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THE RECOVERY OF GROUND-WATER LEVELS IN BROOKLYN, NEW YORK FROM 1947 TO 1950

By Norbert J. Lusczynski

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THE RECOVERY OF GROUND-WATER LEVELS IN BROOKLYN, NEW YORK FROM 1947 TO 1950

ABSTRACT

As a result of condemnation proceedings by the City of New York, the New York Water Service Corp. on June 29-30, 1947, stopped operating permanently its entire ground-water facilities, which served about 350,000 inhabitants in the Flatbush section of Kings County (Borough of Brooklyn in New York City) in western Long Island, N. Y. This corporation, operating within the city limits under a franchise granted by the City of New York, was the last and largest of the several private companies that furnished public water supply to residents of Brooklyn during the past 50 yr or longer. The New York Water Service Corp. utilized as many as 35 wells, which were screened in the shallow water-table formation and in the deeper artesian aquifers lying in its franchise area of about 6 sq mi in the approximate center of Brooklyn.

Withdrawals by this corporation averaged more than 25 mgd during the last 15 yr, having increased gradually since 1904 from about 4 mgd. A reduction of more than 50 percent in the net ground-water withdrawals in the county was realized by the shut-down of pumping of the Flatbush wells. As a result the water table, which was far below sea level for many years, recovered as much as 19 ft at some places in central Brooklyn from June 1947 to December 1950. In the artesian aquifers, similar large recoveries in the piezometric levels also were recorded, which likewise had been appreciably below sea level before the shut-down.

Detailed water-level data, contour maps, profiles, and hydrographs of ground-water levels for the period from 1903-50 are presented and discussed in this report. A compilation of the withdrawals by public water-supply companies and industrial concerns is included. The geology of Kings County is reviewed in brief. Data on the chloride content of well water, pumped during the last month of operation of wells in Flatbush by the New York Water Service Corp., are given also, and compared with salinities before and after the shut-down. More positive answers to special geologic and mutual-interference problems are made possible by data on the recovery of water levels in western Long Island resulting from the large-scale shut-down of pumping from the water-table and artesian formations.

INTRODUCTION

The United States Geological Survey has been cooperating since 1932 with the New York State Water Power and Control Commission in making rather intensive studies of the quantity and quality of ground water in western Long Island. The program provides for the collection and interpretation of hydrologic data as related to ground-water conditions in Kings and Queens Counties. The main purpose of these investigations is to record and report the trend of water levels as affected by precipitation, pumping, and artificial recharge, and to map periodically the changing position of the water table and of the piezometric levels in the water-bearing formations in western Long Island. Prior to 1930, water levels in northwestern Brooklyn had declined to dangerously low levels owing to overpumping by industrial and public-supply wells. This condition brought about salt-water contamination in Brooklyn as evidenced by long-term records of the saline quality of ground water.

The many data on water levels, chloride content, and pumpage presented in this report were obtained throughout the years as part of the regular ever-expanding cooperative program. However, it was necessary to measure about twice as many wells in Brooklyn from 1947-50 in order to record the recovery of water levels in western Long Island in as much detail and as accurately as possible.

This report was prepared under the general direction of A. N. Sayre, chief of the Ground Water Branch, U. S. Geological Survey, and under the immediate supervision of M. L. Brashears, Jr., district geologist, for New York and New England. The compilation of data, tables, and illustrations was made with the assistance of the following present and former members attached to the technical staff of the Mineola office of the New York-New England District: J. J. Geraghty, H. D. Wilson, Jr., C. M. Roberts, L. R. Wistoft, J. F. Hoffman, and Mrs. M. M. Brosge.

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The writer expresses his sincere appreciation to Col. T. H. Wiggin, consulting engineer, New York City, to whom several

references are made in this report in connection with previous studies on the ground-water resources in western Long Island. Acknowledgment is made also to John C. Thompson, executive engineer, and A. H. Johnson, associate engineer, New York State Water Power and Control Commission who offered many helpful suggestions and constructive criticism.

Many valuable data on withdrawal and salinity of ground water were furnished for this report through the courtesy of the New York Water Service Corp., Jamaica Water Supply Co., and the New York City Department of Water Supply, Gas and Electricity. These organizations allowed members of the U. S. Geological Survey access at all times to their wells and well stations, and provided physical assistance in the preparation of the wells for the periodic collection of water-level and other records. Private owners in western Long Island, including those who purchased property from the New York Water Service Corp. in Flatbush, also permitted water-level measurements to be made at wells on their property.

GEOLOGY

The geology of western Long Island, particularly that of Brooklyn, will be sketched only briefly here, as it has been discussed at length by De Laguna (1948) and Suter and others (1949).

Long Island is composed of coastal-plain sediments lying unconformably on a floor of metamorphic and igneous rocks of pre-Cambrian age. A considerable thickness of unconsolidated sediments of Upper Cretaceous age is overlain in most places by a relatively thin mantle of outwash and till comprising the upper Pleistocene deposits. The underlying bedrock, which consists chiefly of gneiss and schist, crops out in a small area in northwestern Queens County and slopes to the southeast at about 80 ft to the mile. The lower section of the Cretaceous sediments is considered to be the Raritan formation and is composed of a clay member which overlies an extensive artesian aquifer called the Lloyd sand member. The upper section of the Cretaceous sediments, called the Magothy (?) formation, is largely fine sand interspersed with numerous relatively thin lenses of clay.

In Kings County in western Long Island, the Pleistocene deposits rest unconformably on the Cretaceous sediments, except in the northwestern section where these sediments have been removed almost entirely. In this county, the Pleistocene deposits are in general much thicker than the Cretaceous, as shown by the geologic cross section (fig. 1), whereas the opposite is generally true elsewhere on Long Island.

The early glacial deposits consist of highly permeable water-bearing glacial outwash--the Jameco gravel--which is overlain by beds of interglacial clay, silt, fine sand named Gardiners clay and associated sand. The Jameco gravel overlies the Cretaceous sediments in central and southern Brooklyn and extends to the northwest beyond the limit of the Cretaceous. The uppermost and youngest sediments on Long Island--all those above the Gardiners clay and associated sand, with the exception of the very small accumulations of Recent material--consist of glacial outwash and till. The more recent of the two terminal moraines on Long Island, the Harbor Hill moraine of Wisconsin age, bisects Brooklyn in a direction approximately northeast to southwest. Glacial outwash is found south of the moraine and till north of the moraine. These were recently classified by De Laguna (1948) in one group as upper Pleistocene deposits.

HYDROLOGY

Local precipitation, averaging about 45 in. annually, is the source of all fresh ground water in Long Island. The percentage of precipitation recharging ground-water reservoirs in Brooklyn was reduced rapidly during the first 25 yr of this century by the works of man--buildings, streets, sidewalks, and sewers--which paralleled the tremendous increase in population in Kings County and the huge industrialization of the northwestern section. The aquifers in Brooklyn are still replenished by precipitation in the county and to some degree by underflow from adjacent Queens County.

In Brooklyn, ground water in the upper Pleistocene deposits occurs chiefly under water-table conditions, although interspersed layers and lenses of clay cause some degree of local confinement, especially in areas north of the Harbor Hill moraine. These Pleistocene deposits are the main source of water supply in Brooklyn. The Jameco gravel is primarily an artesian aquifer, which has circuitous and indirect hydraulic communication with the overlying and underlying aquifers. The interconnection with the upper Pleistocene deposits is provided through the interglacial Gardiners clay, which in many sections in Kings County is relatively sandy. The Gardiners clay has been removed by erosion in some places. In the southeastern section, where the Jameco gravel overlies the sands of the Magothy (?) formation, the two aquifers function essentially as one hydrologic unit. The Lloyd sand member of the Raritan formation, the deepest aquifer on Long Island, is found only in southeastern Brooklyn. It underlies a fairly thick and relatively impermeable clay. Therefore, any flow of ground water from and to the Lloyd sand member would necessarily take place through erosional unconformities, along the contact with bedrock, and through the clay member of the Raritan formation.

Definitions for a few of the basic terms or expressions used in this report are given, as follows:

Coefficient of storage is the cubic feet of water discharged from each vertical column of the aquifer with a base 1 ft square as the water level falls 1 ft. For water-table conditions, the coefficient of storage is equal to the specific yield of the material unwatered during pumping; for artesian conditions, the coefficient of storage is equal to the water obtained from storage by the compression of a column of water-bearing material

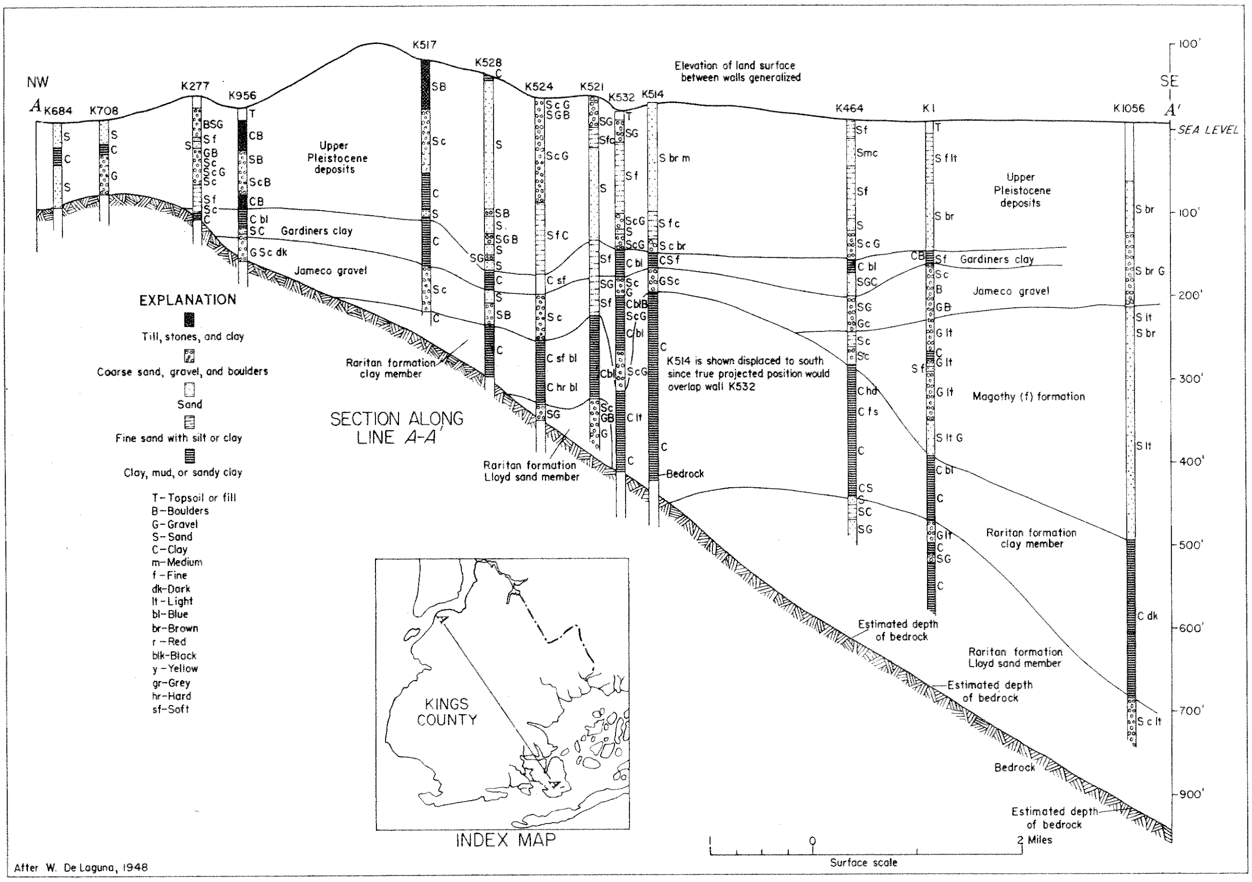


Figure 1.--Geologic section of Kings County, Long Island, N. Y.

whose height equals the thickness of the water-bearing material and whose base is 1 ft square.

Coefficient of permeability in field terms is the rate of flow of water, in gallons a day, that percolates under prevailing conditions through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of bed and for each foot of hydraulic gradient.

Coefficient of transmissibility is the product of the field coefficient of permeability and the thickness of the saturated portion of the aquifer.

Cone of depression of a well from which water is being discharged at a given rate is the depression produced in the water table or other piezometric surface by the withdrawal of water. A hydraulic gradient is established from all directions towards the well; it increases from zero slope at the point where the water levels are not affected by the pumping to a maximum slope at the pumped well. After a sufficient shut-down period, the water levels return to the original levels as the water-bearing formation is replenished.

Safe withdrawal is the net pumping rate at which water can be withdrawn from water-bearing formations without depleting and/or contaminating the supply to such an extent that withdrawal at this rate is no longer economically feasible.

PUMPAGE

Because of the abundance of rainfall and of the widespread occurrence of porous and highly productive water-bearing material, the ground-water resources of Long Island have been utilized extensively for many years for public water supply, industrial, agricultural, and domestic uses. In Kings County as elsewhere on Long Island, the upper Pleistocene deposits which consist principally of outwash sand, gravel, and till, proved to be the major source of ground water. The Jameco gravel was developed in the county in two different periods, first by the City of New York from about 1904-17 and more intensively by the New York Water Service Corp. from 1927 to 1947. As the sands of the Magothy (?) formation and the Lloyd sand member of the Raritan formation were found only in the southeastern section of Brooklyn, only small amounts of the limited supply of ground water in these two aquifers were removed by a few wells.

The development of ground water in Kings County proceeded at such a fast pace that before World War 1 the rate of withdrawal began to exceed the rate of replenishment. The supplies would have been decreased at a faster rate had it not been for the return to the aquifers of small amounts of water pumped for industrial uses, in compliance with the water-conservation law passed by the State in 1933.

The net withdrawal for public supply and industrial uses in Kings County (pl. 1) increased from 28 mgd in 1904 to a maximum of 75 mgd in 1929, and decreased to 55 mgd in 1946; pumpage averaged 60 mgd from 1904-47. These quantities include fresh water and undoubtedly some small amounts of diluted sea water, which continued permeating slowly but steadily to the pumped wells after the water levels had been lowered below sea level because of overpumpage.

The net withdrawal for industrial and other uses (excluding public supply) increased from about 14 mgd in 1904 to about 52 mgd in 1927-28 and subsequently decreased to about 23 mgd in 1947; it averaged about 36 mgd from 1904-47. Such pumpage data for 1904-36, computed by Henderson, were shown by Suter (1937, p. 37). Withdrawals for 1937-47 were interpolated by the U. S. Geological Survey from earlier data and those furnished by the New York State Water Power and Control Commission for 1948-50. Actually the gross withdrawals in Brooklyn (for all industrial and other nonpublic-supply uses) were greater by the amount of water returned to the aquifers through recharge wells and pits. This form of artificial recharge amounted to about 1 to 2 mgd in the early 1930's, was computed to be 7 mgd in 1947, and is increasing every year.

