Dispersal of Plating Wastes and Sewage Contaminants in Ground Water and Surface Water, South Farmingdale-Massapequa Area, Nassau County, New York

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By N. M. PERLMUTTER *and* MAXIM LIEBER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

Prepared in cooperation with the Nassau County Department of Public Works and the Nassau County Department of Health

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[Plates are in pocket]

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By N. M. Perlmutter and Maxim Lieber [1]

ABSTRACT

The latest in a series of four studies made in southeastern Nassau County, N.Y., from about 1949 to 1964 afforded an unusual opportunity to compare the dispersal of heavy-metal ions discharged into ground water in the metal-plat'ng-waste effluent from an industrial plant with the dispersal of detergents from several hundred domestic cesspools and septic tanks. The contaminated ground water is moving through highly permeable beds of sand and gravel of the upper glacial aquifer. The quality of the water in the underlying Magothy aquifer, a major artesian unit, is apparently unaffected by these contaminants.

Plating wastes containing cadmium and hexavalent chromium have seeped down from disposal basins into the upper glacial aquifer intermittertly since 1941. This seepage has formed a plume of contaminated water about 4,300 feet long, as much as 1,000 feet wide, and as much as 70 feet thick. The plume extends downgradient to the headwaters of Massapequa Creek, a small stream which forms a natural drain for part of the contaminated ground water, while the remainder moves slowly downgradient as underflow beneath and parallel to the stream channel.

The maximum observed concentration of hexavalent chromium in th? ground water was about 40 mg/l (milligrams per litter) in 1949, but since the start of chromium-treatment operations in 1958, concentrations of chromium have decreased to less than 5 mg/l in most of the plume. Concentrations of cadmium were generally less than 1 mg/l at most test wells, but a sample from one we'l close to the disposal basins contained about 10 mg/l. Concentrations of the heavy metals

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in Massapequa Creek decreased from about 3 mg/l of chromium and 0.1 mg/l of cadmium at the headwaters of the stream to zero near the mouth.

No public-supply wells have been contaminated by metal-plating wastes, and none are in the predicted path of the plume except for a part of New York City's supplementary ground-water system, composed of wells and infiltration galleries, about 2.5 miles downgradient from the plume. This system which is operated infrequently (mostly during drought periods) is in no immediate danger of contamination by plating wastes owing to the slow rate of movement and dilution of the contaminated water.

Although the physical and hydraulic properties of the water-bearing deposits do not completely satisfy the basic assumptions of classical dispersion concepts and formulas, comparison of field observations of the spread of the heavy metals with theoretical estimates was useful in evaluating the role of various dispersal mechanisms. The data suggest that the natural velocity and direction of the ground-water movement account for most of the longitudinal spread, and the pattern and rate of injection of the plating wastes and the heterogeneity of the deposits account for most of the lateral spread of the contaminants. The vertical extent of the contaminants is controlled chiefly by the head relations at and near the disposal basins, the vertical permeability of the beds, and the natural regional flow pattern.

The detergent constituent alkybenzenesulfonate, referred to as MBAS (methylene blue active substance) in this report, also was investigated. MBAS may cause foaming of water locally, but it is not toxic at the low concentrations determined in the report area. Concentrations of MBAS were greatest in the upper 20 feet of the upper glacial aquifer, where they ranged from less than 0.02 to about 5 mg/l at most test wells. Traces of MBAS were found as deep as 70 feet below the water table near the bottom of the upper glacial aquifer, but no evidence was found of widespread downward seepage of this contaminant into the underlying Magothy aquifer. Concentrations of MBAS in Massapequa Creek ranged from a few tenths of 1 mg/l to as high as 1.7 mg/l.

Public sewers now under construction 1968 in southeastern Nassau County will help reduce contamination of the upper glacial aquifer, but some contaminants such as nitrate, MBAS, and heavy metals probably will remain in the water for many years after sewering is completed.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

Ground water, derived from precipitation on Long Island, is the sole source of supply for nearly 1.5 million people and several thousand commercial establishments and light industries in Nassau County (fig. 1). In 1966, pumpage for all uses averaged about 215 mgd (million gallons per day).

Since the 1940's, construction of numerous one-family homes and some light industrial plants in parts of Nassau County have resulted in increasing contamination of the upper part of the ground-water reservoir, both by seepage of effluent from cesspools and septic-tank
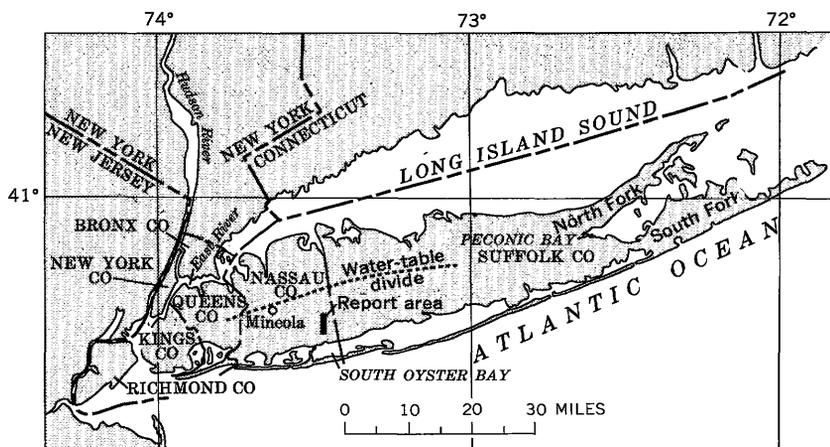
FIGURE 1.—Location of the area in Nassau County investigated for plating-waste and detergent contamination.

systems and by industrial wastes discharged accidentally or intentionally into the ground water.

Although the southwestern part of the county was largely sewered by 1964, residual contamination in the shallow ground water in the sewered area and continued contamination of the ground water in the unsewered northern and eastern parts of the county constitute a significant limitation on the use of a major shallow aquifer as a source of water for public supply. As a result of actual or potential contamination, most public-supply wells tapping this shallow aquifer have been abandoned, or withdrawals from them have been substantially reduced. Furthermore, this contamination, if unchecked, may represent a long-term threat to the future availability of water of suitable quality from an underlying major artesian water-bearing unit, the Magothy aquifer, that is in hydraulic continuity with the shallow aquifer. The Magothy aquifer is the chief source of water for public supply in Nassau County.

This report is based chiefly on the results of the latest of a series of special investigations, begun in 1949, of contamination of shallow ground water in southeastern Nassau County. Most of the new data presented in this report were collected between 1962 and 1964, and a few additional samples were collected from 1965 to 1968. The two principal heavy-metal contaminants investigated were cadmium and hexavalent chromium contained in metal-plating waste fluids which seeped down to the ground water from a cluster of disposal basins. Contamination from detergent residues that have seeped down to the

ground water in the effluent from numerous individual cesspools was also investigated.

Most of the test wells drilled during this and previous investigations have been removed from the ground, but results of analyses of water collected from several remaining wells in March 1968 suggest that the boundaries of the plume containing plating wastes have not changed significantly from those shown on the illustrations in this report. The results also indicate that high concentrations of heavy metals are still in many parts of the plume of contaminated water despite treatment of the wastes.

In addition to a review and interpretation of the results of earlier investigations of the plating-waste contaminants, this report also contains: (1) The latest data on the shape and concentration distribution of the plume of contaminated water near its disposal-basin source and at its leading edge, (2) documentation of the occurrence of plating-waste contaminants in Massapequa Creek, (3) a discussion of the mechanisms causing dispersal of the contaminants, and (4) the first delineation of the vertical and areal extent of detergent contamination in the report area.

Ingestion of heavy metals may be harmful, and detergents, although considered to be nontoxic, are of concern because they commonly indicate contamination of sewage origin and cause foaming of water. Because the concentrations of both the heavy metals and the detergents in the shallow ground water exceed the limits recommended in drinking water by the U.S. Public Health Service (1962), data on the occurrence and movement of these contaminants are of considerable interest to local water-supply and public-health officials. The principles and patterns of contamination discussed in this report are applicable, however, not only to the report area but to other areas in Long Island and elsewhere which have similar ground-water environments.

The detailed study in the South Farmingdale area has resulted in a well-documented case history of the dispersion of contaminants in ground water under field conditions. Moreover, the investigation provided an unusually good opportunity to use the occurrence of the heavy metals to trace the movement of the contaminated ground water through a porous medium and to determine its pattern of seepage into an effluent stream.

