Metal Molds for Water or Other Liquids

A.S.A. A21.8-1953, Cast Iron Pipe Centrifugally Cast in Sand-Lined Molds for Water or Other Liquids

A.S.A. A21.10-1952, Short Body Cast Iron Fittings 3 to 12-in., for 250 psi Water Pressure, plus Water Hammer

A.S.A. A21.11-1953, A Mechanical Joint for Cast Iron Pressure Pipe and Fittings

Other useful A.S.A. specifications relating to water pipe are as follows:

A.S.A. B16.1-1948, Cast Iron Pipe Flanges and Fittings, Class 125

A.S.A. B16b-1944, Cast Iron Pipe Flanges and Fittings, Class 250

It will be noted that cement mortar lining is included as one of the specifications above listed and such lining has now a 35-year record of successful service, generally with little apparent deterioration in carrying capacity. Cement linings over 100 years old have been known to give good service, but the cement was of the old, "natural" type and not the Portland cement of the present day. The thicker cement lining covered by Specifications A.S.A. A21.4-1953 above, rather than a thin lining often supplied without stated charge, is recommended. Capacity, the element of paramount value in a pipe line, is too important to justify minor economies.

Section 13.4-2 - Joints for Cast Iron Pipe. The kind of joint for cast iron pipe, whether bell and spigot and sand-sulphur joints, or mechanical joints with rubber gaskets and bolted connections, or cast iron screw joints, is immaterial except that bolts, if used, should be corrosion resistant. There are at least two proprietary joints, made tight with

---

*This committee was formed and operates under the auspices and rules of the American Standards Association which is indicated by the initials A.S.A. prefixed to the numbers of the specifications.

rubber gaskets but without bolts, which are having considerable use, though not yet passed on by specification-making committees.*

Section 13.4-3 - Cement-Asbestos Pipe. This type of pipe has been in extensive use in this country for 25 years or so and much longer in Italy. The author has used it and recommends it, in somewhat heavier than the standard class for the particular pressure existing, for use in salty ground such as occurs in filled marshland near the sea shore, since cast iron pipe suffers more or less corrosion on its exterior surfaces in such ground. A wrapping of cloth and mortar for cast-iron pipe is effective and obtainable but relatively costly.

For most other locations, particularly where sewers, gas mains and telephone or power ducts are likely to be located ultimately, and expensive pavements placed, the author believes cast iron pipe, which is stronger and not liable to puncture, has the qualities called for in a bonded investment which should have the tested certainty of resistance to injury and of extremely long life for which water supply pipe lines have always been noted. In many cases the cost of cutting and replacing paving is the largest item in the original cost or cost of repair of pipe lines and permanence is of paramount interest.

Section 13.4-4 - Reinforced Concrete Pipe. This type of pipe has also great strength and proven durability and in sizes 16 inch and larger is acceptable for any location, such as for inter-connecting mains, not requiring a multiplicity of service connections. The current, and an entirely acceptable type, consists of a water-tight, plate-steel cylinder, lined with concrete, wrapped with high strength wire under tension (so-called prestressing) and protected outside by a mortar coating. Joints consist of a broad, steel socket ring of substantial thickness, containing a groove about 3/4" wide x 3/8" deep, a similar spigot ring, but without socket groove, both rings being securely welded to the above mentioned steel cylinder at opposite ends thereof. A ring of live rubber of circular cross section is placed in the socket groove and is pressed so as to fill and project about 1/32 inch from the square socket by forcing the spigot of one pipe into the socket of the adjacent pipe. Concrete or mortar completely surrounds the metal work. The close clearances between socket and spigot rings, 1/32 inch, and the mortar protection are a reassurance as to the longevity of the rubber.

STORAGE IN GROUND AND IN TANKS

Section 14.1 - General. In Section 7.3 it was explained that a total storage capacity equal to 25 per cent of the total peak day consumption has been generally found adequate to supply the difference between a pump capacity equal to the average rate of use for the peak day and the excess rate of use which, on the peak day, generally occurs during about 5 hours between 4 P.M. and 9 P.M., approximately, on a hot summer evening. It was

*It should always be considered whether a type of joint should be used, such as the sand-sulphur joint, which will not pull out when the earth backing is removed.

explained that any part of this storage could be in the ground, i.e, in the water-bearing formation, but in that case, a corresponding increase in well and pump capacity would be required.

Section 14.2 - Elevated Tanks vs. Tanks at Ground Level. This question is one on which opinions differ. The author and a considerable number of other water supply engineers, with whom he has acquaintance, have found that more than one elevated tank in different locations within a zone of uniform hydraulic grade, (see Section 12.2), will not generally work well together during the peak hours, but that one of two tanks, or more than one if there are several, is likely to be empty or well-depleted before the main peak comes on. One large water company on Long Island, having several elevated tanks in the same zone of pressure, has solved this difficulty by a complicated but effective multiple system of both fill controls and draw controls on each tank.

Tanks at ground level, with several automatically-started-and-stopped pumps of varying capacities, avoid the difficulties of elevated tanks stated above. Proponements of elevated tanks state, however, that care in operating well-pumps can avoid the difficulties of elevated tanks and retain their two advantages, viz., (1) to avoid too frequent stopping and starting of automatic well pumps, and (2) to have a supply - limited to be sure, but often adequate - available without pumping, to increase a fire-fighting supply or tide over a short period of power or well-pump failure. It should be said, however, that when elevated tanks are full, which is often the case in other than a few summer days of extra high consumption, the altitude valves at the tanks automatically close their inlets and the system is just as closed as without tanks. Moreover, when tanks at ground level are filled by back-flow from the distribution system, the same condition of relief of system pressure occurs, when tanks are less than full, as occurs with elevated tanks.

The question whether to have elevated tanks is often settled in the negative by the opposition of householders to such a tank within the area where it would be useful.

The writer has done considerable consulting work for one large water company on Long Island at which there are no elevated tanks situated where they could supply either of the two advantages above listed and where those in responsible charge state that no difficulty is experienced in the too-frequent starting and stopping of well pumps. In that plant ground storage tanks or reservoirs constitute nearly all the storage and it has even been very difficult to overcome the objection of householders, and consequently of zoning boards of appeal, to the storage tanks at ground level. Landscaping or expensive special construction has been required.

Section 14.3 - Conclusions and Recommendations of the Author as to Storage.

1. Admittedly elevated storage, apart from cost, has more desirable properties than storage in any other form, provided (a) it consists of only one tank in any separate pressure zone; or (b) if of two or more tanks, has them either very close together or so heavily cross-connected that their water levels remain practically identical; or (c) they have effective automatic fill-and-draw controls; or (d) have surplus automatically controlled well capacity near the tank.

2. Tanks at ground level, with automatically started and stopped pumps adjacent, have the advantage of lesser first cost and in the author's experience have not caused noticeably too-frequent starting and stopping of pumps. This is because (a) centrifugal pumps, the type almost invariably used, have a reduced output as the pressure rises and have no output when the pressure rises to the so-called "cut-off" pressure; (b) because pipe distribution systems nearly always have a leakage of 12 to 15 per cent; and (c) when the tanks are filled by back flow from the distribution system, there is relief of pressure into the tanks unless they are full, just as in the case of elevated tanks.

   It may be said that the increasing use of the very much tighter mechanical rubber-gasket joints might reduce the cushion effect caused by pipe line leakage.

   The arrangement of tanks at ground level which is most economical of power is with a supply well or wells adjacent. This permits the well-pumps to have only sufficient power to deliver water to the top of the tank instead of to the zone pressure, 45 lbs. or so higher. This arrangement eliminates the cushion effect but, conditions do not generally permit many of the tanks to have this low-lift pumpage feature.

3. Storage in the Ground. This is simple, requiring merely excess well and well-pump capacity. There may be locations near the shore, where even the moderate, temporary lowering of the ground water table would cause some rise of chloride. This is a matter of proper engineering.

4. Economic Comparison Needed. In any particular case, economic comparison should be made between the various storage possibilities above described. As mentioned in Section 14.2 above, the objections of householders and zoning boards of appeal to elevated tanks frequently rules them out and may be expected to do so increasingly as the population fills in. The author has no engineering objections to offer to any part or the whole of the storage being of the elevated kind provided it meets any one of the conditions stated in paragraph numbered 1. above. However, storage at ground level is likely to be more economical than elevated storage in total annual cost, i.e. capital and depreciation charges plus operating expenses.

   Storage in the ground has not generally been given the weight to which it is entitled. It should be included in any study of a particular case. A promising condition for its employment is before a zone has become thickly populated.

Section 14.4 - Suitable Types of Reservoir and Tank Storage. By reservoirs is here meant storage above ground other than cylindrical or spherical tanks. This would include all-masonry reservoirs or those with paved earth embankment. In any case, they must have tight roofs except for an adequate area of ventilating openings guarded from the flies which produce red worms by non-corrodible screens finer than those which suffice for the exclusion of house flies, these screens being protected from injury by strong non-corrodible screens of coarser mesh.

Elevated tanks will be of steel, of one of the pleasing designs available, with the same type of ventilating provisions as described above for reservoirs. Air inlets should be provided around the whole periphery of the tank, with a ventilator of liberal size in the center of the roof. In order to insure proper inspection, ladders on elevated tanks should be surrounded by cages, otherwise operating personnel with but few exceptions will not use the ladders.

Tanks at ground level may be of steel or prestressed concrete. The latter is more easily made inconspicuous, but the author always sinks it five feet or so into the ground and surrounds it to the water line with a grassed embankment, since the technique of preventing all seepage is not yet generally successful and even the invisible escape of moisture invites damage by frost in the climate of states above the Mason and Dixon line. A design of prestressed concrete tank with a thin steel interlining has been in use for several years but, judging by the author's experience with damage by freezing to cement lining in exposed steel pipe, damage by frost might occur to the mortar lining within the steel interlining of a tank. A concrete dome roof is most economical. With embankment built to water line, it may be colored and conveniently hidden by vines if required by zoning authorities.

SUGGESTIONS FOR IMPROVED LAWS, REGULATIONS OR PRACTICES

Section 15.1 - Explanation. In the investigations for this report the author has noticed a number of seeming defects in the laws or the regulations or the practices governing organizations having charge of water supply development in Suffolk County. Some of these defects are a bar to effective action. They are mentioned below in the hope of stimulating inquiry and possible improvement.

Section 15.2 - Lack of Centralized Planning Authority and Suggestions for Correcting This Omission. The Suffolk County Water Authority apparently has authority only ever the eleven plants which it acquired by condemnation from the South Bay Consolidated Water Co., and/or New York Water Service Corporation, or may build or may acquire from willing sellers, either of which can occur only if the new property will be self-supporting. In other respects the Authority seems to be only on a par with the owners of any water supply in the County, also with any developer of a new supply. The only actual authority lies with the Water Power and Control Commission, which, however, does not have the authority or have the necessary personnel to plan new supplies but only to approve, modify, or disapprove them.

The late Russell Suter, under whose wise administration as Executive Engineer, the Water Power & Control Commission attained its present deservedly high reputation, wrote in the Commission's Bulletin G.W.-2, dated 1937, that only by centralized control could the full development of Long Island's water resources be accomplished.

It is the author's opinion that there should be a continuing planning agency for Suffolk County's water supply development. The author explained in a preceding part of this report, Section 6.1, that a definite plan to follow in detail could not be made yet but would be a matter of

continuing study. An agency to do this is required. The Water Authority may have been intended to be that agency; if so, the laws which constituted it seem not to have accomplished the original purpose. The Authority should apparently be unmistakably endowed with functions somewhat as follows:

1. To receive and study all data on the operation of water plants, including those for irrigation, and on new wells, data on geology, static ground water levels, chemical analyses of the water, etc.; to set standards for design and construction and be authorized and obligated to examine and approve or to propose revisions to all plans for additional water supplies and to appear before the Water Power and Control Commission in support of its views; also to make supplemental engineering investigations at any plant or elsewhere if in its opinion they are necessary to guide its action.
2. To take over and operate, under just arrangements, water supplies which the owners, municipal or private, elect to have so operated; also to take over the responsibility for improving or extending such supplies.
3. To be permitted to accumulate a reasonable amount of surplus funds and to use it to make extensions in advance of, but in anticipation of, sufficient customers to support such financing. Such extensions would not include the distribution systems of new developments but would include pipe lines connecting existing supplies with new distribution systems where such connections were found to be the best engineering solution.
4. To originate, or to cooperate with the Water Power and Control Commission and the U.S. Geological Survey in the planning, execution and operation of exploratory wells, additional water level wells and outpost wells.
5. Provisions would of course have to be made for financing such of the increased activities of the Authority as would not be immediately self-supporting. An engineering division for the continued study of all the data and the proposed new developments would be necessary. A competent geologist and a chemist and bacteriologist would be needed in addition to engineers.

Section 15.3 - Water Supply Data Needs to be Made More Available. Data of tremendous value relating to the ground water of Long Island is being collected by the various agencies that have been established for that purpose. These agencies are the State Water Power and Control Commission, the U.S. Geological Survey, and, of course, each individual water supply organization. Owing to the limitations of money and personnel, and in some cases the existence of non-resident control and regulations, important data - and particularly the correlation of it with previous data and conclusions - respecting geology, water levels, salt water intrusion, etc. are not now available in published form promptly, as is desirable. The regulations of the U.S. Geological Survey are understood to require the submission of all papers containing conclusions to Washington. This is a long process and automatically limits the release of current U.S.G.S. information to individual measurements which have little meaning until correlated by the receiver, who generally is not in a position to do so. These precautions are of course designed to prevent hasty or amateur opinions from being released, but the long delay may result in a period where rumors are substituted for facts and rational conclusions.

The Water Power and Control Commission seems not to be limited in releases as is the U.S.G.S., but the Commission's personnel is not sufficient to make frequent releases and moreover the important cooperative studies of a scientific nature are the province of the U.S.G.S.

Special items of information which the inquirer believes to be available may be obtained promptly by telephone, correspondence or by personal visit to the offices of the Commission and U.S. Geological Survey. These busy officials are always cooperative and generous with their time but one sees that they have a fund of data, and particularly their correlations, which are not yet available in bulletins and, even if known to exist, cannot be obtained in short visits or correspondence. N.B.

The water supply branch of the Engineering Department of Nassau County collects much data for its own use and cooperates with the Commission and the U.S. Geological Survey; and items of information possessed by the County, are always courteously supplied on request, but the general mass of their data is not available in publications.

It is understood that the informative and the research activities of the Commission and the U.S.G.S. are regularly supported financially by the cooperation of the U.S., the State of New York, the counties of Nassau and Suffolk and the Suffolk County Water Authority, with contribution at times from private companies interested in some phase of their research work. It seems to this author that each of the agencies should issue at regular intervals, say quarterly, some sort of bulletin which will be not merely a list of activities, or a list of water levels or a list of new wells, but will contain comments on what changes, or tendencies or new disclosures are revealed by these observations. Important conclusions may be stated guardedly, pending review by higher authority, but the opinions of the research men on the ground are certainly of great value and it seems right that they should not be lost or unnecessarily delayed.

Section 15.4 - Need for Additional Data. A study of the various bulletins issued by the Water Power & Control Commission reveals some voids which the Commission should have the power to fill. The following will be noted.

(a) A considerable number of wells are not included in the bulletins.

(b) Geological formations are not noted.

(c) Ground elevations are not noted.

(d) Whether wells are gravel-packed seems not to be given.

(e) Initial chemical analyses are not given. In some of the bulletins a list of wells is given for which chloride contents are available in the Commission's Jamaica office. This is doubtless planned to cover present critical locations and is useful. But a careful continuous study needs more information, including other elements than chloride content, particularly iron, manganese and hardness, pH, alkalinity and nitrates. The annual report of pumpage from Long Island ground water sources, issued by the Commission about May 1, of the following year, is a very useful document but suffers, through no fault of the Commission, in the following respects:

(f) Only a rough estimate is possible for the pumpage from agricultural wells. Over these, by law, the Commission has no jurisdiction. The estimate of pumpage in Suffolk county from agricultural wells for the year 1955 is about the same as that for the public supplies.

(g) The existence of and the pumpage from private wells, smaller than 45 g.p.m., is excepted by law from the province of the Commission. Pumpage from such wells is necessarily a rough estimate as even the number of such wells, which is very large, is a rough estimate. The estimated pumpage from these wells for 1952 was somewhat larger than that for all the public supplies combined. For 1955 a sharp reduction was shown for private wells with pumpage from public supplies over twice that from private wells. To permit the Water Power & Control Commission to make its records more complete and accurate, the Commission apparently needs further definite authority to require records about as noted below.

1. Owner of each well which is subject to approval of the Commission to supply the following information additional to what is now required:

   (a) Statement from a licensed surveyor giving the elevation of the ground at the well above mean sea level.

   (b) Signed report from a water chemist on the chloride content, pH, hardness, alkalinity, nitrates, iron and manganese found in a sample of the water after several hours of pumping either from the preliminary test well or the service well. For certain wells near salt water, to be designated by the Commission, to supply chemical analyses at intervals to be designated by the Commission.

   (c) To have adequate samples taken of the ground formation encountered in the well for each 5 feet of depth and at changes, placed in air-tight jars conveniently arranged for inspection, and to notify the Commission promptly after completion of the well when and where they may be examined. (The author assumes that the U.S.G.S. would examine and classify the formations to the extent which they thought necessary and would make the results available to the Commission for its bulletins.)

   (d) If not already the custom, to report not later than January 31 the total metered pumpage for the previous calendar year.

   (e) To report the static level above or below mean sea level for some time within 15 days of Jan. 1 and August 1 of each year.

2. Each owner of a well not subject to Commission approval, to report to the Commission, before some date to be set by the Commission, the existence, location, size and depth of such well, the capacity of the pump, the home or industry served and the approximate annual pumpage; also to report any discontinuance of such well when it occurs. The first report under this provision would serve to establish a list of such wells, which does not now exist. No proper care and study of the County's water supply problems can be made without an inventory of all wells. Discontinued wells, which will doubtless be frequent as public supplies increase, should be carefully plugged to prevent possible pollution of the ground water.

The information above listed is of a kind that the agency charged with making a continuing study of Suffolk County ground water, as discussed in Section 15.3, would wish to have for its study. The author assumes that the same agencies - Water Power & Control Commission and U.S.G.S. - would continue to collect it for their own use as well as that of the public and other official agencies.

Section 15.5-1 - Some Exploration Wells seem to be Needed Now. It is the custom in this modern age to make borings in order to intelligently plan important engineering works. This custom has been followed only to a limited extent in the water supply engineering of Long Island. Each new water supply well has of course served also as an exploratory one, and there are many of the shallower wells from which the upper formations in Suffolk County are rather well known; but Suffolk County, below the glacial outwash is to a considerable extent a virgin field, much dependence being placed on its surprising conformity, where tested, with the base-rock slope projected easterly from its known slope in Kings, Queens and Nassau counties.

Section 15.5-2 - List of the Deeper Wells in Suffolk County. The author has attempted below to list the deeper wells which have been sunk to a considerable depth below the glacial sands and gravels. The more important ones appear to be as follows:

16 wells not far from the Long Island Sound shore, sunk into the Lloyd formation which is not nearly so deep there as in the southerly part. 10 of these wells have good water and the other 6 have salty water and are not used.

A gravel-packed well, drilled in 1956 for the Authority in the southeastern part of Huntington, thought to be in the Magothy, useful depth 558 feet, maximum depth 640 feet, having the extraordinary specific yield of 319 gals. per minute per foot of drawdown in a test at the pumping rate of 1600 to 1700 gals. per minute, continued for 3 days of 2 - 8-hour shifts each. Total length of screen 75 feet, in 4 different sections, the sections being separated by blank casing of various lengths up to 35 feet.

2 wells to and into bed rock at the Brookhaven National Laboratory, respectively 1562' and 1498' to bed rock. Not found worth developing for water supply.

Wells listed below, being the deeper wells sunk for the Walter E. Spear, New York City Board of Water Supply, Suffolk County Water Study of 1907 and 1908, described in the 2 volume report dated 1912. Information on stove-pipe wells listed below is contained in Volume 1, pages 198, 226-252 and sectional profiles on sheets 47, 48 and 49:

No. 4	Stove-pipe	Well	at Lindenhurst,	370'	deep
No. 1	"	"	" East Islip,	809'	"
No. 6	"	"	North of Islip,	468'	"
No. 7	"	"	North of Patchogue,	463'	"
No. 8	"	"	at Brookhaven, 1 mile No. of P.R. Sta.	931'	deep.

2 so-called geological wells, depths not found in the Spear report, but over 370' and 380' respectively.

5 wells on the barrier beach south of Suffolk County mainland, varying from about 400 to 640' deep, all in use.

1 well at Fire Island, not a water well, drilled very recently, reaching bed rock at a depth of 1948 feet.

There should be mentioned also an observation well drilled into Lloyd, by the County of Nassau, at about mid width of the Island in Nassau County near the Suffolk County line. It is said to yield good water is samples.

Section 15.5-3 - Spear Stove-Pipe Wells with Small Water Level Well. The Walter E. Spear stove-pipe wells were of a common Pacific Coast type, in which a 2-layer steel pipe in short sections is bailed and jacked down and afterwards perforated opposite one or more water-bearing formations by an expanding tool. In the above cases pumping tests were made and gave good yields, but the depths of the perforated stretches seem not to be given. They were probably 200 feet or less as in the Spear plan for taking water from Suffolk County for New York City the wells were to be about 100 and 200 feet deep, entirely in the "yellow sands and gravels," i.e., above the clay beds which characterize the Magothy.

It is interesting to note, which the author did only after writing Section 8.8 of this report, that Mr. Spear sunk along-side each stove-pipe well, about 6 inches away, a water level well, such as the author has recommended in Section 8.8 of this report. The careful measurements made in his pumping tests showed that by far the greater part of the drawdown was caused by resistance in the screen. Those wells were not gravel-packed, which would have less screen loss but still only ascertainable by the use of an auxiliary small well.

Section 15.5-4 - Conclusions. Considering the large areas of Suffolk County without deeper wells, as shown from the list of wells in Section 15.5-2 above, and the importance of a better general knowledge of the ground water formations in Suffolk County, the author believes there is justification for sinking a few exploratory wells at locations which should be selected with the advice of the Water Power and Control Commission, the U.S. Geological Survey and the Authority's geological consultant.

Section 16 - Need for Contour Maps. There are two sets of contour maps of Long Island, one set, made by the U.S. Geological Survey in 1901-1903, in 16 sheets, on a scale of 1:62,500, or approximately a mile to the inch, and the other made by the Corps of Engineers, U.S. Army, in 1943-1944, in 60-65 sheets, on a scale of 1:24,000, or 2,000 feet to the inch.

Each of these maps has contours showing, by sepia-colored lines, the approximate ground elevations at 20-foot intervals of elevation above the so-called Datum Plane, which was established many years ago from mean sea level at Sandy Hook. The author is informed that, due to gradual geologic changes, the present mean sea level is about 0.6 ft. higher than the official Sandy Hook datum, but no change is contemplated in datum of levels as only confusion would result. The sea has encroached on the land 0.6 foot in approximately 50 years.

The maps are neither of them as true to elevation or as complete in area covered by contours as is desirable, and the 20-foot interval is too great to give needed elevations near the shores, particularly where, as on

the south shore, the slopes of the land are gentle. Furthermore, the maps are now too old to indicate much about the present condition of the county. An automobile road-map is more useful in many respects but an up-to-date contour map,* on a scale of say 2,000 feet to the inch, with the whole area of the County covered by contours and the contour interval reduced to say 5 feet for the flatter parts, would be of great use in the continued study of the water supply and for many other purposes. New and more complete editions would be required as the development advanced.

Section 17 - Importance of Water Supply Requires Cooperation of All Governmental Agencies and of Citizens. In closing this part of the report, which from Section 6.1 to this Section 17 is directed to a statement of important topics relating to a Comprehensive Plan, the author cannot do better, in emphasizing the need of the cooperation of national, state, county and municipal governments as well as of citizens and organizations of citizens, in guarding and developing the water supply, than to quote briefly from President Eisenhower's "Report on the State of the Union", January 10, 1957:

> "I would like to make special mention of programs for making the best uses of water, rapidly becoming our most precious natural resource,....."
> (underscoring is by this author)

Section 18 - Type of Plan which has been offered Herein. The non-technical reader may have a feeling of disappointment that the "plan" described herein does not include, on the general map, a proposed layout of future wells, pipe lines and tanks. The reader is referred back to Section 6.1 of the report wherein is explained the impracticability of drawing such a plan for 920 square miles of territory plus its islands and barrier beaches, with existing plants generally widely separated and with the order of development practically in the hands of real estate developers and business enterprise.

Unlike the plan for a distant water supply, for which a map would be made showing the distant source, a connecting aqueduct and other main details, Long Island supplies are everywhere beneath the territory to be supplied and their major economy consists of a multiplicity of wells and relatively small pipes installed in the very districts which they serve. These are installed only as needed to keep pace with the growth of population, until in the end, in the distant future there will be an interconnected net work of piping between the many wells which must ultimately be rather closely spaced in order to get all the available water without intrusion of salt water.

To enumerate what the report has shown and attempted to show would require unnecessary repetition. In general terms the report contains the author's views as to the quantity of water available and as to the organization and/or operation of all the governmental agencies having to do with

*The author has very recently heard that surveys for a new set of maps with 10-foot contour interval has been begun but has no further knowledge of this project.

the water supply and the need of cooperation between them; also the author's views as to the general principles which should govern all phases of the progressive development of the water supply in Suffolk County, and its safe-guarding from pollution of all kinds, including that from salt water intrusion.

A paramount recommendation in the report is to so limit the ultimate population in Suffolk County, by density zoning, that the available water supply would continue to be sufficient, since it is not evident where an additional supply could be obtained at a practicable cost. Such a plan will require cooperation of all the planning agencies of the County, since the author's study is known by him to be only a first approximation, requiring much more complete study.

APPENDIX A

GEOLOGY OF SUFFOLK COUNTY

NEW YORK

BY R.M. LEGGETTE

APPENDIX to a REPORT PREPARED by

THOMAS H. WIGGIN

for the

SUFFOLK COUNTY WATER AUTHORITY

JANUARY, 1957

OFFICE OF
Leggette, Brashears & Graham
Consulting Ground Water Geologists
551 Fifth Avenue
New York

CONTENTS

Page

Introduction A1

Historical Geology A3

Pre-Cambrian Era. A4

Cretaceous Period A4

Tertiary Period A5

Pleistocene Epoch A6

Recent Epoch. A7

Stratigraphy A7

Bedrock A11

Lloyd Sand Member A11

Raritan Clay Member A13

Magothy (?) Formation A13

Jameco Gravel A14

Gardiners Clay. A14

Upper Pleistocene Deposits. A16

Recent Deposits A16

Bibliography A18

TABLES

Page

Table 1. Geologic formations in Suffolk County, N.Y. and their water-bearing properties. A7-A8

2. Log of Well S 6409 at Brookhaven National Laboratory, Suffolk County, N.Y.. . . . . A8-A10

ILLUSTRATIONS

Figure 1. North-south geologic section in western Suffolk County, N.Y. A2

2. Bedrock contour map of Long Island area A12

3. Geologic section across islands south of Islip, Suffolk County, N.Y. A15

INTRODUCTION

The geology of Suffolk County is so intimately related to the geology of Long Island as a whole that any attempt to discuss it without reference to the structure of the entire island is unsatisfactory. The major geologic events that have occurred in the area have affected all parts of the island in a more or less similar manner, and as a consequence, the major geologic formations of Suffolk County are continuous with and similar in composition to those in Kings, Queens and Nassau Counties.

Long Island is composed of unconsolidated deposits of sand, gravel and clay laid down in more or less parallel beds on a hard bedrock surface. The rock floor of the island dips gently in a southeasterly direction, and as a result, the unconsolidated materials are relatively thin along the north shore and thicken appreciably toward the Atlantic Ocean (see figure 1). At some localities in the extreme western part of Long Island, the bedrock floor is only a few tens of feet below land surface, and is actually exposed at the surface in a few places in northwestern Queens County. In southern Suffolk County, however, the bedrock floor is as much as 2,100 feet below sea level beneath Fire Island.

Long Island is geologically a part of the Atlantic Coastal Plains, and on the basis of origin, age and structure is more directly related to the coastal region of New Jersey than to the New York-New England areas nearby. There is a close interrelationship of the geologic deposits from one end of the island to the other, a fact which is particularly significant insofar as ground-water resources are concerned. For example, extensive clay beds occur beneath much of the surface of Long Island, thereby retarding ore prohibiting the natural movement of water vertically from aquifers confined by clay layers. As a result, many of the deep wells in topographically low areas along the shores are flowing wells. Also, the coarse permeable sands and gravels that constitute the best water-yielding beds are more or less interconnected laterally, so that pumping of water from wells in one area may affect the quantity available in adjacent areas. Because of these factors, it is important to define the dimensions and water-yielding characteristics of the formations in order to properly plan the development of the island's ground-water resources.

Since 1750, when an early student of Long Island geology expressed the opinion that the island had been formed by marine currents depositing sediments brought down to the sea by nearby rivers, numerous papers and reports have been written concerning the origin and the geology of Long Island. Although the earliest investigators presented vague and often erroneous theories of how the island had been formed, they nonetheless contributed important observations on the character and distribution of the different geologic units. More recent studies, aided immensely by the large number of deep-well records now available in the western part of the island, offer much more satisfactory explanations for the formation and geologic history of Long Island.

The agency most directly engaged in continuing studies of the geology and ground-water resources of Long Island is the Ground Water Branch of the U.S. Geological Survey in Mineola, Nassau County, N.Y. These studies have been financed partly by the Federal government, and partly by Suffolk County, Nassau County and the New York State Water Power and Control Commission. The results of these studies have been released in numerous reports on the

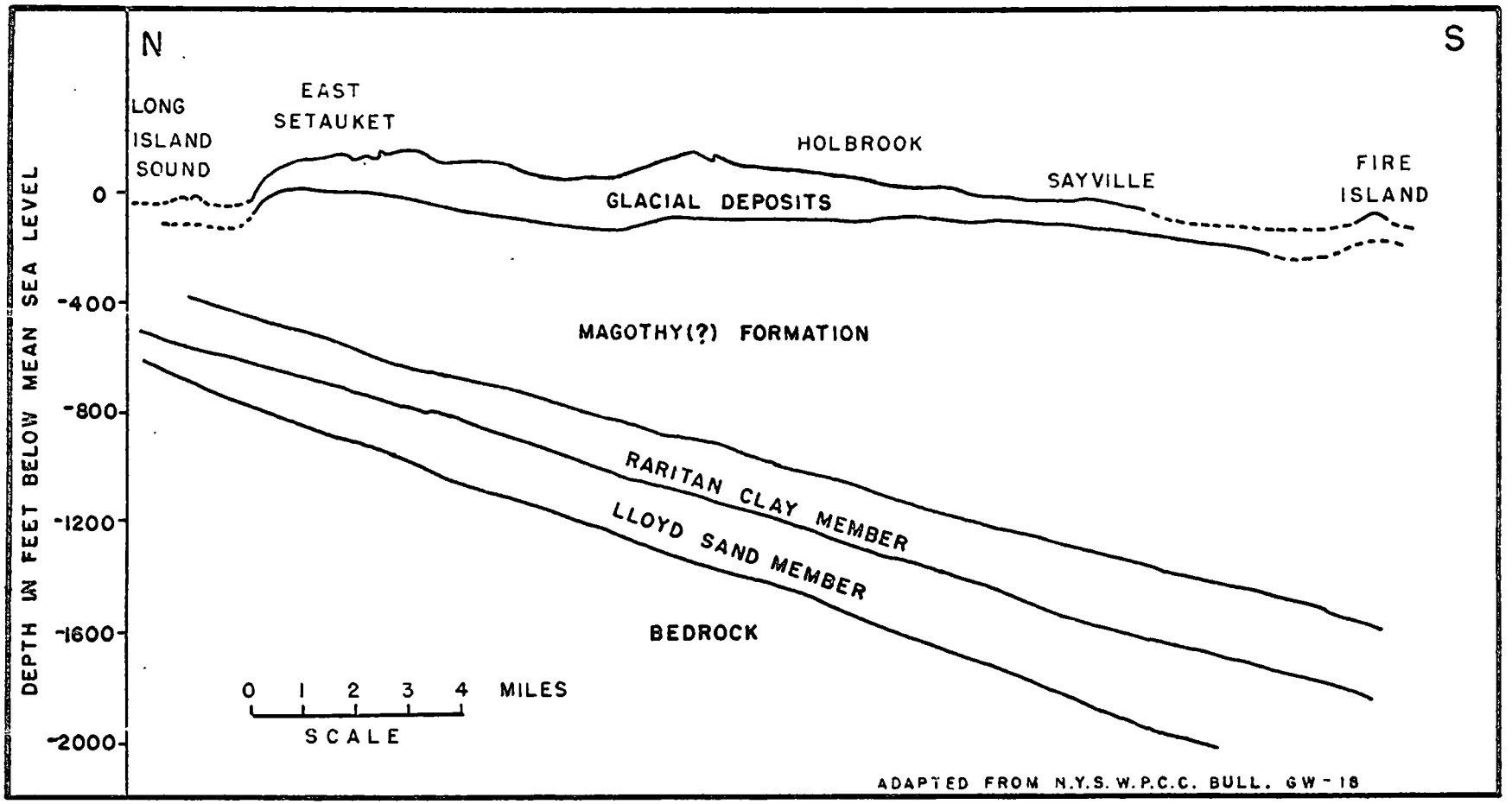


FIG. 1 - NORTH-SOUTH GEOLOGIC SECTION IN WESTERN SUFFOLK COUNTY, N.Y.

geology and ground-water resources of the island. Two of the most detailed reports on the geology of the island are those by M.L. Fuller (1914) and by R. Suter, W. deLaguna, and N.M. Perlmutter (1949). (See bibliography.) Logs of most of the wells on Long Island may be examined in the offices of the New York State Water Power and Control Commission, Jamaica, Queens County, N.Y.

HISTORICAL GEOLOGY

Before discussing the general geologic history of Long Island, it seems desirable to outline briefly some of the basic facts known about the geologic history of the earth itself. These will serve to acquaint the layman reader with the broad scope of geologic time and with some of the tremendous events that have helped to shape the earth.

According to the best present calculations, the earth is between five and seven billion years old. These figures have been derived from studies of radioactive minerals, rates of deposition of sediments, and certain astronomical data. During this incredibly long history, seas have inundated the continents periodically, mountain ranges have been worn away and rebuilt many times and great rivers have come into existence to last for millions of years, only to disappear eventually.

The records of these numerous changes are preserved to a greater or less degree in the rocks and sediments of the earth. For example, ancient lava flows tell of volcanic activity in the remote past; beds containing fossil remains of sea animals attest to former marine inundations in areas that are now many hundreds of miles from the sea. Geologists are able to reconstruct the general sequence of events from such evidence, and have compiled a broad record of the earth's history and the many widespread geologic modifications that have taken place. This record is divided into major time periods, each of which represents many millions of years.

On Long Island, the bedrock foundation and the overlying beds of sand, gravel and clay represent three major periods of time in earth history. The bedrock, which constitutes the floor of the island, is the oldest unit of all and at least part of it was formed more than half a billion years ago in what is called the Pre-Cambrian Era of the earth's history. Most of the unconsolidated deposits above the bedrock were laid down in a later period, referred to as the Cretaceous period, which ended about 60 million years ago. Soon after Cretaceous time, in what is called the Tertiary period, erosion was the dominant force at work on the island. The uppermost sediments, which form the surface layers of the island, were deposited during the Ice Age, which in North America ended perhaps ten thousand years ago.