Two major factors contributing to the large decrease in industrial pumpage in Brooklyn from 1928-47 were (1) the water conservation law passed by the New York State Legislature in 1933, and (2) the gradual elimination of ice plants. In connection with (1), the State law required that all water used for cooling and similar purposes that was pumped from wells constructed after 1933 whose individual capacity was greater than 100,000 gpd must be returned to the same aquifer from which the water was taken. Although the law could not be applied to wells already in existence at the time of its passage, it was enforced just as effectively on replacements of the older wells as on new wells. In connection with (2), as the electric or gas refrigerator gradually replaced the ice box, with which most homes had been equipped previously, the reduction in demand necessitated the shut-down of many ice plants. As a result, pumpage by ice plants decreased from 18 mgd in 1936 to 4 mgd in 1947.

The New York Water Service Corp., the New York City Department of Water Supply, Gas and Electricity, and several small private companies pumped an average of 23 mgd for public supply in Brooklyn from 1904-47. During this period, the pumpage was as much as 33 mgd in 1909 and as little as 13 mgd in 1918-19 (pl. 1). Before 1916 the New York City Department of Water Supply, Gas and Electricity withdrew relatively large quantities of ground water for public supply at three pumping stations in Brooklyn. However, after 1917 only negligible quantities of water were pumped, in periods of emergency only, by this Department in Kings County. After this date, surface-water supplies from the reservoir system in upstate New York were available for distribution. On the other hand, the New York Water Service Corp. increased its withdrawals from about 4 mgd in 1904 to more than 27 mgd in 1947, to average more than 18 mgd for the last 44 years of its operation in the Flatbush section of Brooklyn.

Pumpage for public supply was analyzed further to indicate withdrawals by source formation, as had been done by Thompson and Leggette (1936, pp. 20-24) for pumpage from 1904-34. The New York City Department of Water Supply, Gas and Electricity derived as much as 9 mgd (pl. 1) from the Jameco gravel and, in addition, small amounts from the Cretaceous aquifers for several years before 1917. After this date withdrawals in Brooklyn by the City of New York were practically negligible. The New York Water Service Corp. on the other hand began developing artesian supplies in 1927. The construction of the deeper wells progressed at such a fast pace that by 1933 as many as 16 mgd were being extracted from the artesian aquifers. All these newer wells were screened in the principal beds of the Jameco gravel except one, which was screened in the Lloyd sand member of the Raritan formation.

After 1933 three additional developments of the deeper aquifers were made but were restricted to locations in the northwestern section of the franchise area of the New York Water Service Corp. at the greatest possible distance from salt water. At the same time, the total withdrawals from the artesian formations were reduced gradually from the high rate of 16 mgd to about 7 mgd in 1947. In the meantime, however, the salinity of the artesian waters increased steadily.

During the 44-year period from 1904-47, more than 72 percent of the public water supply was obtained by wells screened in the upper Pleistocene (glacial) deposits, about 26 percent by those in the Jameco gravel, and less than 2 percent by those in the Cretaceous sediments. A breakdown of pumpage for industrial and other uses by formation source, would have shown that most of the water was pumped from the shallow water-table aquifers.

Sufficient ground water was removed from the aquifers in Kings County from 1904-47 to inundate the county having a surface area of about 71 sq mi to a depth of about 63 ft, if it were physically possible. Precipitation for the same period totaled about 152 ft. Part of the difference of about 89 ft was lost to the sea by underground outflow in the early years and by sewer outflow during the late years. The remainder was consumed by evapotranspiration.

SALT-WATER INTRUSION

As a result of continuous pumping in excess of the safe withdrawal, ground-water levels in Kings County were gradually lowered below sea level in all but the extreme southern section of the county. This situation led to salt-water encroachment, as about 70 percent of Brooklyn is surrounded by sea water having a chloride content ranging from 10,000 to 20,000 ppm. Sea water entered the shallow and artesian water-bearing formations in Kings County by induced infiltration from all directions except the northeast and parts of the southwest. Slowly, but more or less steadily, it moved landward downgradient toward the apex of the cone of depression in northwestern Brooklyn. Because of this intrusion, the chloride content began to increase first in coastal wells and later in wells at greater distances from the shore line.

The rate of increase of salinity at any one locality varied with many factors: (1) rate of overpumping, (2) rate of fresh-water replenishment, natural or artificial, (3) coefficient of transmissibility and coefficient of storage (or specific yield) of the aquifer, (4) distance from the source of contamination, and (5) ability of the sands, gravels, and clays composing the water-bearing zones to remove or reduce chemically or perhaps to absorb or absorb some small percentage of the chloride ions of the encroaching sea water.

Water pumped for public supply was sampled at frequent and regular intervals by the New York Water Service Corp. during the many years of its operation in central Brooklyn. Water samples were taken from industrial wells only occasionally before the middle 1930's after which time the U. S. Geological Survey began a gradually expanding systematic program of sampling at many selected industrial wells in Brooklyn and particularly in the northwestern section of the county. The first map on record depicting isochlors and chloride content of water in Brooklyn was prepared by Wiggin, Sanborn, and Brush (1933, exhibit J). Their study showed that in 1932 the chloride content was already high at some wells in the upper Pleistocene deposits near the shore line of the county. They found that the artesian water in this locality was even more highly contaminated by salt water than was the unconfined water. However, in the central third of Kings County at the greatest distances from sea water, the salinity in the water-table and artesian aquifers was shown by them to be less than 40 ppm in general and not more than 80 ppm in 1932.

Because withdrawals in Brooklyn were in excess of replenishment for years, the chloride content of water pumped from the upper Pleistocene deposits within a mile or two of the shore line in the northwestern and southeastern sections of Kings County increased very rapidly during the 15-yr period ended in 1947. Concentrations ranging from 1,000 to 8,000 ppm were indicated at many coastal wells in 1947. At many others, the salinity was less than 1,000 ppm but more than 100 ppm. The quantity of salt water induced along the upper Pleistocene deposits as far landward as central Brooklyn was apparently small, because in this locality by 1947 the chloride content of ground water was low. Either the contamination was slight, or recharge from precipitation provided a sufficient compensating effect. Records on the quality of the shallow ground water indicate that the rate of increase in salinity in the upper Pleistocene deposits varied to a certain extent with the changing average rates of precipitation, from month to month, season to season, and year to year.

At all times since 1932, water pumped from wells screened in the Jameco gravel was in general much more contaminated by salt water than the water removed from the upper Pleistocene deposits. The intrusion into this artesian aquifer was faster and also farther landward. Such action is explainable because the coefficient of storage, an important hydraulic characteristic of an artesian formation, is much smaller than the specific yield of the overlying water-table formations in Brooklyn.

The chloride content of water pumped by the New York Water Service Corp. from the water-table and artesian aquifers for public supply is listed by years in table 1, for the period 1927-47.

Although more than 72 percent of the total withdrawals for public supply were from the shallow aquifers, the chloride count increased rather slowly in these formations. The salinity had not reached 200 ppm in any of the water-table wells and was much less at many of them by 1940. Recharge from precipitation, a large coefficient of transmissibility, and a relatively large storage capacity of the aquifer effectively prevented large increases. After 1940, as the withdrawals from the upper Pleistocene deposits were increased because of the demand and the higher percentage of chloride in the artesian formations, the chloride content in these water-table wells increased more rapidly. By 1947 it was as much as 710 ppm (fig. 2) at one of the older wells (in use before and after 1920) in the southern half of the franchise area of the New York Water Service Corp. In the northern half, the salinity at several wells constructed after 1940 increased slightly but was less than 100 ppm in June 1947.

Pumping from the deeper artesian wells, started in 1927 by the New York Water Service Corp., had increased rapidly to 16 mgd in 1933. As a result, the salinity of the water in the artesian wells in the southern section of the franchise area of the New York Water Service Corp. began to increase very rapidly. It rose to more than 100 ppm at wells K521, K523, and K525 (index map, fig. 8) after they had been pumped less than 5 yr. As soon as this was recognized, pumping from the deeper wells was reduced and recharging the deeper wells from the shallow formations was tried at various times. These practices retarded the intrusion only slightly. Although wells K523 and K525 were used only in times of emergency, and there was a gradual reduction of pumping in the other artesian wells, the contamination continued to increase each year; by 1947 it had spread to practically all sections of the franchise area of the New York Water Service Corp. This spread of contamination was due primarily to the fact that the artesian formations developed for ground water have a low storage capacity, and the natural recharge of fresh water percolating from the overlying and underlying aquifers continued to be less than the withdrawals. Recharging some of the deeper wells with water from the shallow formations also proved to have only a temporary and more or less local effect in reducing the salinity. This recharging was done perhaps as much to utilize more efficiently the limited supply of ground water as to reduce the salinity of the artesian water.

In 1947, all except two of the New York Water Service Corp. wells screened in the Jameco gravel yielded water having a chloride content greater than 260 ppm and as high as 830 ppm (fig. 2). The salinity of water in two wells, K517 and K526, in the extreme northwestern corner of the franchise area (approximately in the geographical center of Brooklyn) was less than 100 ppm. At well K520 in the extreme northeastern corner of the franchise area, the chloride content had increased by January 1946 to 1,550 ppm. This content represents the highest for any well sampled by the New York Water Service Corp. in the Flatbush section of Brooklyn.

When the pumping in Flatbush was shut down in June 1947, the water levels recovered rapidly (tables 2 and 3 and fig. 5). However, brackish water continued to move, at a decreased rate, in a landward direction toward the bottom of the cone of depression in the northern section of Brooklyn, where the water table in December 1950 was still below sea level. The direction of flow was reversed only in the southern and southeastern areas (fig. 4), where the water levels by December 1950 returned to altitudes above sea level.

As the New York Water Service Corp. wells in the Jameco gravel in the southern half of Brooklyn were abandoned in June 1947, the trend of the chloride content in the Jameco gravel could not be ascertained at these wells after their shut-down. One of the wells, K522, was pumped by an industrial firm during the recent "water shortage" in New York City. Water sampled for chloride content at this well shows a somewhat lower salinity than that before the shut-down. Data available for wells in the Jameco gravel in northwestern Brooklyn show, in general, a diminished rate of increase in salinity.

Contamination of ground water by sea water is usually a rather slow process and in Brooklyn it took place and increased during many years of overpumping. The opposite trend, the freshening of ground water will require approximately a corresponding number of years. No large change in the salinity was noted 3½ yr after the shut-down of pumping from the shallow formations. In fact, the beneficial effect is expressed, in general, only in a decrease of the rate of increase in salinity of ground water.

TREND OF THE WATER TABLE AND ARTESIAN LEVELS FROM 1903 TO 1947

The trend of ground-water levels in Brooklyn is an expression of changes in storage in the underground aquifers. Changes in storage result from differences between recharge and discharge. In this area ground-water recharge is derived from (1) direct precipitation, (2) underflow from beyond the county, (3) water returned artificially through wells, and (4) inflow of sea water. Discharge is by means of (1) withdrawals by wells, (2) evapotranspiration, (3) sewer outflow, (4) stream runoff, and (5) underflow to sea. When recharge exceeds discharge during

Figure 2.--Chloride content of ground water in the New York Water Service Corp. wells in Kings County, N. Y.

Table 1.--Chloride content, in parts per million, of water pumped by the New York Water Service Corp. in Kings County, N. Y., 1927-47

[Data furnished by Mount Prospect Laboratory, City of New York Water Service Corp. For data on location of wells see figures 2, 3, and 8 and table 2]

Well no.	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	a1946	b1947
Wells screened in the upper Pleistocene deposits (water-table wells)																					
K501	18	22	23	20	21	19	32	40	72	..	72	224	61	...	...	146	603	793	436	758	c495
dK503	25	21	22	21	22	22	28	28	30	28	25	39	150	145	...	...	513	709	360	548	424
K504	...	...	...	...	...	22	104	146	60	31	33	50	53	72	87	94	107	102	207	281	309
K506	14	19	21	25	30	27	35	30	28	26	25	28	26	27	29	27	27	34	31	33	34
K507	24	...	44	39	38	35	37	37	35	40	40	45	46	46	47	45	40	39	38	35	35
K508	27	31	33	28	29	31	31	31	30	28	28	27	25	24	49	266	544	561	265	505	508
K510	24	27	28	25	27	25	27	25	27	24	25	28	56	128	229	307	366	370	497	707	624
K512	20	23	24	21	24	22	25	26	27	26	28	28	33	129	235	274	510	464	451	461	710
K513	22	23	24	23	43	183	73	90	112	84	93	91	139	177	228	250	315	820	418	695	327
K514	13	12	25	42	48	65	47	154	...	51	74	69	103	110	217	247	303	194	384	665	323
K516	21	21	28	28	33	34	35	39	42	45	45	48	46	48	52	50	52	56	60	64	65
K527	...	...	...	...	...	...	...	59	58	53	49	48	46	43	44	41	41	40	47	49	59
dK529	...	...	...	...	...	...	...	29	25	23	23	23	90	144	251	340	445	...	...	...	...
K530	...	...	...	...	...	...	...	...	...	33	31	77	146	288	360	180	283	699	268	152	483
K1232																					
K1233	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	17	23	34	30	32	33
K1234																					
K1329	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	59	52	48	48	48	50
K1331	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	72	166	66	65	66
K1338	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	22	24	23	25	27
K1343	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	21	24	26	29	31
K1351	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	43	67	76	84
K1357	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	30	22	22	22
K1359	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	45	42	43	46
K1360	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	59	171	263	301
K1363	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	26	28	30
K1516	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	35	40
eK1517	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	345	...
Wells screened in the Jameco gravel (artesian wells)																					
K517	4.2	4.2	4.2	5	4.8	5	7.6	11	13	14	13	12	12	16	22	24	33	42	53	63	84
K519	...	...	7.8	12	14	18	24	36	50	60	81	99	113	130	150	183	203	225	285	369	383
K520	...	...	15	19	19	15	25	24	27	31	41	...	62	101	161	263	448	696	1410	1550	...
K522	...	...	...	20	28	27	30	24	21	22	27	50	110	170	280	348	386	445	432	451	434
K523	...	...	...	22	23	26	120	490	44	60	...	...	...	...	...	...	...	...	...	...	...
K524	...	...	...	...	68	75	68	52	61	74	79	90	112	121	113	180	227	272	428	670	830
K525	...	...	...	...	47	130	198	272	f44	f119	f91	...	...	...	...	...	...	...	...	...	...
gK526	...	...	...	...	9.0	12	14	16	19	20	...	25	22	23	33	55	...	39	45	50	65
K528	...	...	...	...	...	...	...	40	31	29	34	38	43	61	94	278	833	...	...	...	...
gK531	...	...	...	...	...	...	...	...	...	...	23	23	16	21	34	...	...	...	250	340	375
K526 K531	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	54	84	140	194	245	263
Well screened in the Lloyd sand member of the Raritan formation (artesian well)																					
K521	...	...	29	16	68	133	260	262	f46	f43	f45	f213	f173	402	500	519	420	517	525	500	...

a Records for 1927-46 represent year-end data except that in 1946 for well K521 the chloride content for January is listed.
b For 1947, records for June are listed.
c Underlined numbers are shown in figure 2.
d Wells K503 and K529 are at same site.
e Well K1517 is near well K1479.
f Chloride content decreased by recharge from upper Pleistocene deposits.
g Wells K526 and K531 are at same site.

a given period, storage increases and water levels rise. Conversely when discharge exceeds recharge, storage decreases and water levels decline. Thus water-level records are important indicators in maintaining an inventory of ground-water supplies.