LOCATION AND DESCRIPTION OF THE AREA

The general area of this investigation, referred to as the overall report area, is in southeastern Nassau County (fig. 1) and includes parts of the South Farmingdale and Massapequa Water Districts (pl. 1). Intensive test drilling and sampling of the ground water and

surface water were restricted chiefly to about a ½-square-mile section of the northern part of the overall report area, referred to as the principal study area (pl. 1). In addition, parts of Massapequa Creek as far south as Sunrise Highway and selected public-supply installations downgradient from the source of plating wastes (pl. 1) were also examined for evidence of contamination.

The land surface in the overall report area is a gently rolling glacial-outwash plain. The surface slopes southward from about 70 feet above sea level at the northern boundary of the area to about 20 feet above sea level at Sunrise Highway. The surface-drainage system consists of Massapequa Creek, a small effluent stream, which starts in the northern part of the report area where it receives inflow from several short tributaries. These tributaries combine near Southern State Parkway to form the main stream, which flows south in a narrow channel to Great South Bay, about 2 miles south of the overall report area. (See "Seepage to Massapequa Creek.")

An industrial park, which includes a metal-plating plant and several other industries, is in the extreme northern part of the report area. During World War II, the industrial park was occupied by an aircraft company, whose plating-waste effluent was the source of much of the heavy-metal contamination described in this report.

South of the industrial park is a residential area composed chiefly of small homes built mainly between 1946 and 1962. This area is supplied by deep wells of the South Farmingdale and Massapequa Water Districts (pl. 1). No public sewers have been constructed in the area to date [1968], and all sanitary wastes are recharged to ground water by means of individual cesspools and seepage fields. (See "Disposal and degradation of domestic wastes.")

HISTORY OF CONTAMINATION AND RELATION TO EARLIER INVESTIGATIONS

The first official recognition of the occurrence of chromium in the groundwater of Nassau County resulted from a routine sanitary survey of the water-supply system in a former aircraft plant at South Farmingdale (marked "industrial park" on pl. 1). The survey, which was made by the Nassau County Department of Health in 1942 (Davids and Lieber, 1951, p. 528), showed that water from a well near a basin used to dispose of wastes from metal-plating operations contained about 0.1 mg/l (milligram per liter) of chromium. It was not determined whether the chromium was in the form of the nontoxic trivalent ion or the toxic hexavalent ion. Consequently, the owners of the plant were advised by Health Department officials to prohibit the use of the water from the contaminated well for drinking and

to initiate treatment for removal of chromium from the plating wastes.

Because of a shortage of trained personnel during World War II, no further investigation of the chromium contamination was made until June 1945, when the New York City Department of Water Supply, Gas, and Electricity installed a series of shallow test wells in an area extending several hundred feet south of the aircraft plant. The chromium content of the water from the test wells, which penetrated the water table for a short distance only, ranged from zero to a trace, therefore contamination by subsurface flow was not considered to be a serious threat to New York City's auxiliary ground-water system at Massapequa, several miles to the south (pl. 1).

After the publication of a revised set of drinking-water standards by the U.S. Public Health Service in 1946, which recommended a limit of 0.05 mg/l for hexavalent chromium in drinking water, the New York State Department of Health requested that the new owners of the metal-plating facilities present plans for the removal of chromium from the plating wastes before disposal into the ground-water reservoir. In 1948, the New York State Department of Health analyzed another set of samples from the test wells drilled in 1945, and samples from a shallow domestic well about 1,500 feet south of the disposal basins were also analyzed. The results showed about 1 to 3.5 mg/l of hexavalent chromium, 0 to 0.24 mg/l of cadmium, and 0.06 to 0.16 mg/l of copper and aluminum in the water. The determination of cadmium was the first reported occurrence of this metal in Nassau County ground water.

Recognizing that the full extent of the contamination could not be assessed by resampling the few existing wells, and aware of the potential danger to public-water supplies, the Nassau County Departments of Health and Public Works made a joint investigation of the contamined area in 1949 and 1950 (Davids and Lieber, 1951), which included the drilling and sampling of about 40 test wells (pl. 1A). Although. it was known that the plating-waste effluent contained several heavy metals, the investigation in 1949 was restricted to the determination of hexavalent chromium, which has the greatest concentration and toxicity.

Despite the completion of a waste-treatment unit for chromium in 1949, discharge of effluent containing cadmium and other metals continued at the disposal basins. After 1.2 mg/l of cadmium was determined in a sample of treated effluent from one of the disposal basins in 1953, a new test-drilling program, including the construction of 22 sampling wells (pl. 1B), was begun in that year to determine the extent of cadmium contamination downgradient from the disposal basins (Lieber and Welsch, 1954).

In 1958, additional test wells were drilled and samples of contaminated water were collected in the northern part of the plume (pl. 1C), but that study was not completed. The results are included in this report. In 1962, the U.S. Geological Survey, in cooperation with Nassau County Departments of Health and Public Works, began the latest and most detailed investigation of the extent, chemical composition, and pattern of movement of the contaminated water. This investigation included the drilling and sampling of about 100 test wells (pl. 1D) and extensive sampling of Massapequa Creek (pl. 1). Short articles on some of the significant results of the latest investigation were published by Perlmutter, Lieber, and Frauenthal (1963) and by Lieber, Perlmutter, and Frauenthal (1964).

No information on detergent contamination in the report area was obtained in the earlier studies, but owing to wide interest in this type of contaminant all the samples collected during the latest investigation were analyzed for detergent as well as for heavy-metals content. A summary of some of the results of the detergent analyses was published in 1964 (Perlmutter and others, 1964).

METHODS OF INVESTIGATION

FIELD TECHNIQUES

During 1962 and 1963 about 100 test wells were installed, mostly along lines approximately prependicular and parallel to the direction of ground-water flow, between the plating-waste disposal basins and Massapequa Creek (pl. 1D). Groups of test wells were also driven to several depths beneath the bed of the stream and at several points along its banks.

Most of the test wells were constructed of 1¼-inch steel casing with a 3-foot-long wellpoint attached to the bottom. The wells were driven to depths ranging from 8 to 75 feet below land surface, but most of them were finished at depths of from 40 to 50 feet. Water samples were collected at about 5-foot intervals by hand pump during the driving operations. Driving was continued at most sites until the samples showed no detectable contamination, or until the limit of driving was reached. A few private wells in the area were also sampled. Chemical analyses of the samples were generally completed within 24 hours after collection.

The method of well construction and the sampling procedure previously outlined probably afforded little opportunity for interbed mixing of water by downward leakage along the outside of the drive pipe. Conceivably, in a few places, thin zones of water having higher or lower concentrations than the observed values may occur between the intervals sampled. Such conditions are probably not common, and therefore

the concentration patterns illustrated in this report are believed to be reasonably accurate. Furthermore, the approximate lines of equal concentrations shown on the hydrogeochemical profiles (pls. 2–5) probably average out minor discrepancies resulting from the sampling procedures.

The geologic characteristics and the water quality of the deeper strata were determined from four 6-inch wells drilled by the cable-tool method to depths ranging from 97 to 140 feet. Samples were pumped at several depths in these wells from a wellpoint inserted inside the 6-inch casing and driven a short distance below the casing, or the wellpoint was exposed to the strata by pulling back the casing. Most of the water samples collected by this method were unsatisfactory, however, due to mixing of the native ground water with drilling water.

Nearly all the well numbers used in this report are field numbers assigned serially during this investigation to temporary test wells and test holes. A few numbers preceded by the prefix "N" were assigned by the New York Water Resources Commission to selected permanent wells and significant test wells (number followed by the letter "T").

Samples of stream water were collected at 22 sites on Massapequa Creek to determine the load of contaminants carried by the stream during various stages of flow. Measurements of discharge of Massapequa Creek were obtained at one regular U.S. Geological Survey recording gaging station at Massapequa (point U, pl. 1) and by current-meter readings at 15 miscellaneous stations (pl. 1 and table 8). Records of daily discharge at the Massapequa gaging station, from December 1936 to September 1955, are given in a report by Sawyer (1958). Measurements since 1955 are published in U.S. Geological Survey water-supply papers and in annual reports of streamflow in New York State, also published by the Geological Survey.

LABORATORY TECHNIQUES

Nearly 2,000 chemical analyses were made of well and stream samples in the report area, chiefly for hexavalent chromium, cadmium, and detergents. Most of the analyses were made by the Nassau County Department of Health, in accordance with procedures given in "Standard Methods" (American Public Health Association, 1946, 1955, and 1960). Four complete chemical analyses and two spectroscopic analyses were made by the U.S. Geological Survey, using methods outlined by Rainwater and Thatcher (1960) and Haffty (1960). Concentrations of chromium as low as 0.01 mg/l were generally considered significant in this investigation. Some of the problems and interferences encountered in making chromium determinations were described briefly by Lieber, Perlmutter, and Frauenthal (1964).