The materials above the bedrock are more than 2,000 feet thick in some places, and it is believed that millions of years elapsed during their slow deposition. Even though such a period of time may seem long, it nevertheless represents but a small fraction of the entire history of the earth. The gaps in the record cover a far greater part of earth history than do the sediments actually found on the island. Although it is possible that deposition of sediments occurred in the Long Island area during many of the unrepresented time intervals, all traces of such deposition have been removed by subsequent erosion.

In one sense, the true geologic history of Long Island can be said to begin at the time of formation of the bedrock floor. For the several ages of earth history represented, each major geologic event has left some record in the subsurface deposits. It is beyond the scope of the present report to discuss this chronology in detail, and only a brief outline of the major events and their influences on the geologic nature of Long Island will be given. For convenience in presentation, these events will be discussed within the framework of accepted geologic age names, beginning with the earliest period that has left a significant record on Long Island and ending with the most recent.

Pre-Cambrian Era

By the end of the Pre-Cambrian Era, the major portion of the earth's history had already elapsed, although the earth's plant and animal life as we know it today was just beginning. In the Long Island area, the record of those early periods is obscure, and about all that is known with certainty is that a long sequence of geologic events formed the very hard crystalline rocks which now constitute the foundation on which the island is built.

Cretaceous Period

Prior to and during the early part of the Cretaceous period, which began several hundred million years after the close of the Pre-Cambrian Era, the ancient bedrock floor of Long Island was gradually worn down by erosion to an almost featureless plain near the sea level existing at that time. The surface of this rock plain was probably gently rolling, with shallow stream valleys and low hills perhaps 100 feet in height. Because of exposure to the elements over very long periods of time, the upper part of the bedrock became weathered and decomposed to depths of perhaps as much as 50 feet.

By middle Cretaceous time, this nearly level surface had begun to tilt slowly toward the southeast, as part of a broad arching process that occurred along the entire east coast of North America. Along the crest of the arch, which roughly paralled the present Appalachian mountains, streams began their erosive work and flowing seaward, deposited clay, sand and gravel on the gently sloping bedrock near the sea. The tilting of the rock floor and the steady accumulation of sediments continued slowly throughout the remainder of the Cretaceous period, with the result that each new sedimentary unit overlapped the preceding one and as tilting progressed, each unit became thicker in the seaward direction. This sequence of events was not limited to the Long Island area, but occurred in a widespread zone along most of the coastal portion of the eastern United States.

In the Atlantic Coastal Plain, from Long Island southward, geologists recognize several well-defined geologic units in the Upper Cretaceous sediments. Most of these units are quite extensive and a few of them are known to be continuous for several hundred miles. On Long Island, two such major units are recognized. The lower of these, the Raritan formation, lies just above the bedrock floor. The upper unit is called the Magothy (?) formation. The Raritan formation consists of two members, the Lloyd sand member at the bottom and a clay member at the top.

The Cretaceous deposits are not as well known in Suffolk County as in other parts of the island. It is possible that some of the broad geologic interpretations made for western Long Island do not apply to Suffolk. However, logs of the few deep wells in Suffolk show the same general relationships that have been established in the western area and it is probable that the geologic framework is generally similar throughout the island.

The Lloyd sand member is composed largely of sand and gravel which was deposited by fast-flowing streams draining the elevated parts of the Appalachian arch. The contact between the Lloyd sand and the overlying clay member shows a gradation from coarse materials below to the fine-grained sediments above, indicating that a widespread change in depositional environment took place at the end of Lloyd time. Many factors may have contributed to this change in environment, such as a major long-term decrease in rainfall, a lowering of the Appalachian arch or a rise in sea level. Any of these could have so reduced stream velocities that only fine-grained materials were transported. In places, lenses of sand and gravel are found in the clay member, indicating that stream velocities were sometimes high enough to transport such coarse materials. The presence of plant fossils and the lack of marine remains suggest that the clay was deposited on broad flood plains perhaps just above sea level. The upper surface of the clay member is somewhat irregular in places, indicating that some erosion occurred before the overlying sediments were laid down.

The geologic unit directly above the Raritan clay member is referred to as the Magothy (?) formation. The question mark indicates uncertainty in geologic correlation with known Magothy deposits in other areas. In New Jersey, the Upper Cretaceous deposits above the Raritan clay have been divided into several recognizable geologic units, the lowermost of which has been assigned the name Magothy. On Long Island, however, the Cretaceous deposits above the Raritan clay have not been satisfactorily separated into units, because of the lack of fossils or other distinguishing features. Tentatively, the U. S. Geological Survey has assigned the name Magothy (?) to all Upper Cretaceous materials above the Raritan formation on Long Island.

During Magothy time, meandering streams flowing seaward from the Appalachian arch deposited materials ranging in size from clay to coarse gravel. Most of the individual beds in the formation are not continuous laterally over any great distance and the entire formation is best described as consisting of predominantly sandy lens-like beds. It is believed that the flood plains and stream beds on which much of the deposition occurred were not far above sea level at that time. The presence of beds and fragments of lignite, a low-grade type of coal derived from vegetation, suggests that part of the time the Magothy environment was swampy.

Tertiary Period

During the Tertiary period, erosion was the dominant geologic force at work on Long Island. The broad valley now occupied by Long Island Sound was first formed at this time by the erosive action of an ancient stream that is believed to have drained eastward. There are insufficient data available to delineate accurately the channel of this old "Sound River" or the watershed that supplied it. Certainly, the Connecticut River was one of the main tributaries of the system and it is possible that the Sound River was in some manner connected with the Hudson River

drainage to the west. Geologists, however, are not agreed as to the exact history of Long Island Sound and it is not likely that this problem will be resolved until more is known about the geology of the area.

During the Tertiary period, the uppermost beds that had been deposited in late Cretaceous time were removed by erosion and a rolling, somewhat irregular topography was developed on the upper surface of the Magothy (?) formation. In western Suffolk County this old surface is above sea level in many places and clay, sand and gravel of Magothy age are exposed in areas where the Ice Age sediments are not present. In most of Suffolk County, however, the top of the Magothy is generally below sea level and is covered by sediments of younger age.

Pleistocene Epoch

During the Pleistocene epoch, which is commonly referred to as the Ice Age, great continental ice sheets developed and spread over much of the northern parts of Europe and North America. During four major advances from central Canada, thick glaciers extensively modified the face of the land by erosion and deposition. The great ice sheets extended southward into the northern part of the United States, and in the east coast area, at least two of these ice sheets reached as far south as Long Island. The southerly limit of ice advance on Long Island is marked by two moraines that form the ridges which extend from the Narrows in the west to Montauk Point and Orient Point in the east.

Theories differ as to the cause of the great Ice Age. In general, most scientists agree that the amount of heat received from the sun diminished during the Ice Age, possibly because of atmospheric conditions on the earth or because world-wide weather patterns were altered. Regardless of the specific cause of glaciation, conditions were such that great masses of ice and snow accumulated and these exerted a profound effect on the face of the land. In southern New England and Long Island, it is estimated that the ice may have been as much as several thousand feet thick. Glacial deposits have been found on the tops of the highest mountains in the region. The ice must have been at least several hundred feet thick to override such places as the Palisades of New Jersey and the highest hills on Long Island.

The ice sheets which reached Long Island transported tremendous amounts of clay, sand, gravel and boulders from areas to the north. These materials were deposited by the ice itself and by melt-water from the ice and now from the uppermost beds over most of the island. Geologists have recognized as many as ten different sedimentary units laid down on Long Island during the Ice Age. Many of these are of limited areal extent and only a few of them have an important bearing on the occurrence and movement of ground water.

Most of the glacial deposits of sand and gravel on the island were laid down by streams flowing seaward from the melting ice sheets. Extensive beds of clay in the Ice Age deposits on Long Island were laid down in bays during intervals when the ice had melted back far to the north. The moraines and some of the shallow materials in other parts of the island are composed largely of deposits known as glacial till. These deposits consist of an unsorted mixture of clay, silt, sand, gravel and boulders. The till was laid down beneath the ice and near its edge where melting occurred.

Recent Epoch

The Recent epoch is the time interval from the end of the Ice Age to the present. It covers a period of about ten thousand years. The most important geologic forces at work on Long Island during Recent time have been the tides and ocean currents along the shore. These have built the many off-shore bars, islands, beaches and spits which are conspicuous features of the shoreline areas. Less important geologically is the action of small streams on the island, which have been slowly eroding the glacial sediments and redepositing the materials on deltas and flood plains.

From a ground-water standpoint, one of the most important geologic events of Recent time is the slow rise in sea level that has accompanied the melting of the last great ice sheets. Geologists estimate that sea level during the Pleistocene epoch may have been from 200 to 300 feet lower than at present. There is also evidence that, at times, it was considerably higher than at present. Under conditions of low sea level the formations underlying what is now Long Island could have contained only fresh ground water derived from rainfall and the melting of the ice. The atlantic shoreline of Long Island at that time must have been many miles seaward of its present position, and Long Island Sound was probably above sea level. Later, when the ice front had begun to recede to the north, sea level began to rise and encroachment of the sea began. There is considerable geologic evidence to show that areas along the shore that are now under water were dry land only a few thousands of years ago. In addition, there is indirect evidence that salty water is invading the artesian formations, but at extremely slow rates.

STRATIGRAPHY

The deposits above the bedrock floor of Long Island are composed of unconsolidated clay, sand and gravel. These deposits have been laid down in more or less parallel strata, one above the other, with the oldest formation lying on the bedrock floor. The individual formations can generally be distinguished from each other on the basis of stratigraphic position, thickness, composition or other characteristics. Some of the distinguishing characteristics of the individual formations, such as thickness and permeability, are especially important from a ground-water standpoint and play an important part in controlling the recharge, movement and discharge of the subsurface waters.

In the following section, each of the major geologic units is discussed in some detail, beginning with the bedrock floor and proceeding upward through the entire series of deposits. Table 1 lists the major units and briefly summarizes their water-bearing characteristics. Table 2 gives the log of Well S 6409 at Brookhaven National Laboratory and shows in detail the nature of the unconsolidated sediments of Suffolk County and their geologic ages.

Table 1 - Geologic formations in Suffolk County, N.Y. and their water-bearing properties

Unit	Water-bearing properties
Recent deposits	Limited to shoreline areas and stream valleys. An important source of water for small wells in beach areas.

Table 1 -(Cont'd)

Upper Pleistocene deposits:	
Till	Relatively impermeable, but contains some beds of sand and gravel. Is not an important source of water.
Outwash	Occurs extensively in central and southern parts of Suffolk County. The most productive water-bearing unit in the county. Most wells in the county tap the outwash deposits.
Gardiners clay	Relatively impermeable and is not a source of ground water.
Jameco gravel	May not be present in Suffolk County. A very productive bed in parts of western Long Islang.
Magothy (?) formation	Thickest water-bearing formation in Suffolk County and probably contains much good water-bearing material. Has not been tapped extensively and its ground-water potential cannot be estimated without extensive test drilling.
Raritan formation:	
Clay member	Relatively impermeable and not a source of water. Occurs widely in Suffolk County and is chiefly responsible for artesian conditions in under-lying Lloyd sand.
Lloyd sand member	A productive water-bearing bed in western Long Island but its potential in most of Suffolk County is virtually unknown. Because of its depth, little use is made of it as a source of water at present. Tapped by a few wells in northwestern part of county.
Bedrock	Relatively impermeable and not a source of water.

Table 2 - Log of Well S 6409 at Brookhaven National Laboratory in southeast corner of Camp Upton, Upton, N.Y. Drilled by Layne-New York Co., Inc., October 28, 1948. Altitude of land surface 113 feet. (Geologic correlations by U.S. Geological Survey).

	Thickness (feet)	Depth (feet)
Upper Pleistocene deposits:		
Sand, gravel and boulders.	46	46
Sand, fine gravel.	41	87
Medium fine sand	65	152
Coarse brown sand.	18	170

Table 2 - (Cont'd)

	Thickness (feet)	Depth (feet)
Upper Pleistocene deposits: (Cont'd)		
Coarse brown sand and fine gravel	13	183
Coarse gravel and black silty clay	12	195
Gardiners clay:		
Blue clay	13	208
Magothy (?) formation:		
Fine gray sand	12	220
Fine gray sand, streaks of clay	14	234
Sandy clay and mica	19	253
Streaks of sand and clay	10	263
Sand, clay and mica	21	284
Cemented sand	1	285
Coarse gray sand, streak of cemented sand	7	292
Cemented sand	3	295
Hard packed sand	16	311
Fine sand and large gravel	7	318
Fine to coarse sand and large gravel	31	349
Blue clay	9	358
Blue clay and streaks of large gravel	15	373
Streaks of sand and clay	33	406
Sandy clay	17	423
Blue sandy clay	54	477
Streaks of fine sand and gray clay	43	520
Clay, sand, and lignite	7	527
Sandy clay	35	562
Streaks of sand and clay	15	577
Streaks of fine sand, clay and lignite	39	616
Fine sand and white clay	4	620
Hard white clay	1	621
Coarse sharp white sand	10	631
Coarse sand and streaks of white clay	9	640
Hard white clay	2	642
Clay, sand and lignite	22	664
Clay	5	669
Clay, sand and lignite	10	679
Streaks of coarse sand and lignite	33	712
Streaks of blue and white clay and sand	54	766
Medium to coarse white sand	53	819
Sand, clay and mica	43	862
Streaks of sand, clay and large gravel	38	900
Hard packed sand and streaks of clay	27	927
Medium sand, gravel and clay streaks	33	960
White clay, large gravel and fine sand	10	970
Hard packed sand, white and red clay streaks	122	1092

Table 2 - (Cont'd)

	Thickness (feet)	Depth (feet)
Raritan clay member:		
Sandy clay and streaks of hard blue clay.	29	1121
Sand, clay and hard streaks of lignite.	23	1144
Fine muddy sand and streaks of blue clay.	11	1155
Sandy blue clay and streaks of iron pyrites	5	1160
Tough blue clay	6	1166
Blue clay and hard streaks of wood.	22	1188
Tough blue clay, hard lignite and sand rock	45	1233
Sandy clay.	12	1245
Sand, gravel and clay streaks	23	1268
White sandy clay.	10	1278
Lloyd sand member:		
White sandy clay, streaks of sand and gravel. . . .	57	1335
Coarse sand and gravel.	15	1350
Coarse sand and gravel and white clay	17	1367
White sandy clay, sand and gravel	5	1372
Black clay, streaks of white sandy clay	12	1384
Large gravel, streaks of brown clay	3	1387
Soft streaks of brown clay, white sandy clay and gravel	25	1412
Large gravel, coarse sand and streaks of clay . . .	24	1436
Sandy white streaks of hard clay.	32	1468
Large gravel and sandy clay	11	1479
Sandy white clay, streaks of fine gravel.	10	1489
Sandy white clay.	34	1523
Tough red clay.	10	1533
White clay and sand	29	1562
Bedrock:		
Gneiss.	29	1591

Casing: 12 and 8 inches.

Screen: 25 feet of 8-inch with bottom at 1434 feet.

Pumping test:

October 28, 1948.

Duration:.	10 hours
Static water level:. .	83 feet
Drawdown:.	117 feet
Yield:	125 gpm

	Elev.
Ground	113
Static	30
Draw down level	- 4

Bedrock

The ancient bedrock floor beneath Long Island is composed of the same types of rocks that are exposed at many places on the nearby mainland. The bedrock floor is actually the deeply buried seaward extension of those inland rocks. The chief kinds of rocks identified beneath the island are schist, gneiss and granodiorite, with localized occurrences of granite, pegmatite and limestone. According to records of some deep wells, the upper part of the bedrock is partly decomposed, indicating that the old rock surface was exposed to the action of wind, rain and other agents of weathering for a long period of time before it was covered by younger materials.

The bedrock surface has a dip of about 60 to 80 feet per mile in a general southeastly direction. Along the north shore of Suffolk County, at places such as Lloyd Neck and Orient Point, the bedrock surface is only about 500 to 600 feet below sea level. At the western end of Fire Island on the south shore, the bedrock has been estimated by the U.S. Geological Survey to be as much as 2,100 feet below sea level.

Figure 2 is a bedrock contour map of the Long Island area adapted from a report by Oliver and Drake (see bibliography). This map is based on well records from Long Island and seismic investigations in adjacent waters. In general, the contours are believed to be accurate to within a few hundred feet. Bedrock maps of Long Island prepared by the U.S. Geological Survey and published in N Y. State Water Power and Control Commission Bull. GW-18 (see bibliography) show conditions generally similar to those in figure 2, although there are discrepancies of a few hundred feet in the Fire Island area.

The bedrock beneath Suffolk County has no practical value as a source of water supply. Although it is likely that wells drilled into the bedrock would produce small quantities of water from fractures and similar openings, much greater amounts can be obtained from the overlying sediments. In adjacent parts of New York and Connecticut, where the bedrock is commonly the only available source of ground water, the average yield of rock wells is only a few gallons per minute. In Suffolk County, no bedrock wells are presently in use.

Lloyd Sand Member

The Lloyd sand, the lowermost water-bearing unit in Suffolk County, is composed mainly of medium to coarse sand and fine to medium gravel. In some areas it contains beds of clayey sand and layers of solid clay. Nowhere on Long Island does the Lloyd sand crop out at the surface. The top of this sand occurs at depths ranging from about 200 feet below sea level in the northwestern part of the county to about 1,700 feet below sea level along the south shore. The total thickness of the unit ranges from about 150 feet in northwestern Suffolk County to more than 300 feet in the southern part of the county. A test well recently drilled at Great South Beach on Fire Island encountered bedrock at a depth of 1,915 feet. Although no geologic correlation of the log of this well has yet been made, it is interesting to note that more than 300 feet of material composed predominantly of sand and gravel, believed to be the Lloyd sand, was encountered directly above the bedrock. It is understood that the water in this sand and gravel was fresh.

The Lloyd sand contains ground water under artesian conditions. As far as is known, it is overlain everywhere in the county by the Raritan

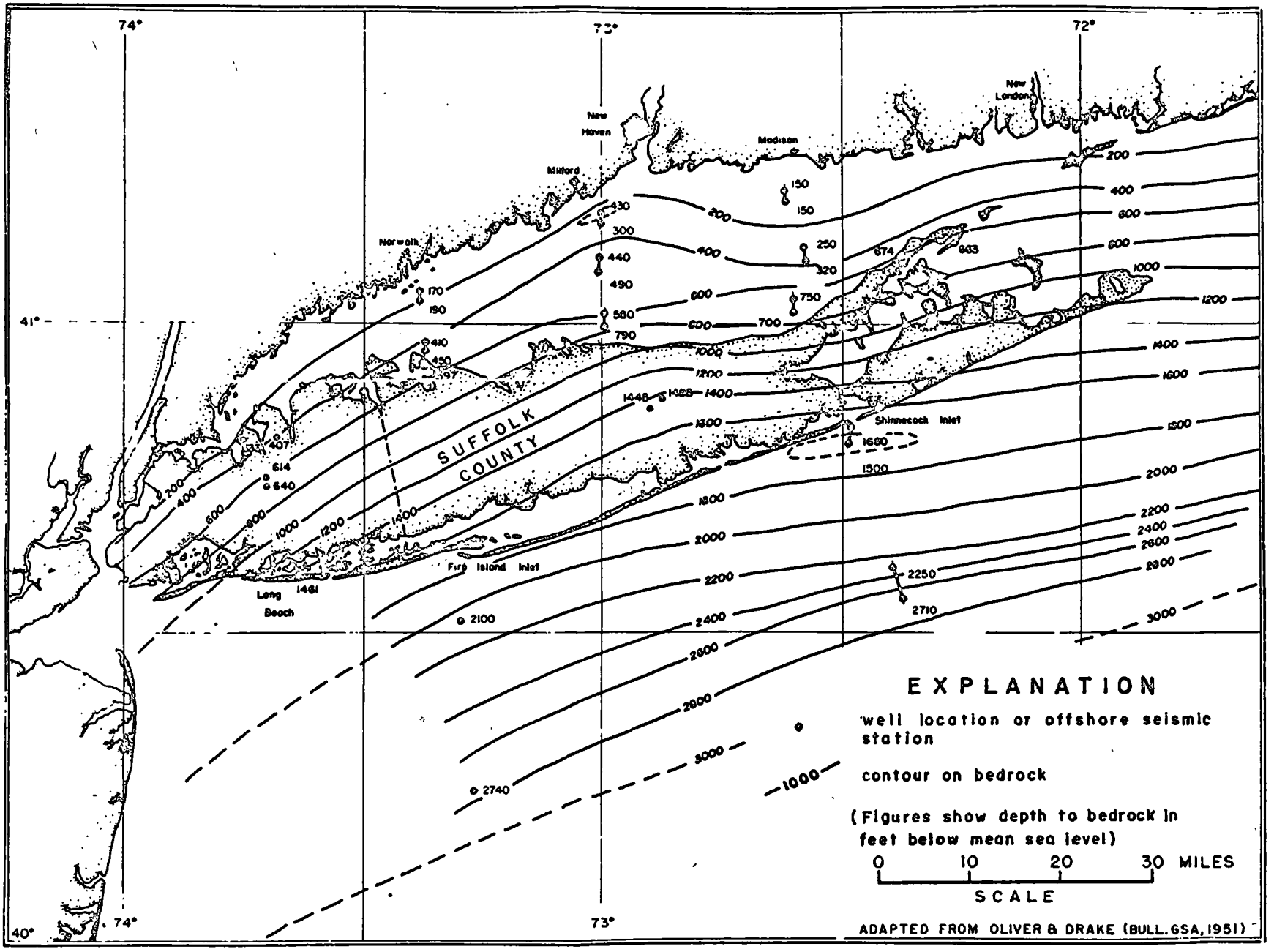


FIG. 2 - BEDROCK CONTOUR MAP OF LONG ISLAND AREA

clay, which separates it from the higher sands of the Magothy (?) formation. In general, water levels in Lloyd wells in the center of the county are lower than those in shallower nearby wells. However, in shore areas, water levels in Lloyd wells are generally higher than those in shallower wells. Many Lloyd wells along the shore discharge by natural flow.

Most of the production wells that obtain water from the Lloyd sand in Suffolk County are located in the northwestern part of the county, where the formation is encountered at relatively shallow depths. Throughout the rest of the county, only a few test wells and observation wells have been drilled into the Lloyd. Pumping tests at the deep wells at Brookhaven National Laboratory indicate that the Lloyd sand in that area is not a very productive water-bearing unit. A few Lloyd wells along the north shore have yielded only salt water. In the North Fork, an old deep well at Greenport (Well S490) yielded fresh water from the Lloyd sand. A few miles farther east, at Orient Beach State Park, another deep well (Well S 189) yielded only salt water from the Lloyd. Although this well penetrated the entire thickness of the Raritan formation, it encountered only 14 feet of sand and gravel at a depth corresponding to the Lloyd sand. The deep well at Greenport encountered only about 20 feet of coarse sand at the depth of the Lloyd. In the South Fork, deep wells in the Magothy (?) formation have encountered salt water and it is likely that the Lloyd sand in this area is also contaminated.

Raritan Clay Member

Everywhere in Suffolk County, as far as is known, the Lloyd sand is overlain by the relatively thick deposit known as the Raritan clay. This unit is composed chiefly of clay and silty clay, with some interbedded layers of sand. The clay is commonly gray, but red, white, yellow and mottled colors have also been observed. Lignite and pyrite are abundant in many places.

In Suffolk, the clay unit is believed to range from 100 to 300 feet in thickness. Like the underlying Lloyd sand and the bedrock floor, the Raritan clay is nearest the land surface in the northwestern part of the country. Wells in that area encounter the clay at depths of about 100 feet below sea level. The Raritan clay is at its maximum depth along the south shore, where it is estimated to be more than 1,400 feet below sea level.

Although the Raritan clay is entirely saturated with ground water, its low permeability prevents it from yielding water readily to wells and it is therefore not a water-producing unit. Conceivably, some of the sandy zones in the clay might yield water but the supply would be limited and the wells would soon lose capacity.

Magothy (?) Formation

The Magothy (?) formation is generally composed of irregular lens-like beds of gravel, sand, sandy clay and clay, commonly containing thin layers of lignite and pyrite. Most of these sediments are fine-grained and contain considerable amounts of mica and fine particles of lignite. The predominant color is gray, although brown, yellow, pink and red layers are not uncommon. The individual beds in the formation generally do not have a wide lateral extent and none has been correlated over distances of

much more than a mile or two, except a coarse sand and gravel bed that is encountered near the bottom of the unit in many wells. Like the underlying Raritan formation, the Magothy (?) formation thickens toward the southeast in the down-dip direction. At the south shore the unit is believed to be more than 1,300 feet thick. Although in some places along the north shore, it is only a few hundred feet thick.

The upper surface of the Magothy (?) formation on Long Island is highly irregular, indicating that the formation underwent a considerable amount of erosion before the deposition of the overlying glacial materials. In western Long Island, where much information is available from well borings, the altitude of the Magothy surface ranges from more than 200 feet above sea level to as much as 300 feet below sea level. According to maps prepared by the U.S. Geological Survey, the Magothy surface in Kings, Queens, Nassau and in parts of western Suffolk shows numerous hills, valleys and relatively flat areas. In central and eastern Suffolk County, however, well data are scanty and very little is known concerning the configuration of the Magothy surface. In these areas, the top of the Magothy is believed to be as much as 100 feet or more below sea level.

Although the Magothy (?) formation has the largest ground-water supply potential of any geologic unit in Suffolk County, no extensive use has been made of this source to date because adequate yields can still be obtained from shallow wells screened in the glacial deposits.

It is believed that the Magothy (?) formation contains only fresh water beneath the south-shore bays and islands in central and western Suffolk County. Wells in those areas drilled deep enough to penetrate the extensive Ice Age clay beds usually flow and yield fresh water. Figure 3 is a north-south section across the islands south of Islip, showing the general relationship of the Ice Age clays to fresh-water zone in the Magothy (?) formation.

Jameco Gravel

The Jameco gravel is not known to occur widely in Suffolk County, although beds of Jameco age may be present in places. Early investigators tentatively considered certain gravel beds in eastern and northern Suffolk County as part of the Jameco formation but recent reports by the U.S. Geological Survey have questioned this correlation. If any Jameco deposits do exist in Suffolk County, they are not extensive enough to be important from a ground-water viewpoint.

Gardiners Clay

The unit known as the Gariners clay as named after Gardiners Island at the extreme eastern end of the island, where early investigators observed outcrops of the unit above sea level. In central and western Long Island, beds correlated as the Gardiners clay occur only at depths below sea level and their exact stratigraphic relationship with the clays on Gardiners Island is obscure. The Gardiners clay is the only major geologic unit on Long Island that can be traced from place to place on the basis of its fossil content.

The Gardiners clay consists chiefly of dark gray or greenish gray silty clay, although lenses of sand are found in the unit in many places.

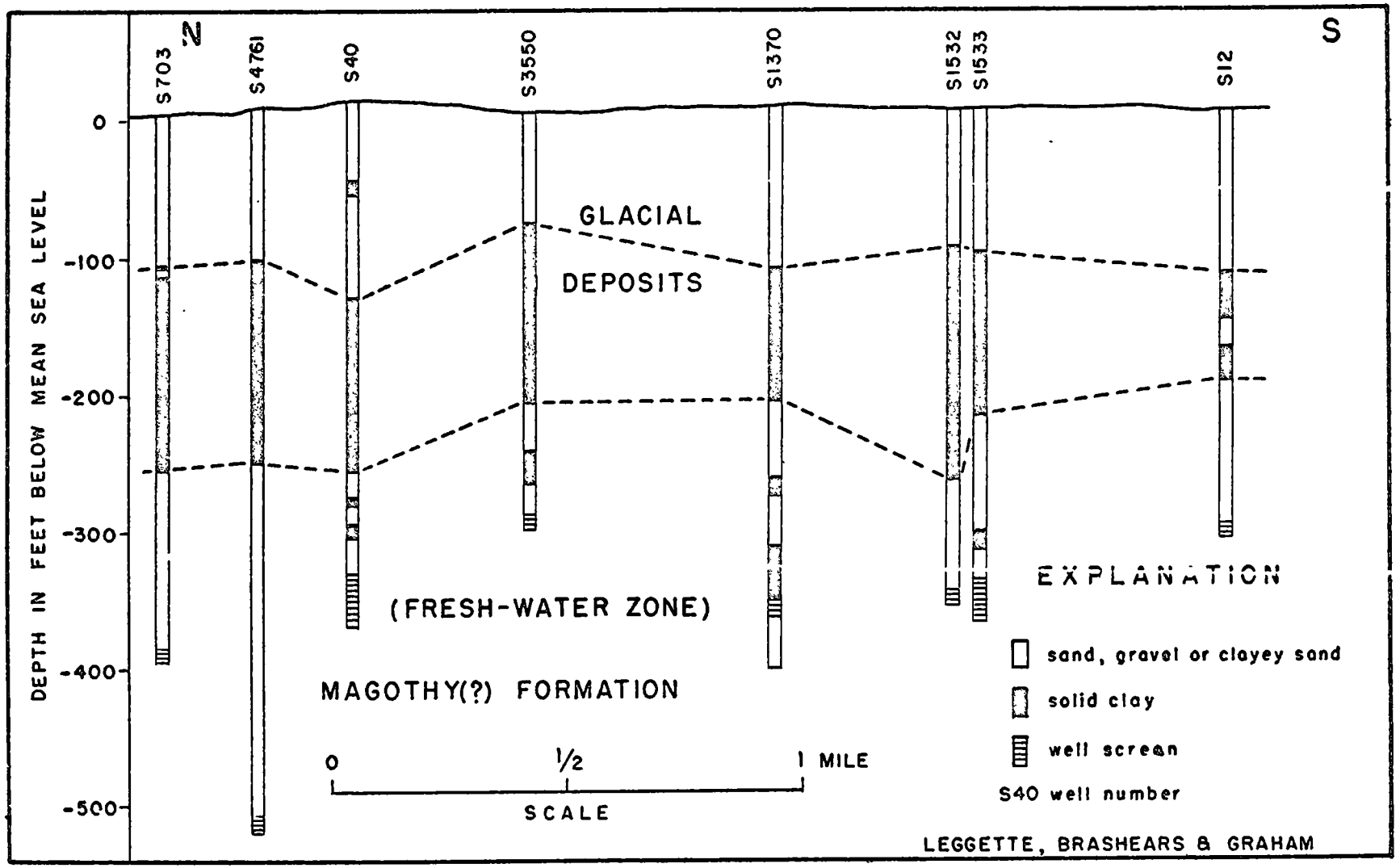


FIG. 3 - GEOLOGIC SECTION ACROSS ISLANDS SOUTH OF ISLIP, SUFFOLK COUNTY, N.Y.

Generally, the clay contains shell fragments, woody material and remains of microscopic marine plants and animals. Because of its clayey character, the Gardiners is not a water-producing unit. However, it is an effective confining bed and is largely responsible for the artesian conditions in the underlying sands.

The distribution, depth and thickness of the Gardiners clay in Suffolk County are not well known. Logs of a few wells in the county report fossiliferous clay, which has tentatively been correlated as Gardiners. Available data suggest that the Gardiners underlies much of the south-shore area and may extend inland for several miles. Samples from several test wells at Brookhaven National Laboratory in central Suffolk County indicate that the Gardiners is present in this area. At that location, the upper surface of the clay is about 65 feet below sea level and the bed itself is only about 10 feet thick.

Upper Pleistocene Deposits

The upper Pleistocene deposits consist of two major types, till deposits and outwash deposits. The till deposits, which generally occur at the land surface or at shallow depths, are composed of heterogeneous mixtures of material ranging in size from clay to boulders. The morains that extend eastward through northern and central Suffolk County to Montauk and Orient Points consist mainly of till. These moraines mark the southernmost limit of ice advance. The till is not an important source of ground water.

Beneath the till-covered areas and exposed at the surface over most of the remaining parts of the county, are deposits of stratified sand and gravel known as "outwash". The outwash materials were laid down by the water draining outward from the ice sheets. They are highly variable in thickness and composition and include sand grains and pebbles of many different types of rock. These sediments are generally brown colored, in contrast to the gray to white color of the older and deeper Cretaceous deposits. In some areas, layers of clay are interbedded with the outwash. The upper Pleistocene deposits in Suffolk County, although thin in some areas, are as much as several hundred feet thick in places. They lie directly on the underlying Magothy (?) formation, except in places where the latter is covered by localized beds of Jameco gravel or Gardiners clay.

The sand and gravel beds of the upper Pleistocene deposits are highly permeable and constitute the most readily available source of ground-water supply in Suffolk County. The water table, or upper surface of the saturated zone, generally occurs in these deposits within a few tens of feet of the land surface, except in the higher areas.

Recent Deposits

Recent deposits in Suffolk County occur extensively only in the shore areas, where currents and tides have built offshore bars, spits, beaches and islands. In addition to these visible shore features, deposits of clay, silt and sand have accumulated slowly during Recent time in the sheltered shallow-water bays and lagoons along the shores.

Most of the Recent sediments, except those deposited on the bottoms of the bays, are composed of clean, water-worn sand and gravel. In places, beds of clay and peat are encountered at shallow depths, indicating that these areas were once swampy or slightly below sea level. In general, the Recent deposits are thin and are underlain by upper Pleistocene deposits.

The Recent offshore bars and small islands contain local bodies of fresh ground water that are replenished entirely by precipitation directly on those areas. Although fresh water can also be obtained in most of these localities from deep wells tapping the artesian formation, it is generally more economical to obtain moderate supplies from the shallow deposits.

Respectfully, submitted,

R.M. Leggette

BIBLIOGRAPHY

1. Burr, W.H., Hering, R., and Freeman, J.R., Report of the Commission on additional water supply for the City of New York. Martin B. Brown Co., New York, 1904.

2. Fuller, M.L., The Geology of Long Island, N.Y. U.S. Geol. Survey Prof. Paper 82, 1914.

3. Johnson, A.H., and Waterman, W.G., Withdrawal of Ground Water on Long Island, N.Y. N.Y. State Water Power and Control Commission Bull. GW 28, 1952.

4. Leggette, R.M., Long-time records of ground-water levels on Long Island, N.Y. Trans. Amer. Geophys. Union for 1936, pp. 341-344, 1936

5. Leggette, R.M., Records of Wells in Suffolk County, N.Y. N.Y. State Water Power and Control Comm. Bull. GW 4, 1938.

6. Lusczynski, N.J., and Johnson, A.H., The water table in Long Island, N.Y., in January 1951. N.Y. State Water Power and Control Comm. Bull. GW 27, 1951.

7. Merrill, F.J.H., and others, U.S. Geol. Survey, Geol. Atlas, New York City Folio (No. 83). 1902.

8. N.Y. State Water Power and Control Comm. Record of Wells in Suffolk County, N.Y., Supplement 2. Bull. GW 31, 1952.

9. Oliver, J.E., and Drake, C.L., Geophysical investigations in the emerged and submerged Atlantic Coastal Plain, Part VI: The Long Island area. Bull. Geol. Soc. of America, Vol. 62, No. 11, Nov. 1951, pp. 1287-1296.

10. Roberts, C.M., and Brashears, M.L., Jr., Records of wells in Suffolk, County, N.Y., supplement 1. N.Y. State Water Power and Control Comm. Bull. GW 9, 1945.

11. Spear, Walter E., Long Island sources--an additional supply of water for the City of New York. Board of Water Supply of the City of New York, 1912.