In the Brooklyn area the natural regimen of ground water has been strongly affected by (1) the construction of buildings and streets which effectively prevent recharge from direct precipitation over a large part of the area, and (2) heavy withdrawals of ground water by pumping from wells. The effects of these factors are strongly indicated by records of water levels that have been obtained since 1903.

Of the many causes set forth above, precipitation, pumping, and sewer runoff played the principal roles in the conditioning of events responsible for the major changes of water levels in Brooklyn.

The water table in 1903 was above sea level in the entire borough of Brooklyn and near the Queens County line was as high as 20 ft above sea level. This is clearly indicated by the contour map for 1903 prepared by Wiggin with the cooperation of Brush and Sanborn (1933, exhibit A) for the hearings in connection with the application before the New York State Water Power and Control Commission by the City of New York for the development of additional ground-water supplies in western Long Island. Their 1903 contour map has been reproduced in plate 2; it includes contours for Queens County as mapped by Spear, Burr, and others (1904).

Leggette (1940, pp. 529-552), Jacob (1945), and other investigators concluded from detailed studies of precipitation records that ground-water levels in Long Island for several years before and after the turn of the last century had been record high since the early 1800's. The very high precipitation rate for many years before the beginning of the twentieth century and the inconsequential withdrawals of ground water during the earlier years allowed the water table to continue rising gradually and persistently to the extremely high levels observed in 1903.

During the next 30 yr period ended in 1933, the water table declined rapidly to dangerously low levels in Brooklyn. The primary contributory factors were the reduction of natural recharge (to the underlying aquifers) caused by the works of man--sewers, buildings, streets, sidewalks, pavements--and the continued heavy withdrawal in excess of replenishment. The building improvements were necessitated by the rapid increase of population in Kings County and the industrialization and commercialization of the northwestern section. To make matters worse, the precipitation was below normal during most of these years, especially during the early 1930's, and as a result, the decline of water levels was accelerated. .

By 1933 a huge craterlike depression of the water table had developed. The water table declined to stages below sea level in most of Brooklyn and was more than 15 ft below sea level in the northwestern section. Such tremendous, and for the most part unsuspected, changes for the worse were reported in a contour map for 1932 prepared cooperatively by Wiggin, Brush, and Sanborn (1933, exhibit A). This map has been reproduced in plate 2. The rather extreme low levels to which the water table had receded was a revelation to many engineers, some of whom were previously of the opinion that no radical change in the position of the water table had taken place in Kings County since 1903, and that additional large ground-water developments in Brooklyn were still possible.

As soon as the seriousness of the situation in western Long Island was fully comprehended, the New York State Legislature passed on April 28, 1933, section 521a of the water conservation law, to protect the public water supply on Long Island from further overdevelopment. This law empowered the New York State Water Power and Control Commission to act on all new applications for additional water supply on Long Island for all wells having a capacity greater than 100,000 gpd, and required that all water pumped for cooling and similar purposes be returned to the aquifer from which it was taken. The Commission was not given any jurisdiction over wells already in place and in use, or of any agricultural wells constructed for agricultural uses.

One of the first technical contributions by the New York State Water Power and Control Commission, which resulted from the water conservation law passed in 1933, was a more detailed map depicting water-table contours in 1936 for all of Long Island. This map prepared under the supervision and direction of Suter (1937, opposite p. 49) was based on more field data than the 1933 map. The western section of Suter's map duplicated in plate 2 shows that the reserves in the water-bearing formations in Kings County were more depleted than first suspected in 1933. Water levels as low as 35 ft below sea level were reported for 1936 in northwestern Brooklyn.

A few years later, Jacob (1945 a) prepared the water-table map for western and central Long Island, N. Y. for May 1943. He indicated levels as low as 25 ft below sea level in Brooklyn and was aware that lower levels existed locally at and near pumped wells in the "crater area" (pl. 2). From May 1943 to the time of the general shut-down of pumping in Flatbush in June 1947, only small changes in water levels were observed in Brooklyn. It was thus considered that contours of water levels on the map of 1943 approximated, in general, the position of the water table in June 1947.

The trend of water levels in Kings County from 1903-47 can be summarized as follows: Because of overpumping, works of man, and below-normal precipitation, the water table declined very rapidly from a position several feet above sea level in 1903 to many feet below sea level in 1933. The decline persisted through 1940, and water levels more than 25 ft below sea level were general in sections of northwestern Brooklyn. After 1941 slight recoveries were indicated at some wells; at most of the others the levels dropped very little. The declaration of the downward trend in most localities, and its reversal at some wells, were attributable to the gradual reduction of pumping, to the above-normal precipitation, and to artificial recharge. In general, in more than 75 percent of Kings County water levels remained below sea level for more than 30 yr.

Comparatively little is known about the piezometric levels in the Jameco gravel, an artesian aquifer, and much less about levels in the deeper artesian formations in Brooklyn, for the period 1903-33. However, it can be assumed that the piezometric surface in the Jameco gravel was above sea level in 1903, and perhaps at approximately the same altitude as the water table. It may also be assumed that, as the Jameco gravel was pumped for only a few years during the period 1903-26, piezometric levels were higher than the water table during most of this period. After 1926 the artesian levels declined very rapidly because excessive withdrawals were made from the Jameco gravel by the New York Water Service Corp. for public water supply in Flatbush and by industrial concerns in sections of northwestern Brooklyn.

The levels in 1933 and the trend of levels between 1933-47 are suggested by a few nearly continuous records for a relatively small number of artesian wells in Brooklyn. However, the available data are incomplete and too few to allow an accurate plotting of an isopiestic map for any date. It appears more likely than not, that from 1933-47, the water table in the upper Pleistocene deposits and the piezometric surface for the Jameco gravel were at approximately the same altitude. There certainly is less doubt about this being true in 1947, especially in the Flatbush section of Brooklyn, as is evidenced by water-level records obtained just before and after the general shut-down of pumping in June 1947.

RECOVERY OF WATER LEVELS FROM JUNE 1947 TO DECEMBER 1950

Water-Table Deposits

The water table in Kings County, as measured at many observation wells shown in figure 5 and listed in tables 2 and 3, recovered rapidly from June 1947 to December 1950, as a result of the complete cessation of pumping in central Brooklyn. For about $1\frac{1}{2}$ yr before the shutdown in June 1947, the New York Water Service Corp. pumped at an average rate of about 21 mgd from about 26 wells screened in the upper Pleistocene (water-table) deposits within its franchise area.

By December 1950, ground-water levels rose (fig. 4) from below sea level to above sea level in more than the entire southern half of Kings County; and in the southwestern section, levels as high as 4 ft above sea level were measured. In northern Brooklyn also, where the water table had receded previously to levels as much as 35 ft below sea level, appreciable improvement of water levels in the ground-water conditions were noted after the shut-down; in this section of the county, the recovery ranged from 1 ft to as much as 11 ft. In general, the amount of rise decreased with an increase in distance from the previously pumped wells (fig. 5) and ranged from more than 19 ft in central Brooklyn to about 1 ft near the perimeter of Kings County. The net gain in storage in the water-table formations in Brooklyn was about 20 billion gallons from June 1947 to December 1950.

The recovery in the western section of Queens County, being small, overshadowed by the greater effect of the ever-increasing pumping by private companies furnishing public supply and also by industrial concerns. An increase in pumping and the precipitation trend caused a net drop in levels in western Queens County from June 1947 to December 1950.

Recoveries at several intervals after the shut-down are illustrated by the profiles of the water table at three cross sections (fig. 6) shown on the index map (fig. 3). Levels measured on June 30, 1947, during the first day of the shut-down (after the pumps were shut off), constitute the basis of recovery. Profiles for 1947-50 are compared to those for 1903 which were drawn from Wiggin's contour map (1933, exhibit A). In spite of the relatively large recovery of water levels in Brooklyn in $3\frac{1}{2}$ yr, the water table in December 1950 was still many feet below that reported for 1903, at which time the water table in Brooklyn had been above sea level everywhere and as high as 20 ft above near the Queens County line.

The trend of water levels in Kings County differed radically from that in other parts of Long Island before as well as after the shut-down of pumping by the New York Water Service Corp. In Brooklyn, the pumpage pattern is reflected much more prominently than variations in precipitation. Elsewhere on Long Island, the opposite is generally true. Monthly hydrographs from 1932-50 for four wells in Kings County (fig. 7) contrast strikingly with that expressing the average level of 14 selected wells in Nassau and Suffolk Counties and illustrate effectively the point under discussion.

Of the chosen wells in Kings County, records at well K1264 reflect conditions in

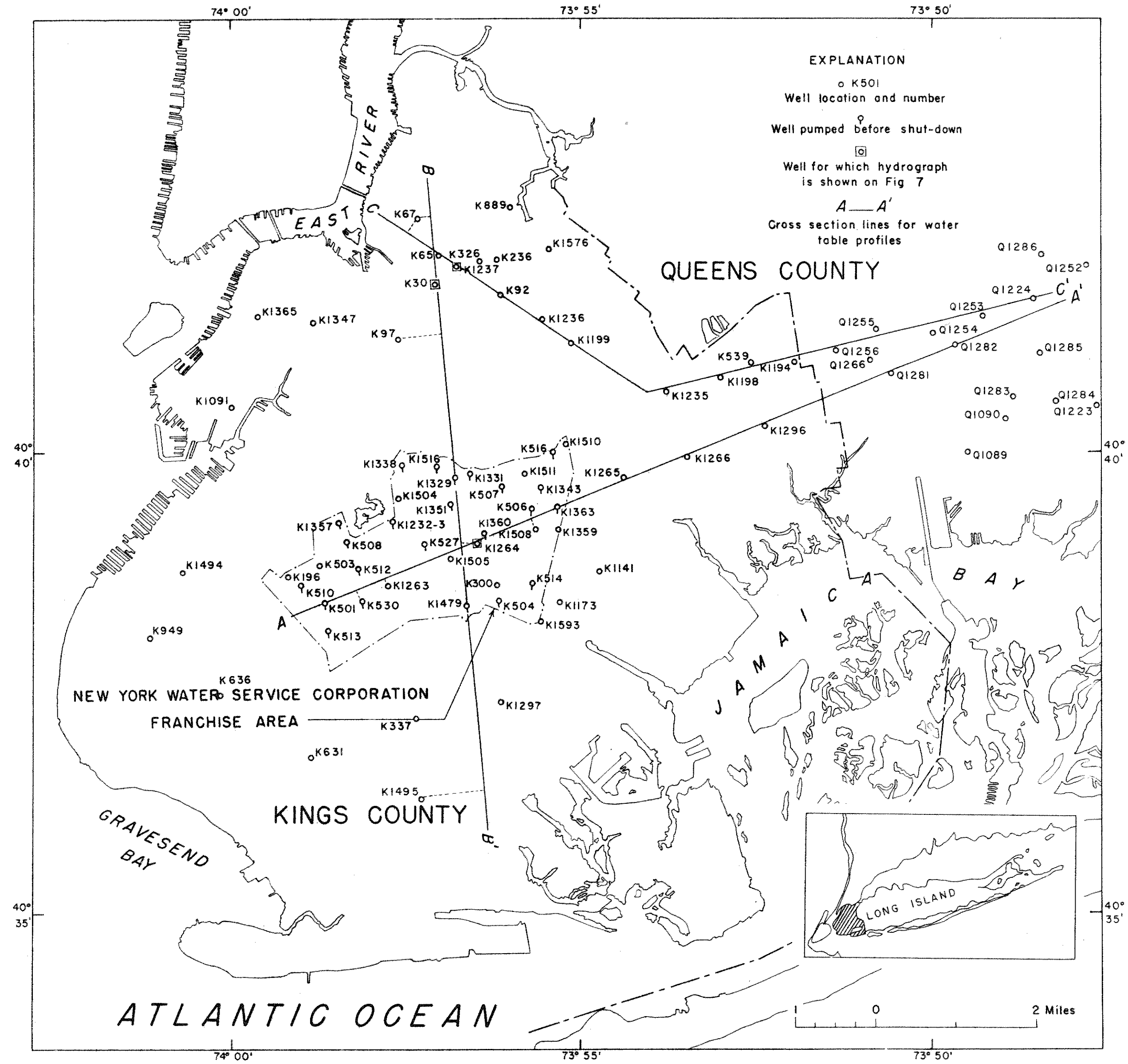


Figure 3.--Index map showing water-table wells and cross-section lines in Kings and Queens Counties, N. Y.