Acceptable procedures for the analysis of cadmium in waste water and recommended limits in public-water supplies were not available in 1953 when high concentrations of cadmium were determined in the ground water at South Farmingdale. It was not until 1955 (American Public Health Association, 1955) that a tentative procedure for the analysis of cadmium in waste water was published and was used in the subsequent investigations at South Farmingdale. An improved method for the dithizone extraction of cadmium (Ganotes and others, 1962) was used during part of the latest investigation.

Because of the inherent difficulties in determining cadmium by standard analytical procedures, including possible interferences from other metals, concentrations of less than 0.03 mg/l of cadmium were generally considered to be approximate.

The third major contaminant determined in the water was the surfactant constituent in household detergents referred to in this report as MBAS (methylene blue active substance). The standard method for the determination of surfactant content, known as the methylene blue test (American Public Health Association, 1960, p. 246–248), does not distinguish between the several types of surfactants that may be in the water. ABS (alkylbenzenesulfonate), which was the most common type used in detergent manufacturing prior to 1965, doubtless was the chief detergent contaminant in the water sampled during this investigation. (See "Composition of detergents.")

ACKNOWLEDGMENTS

Geological Survey; former Commissioner E. F. Gibbons, Nassau County Department of Public Works; and Commissioner J. H. Kinnaman, Nassau County Department of Health. The report was completed under the supervision of G. G. Parker, former district chief, New York District, and B. L. Foxworthy, former hydrologist-in-charge, Mineola, Long Island, N.Y.

HYDROLOGIC SYSTEM

An understanding of those elements of the hydrologic system that control the occurrence, movement, and chemical quality of the water is essential to an appraisal of water-contamination problems in the area. The part of the hydrologic system that is of principal concern in this investigation is the ground-water reservoir, which is the source of all the fresh water used in Nassau County. The ground-water reservoir in the South Farmingdale area consists of about 1,300 feet of saturated unconsolidated deposits resting on crystalline bedrock (Suter and others, 1949, pl. 8) ; however, intensive study of hydrologic conditions was confined chiefly to the upper 100 feet of the reservoir, which is most susceptible to contamination.

Figure 2 is a schematic representation of the upper part of the
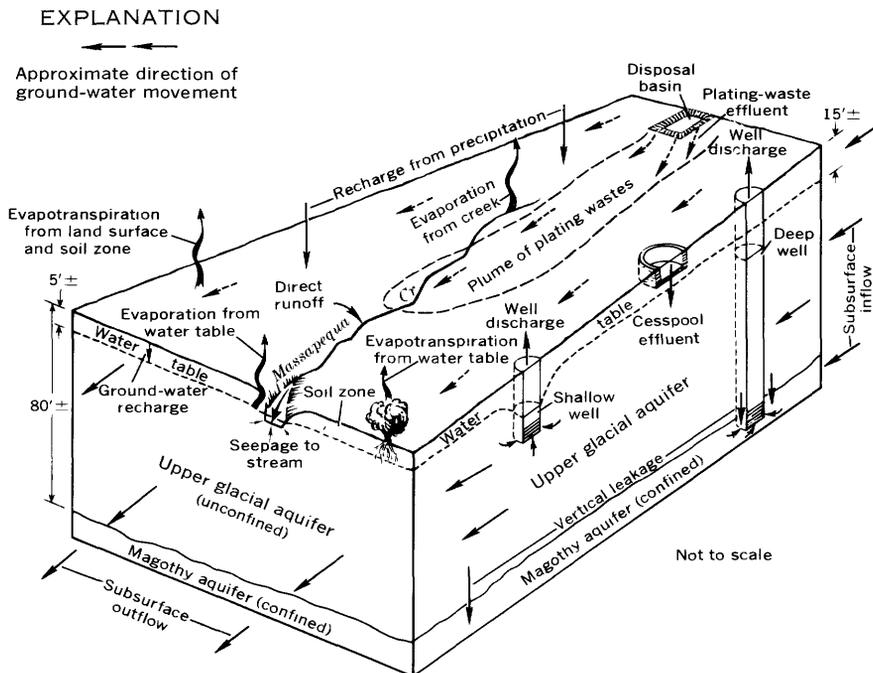
FIGURE 2.—The hydrologic system in the South Farmingdale-Massapequa area.

ground-water reservoir and of the other pertinent elements of the hydrologic system in the report area. The upper part of the reservoir consists of two major hydrogeologic units: (1) The upper glacial aquifer, which corresponds with the geologic unit known as the upper Pleistocene deposits, and (2) the Magothy aquifer, which includes the Magothy Formation and younger undifferentiated formations of Late Cretaceous age (Perlmutter and Todd, 1965).

Water enters the ground-water reservoir by direct infiltration of precipitation, by lateral subsurface inflow, and by artificial recharge. The top of the zone of saturation in the unconfined upper glacial aquifer is called the water table (fig. 2). The underlying Magothy aquifer contains water under artesian pressure, and the heads in that aquifer range from slightly lower than the water table at the northern end of the overall report area, to slightly higher at the southern end. Consequently, under natural conditions the upper glacial aquifer locally loses some water to and gains some water from the Magothy aquifer. The quantity of water interchanged naturally between the aquifers in the report area is presently small. Ground water is discharged from the area by seepage to Massapequa Creek, by subsurface outflow, by evapotranspiration, and by loss of part of the water pumped from wells due to consumptive use.

As water moves through the report area, its dissolved-solids content increases mainly because of contributions from plating wastes and household sewage. Airborne contaminants dissolved in precipitation that falls on the area, fertilizer chemicals carried down to the water table by the infiltrating water, and solution of some mineral matter from the aquifer materials also contribute some dissolved substances to the ground water.

WATER-BEARING UNITS

The upper glacial aquifer extends from the water table, at depths of about 0 to 15 feet below land surface, to the top of the Magothy aquifer, at depths of about 80 to 140 feet below land surface (fig. 2 and pl. 2). This aquifer consists chiefly of beds and lenses of fine to coarse sand and gravel. In some parts of the aquifer, thin lenses and beds of fine to medium sand, and less commonly of silt, are interbedded with the coarser beds, particularly in the lower part of the unit.

Table 1 compares the physical properties of representative samples of the water-bearing units, South Farmingdale area. Curves of particle-size analyses of the two most common lithologic types are shown in figure 3. These curves show that the texture of the samples from the 42-foot depth ranges from fine sand to medium gravel and contains

TABLE 1.—*Comparison of the physical properties of selected samples of the water-bearing units, South Farmingdale area*

[Analyses by U.S. Geological Survey. WRC well number from New York State Water Resources Commission. Effective grain size is the diameter of a grain of such size that 10 percent of the grains by weight is finer; mean grain size is the diameter of a grain of such size that 50 percent of the grains by weight is finer; and the uniformity coefficient is the ratio of the diameter of a grain that has 60 percent of the grains by weight finer than itself to the diameter of a grain that has 10 percent finer. Specific gravity is estimated]

Well		Description	Depth (feet)	Grain size (mm)		Uniformity coefficient	Specific gravity	Dry weight (g per cc)	Total porosity (percent)	Permeability (gpd per sq ft)
Field No.	WRC No.			Effective	Mean					
1A	N7543	Brown, fine to very coarse sand and some gravel.	42-43	0.28	0.86	4	2.68	1.76	34.3	1600
1A	N7543	Brown, fine to medium sand	72-73	.16	.29	2.1	2.68	1.67	37.7	440
77A[1]		Brown, medium to very coarse sand and gravel.	10-11	.27	1.10	7.4	---	---	---	---
77A		do	15-16	.18	1.15	10.5	---	---	---	---
77A		do	20-21	.23	.80	4.8	---	---	---	---
77A		do	25-26	.18	.95	7.5	---	---	---	---
77A		Brown, fine to very coarse sand and some gravel.	30-31	.17	.42	3.0	---	---	---	---
77A		Brown, fine to very coarse sand	35-36	.12	.42	4.3	---	---	---	---
77A		Brown, medium to very coarse sand and gravel.	40-41	.29	.94	4.4	---	---	---	---
77A		do	45-46	.30	1.10	4.3	---	---	---	---
77A		Brown, fine to medium sand and a trace of gravel.	50-51	.14	.26	2	---	---	---	---
80	N7545	Gray, very fine to fine silty and clayey lignitic sand.	85-86	.003	.15	50	2.68	1.59	40.7	---