12. Suter, Russell, Engineering report on the water supplies of Long Island. N.Y. State Water Power and Control Comm. Bull. GW 2, 1937.

13. Suter, R., de Laguna, W., and Perlmutter, N.M., Mapping of geologic formations and aquifers of Long Island, New York. N.Y. State Water Power and Control Comm. Bull. GW 18, 1949.

14 Thompson, David G., and Leggette, R.M., Withdrawal of ground water on Long Island, N.Y. N.Y. State Water Power and Control Comm. Bull. GW 1, 1936.

15. Veatch, A.C., and others, Underground water resources of Long Island, N.Y. U.S. Geol. Survey Prof. Paper 44, 1906.

APPENDIX B

POPULATION FORECASTS FOR SUFFOLK COUNTY

By Thomas H. Wiggin

Section B-1 - General Explanation. The author has not found forecasts to be reliable. They have generally been too optimistic, but where the actual growth is assured, as is the case of Suffolk and Nassau Counties barring some unforeseeable catastrophe, it is almost certain that the error in forecasting will be in trying to fix the date when a given population will be reached rather than in the forecast that it will be reached.

As this report deals principally with a plan for ultimate development and methods of pursuing it, rather than the actual date at which the ultimate development will be needed, it is not too important when that date will be reached. The author's emphasis is on the importance of not allowing the ultimate population to exceed the ability of the County's ground water resources to support the ultimate population, at least unless and until the purification of sea water comes within economic reach.

However, it is necessary to have an intelligent idea of the rates of growth of various sections of the County and to that end a study of past growth is the first step. An accompanying table, B-1, shows the growth of each town in Suffolk from 1910 to January 1, 1956, also the growth of the County as a whole and that of Nassau County as well.

Section B-2 - Sources of Information. The sources of information are the Legislative Manual of New York State for 1910 to 1950 inclusive and the 1956 publication "Population Survey" of the Long Island Lighting Co., containing population forecasts for 1952, 1954,and 1956. The Legislative Manual gives the official census figures as of April first of the given years, whereas the population figures of the Long Island Lighting Co. are for January 1 of the years 1952, 1954 and 1956. These Power Co. estimates are in great detail, involving the dividing of the County into very small districts, studying each district and combining the counts for the districts in each town.

Section B-3 - Population Growths in Each Town. In the author's Table B-1 the population is by towns and also for the whole county of Suffolk. For comparison the whole of Nassau County is also treated. Figures in the table between the population records of the years given are the computed yearly percentage increases (or decreases) in population which obtained during the period between the two population figures. These yearly percentages were computed on the geometrical progression basis, i.e., the percentage figures are such that if they were applied each year during the interval in question to the given or the computed population of the previous year, they would make up the increased (or decreased) population which did occur.

As an example take the 4.7% increase in the first column between the Babylon populations for 1910 and 1915: the average yearly percentage increase given in the table is 4.7. The multiplier ("ratio" in geometrical progression) is therefore 1.047. 9030 x 1.047 x 1.047 x 1.047 x 1.047 x 1.047= 11190 within reasonable accuracy. The percentage decreases are estimated only approximately.

APPENDIX B · TABLE B-1

POPULATION GROWTH OF SUFFOLK COUNTY BY TOWNS AND OF SUFFOLK AND NASSAU COUNTIES AS WHOLES

Year	Babylon	Brook-haven	East Hampton	Hunting-ton	Islip	River-head	Shelter Island	Smith-town	South-hampton	South-hold	Indian Reservation		TOTAL	TOTAL Nassau County
											Passpatuck	Shinnecock		
1910	9,030	16,737	4,722	12,004	18,346	5,345	1,064	7,073	11,240	10,577	-	-	96,138	83,930
	4.7%	3.3	1.7	4.9	-1.8±	1.36		- 5±	3.6	- 1±			1.7	6.8
1915	11,190	19,591	5,164	15,244	17,658	5,730	1,155	4,988	13,453	10,008	18	143	104,342	116,825
	0.2	2.1	- 1±	-1.7±	3.2	0+		12.8	- 2±	0+			1.1	2.6
1920	11,315	21,847	4,852	13,893	20,709	5,753	890	9,114	11,614	10,147	-	112	110,246	126,120
	10.7	3.1	3.5	8.6	0+	3.5		5.5	5.7	1±			7.7	10.5
1925	15,952	25,531	5,782	20,955	20,849	6,803	1,096	11,954	15,393	10,716	-	177	143,208	207,640
	7.1	2.0	2.7	4.1	9.7	3.1		- 0±	0±	1.7			2.4	7.9
1930	19,291	28,291	6,569	25,582	33,194	7,956	1,113	11,855	15,341	11,669	34	160	161,055	303,053
	4.7	2.6	0	2.2	4.4	1.14		1.7	0-	0.3			2.8	3.0
1940	24,297	32,117	6,529	31,768	51,182	8,922	1,073	13,970	15,295	12,046	-	156	197,355	406,748
	13.3	3.3	-0.3±	4.1	3.3	1.3		4.1	1.0	-0.3			3.4	5.2
1950	45,556	44,522	6,325	47,506	71,465	9,973	1,144	20,993	16,830	11,632	-	183	276,129	672,765
	19.2	7.5	6.1	9.9	7.9	7.2		4.4	7.9	3.8			9.0	12.5
1952	61,743	50,687	7,096	55,052	80,825	11,280	1,172	22,546	19,245	12,564			322,212	830,655
	10.9	7.6	13.1	11.0	9.3	4.6		4.4	2.5	5.1			8.6	6.3
1954	75,972	58,721	9,112	66,985	96,543	12,387	1,200	24,575	20,217	13,861			379,573	966,841
	5.8	7.2	6.[illegible]	11.8	11.4	5.35		5.2	8.9	5.0			9.2	6.2
1956	88,527	67,644	10,261	83,701	119,340	13,736	1,230	28,381	23,955	15,308			452,083	1,087,118

NOTES:
1. Population figures from 1910-1950 inclusive are official census figures taken from the N.Y. State Legislative Manual; 1952, 1954 & 1956 are from the 1956 publication "Population Survey" by Long Island Lighting Co.
2. Figures in the horizontal lines between population figures are population growths in the respective time intervals, reckoned in geometrical progression.
3. Populations from 1910-1950 incl. are as of April first in the given year. Population figures in 1952, 1954 & 1956 are as of January 1st of those years. The time interval between population figures in 1950 & 1952 is 1 yr. and 9 months or 1.75 years.

This method of showing growth was chosen in order to give, in as comparative a manner as seemed practicable, the annual percentage growths in the various periods for each Suffolk County town and for the two counties. The exact percent of growth in any particular year cannot of course be known because the census counts occurred at intervals of 5 or 10 years and the Power Co's estimates were at 2 year intervals.

Section B-4 - Comments on Population Growth as Shown by Table B-1

(A) In 1910 Suffolk County had a somewhat greater population than Nassau County. In those days, both counties were predominately rural and the much greater area of Suffolk County gave it a greater population. The areas of the two counties are respectively 920 and 274 sq. miles.

(B) By 1915, Nassau County had forged ahead and by Jan. 1, 1956 it had 2.4 times the population of Suffolk County and about 8 times the density of population of Suffolk County. Equal density in Suffolk County would give that County a population of about 3,650,000 which is about 300,000 more than the author's preliminary figures gave for the population which the available ground water supply would safely support. (See main report, Section 4.4)

(C) While the rate of growth of Nassau County was greater than that of Suffolk County for the whole period 1910 to 1952, the Suffolk County growth was larger, percentage-wise, from 1952 to 1956.

(D) The growth of both counties, particularly Suffolk, slumped in the period 1915 to 1920, probably because of the 1st world war. County growths recovered and were high between 1920 and 1925. but were relatively down, except for Nassau County between 1925 and 1930, in the period 1925-1950, which contained the great depression and World War 2.

(E) The percentage growth in the separate towns of Suffolk was very varied in the different periods. Babylon, near the Nassau County line and within commuting distance of N.Y. City, had the greatest percentage growth and the growth was well sustained from 1920 on. The Huntington and Islip growths were also high, particularly from 1950 on. All the other towns, except Shelter Island, had good growths from 1950 (Smithtown from 1940) on.

Section B-5 - Population Forecast for Suffolk County. The writer has set down in Table B-2 some figures of future growth which from present indications seem to be conservative. They are not estimated by the geometrical ratio method but by the use of estimated average yearly numerical increases. The writer was influenced by the feeling that the tremendous rates of new housing which have prevailed during the past few years could not be quite sustained over a long period because of the distance of a considerable part of the county from the metropolitan district and probably some slowness in the starting in the eastern parts of industries which would be needed to support the growth, particularly in areas farther from the water front; but that the great beauty of the county and its richness in recreational opportunities would tend to offset the slowing effects above mentioned.

There will doubtless be a very considerable increase in summer population, which will mean need for water supply facilities during the months when per capita rates of consumption are highest. However, as such summer residents will generally have their legal residences elsewhere, they will not show in the official population figures. It is of interest to note that the original development at Montauk was done by a man with a vision of a summer resort somewhat similar to that at Palm Beach as a winter resort; further, that there are a large number of residences used mainly in summer and that a 750 acre tract in East Hampton on Gardiner's Bay, has recently been reported to have been purchased with the purpose of making a large development with perpetual rights on the Bay.

APPENDIX B - TABLE B 2

FORECAST OF POPULATION GROWTH OF SUFFOLK COUNTY

Year	Average Yearly Growth	Population
1930		161,100
	3,630	
1940		197,400
	7,870	
1950		276,100
	26,000	
1952 (Jan. 1)		322,000
	29,000	
1954 (Jan. 1)		380,000
	36,000	
1956 (Jan. 1)		452,000
	33,000	
1960 (Jan. 1)		584,000
	30,000	
1970 (Jan. 1)		884,000
	30,000	
1980 (Jan. 1)		1,184,000
	25,000	
1990 (Jan. 1)		1,434,000
	25,000	
2000 (Jan. 1)		1,684,000

Notes:
1. Population figures for years 1930,1940 and 1950 are from the U.S. Census.
2. Population figures for years 1952, 1954 & 1956 are from the pamphlet "Population Survey 1956" of the Long Island Lighting Co. Its figures are in great detail and are believed to be very reliable. Its population estimates are for Jan. 1 of each year given.
3. Time interval between figures for 1950 and Jan. 1, 1952, is assumed to be 1 3/4 yrs. as the 1950 census figures are stated to be as of April 1 of that year.

Section B-6 - Comments for Forecast. The writer will close this discussion of population growth by reiterating his opinion that the County will continue to grow and that it does not make much difference in general planning for the development of the ground water supply in just what decade a given population will be reached. The main objective is to plan as wisely as present knowledge of the geology and ground water supply technique permits, to have active and coordinated organizations continuing their study to improve and complete this knowledge and to keep the general plan revised as will be indicated by such increased knowledge.

APPENDIX C

by

GEORGE D. NORCOM
CONSULTANT

REPORT ON THE QUALITY OF THE WATER SUPPLIES OF SUFFOLK COUNTY, LONG ISLAND, NEW YORK.

This report on the quality of the water supplies of Suffolk County has been prepared at the request of Mr. T.H. Wiggin, Consulting Engineer, and is intended to accompany his comprehensive report and forecast on the water supply of Suffolk County. In this report it is the intention to describe the general type of water supply available, to present analytical data indicating the chemical characteristics of the existing water supplies, to indicate the type of water treatment required, to discuss the sources of possible contamination and methods for the protection of these water supplies. The writer has been rather closely associated with these aspects of the water supplies now operated by Suffolk County Water Authority, since 1930. During the early part of this period, Suffolk County was largely a pleasant rural region with scattered urban communities with abundant supplies of well water readily available. The situation has changed since the end of World War 2 with housing developments pushing rapidly eastward and the unprecedented growth of population and industry. It is indeed time to make an appraisal of the ultimate water supply needs of the County and to consider ways and means of providing adequate water supply for the future and protecting this water supply from contamination and possibly from destruction in some cases by hordes of well meaning people intent on material progress.

Water Quality Requirements.

A safe, adequate and readily available water supply is probably the most essential requirement of life. Such a water supply is necessary not only for drinking and domestic use, but also for irrigation and industrial use, for fire protection and for the disposal of sewage by water carriage.

The Manual of Water Quality and Treatment of the American Water Works Association epitomizes the characteristics of good quality in drinking water as follows:

"A water supply should be clear, of neutral taste, of reasonable temperature, neither corrosive nor scale forming, not so mineralized as to produce unfavorable physiological effects and containing no organisms capable of producing intestinal infection." It may be added that a water supply intended for human consumption should be free from any domestic or industrial waste materials in sufficient amount as to be deleterious or distasteful to consumers of the water.

Supervision and Control of Water Quality.

The primary responsibility for the supervision and control of water quality rests with the water utility whether it is privately or publicly owned and operated. This is a function of the plant operator who acts under direction of

management. The local operator is in close contact with the water supply and with the consumers. He is in direct charge of the operation of pumping stations and the distribution system, he visits the pumping stations frequently, operates water treatment apparatus, collects water samples and makes sanitary inspections in addition to his many other responsibilities as manager and local representative of the utility. The local manager prepares and submits regular operating and water treatment reports to the proper authorities.

Suffolk County Water Authority retains a consulting sanitary engineer who reviews reports of water treatment and analysis, makes regular sanitary inspections of all plants, and advises as may be required. The Authority has an arrangement whereby samples of water from various sources of supply are examined in an approved laboratory. The Authority is planning to install a modern water analysis laboratory in a new office building which is to be constructed in the near future.

Supervisory control of water quality is vested by law in federal, state and local health agencies. The United States Public Health Service has supervision of all drinking and culinary water supplied by common carriers in interstate commerce. In New York State, the State Water Power and Control Commission has broad powers of control over the allocation of new and additional water supply including methods of treatment and protecting from pollution. The State Department of Health has general supervision of the quality and sanitary protection of all water supplies in the state. This Department also exercises general supervision of sewage and waste disposal plants. The Department of Health also operates a system of licensing of water treatment and sewage treatment plant operators. Many cities and counties in the state have highly organized and equipped health departments. In such cases many administrative duties in connection with water supply and sanitation are performed locally.

Standards of Water Quality.

Standards for the quality of drinking water in the United States are based on the U.S. Public Health Drinking Water Standards of 1946. Although these standards were originally issued specifically for the regulation of drinking water used on common carriers they have been generally adopted by state regulatory agencies and by the American Water Works Association. This document is too voluminous for inclusion in this report and anyone sufficiently interested may obtain a copy, however the most important provisions may be summarized as follows.

1. "As to source and protection, the water supply shall be from a source free from pollution or a source adequately purified by natural agencies, or adequately protected by artificial treatment."
2. "The water supply system in all its parts should be free from sanitary defects and health hazards and all known sanitary defects and health hazards shall be systematically removed at a rate satisfactory to the reporting agency and to the certifying authority."
3. "As to bacteriological quality - Sampling - the bacteriological examination of water considered under this section shall be of samples collected at representative points throughout the distribution system."

Detailed specifications are given regarding the frequency of sampling, the location of sampling points, the minimum number of samples to be collected and examined, action to be taken if the result of examination are unsatisfactory, and inspection of laboratories. The methods used, the provisions of the

bacteriological standards and methods of application are then specified. The procedure provides for the use of a standard sample composed of five standard portions of either 10 ml. or 100 ml. each. The procedure using 10 ml. portions and its applications are described as follows:

"321. Of all the standard ten milliliter (10 ml.) examined per month in accordance with the specified procedure, not more than ten (10) per cent shall show the presence of organisms of the coliform group.

"3.22 Occasionally three (3) or more of the five (5) equal ten milliliter (10 ml.) portions constituting a single standard sample may show the presence of organisms of the coliform group, provided that this shall not be allowable if it occurs in consecutive samples or in more than:

(a) Five (5) percent of the standard samples when twenty (20) or more samples have been examined per month.
(b) One (1) standard sample when less than twenty (20) samples have been examined per month.

Provided further that when three or more of the five equal ten milliliter (10 ml.) portions constituting a single standard sample show the presence of organisms of the coliform group, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality."

4.1 As to physical characteristics. - "The turbidity of the water shall not exceed 10 p.p.m.* (silica scale) nor shall the color exceed 20 (platinum-cobalt scale). The water shall have no objectionable taste or odor".
4.2 As to chemical characteristics. - "The water shall not contain an excessive amount of soluble mineral substance, nor excessive amounts of any chemicals employed in treatment --".
4.21 "The presence of lead in excess of 0.1 p.p.m., of fluoride in excess of 1.5 p.p.m., of arsenic in excess of 0.05 p.p.m., of selenium in excess of 0.05 p.p.m., of hexavalent chromium in excess of 0.05 p.p.m. shall constitute grounds for rejection of the supply --".

"Salts of barium, hexavalent chromium, heavy metal glucosides or other substances with deleterious physiological effects shall not be added to the system for water treatment purposes."

4.22 "The following chemical substances which may be present in natural treated waters should preferably not occur in excess of the following concentrations where other more suitable supplies are available --".

Copper (cu), 3.0 p.p.m. Iron (Fe) and Manganese (Mn) together 0.3 p.p.m. Magnesium (Mg), 125 p.p.m. Zinc (Zn), 15 p.p.m. Chloride (Cl), 250 p.p.m. Sulphate (SO_4), 250 p.p.m. Phenolic Compounds, 0.001 p.p.m.

Total solids should not exceed 500 p.p.m. However, if such water is not available a total solids content of 1000 p.p.m. may be permitted. The standards include certain limitations for chemically treated waters. It should be noted that the standards do not attempt to establish specific limitations for all objectionable substances that might gain access to water supply by contamination with industrial or other types of waste. Emphasis is placed upon adequate protection of water supply from liquids or chemicals of unsafe, unknown or questionable quality.

* Parts per million parts by weight.

Water Supplies of Suffolk County.

Geologic conditions as related to water supply and considerations of quantity of water are covered in other sections of the general report. To the best of our knowledge, all of the public water supplies of Suffolk County are obtained from underground sources. Except for the portion lost by run off and evaporation, the rain water sinks directly into the sands and gravels forming the surface of the land. The ponds and streams are for the most part fed from under ground sources. There is a constant escape of under ground water to the sea in the subsurface beds of sand and gravel.

Public and private water supplies are obtained by means of wells. There are still a great many domestic wells and wells for irrigation purposes throughout the county. For the larger water supplies the most common type of wells are simple tubular steel wells equipped with strainers. The deep well turbine is the most popular type of pump although a number of plants are operated by direct suction. Most pumping stations are electrically operated and many have standby power in the form of oil or gasoline engines.

Water Analysis.

In the tables accompanying this report will be found the results of recent chemical analysis of a large number of the water supplies of Suffolk County. In the case of the supplies of the Water Authority, the tables show the results of representative routine chemical analyses made during the past twelve months. In the case of water supplies other than those of the Water Authority, the tables show the results of recent routine analysis by the State Department of Health or by the Merrick Laboratory of New York Water Service Corporation. These tabulations are supplemented by additional tables showing the results of special determinations of Free Carbon Dioxide and Nitrate. It will be noted that there is some lack of conformity in the results presented and this is due to the fact that we have used data that was readily available rather than having a large number of complete analyses made specifically for this report.

Bacteriological Quality.

Extensive tabulations of the results of bacteriological examination of samples of water from the wells of Suffolk County have not been included in this report. Since about 1932 the writer has supervised the laboratory control of the water supplies now operated by Suffolk County Water Authority and has regularly reviewed the results of water analysis. In all this time he cannot recall an instance where a properly collected sample from a fully developed operating well has shown unsatisfactory bacteriological results. Samples from wells in course of construction or redevelopment may show unsatisfactory results for a time but they have never failed to clear up after disinfection and pumping to waste for a sufficient time. The writer cannot speak with the same assurance regarding the bacteriological examination of wells not operated by the Authority but the following communication from Mr. H.V. Davids, P.E., Director of Environmental Sanitation of the Suffolk County Department of Health, confirms the general statement that the public water supplies of Suffolk County are consistently satisfactory from a bacteriological standpoint.

"Over the years the records in our office indicate that in general the bacteriologic quality of the sources of the public water supplies in Suffolk

County are consistently found to be free of coliform organisms and, therefore satisfactory from the bacteriologic standpoint. This general statement also holds true for the majority of the distribution samples collected and analyzed by the Health Department.

When any isolated samples are found to be positive for coliform organisms in the public water supplies, the source of the contamination has been traced to incidental contamination after the water has been pumped from the water bearing stratum. It is usually found that it is either due to a sanitary defect in the construction of the well, storage facilities or improper or inadequate disinfection of a portion of the distribution system which has been recently installed, or repaired."

Chemical Quality.

Most of the wells in Suffolk County take their water from the superficial or glacial formation and most of them are less than 150 feet in depth. The deep wells at Huntington are somewhat less than 500 feet deep and we are informed that there are several wells on Fire Island Beach about 400 feet deep that yield water of good quality. (R.E. Cook - Jr. A.W.W.A. 30:322 (1938)). Attempts to obtain deep well water at Sag Harbor, Orient Beach and Greenport failed because of sea water contamination.

The data at hand* indicate that the well waters of Suffolk County are generally soft, low in alkalinity and mineral content and high in free carbon dioxide, marking them as exceptionally corrosive to metals and pipe lines.

The proximity of the sea poses a constant threat of salt water intrusion which may take place when the available fresh water head is overbalanced by the head of the sea water. When this occurs the salt content of the sea water causes an increase in the chloride content of the well water. Minor increases of chloride may occur from domestic or industrial contamination of the ground water but this rarely amounts to more than a few parts per million. An examination of the water analysis tables shows a minimum chloride content of 4 p.p.m. on the wells listed and it is entirely possible that a content of 10 or 12 p.p.m. may be due to chloride of domestic or industrial origin travelling with the ground water. It will be noted however, that many wells located in the easterly part of the county have chlorides ranging upwards from 20 p.p.m. to 130 p.p.m. These wells are located in most instances on the eastern peninsulas sometimes called the "flukes" or close to large bodies of salt water.

An example of sea water intrusion occurred at Port Jefferson following a severe storm in October, 1955. Up to this time the wells had yielded a water of exceptionally fine quality with a chloride content of 5 p.p.m. Samples taken after the storm had subsided showed that the chloride in two of the wells had increased to about 135 p.p.m. After a period of experimental pumping, two of the older wells were abandoned and sealed and one was replaced. The chlorides have now declined almost to normal.

A second consideration is the presence of iron and manganese. Water quality standards state that the amount of these two substances taken together should not exceed 0.3 p.p.m. It appears that two general classes of water should be noted in this regard: iron and manganese of shallow swamp origin, and iron associated with little or no manganese from the

* See tables, pages C11, C12 and C13.

older geologic formations. In the first class are wells located along the south shore yielding water with iron up to 0.1 p.p.m. and manganese up to 0.25 p.p.m., or more at times. (Amityville, Babylon, Bayshore). In the second class are wells near the east end of the island with iron up to 4.8 p.p.m. and mere traces or no manganese. (Sag Harbor, Southold, Greenport). The behavior of iron and manganese in certain wells will be described in more detail in another section of this report.

Finally, there is the consideration of corrision of metals and tuberculation of pipe lines. Generally speaking all of the underground waters of Suffolk County are corrosive although the waters of the north shore wells are somewhat less corrosive than those of the south shore. Methods for corrosion control will be described under water treatment.

Significance of Results of Chemical Analysis.

In order to facilitate the interpretation of the results of chemical analysis submitted herewith and to clarify the discussion of water treatment that follows, the significance of the principal physical and chemical determinations may be briefly described as follows.

In the absence of mineral acids, salts of strong acids and weak bases and possibly certain organic acids, Free Carbon Dioxide is assumed to be the same as the total acidity in natural Long Island well waters. Free carbon dioxide is an important cause of corrosion.

In a natural water, Alkalinity represents the total content of carbonates, bicarbonates and hydroxides. Normally, the Alkalinity of the Long Island well waters is all bicarbonate. Alkalinity is expressed in terms of Equivalent Calcium Carbonate.

The term pH is used to designate the hydrogen ion concentration of a water. It is a convenient measure of intensity, not quantity. The pH scale runs from 0 to 14 and the number 7.0 represents exact neutrality. In decreasing order below 7.0 the numbers indicate increasing intensity of acidity; in increasing order above 7.0 the numbers indicate increasing intensity of alkalinity.

Hardness in water is caused principally by the salts of the elements Calcium and Magnesium and these salts have soap consuming power. Temporary hardness is due to the presence of bicarbonates and permanent hardness is due to the presence of chlorides and sulphates of these elements. The U.S. Geological Survey has classified waters according to hardness as follows: Soft 0 to 55, Slightly Hard 56 to 100, Moderately Hard 101 to 200, Very Hard 201 to 500. Hardness is expressed in terms of parts per million of equivalent Calcium Carbonate.

The chloride content of water represents the total chlorides present as Cl. Sea water contains about 19,000 parts per million of chlorides as Cl so that a small increment of sea water added to fresh water will increase the chloride sharply. This test is very accurate.

Iron or Manganese either separately or together often occur naturally in under ground waters. When such waters are exposed to the air in open streams and in the presence of alkalinity these substances are largely precipitated by natural reactions. In underground waters or acid waters how-

ever, they persist and if present in amounts exceeding about 0.3 p.p.m they become increasingly abjectionable due to staining of procelain and discoloration of fabrics in the laundry. The trouble is intensified by the use of bleaching and disinfecting agents containing free chlorine.

Compounds of Nitrogen are described in the following statement from "Standard Methods of Water Analysis." Ammonia nitrogen is present in variable concentrations in many surface and ground waters. A product of microbiological activity, ammonia nitrogen is sometimes accepted as chemical evidence of sanitary pollution when encountered in raw surface supplies. Its occurrence in ground supplies is quite general as a result of natural reduction processes --. Nitrate represents the most highly oxidized phase in the nitrogen cycle and normally reaches important concentrations in the final stages of biological oxidation.---In excessive amounts, it is suspected of contributing to, or being associated with the illness known as infant methemoglobinemia (blue babies)---A stage in the nitrogen cycle, Nitrate occurs in water as an intermediate in an oxidation or reduction process." The nitrogen determinations are considered to be of value in studying the past history of a water supply but reliance is now placed very largely on the bacteriological examination as an index of the purity of drinking water. It should be noted that Nitrate is a constituent of most fertilizers and it is likely to occur in considerable quantity in ground waters underlying agricultural operations.

Variations in Iron and Manganese.

In the absence of contamination by sea water or by waste materials, the chemical characteristics of a well water in Suffolk County may be expected to vary somewhat with the seasons and with the quantity pumped, however in the case of two plants of the Authority the fluctuations in iron and manganese have been great enough to warrant special mention.

For many years it has been recognized that the Greene Avenue wells at Amityville developed sufficient iron and manganese at times of heavy pumpage to cause consumer complaints of stained fabrics and discolored water. The record for the past three years shows the following results.

1953	Maximum	July	Fe	0.38	Mn	0.45	Minimum	May	Fe	.12	Mn	0.35
1954	"	July	Fe	0.48	Mn	0.62	"	Nov.	Fe	.14	Mn	0.42
1955	"	Jan.	Fe	0.10	Mn	0.25	"	July	Fe	.06	Mn	0.25

Operation of the new well at North Amityville has made it possible to reduce the output at Greene Avenue with a consequent reduction in these constituents.

In a memorandum dated October 19, 1939 Mr. T.H. Wiggin describes an objectionable increase in manganese that took place at West Babylon pumping station in May, 1939. At that time the station had six 8 inch wells about 60 feet deep pumped by suction and the output was relatively high. The manganese was traced to the most southerly well, No. 6 which was shut off. By August the manganese had progressed to Well No. 5 which is about 80 feet north of Well No. 6. This well was shut off leaving only four wells in service. The manganese in the affected wells reached the high figure of 2.0 p.p.m. It is the recollection of the writer that the remaining four wells were kept in service for some time following this incident without developing serious trouble from manganese.

It is understood that four of the six old wells have now been replaced by new 10 inch single cased wells and the pumpage has been carefully controlled. The record for the last three years shows the following results for iron and manganese:

1953	Maximum	Oct.	Fe 0.30	July	Mn. 0.10	Minimum	Dec.	Fe 0.04	Mn. 0.05
1954	"	Oct.	Fe 0.28	June	Mn. 0.14	"	Apr.	Fe 0.06	Mn. 0
1955	"	June	Fe 0.32	June	Mn. 0.05	"	Feb.	Fe 0.22	Mn. 0

Water Treatment.

The well waters of Suffolk County are naturally of excellent bacteriological quality and do not ordinarily require treatment to render them safe for drinking. It is of greatest importance to maintain their natural purity in the face of increasing population and industrial expansion. In the past this has been accomplished by the acquisition of protective lands surrounding the wells, by using approved methods of construction and by the enactment of protective rules and regulations. Continuous chlorination is practiced as a factor of safety at a few plants but in most cases the well waters are not chlorinated, however the health department advocates the installation of chlorination equipment for use in emergencies or during periods of excessive demand when distribution pressures fall to low levels.

The well waters in their natural state are corrosive to metals and some form of treatment to inhibit corrosion is desirable. The north shore well waters are somewhat less corrosive than those of the middle of the island and the south shore and in many instances they are used with corrective treatment. The treatments used to inhibit corrosion generally consist of the carefully controlled addition of an alkali such as lime, soda ash or caustic soda. Certain complex poly-phosphates are also used, notably a commercial product called Calgon. Sometimes the treatment combines both methods. The alkali treatments are usually adjusted to produce a predetermined hydrogen ion concentration. If the water to be treated contains iron and/or manganese much in excess of 0.3 p.p.m. the treatment must be designed to avoid precipitation of these substances. The poly-phosphates tend to hold iron and manganese in solution except in hot water.

If the iron and manganese are high enough to cause serious staining and discoloration, treatment for their removal is desirable and often necessary. In such cases aeration or chemical treatment followed by filtration or a system of ion-exchange is used. Iron removal plants are operated at Sag Harbor and Riverhead pumping station No. 1. Treatment plants of this type are expensive to build and to operate. In view of the prevelance of iron in some of the well waters in the eastern parts of the county, it may ultimately be necessary to decide whether to construct iron removal plants or to transport water by pipeline from sources low in iron if such can be found nearby. Local conditions will govern the decision.

There is no economical method of converting sea water to drinking water on a large scale and if wells are badly affected by the sea water intrusion there is no alternative to importing a satisfactory supply except the possibility of spreading a large number of shallow wells over a wide area.

Control of Pollution.

The protection of the quality of the water supplies of Suffolk County from deterioration or destruction by pollution is fully as important as the conservation and allocation of the supplies. Pollution of the water supply sources cannot be permitted.

In another section of this report entitled, "Report on the Possibility of Recovering Sewage to augment the Underground Waters of Suffolk County" (See Appendix D) the writer has described in detail the nature of sewage and industrial wastes and the possible effects of permitting them to mingle with the underground waters of high natural purity. The conception of the provision of protective lands surrounding the wells to guard against incidental local pollution of the underground waters by individual septic tanks and cesspools has been described. The danger involved in the underground disposal of effluents from large scale sewage disposal plants and industrial waste treatment plants has been discussed.

It has been developed that certain chemical wastes are capable of travelling for great distances underground, consequently if their disposal to the ground is permitted, large areas of land in the direction of ground water flow cannot prudently be used for well locations. This means the loss of potential water supply sources. The writer is convinced that the ultimate disposal of sewage and waste effluent from communities and industries should be tidewater and that in planning the development of the county this should be taken into account.

It appears that at the present time the public agency exercising control of pollution on a countywide basis is the County Health Department acting in its own right and also in its capacity as local representative of the State Health Department and the State Water Pollution Control Board. This control is exercised largely by a system of permits whereby all plans for sewage and waste disposal must be approved by this agency. Unfortunately it is possible under this system for an industry to obtain a permit for a certain type of waste disposal system and later change to an entirely different process of manufacture so that the disposal system is no longer capable of handling the new kinds of waste. Of course adequate policing would detect the change, therefore it is important to have an efficient system of inspection and supervision. Industry does not willingly throw away anything of value and it is always willing and anxious to provide ways and means of recovering waste materials. Great progress has been made in the art of industrial waste treatment, but if harmful or undesirable substances are present in the waste and if through ignorance, carelessness or accident they are not removed by the treatment plant and are returned to the ground, widespread and long lasting damage to ground water could and probably would result. Wastes that cannot be treated in such a manner that the treatment plant effluent can be returned to the ground by percolation without damage to the underground waters should be disposed of at sea, or if this is impractical as may be the case with radioactive wastes, they must be stored in a safe manner or permanently removed. A great deal of research is being done in the field of atomic energy and it is hoped that a satisfactory solution to this problem will be forthcoming.

If water supplies are damaged, recourse may be had to the courts and compensation may be obtained but this will not restore the fundamental purity of the water supply nor will it remove the pollution which may

travel for considerable distances with the underground waters.

Conclusions and Recommendations.

This report deals with the quality of the underground waters of Suffolk County. Since the writer has very little information on the deep seated waters the information presented is confined almost entirely to the superficial or glacial formations. It has been shown that with certain exceptions, the wells in these formations yield clear, cool, soft water of great natural purity. The exceptions have to do with wells located in the extreme eastern portions of the county where the iron content may be excessive and salinity may be high due to intrusion of sea water. Iron can be removed by treatment but excessive salinity would be fatal to the wells involved.

The rapid development of the western part of the county and the constant eastward movement of population and industry create serious problems of conservation and protection of water supplies. Conditions in western Suffolk County are already somewhat analagous to those in Nassau County.

From the point of view of water quality the most important consideration is the protection of the water supplies from pollution by sewage and industrial wastes. Throughout this report the writer has taken the position that such pollution cannot be permitted.

It is recommended that the Water Authority continue the policy of acquiring well sites of sufficient size to provide generous protective areas surrounding the wells.

It is recommended that the Water Authority encourage and support the creation of water catchment areas such as public lands, parks, forest reserves, recharge basins and the like.

It is recommended that the Water Authority promote a close liason with health departments, zoning boards, planning commissions and local governmental agencies for the conservation and protection from pollution of the water supply resources of the county. Consideration should be given to the organization of a county water pollution control board and enactment of a sewage and waste disposal ordinance.

It is understood that the Water Authority will construct a laboratory in the near future and will employ competent personnel in this department. At that time it should be possible to make field inspections and make such tests as may be necessary to detect actual or potential pollution of water supply sources and make recommendations for abatement. In this work it will also be important to maintain liason with governmental authorities in order to obtain entry and make inspections of sewage and industrial waste disposal facilities.

(signed) George D. Norcom
Consultant

Dated: November 8, 1956.

CARBON DIOXIDE AND NITRATE ANALYSES
WELLS OF SUFFOLK COUNTY WATER AUTHORITY
SAMPLES COLLECTED AUGUST 30 TO SEPTEMBER 15, 1956.