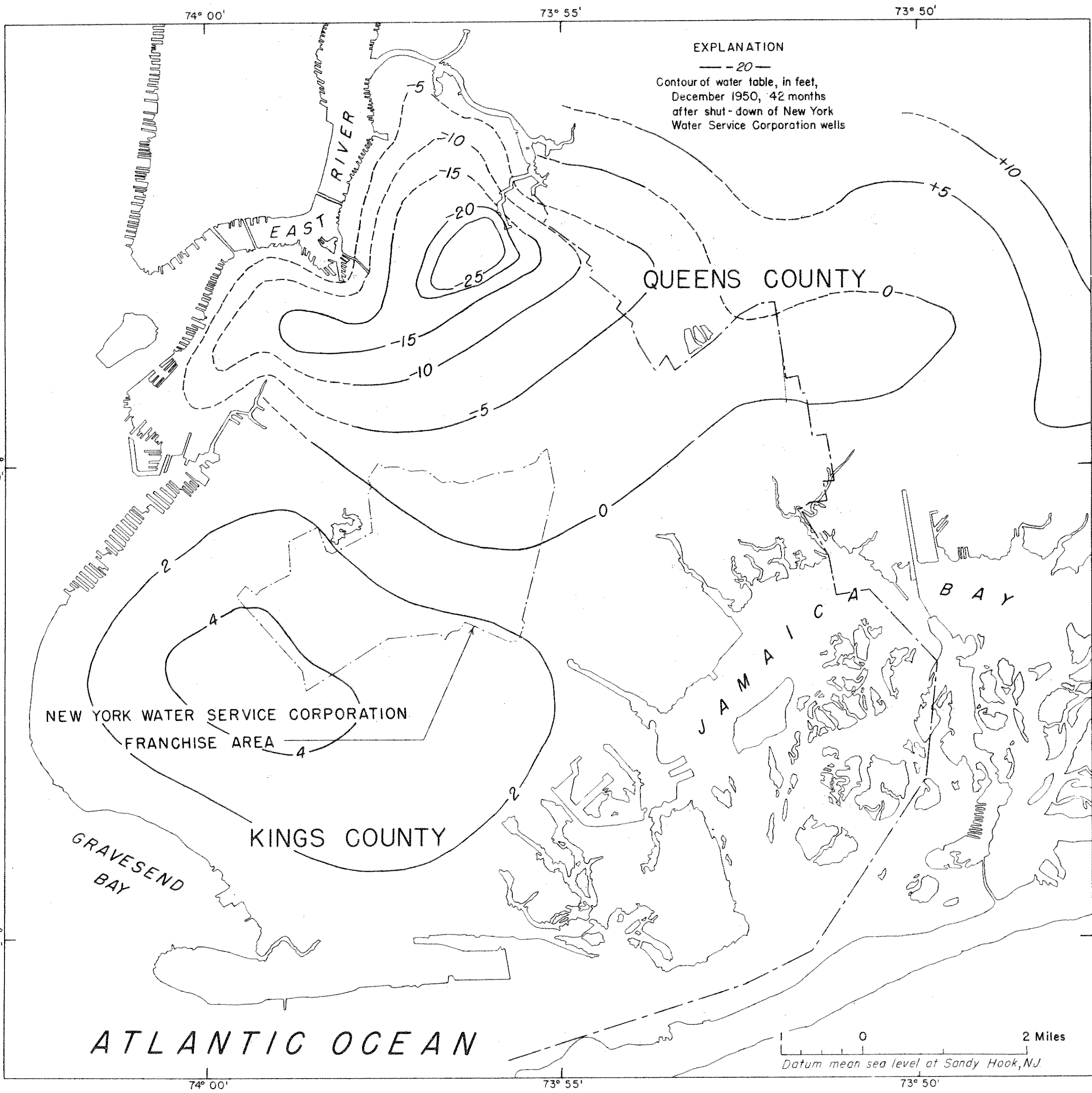


Figure 4.--Position of water table in Kings and Queens Counties, N. Y., in December 1950.

Table 2.--Ground-water levels, in feet, mean-sea-level datum, in wells in Kings and Queens Counties, N. Y., from June 1947 to December 1950

[Status of well: NP, well idle before shut-down, June 1947; P, well pumped before shut-down]

Well no.	Location	Status of well	June 1947	July 1947	Sept. 1947	Dec. 1947	June 1948	Dec. 1948	Dec. 1949	Dec. 1950
	Wells screened in the upper Pleistocene deposits (water-table wells)									
K30	Park and Nostrand Aves....................	...	a-28.00	a-28.1	a-27.9	a-27.2	a-24.9	a-23.5	-20.3	-19.3
K65	125 Middeton St........................	...	-25.73	-25.9	-25.7	-25.2	-23.7	-22.5	-19.6	-19.0
K67	179 Marcy Avenue.......................	...	b-20.47	-20.8	-20.5	-20.0	-19.2	-18.0	-16.0	-15.3
K92	5 Lewis Ave............................	...	-22.71	-22.8	-22.6	-21.3	-19.9	-18.7	-14.5	-13.4
K97	32 Lexington Ave.......................	...	-25.42	-25.5	-25.2	-24.1	-21.3	-19.3	-15.8	-14.9
cK196	12th Ave. and 57th St..................	...	-3.52	-3.5	-1.7	-.5	1.4	3.6	4.1	3.9
cK501	363-65 Dahill Rd.......................	P	-4.80	-3.4	-2.4	-1.0	1.6	2.6	3.1	3.1
cK503	401-03 McDonald Ave....................	P	-7.63	-5.9	d-4.4	-2.4	.7	2.2	3.2	3.0
cK504	Foster and Albany Aves.................	P	-10.30	-8.2	-6.7	-4.5	-.5	.5	1.4	2.0
cK506	723-25 Utica Ave.......................	P	-19.31	-16.0	-14.0	-11.8	-7.5	-5.3	3.1	2.4
cK507	543-45 Troy Ave........................	P	-21.48	-18.4	-15.9	-12.9	-8.6	-6.0	-3.2	2.4
cK508	807 Caton Ave..........................	P	-12.05	-9.6	-7.3	-4.9	-1.0	1.1	2.6	[illegible].4
cK510	Louisa and 36th Sts....................	P	-5.36	-4.0	-2.8	d-1.2	e1.5	e2.7	.....	.....
cK512	520 Coney Island Ave...................	P	-10.27	-8.4	d-6.3	-4.1	e.0	e1.5	.....	.....
cK513	865 McDonald Ave.......................	P	-1.63	-.9	-.4	.5	e2.8	e3.3	.....	.....
cK514	1267 Utica Ave.........................	P	-10.12	-9.2	-7.8	-5.5	e-1.3	e-.3	.....	.....
cK516	Near E. 98th St. and Rutland Rd..........	P	-18.05	-15.2	-13.8	-11.9	e-8.5	e-6.3	.....	.....
cK527	14-24 Erasmus St.......................	P	-16.0	-13.6	-10.9	-8.6	e-4.5	e-2.5	.....	.....
cK530	912 Crotelyou Rd.......................	P	-5.73	-4.9	d-3.6	-2.0	d1.6	2.2	2.9	3.1
K539	Atlantic Ave. and Logan St.............	...	-3.16	-3.3	-3.4	-3.3	-2.0	-1.7	-.7	-.9
K889	199 Bogart St..........................	...	-36.69	-35.6	-37.1	-35.7	-30.8	-27.9	-27.9	-24.0
K1141	Ave. D and E. 88th St..................	...	b-7.32	-7.1	-6.5	-5.1	-1.4	-.9	.3	1.4
K1173	5819 Foster Ave........................	...	b-5.40	-6.3	-5.8	-4.6	-1.2	-.2	.....	.....
K1194	Atlantic Ave. and Nichols St............	...	-3.04	-3.3	-3.6	-3.4	-2.2	-2.0	-1.3	-1.7
K1198	Cleveland and Fulton Sts................	...	-5.03	-5.2	-5.3	-4.9	-3.5	-2.6	-1.4	-1.3
K1199	Jefferson and Howard Sts................	...	-15.35	-15.3	-15.2	-14.5	-12.3	-10.7	-7.6	-6.1
cK1232	18 Woodruff Ave........................	P	-17.32	-13.7	-10.5	-7.7	-3.2	-.8	1.3	.....
cK1233	18 Woodruff Ave........................	P	-17.25	-13.6	-10.8	-7.9	-3.3	-.7	1.3	.....
K1235	Fulton and Pennsylvania Aves............	...	-8.52	-8.8	-8.1	-7.9	-6.4	-4.8	-2.2	-2.2
K1236	Lexington and Patchen Ave...............	...	-18.25	-18.2	-17.6	-17.1	-15.5	-13.7	-9.9	-8.6
K1237	Delmonico Place and Hopkins St..........	...	-35.86	-36.0	-35.2	-34.1	-33.0	-29.8	-26.4	-26.4
cK1263	E. 16th St. and Cortelyou Rd............	...	-10.49	-9.7	-7.6	-5.1	.9	.7	2.0	2.1
cK1264	E. 57th St. and Snyder Ave..............	...	-51.39	-13.7	-11.3	-8.7	-4.1	-2.1	-.3	.3
K1265	Thatford St. and Riverdale Ave..........	...	b-9.79	-9.9	-9.4	-8.2	-5.3	-3.1	-.9	.....
K1266	Vermont and Livonia Sts.................	...	b-5.14	-5.3	-5.3	-4.9	-3.5	-2.1	-.8	.2
K1296	Blake Ave. and Crystal Sts..............	...	b-.99	-1.3	-1.3	-1.1	.1	-.4	.4	1.0
cK1329	528-36 New York Ave.....................	P	-21.55	-19.4	-16.5	d-14.0	e-9.5	e-7.5	.....	.....
cK1331	565-67 East New York Ave................	P	-21.58	-19.2	-16.7	d-13.9	e-9.6	e-7.5	.....	.....
cK1338	1015-17 Franklin Ave....................	P	-20.41	-18.6	-16.5	-13.8	- .3	-6.0	-2.6	-2.0
cK1343	983-85 Winthrop St......................	P	-18.86	-15.8	-13.9	d-11.3	e-7.7	e-5.5	.....	.....
K1347	De Kalb and Fulton Sts..................		-21.43	-23.7	-23.2	-21.9	-21.7	-19.1	-17.3	-17.1
cK1351	710-22 Parkside Ave.....................	P	-19.0	-16.8	-14.1	-11.1	-6.9	e-4.8	.....	.....
cK1357	35 Reeve Pl.............................	P	-14.6	-11.0	-8.6	-6.2	-2.1	e.5	.....	.....
cK1359	145-47 E. 57th St.......................	P	-13.74	-11.9	-10.4	-8.5	-4.5	-3.0	-1.0	-.2
cK1360	3909-11 Church Ave......................	P	-17.51	-14.7	-12.2	d-9.7	e-5.0	e-3.0	.....	.....

cK1363	369-71 Ramsen Ave......................	P	-15.99	-13.5	-11.8	-9.8	e-5.9	e-3.7	.....	.....
cK1479	Foster and New York Aves................	P	a-9.92	a-7.7	a-6.2	a-4.2	a-.1	a1.2	.....	.....
K1495	Ave. S and E. 16th St...................		b2.35	2.0	2.1	2.7	3.3	3.6	2.8	3.2
cK1504	634-36 Flatbush Ave.....................	NP	-18.11	-16.8	d-13.9	-10.8	e-6.8	e-4.5	.....	.....
cK1505	1594 Nostrand Ave.......................	NP	-14.14	-12.6	-11.6	-7.8	-2.6	e-.5	.....	.....
cK1508	340-42 E. 52d St........................	NP	-16.15	-14.0	-12.6	d-10.8	e-6.1	e-4.0	.....	.....
cK1510	1234-40 East New York Ave...............	NP	-15.97	-14.9	-13.7	-11.9	-8.9	-6.5	-3.8	-3.0
cK1511	517 Utica Ave...........................	NP	a-20.32	a-18.4	a-16.0	a-13.2	e-9.0	e-6.5	.....	.....
cK1516	311 Empire Blvd.........................	P	-21.56	-19.0	-16.7	f-11.5	f-8.1	-6.5	-3.1	-2.5
Q1089	N. Conduit Ave. near L.I.R.R............	...	1.70	1.52	1.09	1.50	1.69	1.37	1.9	2.1
Q1090	Hawtree Cr. Rd. near 133d Ave...........	...	3.19	2.93	2.40	2.42	2.98	2.02	2.2	2.2
Q1223	Rockaway Blvd. and 142d Pl..............	...	7.37	7.03	6.34	5.94	6.55	4.65	5.0	5.7
Q1224	102d Ave. near 229 Van Wyck Blvd........	...	6.91	6.58	6.54	6.26	7.08	7.6	.....	.....
Q1252	Liberty Ave. and 157th St...............	...	12.12	.....	11.23	11.33	12.86	12.34	11.8	9.7
Q1253	101st Ave. and 121st St.................	...	1.59	1.36	.99	1.11	1.93	1.62	1.2	.6
Q1254	101st Ave. and 108th St.................	...	-2.59	-2.74	-3.26	-3.04	-2.28	-2.14	-4.4	-3.6
Q1255	Atlantic Ave. and Woodhaven Blvd........	...	-5.29	-5.79	-6.25	-5.50	-4.37	-4.50	-3.4	-4.2
Q1256	95th Ave. and 82d St....................	...	-3.65	-4.06	-4.45	-4.04	-2.88	-2.96	-2.4	-2.8
Q1266	Near 91st St. and 97th Ave..............	...	a-5.57	a-6.25	a-4.54	a-4.02	a-2.86	a-5.27	-2.6	-3.0
Q1281	Liberty Ave. and Woodhaven Blvd.........	...	-1.75	-2.02	-2.54	-2.18	-1.26	-1.51	-1.3	-.9
Q1282	Liberty Ave. and 113th St...............	...	.33	-.28	.10	-.72	.14	.....	2.3	2.8
Q1283	Rockaway Blvd. and 121st St.............	...	3.29	3.01	2.27	2.43	2.95	1.75	2.7	2.9
Q1284	Rockaway Blvd. and Lincoln St...........	...	6.29	5.65	5.79	5.48	5.76	5.54	8.6	7.0
Q1285	132d St. and 111th Ave..................	...	5.73	5.41	4.74	5.01	5.48	4.46	4.2	3.9
Q1286	144th Pl. near Jamaica Ave..............	...	9.22	8.98	8.23	8.20	9.35	9.05	8.4	7.0
	Wells screened in the Jameco gravel (artesian wells)									
K19	604 Pacific St..........................	...	a-24.21	a-23.4	a-22.8	a-21.3	a-19.1	a-16.7	-13.8	-13.2
cK517	311 Empire Blvd.........................	P	-20.50	-18.5	-16.9	-14.5	d-10.4	e-8.0	.....	.....
cK519	543-45 Troy Ave.........................	P	-18.78	-16.4	-14.6	-12.4	-8.7	-6.1	-3.7	-3.0
cK520	Near E. 98th St. and Rutland Rd.........	NP	-16.99	-15.3	-13.9	-11.8	e-8.7	e-6.0	.....	.....
cK522	14-24 Erasmus St........................	P	-15.69	-13.4	-11.0	-8.0	-3.5	-1.1	.8	1.1
cK523	267 Newkirk Ave.........................	NP	a-1.32	a-1.1	a-.6	a.4	a2.4	a2.9	2.8	3.1
cK524	723-25 Utica Ave........................	P	-18.70	-15.8	-13.8	-11.2	-6.8	-5.4	-3.1	-2.4
cK525	363 Dahill Rd...........................	NP	a.59	a1.0	a1.5	a2.2	a4.1	a4.7	4.4	4.6
cK526	1015-17 Franklin Ave....................	P	-20.49	-18.7	-17.3	-15.3	-11.7	-9.2	-6.2	-5.7
cK528	710-22 Parkside Ave.....................	NP	-19.41	-17.2	-14.4	-12.1	-8.1	e-5.7	.....	.....
cK533	Near E. 98th St. and Rutland Rd.........	...	a-16.64	a-15.0	a-13.5	a-11.4	a-8.3	e-5.5	.....	.....
K1591	Blake Ave. and Crystal St...............	...	-1.45	-1.7	-1.9	1.7	-.3	-.5	.2	.6
Q350	Near Rockaway Blvd. and Centreville St...	...	a-.06	a-.14	a-.20	a-.45	a.02	a.43	.3	1.0
Q1459	Sunrise Highway and 79th St.............	...	a-.64	a-.92	a-1.22	a-1.00	.....	.....	.....	.....
	Wells screened in the Lloyd sand member of Raritan formation (artesian wells)									
cK521	1063 Utica Ave..........................	NP	a3.33	a2.9	a2.9	a3.3	a4.5	a5.9	5.1	6.3
K1057	Floyd Bennett Field.....................	...	a8.7	a7.8	a7.2	a8.4	a8.9	a9.7	8.5	9.2
Q543	Rockaway Beach Blvd. and Beach 110th St..	...	a8.2	a7.2	a6.9	a8.3	a8.9	a9.3	9.1	9.3

a Water-level measurements from observation well equipped with water-stage recorder.
b Water-level readings made during last week in June 1947.
c Observation wells in franchise area of the New York Water Service Corp.
d Water level determined from hydrographic plotting.
e Water level determined from profile studies.
f Water level affected by pumping in vicinity.