[1] Near well 77, plate 2.
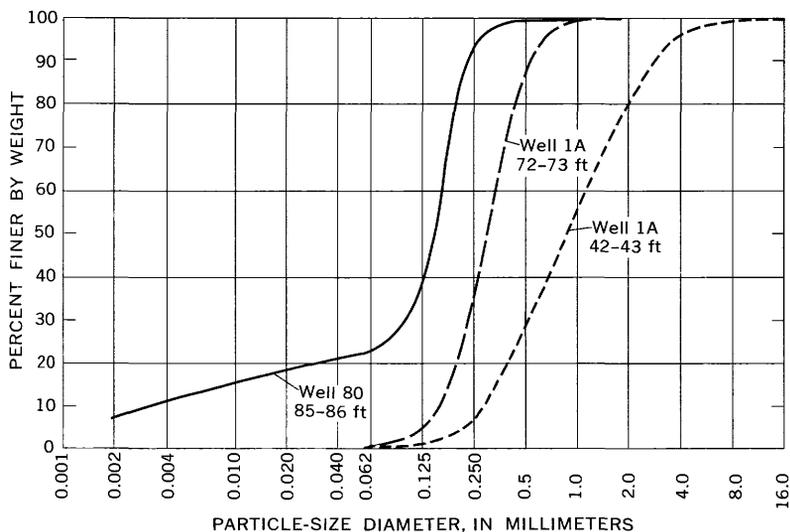
FIGURE 3.—Grain-size analyses of samples of the upper glacial aquifer (well 1A) and of the Magothy aquifer (well 80).

only about 1.5 percent (by weight) of silt and very fine sand. The sample from the 72-foot depth consists mainly of fine to coarse sand and contains about 5 percent of silt and very fine sand.

The effective and mean grain sizes of all samples from the upper glacial aquifer that were tested (table 1) ranged from 0.12 to 0.30 mm (millimeter) and 0.26 to 1.15 mm, respectively. The uniformity coefficients ranged from 2 to 10.5; the smaller coefficient signifies better sorting. The total porosity averaged about 35 percent, and laboratory determinations of the coefficients of permeability of two samples were 440 and 1,600 gpd per sq ft (gallons per day per square foot). The coefficient of permeability is the rate of flow of water in gallons a day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60° F (O. E. Meinzer. See Wenzel, 1942, p. 7). The higher permeability value, which corresponds closely with results from pumping tests in wells screened in glacial outwash in other parts of Long Island, probably is representative of the average horizontal permeability of the upper glacial aquifer as a whole. The permeability of the deposits in the horizontal direction is probably about 5 to 10 times greater than that in the vertical direction owing mainly to stratification.

Sand-size particles in the upper glacial aquifer consist chiefly of clear and iron-stained quartz grains; about 10 to 20 percent miscellaneous dark minerals, including biotite, chlorite, hornblende, and limonite; and grains of granite, schist, gneiss, and other rocks. Gravel-size particles are composed of quartz and various igneous and metamorphic rocks.

Records of a few scattered borings (wells 77B and 80, pl. 2) suggest that in places a greenish-gray silty and sandy clay about 8 to 10 feet thick intervenes between the lower part of the upper glacial aquifer and the underlying Magothy aquifer. This clay seems to underlie part of the valley of Massapequa Creek and probably extends at least as far north as the vicinity of Plitt Avenue (pl. 1D), but its continuity and lateral extent are unknown. The washed residue from a sample of the clay collected at a depth of 75 feet below the land surface at well 77B consists chiefly of quartz, an abundance of brown and black biotite and chlorite, a trace of glauconite, some brown plant material, and a few foraminifera of Pleistocene age. The occurrence and character of this marine clay suggests that it may be a northerly extersion of the "20-foot" clay (Perlmutter and Geraghty, 1963, p. 36–37 and fig. 7) or possibly of the Gardiners clay (Suter and others, 1949, p. 22–24 and pl. 21).

The top of the underlying Magothy aquifer [pl. 2] is an irregular ancient erosional surface, which is usually indicated by the occurrence of beds of gray fine sand and clay. The Magothy aquifer is about 700 feet thick in the report area and is underlain by a confining unit known as the Raritan clay. The grain size, sorting, and texture of the beds in the Magothy aquifer vary both vertically and horizontally. The predominant grain size is fine sand, but thin beds and lenses of silt and clay as well as mixtures of all three types are common. Beds of coarse sand and gravel are generally found in the lowermost part of the aquifer only. A cumulative curve of a grain-size analysis of a typical sample of fine-grained sediment from the Magothy aquifer near the contact with the overlying glacial deposits is shown in figure 3, and selected physical properties are given in table 1. The poor sorting of the sample is indicated by the high uniformity coefficient. Other parts of the Magothy aquifer beneath the report area are poorly to moderately well sorted.

The average coefficient of permeability of the Magothy aquifer in the horizontal direction is estimated to be 500 gpd per sq ft, but the average permeability in the vertical direction is much lower, possibly less than 10 percent of that in the horizontal direction, owing to lenses and beds of silt and clay in the aquifer. Sandy beds of the Magothy aquifer consist almost entirely of quartz and have only a trace of

heavy minerals and muscovite (white mica) ; silty beds consist chiefly of quartz, muscovite, and a small percentage of heavy minerals; and clayey beds consist chiefly of kaolinite (a clay mineral) and muscovite. Particles and thin layers of lignite (low-grade, brownish-black coal) and marcasite (iron sulphide) are abundant in the deposits.

The cation-exchange capacities of one sand and one clay sample from the Magothy aquifer are given in table 2. The samples tested have a relatively low ion-exchange capacity, although the clay sample has an ion-exchange capacity about 40 times greater than that of the sand. These results are not necessarily typical of the aquifer as a whole, owing to the small volume tested.

TABLE 2.—*Cation-exchange capacity of the Magothy aquifer*

[Analyses by U.S. Geological Survey. WRC well number from New York State Water Resources Commission]

Well		Depth of sample below land surface (feet)	Description	Cation-exchange capacity (meq. per 100 g)
Field No.	WRC No.			
1A_____	N7543	119–120	Gray lignitic clay and silt_____	8. 5
80_____	N7545	93–97	Gray, fine to medium sand and trace of silt.	. 2

ROUTING OF WATER THROUGH THE UPPER GLACIAL AQUIFER

An understanding of the patterns, rates, and quantities of water moving in different parts of the hydrologic system is useful in evaluating the fate of contaminants entering the system. This section deals chiefly with the elements of the water balance in the unconfined upper glacial aquifer which contains the contaminated water described in later sections. The hydrologic system in the report area (pl. 1) is believed to be in approximate dynamic equilibrium—that is, over the long term, the ground-water reservoir in the report area is gaining and losing water in about equal quantities and shows no significant net change in the amount of water in storage.

INFLOW

Water enters the report area from both natural and artificial sources. The two natural sources that provide most of the recharge are precipitation and subsurface inflow (fig. 2). The ground-water reservoir is recharged artificially, largely by infiltration of domestic and industrial liquid wastes from cesspools, seepage fields, and disposal basins.

Precipitation on the principal study area averages about 45 inches per year, which is equivalent to an average of about 2 mgd per sq mi

(million gallons per day per square mile). It is estimated that about 50 percent of the average annual precipitation is lost, mainly by surface and near-surface evapotranspiration (evaporation directly from the land surface and soil zone, and transpiration of shallow rooted plants, fig. 2) and by direct runoff into Massapequa Creek. Direct runoff is estimated to be 5 to 15 percent of the total precipitation on the drainage basin (R. M. Sawyer, U.S. Geological Survey, oral commun., 1965). The remainder of the precipitation, which averages about 22 inches annually or about 1 mgd per sq mi, seeps down to the water table. Consequently, the estimated ground-water recharge from precipitation on the 0.6 square-mile area illustrated on plate 1 is about 0.6 mgd.

Subsurface inflow across the northern border of the principal study area originates chiefly as recharge from precipitation and cesspool effluent north of the report area. Such inflow helps dilute the contaminated water originating in the report area. The amount of inflow through each 1-foot-wide strip of the full saturated thickness of the upper glacial aquifer may be estimated from Darcy's law as follows:

$$Q = PIA$$

or

$$(1,500) \left(\frac{1}{500} \right) (80) = 240 \text{ gpd (round to about 250 gallons per day)}$$

where

Q = subsurface inflow in gpd,
P = coefficient of permeability, in gpd per sq ft (assumed average about 1,500 gpd per sq ft),
I = hydraulic gradient in feet per foot (from water-table contour map, pl. 1D), and
A = cross-sectional area of 1-foot-wide strip of the average saturated thickness of the aquifer (assumed average thickness about 80 ft).