SAMPLE	WELLS Size	Depth	pH	CO_2 p.p.m.	NO_3 p.p.m.N.
Amityville - Greene Avenue	8"-10"	60'	5.8	23.0	2.04
N.Amityville - Well No. 2	16"	80'	5.9	22.0	0.96
Babylon - Smith St. No. 5	16"	59'	5.7	24.5	2.00
West Babylon - All Wells	8"	58'	5.7	20.5	0.56
North Babylon Well No. 1	16"	70	5.7	18.0	0.52
Bayport - Well No. 3	12"	102'	6.0	12.0	0.20
Bayshore - All Wells	10"	55'	5.6	24.0	2.04
North Bay Shore - Well No. 1	16"	119'	5.8	11.5	0.84
Bellport - Hart Well	20"	49'	6.1	9.5	0.48
Central Islip - Well No. 1	12"	116'	6.1	10.0	0.40
Huntington - Mixed Raw			6.3	18.0	2.20
Huntington - Shallow Wells	8"	40/58	6.1	25.0	2.08
Huntington - Deep Well No. 1	10"	588	6.4	6.0	0.32
Huntington - Centerport	10"	137	6.4	9.0	2.44
Huntington - C.S. Harbor No.1	12"	257	6.2	15.0	0.72
Huntington - C.S. Harbor No.2	12"	308	6.2	14.0	0.40
Huntington - Woodchuck Hollow	16"	513'	6.3	10.0	1.08
Kings Park - Well No. 3	12"	160'	6.0	14.5	1.84
Oakdale - Well No. 2	12"	94'	6.3	18.0	0.28
Port Jefferson - Well No. 3	12"	85'	6.4	7.0	0.16
Smithtown - Well No. 3	12"	162'	6.2	14.5	0.16
Southampton - Well No. 1	12"	85'	5.8	17.0	2.12
Westhampton	8"-10"	50'	6.2	7.0	0.48

REPORT ON QUALITY OF WELL WATERS OF SUFFOLK COUNTY WELLS
OPERATED BY SUFFOLK COUNTY WATER AUTHORITY.
CHEMICAL RESULTS IN PARTS PER MILLION - RAW WELL WATER.

NAME AND LOCATION	DATE OF SAMPLING	SIZE OF WELL	DEPTH OF WELL	TURB-IDITY	COLOR	pH	TOTAL HARDNESS	ALKA-LINITY	IRON	MANGA-NESE	CHLORIDE	COLIFORM BACTERIA IN 10 Ml.	
Amityville (Greene Ave.)	Sept. 1956	8"- 10"	55'- 75'	0	1	5.6	38	16	0.02	0.08(1)	12	0/5	
N. Amityville No. 1	Sept. 1956	16"	88'	0	1	5.8	26	12	0.02	0.25	7	0/5	
N. Amityville No. 2	Sept. 1956	16"	80'	0	1	5.6	26	12	0.04	0.05	7	0/5	
Babylon (Smith Street)	Apr. 1956	10"- 16"	59'	0.1	1	5.8	18	11	0.03(1)	0.25(1)	7	0/10	
North Babylon	Feb. 1956	16"	70'	0.1	1	5.9	20	9	0.02	0	10	0/5	
West Babylon	Feb. 1956	10"	60'	0	1	5.5	20	9	0.14	0	8		
Bayport (Patchogue)	Sept. 1956	12"	102'	0	1	5.9	20	10	0.02	0.15	7	0/5	
Bay Shore	May 1956	14" -10"	55'	0.2	1	5.9	20	14	0.10	0.18	9	0/25	
N. Bay Shore No. 1	May 1956	16"	119'	10	3	6.1	16	7	0.10	0	6	0/5	
Bellport No. 1	May 1956	20"	49'	1	1	6.0	22	10	0	0	8	0/5	
Bellport No. 2 (New)	May 1956			0	0	6.1	26	13	0.03	0	7		
Central Islip	May 1956	12"	116'	0	1	5.8	14	9	0	0	5	0/10	
Islip Test Well Untreated	Sept. 1956			0	0	5.9	18	7	0	0	5	0/10	
Cold Spring Harbor No. 1	Feb. 1956	12"	257'	0	1	6.1	16	8	0.04	0	4	0/10	
Cold Spring Harbor No. 2	Feb. 1956	12"	308'	0	1	6.1	16	9	0.04	0	4	0/10	
Huntington Shallow Wells	Apr. 1956	8"	42'to 60'	0	1	6.3	40	24	0.04	0	9	0/5	
Huntington Deep Well No. 1	July 1956	10"	588'	0	0	6.6	26	25	0	0	6	0/5	
Huntington - Centerport	Apr. 1956	10"	137'	0	0	6.0	20	16	0.04	0	7	0/5	
Kings Park	Feb. 1956	12"	160'	0	0	5.7	20	10	0.14	0	9		
Oakdale Pump Station	Jan. 1956	10"- 16"	70'- 87'	0	0	6.5	26	15	0.10	0	5	0/5	
Port Jefferson Well No. 2	Nov. 1955	12"	90'	0	0	6.5	20	16	0	0	5.8	0/5	
Port Jefferson Well No. 3	Jan. 1956	12"	85'	0	1	6.4	32	17	0	0	23(2)	0/5	
Sag Harbor	Feb. 1956	10"	113	5	12	6.2	20	14	4.8	0.05	10	0/5	Iron Removal Plant.
Smithtown Well No. 2	Sept. 1956	10"	150'	0	1	6.2	20	19	0.04	0	4	0/5	
Southampton Well No. 1	May 1956	12"	85'	0	0	5.9	76	15	0.02	0	19	0/5	
Southampton Well No. 2	May 1956	12"	92'	0	0	5.9	94	11	0	0	22	0/5	
Westhampton	Sept. 1956	8"- 10"	50'	0	1	5.8	18	10	0	0	7	0/5	

Note (1) In June, 1956 a sample from Babylon, Smith St. showed Iron 0.03 Manganese 0.10.
Note (2) In October, 1956 Chloride was 11.

Note: All Analyses By New York Water Service Laboratory, Merrick, New York.

REPORT ON THE QUALITY OF WELL WATERS OF SUFFOLK COUNTY
WELLS OTHER THAN THOSE OPERATED BY SUFFOLK COUNTY WATER AUTHORITY
CHEMICAL RESULTS IN PARTS PER MILLION. RAW WELL WATER.

PLANT DESIG-NATION	NAME AND LOCATION	NAME AND LOCATION	DATE OF SAMPLING	SIZE OF WELL	DEPTH OF WELL	APPROVED OUTPUT G.P.M.	COLOR	TUR-BID-ITY	pH	AMMONIA NITROGEN FREE	AMMONIA NITROGEN ALB.	Nitrite	Nitrate	ALKALINITY Ca CO_3	HARDNESS Ca CO_3	IRON (Fe)	MANGA-NESE (Mn)	CHLORIDE (Cl)
49	Terrace on Sound-Rocky Pt.	on Sound-Rocky Pt.	May 1956	10"	143'	500	45	Tr.	7.0	0.152	0.006	0.001	0.02	6	16	1.3	-	3.2
30	Shinnecock Shores W.C.E. Quoge	ck Shores W.C.E. Quoge	Apr. 1956	2"	25'	200	0	Tr.	5.8	0.002	0.004	0.001	0.16	5	18	0.4	-	13.
45	Sound Shore Club, Wading River	ore Club, Wading River	Apr. 1956	6"	155'	90	15	5	6.1	0.038	0.026	0.004	0.80	9	30	4.0	-	8
71	Sunnyside W. Co. Lake Ronkonkoma	e W. Co. Lake Ronkonkoma	May 1956		151'	250	0	Tr.	6.2	0.008	0.008	0.003	1.8	14	24	0.6	-	5.8
6	Bridgehampton Water Co. # 1	mpton Water Co. # 1	Apr. 1956	6"	100'	250	0	Tr.	5.9	0.014	0.028	0.001	9.0	8	80	0.2	-	24
6	Bridgehampton Water Co. # 2	mpton Water Co. # 2	Apr. 1956	6"	130'	600	0	Tr.	5.9	0.004	0.012	0.001	1.8	6	62	0.1	-	13
46	Sound View Assoc., Stony Creek	ew Assoc., Stony Creek	Apr. 1956	6"	30'	75	5	Tr.	6.3	0.002	0.004	0.001	0.02	8	22	0.26	-	13
G	Hampton Bays, W. District # 2	Bays, W. District # 2	Apr. 1956	8"	30'	150	10	Tr.	5.8	0.012	0.010	0.001	0.30	5	26	0.20	-	50
18	Home Water Co. Easthampton # 2	er Co. Easthampton # 2	Apr. 1956	12"	36'	800	0	Tr.	6.1	0.012	0.030	0.001	1.8	8	24	0.18	-	15.4
18	Home Water Co. Oak View Highway	er Co. Oak View Highway	Apr. 1956	12"	162.5'	500	0	Tr.	6.3	0.002	0.016	0.001	1.3	11	26	0.6	-	14.6
I	Riverhead Dist., P.S. # 1 E. Well	d Dist., P.S. # 1 E. Well	Mar. 1956	8"	90'	500	30	15	6.9	0.044	0.002	0.001	0.04	27	32	2.2	-	5.4
C	Dering Harbor, Shelter Is. # 1	arbor, Shelter Is. # 1	Mar. 1956	10"	19'	300	5	Tr.	6.6	0.006	0.001	0.001	0.4	10	28	0.35	Trace	19.6
C	Dering Harbor, Shelter Is. # 3	arbor, Shelter Is. # 3	Mar. 1956	2"	35'		0	10	6.8	0.004	0.008	0.005	0.16	19	16	2.5	Trace	13.4
F	Village of Greenport # 1	of Greenport # 1	Mar. 1956	Dug	35'	600	5	Tr.	5.6	0.008	0.040	0.002	10.	9	168	1.2	-	83
F	Village of Greenport # 4	of Greenport # 4	Mar. 1956	8"	80'	200	0	Tr.	5.8	0.020	0.034	0.001	8	8	100	0.2	-	30
F	Village of Greenport # 3	of Greenport # 3	Mar. 1956	6"	55'	100	10	5	6.3	0.022	0.058	0.004	0.5	22	124	1.2	-	87
42	N. Shore Water Co., Rocky Pt. # 1	Water Co., Rocky Pt. # 1	May 1956	8"	160'	200	15	5	5.9	0.034	0.002	0.003	0.9	8	16	1.2	-	6.4
42	N. Shore Water Co., Rocky Pt. # 2	Water Co., Rocky Pt. # 2	May 1956	10"	135'	40	0	Tr.	5.9	0.002	0.006	0.001	1.6	6	26	0.15	-	8.2
8	Culross Beach, Rocky Point	Beach, Rocky Point	May 1956	8"	140'	100	5	10	6.3	0.002	0.002	0.001	0.12	9	16	1.0	-	5.8
7	Crystal Brook Park, Mt. Sinai	Brook Park, Mt. Sinai	Apr. 1956	6"	20'	100	15	Tr.	6.9	0.006	0.004	0.002	0.70	21	34	0.6	-	6.6
2	Amagansett Water Co. # 1	tt Water Co. # 1	Mar. 1956	12"	93'	300	0	Tr.	6.2	0.002	0.018	0.001	6.0	12	88	0.2	0*	27
26	Southold North Fork Water Co.	North Fork Water Co.	Mar. 1956	10"	55'	250	0	Tr.	6.4	0.052	0.040	0.002	16.	10	176	1.5	Trace	37
24	Montauk Water Co. # 10	Water Co. # 10	Mar. 1956	6"	135'	350	20	Tr.	7.0	0.014	0.020	0.016	0.64	19	28	0.6	-	42
24	Montauk Water Co. # 14	Water Co. # 14	Mar. 1956	6"	59'	150	0	Tr.	6.4	0.018	0.012	0.001	1.8	12	42	0.12	-	88
17	Cedar Beach Manor # 1	ach Manor # 1	May 1956	6"	120'	50	0	Tr.	7.6	0.002	0.006	0.001	0.4	26	30	0.25	-	5.8
17	Cedar Beach Manor # 2	ach Manor # 2	May 1956	6"	175'	50	0	Tr.	6.1	0.004	0.010	0.002	3.0	11	54	0.20	-	10
32	Reeves Park Beach Co. Riverhead	ark Beach Co. Riverhead	Apr. 1956	6"	152'	20	10	Tr.	6.2	0.134	0.014	0.040	5.0	11	82	0.50	-	16
38	Shelter Island Heights # 1	Island Heights # 1	Mar. 1956	4"	9'	24	0	Tr.	6.4	0.002	0.010	0.001	0.84	22	42	0.15	-	15.6
38	Shelter Island Heights (Capon)	Island Heights (Capon)	Mar. 1956	3"	35'	16	0	Tr.	6.3	0.002	0.012	0.001	1.0	17	32	0.12	-	15.2
38	Shelter Island Heights Beach (Dug)	Island Heights Beach (Dug)	Mar. 1956	3"	17'		0	Tr.	6.0	0.002	0.016	0.001	0.3	13	40	0.25	-	35
W 5	So. Huntington Water Dist. # 2	ington Water Dist. # 2	July 1956	12"	271'	900	1	0	5.9				5.08	22	55	0.02	0	14
W 6	So. Huntington Water Dist. # 3	ington Water Dist. # 3	July 1956	12"	207'	1000	1	0	6.0				2.16	9.5	31	0.06	0	8
W 7	So. Huntington Water Dist. # 4	ington Water Dist. # 4	July 1956	12"	435'	1200	3	0.1	6.1				0.64	10	16	0.18	0	4
W 8	Eastwood Village # 2	Village # 2	July 1956			500	1	0	5.9				0.24	9.5	12	0.02	0	5
W 9	Bridgehampton	mpton	Aug. 1956	6"	90'	200	1	0	6.3				2.56	21	80	0.04	0	21
W 10	Brookhaven National Lab. # 3	en National Lab. # 3	Aug. 1956	12"	76'	750	2	0	6.0				0.52	16	32	0.02	0	9
W 11	Riverhead Water District # 6	d Water District # 6	Aug. 1956	16"	125'	1050	1	0.1	6.5				0.08	39	40	0.08	0	6
W 12	Brentwood Water District # 1	d Water District # 1	Sept 1956	12"	130'		1	0	5.5				1.04	7	20	0.02	0	7
W 13	Northport Water Company	t Water Company	Aug. 1956	-	-	-	1	0	6.1				0.64	16	16	0.02	0	5
W 14	Montauk Beach Water Co. # 14	Beach Water Co. # 14	Aug. 1956	8"	65'	150	2	0.1	5.6				0.68	15	54	0.04	0	130

Note: Designations in the first column not ions in the first column not prefixed by the letter "W" are the same as those used for same plants in the tab d for same plants in the table on the General Map, Plate 2, bound at the end of the report. The chemical ana he report. The chemical analyses in those cases were made by the State Department of Health. Designations p nt of Health. Designations prefixed by the letter "W" are arbitrary numbers, used for a series of analyse used for a series of analyses made in the New York Water Service laboratory at Merrick, on water samples collecte ck, on water samples collected under the direction of Mr. C. A. Niles.

* 8-31-56
Sample used in analyzing for Mn was collected 8-31-56; other analyses for this plant made on sample collected 3-27-56.

APPENDIX D

by

GEORGE D. NORCOM
Consultant

REPORT ON THE POSSIBILITY OF RECOVERING SEWAGE TO AUGMENT THE UNDERGROUND WATERS OF SUFFOLK COUNTY, LONG ISLAND, NEW YORK.

This report on the possibility of recovering sewage to augment the under ground waters of Suffolk County has been prepared at the request of Mt. Thomas H. Wiggin and is intended to accompany his comprehensive report to Suffolk County Water Authority on the water supply resources of the County.

From the aesthetic point of view, it has always been considered desireable, if not mandatory, in developing a water supply for human consumption, to select a source that is not only ample in quantity but also of the highest natural purity. Once such a supply has been obtained every effort is made to safegard its natural purity. Some of our municipalities have been able to do this by outright purchase or control of entire watersheds. In such cases, the degree of water purification required is usually very simple. Others who obtain their supply from rivers, streams or lakes with large contributory populations and industrial installations have been able to utilize these sources of supply as a matter of necessity. In such cases, elaborate methods of water purification are required. The authorities concerned with conservation and with public health are engaged in a never ending fight against stream pollution.

Natural waters are classified according to best usage in the public interest. In the case of surface waters such usage is subject to rather definite designation, but with underground waters, the cases of deliberate or flagrant pollution have been relatively few and in many instances accidental. Nevertheless, it can be safely stated that it is the intention to protect and conserve all suitable underground waters for the best usage as public water supplies. In his book entitled, "The Conservation of Ground Water", (1) Harold E. Thomas argues that the Nassau County Sewerage system is a waste of water and "a step backward in ground water conservation." The writer disagrees with this view as will appear hereinafter.

Sewage Leaching Plants in Nassau County.

I am informed by the Nassau County Health Department that the communities of Hempstead, Garden City, and Mineola with a combined population of about 75,000, formerly operated sewage disposal plants designed to return the effluent directly to the ground. The idea was not to conserve water but to dispose of sewage. The general plan consisted of primary tank treatment with sludge digestion and the application of tank effluent to natural leaching beds without underdrains. Digested sludge was also applied to open beds. As might be expected, nuisance developed from time to time. Contrary to Mr. Thomas's contention that connection of such plants to the county-wide sewer system "appears to represent a step backward", it was in fact, an important improvement to the communities involved from a sanitary standpoint.

Contamination Possible from Sewage Discharged into The Ground.

To the best of our knowledge, there are no instances on Long Island where sewage is returned directly to the aquifer by means of recharge wells. Even in the case of recharge wells for water used in air-conditioning, great care is taken to prevent contamination of the water returned. Health authorities are generally in agreement that recharge of underground waters with sewage by this method is hazardous in the present state of our knowledge, regardless of the degree of purification of the sewage. It must be borne in mind that in addition to the common bacteria and simple chemical substances known to be normally present in sewage, any of the following contaminants may also be present: pathogenic bacteria of cholera, typhoid, dysentery, anthrax, virus of influenza, poliomyelitis, yellow fever, infectious jaundice, foot and mouth disease, protozoa of amoebic dysentery, ringworm, tape worm, hook-worm, etc.

Sewage and waste water may also contain salts of the following objectionable or poisonous soluble chemical substances: lead, boron, chromium, cadmium, fluorine, arsenic, selenium, cyanide and radio active materials, detergents and any of a host of organic substances. (2)

It is unlikely that any of these contaminants would be detected if present in small amounts by any of the methods of examination ordinarily used in routine water analysis. As previously stated, completely soluble substances, unless altered by chemical reaction, travel with the ground water interminably, like common salt.

Individual Septic Tanks and Cesspools.

Health authorities on Long Island seem to be agreed that the use of individual septic tanks and cesspools with shallow underground dispersion represents the least objectionable method of disposal to the ground of water borne sewage in rural communities and developments. An extreme example of this is in Levittown and an adjacent development in Nassau County where I am informed some 30,000 homes utilize this system of sewage disposal. The public water supply is obtained from five pairs of wells, one superficial and one Magothy in each pair. The shallow wells contained nitrate nitrogen in excess of 10 p.p.m. when drilled and this is reduced by dilution with the deeper water. I am informed that the bacteriological quality of these wells has continued to be excellent.

Progressive Changes in Sewage Disposal.

The development of sewage disposal on Long Island has followed the normal pattern. In Brooklyn and Queens the primitive privy was doubtless replaced by the cesspool and septic tank at the advent of public water supply and these were gradually abandoned when a public sewerage system became available. The transition is now taking place in Nassau and in some cases in Suffolk and will of course, continue to move eastward with the growth of population and industry. Unquestionably the seepage from individual cesspools and septic tanks percolate downward through the superficial formations of sand and gravel and some of it must eventually reach the underground water. Recovery of usable water obtained under these conditions may be termed incidental recovery as contrasted with planned recovery. Water thus recovered is obtained by the widest possible spreading in small amounts and should not be confused with a deliberate plan to retuen sewage to the aquifer in large volume spread over a limited area.

Experience at Flatbush, Brooklyn, New York.

In this connection it is interesting to consider the water supply of the old Flatbush Water Company formerly serving a densely populated section of Brooklyn. It was later operated by New York Water Service Corporation during the period from 1928 to 1947 and Mr. Wiggin and the writer were connected with its operation, until it was taken over by the City of New York and the wells were abandoned. During the period of operation by New York Water Service Corporation the quantity of water supplied averaged about 26 M.G.D. Originally most of this supply was obtained from relatively shallow wells approximately 80 to 150 feet deep but during this operation a number of wells were drilled to depths of 250-425 feet. In the beginning these deep wells yielded large volumes of water of excellent quality but intrusion of sea water into the formation ultimately ruined most of them. Saline water also reached a number of shallow wells.

The intrusion of sea water into the formation rendered the chloride content of these well waters unreliable as a measure of the possible admixture of percolation of water of sewage origin. It is of record in the New York City Water Department that the original normal chloride content of these underground waters was about 5 p.p.m. It is a fact that some of the shallow wells continued to yield water with a chloride of about 30-40 p.p.m. for many years. When the salt water intrusion reached these wells the chloride rose sharply. The nitrate content of these well waters is the best indication of the possible percolation of water of sewage origin into the shallow well formation. It will be noted from the appended tabulation of water analysis, that shallow wells numbers 1 to 16 show a nitrate nitrogen content of 5 to 27 p.p.m. N.

During the entire period of operation under discussion all of the wells and the distribution system were subjected to frequent sampling and analysis by the laboratory of the Company and by the Mt. Prospect Laboratory of the Department of Water Supply, Gas and Electricity of the City of New York. Samples were also collected and examined by the City Health Department. All of the results indicated the water supply to be of satisfactory bacteriological quality. Chlorine was applied at a number of the sources of supply either to remove hydrogen sulphide or as a precautionary treatment for bacteria.

In concluding these remarks on Flatbush, it must be understood that there is no direct proof that the unusual characteristics of this water supply were actually due to percolation of sewage. During the period under discussion and for many years prior to it, the entire area was completely sewered with discharge to tidewater.

Long Travel of Industrial Wastes on Long Island.

In the case of industrial waste disposal in the United States, there have been a number of instances where improperly Surified wastes have been returned to the ground by means of diffusion wells, seepage pits, leaching basins and the like. Such practices have resulted in many cases of contamination of the underground waters. Two cases in point occurred within the past five years on Long Island, (3), (4), when it was found that anodizing wastes from aircraft manufacturing plants had contaminated the underground waters in the vicinity with objectionable quantities of chromium and cadmium compounds. Subsequent studies developed the fact

that these substances persisted in the ground water for distances of 3000 to 3500 feet in the direction of flow of the ground water and in a strip 700 to 1000 feet in width. Fortunately, no public water supply wells were located in the affected area. The source of the trouble was corrected by the installation of plants for the removal or recovery of the offending substances.

Brief Review of Recent Reports on Research in Sewage Utilization.

The recovery of usable water from waste water is a live topic and the literature on the subject is so voluminous that a complete review is beyond the scope of this report and the facilities available.

On the subject of the reclamation and use of water from sewage by the Joint Committee of the Sanitary Engineering Division and Irrigation Division, American Society of Civil Engineers (5), the following statement appears on page 1659:

> "In some cases, water reclaimed from sewage is adaptable for industrial and irrigational usage. There are no known instances in the civilized world where a direct reclamation of water from sewage is used to supplement a domestic (water) supply, although there are many underground strata which receive some measure of repletion from the drainage of cesspools and from rivers carrying the discharge of sewage treatment plants, and otherwise. It is also a fact thay many grossly sewage polluted streams are used as raw water supplies of cities in the United States and other countries, (however) this report is confined to direct reclamation or re-use of products from sewage; further discussion will therefore relate to the use of reclaimed sewage for industrial and irrigation purposes."

With regard to public health considerations the report has this to say. Page 1652.

> "The utilization of products salvaged from domestic sewage should be with a full realization of the public health significance of such use. The potential health hazards incident to the utilization of salvaged products will, to a varying degree, modify their usage. Standards for the use of sewage and its by-products promulgated by health authorities afford the best criteria in this field---."

Outstanding research work on waste water reclamation and the travel of pollution in underground formations has been carried out by the Sanitary Engineering Laboratory of the University of California in studies sponsored by the State Water Pollution Control Board, Sacramento, California. These studies are too detailed and voluminous for comprehensive review in this report.

In the reports of these investigations the term "bacteriologically safe water" and the term chemically "satisfactory" are used to mean that the bacteriological and chemical quality of the water under discussion meets the requirements of the United States Public Health Service Standards. It should be borne in mind that these standards do not attempt to establish limits for all substances that may be harmful to man.

A bulletin entitled, "Field Investigation of Waste Water Reclamation in relation to Ground Water Pollution" (6), described a field investigation of the recharge of underground water by spreading basins. The site for the study was selected adjacent to the sewage treatment plant in the City of Lodi, California. Eight circular spreading basins were constructed with sheet metal dykes. Four of the basins were equipped with sampling facilities so that samples of the percolating liquid could be colledted for bacteriological and chemical analysis at 1,2,4,7,10 and 13 feet below the ground surface. Spreading was studied with three liquids: fresh water, sewage treatment plant final effluent having a B.O.D. of about 10 p.p.m. and settled sewage with a B.O.D of about 100 p.p.m. Some of the principal conclusions are summarized as follows:

"1. A bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid passes through at least four feet of soil.

2. A water of satisfactory chemical quality can be produced from settled sewage or from final effluent, providing high concentrations of undesirable industrial wastes are not included in raw sewage.

3. A highly treated sewage plant effluent must be used for spreading in order to obtain high rates of percolation."

Further investigation of sewage percolation in different soils is needed in order to generalize the conclusions reached with Hanford dry sandy loam.

"Chlorides can be used as an indicator in measuring the suitability of sewage water for re-use. The data show that during the process of water utilization and sewage production the chloride ion concentration increased from 32 to roughly 70 p.p.m. an increase of 38 p.p.m. Employing this figure of chloride increase per cycle of water, at least five cycles would be possible before the concentration reached 250 p.p.m. which is set for the upper limit of chlorides by the standards of the United States Public Health Service. This reuse would be possible even if no dilution were obtained from the ground water."

"In the reclamation of domestic sewage it is possible that an unsatisfactory drinking water would be produced if there were no dilution by ground water. This would result from high nitrate concentrations. Nitrate ion concentrations greater than 10 p.p.m. are generally considered unsatisfactory since nitrates are held to be responsible for infant methymoglobinema." (Commonly known as blue babies).

Publication No. 11 entitled, "Report on the Investigation of Travel of Pollution" (7), describes a 44 month field investigation of the travel of pollution from direct recharge into underground formations. The principal objectives of the work concerned the rate and extent of travel of bacterial pollutants, and the physical problems involved in recharging an aquifer with waste water.

The introduction to this bulletin contains an excellent summary of existing knowledge on the travel of pollution with ground water movement and cites the references on the subject. Space does not permit the inclusion of all of these data in the report. Various observers report confirmed instances of the travel of coliform organisma with ground water through distances of 10 to 232 feet. Uranine dye travelled 450 feet under similar conditions. Chemicals travel farther and faster than bacteria in the ground water.

The experiments described in Publication 11 were conducted at the Engineering Field Station of the University of California in Richmond, California. A well field consisting of a 12 inch gravel packed racharge well and twenty three 6 inch observation wells was developed. The wells penetrated a confined aquifer approximately 5 feet in thickness and overlain by some 90 feet of clay interspersed with thin sand strata. Equipment was provided for supplying primary settled sewage and fresh water in various combinations for injection into the aquifer at various rates, and for redeveloping the recharge well by pumping. The rate of recharge and the rate and extent of travel of bacteria and the movement of chemicals were observed and traced within the limits of the well field. The nature of well clogging and methods of well development were studied.

It was found possible to recharge relatively shallow aquifers with water or sewage under pressure provided the aquifer is overlain by tight soil or other sound strata. A normal type of gravel packed well is suitable for recharge. Injected water or sewage showed a tendency to flow more rapidly in the direction of normal ground water movement. The maximum concentration of coliform organisms at the observation wells showing contamination occurs after injection of sewage begins, then decreases as clogging of the aquifer develops in the vicinity of the recharge well screen. High concentrations of coliform organisms injected over significant periods of time produced peak bacterial numbers on the order of 23 per 100 ml. at a maximum distance of 100 feet in the direction of normal ground water movement. Similar maxima in other directions were observed at distances of 50 feet and 63 feet. Chemical analysis indicated that a mixture of previously injected fresh water and sewage often existed at the most distant observation wells (463 feet south). The continued absence of coliform organisms in these wells is added evidence of the limited distance of bacterial travel.

Attitude of Public Health Authorities.

In reply to a recent inquiry, the writer has received a communication concerning the possibility of returning purified sewage to underground aquifers from Mr. E.A. Reinke, Chief, Bureau of Sanitary Engineering of the Department of Health of California. He states that there have been two such installations in California. One of them is no longer in operation. The one still in use is at Calwa, a small community. Here the effluent from treatment works consisting of Imhoff tanks, contact filter and chlorinator is discharged to a series of lagoons. Excess water is disposed of by pumping into deep wells. For many years samples of the effluent were tested and results were satisfactory. Analysis of water from wells 1200 feet away always showed absence of contamination. He states further that at two other places, Fresno and Atwater, there are sewage disposal projects that include spreading of sewage effluent on land and underdraining this land by pumping from deep wells. The testing of water pumped from these wells generally have not disclosed any coliform

organisims. Mr. Reinke states that it is a matter of conjecture whether of not the State Board of Public Health will permit any further direct discharge of sewage effluent into the underground. He feels that any new proposal for such disposal would be scrutinized very carefully.

In reply to a similar inquiry to the Department of Health of the State of New York, the writer has received a private communication from Mr. Earl Devendorf, Director, Bureau of Environmental Sanitation. His reply is quoted in full and is reproduced by permission of the writer.

> "I have your letter of March 3, 1956 inquiring as to our attitude toward the return of highly purified sewage effluent to the underground waters of Long Island in order to augment the natural ground water.
>
> While we have no fixed opinion concerning such a proposal and have given no thought to it, our reaction, like yours, is unfavorable both from and aesthetic and technical point of view.
>
> There have been on Long Island hundreds of installations made which return sewage effluent to ground waters as, for example the hundreds of cesspools, etc. which have been constructed to serve private homes. However, none of these installations have been made for the purpose of augmenting the ground water supply but simply as a means of providing for disposal of sewage.
>
> In past years some municipal sewage treatment plants were constructed utilizing seepage beds as the ultimate means of disposal but the experience with these was in some instances quite troublesome and these have been abandoned and connections made to the Nassau County trunk sewer system.
>
> In time, if future circumstances and the growth of Long Island, make it necessary, consideration may have to be given to some plan for the salvaging of sewage effluent. However, I think any plan for development of recharge basins or seepage beds for sewage effluents should be about the last resort. In the meantime, in particular locations the use of subsurface methods for sewage disposal is justified and in many cases the only method by which the sewage disposal problems may be solved."
>
> (Signed) Earl Devendorf

Conclusion:

The statements of Mr. Reinke and Mr. Devendorf form a fitting conclusion to this report. If planned recovery of purified sewage is ever considered necessary as a last resort to augment the underground sources of water supply or to create a barrier against sea water intrusion, a very thorough investigation should be made under conditions existing in Sufflok County to determine the methods to be used and the hazards involved. It is quite certain that complete treatment should be required before any sewage or industrial waste effluent is disposed by spreading on the surface of the ground. It appears equally certain that the return of any sewage or industrial waste effluent direct to the aquifer by wells, pipes or other means should not be permitted. It is important

that provision be made for the disposal of sewage sludge in such manner as will not be detrimental to any water supply. Finally, whenever there is evidence of continued failure to dispose of sewage or industrial wastes in a satisfactory manner by use of cesspools or septic tanks, or by surface spreading without contamination of the underground waters, the law should require the construction of suitable facilities for the collection, treatment, and discharge of all such sewage and/or industrial wastes to the sea.

Specific References.

1. The Conservation of Ground Water, Harold E. Thomas. McGraw-Hill Book Co. Inc. 1951.
2. Studies of Waste Water Reclamation and Utilization. State Water Pollution Control Board (Cal.) Publication No. 9 (1954).
3. Davids & Lieber - Water & Sewage Works, Dec., 1951.
4. Lieber & Welsch - Jr. A.W.W.A. June, 1954.
5. Salvage of Sewage - Report of Joint Committee-Trans.A.S.C.E. 107 (1942) 1652.
6. State Water Pollution Control Board, Sacramento, Cal. Pub. No. 6 (1953).
7. State Water Pollution Control Board, Sacramento, Cal. Pub. No. 11 (1954).

General References.

Classification and Standards of Quality and Purity for Waters of New York State - New York Water Pollution Control Board. 1950.

Engineering Report on the Water Supplies of Long Island by Russell Suter, Water Power & Control Comm. New York Bull. GW-2 1937.

Underground Movement of Bacterial and Chemical Pollutants Butler, Orlob & McGauhey. Jr. A.W.W.A. 46: 97 (Feb. 1954).

Development of a Fresh Water Barrier in Southern California etc. Laverty & Van der Groot. Jr. A.W.W.A. 47; 886 (Sept. 1955).

Studies in Water Reclamation - University of California, Tech. Bull. #13 (1955).

Reclamation of Sewage Water - Greenberg & Gotaas. Am. J.P.H. 42: 401 (1952).

Supplement 1

A. Communities in Suffolk County which have public sewerage systems and sewerage disposal plants discharging effluent to tidewater.

Village of Greenport	Village of Northport
Riverhead Sewer District	Port Jefferson Sewer District
Village of Patchogue	Huntington Sewer District
Village of Ocean Beach (Fire Island)	

B. Principal villages, districts, communities, institutions and industries discharging sewage and/or industrial wastes into the ground in Suffolk County by the general method of septic tanks and leaching cesspools.

State Institutions:

Central Islip Hospital	8,775 population
Pilgrim State Hospital	12,500 patients 2,000 employees (875 live on premises).
Edgewood (PSH)	1,600 patients 500 employees (250 live on premises).
Long Island Home	400 population

Hospitals:

South Side Hospital	400 Brookhaven Memorial Hospital 175
Mather Memorial Hospital	79 beds 210 staff (including part time).

Industries:

Grumman Aircraft, Calverton	5,000
Fairchild-Engine Division	3,500 Fairchild Stratos-Division 1300

Note: The above information was furnished by H.W. Davids, P.E., Director of Environmental Sanitation, Suffolk County Department of Health, Riverhead, New York.

Supplement 2

Tabulation of Results of Analysis of Wells of the former Flatbush plant of New York Water Service Corporation, Brooklyn, New York for the month of May, 1945. (From the Monthly Laboratory Report of Department of Water Supply, Gas and Electricity, City of New York by F.E. Hale, Director of Laboratories).

Well No.	Temp. (Fahr.)	Turb.	Color	Odor	Nitrogen in Ammonia Alb.	Nitrogen in Ammonia Free	Nitrogen in Nitrite	Nitrogen in Nitrate	Cl.	Hardness	Alk.	Iron	Bact. per ml.	Coli 10 ml.
1	56	0	1	0	.036	.028	.003	6	756	828	156	0.15	0	0
3	55	0	0	0	.056	.092	.011	8.8	600	855	198	0.10	0	0
4		0	0	0	.048	.160	.007	9.6	126	283	76	0.05	0	0
6		0	0	0	.060	.100	.018	12	30	276	97	.00	0	0
7		0	0	0	.049	.060	.024	16	33	270	160	.00	0	0
8	54	1	1	0	.044	.240	.009	8	718	846	176	.10	0	0
12	56	0	0	0	.036	.040	.003	8.4	515	563	155	.10	0	0
14		0	0	0	.069	.036	.009	6.4	250	429	181	.00	0	0
16		0	0	0	.048	.088	.009	27.	58	357	157	.15	0	0
17		0	0	0	.058	.560	.002	0.4	48	196	109	.10	0	0
19		0	0	0	.048	.420	.002	.2	238	303	104	.10	0	0
20		0	0	0	.088	.144	.003	4.2	880	965	112	.05	0	0
22		0	2	0	.036	.168	.001	2.2	456	562	107	.40	0	0
24		4	1	0	.080	.460	.060	1.0	31	422	89	.45	0	0
26-31		2	1	0	.250	1.7	.024	0.2	160	351	160	.60	0	0
27		0	0	0	.040	.064	.000	11.2	40	337	150	.05	0	0
30	56	0	0	0	.024	.140	.005	8.8	940	761	160	.10	0	0
32-33-34	56	0	0	0	.024	.028	.020	10.4	34	329	173	.10	0	0
36		0	0	0	.060	.112	.000	4.8	26	263	129	.05	0	0
37		0	0	0	.048	.209	.012	6.6	24	296	218	.05	0	0
39	55	0	0	0	.016	.028	.004	7.2	24	364	240	.20	0	0
40		0	0	0	.084	.080	.060	9.6	44	270	94	.05	0	0
41		1	0	0	.060	.052	.001	10.4	50	337	177	.00	0	0
42		0	0	0	.064	.060	.005	8.6	122	323	153	.00	0	0
43		0	3	0	.070	.240	-	9.6	18	213	66	.10	0	0

Chemical Results in parts per million.