Note: Water-level readings taken during last week of month indicated. Readings listed for June 1947 are for the 30th, except those marked with c.

Table 3.--Recovery of ground-water levels, in feet, in Kings and Queens Counties, N. Y., from June 1947 to September 1950

[Recoveries computed on the basis of water levels measured on June 30, 1947, after an approximate 12-hr nonpumping period, except for well K1351 for which the nonpumping water level on July 1, 1947, was used.]

Well no.	Recovery, in feet, for indicated number of months after June 1947						
	1	3	6	12	18	30	42
K30	-0.1	0.1	0.8	3.1	4.5	7.7	8.7
K65	-.2	.0	.5	2.0	3.2	6.1	6.7
K67	-.3	.0	.5	1.3	2.5	4.5	5.2
K92	-.1	.1	1.4	2.8	4.0	8.2	9.3
K97	-.1	.2	1.3	4.1	6.1	9.6	10.5
cK196	.0	3.8	3.0	4.9	7.1	7.6	7.4
cK501	1.4	2.4	3.8	6.4	7.4	7.9	7.9
cK503	1.7	3.2	5.2	8.3	9.8	10.8	10.6
cK504	2.1	3.6	5.8	9.8	10.8	11.7	12.3
cK506	3.3	5.3	7.5	11.8	14.0	16.2	16.9
cK507	3.1	5.6	8.6	12.9	15.5	18.3	19.1
cK508	2.5	4.8	7.2	11.0	13.2	14.7	14.5
cK510	1.4	2.6	4.2	6.9	8.1	....	....
cK512	1.9	4.0	6.2	10.3	11.8	....	....
cK513	.7	1.2	2.1	4.4	4.9	....	....
cK514	.9	2.3	4.6	8.8	9.8	....	....
cK516	2.8	4.3	6.1	9.5	11.7	....	....
cK527	1.4	5.1	7.4	11.5	13.5	....	....
cK530	.8	2.1	3.7	7.3	7.9	8.6	8.8
K539	-.1	-.2	-.1	1.2	1.5	2.5	2.3
K889	1.1	.4	1.0	5.9	8.8	10.9	12.7
K1141	.2	.8	2.2	5.9	6.4	7.6	8.7
K1173	-.9	-.4	.8	4.2	5.2	....	....
K1194	-.3	-.6	.4	.8	1.0	1.7	1.3
K1198	-.1	-.3	.1	1.5	2.4	3.6	3.7
K1199	.0	.2	.8	3.1	4.6	7.8	9.3
cK1232	3.6	6.8	9.6	14.1	16.5	18.6	....
cK1233	3.6	6.4	9.4	14.0	16.6	18.6	....
K1235	.3	.2	.6	2.1	3.7	6.3	6.3
K1236	.0	.4	1.2	2.8	4.6	8.4	9.7
K1237	-.1	.6	1.8	2.9	6.1	9.5	9.5
cK1263	.8	2.9	5.4	9.6	11.2	12.5	12.6
cK1264	1.7	4.1	6.7	11.3	13.3	15.1	15.7
K1265	-.1	.4	1.6	4.5	6.7	8.9	....
K1266	-.2	-.2	.2	1.6	3.0	4.3	5.3
K1296	-.3	-.3	-.1	1.1	.6	1.4	2.0
cK1329	2.1	5.1	7.6	12.1	14.1	....	....
cK1331	2.4	4.9	7.7	12.0	14.1	....	....
cK1338	1.8	3.9	6.6	11.1	14.4	17.8	18.4
cK1343	3.1	5.0	7.6	11.2	13.4	....	....
K1347	-2.3	-1.8	-.5	-.3	2.3	4.1	4.3
cK1351	2.2	4.9	7.9	12.1	14.2	....	....
cK1357	3.7	6.1	8.5	12.6	14.2	....	....
cK1359	1.8	3.3	5.2	9.2	10.7	12.7	13.5
cK1360	2.8	5.3	7.8	12.5	14.5	....	....
cK1363	2.5	4.2	6.2	10.1	12.3	....	....
cK1479	2.2	3.7	5.7	9.8	11.1	....	....
K1495	-.4	-.3	.4	.9	1.3	.4	.8
cK1504	1.3	4.2	7.3	11.3	13.6	....	....
cK1505	1.5	2.5	16.3	11.5	13.6	....	....
cK1508	2.2	3.6	5.4	10.1	12.2	....	....
cK5110	1.1	2.3	4.1	7.1	9.5	12.2	13.0
cK1511	2.0	4.3	7.1	11.3	13.8	....	....
cK1516	2.6	4.9	10.1	13.5	15.1	18.5	19.1
Q1089	-.18	-.61	-.20	-.01	-.33	.2	.4
Q1090	-.26	-.79	-.77	-.21	-1.17	-1.0	-1.0
Q1223	-.34	-1.03	-1.43	-.82	-2.72	-2.4	-1.7
Q1224	-.33	-.37	-.65	.17	.69	....	....
Q1252	....	-.89	-.79	.74	.22	-.3	-2.4
Q1253	-.23	-.60	-.48	.34	.03	-.4	-1.0
Q1254	-.15	-.67	-.45	.31	.45	-1.8	-1.0
Q1255	-.50	-.96	-.21	.92	.79	1.9	1.1
Q1256	-.41	-.80	-.39	.77	.69	1.3	.9
Q1266	-.68	1.03	1.55	2.71	.30	3.0	2.6
Q1281	-.29	-.81	-.45	.47	.22	.4	.8
Q1282	-.61	-.23	-1.05	-.19	....	2.0	2.5

Table 3.--Recovery of ground-water levels, in feet, in Kings and Queens Counties, N. Y., from June 1947 to December 1950--Continued

[Recoveries computed on the basis of water levels measured on June 30, 1947, after an approximate 12-hr nonpumping period, except for well K1351 for which the nonpumping water level on July 1, 1947, was used]

Well no.	Recovery, in feet, for indicated number of months after June 1947						
	1	3	6	12	18	30	42
Q1283	-0.28	-1.02	-0.86	-0.34	-1.54	-0.6	-0.4
Q1284	-.64	-.50	-.81	-.53	-.75	2.3	.7
Q1285	-.32	-.99	-.72	-.25	-1.27	-1.5	-1.8
Q1286	-.24	-.99	-1.02	.13	-.17	-.8	-2.2
	Wells screened in the Jameco gravel (artesian wells)						
K19	0.8	1.4	2.9	5.1	7.5	10.4	10.9
cK517	2.0	3.6	6.0	10.1	12.5	....	....
cK519	2.4	4.2	6.4	10.1	12.7	15.1	15.8
cK520	1.7	3.1	5.2	8.3	11.0	....	....
cK522	2.3	4.7	7.7	12.2	14.6	16.5	16.8
cK523	.2	.7	1.7	3.7	4.2	4.1	4.4
cK524	2.9	4.9	7.5	11.9	13.3	15.6	16.3
cK525	.4	.9	1.6	3.5	4.1	3.8	4.0
cK526	1.8	3.2	5.2	8.8	11.3	14.3	14.8
cK528	2.2	5.0	7.3	11.3	13.7	....	....
cK533	1.6	3.1	5.2	8.3	11.1	....	....
K1591	-.2	-.4	-.2	1.2	1.0	1.7	2.1
Q350	-.08	-.14	-.39	.08	.49	.4	1.1
Q1459	-.28	-.58	-.36	....	....	....	....
	Wells screened in the Lloyd sand member of Raritan formation (artesian wells)						
cK521	0.4	-0.4	0.0	1.2	2.6	1.8	3.0
K1057	-.9	-1.5	-.3	.2	1.0	-.2	.5
Q543	-1.0	-1.3	.1	.7	1.1	.9	1.1

c Observation wells in franchise area of the New York Water Service Corp.

Table 4.--Ground-water levels, in feet, mean-sea-level datum, in additional wells in Kings County, N. Y., for December 1950.

Well no.	Location	Water level	
		Altitude	Date
K236	Bushwick Ave. and Forrest St......	-28.5	Dec. 20, 1950
K300	Avenue D and Albany Ave..........	2.5	Dec. 11, 1950
K326	750 Flushing Ave.................	-25.8	Dec. 12, 1950
K337	Avenue M and 17th St.............	3.4	Dec. 11, 1950
K631	6817 Bay Parkway.................	3.6	Dec. 18, 1950
K636	7010 13th Ave....................	4.0	Do.
K949	68-17 5th Ave....................	3.1	Dec. 12, 1950
K1091	Clinton and Mill Sts.............	-4.4	Do.
K1297	Flatbush Ave. and Kings Highway...	3.5	Dec. 11, 1950
K1365	124 Atlantic Ave.................	-11.3	Dec. 12, 1950
K1494	5205 4th Ave.....................	2.2	Do.
K1576	Knickerbocker Ave. and Starr St...	-17.7	Do.
K1593	1469 Utica Ave...................	2.2	Dec. 18, 1950

Note: Water-level measurements in above wells made for first time in 1950. This list supplements that in table 2. All wells screened in upper Pleistocene deposits (water-table wells). Altitude, in feet, above or below (-) mean sea level (Sandy Hook datum).

the heavily pumped franchise area of the New York Water Service Corp. in Flatbush; water levels at wells K30 and K1237 indicate trends near the bottom of the so-called crater area in the highly industrialized section of northwestern Brooklyn about 2½ miles north of Flatbush. Data at well K1266 portray fluctuations 2 miles east of the franchise area and near the Queens County line. The trend of water levels in these four wells in Kings County is influenced primarily by pumping and to a much lesser degree by precipitation. In direct contrast, the trend of the average level of the 14 selected wells in Nassau and Suffolk Counties reflects the precipitation trend much more closely than the pumping. Previous studies by Leggette (1940), Jacob (1945b), and others emphasize approximate parallelism between precipitation and ground-water level trends in central Long Island.

After the general shut-down of pumping by the New York Water Service Corp. in June 1947, water levels at these wells recovered rapidly. The rise generally varied inversely with the distance from the center of the area of previous heavy pumpage. At wells K1264 and K30, gains of 15.7 ft and 8.7 ft, respectively, were recorded during the 3½-yr period ending in December 1950; at well K1266 the rise was much smaller. On the other hand, the average level of the 14 selected wells portraying the precipitation pattern showed a net drop during this same period.

Artesian Formations

In the early 1930's as much as 16 mgd was withdrawn from the artesian formations within the franchise area of the New York Water Corp.

Later this pumpage was reduced gradually to less than 7 mgd at the time of the general shut-down in June 1947 because of the increasing salinity of the artesian water. (See fig. 2 and table 1.) The chloride content was so high at some of the artesian wells after a few years that they were operated only during periods of emergency. All but one of the artesian wells constructed for the New York Water Service Corp. were screened in the Jameco gravel (fig. 8); well K521 was in the Lloyd sand member of the Raritan formation.

An over-all recovery of water levels, as shown in figure 9 and in table 3, certainly not equal in horizontal directions, followed the cessation of pumping in the artesian formations. In general, the rate of recovery, the total rise, and the altitude of water levels in the Jameco gravel corresponded closely with those in the water-table wells for the first few months after the shut-down. Monthly hydrographs for pairs of wells at each of several locations in Flatbush (fig. 10) portray this parallelism of recovery of water levels in the two aquifers. After the first year, primarily because of the more immediate effect of recharge to the shallow aquifers by precipitation, the water table in general rose at a slightly faster rate than the artesian levels. By the end of 1950 the difference in levels in the pairs of wells at the several sites was not more than 2 ft, 3½ yr after the shut-down.