On the basis of the unit rate of flow calculated above, the total quantity of subsurface inflow in the upper glacial aquifer across the full width (about 3,200 feet) of the northern border of the principal study area (pl. 1) is estimated to be nearly 0.8 mgd.

Water from artificial sources consists chiefly of effluent from domestic waste-disposal systems and plating processes. On the basis of an assumed volume of about 250 gpd of sewage effluent per home and an average concentration of about 2,100 homes per square mile, infiltration of sewage effluent is estimated to be about 0.3 mgd in the principal study area. Nearly all the sewage effluent returned to the upper glacial

aquifer was originally fresh water pumped from deep public-supply wells of the South Farmingdale and Massapequa Water Districts (pl. 1 and table 3).

Partial records suggest that during the early 1940's, possibly as much as 0.3 mgd of water was pumped at the industrial park, mostly from deep wells (pl. 1 and table 3) screened in the Magothy aquifer. After use in metal-plating and anodizing processes, the contaminated water was returned to the upper glacial aquifer by means of disposal basins. The amount of plating-waste effluent recharged in the following decade is uncertain, but it probably ranged from an estimated low of about 0.02 mgd in 1957 to a high of 0.13 mgd in 1953. The estimated recharge of plating wastes and cooling water in 1963 was about 0.05 mgd.

FLUCTUATIONS OF THE WATER TABLE

Although an approximate long-term dynamic equilibrium exists between recharge and discharge in the report area, natural and artificial disturbances of the equilibrium may cause local short-term changes in the amount of ground water in storage. These changes are

TABLE 3.—*Records of selected industrial and public-supply wells, South Farmingdale-Massapequa area*

[See plate 1 for location of wells]

Well	Owner	Screen depth (feet)	Water-bearing unit	Yield (gpm)	Pumpage in 1963 (mgd)
N1840 [1]	Liberty Industrial Finishing Corp.	69–89	Upper glacial aquifer.	350	0
N1965	____do____	143–169	Magothy aquifer.	250	. 06
N4010	____do____	238–268	____do____	500	. 003
N4042	South Farmingdale Water District.	96–154	Upper glacial and Magothy aquifers.	1, 200	. 68
N4043	____do____	317–369	Magothy aquifer.	1, 200	. 867
N5148	____do____	297–331	____do____	1, 300	. 612
N6148	____do____	462–489 533–561	____do____	1, 400	. 591
N7377	____do____	607–628 643–658 608–679 732–758	____do____	1, 400	. 017
Massapequa infiltration gallery.[2]	N.Y. City Dept. of Water Supply, Gas, and Electricity.	_____	Upper glacial aquifer.	15, 000	0
Massapequa well field (106 wells).[2]	____do____	37–105	Upper glacial and Magothy aquifers.	1, 500 (estimated)	0

[1] Not used since 1960.   [2] Reserve supply.
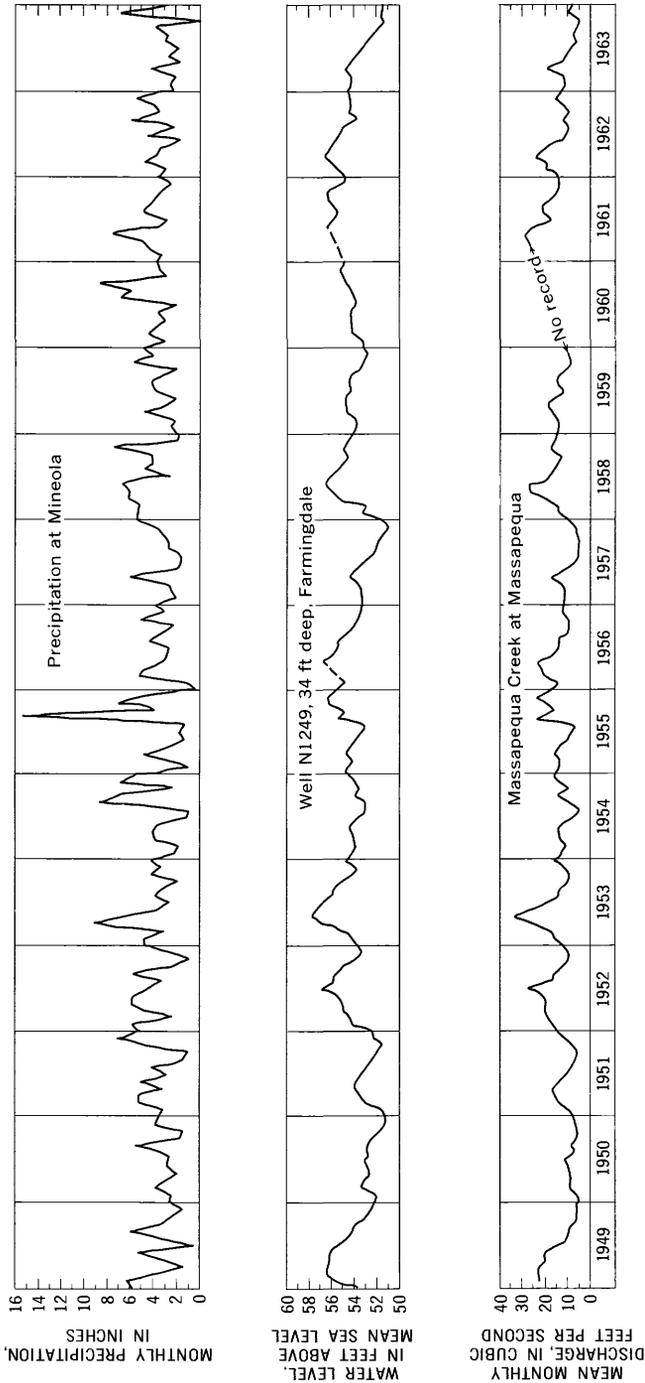
FIGURE 4.—Precipitation, water-table fluctuations, and discharge of Massapequa Creek at Massapequa, 1949–63.

indicated by a rise or decline of the water table and are also indicated by variations in the hydraulic gradient. The natural regional pattern of water-level fluctuations in and near the report area since 1949 is illustrated by the hydrograph (fig. 4) of well N1249, which is about 1 mile east of the center of the report area. The hydrograph shows that the net change in water level from 1949 to 1963 was negligible. Natural seasonal fluctuations of the water table in the report area range from about 2 to 3 feet and generally include a spring high and late fall low. The steep decline in the water table in 1963 is part of the early stage of a decline in the water table due to a regional drought. During periods of peak levels in the spring, the water table rises naturally and intersects the bottom of the disposal basins. At other times, when recharge of plating wastes is at a high rate, the water table probably rises in the form of a local mound, which intersects the bottom of the basins. The relation between fluctuations of the water table and changes in the rate of discharge of Massapequa Creek is discussed under "Seepage to Massapequa Creek."

Because of the lack of deep observation wells in the report area, only scanty data on fluctuations of artesian heads in the Magothy aquifer are available. These data do not suggest any significant net change in the relation between heads in the upper glacial and Magothy aquifers through the end of 1963. The relation of differences in head to vertical movement of the contaminated water between aquifers is discussed in "Movement and spread of plating wastes."

MOVEMENT OF GROUND WATER

Most of the ground water in the report area is moving approximately horizontally except in local areas of recharge and discharge, where vertical or oblique components of flow predominate. The directions of the horizontal components of flow in the upper glacial aquifer are shown by arrows drawn at right angles to the water-table contours (pl. 1D). The principal direction of flow is southerly toward Massapequa Creek, where some of the water seeps into the stream and some moves southeasterly as underflow beneath the stream and the adjoining areas. A local departure from the regional pattern of flow occurs beneath the disposal basins in the industrial park where the flow, at times, is radially outward for a short distance from the center of a low transient mound on the water table and then is diverted southward under the influence of the regional hydraulic gradient.

Vertical components of flow in a section drawn approximately parallel to the direction of regional ground-water flow are shown by arrows on plate 2. The distribution of the heads shown in the section indicate that the direction of most of the flow is nearly horizontal.

Beneath the disposal basins and Massapequa Creek, however, there are significant vertical components of flow. Because recharge from precipitation and from cesspools is intermittent and seeps down in small quantities at many points over a wide area, vertical components of flow from these sources have small magnitude, and their influence is probably restricted to the uppermost part of the zone of saturation.

Substitution of estimated values of the hydraulic gradient, coefficient of permeability, and porosity of the upper glacial aquifer in a velocity formula derived from Darcy's law (see "Pattern and rates of movement") gives a velocity of horizontal ground-water flow of about 0.5 to 1.5 feet per day. For general interpretation in this report, the average horizontal velocity of the ground water is estimated to be 1 foot per day.