APPENDIX E

STATISTICS OF PUBLIC WATER SUPPLIES IN SUFFOLK COUNTY N.Y.

By Charles A. Niles

This appendix, undertaken at the request of Mr. Wiggin, author the main report, consists essentially of a several page table giving the principal facts as to territory and population served, wells and other main items of plant, chemical analyses of water and in some cases treatment given to improve the water of public water supply plants under the various ownerships, viz., the Suffolk County Water Authority, municipalities, water districts and private persons or companies. These plants are shown in location are listed on the large map bound at the end of the main report.

The compilation of the statistical data is the result of search of existing records and extended personal investigations of these plants.

Each state or county supervisory or controlling agency has certain original and yearly records as may be reported to them concerning the first installations and yearly operation of these plants. The larger municipal and privately-owned plants do keep reports but many of the smaller ones do not have complete records.

The basic information, such as identification numbers of the wells, original construction, well capacities and yearly pumping were obtained by employment, by permission, on Saturdays and overtime hours of members of the staffs of the Water Power and Control Commission and Public Service Commission. The Suffolk County Department of Health also permitted examination of its records. A member of its staff was employed on Saturdays and overtime hours to secure information on prepared forms from many of the plants, and also collected water samples for chemical analysis through the cooperation of the Suffolk County Department of Health.

Reports of water analyses of all of the Suffolk County Water Authority plants as well as of some other county systems were supplied by the laboratory of the New York Water Service Corporation at Merrick, which makes the water analyses for the Suffolk County Water Authority.

The statistical table shows that on the mainland of Suffolk County, the wells are generally in the Glacial formation, also that, by constructing deep wells into the Magothy formation, water for public supplies may be obtained on the barrier beaches.

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 1

SUFFOLK COUNTY WATER AUTHORITY PLANTS	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C	T	O	TREATMENT
											G — Glacial; M — Magothy; L — Lloyd							C — Color; T — Turbidity; O — Odor									
Amityville Plant	T	Village of Amityville	1892	4359	4215	16,500	162.21	262.37	72.89	Greene Avenue	S1326G To S1330G	10	55-74	6-10	15-21	300 600 1000	S.P. 300,000	.02	.08	12	38	6	5.6	1			Soda Ash, Lime Chlorine
		North Amityville							293.02	North Amityville	S12016G	16	85	16	27	750		.02	.25	7	26	12	5.8	1			
		Copiague								" "	S14218G	16	85	16	31	750		.04	.05	7	26	12	5.6	1			
		Amity Harbor W.D.	1942	See Plant "A"	under Municipally Owned					" "	S15499G	Proposed Well				750											
Babylon Plant	Q	Village of Babylon	1892	8500	8154	31,500	406.73	458.23	598.2	Smith Street	S4830G	10	51	10	20		E.T. 300,000	Raw .19	.15	7.5	19	10.5	5.9	2	.1		Caustic Soda
		North Babylon								" "	S4831G	10	50	10	20	650		Treated .18	.15	9.0	26	48	7.3	1	.5		
		West Babylon							(312.0)	" "	S13477G	10	60	10	23												
		Deer Park								" "	S13478G	10	60	10	26												
		Village of Lindenhurst								" "	S10641G	16	58	16	21	700											
										West Babylon	S1350G	6	58	6	16												Lime
									(243.64)	" "	S1660G To S1664G	8	47-63	8	16	800											
										" "	S14975G S14976G	Proposed Wells															
									(42.60)	Belmont Road North Babylon	S12710G	16	70	16	28	1000		.02	0	9.0	22	8.0	5.8				
										Sawyer Ave. West Babylon	S15505G	Proposed Well															
Bay Shore Plant	R	Bay Shore	1890	12900	12200	45,200	922.03	1,031.2	479.4	Fifth Avenue Bay Shore	S1692G	10	48	10	20		S.P. 358,000	0.08	0.30	9.0	70.0	46.0	6.3	2	2	0	Lime Chlorine
		North Bay Shore									S1693G	10	66	10	20		E.T. 200,000										
		West Islip									S4015G	10	60	10	20		E.T. 500,000										
		East Islip									S4017G	10	60	10 10	20 20		E.T. 500,000 (1956)										
		Central Islip									S4020G	10	61	10	20	2800		0	0	5.0	18.0	7.0	5.9	0	0		
		Islip Terrace									S4022G	10	58	10	20												
		Oakdale (Part of)									S8321G To S8323GG	10	55-60	10	20												
		Islip Manor									S9904G	10	56	10	20												
											S9905G	10	54	10	26												
											S12141G	10	58	8	25												
											S12142G	10	58	10	26												
										Central Islip	S1243G	12	117	12	40	700		0	0	5.0	18.0	7.0	59	0	0		Lime
											S13558G	12	116	12	38	700											
										North Bay Shore	S13534G	16	126	16	31	900		0	0	5.0	20.0	9.0	5.8	1	0	0	Lime
										Oakdale	S3813G	10	83	10	23	400		0	0	5.0	26.0	17.0	6.4	1	0	0	Lime
											S3814G	24-16	90	16		675											
											S3815G	12	71	12	21	540											

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 2

SUFFOLK COUNTY WATER AUTHORITY PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES SUMMER	SERVICES WINTER	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	DATE FIRST SUPPLY	SERVICES SUMMER	SERVICES WINTER	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	1954	1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C (C — Color; T — Turbidity; O — Odor)	T	O	TREATMENT
Huntington Plant	U	Huntington	1891	8700	8100	32,200	783.9	1891	8700	8100	32,200	783.9	810.1	241.2G	Mill Street	S1301G To S1312G 7 Active	8	55 To 60	8	20 To 26		3 E.T. - 275,000 Each	0.02	0	7.0	28.0	25.0	6.3	1	0		Chlorine, Mill Street
		Huntington Station												60.30L	" "	S12137G To S12140G					1400	E.T. - 300,000											
		Cold Spring Harbor													" "	S18L	10	580	8	100		G.R. - 285,000											
		Centerport													" "	S1313L	10	570	8	100													
		Helesite													" "	S14613G																	
		Village of Huntington Bay		350	Included in above				350	Included in above				255.5G	Centerport	S874G	12	137	12	30	700		0	0	9.0	36.0	19.0	6.4					
		Village of Lloyd Harbor		220					220					457.6M	Cold Spring Harbor	S9279M	12	254	12	37	700		0.32	0	5.0	17.0	11.0	6.1					
															" " "	S12130M	12	308	12	39	700		0.02	0	5.0	16.0	10.0	5.9					
														New Well	Woodchuck Hollow	S14828M	16-12	506	10	85'- in 3 sec-tions	1000		0	0	6.0	24.0	10.0	6.1					
Kings Park Plant	W	Kings Park	1925	1180	1180	4,400		1925	1180	1180	4,400			70.24M	Kings Park	S51M	8	548	8		100	E.T. 250,000	.04	0	13.0	36.0	47	7.2				Soda Ash
	M	Smithtown Water Dist.				See under "Municipal Owned"					See under "Municipal Owned"					S3800G S13248G	12 12	162 164	12	25	200 350												
Patchogue Plant	S	Village of Bellport	1890	7640	7390	28,270	315.33	1890	7640	7390	28,270	315.33	320.11	376.4	Bellport	S1331G	13ft.	31			600		.04	0	7.0	22.0	11.0	5.9					
		East Patchogue													"	S1470G	16	120			1000												
		North Pathogue												(119.9)	Patchogue	S374G						E.T. 215,000											
		Village of Patchogue													"	S92M	10	180			2000	E.T. 500,000											
		Blue Point													"	S3980G To S4002G	8-12	45-60															
		Bayport												(256.6)	Bay Port	S871G	16	106	14	40	700		Raw .02	0.15	7.0	20	10	5.9	1				Lime-Bayport Plant
		Sayville													"	S872G	16	107	14	40	700		Treated .04	0.2	7.0	36	25	7.5					
		Bohemia													"	S9893G	12	102	40	12	700												
		West Sayville																				E.T. 230,000											
		Part of Oakdale																															
Port Jefferson Plant	X	Port Jefferson	1898	1764	1738	6,500	189.0	1898	1764	1738	6,500	189.0	202.9	243.42	No. 1 Port Jefferson	S4372G	12	90	12	27	500	G.R. 250,000			7.0	22	19	6.4	0	0	0	
		Port Jefferson Station													No. 2	S8439G	12	94	12	24	500	S.P. 115,000											
		Terryville													No. 3	S1336G	8	98	8	26	500												
		Village of Poquott														Proposed S14792M	36-16-12	450	12		700												
		East Setaucket																															
	O	Stony Brook, W.D.				See under "Municipal					See under "Municipally Owned"																						
	AA	East Hills, W.D.				See under "Municipal					See under "Municipally Owned"																						

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 3

SUFFOLK COUNTY WATER AUTHORITY PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C (Color)	T (Turbidity)	O (Odor)	TREATMENT
											G — Glacial; M — Magothy; L — Lloyd																
Sag Harbor Plant	V	Village of Sag Harbor	1889	774	713	2860	62.69	59.69	61.52	Sag Harbor	S184G	10	137	8	31	300	S.P. 235,000	Raw 5.2					5.9				Aeration, Alum, Lime
		Part of Village of North Haven									S501G	6	55	6		300		Treated .08					8.2				Filtration, Chlorine
Smithtown Plant	W	Village of the Branch		777	770	2875	89.3	108.0	106.16	Smithtown Branch	S65G	10	155	10		300	S.P. 330,000	.08	0	5.0	21	21	6.2	2			Chlorine
		Smithtown Branch									S1337G	10	142	10		150											
	K	St. James W.D.			See under "Municipally Owned"						S11810G	12	164	27	12	450											
Southampton Plant	Y	Village of Southampton	1894	1580	1430	5900	122.4	123.93	141.74	Southampton	S1340G	16 / 12	87	12		450	E.T. 300,000	0	19.0	76	14	5.9					Soda Ash
											S1341G	12	99	12	23	400			21.0	104	13	5.9					
Westhampton Plant	P	Village of Westhampton Beach	1903	1395	1044	5000	144.47	163.60	155.34	Westhampton	S1345G	8	46	8		1400	S.P. 235,000	Raw .04	0	8.0	14	6.1					Lime
		Westhampton									S1347G	8	46	8				Treated .04	0	8.0	31	23	7.0				
		Village of Quogue									S4038G	8	32	8													
		Quogue									S4042G	8	48	8													
		Suffolk Air Base									S4043G	8	46	8													
											S7383G	10	47	10	20												
											S10328G	10	47	10	20												
											S10733G	10	58	10	20												
											S12702G	10	56	12	20												
MUNICIPALLY OWNED PLANTS																											
Amity Harbor W.D.	A	Amity Harbor W.D.	1942	280	240	1000	1.09	1.31	1.59	Served by S.C.W.A., Amityville Plant																	Soda Ash, Lime, Chlorine
Brentwood W.D.	B	Brentwood W.D.	1935	1000	1000	3700	35.27	36.37	78.75	Brentwood	S619 / S62G	12	130	12	30	480	E.T. 300,000	.02	0	7.0	20.0	7.0	6.1	1			
Dering Harbor, Village	C	Village of Dering Harbor	1890	30	2	125	2.5	6.0	2.12	Dering Harbor	S177G	10	71	8	17	260	E.T. 50,000	0.35		19.6	28.0	10	6.6	5	TR	1	Calgon
											S4050G	8	60	10	15	300	S.P. 100,000										
											S4051G To S4056G	2	32			9											
Dix Hills W.D.	Z	Water District	1954	300	300	1000			4.24	Water District	S203M	10	269	10	20	350	E.T. 500,000	0.40		10.0	34.0	6.0	5.8	0	TR	2	
East Farmingdale W.D.	D	East Farmingdale	1917	790	790	2750				Supplied by Village of Farmingdale Nassau County								1.0		5.4	10	5.0	5.5	7	10	1	
East Hills W.D.	AA	Water District	1954	29	29	100			.50	Supplied by S.C.W.A., Port Jefferson Plant																	
Greenlawn W.D.	E	Greenlawn	1928	3500	3700	10500	158.1	161.1	166.1	No. 1	S31M		202		30	450	S.P. 360,000	.03		4.8	8.0	5.0	6.3	0	TR	1	
		South Greenlawn								No. 2	S5068M	20 / 12	188	37	12	600	E.T. 500,000	.03		6.0	20.0	4.0	6.2	0	TR	1	
		Elwood								No. 3	S11803M		217			700		.10		7.4	34.0	11.0	7.0	0	TR	1	
		Laurel Hill								No. 4	S14521M		546			1500											
		Commack									S14579M	New Well															
Greenport Village	F	Greenport Village	1899	967	877	3600	148.5	161.4	166.1	No. 1 Moores Lane	S1668G	9ft.	35	Dug Well		50	E.T. 300,000	.05	.4	60	162	46	6.5	1	.3		
										" " "	S1669G	16.5ft.	35	"	"	200		.05	.05	92	200	20	6.3	1	.5		
										No. 2 Moores Lane	S1670G	15ft.	35	"	"	400											
										" " "	S1671G	6ft.	48	4	10												
										" " "	S1672G	6ft.	46	4	10												
										" " "	N3978G	6ft.	30	4	10												
										No. 3 Moores Lane	S1673G To S1678G		51.1 To 56.5		44.5 To 56.5	600		.15	.20	127	112	16	5.9	2	1.2		
										No. 4 East Marion	S3697G	8	80	8	16	200		.10	.05	34.9	115	10	5.9	2	1.5		
										" " "	S3698G	8	80.5	8	15.5	200		.05	.05	30.0	87	12	6.1	2	.8		

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 5

PRIVATELY OWNED PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C	T	O	TREATMENT
											(G — Glacial; M — Magothy; L — Lloyd)													(C — Color; T — Turbidity; O — Odor)			
Daniel Bohan	4	Subdivision	1952	35	0	130	1.0	1.0	1.0	No. 1	S9937M	6	275	6		60	H.T. 000										
Daniel Bohan	5	Subdivision	1953	51	0	200	1.0	1.0	1.0	No. 1	S143M		272			45	H.T. 5000										
										No. 2	S14678M		376			40											
Blue Point Community Assoc.	64	Association Boundaries	1951	55	10	220			3.0	No. 1	S9482M	6-4	260	4	10	28	H.T. 1000										
Bridgehampton Water Co.	6	Bridgehampton	1902	450	400	1700	22.3	24.9	24.4	No. 1	S9470G	6	90	6	20	200	H.T. 7,500	.04		21.0	80	21	6.3				
										No. 2	S1666G	6	130	6	20	500		.10		18.0	62	6	5.9				
										No. 2	S1667G	6	130	6	20	500											
Commack Water Co.	50		1953		Will be supplied by Northport Water Works Co.																						
Corrack Water Service Corp.	68				Will be supplied by Northport Water Works Co.																						
Crystal Brook Park Assoc.	7	Association Area	1928	26		90	0.51	0.51	0.51	No. 1	S4632G	6	20	2.5		57	E.T. 11,000	.60		6.6	34	21	6.9	15	TR	1	
Culross Corp.	8	Culross Beach	1927	52	10	200	2.13	2.13	2.13	No. 1	S5401G	8	140	6		100											
										No. 1 New Well	S14612G	8	140	6	10	200											
Davis Park Water Work Co.	11	Davis Park	1951	100		400	0.75	1.75	1.75	No. 1	S9349M	4	340	4	10	10	H.T. 6000										
Dawn Estates	9	Captain Kidd Estates	1949	76	5	300	4.9	13.3	14.2	No. 1	S6513G	8	110	8	11	200	H.T. 10,000										
Deer Lake Water Co.	10	Greenwood Manor	1952	328	328	1200	25.8	26.0	45.7	No. 1	S10105G	10	59	10	13	240	H.T. 15,000	1.0		10.4	46	28	6.0	5	TR	2	
										No. 1	S10106G	10	59	10	13	240											
Eastwood Waterworks, Inc.	12	Eastwood Village	1954	550	550	2000		4.0	25.0	No. 1	S11768G	12	95	12	22	500	H.T. 2-15,000	.02		5.0	12	9.5	5.9	1			
		Dawn Estates								No. 2	S12457G	12	95	12	22	500	E.T. 500,000										
Ferguson Water Supply Co.	13	Pipe Stave Hollow	1928	200	50	750	2.9	3.4	3.8	No. 1	S4102G	6	120	6		50	H.T. 1000	.25		5.8	30	26	7.6				
										No. 2	S4103G	6	189	4	15	100	E.T. 20,000										
Fire Island Beach Club	14	Club Property	1949	30	0	120	1.3	2.37	1.0	No. 1	S7350M	8-6	422	6	20	100	H.T. 15,000										
Fishers Island Estate, Inc.	15	Fishers Island	1927	280		3000	62.4	384.6	67.2	Pond Pumpage	Pond, Well Points, Infiltration System						G.R. 500,000, 300,000	.20		53	38	40	8.0	35	TR	2	Aeration, Filters Alum, Ammonia Soda Ash, Chlorine
Forest Brook Water Supply	21	Forrest Brook Acres	1946	80	80	300	.09	.32	.46	No. 1	S4667G	8	68	8	10	50	H.T. 5,000										
										No. 2	S6172G	4	57	4	6	15											
Green Meadow Water Co.	63	Ronkonkoma Shores	1954		Construction not completed					No. 1	S13620G	12	160	12	30	100	H.T. 15,000										
Green Turf Water Co.	34	Belmont Village	1954	270	270	1000		6.67	2.46	No. 1	S11496G	10	60	10	16	500	H.T. 2-10,000	1.0		6.8	240	60	6.0	1	TR		
											S12638G	6	59	6	11	150											
E. Griffin & Son	16	Reeves Park Estates	1940	50	0	180	0.60	0.40	0.40	No. 1	S2010G	6	162	6	10	20	E.T.-10,000 H.T. 1,500										
E. Griffin & Son	17	Cedar Beach Manor	1949	62	0	230	.35	.54	.71	No. 1	S8119G	6	102	6	10	50	H.T. 15,000										
										No. 2	S11495G	6	175	6	10	50		.35		6.6	34	10	6.3		TR	2	

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 6

PRIVATELY OWNED PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	WELLS Dia. In.	WELLS Depth Ft.	WELLS Screen Dia. In.	WELLS Screen Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C (Color)	T (Turbidity)	O (Odor)	TREATMENT
Groveland Park Assoc.	67	Groveland Park	1928	67	25	235			2.3	No. 1	S1857G	6	174	6		40	H.T. 10,000	.80		15.0	58.0	19.0	6.6	20	5	2	
											S14908G	6	145	6	15	100											
Hallock Acres Water Works	19	Hallock Acres	1924	42	42	150	1.75	1.75	1.90	No. 1	S4145G	8	190	6		20	H.T. 2-1,500	.05		3.6	24	24	7.2		TR		
Home Water Co.	18	Village of East Hampton	1898	1420	1150	6000	180.6	183.6	212.4	No. 1	S2570G	12	90	12	30	800	H.T. 7,500										
										No. 2	S2405G	12	86	12	30	800	S.P. 80,000	.18		15.1	24	8.0	6.1				
										No. 3	S2415G	16	86	12	30	1000	E.T. 125,000										
										No. 4	S7570G	12	162	12	26	500		.60		14.6	26	11.0	6.3				
										No. 5 (New)	S14921G	16	125	16	31	1000											
Indian Head Water Co.	58	Mayfair Estates	1955	400	400	1400			20.5	No. 1	S4184G	12	162	12	26	1000	H.T. 2-15,000	.20		12.6	86.0	10.0	6.4	0	T	1	
										No. 2	S9771G	12	151	12	21	1000		.50		16.2	108.0	10.0	6.3	0	T	1	
Henry Kobb	59	Hunter Manor		Construction not started																							
Lakeview Beach	22	Lakeview Beach	1927	7	0	30	.12	.12	.12	No. 1	S6132G	6	70			8											
Lakoma Manor, Inc.	23	Lakoma Manor	1948	10	0	40	.12	.12	.12	No. 1	S6131G	2	65	2	3	6											
Montauk Water Supply Corp.	24	Hamlet of Montauk	1927	404	280	1500	51.0	52.0	69.8	No. 10	S3615G	6	135	6	20	400	G.R. 250,000	.12		88	42	12	6.4				
										" 11	S3658G	6	55	6	12	600											
										" 11	S3725G	6	55	6	12												
										" 11	S3726G	6	55	6	12												
										" 14	S7642G	6	59	6	15	150		.04		13.0	54	15	5.6	2			
										" 15	S10060G	6	60	6	15	150											
John T. Murtha	25	Pine Grove	1947	27	12	95	.50	.50	.50	No. 1	S9550G	4	127	2.5		10	H.T. 1000										
New Highway Water Co. (34th Nassau)	61	No Construction																									
New Highway Water Co. (Bengren)	62	No Construction																									
New Zone, Inc.	60			See Allen Properties, Inc.																							
North Fork Water Co.	26	Hamlet of Southold	1929	300	260	1100	4.6	4.9	5.0	No. 1	S169G	10	55	8	20	250	H.T. 2-15,000	1.5		37.0	176	10.0	6.4		TR	1	
										" "		10	55	8	20	250											
										No. 2		8	54	7	15	250											
										" "		6	45	6	15	100											
Northport Water Works Co.	27	Village of Northport	1892	6000	4000	22000	321.6	364.4	434.3	No. 1 Washington St.	S2977G	10	59	8		300	G.Rs 1,350.000										
		East Northport								" " "	S2978G	18-12	270	12	40	725	E.T. 100,000	0.10		5.6	12.0	4.0	6.3	0	TR	1
		Asharoken Beach								" " "	S3012G	48-24 16-8	174	8	30	530	E.T. 200,000										
										No. 2 Reservoir Ave.	S11105M	20-16	517	10	50	1500	E.T. 400,000	0.03		6.8	20.0	7.0	6.6	0	TR	1
										" " "	S2972G	8	47	8		300											

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 7

PRIVATELY OWNED PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C	T	O	TREATMENT
												G — Glacial; M — Magothy; L — Lloyd												C — Color; T — Turbidity; O — Odor			
Oakwood Park Corp.	28	Village of Belle Terre	1905	100	50	350	12.0	1.5	3.2	No. 1	S112M	4	245			50	S.P. 113,000	.50		9.0	12.0	7.0	6.3		5		
											S113M	6	330	6	10	85		.05		4.2	12.0	.0	6.7	0	TR	2	
											S114M	8	333	4	20	100											
A. Peckman	30	Shinnecock Shores	1953	95	10	360		3.0	7.5	No. 1	S10876G	10	45	10	15	200	H.T. 7,500-10,000										
										No. 1	S14503G	(4) 2	26	2	3	200		.15		13	20	9.0	5.3	5	TR		
Point O'Woods Assoc.	29	Association Grounds		145	0	550	9.5	8.0	8.0	No. 1	S703M	10-8	408	8	15	150	E.T. 20,000										
Reeves Park Beach Co.	32	Beach Company Property	1940	85	0	320	0.10	1.0	0.60	No. 1	S2017G	2	135	2	4	3	H.T. 300-400-1000										
										No. 2	S1481G	4	138	2	3	3											
										No. 3	S11700G	6	135	6	15	7		5.0		16	82	17	6.5	10	TR	1	
										No. 4	S12160G	6	174	6	15	31											
Ronkonkoma Water Co., Inc.	52	Waltess Estates	1952	60	60	220				No. 1	S9820G	4	94	4	10	40	H.T. 5000										
										No. 2	S14250G	Not Completed															
Scotts Beach, Inc.	35	Scotts Beack	1918	65		240	2.0	6.17	6.0	No. 1	S124M	8-6	670	6	20	25	H.T. 15000										
											S5070M	6	185	6		20											
											S8736M	8	159	8	20	200											
Sea View Utilities	36	Sea View	1946	225	0	1000	7.5	8.0	8.0	No. 1	S4761M	12-8	530	8	15	200	E.T. 30,000	1.0		4.6	20	11.0	5.5	5	6	1	Calgon
H. Seitz	37	Cedar Brook Park	1935	60	4	220	1.3	1.3	1.3	No. 1	S4105G	8	68	6	10	45	H.T. 525-1,500	.25		5.8	30	26	7.6	1	TR		
											S4106G	8	68	6	6	30		.20		10.2	54	11	6.1	1	TR		
Selden Water Co., Inc.	70									Work not started																	
Shelter Is. Heights Assoc.	38	Shelter Island Heights	1900	250	100	9300	26.0	28.0	29.0	Capon Well	Dug Well							0.12		15.2	32	17	6.3		TR	1	
										Orchard Well	"	"				200	G.R. 400,000	0.15		15.6	42	22	6.4		TR	1	
										Beach Well	"	"						0.25		35.0	40	13	6.0		TR	1	
Shirley Water Co.	41	Mastic Acres Unit B	1950	40		150	0.43	0.70	0.98	No. 1	S8986G	6	50	6	10	80	H.T. 5,500	2.0		12.0	14	3.0	5.4	10	10	2	
											S8987G	6	48	6	10	80											
Shore Haven Water Corp.	39	Shore Haven Estates	1955	70		245	No Record			No. 1	S12405G	8	102	8	10	150	H.T. 5,500	0.19		6.2	22	15	6.8		TR	1	
Shorewood Water Co.	40	Village of Shoreham	1905	275	225	1020	9.7	9.4	8.0	No. 1	S8265G	8	186	8	20	500	E.T. 2-50,000										
		Adjacant Area								No. 2	S11464G	8	175	8	20	300											
Anthony Sini	42	Rocky Point	1940	290	130	1100	5.0	5.0	50	No. 1	S2016G	8	150	6	20	200	H.T. 15,000										
		North Shore Beach									S5565G	10	177	10	21	40		1.2		6.4	16	8	5.9	15	5	1	
Smithtown Water Co., Inc.	43	Smithtown Estates	1953	72	72	250	No Record			No. 1	S11891G	12	119	12	22	1000	H.T. 2-15000										
Solid Building Co., Inc.	44	St. James Park					No Record			No. 1	S4216G	4	130	4		35											
Sound Shore Club Corp.	45	Club Property	1934	100	0	375	2.5	2.5	2.6	No. 1	S2651G	2	50	2	3	6	H.T. 3000										
										No. 2	S8895G	6	157	6	66	100		4.0		8.0	30	9	6.1				
										No. 3	S9735G	Well Points				22											
Sound View Assoc., Inc.	46	Association Area	1922	50	9	190		.65	.99	No. 1	S5447G	6	60	6	6	75	H.T. 6,000										
										No. 2	S12430G	6	65	6	10	55		2.6		13	22	8	6.3				

SUFFOLK COUNTY PUBLIC WATER SUPPLIES 1955

Sheet No. 8

PRIVATELY OWNED PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	PUMPAGE, MIL. GALS. 1954	PUMPAGE, MIL. GALS. 1955	PUMPING STATION	WELLS W.P. and C.C. NUMBER	WELLS Dia. In.	WELLS Depth Ft.	WELLS SCREEN Dia. In.	WELLS SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. – Elevated Tank; H.T. – Hydropneumatic Tank; S.P. – Standpipe; G.R. – Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C	T	O	TREATMENT
											(G – Glacial; M – Magothy; L – Lloyd)														(C – Color; T – Turbidity; O – Odor)		
M. Stiriz	48	Patchogue Shores	1937	180	120	660	1.9	1.8	1.8	No. 1	S4321G	4	110	4		100		.5		11.8		5.0	6.1	1	TR	5	
										No. 2	S4322G To S4331G	2-4	110			100 200											
Suffolk Improvement Co.	47	Pond Woods Development	1947	15	15	55	Supplied by Stony Brook Water District, for which latter see under "Municiply-Owned"																				
Sunken Meadow Water Corp.	66			Construction not started																							
Sunnyside Water Corp.	71	Map of S.H.G. Holding Corp.	1955	Construction not completed																							
Swan Lake Water Corp.	69	Pine Crest	1955	Construction not completed							S105037G																
Terraces-On-The-Sound	49	Association Property	1929	100	20	375	9.0	10.0		No. 1	S4146G	8	98	8		30	H.Ts. 21,000										
										No. 2	S4156G	8	147	8	20	200											
										No. 3	S11866G	10	143	10	22	500		1.3		6.2	16	6	7.0	45	TR	2	
D. Timrud	20	Sunken Meadow Estates	1937	15	15	45	.09	.09	.09	No. 1	S2019G	4	100	2		4	H.T. 1,000										
										No. 2	S3354M	4	233	2	3	7											
Le Roy Volgraff	51	Oakwood Development	1927	27	27	95	.50	.50	.50	No. 1	S4148G S4149G	4 4	85 85	4 4	20 20	20 20	H.T. 5,000	.20		6.8	24	14	6.7	0	TR	1	
West Gilgo Beach Assoc.	53	Association Property	1940	90	0	300	1.15	1.35	1.12	No. 1	S1834M	8	304	8	11	45	H.T. 5,000										Calgon
West Meadow Beach Assoc.	55	West Meadow Beach	1951	72	0	250	.31	.30	.33	No. 1	S9214G	6	98	6	10	50	H.T. 5,000										
Wildwood Lake Development Corp.	54	Wildwood Lake Development	1952	110	110	400	22.0	13.2			Supplied by Riverside Water Dist.																
Woodbury Triangle Assoc. Inc.	31	Cold Spring Hills	1916	150	150	460	30.0	27.5	24.7	No. 1	S5M S3572M		260 250			175	H.Ts. 90,000	3.0 .03		4.6 5.2	26 16	23 8.0	6.7 6.6	5 0	10 TR	1 2	
											S3573M S3574M		250 250	Air Lift		700											

SUFFOLK COUNTY PUBLIC WATERSUPPLIES 1955

Sheet No. 4

MUNICIPALLY OWNED PLANTS (Continued)	MAP LETTER OR NO.	AREA SERVED	DATE FIRST SUPPLY	SERVICES Summer	SERVICES Winter	POPULATION SERVED	PUMPAGE, MIL. GALS. 1953	1954	1955	PUMPING STATION	Dia. In.	Depth Ft.	SCREEN Dia. In.	SCREEN Lgth. Ft.	GAL. PER MIN.	STORAGE GALLONS (E.T. — Elevated Tank; H.T. — Hydropneumatic Tank; S.P. — Standpipe; G.R. — Ground Reservoir)	CHEMICAL ANALYSIS Fe.	Mn.	Cl.	Har.	Alk.	ph.	C (Color)	T (Turbidity)	O (Odor)	TREATMENT
											G — Glacial; M — Magothy; L — Lloyd															
Hampton Bays W.D.	G	Hampton Bays	1931	570	510	1100	42.3	41.9	47.7	Foster Avenue	8	30	8	10	150	S.P. 200,000	.20		50	26	5	5.8				Caustic Soda
										" "	10	30	10	10	150	E.T. 150,000										
										" "	10	47	8	10	150											
										" "	8	31	8	10	100											
										" "	12 / 8	385	8	40	350	E.T. 125,000	.75		4.4	6.0	16.0	7.4	1	7	1	
Ocean Beach Village	H	Village of Ocean Beach	1915	500	30	2000	25.0	25.0	25.0	Ocean Beach	8	90	8		560	E.T. 150,000	2.2	0	5.4	32	27	6.9	15	2		Sta. No. 1-Partial
											8	90	8													Aeration and Filtration
Riverhead W.D.	I	Riverhead W.D.	1915	1675	1675	6200	196	206	231	No. 1 Pulaski Ave.	12	105	10		460	Distribution	0.6	0	5.6	32	31	7.2	5	TR	1	
		Riverside W.D.		See under "Municipally Owned"						" " "	12	140	12		850											Sodium Fluoride
										" " "	16	125	16	30	1000		.08	0	6.0	40	39	6.5	1	0.1		
										No. 2 " "																Sodium Fluoride
										No. 3 " "																Sodium Fluoride
Riverside W.D.	J	Riverside W.D.	1929	235	235	830	15.4	21.5	33.8	Supplied by Riverhead W.D.																Chlorine
	54	Wildwood Lake Development	1952	112	112	400			22.3	" " Riverhead Plant	6	415	Flowing Well		60		0.5		3.4	18.0		8.9	5	5	1	
St. James W.D.	K	St. James W.D.	1946	900	860	3340	39.5*	47.3*	47.1*	Supplied by S.C.W.A.	Authority, Kings Park Plant															Soda Ash
Saltair Village	L	Village of Saltair	1921	125	6	500	10.0	5.3	5.0	Saltair	12	271	12		900	E.T. 150,000	.02		14.0	55	22	5.9	1			
Smithtown W.D.	M	Water District	1949	188	188	660	6.8	7.5	8.5	Supplied by Suffolk Co.	20-12	202	12	53	1000	G.R. 1,000,000	.06		8.0	31	9.5	6.0	1			
South Huntington W.D.	N	South Huntington	1925	7800	7800	28000	410.8	46.5	594.6	No. 2	20	405	12	70	1200		0.18		4.0	16	10		3			
										No. 3	20	265	12	73	1200											
										No. 4	Huntington Plant															
										No. 5	Huntington Plant, via Stony Brook W.D.															
Stony Brook W.D.	O	Stony Brook W.D.	1939	728	610	2600	32.6*	34.8*	35.5*	Supplied by S.C.W.A.,																
		Suffolk Improvement Co.								Supplied " "																
PRIVATELY OWNED PLANTS																										
Allen Properties, Inc.	I	Canaan Lake East		143	65	550	0.51	2.5	3.5	No. 1	8	72	8	10	50	H.T. 5,500										
Connected with New Zone Inc., No. 60		Canaan Lake Estates								No. 2	2	60	2		20	H.T. 100										
New Zone Inc.	60									No. 1	8	95	8	20	250	H.T. 7,500	.50		4.0	16	13	61	1	TR	1	
Amagansett Water Co.	2	Amagansett	1929	520	420	2000	50.8	51.7	69.8	No. 1	12	93	10	12	300	E.T. Tank 100,000	.20		27	88	12	6.2				
										"	12	93	10		350											
										"	12	104	10	22	500											
F. M. Appel	3	Waterside Park	1923	33	0	130	0.2	0.18	0.18	No. 1	4	70	4		25	H.T. 5000										
Smiting Hollow Lodge	56	Lodge Property	1953	24	0	90			.12	No. 1	6	113	4	5	25	H.T. 1500										
Devon Holding Corp.	65	Bricklyn At Selden	1955	Construction not started						No. 1	12				750	H.T. 7,500										

*Use; Pumpage is included in plant noted as supplying the water.