Profiles of the piezometric surface (fig. 11) along cross sections indicated on the index map (fig. 8) are plotted for several dates from June 1947 to December 1950. These illustrate that (1) the largest recovery occurred in areas where the Jameco gravel was pumped heavily previously, (2) the cone of recovery expanded rapidly northwestward from well K19 and somewhat more slowly southwestward to and beyond wells K523 and K525, (3) the smallest net change in water levels in the Jameco gravel was measured east of Flatbush near the Kings-Queens County line at wells K1591, Q1459, and Q350, and (4) the

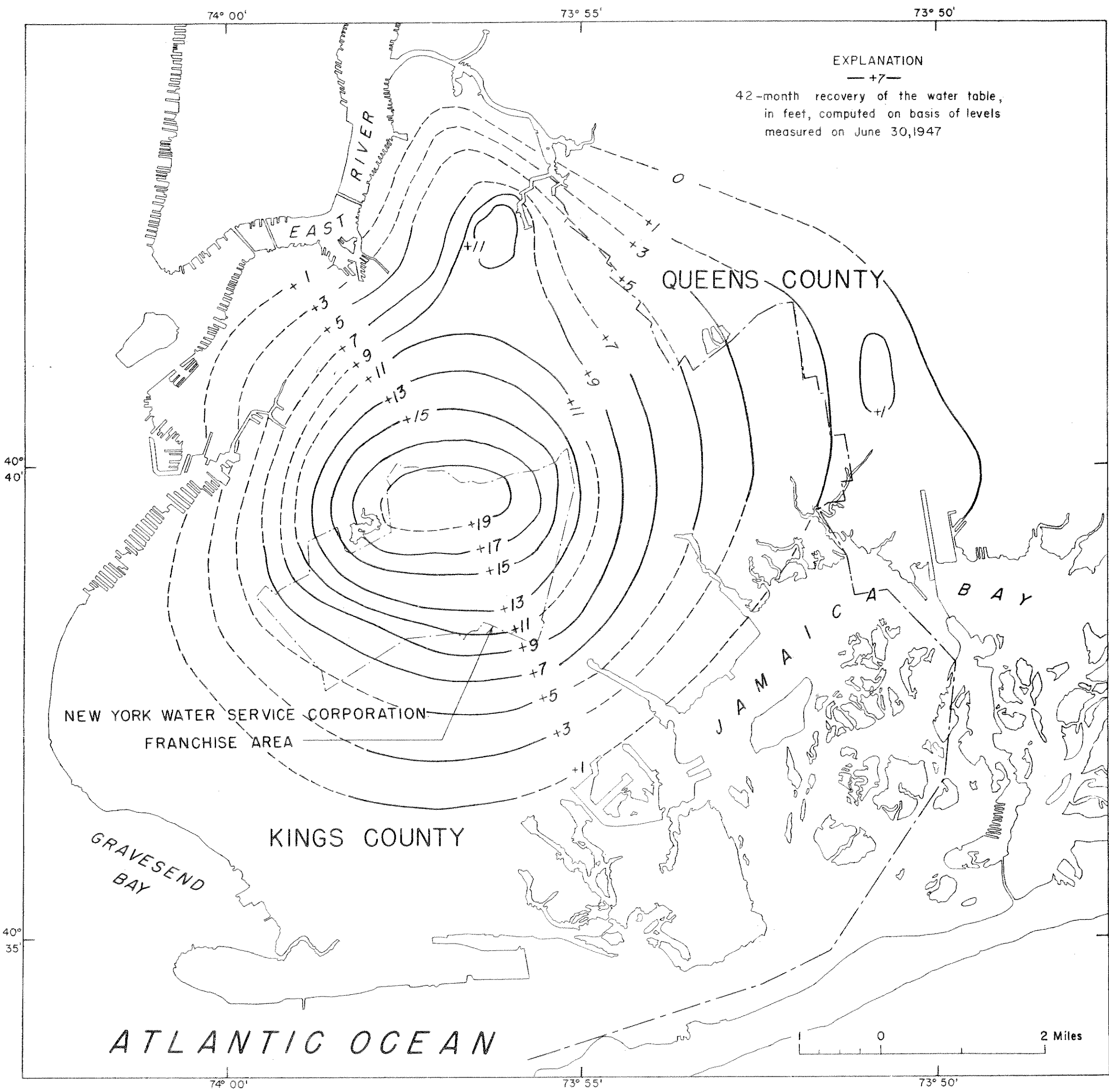


Figure 5.--Recovery of water table in Kings and Queens Counties, N. Y., from June 1947 to December 1950.

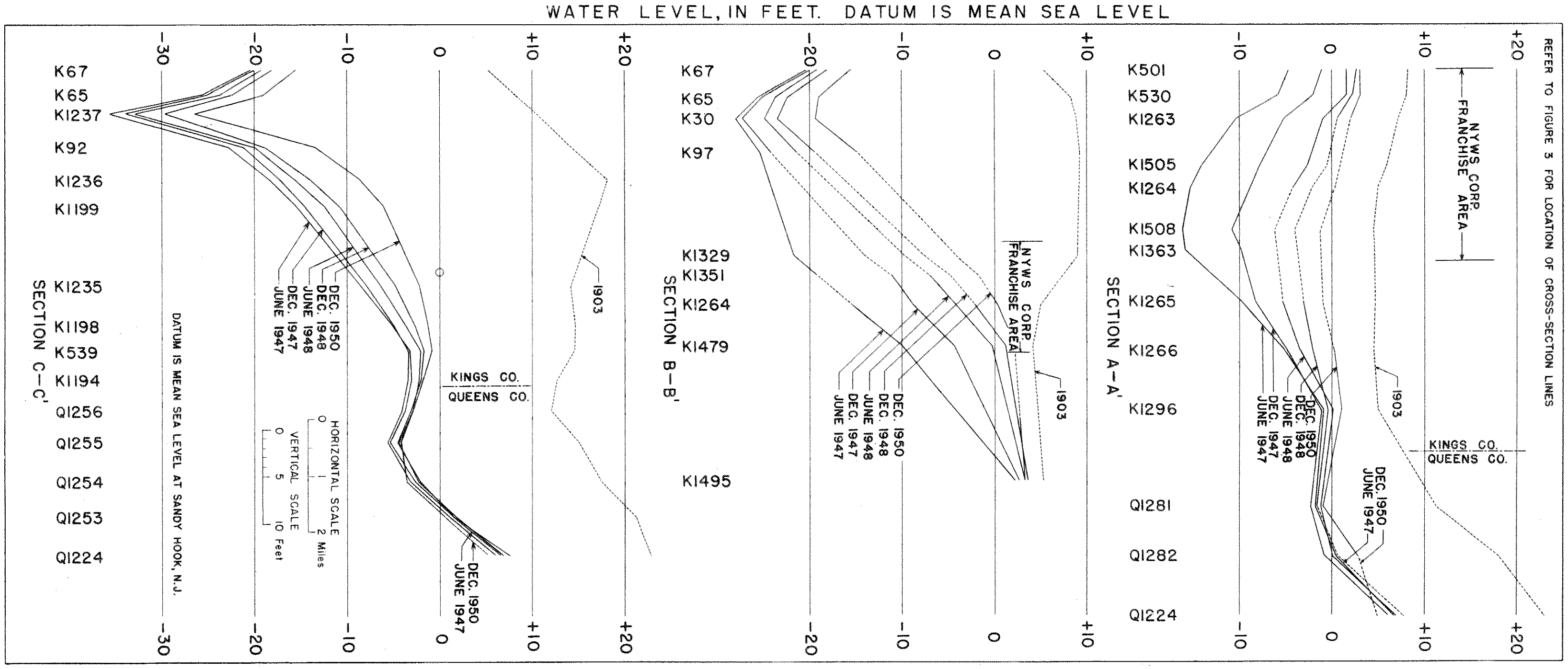


Figure 6.--Profiles of water levels in Kings and Queens Counties, N. Y., in 1903, 1947-50.

aquifer in which well K521 was screened was only remotely connected hydraulically with the principal beds of the Jameco gravel.

The relatively small number of artesian wells and their inadequate distribution geographically fail to provide sufficient basic data for accurate contouring of piezometric levels and recovery. However, a piezometric map and a map showing recovery of water levels in the Jameco gravel undoubtedly, as explained above, generally would be similar --at least in the franchise area of the New York Water Service Corp.--to the water-table contour map (fig. 4) and the recovery map (fig. 5), respectively.

Summary--Recovery of Water Levels in Brooklyn

The large recovery of water levels in the water-table and artesian formations in Brooklyn from June 1947 to December 1950, especially in the Flatbush section and nearby vicinities, is attributed largely to the shut-down of pumping by the New York Water Service Corp. in June 1947. At this time, the total net withdrawals were reduced more than 50 percent from about 50 mgd to about 23 mgd.

However, some of the rise in the water table, perhaps as much as 1 ft and more in some localities, and a small part of the rise of artesian levels in the Jameco gravel express replenishment from precipitation during the 42-month period ending December 1950. Much of the surface area in northern and western Kings County has been made relatively impervious by the works of man. Yet many relatively pervious areas still remain, especially in the southern and southeastern section of Brooklyn, where recharge from precipitation is appreciable.

In general, water levels continued rising without any serious interruption in the northern half of Brooklyn where they were below sea level from June 1947 to December 1950. In southern Brooklyn and especially where the water table rose above sea level, the highest altitudes were reached during 1948. Since then a slight recession consistent with the precipitation pattern was observed at many wells.

By December 1950, only $3\frac{1}{2}$ yr after the shut-down of pumping, a remarkable improvement in the status of water levels in Brooklyn was noted. The water table was below sea level only in the northern half of Brooklyn where the extent of the crater area, or cone of depression, was continually decreasing. In all, the net gain in storage in the water-table formations in Brooklyn from June 1947 to December 1950 was about 20 billion gallons. Another 10 billion gallons will fill the present crater in northern Brooklyn to sea level. The increase in storage in the Jameco gravel was much smaller.

The recovery reached western Queens but was overbalanced by the gradually increasing rate of pumping in this adjacent county.

As the average replenishment from precipitation and the laterial inflow from Queens County continue to exceed net withdrawals and out-flow to sea in Brooklyn, the rising trend can be expected to continue--unless pumping is increased appreciably, or a severe drought is experienced on Long Island. However, although the water table may continue to recover for many years, the record high levels of 1903 may never be reached again under natural conditions. The large increase in population and the industrialization and commercialization of the county contributed significantly to the reduction of the pervious land area, and thus resulted in a permanent decrease of replenishment to the underground aquifers from precipitation.

With the water levels continually recovering, subways, cellars, and subcellars that have not been waterproofed at and below sea level may in time be flooded by the rising water table or artesian levels.

SPECIAL STUDIES

Previous investigators correlating data on the geology of western Long Island were confronted with the following particular questions with respect to the deeper wells and formations in Brooklyn:

1. Are wells K523 and K525 screened in the shallower beds of the Jameco gravel separated hydraulically from its principal beds?

2. Is well K521 screened in the deeper beds of the Jameco gravel or in the Lloyd sand member?

3. Can the continuity of the Jameco gravel from western Queens County to central Kings County be established by pumping or shut-down interference?

The complete shut-down of pumping by the New York Water Service Corp. in June 1947 allowed the collection of very valuable data which combined with other available information provided more positive answers to these questions.

Wells K523 and K525 in the Jameco Gravel

Wells K523 and K525 in the Jameco gravel, more than 2 miles southwest of the center of the area of pumping from the aquifer (fig. 8), were abandoned in the middle 1930's after a few years of heavy pumping because of a high chloride content. After June 1947 water levels at these abandoned wells recovered much more slowly than those at the other wells in the Jameco gravel in the franchise area of the New York Water Service Corp.

Geologic, hydrologic, and salinity data when considered together establish the fact that wells K523 and K525 are screened in the principal beds of the Jameco gravel and that they are artesian wells. The slow rate and small amount of recovery after the general shut-down of pumping in June 1947 suggest (1) somewhat less direct hydraulic connection

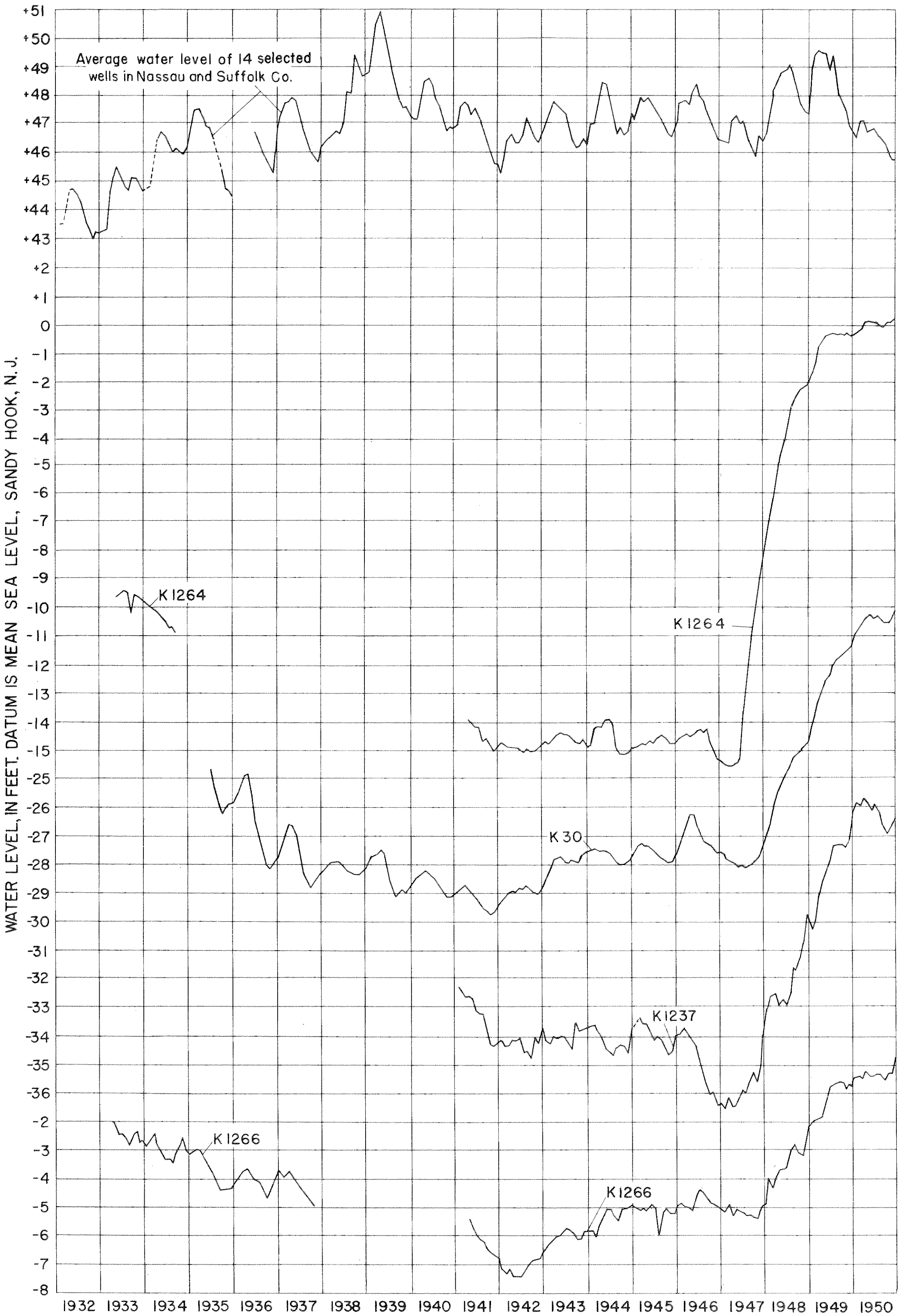


Figure 7.--Monthly water levels in selected water-table wells on Long Island, N. Y., for 1932-50.