OUTFLOW

Water is discharged from the ground-water reservoir by subsurface outflow, seepage into Massapequa Creek, and evapotranspiration. Evapotranspiration includes losses direcctly from the water table and water pumped from wells and subsequently lost by evaporation and transpiration after use for lawn sprinkling.

SUBSURFACE OUTFLOW

Subsurface outflow beneath the southern border of the principal study area (pl. 1) was calculated to be about 1 mgd. The same parameters used to calculate the inflow (see "Inflow") were substituted in Darcy's law except that a lower average hydraulic gradient, 1 foot in 400 feet, was used.

Most of the subsurface outflow from the upper glacial aquifer continues downgradient and ultimately discharges into Massapequa Creek south of the principal study area. Water in the underlying Magothy aquifer also moves southerly as subsurface outflow, and most of it discharges as submarine outflow in the bays and in the Atlantic Ocean, beyond the southern limit of the overall report area. A small quantity may discharge upward into the overlying upper glacial aquifer near the south shore.

SEEPAGE TO MASSAPEQUA CREEK

Outflow from the upper glacial aquifer, which seeps into Massapequa Creek (pl. 1), may contain plating-waste and sewage contaminants which the stream can transport for a considerable distance beyond their points of origin. The presence of such contaminants in the stream may influence the quality of water at pumping installations downgradient from the plume (pl. 1). The stream also acts as a dilutant of the contaminants; consequently, data on variations in stream discharge

and on the rate of pickup of streamflow are essential in assessing the role of the stream as a bearer of contaminants.

Massapequa Creek, although modified somewhat from its natural condition by construction of culverts, storm sewers, and detention basins, is typical of most of the small streams that drain the glacial-outwash deposits of southern Long Island. The headwaters of Massapequa Creek consist of an east and west branch, which start to flow at an altitude of about 50 feet above sea level, about one mile north of Southern State Parkway (pl. 1). The two branches merge just north of the parkway to form the main stream, which empties into South Oyster Bay (fig. 1), about 5 miles south of the area where the flow begins. From Sunrise Highway south, the stream is tidal and contains salty water. The average gradient of Massapequa Creek is about 10 feet per mile, about the same as that of the water table.

The headwaters of the east branch of Massapequa Creek was investigated in detail because it receives the contaminated subsurface inflow from the principal study area. The channel of the east branch (fig. 5) is generally about 10 to 15 feet wide and 2 to 3 feet deep, but under base flow conditions the water in the channel is normally only

FIGURE 5.—The channel of Massapequa Creek near well 37, South Farmingdale (pl. 1), showing a measurement of discharge in December 1962. View is upstream; discharge is about 0.26 cubic foot per second.

a few inches deep or less. Four large detention basins, which are about 2 to 4 feet deep and which were installed to control flooding, silting, and mosquito growth, and Massapequa Pond, an artificial lake near Sunrise Highway (pl. 1), interrupt the relatively uniform profile of the stream channel above its tidal reach.

The flow of Massapequa Creek is sustained mostly by natural seepage from the upper part of the water-table aquifer, as indicated by the upstream bending of the water table contours (pl. 1D) and by the pattern of flow of contaminated ground water beneath and into the stream (pl. 4 and fig. 7). The length of channel containing flow and the discharge of Massapequa Creek vary substantially between seasons and during periods of unusually high or low rainfall. At times the headwaters are dry. The location of the area where the stream begins to flow depends on the relative altitudes of the bottom of the stream channel and of the water table. In December 1962, for example, under approximately average climatic conditions, streamflow started at a point between Sullivan and Plitt Avenues (pl. 1 and fig. 7), where the streambed intersected the water table. In contrast, in October 1963, after 8 months of below-average rainfall (about a 12-inch deficiency) and a corresponding water-table decline of 0.3 to 0.5 foot, the flow started in the vicinity of point C (fig. 7), about 1,100 feet south of the starting point observed in December 1962. In mid-1966, following several years of drought, the start of flow had receded as far south as the Southern State Parkway (see aerial photograph, pl. 1), but in August 1969 flow was observed as far north as the vicinity of Spielman Avenue (pl. 1) due to the recovery of the water table from 1967 to 1969.

The relation between heads at various depths in the upper glacial aquifer and the altitude of the surface of the stream are shown on plate 4. The flow arrows suggest some upward movement of ground water from relatively shallow depths, below the streambed, and lateral movement of water from the upper 10 to 15 feet of the deposits immediately adjacent to the stream.

A summary of the discharge of Massapequa Creek at the gaging station at Massapequa (point U, pl. 1) from 1936 to 1962 is given in table 4. The records show that the monthly mean discharge was generally greatest in April and least in October. A graph of the monthly mean discharge from 1949–1963 (fig. 4) shows that the streamflow correlated closely with fluctuations of the water table. Periods of unusually low flow in 1949–50, 1957, and 1963 coincided with declines of the water table due to below normal rainfall.

Table 8 gives records of miscellaneous discharge measurements at various chemical-sampling points on Massapequa Creek (pl. 1), and figure 8 gives discharge profiles along the stream for selected periods

TABLE 4.—*Mean discharge of Massapequa Creek at Massapequa, 1937–63*

Mean discharge	Date	cfs	mgd
Daily			
Minimum_____	Aug. 3, 1957	3. 0	1. 9
Maximum_____	July 20, 1961	119	76. 9
Monthly			
Minimum_____	Oct. 1942	3. 98	2. 57
Maximum_____	Apr. 1953	33. 5	21. 6
Annual			
Minimum_____	1950	7. 65	4. 94
Maximum_____	1939	16. 9	10. 9
Average discharge_____	1937–63	12. 3	7. 95

of high and low base flow during the investigation. In 1962–63, the pickup in flow in the headwaters of the stream from about point B near Spielman Avenue to point H at Second Avenue (pl. 1 and fig. 8) ranged from about 0.3 to 0.5 cfs (about 0.2 to 0.3 mgd) per 1,000 feet of stream length. The pickup remained about the same downstream to the vicinity of point O. Between points O and R the pickup increased abruptly, about sixfold, owing chiefly to increased inflow of surface water from the west branch of the stream near point R (pl. 1 and fig. 8) and possibly to some increased seepage of ground water in the part of the reach which includes basin 1.

A correlation was made between miscellaneous streamflow measurements at Second Avenue and at the gaging station at Massapequa (point U, pl. 1) to obtain an estimate of the average seepage to Massapequa Creek at the southern border of the principal study area (pl. 1) for use in estimating the water budget. (See "Summary of the groundwater budget.") On the basis of this correlation, the average streamflow at the southern border of the principal study area was estimated to be about 1 cfs or about 0.7 mgd in 1962.

EVAPOTRANSPIRATION OF GROUND WATER

An unknown, but probably small, amount of water is lost locally by direct evaporation from the water table where the depth to water is less than about 5 feet below the land surface. This occurs most likely on the narrow flood plain bordering Massapequa Creek. In the same area some trees and shrubs probably tap the shallow water table and transpire ground water. Such direct evapotranspiration of ground water is greatest during the growing season, from about April to

October, but it is negligible during the rest of the year. Additional losses due to evapotranspiration occur when water pumped from wells is used for lawn sprinkling during the summer. Most of this water is pumped from deep public-supply wells, and a small amount is pumped from shallow private wells. Total loss from evapotranspiration of ground water in the principal study area could not be determined accurately from available data but was estimated to be not more than 0.1 mgd.

SUMMARY OF THE GROUND-WATER BUDGET

The estimates of the approximate balance between the inflow and outflow of water in the upper glacial aquifer in the principal study area in 1962 are summarized in the table which follows. The net change in the amount of ground water in storage in the 0.6-square-mile area was negligible and, therefore, was omitted from the calculations. The estimates represent average conditions, and they probably apply as early as the start of the contamination investigation in 1949.

Ground-water inflow	*mgd*
Recharge from precipitation	0. 6
Recharge from cesspools and disposal basins	. 4
Subsurface inflow	. 8
Total	1. 8
Ground-water outflow	
Evapotranspiration of ground water	0. 1
Seepage to Massapequa Creek	. 7
Subsurface outflow	1
Total	1. 8

CONTAMINATION OF THE GROUND WATER AND SURFACE WATER

CHEMICAL QUALITY OF THE INFLOWING WATER

The wide range in the chemical quality of the water in the upper glacial aquifer and in Massapequa Creek (table 5) is due to a blending of the dissolved constituents in the subsurface inflow entering the area with locally derived dissolved constituents in precipitation, plating-waste effluent, domestic wastes, agricultural fertilizers, stormwater seepage, and other minor sources.