APPENDIX F

PRECIPITATION IN SUFFOLK COUNTY, LONG ISLAND, N. Y.

by T.H. Wiggin

The yield of ground water of Long Island comes from that part of the rain and snowfall which percolates into the ground and is neither pulled back by the force of capillary action and vegetation, and so lost by evaporation and transpiration, or is lost into the sea by underground flow or by coming out from the ground into the streams and thence into the sea.

It seems, therefore, appropriate to include records of precipitation in Suffolk County in this report, and further to compare the precipitation of Suffolk County with that of Nassau County, since our estimates of yield must be largely based on Nassau County where the ground water supply has been more completely developed than in Suffolk County.

Tables 1 and 2, attached to this Appendix F, have been included in furtherance of the above idea. Table 1 gives a record of rainfall in Nassau County for the years 1879 to 1931, inclusive, as compiled by water supply officials of the cities of Brooklyn and New York.

Table 2 gives the available long records of precipitation in Suffolk County, copied from the following documents obtained from the U.S. Department of Commerce Weather Bureau:

1. Climatic Summary of the U.S., Section 83, Eastern N.Y., being climatic data from the establishment of stations to 1930, incl.
2. Similar to No. 1 above but labeled also "Supplement for 1931 through 1952, also "New York No. 26."

3,4 & 5. Climatological data, New York, Annual Summary for 1953, for 1954 and for 1955, respectively.

The author looked for other long precipitation records for Nassau County but did not find any in the U.S. Department of Commerce Weather Bureau records, though some probably exist in the records of the Department of Water Supply of the City of New York, also in Nassau County Engineering Department, and perhaps also in the U.S. Geological Survey. The very long record shown in Table 1 seemed sufficient as it gave results about like those which the author has seen and heard in various cases before the Water Power and Control Commission.

The longest record in Suffolk County appears to be that at Setauket, near the north or Long Island Sound shore about one-half way, in longitude, between the Nassau County line and Riverhead. This record runs from 1886 to the present, with only 1949 missing. The next longest Suffolk County record is that of Cutchogue, running from 1899 to the present but with 11 years missing, viz., 1927, 1939-43, and 1948-52.

The author wondered whether the fact that Setauket and Cutchogue are both near the Sound would make their precipitation records not a fair representation of the whole County. The shorter records of Bridgehampton and Southampton are, therefore, included in Table 2 and the averages of the annual precipitations for the same periods of years do not vary greatly in the various locations as will be noted by certain comparisons in a

frame on Table 2. Table 2 is arranged in parallel columns with the records of all stations which are included on the same horizontal line for each year. A glance along the line for a given year will show the difference between stations in that year. These differences, as would be expected, vary greatly, but the averages (shown in the frame) are rather surprisingly close.

A comparison between the average precipitation at Setauket and that for Nassau County, for the 46 years 1886 to 1931 inclusive, as computed from the figures in Table 2 and 1 respectively, is shown in the frame on Table 2. The Setauket average is 2.48 inches higher than the Nassau County average, which gives credence to Water Spear's impression, contained in his 1912 Board of Water Supply Report, that Suffolk County probably has about 1 inch greater annual precipitation than does Nassau County.

RAINFALL ON LONG ISLAND WATERSHED IN NASSAU COUNTY

Appendix F - Table 1
REPORT OF SUFFOLK COUNTY WATER SUPPLY BY THOMAS H. WIGGIN, JANUARY 1957

Total Monthly Precipitation in inches of depth

PERIODS OF VERY LOW RAINFALL → Average 39.39 in.

Avge. 37.98"

Average 1928-1931 37.13 Inches

	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	TOTALS	Averages 1879/1928	1929	1930	1931	Totals 1879/1931	Averages "
January	3.09	1.28	5.44	4.49	2.81	4.75	3.21	5.79	4.78	4.78	6.46	2.95	4.31	5.03	1.32	2.09	5.08	1.10	2.27	4.12	4.22	4.45	2.21	2.17	3.82	2.97	2.20	4.29	3.29	3.17	3.04	6.10	3.15	1.96	3.64	5.08	8.28	1.64	3.08	3.27	4.88	2.23	2.21	1.34	5.55	4.69	2.03	2.29	1.92	1.12	175.50	35.10	3.12	2.61	2.29	183.52	3.46
February	2.92	1.89	5.68	4.10	4.63	5.87	3.92	7.95	5.60	2.82	2.06	2.52	3.78	1.98	5.71	3.30	0.65	7.04	2.74	3.23	5.02	5.04	0.77	4.99	4.65	3.56	3.00	1.95	1.77	4.76	4.36	3.31	2.55	2.35	2.52	2.32	4.42	4.13	2.06	2.30	8.03	3.84	2.23	2.57	1.89	3.45	2.92	3.08	4.30	179.22	35.84	3.56	3.80	1.87	188.45	3.56
March	3.38	5.18	6.74	2.82	1.29	4.38	1.02	3.47	4.13	4.43	2.40	6.08	3.39	4.52	4.53	1.87	3.18	4.62	3.11	3.45	7.79	3.77	6.97	5.01	5.21	3.58	4.05	4.98	3.27	2.64	3.73	0.81	3.54	7.67	4.69	4.20	0.59	2.44	4.97	1.70	4.27	3.07	3.62	5.50	3.89	1.54	2.92	2.37	1.35	2.78	187.11	37.42	3.70	1.53	2.44	194.78	3.67
April	4.85	2.84	0.55	1.62	1.67	2.52	2.53	4.05	2.89	3.22	4.64	2.69	1.85	2.53	4.70	2.14	3.45	1.42	3.33	3.79	1.47	1.87	8.05	3.62	3.98	4.24	3.18	4.56	3.67	2.17	6.36	3.58	3.56	4.34	6.84	3.62	2.56	3.31	2.41	4.62	2.95	4.81	3.22	2.04	3.25	6.52	2.66	2.02	4.78	170.04	34.01	5.42	1.98	3.49	180.93	3.42
May	1.78	0.72	2.86	4.05	4.07	3.01	2.51	4.64	0.30	4.47	3.15	3.97	2.00	5.23	4.19	5.42	2.29	3.04	4.64	8.99	1.79	4.11	7.17	1.01	9.40	2.44	1.07	3.41	5.11	5.86	1.94	2.29	3.56	5.02	2.64	2.80	4.47	2.67	3.95	2.68	4.32	2.29	3.67	3.15	1.45	5.47	2.43	2.46	3.88	2.24	165.73	33.15	5.38	2.98	3.25	177.34	3.35
June	2.82	1.27	6.09	2.66	3.38	4.92	1.77	3.73	6.71	2.75	3.60	3.96	0.95	2.72	0.81	0.59	1.05	5.90	3.17	0.77	2.21	1.98	0.55	6.03	9.58	3.77	3.41	4.26	5.93	0.62	3.69	4.48	4.85	1.56	2.44	1.97	3.37	4.88	2.77	3.24	2.01	6.38	4.35	6.56	3.36	2.75	3.96	3.13	2.78	6.58	173.07	34.61	2.52	4.04	3.05	192.68	3.45
July	3.57	8.18	0.57	2.36	1.76	3.93	2.35	6.78	3.53	2.60	8.07	5.52	6.60	3.19	1.24	0.81	5.37	3.25	11.68	5.43	5.07	4.69	5.93	2.42	3.16	5.03	2.33	5.60	1.65	3.92	1.91	0.59	2.79	3.48	1.71	3.70	4.16	2.84	5.61	3.95	7.33	3.56	3.24	3.86	2.24	0.96	6.88	5.76	7.17	5.65	203.98	40.80	0.88	3.84	1.82	210.52	3.98
August	8.99	6.56	1.62	1.75	2.20	4.31	6.19	1.50	5.56	5.02	3.92	4.73	4.09	2.58	4.67	0.56	3.79	3.29	2.62	4.83	3.59	3.76	4.03	3.34	7.67	10.76	4.54	2.54	1.45	3.87	7.06	2.33	2.57	2.81	2.46	2.44	6.93	1.64	1.96	3.28	7.33	2.89	3.75	4.77	1.36	5.62	1.35	6.76	8.05	5.82	215.96	43.19	1.18	5.19	4.96	227.29	4.29
September	1.21	2.50	2.72	10.63	3.09	0.29	0.94	2.64	3.27	7.75	8.51	6.49	3.04	1.73	2.02	4.89	1.73	3.55	1.51	2.44	5.17	2.10	3.36	5.54	2.05	4.58	4.51	1.45	8.32	0.91	3.59	1.60	1.85	3.92	1.45	0.26	1.84	1.50	2.09	5.26	3.30	2.95	2.56	1.02	3.38	3.48	2.64	3.37	3.98	4.29	164.30	32.86	2.81	0.93	0.87	168.91	3.19
October	1.07	3.55	2.32	2.42	6.69	2.58	5.36	3.93	2.79	3.73	3.33	7.39	3.47	6.49	5.33	7.12	3.37	1.76	1.51	5.81	2.76	3.22	1.95	8.68	6.65	3.38	2.86	5.97	4.10	1.83	1.85	1.98	7.12	1.27	8.48	1.77	3.90	1.22	5.71	0.67	2.32	0.90	3.23	2.79	5.22	0.27	5.30	3.92	7.49	1.81	180.49	36.10	3.59	2.45	3.27	189.80	3.58
November	1.98	2.52	2.66	0.90	1.66	3.01	4.50	3.40	2.54	3.91	8.59	1.01	2.02	6.09	2.58	3.33	3.49	2.91	5.00	6.00	2.69	4.16	1.28	2.13	1.54	1.87	1.81	1.46	5.28	0.74	1.57	5.46	6.43	2.97	1.92	2.04	1.68	2.02	0.29	2.90	3.54	4.17	3.31	1.02	3.23	1.99	2.81	4.43	4.30	2.46	149.60	29.92	2.85	5.25	0.70	158.40	3.52
December	3.95	4.27	2.28	2.03	3.97	5.82	2.55	3.50	3.56	2.97	1.81	4.84	3.68	1.66	2.52	4.76	2.19	0.94	4.83	2.36	1.82	2.28	7.65	7.04	3.43	2.44	3.86	3.65	4.12	2.95	4.51	2.14	4.12	4.62	3.71	5.78	4.33	4.32	2.98	6.67	3.00	5.33	2.48	3.00	4.12	2.44	3.13	3.54	3.42	1.64	179.01	35.80	3.08	2.49	1.86	186.44	3.52
The Year	39.61	40.76	39.53	39.83	37.22	45.39	36.85	51.38	45.66	48.45	56.54	52.15	39.18	37.75	39.62	36.88	35.64	38.82	46.41	51.22	43.60	41.43	49.92	51.98	52.14	48.62	36.82	44.12	49.23	34.44	43.61	34.67	52.81	41.73	43.86	35.98	46.53	32.61	37.88	40.54	53.28	42.42	36.00	37.62	38.94	39.18	39.03	43.13	49.53	43.47	2144.01	42.88	38.09	37.09	29.87	2249.06	42.44

1879 to 1895 both inclusive from "History and Description of the Water Supply of the City of Brooklyn" by I. M. de Varona, 1896.
1896 to 1928 " " " records of Borough Engineer's Office, Brooklyn.
1879 to 1910 Inclusive measured at Hempstead Storage Reservoir.
1911 to July 1915 " " " Rockville Center.
Aug. 1915 to Dec. 1931 " " " Baldwin (Milburn Pumping Station).

NOTE: DATA FOR 1929, 1930 & 1931 ON 2ND SHEET OF THIS COMPILATION BY NY CITY, WAS TRANSFERRED TO THIS SHEET, ALSO LOW RAINFALL AVERAGES ADDED ALONG TOP OF SHEET, BY T.H. WIGGIN, JANUARY 1957

Prepared by Division of Investigation, Design and Statistics.
City of New York, Department of Water Supply, Gas and Electricity.

APPENDIX F. TABLE 2

ANNUAL PRECIPITATION IN SUFFOLK COUNTY, LONG ISLAND, N.Y. INCHES

YEAR	SETAUKET	CUTCHOGUE	BRIDGEHAMPTON	SOUTHAMPTON
1886	48.55			
1887	49.08			
1888	51.52			
1889	53.87			
1890	53.94			
1891	47.35			
1892	39.41			
1893	48.58			
1894	46.03			
1895	39.21			
1896	37.38			
1897	59.26			
1898	58.00			
1899	39.63	47.06		
1900	47.34	48.26		
1901	51.98	56.04		49.38
1902	48.90	49.24		52.92
1903	48.31	50.86		43.14
1904	45.32	45.44		45.39
1905	38.98	38.62		44.71
1906	52.01	44.75		46.72
1907	46.72	45.43		43.94
1908	37.76	34.70		34.80
1909	41.16	45.43		42.75
1910	33.57	39.90		37.01
1911	46.52	53.78		50.29
1912	41.32	49.02		42.86
1913	45.20	44.53		46.62
1914	38.53	37.70		39.95
1915	45.85	48.98		47.33
1916	38.26	42.67		41.79
1917	36.28	41.49		36.70
1918	43.04	44.69		Ave 43.90"
1919	51.09	51.44		
1920	55.77	50.94		
1921	44.22	41.46		
1922	41.98	43.72		
1923	48.43	44.73		
1924	38.18	38.18		
1925	38.59	38.26		
1926	40.97	41.52		
1927	56.85	-		
1928	43.12	46.06		
1929	46.32	47.91		
1930	35.48	41.65		
1931	41.54	40.27	39.77	
1932	40.96	44.73	52.51	
1933	45.49	53.19	58.60	
1934	47.64	47.93	45.14	
1935	35.44	35.83	38.41	
1936	52.73	46.00	48.14	
1937	43.24	44.69	43.43	
1938	51.32	48.03	48.85	
1939	41.56	-	45.73	
1940	45.12	-	43.49	
1941	36.19	-	37.51	
1942	48.89	-	49.84	
1943	39.75	-	33.51	
1944	47.78	48.52	44.49	
1945	43.71	47.22	42.43	
1946	37.57	43.53	39.73	
1947	46.04	43.63	39.77	
1948	48.63	-	47.84	
1949	-	-	35.57	
1950	46.10'	-	37.32	
1951	44.08	-	46.91	
1952	44.09	-	48.91	
1953	52.64	51.18	34.75	
1954	E 50.35	41.68	53.04	
1955	48.75	35.15	43.45	
Ave.	45.27" 1886-1955	Ave.	43.97" 1931-1955	

E - Estimated

Comparative Averages for the Same Years

1899 - 1938	
Setauket	44.15"
Cutchogue	45.00"
1901 - 1917	
Setauket	43.33"
Cutchogue	45.21"
Southampton	43.90"
1931-- 1955	
Setauket	44.98"
Bridgehampton	43.97"
1886 - 1931	
Setauket	45.25"
Nassau County (From Table 1)	42.82"
Difference	2.43"

APPENDIX G - by T. H. WIGGIN

GHIJBEN-HERZBERG AND HUBBERT THEORIES OF FRESH WATER-SALT WATER BALANCE IN PERMEABLE SANDS AND GRAVELS

Section G1 The Ghijben-Herzberg theory, in brief, postulates that in a permeable ground formation, accessible to sea-water, the level of the top of the sea-water in the formation will be about 40 times as deep below sea level as the ground water table above it stands above sea level.

The Ghijben-Herzberg theory was first stated in about 1888 by a Dutch engineer named W. Badon Ghijben in connection with the serious ground water problem of Holland, which has been progressively solved by that intelligent nation. At about the turn of the century Baurat Herzberg independently discovered and announced the same principle, hence their names are coupled in writing of it. Each of these men predicated his theory on similar observations that "in wells near the sea coast the salt water was not encountered at sea level but at a depth below sea level of the order of 40 times the height of fresh water above sea level." (The wording is that of Hubbert.-T.H.W.). This condition was immediately mathematically explained by these two independent observers by the fact that salt water is generally about 2-1/2 per cent heavier per unit volume than fresh water. (Note: This ratio of 40 would of course increase if the sea-water were diluted with fresh water, as is the case to a constantly varying extent in the bays, Great South Bay, Moriches Bay and Shinnecock Bay south of Suffolk County. T.H.W.)

Section G2 - Work of Rene D'Andrimont

In 1902 and subsequently a French mining engineer and geologist, named Rene D'Andrimont, made further investigations, partly by model experiments, * on the subject of fresh water-salt water balance. A clear statement of his findings, freely translated by this author is as follows:

"Here are the phenomena which I have observed: Salty water, colored yellow, went to the bottom, The depth at which the zone of transition (between fresh and salty water.-T.H.W.) is found was everywhere proportioned to the level of the top of the fresh water. (From D'Andrimont's Fig. 1, "level of the top of the fresh water" is the height of static ground water level above mean sea level. T.H.W.) The form of the surface of separation between the fresh water and the salty water was exactly what I indicated in the first memoir I published on this subject, the 25th of May 1902, when I possessed only the observations made at the isle of Nordeney and which demonstrated that a lens of fresh water could float on salt water, which is more dense.

"A zone of diffusion of little importance is formed. After 8 days of rest, the line of separation between salty water and fresh water is still very definite. I made concurrently the contrary test, that is, the salty water was placed on the fresh water; at the end of a very short time, the salt water mixed itself with the fresh water. During the whole period of feeding in fresh water, it flowed out all along the shore.

"When one produces artifically a draft of water from the upper part of the fresh water, there is formed a protuberance in the surface of separation between the fresh water and the salt water (i.e., the surface of separation

* See Soc. Geol. Belgique Annales, Vol. 32, pp. M115-M120, 1905.

between fresh and salt water rises, toward, and perhaps to, the cone of depression. T.H.W.)

"If an oscillation is caused, similar to a tide, the surface of delimitation between fresh and salt water oscillates equally."

Section G-3 - Hubbert Theory. Professor M. King Hubbert of Harvard University wrote an exhaustive mathematical monograph, entitled "The Theory of Ground Water Motion," published in the Journal of Geology, Vol. 48, January-December, 1948, pp. 785-944. On pages 924 et seq. of this monograph professor Hubbert comments at some length on the Ghijben-Herzberg "law" (Quotation marks by Hubbert. T.H.W.), which was pronounced fallacious because it does not take into account the diffusion effect of the continual escape of fresh water into the sea which of course must take place if the ground water table is above sea level. The height above sea of the fresh water table is of course a principal factor in the application of the Ghijben-Herzberg law.

Professor Hubbert gives a diagram, figure 42, and a mathematical explanation of what is stated to be the true law, and how the results obtained by it differ—give greater depths for the top of salt water—from those obtained by the Ghijben-Herzberg theory. The Hubbert theory is stated to be in harmony with the basic equations for the movement of ground water derived in the earlier parts of the monograph.

Section G-4 - Review of Papers in Preparation by the U.S. Geological Survey, Bearing on the Ghijben-Herzberg and the Hubbert Theories. Two important papers, bearing on the subject matter in the title above, were delivered on December 29, 1956 before a joint meeting of the American Association for the Advancement of Science and the Geological Society of America. They were as follows:

(1) Relation between fresh and salty ground water in southern Nassau and southeastern Queens counties, Long Island, N.Y. By N.M Perlmutter and J.E. Upson. Paper delivered by N.M. Perlmutter.

(2) Concepts and principles of salt-water encroachments. Delivered by N.J. Luszynski.

These three authors are all members of the U.S.G.S. organization at Mineola, N.Y. Paper (1) records an investigation made in cooperation with the Water Power and Control Commission and the Nassau County Department of Public Works. It is understood that these papers have to be cleared at Washington before copies will be available for study. This author heard them delivered. A 17 line abstraction of the first mentioned paper was available in the program of the meeting. It contains the following statements:

"More than 160 mgd (million gallons daily) of fresh water has been pumped from this area.

"The salty ground water has chloride concentrations ranging from 40 to about 18,000 ppm (part per million), generally more than about 2,000 ppm. It occurs in several bodies, seaward of and beneath the fresh water in the respective aquifers, and is in contact with the fresh water through zones of diffusion. The largest salt-water body, confined under artesian pressure, is in the Jameco gravel and the Magothy (?) formation beneath extreme southwestern Nassau County and adjoining areas. This body is thought to have occupied approximately its present extent since about

1900. . .The rate of encroachment under present conditions probably is less than 100 feet per year."

"Although the presence of the salty water constitutes a threat, existing fresh-water supplies are in little immediate danger."

"Application of the Ghijben-Herzberg formula to compute depths to salt water beneath fresh water gave erroneous results. More nearly accurate depths were computed from a formula adapted from Hubbert." (Italics mine. T.H.W.)

The paper numbered (2) above was in explanation of many diagrams contained therein, illustrating conceptions of how fresh water and salt water in a formation would react vis a vis each other under various conditions. No abstract of this paper was available.

Section G-5 - Comments by Author on Ghijben-Herzberg vs. Hubbert Theory. The simple 40 to 1 Ratio of the Ghijben-Herzberg theory has had wide acceptance at least since its second announcement in about 1900. The investigations by D'Andrimont in 1902-1905 and his model tests doubtless aided in its acceptance. Water E. Spear in 1908 (published report by the N.Y. City Board of Water Supply in 1912) included a diagram of it as did Russell Suter in Bulletin G.W. 2, 1937, of the N.Y. State Water Power and Control Commission. The elaborate monograph of M.K. Hubbert in 1940 (See Section G-3 above) was apparently the first scientific attack on it, and now the U.S.G.S. paper, numbered one in Section G-4 above, finds by full scale applications of the Ghijben and the Hubbert theories that the Hubbert theory gives a fair correspondence with nature and the older theory does not.

This author's comments in brief are as follows:

1. It is obvious the Ghijben theory takes no account of the condition of diffusion caused by flow of fresh water into the salt water. The Ghijben theory treats of the matter as if both fresh and salt water are static, yet uses the super-elevation of the fresh ground water as one of the two factors in its basic equation and such super-elevation must cause flow, not a static condition.
2. The question may be asked whether the elaborate mathematical theory of Hubbert, requiring 59 pages to elucidate, can be correctly applied to the conditions of diffusion existing in the zone of contact between the outward-flowing fresh water and the otherwise static body of salt water. The author has made no critical examination of Hubbert's mathematics but trusts that the U.S.G.S. papers numbered (1) and (2) not yet available for study (See Section G-4 above) will treat of this matter as well as giving the practical tests which were made of the two theories.
3. The author will be interested in the effect of variations in the salt content and hence the specific gravity of the salt water as found and used in the computations made in the investigations made for paper number (1) (See Section G-4 above). In the zone of diffusion there must be gradations in salinity and specific gravity. The Hubbert theory seems to require the choice of specific gravity. The lower the specific gravity, the deeper will be the surface of division between fresh and salt water.

4. It would seem that the Ghijben theory would be the limit, or asymtote, to which the calculation by the Hubbert theory would approach as the use of water increased and the water table was lowered so that the flow of fresh water toward the sea became more gentle and the division surface between fresh and salt water became more definite. The end point of no flow could not be reached practically as at that point there would be no super-elevation of the ground water table, no flow of fresh water to the sea, and salt water at sea level would underlie the whole area. This is, of course, an imaginary rather than a practical end point, but even at the point of practically full development, the Ghijben theory might not be found much in error.

5. It does not seem that any theory for computing the depth to the top surface of the salt water will take the place of outpost wells, though there is always gain in having a correct theory by which to interpret observations.

INFILTRATION GALLERIES - APPENDIX H

By T. H. Wiggin

With particular reference to the galleries owned and used by the City of New York at Massapequa and Wantagh, Long Island, N.Y. Information largely from the October 18, 1956 special report to the author by Angus D. Henderson, Consulting Engineer.

H-1 - General. While vertical wells with screens for admitting the ground water are generally used for obtaining water supplies from the ground, there are a few examples of a different type of construction, viz., infiltration galleries. These are pipe lines, with open joints surrounded by gravel, laid somwhat below the water table in trenches on a slight downward grade toward points of pumping. Residents on the barrier beaches sometimes make use of the same principle on a small scale by laying short perforated pipes horizontally in trenches, the pipes being below the fresh water table but above the salt water level.

On Long Island, in Nassau County, there are two notable and very successful infiltration galleries, viz., those constructed for the City of New York, in 1903 and 1904, at Massapequa and Wantagh.

Believing that this type of construction has great advantages, particularly near salt water, in obtaining ground water without tending to dip down into the underlying salt water, as do wells, and believing further that this type of construction has been neglected, the writer engaged Mr. Angus D. Henderson, consulting engineer who was for many years connected with the City of New York's ground water supplies on Long Island, to collect the available information on the Massapequa and Wantagh galleries. The following passages are quoted from his excellent report to the author dated October 18, 1956.

Section H2 - DESCRIPTION OF MASSAPEQUA AND WANTAGH INFILTRATION GALLERIES

"The galleries are constructed of heavy vitrified clay tile pipe with bell and spigot joint laid at a depth of 20/25 feet beneath the ground surface. At the ends of the galleries, 20" tile pipe was used, gradually increasing to 38" at the center. In some places, twin 33" pipe was used. The galleries were installed with open joints, the ends of the lines being higher than the center.

"The Massapequa gallery is slightly over 18,000 feet long; the Wantagh gallery about 12,000 feet, but 1,800 feet of this is cast iron pipe with lead joints where it passed through an area which was rather well built up at the time of installation, with many cesspools. The galleries were constructed to elevations based on the Brooklyn Navy Yard high water datum which had been carried by levelling to Eastern Nassau County. During the levelling operations, an error was made in the Smith Pond area so that, in Eastern Nassau County, this datum is about 1.7' above MSL instead of the approximate 2.5' at the Brooklyn Navy Yard. In the discussions which follow, I have made this correction although I have not made it on the various drawings.

"The ends of both galleries are about 0.3' above MSL (MEAN SEA LEVEL). The center of the Wantaugh gallery at the pump well is about 3.3' below MSL, and the Massapequa gallery about 4.3' below MSL. The bottom of the pump well at the center of each gallery is about 9.5' below MSL.

Section H-3 - METHOD OF CONSTRUCTION

"I have been told, and believe it to be true, that these galleries were constructed by excavating a wide trench with horse-drawn scrapers. Dewatering was accomplished by temporary pumps which delivered water to the conduit system during the construction period.

"My understanding is that, once the central pump well had been constructed, no difficulties arose in dewatering by this simple method. In plain words, the completed portion of the gallery was able to dewater the immediately adjacent area as construction progressed.

"When the tile pipe was placed in the trench, the top of the joint was covered with a layer of burlap and large gravel placed about the joint, and the trench was then backfilled.

"Manholes were installed about 260' apart. There appears to have been no good reason for such frequent manholes as, to the best of my knowledge, very few of them have ever been opened and entered. If they are necessary at all, a much larger spacing could be used.

"I have been told that, on the few occasions when the gallery has been entered (and I know it has not been entered since 1930) numerous cracks in the tile pipe have been observed. Apparently, the overburden was too heavy for the strength of tile pipe available. However, to the best of my knowledge, there have been no failures, the cracked pieces of pipe remaining in place.

Section H-4 - Historical Background.

"The following historical background may be of interest to you. It is quoted from a "Report of the Commission on Additional Water Supply for the City of New York" dated November 30, 1903:

> "Mr. de Varona* proposes that the present method of collecting ground water by means of driven wells be largely replaced by one based on the use of an infiltration gallery composed of a long line of large vitrified clay pipes varying from 20 to 36 inches in diameter, buried about parallel to the present aqueduct and at a sufficient depth below the water table to intercept the ground water and conduct it to a collecting well midway of the gallery, from which it is to be lifted by pumps into the aqueduct. The vitrified clay pipes are to be laid with joints slightly open and are to be covered over with a layer of gravel so as to allow water to enter them freely. The first plant of this kind in the Brooklyn system is now being constructed at Wantagh under the designs, specifications and supervision of Mr. de Varona.
>
> *Mr. I.M. de Varona was Chief Engineer of Water Supply of the City of Brooklyn and later of Water Supply of Greater New York City.

Section H-5 - OPERATING RECORD: A table summarizing the operating records of these galleries follows:

MASSAPEQUA & WANTAGH INFILTRATION GALLERIES

OPERATING RECORD

Condensed from Report by Angus D. Henderson to T.H. Wiggin

YEAR	MASSAPEQUA GALLERY - 1800' LONG					WANTAGH GALLERY-EFFECTIVE LENGTH 10200'				
	No. of Months Operated	Rate of Pump'g Ave.* Mgd.	Rate of Pump'g Max.# Mgd.	Chloride Ave. P p.m.	Chloride Max. p.p.m.	No. of Months Operated	Rate of Pump'g Ave.* Mgd.	Rate of Pump'g Max.# Mgd.	Chloride Ave. p.p.m.	Chloride Max. p.p.m.
1	2	3	4	5	6	7	8	9	10	11
1904	0	-				0				
1905	1	1.9				9	5.8			
1906	12	9.4				12	11.5			
1907	12	13.5				10	9.6			
1908	11	16.4				7	14.1	15.9		
1909	12	16.7				11	12.1	16.1		
1910	12	17.4				12	10.3			
1911	12	17.1				12	10.9			
1912	12	15.5	24.0			10	11.2			
1913	12	18.5				12	12.0	16.2		
1914	12	19.2	24.3			12	11.1			
1915	12	19.2				8	17.2			
1916	12	21.2	23.5			12	14.3			
1917	4	11.8				3	7.6			
1918	0	0				0	-			
1919	-	-				0	-			
1920	4	0.2				3	0.3			
1921	6	7.9				5	6.8			
1922	12	11.5				7	6.1			
1923	12	15.4				9	9.7			
1924	12	7.8				8	4.6			
1925	12	7.1				4	7.7			
1926	12	18.1	26.5			11	8.8			
1927	8	8.9				0	0			
1928	3	20.6	24.8			4	4.4			
1929	12	19.0				11	9.8	16.9		
1930	12	22.1	24.7			12	13.1	16.1		
1931	12	20.4	24.0			12	13.5	16.0		
1932	11	10.6				12	7.1			
1933	11	5.2				12	7.1			
1934	12	14.1				11	5.6			
1935	11	13.8				11	7.4			
1936	12	14.7				11	9.2			
1937	9	11.1				7	11.2			
		After 1937, information fragmentary								
1949	9	13.9	19.0	7.3	7.6	8	10.0	12.0	10.8	11.2
1950	7	13.5	18.0	7.5	8.0	6	8.1	11.0	11.2	12.4
1951	0					0	0			
1952	1					12 days				
1953	56 days	16.3				52 days	10.9			
1954	232 days	15.3				214 days	10.4			
1955	0					0	0			

*Ave. based on 365 days for 12 mos. operation and No. of mos. x 30.4 for partial years.

#Max. based on ave. of max. month or on record of max day where given.

Diminution in 1917 to 1921 due to starting of Catskill Supply System.

Section H-6 - EFFECT ON GROUNDWATER LEVEL

"The available information indicates that, when the galleries are in full operation, there is widespread lowering of the general groundwater table. The water level at the galleries themselves is lowered to approximately mean sea level at their center, and measurable lowering occurs for distance upslope of as much as 6,000 feet.

"The slope near the gallery is very steep and rapidly flattens out proceeding North up the slope.

"Apparently during the very early days of operation there may have been some chloride intrusion, or at least the City was worried about it possibility. During that period, operating procedures required that a crown of water be kept on the South side of the gallery between the gallery and Great South Bay 3' above the Brooklyn Datum or almost 5' above mean sea level. No difficulties were encountered in maintaining such a crown while operating the galleries at rated yields for long periods of time and, to the best of my knowledge, operations never had to be curtailed in order to meet this requirement.

Section H-7 - RECONSTRUCTION IN 1949

"Prior to 1949, the pumping equipment for the galleries was housed in temporary frame buildings which were part of the original construction, and pumping was done by steam driven reciproacating pumps.

"In 1949, modern brick buildings were constructed immediately above the pump wells and electrically driven centrifugal pumps were installed. These pumps lift the water from the pump well and discharge it to the old brick conduit. It flows through the brick conduit to the Millburn Pumping Station where, combined with other water, it is repumped to New York City and the Rockaways.

Section H-8 - PRESENT YIELD OF GALLERIES AFTER APPROXIMATELY FIFTY YEARS OF OPERATION.

"During 1949, the Massapequa gallery was operated at rates as high as 19,000,000 gallons per day for thirty days and more; and the Wantagh gallery at 11.6 MGD for thirty days or more. Pumpage during late 1949 was accurately measured. Pumpage prior to that time was measured with considerably less accuracy, and the reported figures are probably higher than the actual pumpage by 10 or 15%.

"In my opinion, the galleries not only have not fallen off in yield during this long period of use but they appear to have slightly improved in spite of other diversions of water in the area.

"The quality of water has been excellent over their entire life.

"I believe that, in favorable locations, a properly constructed gallery represents the best, most permanent and most economical method of securing large quantities of groundwater. The anticipated life of such a gallery is at least fifty years, and may be much longer. The gallery structure itself can be expected to outlive the pumping equipment by many years.

"With modern construction methods, construction costs for installing such a gallery should not be exorbitant and, when based on the expected long life, the annual fixed charges probably would prove lower than any other method of groundwater abstraction.

Section H-9 - SUMMARY

"The statements and conclusions which I have expressed in this letter have been very carefully considered. I also believe that my experience with these galleries and with well construction generally would give these conclusions great weight.

"I feel certain that you will concur with me in the conclusions."

Note - the above quotations from Mr. Henderson's report are verbatim and contain all his descriptive portions and his statements of opinion. The tabular matter relating to operation records have been condensed in the table by the undersigned in order to save space. Mr. Henderson's high opinion of infiltration galleries is shared by the author who has known for many years of the excellent performance of the two galleries above described.

T.H. Wiggin

APPENDIX J. OF REPORT ON SUFFOLK COUNTY
WATER SUPPLY by T.H. WIGGIN

ENGINEERING REPORT
ON
DATA BASED UPON EXPERIENCE IN NASSAU COUNTY, N.Y.
ON REPLENISHMENT OF GROUND WATER THROUGH MEDIUM
OF ARTIFICAL RECHARGE STORM WATER BASINS
AND
THE OUTPOST OBSERVATION WELL PROGRAM TO ASCERTAIN
THE MOVEMENT OF THE SALT WATER FRONT FROM TIDAL
WATERS, AND THE FLUCTUATION OF STATIC GROUND WATER
LEVELS IN ARTESIAN WELLS.

JANUARY 1957 by W. FRED WELSCH, P.E.-L.S.

RECHARGE BASINS

Long Range Comprehensive Plan - Since the year 1935, the County of Nassau has been engaged in the construction, maintenance and operation of large acreage impounding (detention) and storm water artificial groundwater, recharge basins for the replenishment of ground water as a conservation measure. This has been done in accordance with the long range master comprehensive drainage plan which was prepared for the Nassau County Sanitation Commission under the author's direction and recommendation and in 1936 was approved by the New York State Department of Health and adopted by the Board of Supervisors. This plan has been followed up to the present time with few variations. About 100 square miles of the approx. 274 sq. miles of Nassau County has been found suitable for the salvage of water by these basins. Recharge basins have a threefold purpose-

(1) To replenish the ground water supply by returning to the ground the storm water run-off from rainfall which otherwise would be carried off to streams thence to tidal salt waters.

(2) To provide drainage outlets without construction of long conduits to streams or tide waters.

(3) To reduce the size of conduits required for storm water drainage by impounding waters during peak flows.

Recharge basins are also used for the discharge of air conditioning waste water and uncontaminated water used for industrial processing at industrial plants.

There are a considerable number of similar basins in Suffolk County but none in Kings and Queens Counties, but about 40 years ago the City of New York built and operated a number of spreading areas for salvaging water from Forest Stream.