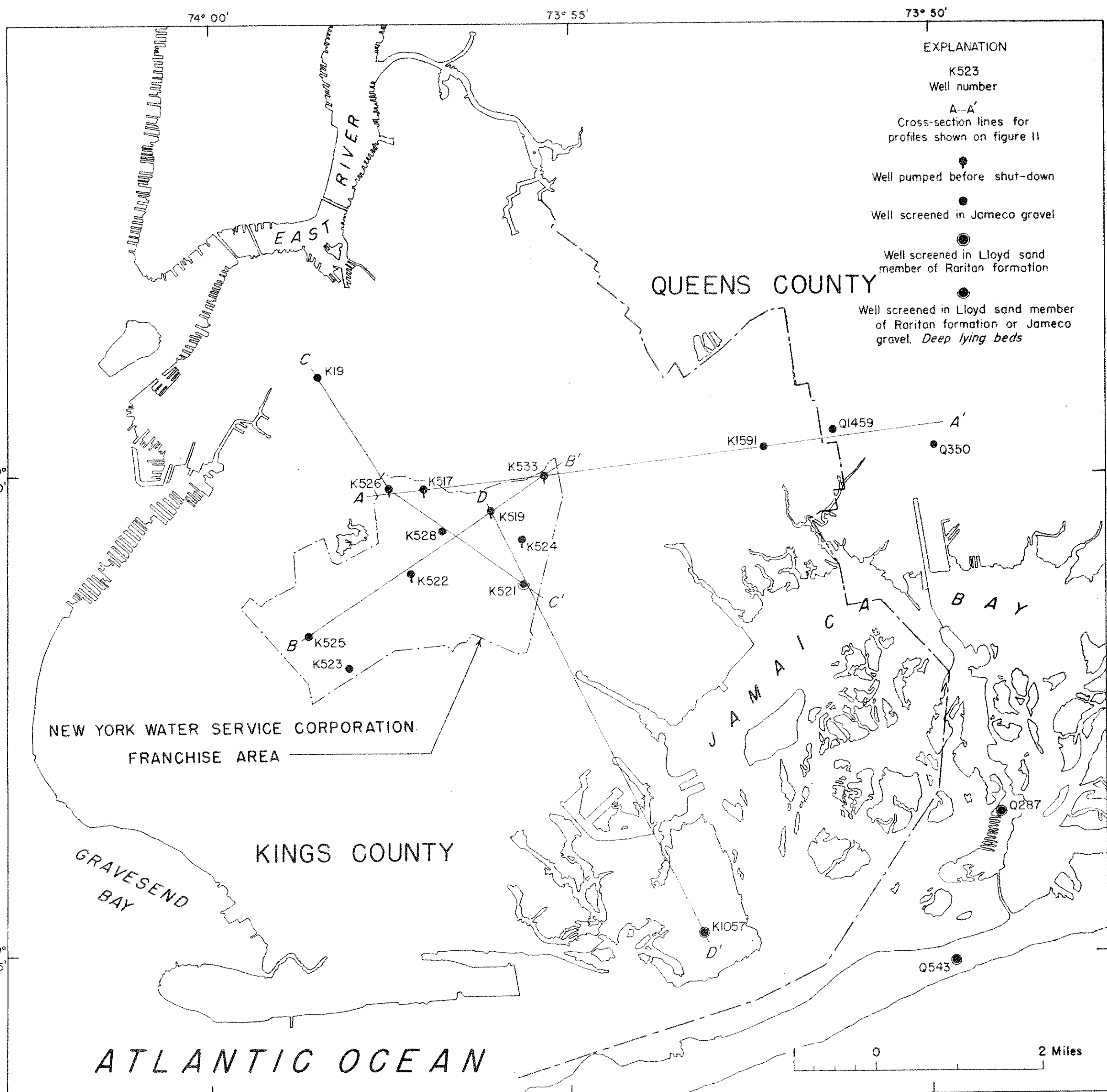


Figure 8.--Index map showing artesian wells and cross-section lines in Kings and Queens Counties, N. Y.

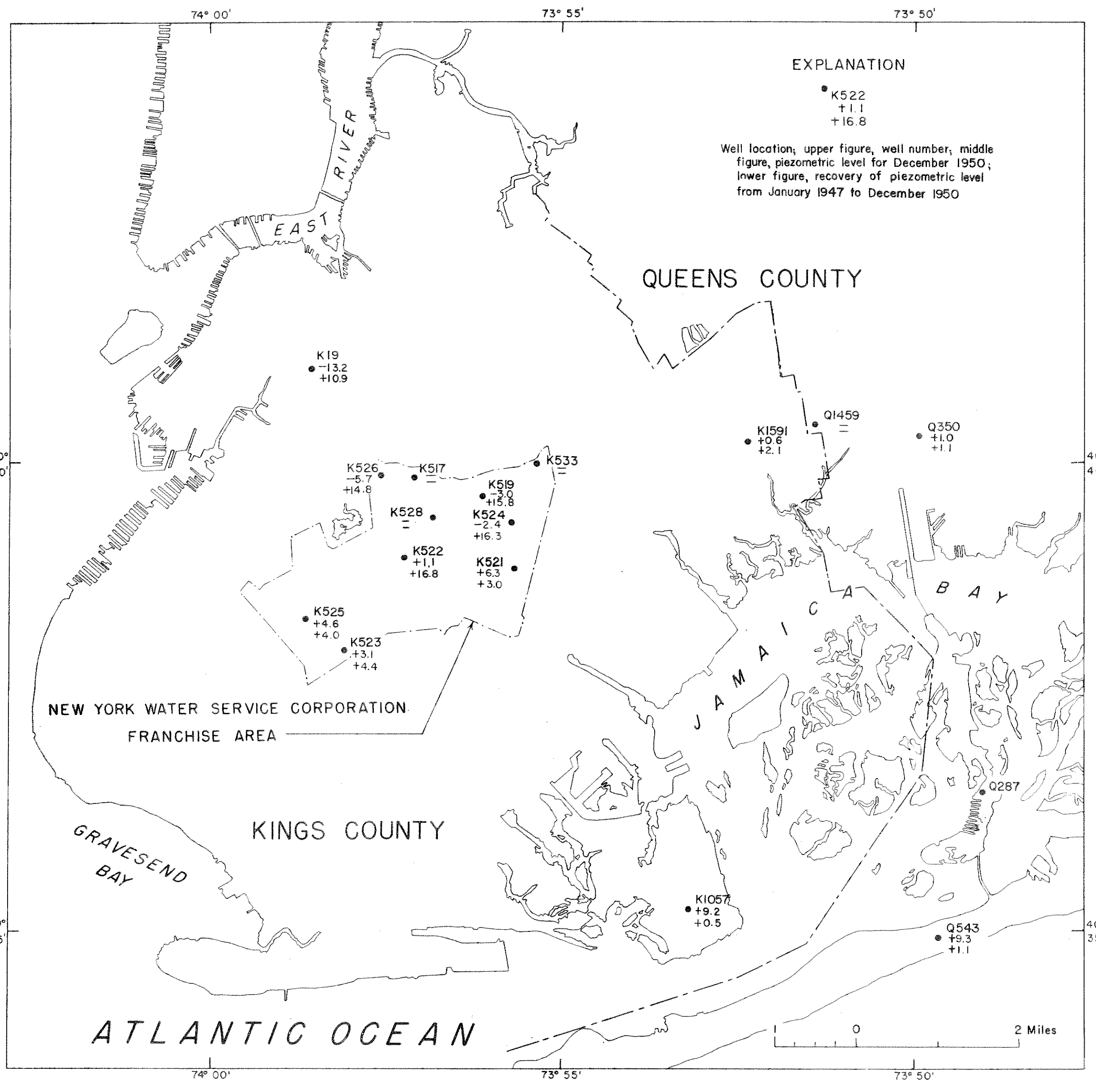
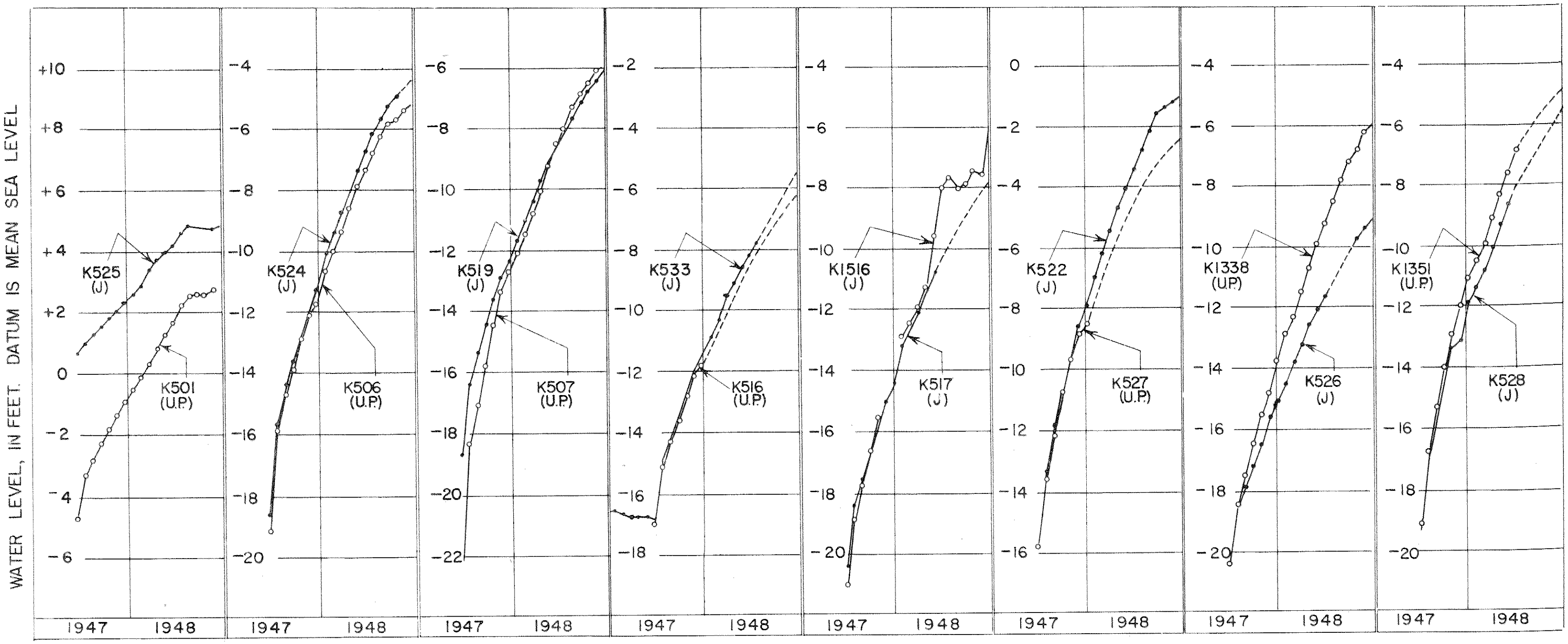


Figure 9. Recovery of water levels in artesian wells in Kings and Queens Counties, N. Y., from June 1947 to December 1950.



For above pairs of wells, the water-table wells are within 100 feet of the artesian wells. All wells are located in the franchise area of the New York Water Service Corporation

o Monthly water level in water-table well

• Monthly water level in artesian well

-------- Levels computed on basis of profiles, contours, and trend of recovery

(U.P.) Upper Pleistocene deposits

(J) Jameco gravel

Figure 10.--Comparison of water levels in water-table and artesian wells in Kings County, N. Y.

with the Jameco gravel to the east, (2) and rather indirect hydraulic interconnection with the overlying water-table deposits. The level in well K525 was about 2 ft higher than that in the nearby shallow water-table well K501, 50 ft away. Moreover, the nonpumping water level in well K525 at all times was higher than any measured not only in the other wells in the Jameco gravel but also in the water-table formations. This significant hydrologic evidence suggests that the recharge to the Jameco gravel at wells K523 and K525 may originate from the deeper formation, perhaps from the Lloyd sand member of the Raritan formation.

That well K525 is artesian is confirmed by the comparison of salinity data. The chloride content of water samples from the nearby shallow well K501 increased at a much slower rate than from well K525 (table 1). The extremely rapid increase in salinity in well K525 when pumped could have occurred only under predominantly artesian conditions--that is when the coefficient of storage was low. Then too, the difference in the rate of increase of salinity in these two adjacent wells screened in separate aquifers indicates that the Gardiners clay, in general, prevented rapid movement of ground water to and from the upper Pleistocene (water-table) deposits.

The above reasoning and conclusions with respect to well K525 apply, in general, to well K523.

Well K521 in the Lloyd Sand Member of the Raritan Formation

Data on piezometric levels in the Lloyd sand member of the Raritan formation were included in figures 11 and 12 primarily to illustrate graphically that the water levels in well K521 were much higher than those measured at wells in the Jameco gravel and that the trend of levels and pattern of fluctuation for well K521 corresponded much more closely with those for well K1057 screened in the Lloyd sand member of the Raritan formation.

The piezometric level in well K521 was at altitudes of 3 to 6 ft above mean sea level for more than a year before and after the shut-down. Thus at all times it was not only above the levels in other observation wells in the Jameco gravel but also higher than any level measured in the shallow water-table formations in Brooklyn. Only at one observation well in Kings County was a measured level higher than in well K521. That measured level was in well K1057, 4½ miles to the south screened in the Lloyd sand member, strongly suggesting that aquifer as a source of recharge.

Of particular significance and importance is the fact that artesian levels computed for a theoretical well in the principal beds of the Jameco gravel at the site of K521 were lower by several feet than those actually measured in well K521 since the shut-down. The calculations were based on available water-level data for nearby wells screened in the Jameco gravel and on the hydraulic characteristics of this aquifer.

A study of the salinity trend in the artesian wells provides further justification for the classification of well K521 as a well screened in the Lloyd sand member. Three years after the start of pumping in 1929 the salinity of ground water sampled from well K521 had increased from 29 ppm to more than 200 ppm. At all other wells in the Jameco gravel in the vicinity of well K521, the rate of increase was so much slower that salinities of more than 200 ppm were not measured until about 1942, 10 yr later.

No immediate and direct interference was detected at well K521 after the shut-down of pumping at well K524 only 1 mile to the north. Well K521 not only failed to respond to the general recovery of piezometric levels in the Jameco gravel but also indicated an opposite trend more consistent with that in the Lloyd sand member. On the other hand, the shut-down of pumping in November 1949 from well K619, screened in the Lloyd sand member, was reflected in well K521 located 2 miles to the west.

In view of all the hydrologic, salinity, and geologic evidence, it is concluded that well K521 reflects much more closely the behavior pattern of wells screened in the Lloyd sand member than of those in the Jameco gravel, and for all practical purposes it can be considered as a well screened in the Lloyd sand member.