A brief description of the character of the inflowing water is given in table 6 to provide background information for evaluating changes in the quality of the water as it moves downgradient. Nearly all the sub-

surface inflow in the upper glacial aquifer is slightly to moderately contaminated chiefly by domestic wastes and by other minor contaminants that have seeped down into the shallow aquifer north of the report area. The degree of contamination of the inflowing water in the upper glacial aquifer is suggested by comparison (table 6 and fig. 6) of the results of a chemical analysis of a sample of contaminated water from well 65 at the north end of the report area with that of a sample of apparently uncontaminated water from well S24774 located near the ground-water divide in a sparsely settled area of Suffolk County, about 10 miles east of South Farmingdale. The analyses show that pollution-indicating characteristics such as the chloride, nitrate, sulfate, hardness, and dissolved-solids content are two to three times greater in the contaminated inflowing water of the report area than in the uncontaminated water. Further deterioration in the quality of the inflowing water by contributions from plating and domestic wastes is described in the sections which follow.

An indication of the dual role of precipitation as a major dilutant and as a contributor of dissolved constituents to water in the upper glacial aquifer is given by results of chemical analyses of the precipitation (table 7). According to the median values of the samples collected, the precipitation is generally acidic, very soft, and has a low dissolved-solids content. The extreme ranges in the concentrations of the constituents in the precipitation are chiefly due to variations in the direction of movement and intensity of the individual storms and in the amount of industrial pollutants and dust in the air (compare, for example, the high and low concentrations of nitrate, sulfate, and dissolved solids).

As the part of the precipitation that seeps down to the water table passes through the soil zone, it picks up various ions such as sodium, potassium, chloride, nitrate, and sulfate. This results in an increase in the dissolved-solids content of the downward moving water. From the soil zone, the water moves down through the remainder of the zone of aeration and into the zone of saturation in the upper glacial aquifer where it mixes with the main body of contaminated ground water .

The chemical composition of water from Massapequa Creek, which consists almost entirely of seepage from the upper glacial aquifer, is represented by the analyses of samples collected near Radcliffe Avenue (table 5). These samples are free from plating wastes but contain some sewage contaminants. The composition of the streamflow closely resembles that of water in the upper glacial aquifer, except for the higher bicarbonate content and total hardness. Samples collected farther downgradient where the stream intersects the plume of plating wastes show that the presence of low concentrations of plating wastes

TABLE 5.—*Chemical analyses of ground water, water from*

[Dissolved constituents in milligrams per liter. Analyses by Nassau County Department of Health except York City Department of Water Supply, Gas, and Electricity. All wells are screened in the upper of investigation" for explanation of laboratory procedures]

Well No. or sampling point	Date of collection	Depth of well (feet)	Iron (Fe)	Manganese (Mn)	Chromium (Cr) Total	Chromium (Cr) Hexavalent (Cr^{+6})	Nickel (Ni)	Copper (Cu)	Cadmium (Cd)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
												Ground
49	1- 7-63	48.6	0.80				<0.01		<0.01			
65 (N8193)	11- 7-62	54	1.8	0.48						10	2.6	15
65	11- 7-62	54			<0.01	<.01	<0.25	<0.05	<.01			
67	1- 7-63	63	1.2			<.01			.04			
73	10-22-62	62	4.4	.40	<.01	<.01	<.25	.27				
77 (N8194)	11- 7-62	59	.22	.50						4.8	1.1	39
77	11- 7-62	59	.11	.85	6.0	6.0	<.25	<.05	.40			
77	11- 7-62	59	.63	.06	5.9			.01	.03			
81	11-15-62	61	.99	<.05	<.01	<.01	<.25	.12	<.01			
N1840	6-16-60	89	<.03	.90								
N1965	10-22-62	169	.13	<.05	<.01	<.01	<.25	<.05	<.01			
	8-12-64	169	.21	.09						1.7	.4	3.8
N4010	10-22-62	268	.04	<.05	<.01	<.01	<.25	<.05	<.01			
Massapequa 2	1-12-65	37-105	7.0									
Massapequa gallery	2- -65		.2	.82								
												Water from
Near Radcliffe Ave	10-22-62		0.06	<0.05	<0.01	<0.01	<0.25	0.07	<0.01			
Do	2- 6-63		.39	1.2		<.01			<.01			
Near well 53	2- 6-63		.22	.8		<.01			<.01			
Near well 49	11- 7-62		.38	2.2						22	3.4	24
Do	11- 7-62		.18	.25	1.2	1.2	.75	<.05	.03			
Do	11- 7-62		.08	2.4	1.2		<.00	.00				
Do	2- 6-63		.11	2.6		1.3			.09			
Near Franklin St	8- 6-64		.22	.35		<.01			<.005			
Massapequa Pond	3- 8-65		.27	.05								
Do	3- 8-65		1.6	1.4								
												Plating-waste
Tank (raw)	5-11-60				29	29	1.2					
Do	3-29-62				28	27			11			
Recharge basin (treated).	5- 2-62				1	1	<.25		.55			
Do	7-19-62				3.1	<.01			.37			
Do	9-17-62				4.6	.06			3.4			
Do	11-15-62				35	21	<.25	0.24	2.7			
Do	1-23-63				3.6	<.01	.75	3.0	7.5			
Do	1-30-63				5.4	.28	1.0	.64	5.2			
Do	5-20-63				6.2	6.0	1.0	.42	9.4			
Do	7-29-63				3.6	<.01	.50	1.0	2.1			
Do	9-24-63				3.3	.38	.50	.70	.01			

1 Aluminum, 0.14; barium, 0.06; boron, 0.06; cobalt, 0.01; lead, 0.005; lithium, 0.0002; rubidium, 0.01; silver, 0.0002; strontium, 0.06; titanium, 0.005; zinc, <0.02.

Massapequa Creek, and raw and treated plating-waste effluent

where indicated otherwise in "Remarks" column: USGS, U.S. Geological Survey; NYCDWSGE, New
glacial aquifer except N1965 and N4010 which are screened in the Magothy aquifer. See section or "Methods

Potassium (K)	Bicarbonate (HCO3)	Sulfate (SO4)	Chloride (Cl)	Nitrate (NO3)	Dissolved solids	Total hardness as CaCO3	Alkalinity as CaCO3	Specific conductance (micromhos at 25° C)	pH	Remarks
water										
--------	19	--------	--------	--------	208	40	16	--------	5.9	MBAS, 0.1.
4.6	2	41	16	16	116	36	2	209	4.8	Analyst, USGS. Non-carbonate hardness, 34; SiO2, 8.3; F, 0.2.
--------	29	--------	--------	--------	238	42	24	--------	6.0	MBAS, 0.26.
--------	22	--------	20	20	142	36	18	--------	5.6	MBAS, 1.1.
5.7	19	57	16	16	173	17	16	270	6.2	Analyst, USGS. Non-carbonate hardness, 1; SiO2, 13; F, 0.1.
--------	17	--------	17	13	177	16	14	--------	6.2	Yellow color. MBAS, 0.26.
--------	--------	--------	--------	--------	218	--------	--------	--------		Analyst, USGS. See additional spectrographic results.[1]
--------	13	--------	14	22	99	26	11	--------	5.9	MBAS, 0.20.
--------	55	--------	21	9.9	165	46	45	--------	6.2	
--------	2	--------	5.8	7	--------	0	2	--------	4.6	Company well 3. Temp 56.2°F. MBAS, <0.02.
.6	3	1.6	4.8	5.1	24	6	3	38	5.4	Analyst, USGS. SiO2, 5.4; CO3, 0; F, 0.1.
--------	2	--------	4.6	3.4	33	6	2	--------	4.6	Company well 4. MBAS, <0.02.
--------	5	--------	18	3.5	--------	18	4	--------	5.6	Analyst, NYCDWSGE. Composite sample. MBAS, 0.04.
--------	39	--------	20	16	--------	56	32	--------	5.4	Analyst, NYCDWSGE. MBAS, 0.90.
Massapequa Creek										
--------	73	--------	21	35	194	82	60	--------	6.4	MBAS, 1.7.
--------	--------	--------	14	--------	--------	--------	--------	--------	6.2	MBAS, 1.0.
--------	--------	--------	17	--------	--------	--------	--------	--------	6.1	MBAS, 1.1.
6.2	48	52	18	19	175	69	39	310	6.2	Analyst, USGS. Non-carbonate hardness, 30; SiO2, 7.5; F, 0.0.
--------	44	--------	13	--------	187	64	35	--------	6.1	MBAS, 1.1.
--------	--------	--------	--------	--------	222	--------	--------	--------		Analyst, USGS. See additional spectrographic results.[2]
--------	--------	--------	21	--------	--------	--------	--------	--------	6.2	
--------	--------	--------	18	16	151	46	--------	--------	7.2	MBAS, 0.68.
--------	54	--------	19	22	--------	64	44	--------	6.2	North end. MBAS, 0.8.
--------	39	--------	28	17	--------	58	32	--------	6.6	South end. MBAS, 0.7.
effluent										
--------	--------	--------	--------	--------	--------	--------	--------	--------	4.4	
--------	--------	--------	--------	--------	--------	--------	--------	--------	3.6	
--------	--------	--------	--------	--------	--------	--------	--------	--------	8.3	Cyanide, <0.02.
--------	--------	--------	--------	--------	--------	--------	--------	--------	7.7	MBAS, 0.35.
--------	--------	--------	--------	--------	--------	--------	--------	--------	6.6	
--------	--------	--------	--------	--------	--------	--------	--------	--------		MBAS, 0.62.
--------	--------	--------	--------	--------	--------	--------	--------	--------	4.3	MBAS, 0.46.
--------	--------	--------	--------	--------	--------	--------	--------	--------	5.7	Cyanide, <0.01. MBAS, 0.46.
--------	--------	--------	--------	--------	--------	--------	--------	--------	6.1	
--------	--------	--------	--------	--------	--------	--------	--------	--------	3.7	
--------	--------	--------	--------	--------	--------	--------	--------	--------	5.0	