The actual locations for recharge basins are selected in accordance with the following factors:

(1) Study of the topography with aid of a contour map and selection of an appropriate area or watershed and of the basin site to which the selected area will drain by gravity.

(2) Position of main ground water table with reference to the topographic surface.

(3) Nature and extent of topsoil.

(4) Geology of material overlying the ground water table.

(5) Frequency, distribution, intensity and duration of the rainfall.

(6) Estimated quantities of storm water run-off to be collected at given collection points in the area.

(7) Economical maximum rates of recharge at given points.

Geological Investigation of Proposed Sites of Basins

In order to show whether a proposed basin site is suitable with respect to its function of allowing collected surface water to percolate into the ground, the nature of the ground is investigated by drill holes extending to a depth of at least 20 feet below the level of the ground water-table. Samples of the ground encountered in each hole are taken by a soil sampler of the split-steel-tube type, made with a trap door at the bottom of the sampler, above the cutting edge. This sampler is driven into the formation at intervals in depth and samples thus obtained are examined for size of particles by sieve analysis and in other ways for permeability, capillarity and frictional resistance to percolation. If clay lenses are found during excavation for the basin, they are removed so far as practicable.

An aerial photograph Exhibit A shows view of impounding and recharge basins at Basin #123 and Exhibit B is a photostat of the impounding and recharge basins at Rockaway Road and Old County Road, Garden City.

There are 385 storm water recharge basins in the County; 264 are owned and maintained by the County and 14 maintained but not owned by the County. Others are owned and maintained by the State, villages and towns in the County.

Rules and Regulations. - In accordance with the County Government law of Nassau County, all plans for storm water drainage and recharge basins require approval by the Nassau County Planning Commission and the Commissioner of Public Works.

All storm water drainage systems and storage basins shall be constructed in accordance with the specifications of the local municipal authority (if any) and the Nassau County Department of Public Works. No excavation for a basin shall be made unless and until there shall be constructed a permanent galvanized chain link fabric fence six (6) feet high with brackets one (1) foot high on posts to bear three (3) strands of barbed wire entirely surrounding the proposed excavation.

A concrete curb not less than six (6) inches wide by twenty-four (24) inches deep shall be provided under the entire length of the fence including the gates.

Design: Though the earlier recharge basins, comprising more than one half the total, were single basins, the later and approved design is for basins in two parts of approximately equal size*, the first being a settling basin to remove the sediment, which sould otherwise prevent percolation into the ground, and the second a seepage or percolation basin. These two basins are separated by a dyke but connected by conduits with control gates. In some locations the seepage basin may be at a different (lower) level from the settling basin. Ramps are required for access of maintenance equipment.

The combined capacity of the two parts is made sufficient to impound the estimated runoff from the tributary area, caused by a 5 inch rainfall in two days, this being such a rain as is shown by statistics to be likely to occur once in about 5 years.

The estimation of the run-off requires the choice of certain coefficents selected by judgement according to steepness of the ground and the condition of its surfaces as it may be expected to be 30 years in the future, after residential and business development have increased the percentage of impervious area due to roofs and pavements. As illustrations of these judgement coafficients, 60% of rainfall is a usual figure for residential areas along the steep north shore and 40% for the gentler slopes generally met elsewhere. But 90% is a common figure for business areas, where much more roof and paved area is usual. The total volume of run-off for a given area from the assumed 5-inch rain will be: area in square feet x 5/12 x coefficient of run-off.

Since the settling basin part will silt up within a year or two, it is not counted on for recharge purposes nor is the percolation from the percolation basin counted on to reduce the required storage for the run-off from the 5-inch two-day design storm, but the total capacity of the two basins is designed to store the total run-off from the storm and seepage from the percolation basin between storms is counted on to empty the basins to prepare them for the next storm.

Experience has shown, allowing for the human element in maintaining the basins, that the dependable seepage rate is 24 gallons per square foot per day of 24 hours or about one million gallons per acre per day. Elaborate tests** extended over several years on a small basin within the settling basin at Rockaway Road, shown on Exhibit B, indicated much higher rates of seepage; however in design a factor of safety of at least 2 should be used. This is provided in effect by the use of the volumetric determination with the 5 inch rain as the basis for design for a depth of 10 feet and a horizontal surface area which includes the side slopes.

A very rough estimate of artificial recharge through this method of replenishment in Nassau County is 40 million gallons per day based upon the run-off estimate from tributary watershed areas to the basins, at the present time. Detail studies are in progress to estimate this replenishment more exactly.

* See Exhibits A & B.

**See "Progress Report on the Disposal of Storm Water at an Experimental Seepage Basin near Mineola, N.Y." by H.D. Brice, C.L. Whitaker and R.M. Sawyer of U.S.G.S., Surface Water Branch, covering seepage tests from 1949 to 1952 inclusive.

Analysis of Water From Storm Water Recharge Basins: Samples of water were taken by yourself, Charles A. Niles and the writer at the following three recharge basins in May 1956:

Basin #120 - Raff Avenue & Carnation Avenue, Floral Park
Basin #121 - Stewart Street, Floral Park
Basin #123 - Old Country Road & Rockaway Road, Garden City

Chloride, iron and dissolved solids content: Department of Public Works Laboratory report dated May 25, 1956, Exhibit C.

Phenol content: Water in basins at same locations set forth above sampled by Willard G. Sweeney, Chemist, on November 1, 1956. Laboratory report dated November 2, 1956, Exhibit D.

Note that no phenol was indicated for samples at Basins #120 and #123 but at #121 it was 0.01 p.p.m. In accordance with United States Public Health standards the maximum is 0.001 p.p.m. It is obvious that the higher content in Basin #121 is reduced to a negligible amount by dilution when the recharge water seeps into ground water below the basins.

The phenols no doubt originate from the storm water run-off where street pavements and roads had been surface treated with tar bituminous material. No phenol is present from asphaltic surface treatment.

The analysis shows that the chlorides and dissolved solids are below the maximum permitted and only in Basins #120 and 121 the iron content was above the maximum.

In accordance with the information furnished by Terrance McCormack, Director of the Division of Sanitation of the Nassau County Department of Health, there has been no indication of contamination bacteriologically or chemically in any public water supply well where the latter are located in proximity to any of the artificial recharge basins in the county.

Costs: The average cost of construction of the recharge basins is difficult to determine as aid was rendered by other departments of the County to the Department of Public Works, also financial assistance was given by the Federal Government under W.P.A. on a number of the projects.

In recent years, costs have varied for the reason that the material excavated by the contractors has been transported to be used as fill at other locations and at values in accord with supply and demand, but usually less than $1.00 per cubic yard. On one project the contractor paid the County one cent per cubic yard which amounted to $7,200.00 instead of being paid for excavation.

The cost of installing the chain link fence and concrete curb hereinbefore described for labor and material is about $5.00 per running foot.

On one of the projects landscaping cost $13,647.00 including planting trees and shrubs $5,500.00, grass seeding $1,200.00, park benches $12.00 each and excavation additional. Landscaping includes topsoiling, seeding, liming, fertilizing and screen planting.

The method of paying for the recharge basins constructed by the County including maintenance and operations is based upon an advalorem tax

county wide. In new developments, the developer pays the entire cost of construction. Municipalities dedicate the ownership to the County for subsequent maintenance and operation by the County.

Maintenance of Recharge Basins: To keep seepage at maximum values, the seepage basin floors are harrowed with a smooth wheel harrow usually twice a year. The surface penetration is two inches with depth controlled by a hydraulic lift on the tractor. Harrowing is done when the basin floors are dry and when weed growth is small This operation kills all weed growth and keeps the bottom at all times clean and the surface open and porous.

Due to the protection afforded by the settling basin, there is no large amount of silt accumulated in the seepage basins. However, if the thin layer of silt which does accumulate is not broken up, it seals the surface and will in a short time diminish the basin's capacity for seepage. It was found that the harrow method with controlled depth was the best answer. Harrowing in the settling basins is only for weed control.

Experience has shown that weed killing does not open up the surface; oxidation of organic matter forms a gas which retards seepage. Many of the basins have been treated in the manner above described for over ten years after which in some cases it has become necessary to remove the top mixture of silt and gravel and replace it with clean gravel and sand. A bulldozer and trucks are used for this purpose.

Maintenance forces consist of patrols of one foreman and five men, trucks and equipment. Each patrol maintains about 60 recharge basins.

The use of kerosene flame-throwers to remove deep-rooted weeds has been tried and abandoned; also the use of sodium arsenate has been discontinued as a weed-killer for the reason that it is toxic and would contaminate the ground water.

At locations where the basins have been constructed by the County Department of Public Works, they have been graded, landscaped, planted, and developed into park areas for recreational use, with winding paths, flowering scrubs, and park benches so that from an esthetic standpoint they are an asset to the community and in addition replenish the ground water supply, our heritage - one of the most valuable of our natural resources.

Mosquito Control: Since some water stands in the basins after storms until it disappears by percolation into the ground or evaporates, and stands for a longer time in the seepage basins due to the silt, it is necessary at times to treat the bottoms of the basins to prevent breeding of mosquitoes.

The Mosquito Control Division of the Nassau County Department of Public Works uses 2 per cent D.D.T. emulsion (stable) at the rate of 12 gallons per acre in the impounding basin to eliminate mosquito breeding, which emulsion does not contaminate the ground water in view of the high dilution factor. A 5 percent solution would not kill fish life. The spraying with this emulsion is done about once every two weeks, depending upon the breeding season and temperature and clarity of the water. Some locations only require treatment once a season.

Diffusion Wells: In some locations in Nassau County where saving in cost will result - and the same idea has been used in Suffolk County and in the Borough of Queens, New York City - a so called diffusion well design has been used to collect the run-off from some areas lesser than those served by recharge basins. Certain parking fields and street intersections are examples of such practice.

The nature of these diffusion wells is shown by the three photographs included as exhibits E, F and G. The diffusion wells consist of prefabricated, reinforced concrete pipe sections with flared openings in the barrels for release of the water into the ground. One type of pipe section is 7-1/2 feet in diameter and 4 feet in length; the other is 10 feet in diameter and 6 feet in length. The larger sections have walls 7 inches in thickness up to a depth of 60 feet and 10 inches for greater depths. Sections are fastened together in six places with vertical steel straps through the slotted openings, double straps being used for depths over 60 feet. The bottom section has a steel cutting edge to help sink the well by the open caisson method. A cast iron frame and cover in the reinforced concrete slab over the diffusion well provides access for cleaning out the bottoms of the diffusion wells. Catch basins through which the water to be diffused reaches the wells are provided with space for the removal of heavy silt.

Tests have indicated diffusion rates up to 440 gallons per square foot of seepage area per day, seepage area being reckoned as noted under (b) below. The wells work best when their bottoms are not less than 6 feet below the highest ground water level. Designs are based on the following rules:

(a) The volume capacity below the invert of the discharge inlet shall equal the run-off from a 4-inch rainfall in one (1) day, based upon a composite coefficient of run-off which takes due account of the rapid run-off and short time of concentration from this type of area.

(b) The seepage capacity is equal to the square feet of openings in the side walls plus the area of the bottoms multiplied by an estimated rate of seepage which depends upon the perviousness of the subsurface materials. The maximum rate of seepage, used only for the most pervious ground, is 440 gallons per square foot in 24 hours.

(c) The volume capacity as computed under (a) shall not be less than the seepage capacity under (b).

OUTPOST OBSERVATION WELLS

The County of Nassau and the State Water Power and Control Commission have been engaged in a co-operative project with the United State Geological Survey in the installation of outpost observation wells since the year 1952 in the southwest area of the County. The purpose of the program is to safeguard the public water supply systems by obtaining early notice of salt water intrusion into the underground waters and of dangerours lowering of the fresh water table.

Attached hereto is a map Exhibit H entitled "Observation Wells on Long Island, N.Y. (Exclusive of Nassau County Grid System) Nassau County Department of Public Works in Co-operation with the United States Geological Survey, Division of Sanitation and Water Supply, Mineola, New York, dated

November 1950, Revised 6/7/54."** This map shows the location and State numbers of the following: water table wells, Lloyd wells, selected wells, Magothy wells, Jameco wells and recorder wells. The selected wells, consist of 14 wells in the glacial formation (Upper Pleistocene), of which 7 are located in Nassau County and 7 in Suffolk County.

A tabulation showing the geologic formation, state number, casing diameter, screen setting and location of each outpost artesian well is shown on Exhibit J.#

Exhibit K* is a tabulation showing water level average M.S.L. each month and the annual average for the 14 selected glacial observation wells location shown on the map.

Co-operative Work. The work on outpost wells was progressed in accordance with a co-operative agreement dated September 19, 1951 between Nassau County and the United States Geological Survey Department of the Interior and between the Water Power and Control Commission and the survey. The Long Island Water Corporation also contributed funds for the work.

1st Stage	Year 1952	
Nassau County		$10,000.00
Water Power & Control Commission		10,000.00
Long Island Water Corporation		10,000.00
	Sub Total	$30,000.00
United States Geological Survey		30,000.00
	Total	$60,000.00

2nd Stage	Year 1953	
Nassau County		$10,000.00
Water Power & Control Commission		10,000.00
	Sub Total	$20,000.00
United States Geological Survey		20,000.00
	Total	$40,000.00

Grand Total $100,000.00

The first group of 10 observation wells was completed with funds and services made available in the fiscal year 1952 and the second group of 3 wells with funds made available in the 1953 federal fiscal year.

Other outpost wells not listed in the cost of well construction which follows were installed by the Nassau County Department of Public Works, with its forces and equipment under the author's direction, and the United States Geological Survey.

**This map is not reproduced in the Wiggin Report but a tracing and several prints have been filed with the Suffolk County Water Authority. Detailed information on data derived from the use of these wells will doubtless be found in the report, when available, which is mentioned in Section G4 of the Wiggin Report on Suffolk County Water Supply. Section G4 is in Appendix G

Not included in report but filed with the Authority.

* Not included in report but filed with the Authority.

The contract cost of installations by the well drilling contractor under Federal Contracts is listed on Exhibit L entitled "Outpost Well Costs", a grand total of $73,102.00 actural cost which includes core samples, well casings, screens, electric logging and development of the wells.

In the 1956-57 year program, an appropriation in the amount of $6,000 has been recommended by the author for co-operative work by Nassau County to be matched by an equal amount by the United States Geological Survey, a total of $12,000.00 for the installation and services of an additional outpost well in the northwest area of the County which is also a potential critical area due to heavy pumpage by the public water supply systems. In addition the Department of Public Works installed observation wells of less depth in the artesian formations.

Chloride Content of Water Samples-Outpost Observation Wells.

A typical laboratory report of the Nassau County Department of Public Works is shown on Exhibit M showing well number, time sampled, date and clorides p.p.m. for the outpost wells sampled. With the exception of 2 of the wells which indicated low chloride content, well #3861 at Cedarhurst has varied from 16,000 p.p.m. to 22,000 p.p.m. and N-3862 at Lawrence a small range above and below 1,920 p.p.m.

Maintenance and Operation of Outpost Wells. The outpost wells are maintained by the United States Geological Survey and samples of water taken by the Department of Public Works for chloride analysis in the laboratory of the Department monthly.

Conclusions - Outpost Wells. - There is every indication that the salt water front has moved inland beyond well #3861 at Cedarhurst and well #3862 at Lawrence in the Magothy formation and the chloride content at a greater depth below the screen is as high as that at the Cedarhurst outpost well. It is estimated that the salt water front is moving inland in the Magothy formation at a rate of one hundred feet a year in view of the heavy concentration of pumpage in the southwest area, also a downward trend of static water levels in the Magothy and Lloyd aquifers.

In the northwest area of the County, there is also a downward trend of static water levels in the artesian formations due to a heavy concentration of pumpage by the public water supply systems.

REFERENCES

Published articles prepared by the author.

Comprehensive Drainage Plan and Summary Report Nassau County Sanitation Commission 1935.

Conservation of Ground Water Resources, Nassau County, N.Y.

Water Works Engineering 1949, August - p.p. 708-710 and 741.

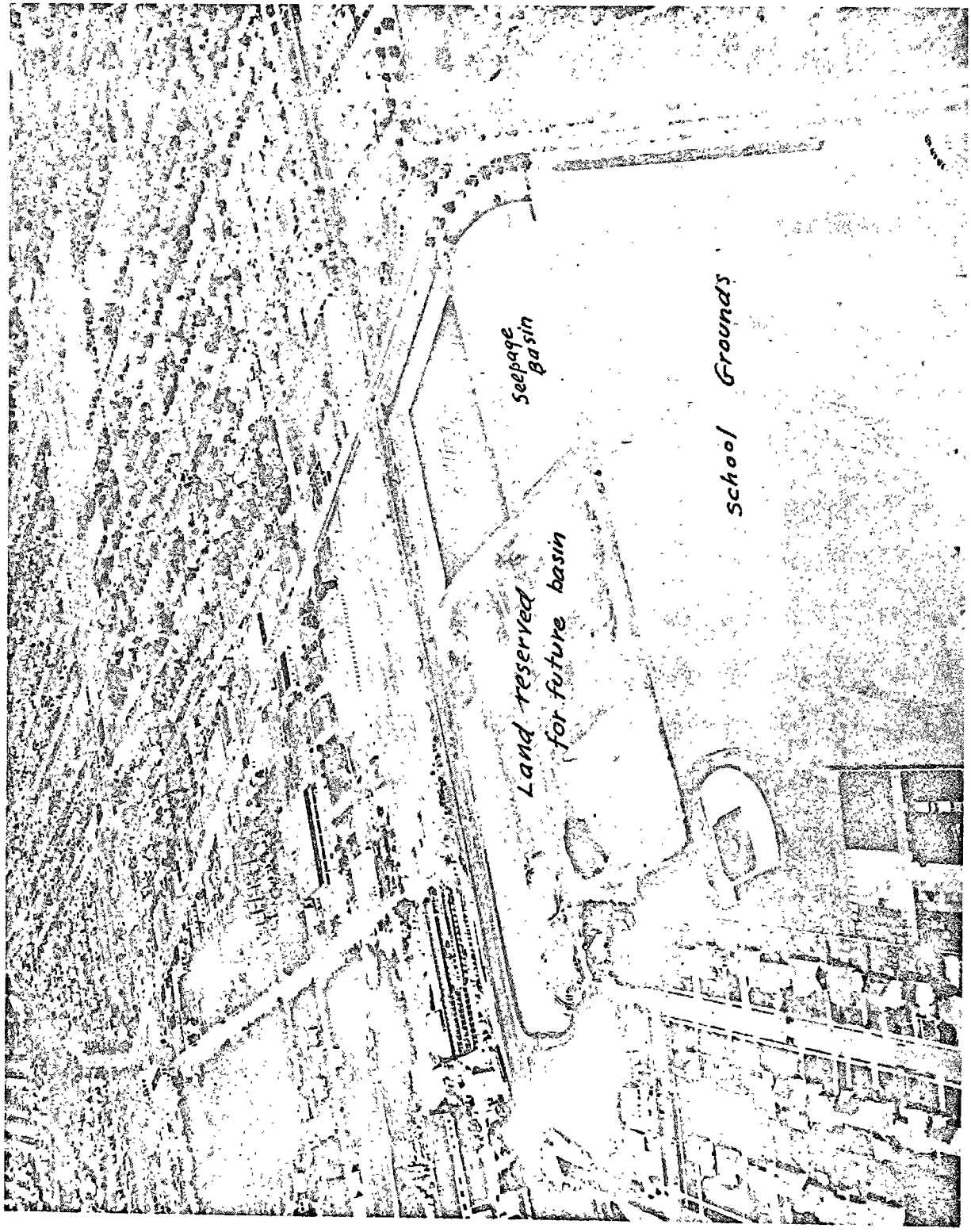
Outpost Observation Wells - American City 1952, May , p.p. 106-107.

Water and Sewage Works 1956, Volume 103 - p.p. 468 to 473.

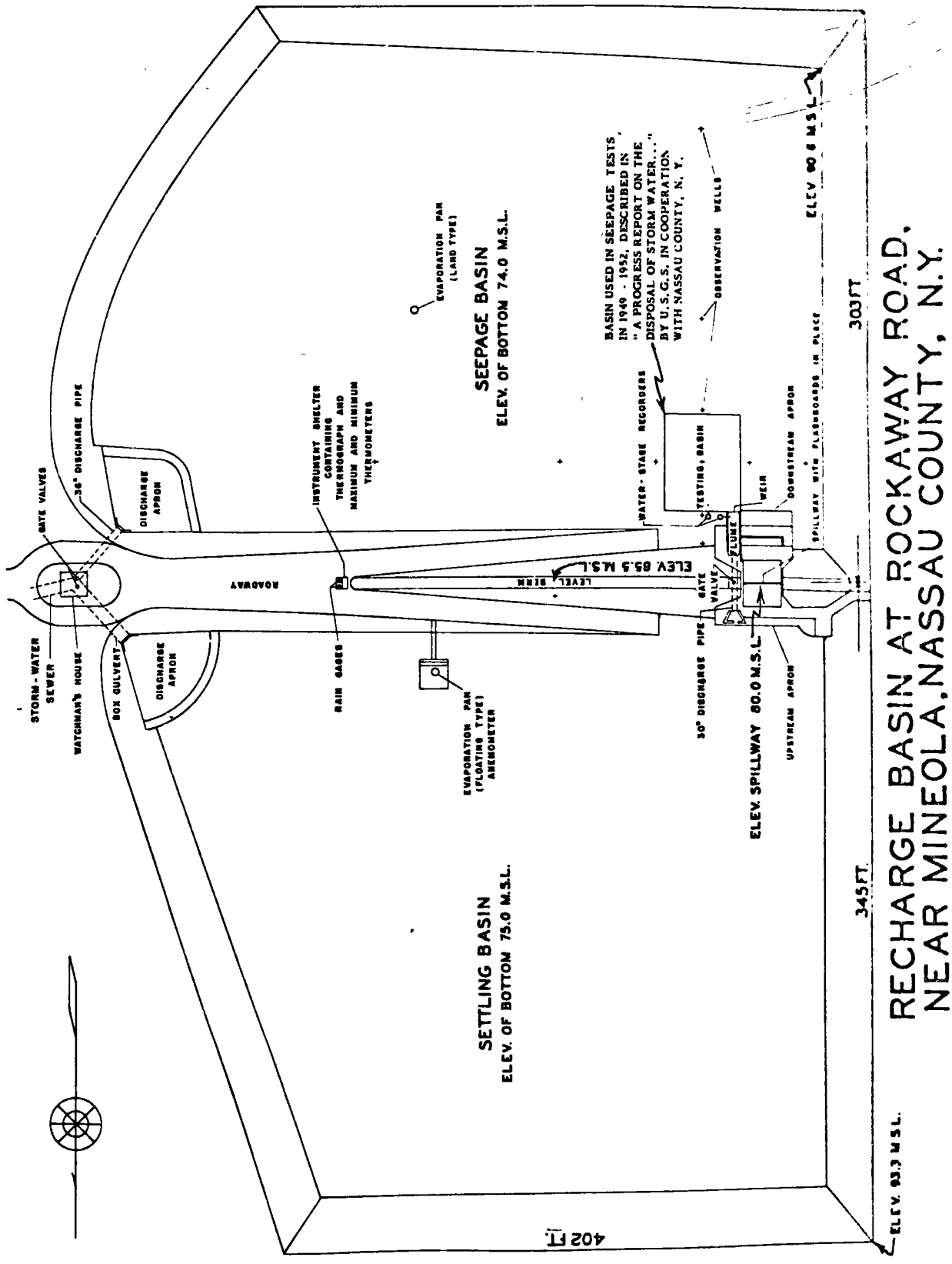
Diffusion Wells, American City, January 1955, p. 98.

Diffusion Wells - Questioned and Defended - American City April 1955, p. 7.

January 1957. (Signed) W. Fred Welsch, P.E.-L.S.



RECHARGE BASIN NO. 123
ROCKAWAY & OLD COUNTRY ROADS
Garden City, N. Y.


RECHARGE BASIN AT ROCKAWAY ROAD,
NEAR MINEOLA, NASSAU COUNTY, N.Y.
SEEPAGE BASIN
ELEV. OF BOTTOM 74.0 M.S.L.
SETTLING BASIN
ELEV. OF BOTTOM 75.0 M.S.L.
ROADWAY
STORM-WATER SEWER
WATCHMAN'S HOUSE
GATE VALVES
30" DISCHARGE PIPE
BOX CULVERT
DISCHARGE APRON
DISCHARGE APRON
INSTRUMENT SHELTER CONTAINING THERMOGRAPH AND MAXIMUM AND MINIMUM THERMOMETERS
RAIN GAGES
EVAPORATION PAN (FLOATING TYPE) ANEMOMETER
EVAPORATION PAN (LAND TYPE)
ELEV. 85.5 M.S.L.
LEVEL BERM
BASIN USED IN SEEPAGE TESTS IN 1940 - 1952, DESCRIBED IN "A PROGRESS REPORT ON THE DISPOSAL OF STORM WATER..." BY U.S.G.S. IN COOPERATION WITH NASSAU COUNTY, N.Y.
WATER-STAGE RECORDERS
TESTING BASIN
OBSERVATION WELLS
GATE VALVE
30" DISCHARGE PIPE
PLUME
WEIR
ELEV. SPILLWAY 80.0 M.S.L.
DOWNSTREAM APRON
UPSTREAM APRON
SPILLWAY WITH FLASHBOARDS IN PLACE
ELEV. 80.0 M.S.L.
ELEV. 83.3 M.S.L.
303 FT.
345 FT.
402 FT.

Appendix J Exhibit "C"

1 c.c. Mr. Guibert
6 c.c. Mr. Welsch
1 c.c. Lab.

COUNTY OF NASSAU

Inter-Departmental Memo

May 25, 1956

To : Mr. W. Fred Welsch

From : Willard G. Sweeney

SUBJECT: Analysis of Water from Storm Water Basins

LABORATORY REPORT

Lab. No.	W 42/56	S.W.Basin #120	Raff Ave.& Carnation Ave. Floral Park
Lab. No.	W 43/56	S.W.Basin #121	Stewart St., Floral Park
Lab. No.	W 44/56	S.W.Basin #123	Old Country Rd.& Rockaway Rd.

Analysis

	Chlorides	Iron	Dissolved Solids
W 42/56	6 ppm	0.4 ppm	218 ppm
W 43/56	2 ppm	0.8 ppm	212 ppm
W 44/56	4 ppm	0.1 ppm	132 ppm

Willard G. Sweeney
Willard G. Sweeney
Division of Laboratories

WGS/mg

1 c.c. Mr. Guibert
6 c.c. Mr. Welsch
1 c.c. Lab.

COUNTY OF NASSAU

Inter-Departmental Memo

November 2, 1956

To :
Mr. W. Fred Welsch
From :
Willard G. Sweeney

SUBJECT:
Test for Phenol in Storm Water Basins
Laboratory Reports W-67; W-68 and W-69

On November 1, 1956 the Laboratory sampled three storm water basins. The period was selected because it followed a new record rainfall. The test method used was that outlined in Standard Methods for Examination of Water and Sewage, 9th Edition, APHA, using dibromoquinonechlorimide indicator.

RESULTS

Sampled November 1, 1956 by D. A. Gorton

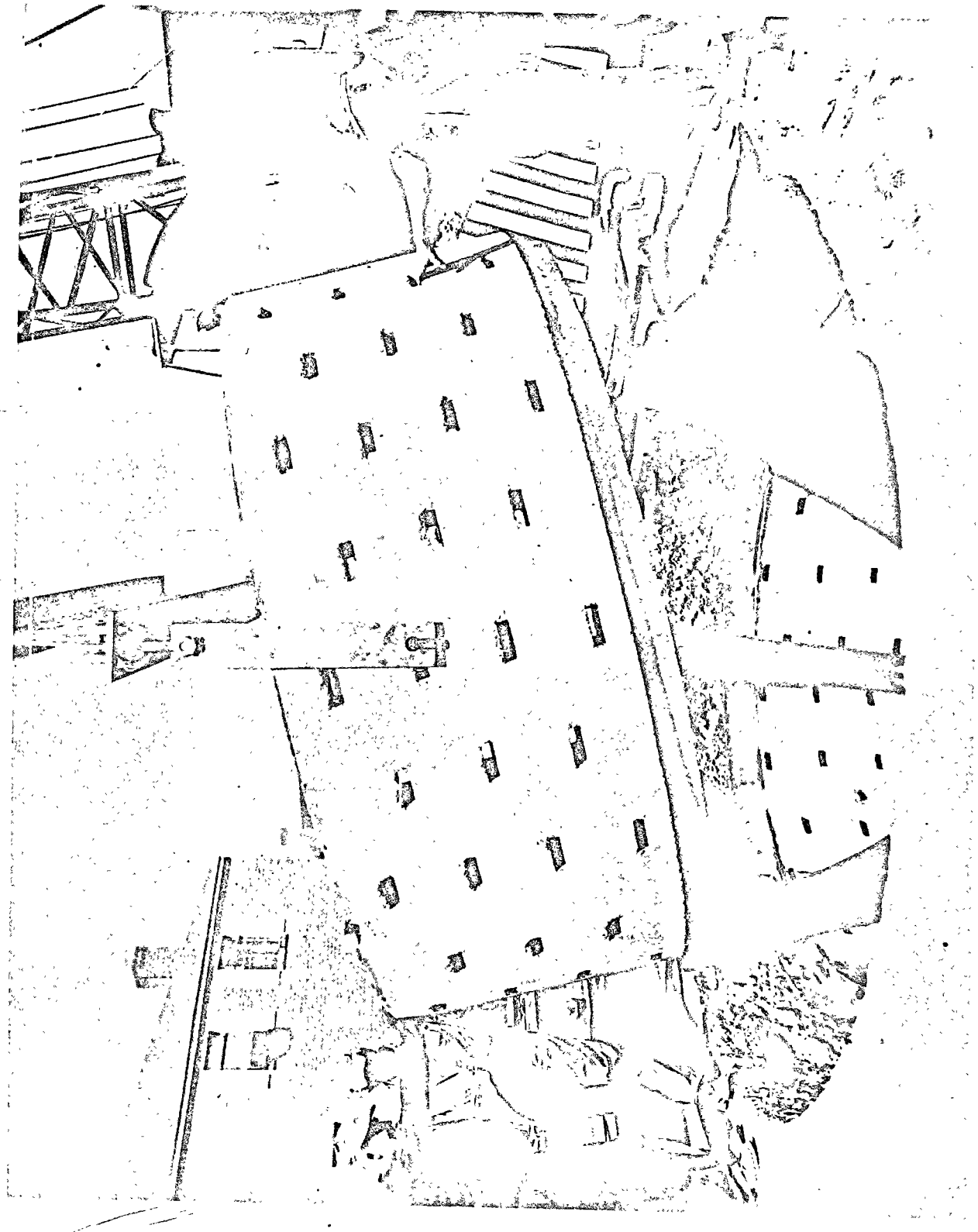
Report No. W-67/56 Storm Water Basin 123, Old Country Road and Rockaway Avenue, Garden City
0.01 ppm

W-68/56 Storm Water Basin 120, Raff Avenue and Carnation Avenue, Floral Park
0.00 ppm

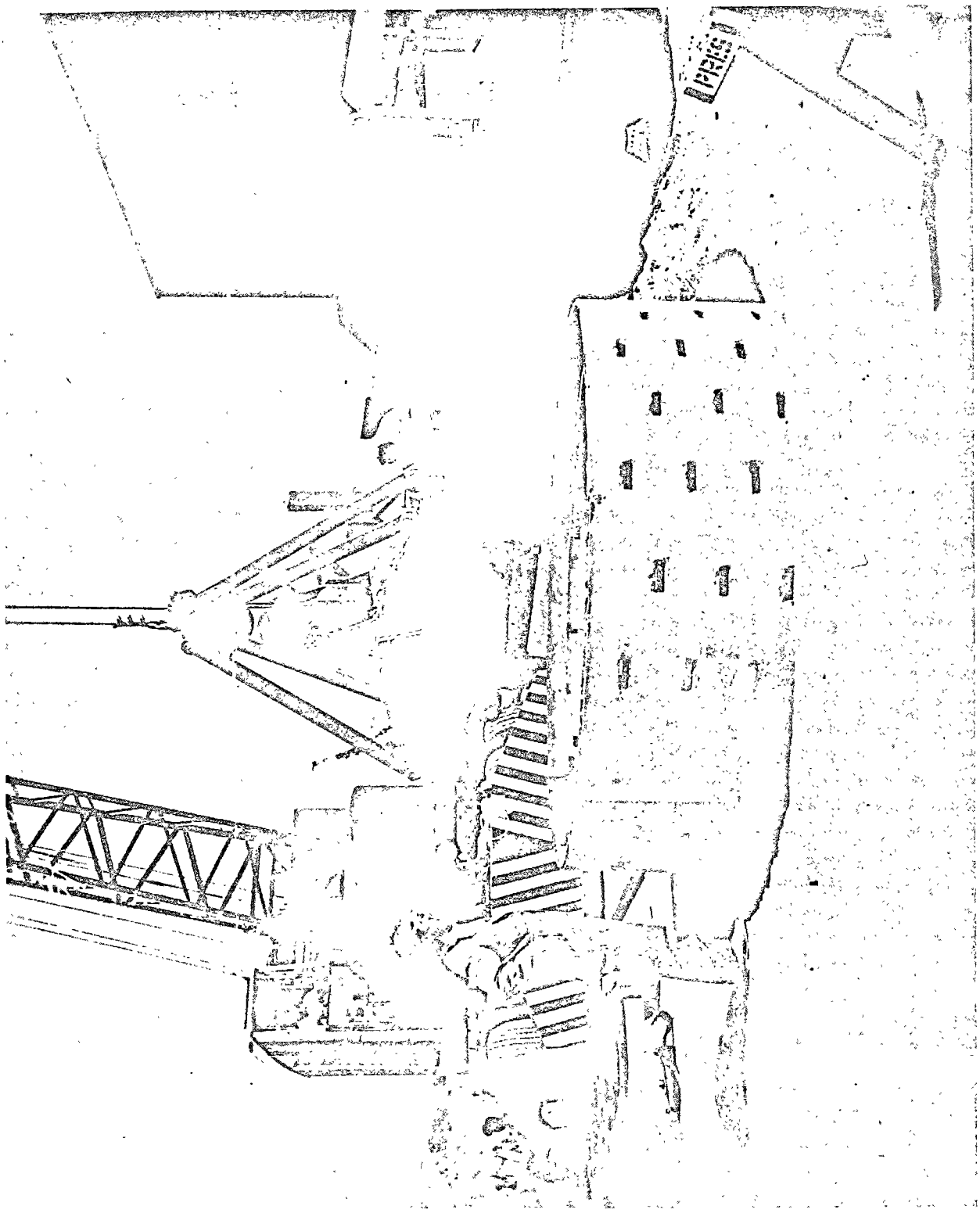
W-69/56 Storm Water Basin 121, Stewart Street, Floral Park
0.01 ppm

Willard G. Sweeney
Willard G. Sweeney

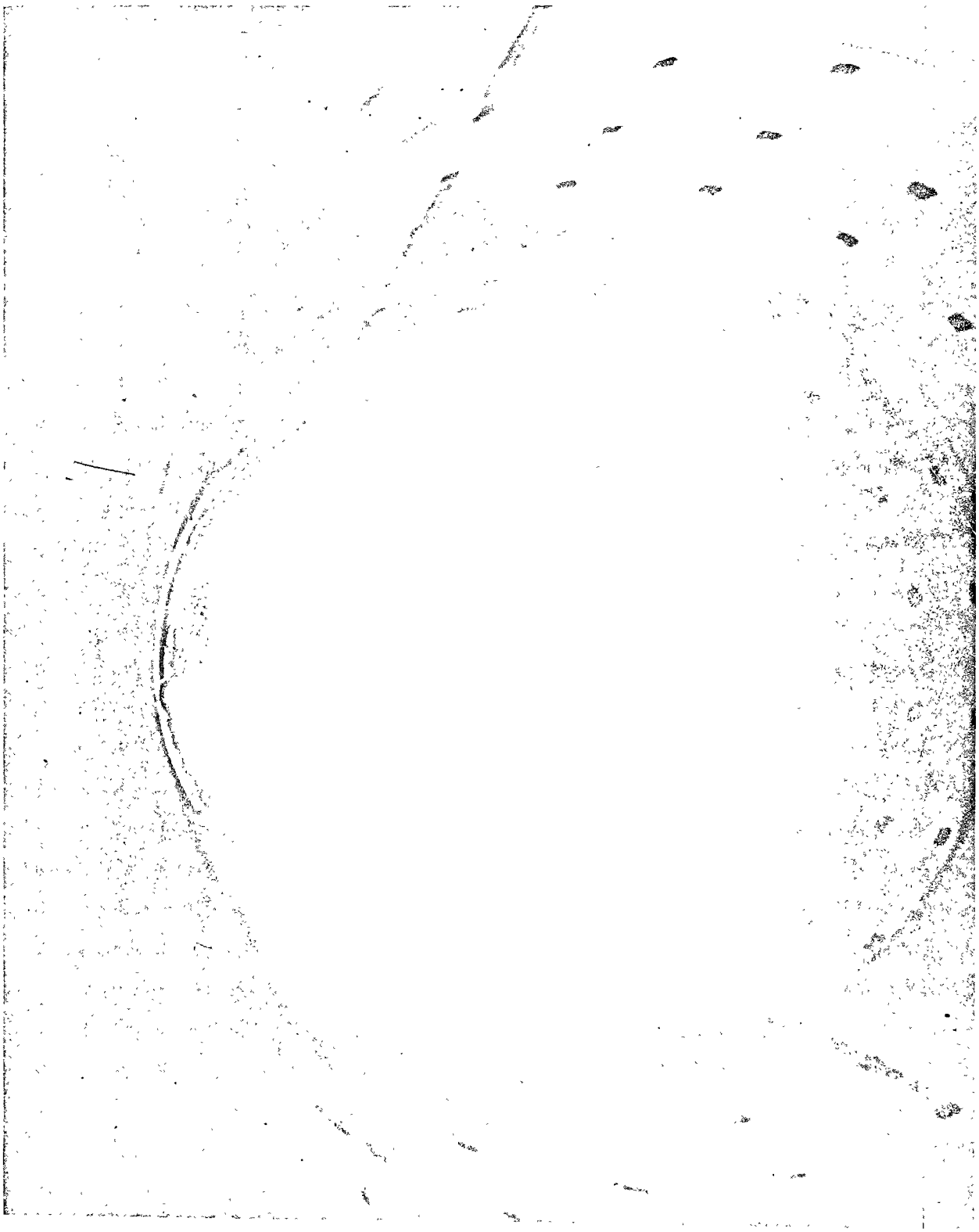
WGS/mg



DIFFUSION WELL FOR SURFACE WATER



DIFFUSION WELL FOR SURFACE WATER



DIFFUSION WELL FOR SURFACE WATER

Exhibits H, I, J and K are referred to in the text
but not included in this document.