Mutual Interference in the Jameco Gravel

In an earlier unpublished report, Ferris (1942) noted marked interference between many wells in the Jameco gravel in central and northwestern Brooklyn. He also observed mutual interference between several wells in the Jameco gravel in southern Queens County; such an interconnection was then traced by him step by step from southern Queens County westward to the wells in the Jameco gravel in eastern Kings County pumped infrequently by the New York City Department of Water Supply, Gas and Electricity at the New Lots pumping station. However, the final connecting link of hydraulic continuity in the Jameco gravel was not established by Ferris because of the lack of data for this purpose.

It was therefore hoped that the complete shut-down of pumping by the New York Water Service Corp. on June 1947 would provide definite information as to the extent, if any, of the hydraulic connection between the beds of the Jameco gravel in Kings and Queens Counties. For this purpose three recorders were installed before the shut-down of wells K1591, Q1459, and Q350 near the Kings-Queens County line to intercept any possible effect resulting from the large reduction of pumping from the Jameco gravel in central Brooklyn.

Geologic evidence points to the unquestionable presence and the continuity of the Jameco gravel from Kings to Queens County. However, the Gardiners clay in eastern Kings County overlying the Jameco gravel was established by correlation studies (De Laguna, 1948; Suter and others, 1949) as being more sandy than clayey. This suggests the possibility of a more direct hydraulic inter-

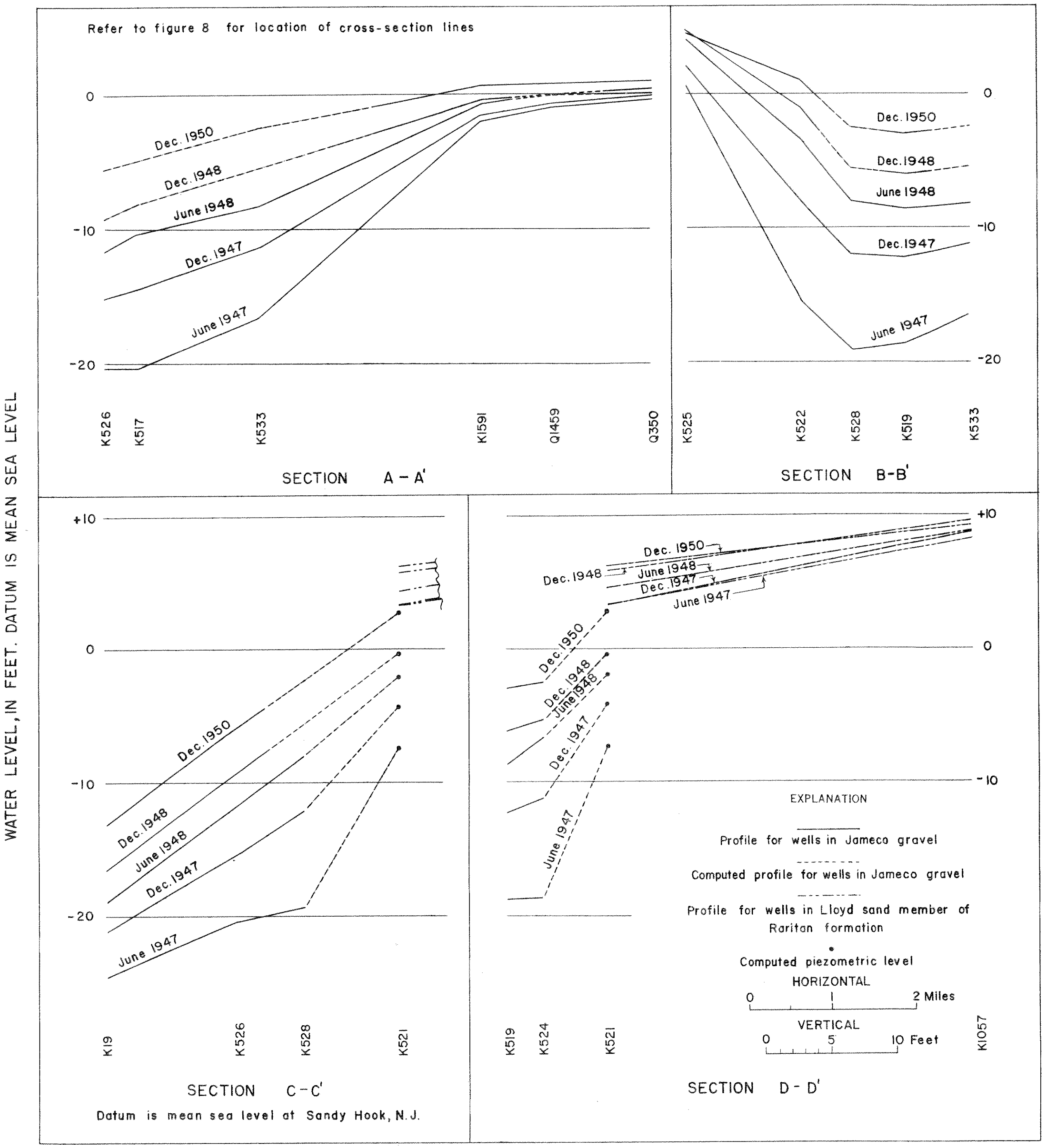


Figure 11.--Profiles of artesian levels in Kings and Queens Counties, N. Y., in 1947, 1948, and 1950.

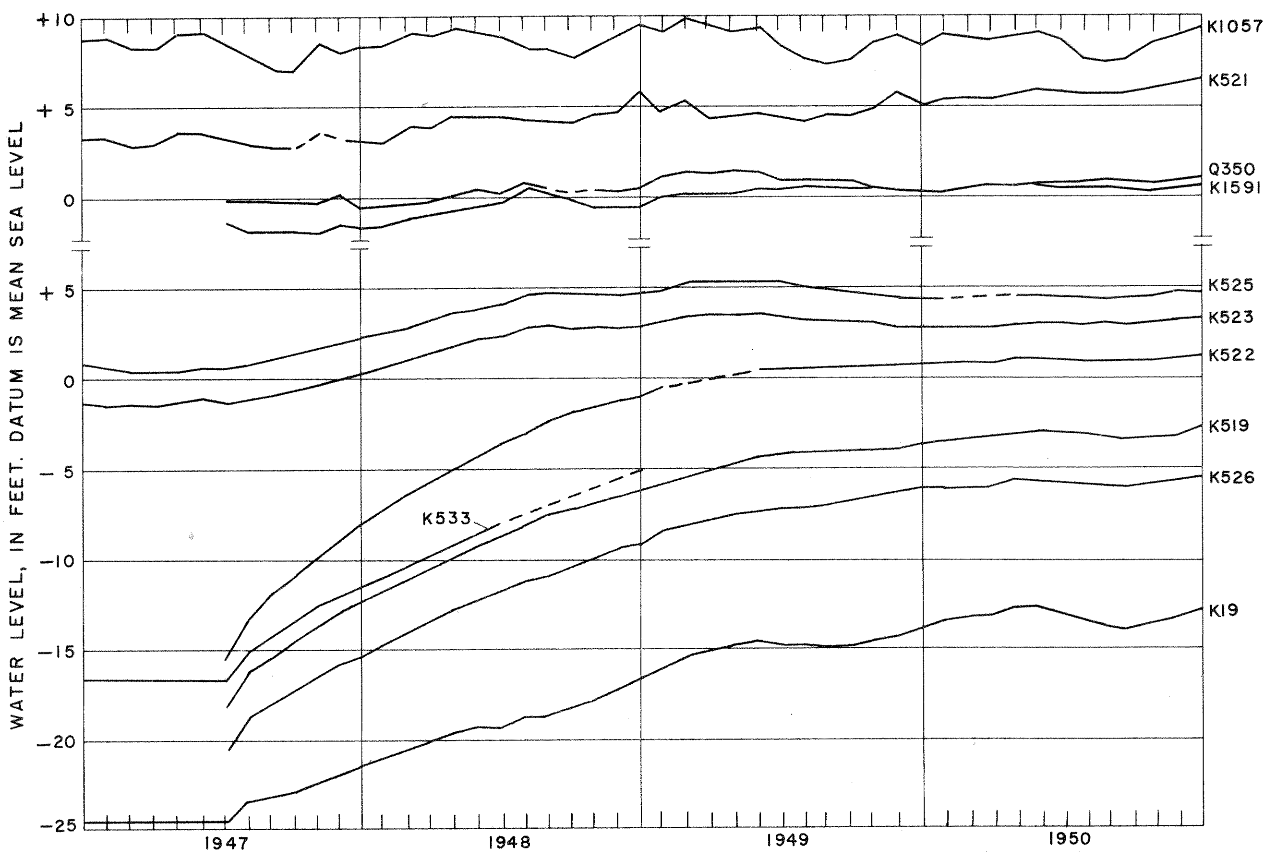


Figure 12.--Hydrograph showing monthly water levels in artesian wells in Kings and Queens Counties, N. Y., during 1947-50.

connection of the Jameco gravel with the overlying water-table deposits. Hydrologic evidence obtained before and since the shut-down in 1947 provides the following support to this supposition as (1) The cone of recovery in the Jameco gravel expanded eastward from Flatbush to Queens County no faster than that in the shallower water-table deposits, and (2) the trend and fluctuation of water levels in the two aquifers at the New Lots pumping station reflect very closely the precipitation pattern as indicated at wells K1296 and K1591 in tables 2 and 3.

Thus the attempt to define the continuity of the Jameco gravel by the recovery of water levels resulting from the large shut-down in pumping failed because the Jameco gravel functions more as a water table and less than an artesian aquifer in eastern Brooklyn. However, the fact that the Jameco gravel was connected almost directly hydraulically with the upper Pleistocene deposits was established instead.

SAFE WITHDRAWAL

For several years before the complete shut-down of pumping by the New York Water Service Corp., total net withdrawals in Kings County for all uses averaged more than 60 mgd. At this rate of pumping, water levels remained below sea level and the salinity of ground water increased. Such conditions defined overdevelopment. After June 1947, when the total net pumpage was reduced to about 23 mgd, replenishment exceeded withdrawal. In general, water levels recovered rapidly and were still rising practically everywhere in Brooklyn in December 1950. It can be concluded that the safe withdrawal of water-bearing formations in Brooklyn is between 23 mgd and 60 mgd.

The net replenishment to storage attributable to the recovery in the water-table aquifer in $3\frac{1}{2}$ yr was about 20 billion gallons, representing a rate of about 17 mgd. The increase in storage in the Jameco gravel was much less. The total accretion rate from precipitation and underflow from Queens County is the sum of the average rate of net pumping (23 mgd) and of increase in storage (17 mgd), which totals to about 40 mgd. On this basis, with an assumed safety factor of 25 percent, the safe withdrawal of the water-bearing formations in Brooklyn is about 30 mgd for a sufficiently well-planned and coordinated development in the county. In this connection it is interesting to note that Suter (1937, p. 11) calculated the highest degree of development in 1936 as 40 mgd for Kings County.

Most of the present pumping in Brooklyn is concentrated in the northern sections, where the water table is still below sea level. The safe withdrawal from this area is probably not much more than the present net withdrawal of about 13 mgd. The remaining 17 mgd, or about 9 mgd more than the present pumpage, can be pumped from southern Brooklyn where the water levels are now above sea level.

The Jameco gravel was highly overdeveloped by the New York Water Service Corp. at 16 mgd in 1933. When withdrawals from this artesian aquifer were reduced to average 10 mgd during the period 1941-47, the salinity of ground water in central Brooklyn kept increasing. Experience thus shows that most of the withdrawals in Brooklyn must be made from the shallow water-bearing formations and that the safe withdrawal from the Jameco gravel is not much more than 5 mgd.

The present ever-increasing concentration of population in many sections in the United States demands comprehensive and integrated planning of surface- and ground-water development on a regional basis. To an increasing extent through the years, engineers have proposed recharging underground aquifers with some of the excess surface water that cannot be detained in surface-water reservoirs during certain seasons of the year. In this connection it is of interest that the capacity of the ground-water reservoirs of only the water-table deposits in Brooklyn (assuming sea level as approximately the high flow line) was computed to be at least 200 billion gallons. If as little as 10 percent, representing a potential of about 20 billion gallons, can certainly be realized as usable storage, the availability and utilization of this water can play at least a minor role in any integrated planning.

CONCLUSIONS

The expanded program for recording the recovery of water levels in Brooklyn from June 1947 to December 1950, and the over-all study and integration of hydrologic, geologic, salinity, and pumpage data provided much basic information pertaining to the hydrology and geology of western Long Island, which could not have been obtained otherwise. Hydrologic answers to some geologic problems were obtained.

This report offers the following findings and conclusions:

1. The crater area or the huge cone of depression in Brooklyn was more than two-thirds refilled in the $3\frac{1}{2}$-yr period after the shut-down of pumping about 27 mgd of pumpage by the New York Water Service Corp. in central Brooklyn. By December 1950, the water table recovered appreciably and was below sea level only in northern Brooklyn where the cone of depression was decreasing gradually.

2. The improvement of ground-water conditions in Brooklyn augmented very little the available ground-water supplies in the franchise area of the Woodhaven section of the New York Water Service Corp. in western Queens County. The recovery of as much as 19 ft in central Brooklyn and as little as 1 ft around the perimeter of the county extended into Queens County, but was overbalanced by the gradually increasing pumping in Queens County.

3. The landward advance of salt water in the water-bearing formations, and particularly in the Jameco gravel, an artesian formation, was decelerated in 1947. Under normal conditions many years will elapse before the underground supplies in Brooklyn are entirely fresh.

4. The safe withdrawal at the present time is ascertained at about 30 mgd, if pumpage is distributed equally throughout the county and most of the withdrawals are made from the shallow water-bearing formations.

5. Indirect hydraulic interconnection of the water-table deposits with the Jameco gravel was verified in central Brooklyn. Throughout the years, ground water percolated downward or upward through the Gardiners clay, depending on the relation of water levels in these two main aquifers in Kings County.

6. Geologic continuity of the Jameco gravel from Kings into Queens County was accepted. But near the Queens County line in eastern Brooklyn the Jameco gravel appeared to have a more direct hydraulic connection with the shallower aquifer and thus functioned much more as a water-table than as an artesian aquifer.

7. No positive substantiation of any principal hydraulic interconnection of the Jameco gravel with the Lloyd sand member of the Raritan formation was observed from the detailed studies. The high static level at well K525 suggests that the recharge to the Jameco gravel where this well is screened could have its source in the deeper Lloyd sand member.

8. Hydrologic, geologic, and salinity evidence defined well K521 as screened in the Lloyd sand member of the Raritan formation.

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