OUTPOST WELL COSTS

Well No.	Location	Screen Bottom	COST 1952 Contract
N-3861	Cedarhurst	530'	$7,226
3862	Lawrence	305	7,231
3864	Valley Stream	470	7,039
3865	Oceanside	563	8,718
3866	Hewlett	411	5,669
3867	Green Acres	515	6,717
			$42,600
			1953 Contract
4149	Merrick	562	$11,042
4150	Freeport	745	11,962
4266	Great Neck	370	7,498
			$30,502
		GRAND TOTAL	$73,102

HLF-ec

11/15/56

1 c.c. Mr. Guibert
6 c.c. Mr. Welsch
1 c.c. Lab.

COUNTY OF NASSAU

Inter-Departmental Memo

May 15, 1956

To Mr. W. Fred Welsch

From Willard G. Sweeney

SUBJECT: Laboratory Report - W 31-41/56

Sample of: Well Water
Sampled by: Mr. E. Ogle

Lab. No.	Well No.	Time Sampled	Date	Chlorides PPM
W-31	N-1379	12:35 PM	5-7-56	2
W-32	N-2790 Bay Park	12:30 PM	5-4-56	5
W-33	N-3861	11:40 AM	5-1-56	16,000
W-34	N-3862	11:15 AM	5-2-56	1,920
W-35	N-3864	12 Noon	5-7-56	4
W-36	N-3865	12 Noon	5-4-56	5
W-37	N-3866	12:25 PM	5-2-56	3
W-38	N-3869	12:05 PM	4-30-56	5
W-39	N-3932	12:20 PM	5-1-56	6
W-40 *	N-4062	10:20 AM	5-2-56	80
W-41	N-4213	12 Noon	4-30-56	4

Willard G. Sweeney

Willard G. Sweeney

WGS/mg

* Casing leaks - replace.

APPENDIX K - COMPILED by T.H. WIGGIN
FROM DATA FROM A.H. JOHNSON

DIFFUSION WELLS FOR RETURNING USED WATER TO THE GROUND

Based on information and data from Aruthur H. Johnson, Associated Engineer of Water Power and Control Commission.

Since enabling legislation was enacted by N.Y. State on April 28, 1933, it has been the policy of the Water Power and Control Commission to require that the water from all industrial wells drilled thereafter, having capacities in excess of 69.4 gallons per minute (100,000 gals. per 24 hrs.), be returned to the ground in an uncontaminated condition through diffusion wells or other approved structures.

The policy began to be effective in 1934 and the number of installations thereafter increased rapidly until the count stood as follows on Jan. 1, 1956:

Diffusion Installations

County	Total Installations	Total in Use
Kings	304	242
Queens	230	187
Nassau	479	472
Suffolk	137	137
Total	1150	1038

Note: - These installations do not include those mainly for street drainage described in Appendix J.

Design. - In the development of this new type of equipment for conserving ground water, a considerable number of trial and error designs were tried before the essential were finally understood. The Water Power and Control Commission pursued the wise policy of conferring with groups of well drillers and water supply engineers who were struggling with the problem of design on behalf of owners. From this cooperation and experience the Commission derived not a fixed design, but certain fundamental principles which the Commission has used as requirements in examining designs submitted to it for approval. These, in the words of Arthur H. Johnson, Associated Engineer of the Commission, in charge of the Long Island office of the Commission, are contained in the following quotation from his letter to the author, dated Feb. 6, 1956.

"No particular design is prescribed and no specifications have been drawn up by the Water Power and Control Commission. In checking any proposed design the Commission's engineers require that the following conditions be met:

1. The effective area of the diffusion well screen must be at least twice the effective area of the supply well screen.

2. The actual area of openings of the diffusion well screen must be at least twenty-five percent greater than the corresponding area of the supply well.

3. All water must be returned to the same aquifer from which it was secured.

4. The probable build up at the diffusion well must be such that the water will not flow above the ground surface or be likely to cause building foundation trouble or cellar flooding.

Within the above restructions three different types of diffusion wells have been developed:

1. Standard. Similar in general outline to Enclosure A. This type constitutes the large majority of installed diffusion wells. The screens are set above the static water level, below it, or half above the half below.

2. Indirect Method. This method, Enclosure B, was used successfully in a location where diffusion was difficult and a second installation was made in a similar location last fall.

3. Cesspool method. This method, Enclosure C, has been used successfully in several locations on the South Shore where the static water level is very close to the ground surface."

Copies of Enclosures A. B. & C. will be found at the end of this appendix.

Temperature of Ground Raised: - From early in the experience with these diffusion installations, it was found that diffused water from cooling systems caused an appreciable rise in water from supply wells located even as much as 100 or more feet away, sometimes under different ownership, sometimes causing controversies. In King's County, in localities were wells are close together, an average annual rise in water temperature of as much as 1-1/4 degrees F. has been noted over a period of years, and a temperature as high as about 80°F.has been reached in at least one place, though in general 4 or 5 degrees, viz. from about 55° normal to 60°, is important in cooling water. In some cases auxiliary mechanical cooling equipment has been required.

Some cases of inconvenient temperature rise have been encountered in Nassau County as wells have been located closer together with increasing population. Wells have been sometimes located in deeper aquifers to improve temperature conditions.

Temperature has not become a factor in wells for public water supply which are generally deeper than most other wells.

Capacity of Diffusion Installations:- Mr. Johnson has supplied the following data on Suffolk County installations:

The total capacity of the 137 installations in Suffolk County in use on Jan. 1, 1956 was 12,558 g.p.m. or an average of about 90 g.p.m.

The estimated quantity of water diffused in the year 1955, as given in the "Report of Pumpage" by the Water Power and Control Commission for that year is as follows:

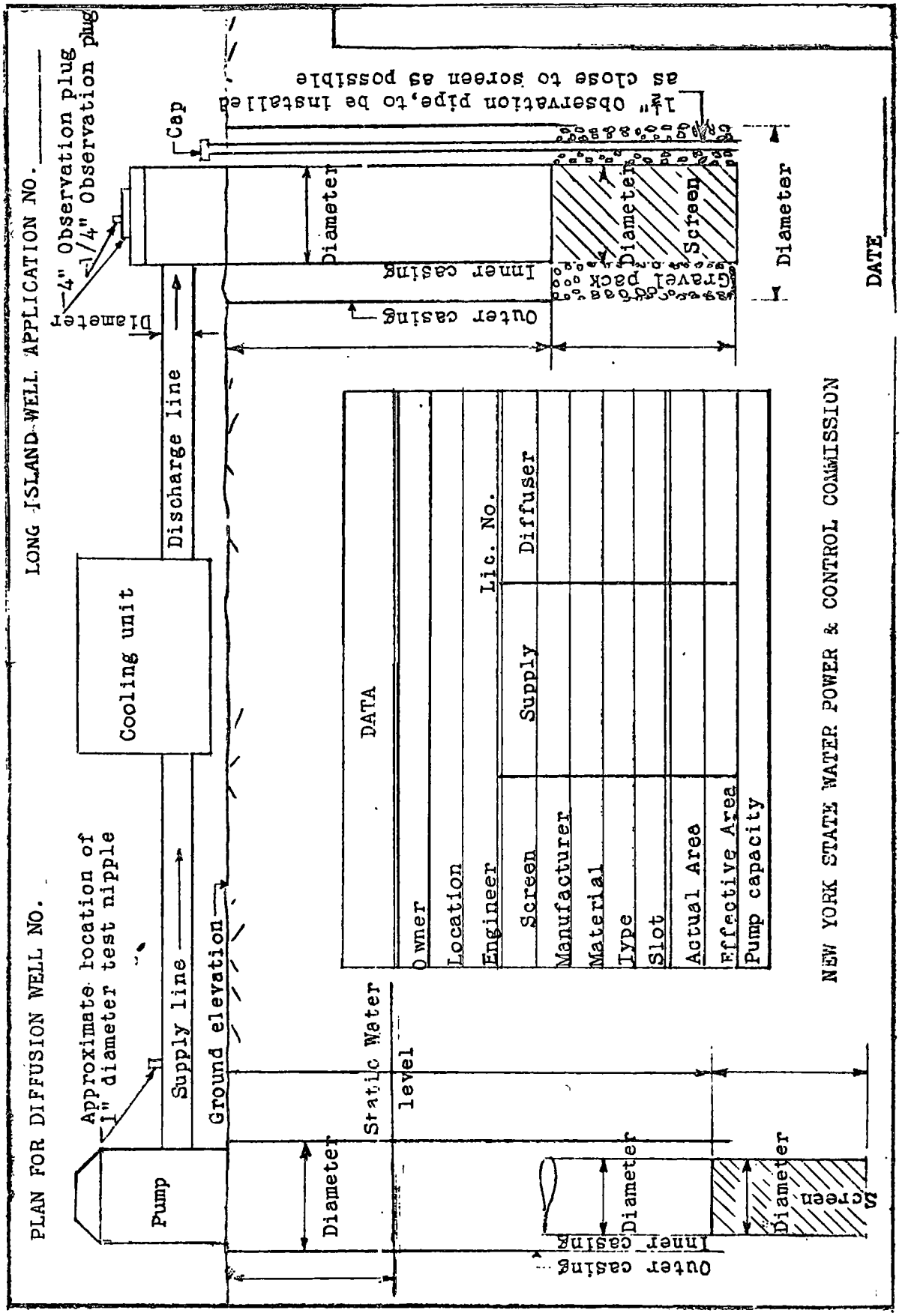
County	Quantity of Water Diffused. For Year, M.G.	Ave.Mgd.
Kings	4644	12.7
Queens	2953	8.1
Nassau	5081	14.0
Suffolk	5318	14.6
	17996	49.4

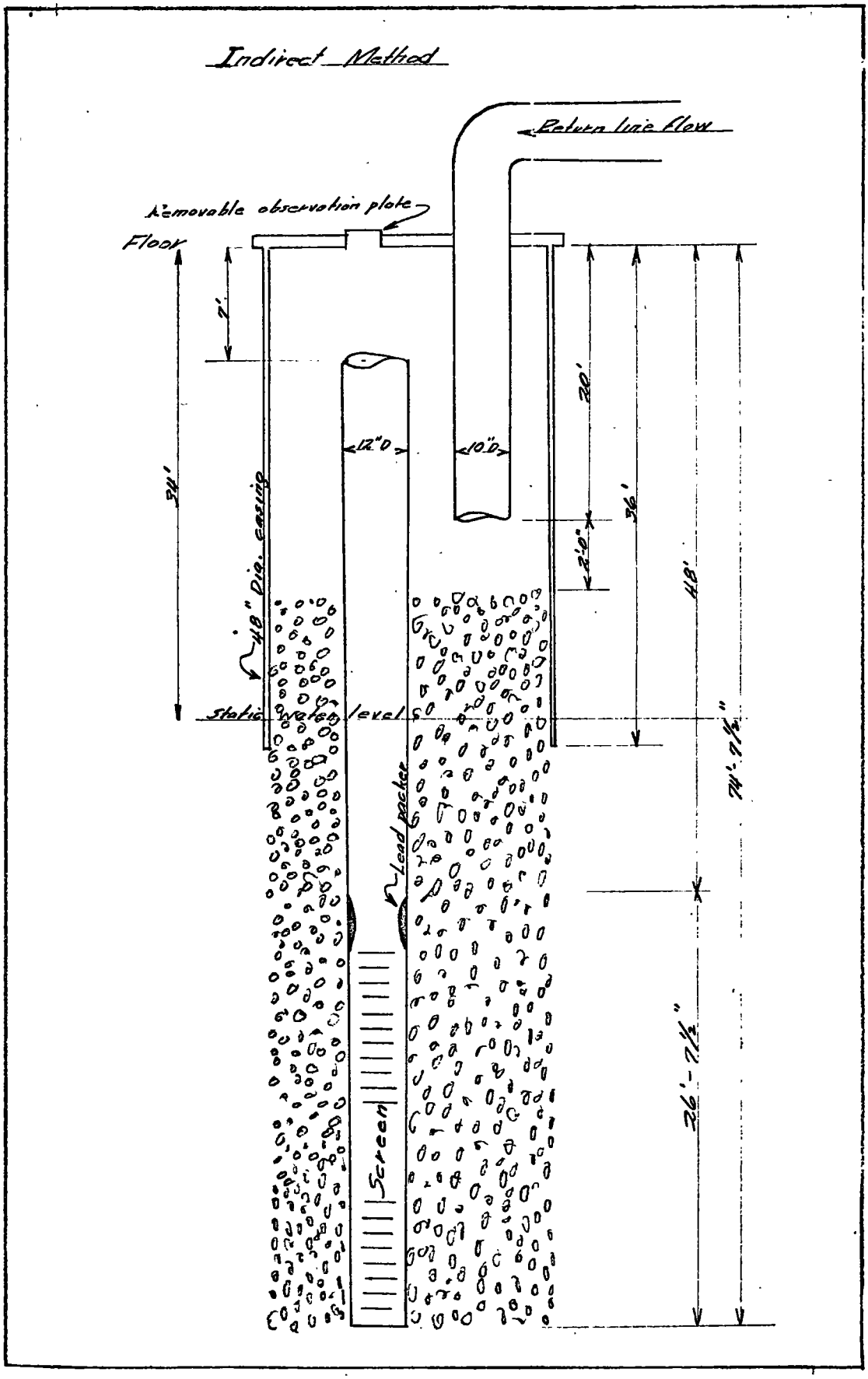
The above quantities include pumped water returned, after use, directly to the ground either into the regular diffusion equipment described in this appendix or into recharge basins (which sometimes receive such water in addition to surface water drainage) or into any other type of equipment from which water percolates into the ground.

As is stated in the 1955 Report of Pumpage, the figures for diffusion in Suffolk County may be high because they contain the capacity of older wells which have not been inspected in recent years.

REFERENCES

Papers by Arthur H. Johnson in A.W.W.A. Journal for Nov. 1948, p.p. 1160-1164 and April 1955, p.p. 348-354.


LONG ISLAND WELL APPLICATION NO. _____
PLAN FOR DIFFUSION WELL NO. _____
Pump
Approximate location of 1" diameter test nipple
Supply line
Ground elevation
Static Water level
Diameter
Outer casing
Inner casing
Diameter
Screen
Diameter
Cooling unit
Discharge line
Diameter
1/4" Observation plug
4" Observation plug
Cap
1½" observation pipe, to be installed as close to screen as possible
Outer casing
Inner casing
Gravel pack
Diameter
Screen
Diameter
DATE
DATA
Owner
Location
Engineer
Lic. No.
Supply
Diffuser
Screen
Manufacturer
Material
Type
Slot
Actual Area
Effective Area
Pump capacity
NEW YORK STATE WATER POWER & CONTROL COMMISSION


Indirect Method
Return line flow
Removable observation plate
Floor
7'
34'
20'
36'
48'
12"D
10"D
2'-0"
48" Dia. casing
Static water level
Lead packer
Screen
74'-7½"
26'-7½"

Cesspool Method

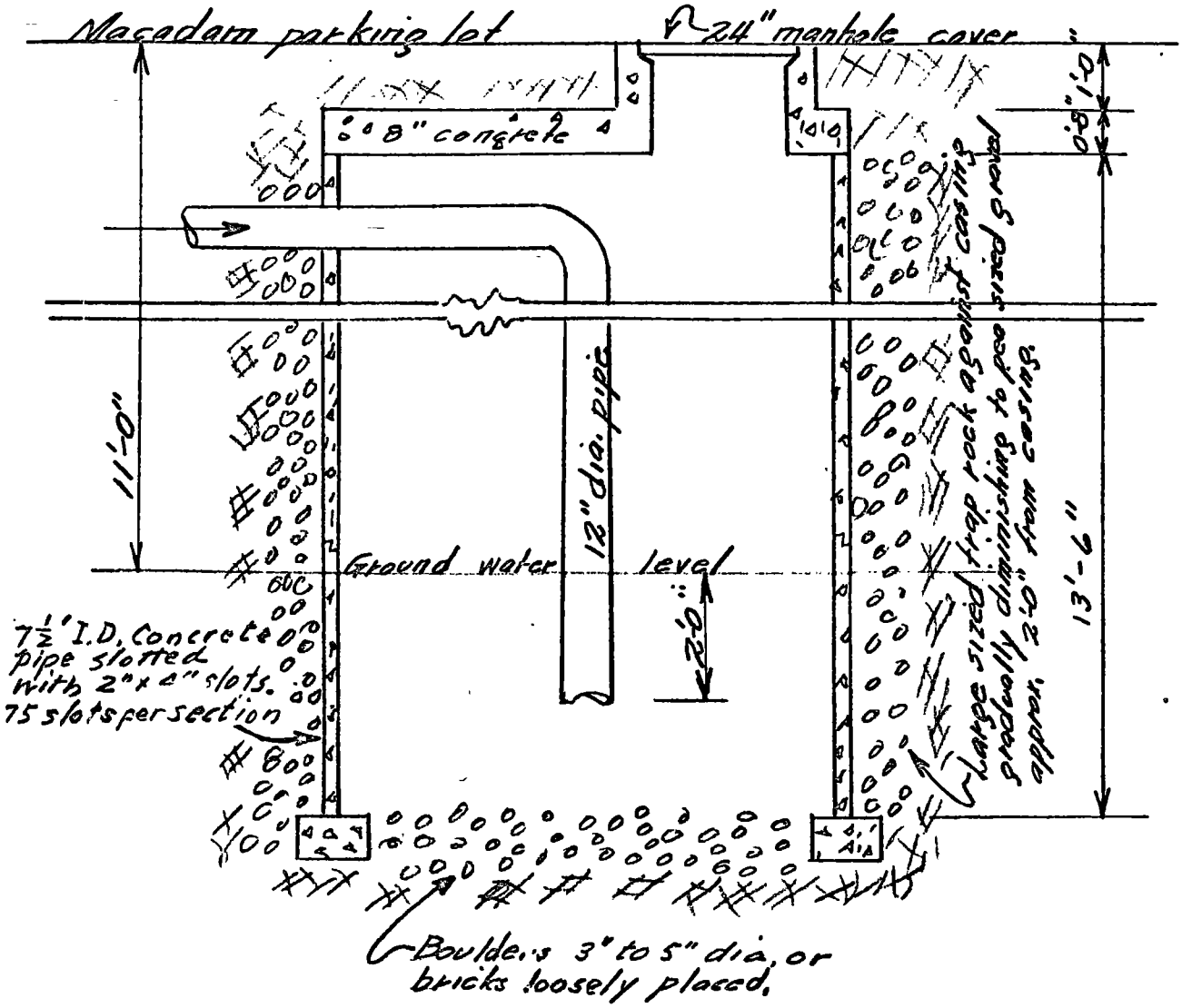
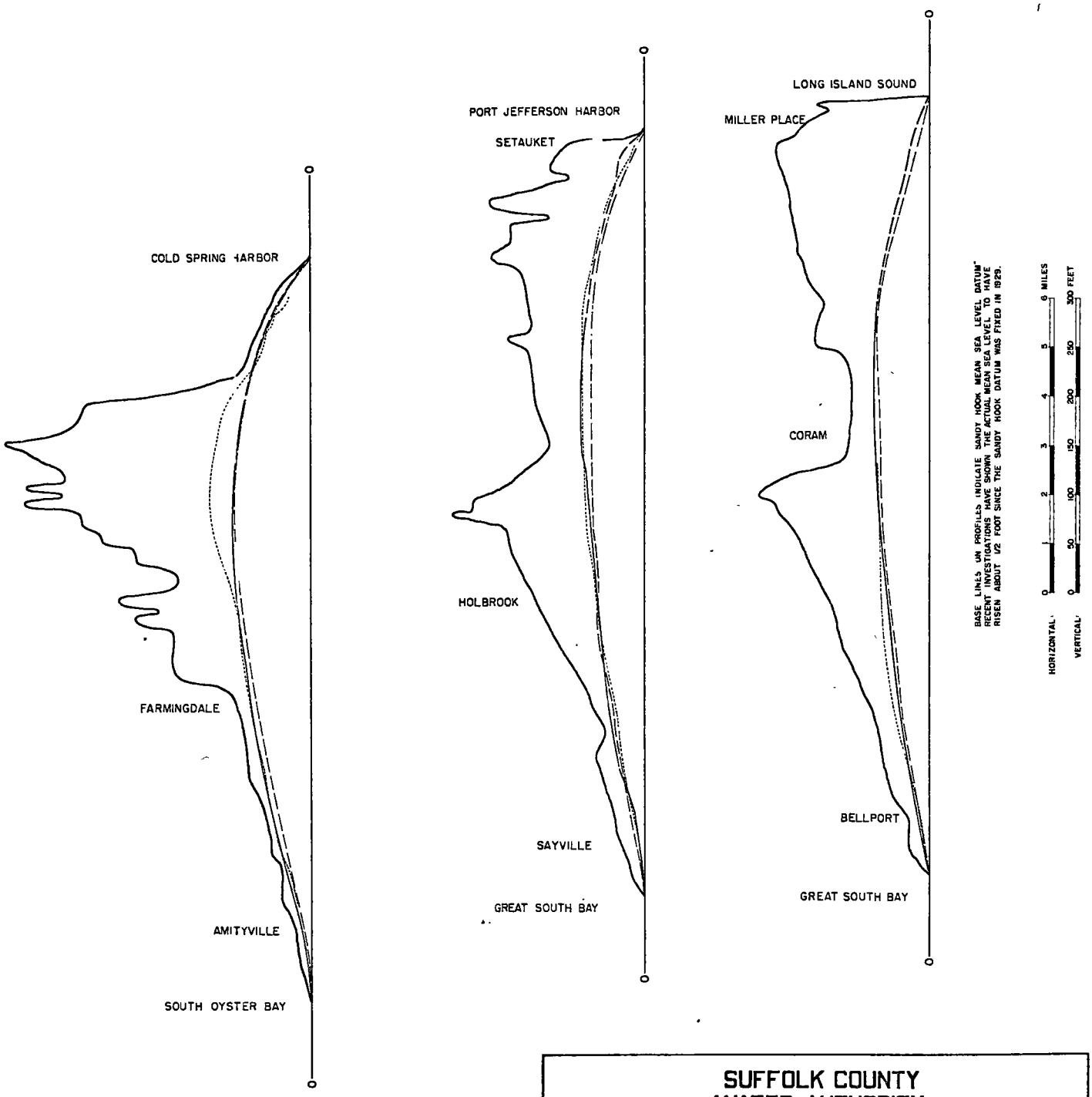


PLATE NO. 1



LEGEND

- WATER LEVELS OF JULY 1, 1903
- WATER LEVELS OF ABOUT JAN. 1, 1951
- WATER LEVELS OF ABOUT JAN. 1, 1956
- APPROXIMATED WATER LEVELS OF ABOUT JAN. 1, 1951
- APPROXIMATED WATER LEVELS OF ABOUT JAN. 1, 1956

NOTE

THE WATER LEVEL PROFILES SHOWN ON THIS DRAWING FOR 1903 AND 1951 AND THE PROFILES OF THE LAND SURFACE WERE TRACED FROM A PRINT OF THE ORIGINAL DRAWING ON WHICH THESE PROFILES, AS WELL AS THOSE FOR NASSAU, QUEENS AND KINGS COUNTIES, WERE MADE FOR PLATE 4 OF BULLETIN G.W. 27 DATED 1951 OF THE NEW YORK WATER POWER AND CONTROL COMMISSION, PREPARED BY THE U.S. GEOLOGICAL SURVEY IN COOPERATION WITH THE NEW YORK WATER POWER AND CONTROL COMMISSION AND NASSAU & SUFFOLK COUNTY OFFICIAL ORGANIZATIONS

THE PROFILES ON THE PRESENT DRAWING FOR JAN. 1, 1956 ARE PLOTTED FROM CONTOURS OF GROUND WATER LEVELS ON MAP OF WATER POWER & CONTROL COMMISSION DATED JANUARY 1956

SUFFOLK COUNTY
WATER AUTHORITY

PROFILES OF WATER TABLE ELEVATIONS IN SUFFOLK COUNTY FOR JULY 1, 1903, JAN. 1, 1951, JAN. 1, 1956

FOR REPORT ON

WATER SUPPLY

FOR WHOLE OF

SUFFOLK COUNTY

JANUARY 1957

THOMAS H. WIGGIN
CONSULTING ENGINEER

PLATE NO. 2

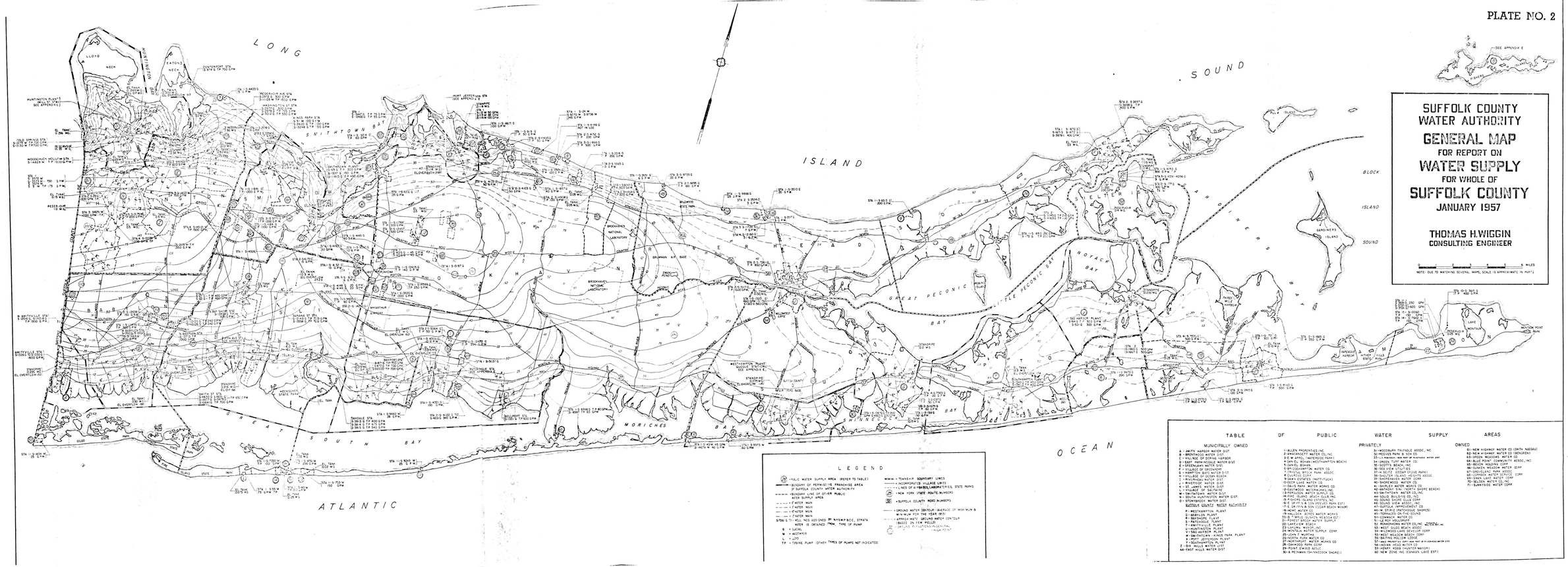


TABLE OF PUBLIC WATER SUPPLY AREAS

MUNICIPALLY OWNED

A - AMITY HARBOR WATER DIST
B - BRENTWOOD WATER DIST
C - VILLAGE OF DERING HARBOR
D - EAST PATCHOGUE WATER DIST
E - EAST SETAUKET WATER DIST
F - VILLAGE OF GREENPORT
G - HAMPTON BAYS WATER DIST
H - HUNTINGTON WATER DIST
I - LAKE RONKONKOMA WATER DIST
J - RIVERSIDE WATER DIST
K - ST. JAMES WATER DIST
L - VILLAGE OF SALTAIRE
M - SOUTH BAYSHORE WATER DIST
N - SOUTH HUNTINGTON WATER DIST
O - STONYBROOK WATER DIST
SUFFOLK COUNTY WATER AUTHORITY
P - WESTHAMPTON PLANT
Q - AMBERLON PLANT
R - BAYSHORE PLANT
S - BROOKHAVEN PLANT
T - SMITHTOWN PLANT
U - HUNTINGTON PLANT
V - EAST MORICHES PLANT
W - SMITHTOWN - NORTH PARK PLANT
X - SOUTHAMPTON PLANT
Y - SOUTHAMPTON PLANT
Z - DIX HILLS WATER DIST
AA - EAST HILLS WATER DIST

PRIVATELY OWNED

1 - ALLEN PROPERTIES INC.
2 - AMAGANSETT WATER CO. INC.
3 - BAY HEAD WATERWORKS
4 - BAY ROAD (WESTHAMPTON BEACH)
5 - BAYVIEW BEACH
6 - BRIDGEHAMPTON WATER CO.
7 - CRYSTAL BROOK PARK ASSOC.
8 - DAVID PARK
9 - DAWN ESTATES (MATTITUCK)
10 - DEER LAKE WATER CO.
11 - DAVID PARK WATER WORKS CO.
12 - EASTWOOD WATERWORKS INC.
13 - EAST HAMPTON WATER CO. INC.
14 - FIRE ISLAND BEACH CLUB INC.
15 - FISHERS ISLAND ESTATES INC.
16 - FIRE ISLAND BEACH CLUB (WEST END)
17 - G. OR ITVIN & SON (CEDAR BEACH WINOR)
18 - HOWE WATER CO.
19 - HALLOCK ACRES WATER WORKS
20 - FIRE ISLAND (WILLIAMSBURG EST.)
21 - FOREST HILLS WATER SUPPLY
22 - LAKEVIEW BEACH
23 - LAKONA MANOR INC.
24 - LAKE SUPPLY WATER CORP.
25 - JOHN T. MURTHA
26 - NORTH PORK WATER CO.
27 - NORTH SHORE WATER WORKS CO.
28 - PARKWOOD INC.
29 - POINT DWIGHT ASSOC.
30 - R. PETMAN (WINDSOR SHORES)
31 - MOODBURY TRIANGLE ASSOC., INC.
32 - REEVES PARK & SON CO.
33 - (A PRIVATE WATER CO. OF MATTITUCK WATER DIST
34 - SHEETS TURF WATER CO.
35 - SEA BEACH BEACH
36 - SEA VIEW UTILITIES
37 - H. SELTZ (CEDAR GROVE PARK)
38 - SHORE ACRES WATER WORKS ASSOC.
39 - SHORELANDS WATER CORP.
40 - SHORE WOOD WATER CO.
41 - SAVILLE WATER WORKS CO.
42 - SOUTHAMPTON WATER CO. (CEDAR BEACH)
43 - SMITHTOWN WATER CO., INC.
44 - SOUTH BUILDING CO. INC.
45 - SOUND SHORE CLUB CORP.
46 - SUFFOLK WATER WORKS
47 - SUFFOLK IMPROVEMENT CO.
48 - M. STRIZ (WATCHOGUE SHORES)
49 - TERRALES (WHITE SOUND)
50 - COMMUNITY WATER CO.
51 - TOWN & VILLAGE WATER CO.
52 - MONROVIA WATER CO. INC.
53 - WEST GULDS BEACH ASSOC.
54 - WEST HAMPTON BEACH CORP.
55 - WEST MEADOW BEACH CORP.
56 - BAITING HOLLOW LODGE
57 - (AND PRIVATE WATER WORKS CO. OF A PUBLIC WATER DIST
58 - CRAFT WATER CO.
59 - HOWARD KOBB (HUNTER MANOR)
60 - NEW ZONE INC (SENECA LAKE EST)

OWNED

61 - NEW HIGHWAY WATER CO (34TH NIDSMU)
62 - NEW HIGHWAY WATER CO (BENGHEN)
63 - BLUE POINT WATER CO. INC.
64 - BLUE POINT COMMUNITY ASSOC., INC.
65 - BEVON HOLDING CORP.
66 - SUNICH MEADOW WATER CORP
67 - GRUNSLANE PARK ASSOC.
68 - HAMPTON HILLS WATER CORP
69 - SWAN LAKE WATER CORP
70 - SELDEN WATER CO. INC.
71 - SUNRYSIDE WATER CORP