[2] Aluminum, 0.04; barium, 0.08; boron, 0.08; cobalt, 0.004; lead, 0.007; lithium, <0.0002; rubidium, 0.016; silver, 0.0004; strontium, 0.1; tin, 0.003; titanium, 0.003.

do not radically alter the gross chemical character of the water in the stream. (Compare geochemical patterns C, D, and E, fig. 6.) Water in Massapequa Pond, near the mouth of the stream, has the same general chemical character as the water upstream, but the concentrations of the dissolved constituents at the time of sampling (table 5) were generally lower owing to dilution by surface runoff and by inflow of less contaminated ground water.

TABLE 6.—*Comparison of the chemical quality of contaminated and uncontaminated water in the upper glacial aquifer*

[Analyses by U.S. Geological Survey. Dissolved constituents in milligrams per liter]

Constituent	Contaminated water [1]	Uncontaminated water [2]
Silica	8. 3	9. 4
Iron	1. 8	. 13
Manganese	. 48	. 06
Calcium	10	2. 3
Magnesium	2. 6	1. 1
Sodium	15	5. 1
Potassium	4. 6	1. 2
Bicarbonate	2	11
Carbonate	0	0
Sulfate	41	5. 4
Chloride	16	5. 1
Nitrate as NO_3	16	. 5
Dissolved solids	116	44
Total hardness as $CaCO_3$	36	10
MBAS	. 26	------------
pH	4. 8	5. 1
Specific conductance (micromhos at 25° C)	209	47

[1] Well 65, South Farmingdale, Nassau County, N.Y.; screened 52–54 feet below land surface; depth to water table, 13 feet; date sampled, Nov. 7, 1962.
[2] Well S24774, Brentwood, Suffolk County, N.Y.; screened 100–110 feet below land surface depth to water table, 76 feet; date sampled, Nov. 19, 1965.

TABLE 7.—*Range in chemical quality of precipitation, Mineola, N.Y., 1965–66*

[Analyses by U.S. Geological Survey. Dissolved constituents in milligrams per liter]

Constituent	Low	Median	High
Calcium	0. 4	1. 4	4. 3
Magnesium	. 15	. 4	1. 4
Sodium	. 4	1. 1	2. 5
Potassium	0	. 1	. 4
Ammonium as NH_4	0	. 3	1. 1
Bicarbonate	0	0	0
Carbonate	0	0	0
Sulfate	0	6. 1	15
Chloride	. 9	1. 8	4. 5
Nitrate as NO_3	. 2	. 5	4
Hardness as $CaCO_3$	2	5	16
Dissolved solids	3	12	25
pH	4. 3	4. 4	4. 8
Specific conductance (micromhos at 25° C)	23	49	83

SAMPLE	DOMESTIC WASTES	PLATING WASTES	YEAR SAMPLED
A	−	−	1965–66
B	−	−	1965
C	+	−	1962
D	+	+	1962
E	+	+	1962
F	−	−	1964

+contamination present
−contamination absent
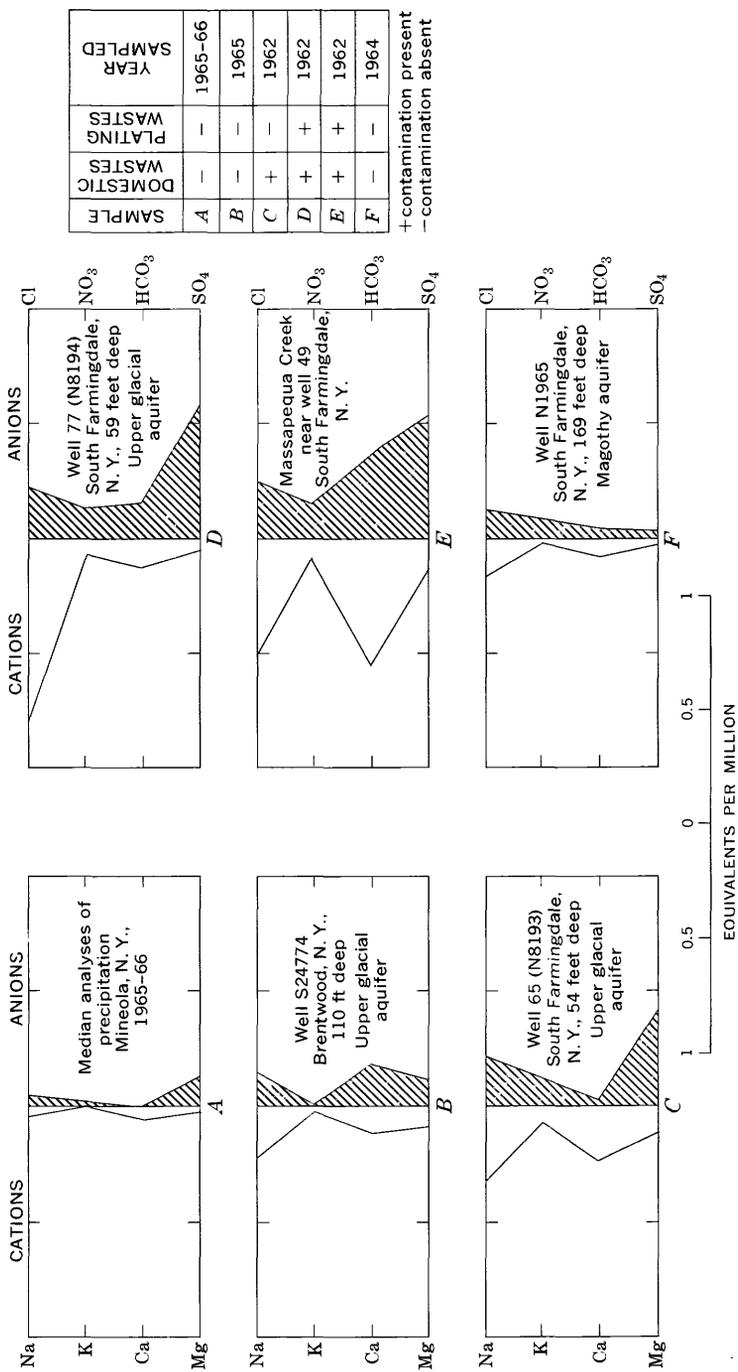
FIGURE 6.—Geochemical diagrams comparing chemical composition of precipitation, ground water, and water from Massapequa Creek.

The temperature of the ground water measured in various test wells in the upper gracial aquifer, mostly in the summer and fall of 1962, ranged from about 11° to 18°C (51.8° to 62.4°F) and averaged about 14°C (57.2°F). Stream temperatures ranged from about 5° to 30°C (41° to 86°F). It is not likely that the small differences in density and viscosity of the water, which resulted from the observed ranges in water temperature, significantly influenced the dispersion of the contaminants described in a later section of the report.

Uncontaminated water in the Magothy aquifer in the report area is excellent in quality and, with little or no treatment, is suitable for virtually all uses. The water has a dissolved-solids content of about 20–30 mg/l and contains correspondingly low concentrations of individual dissolved constituents, as shown by the analyses for wells N1965 and N4010 (table 5). Comparison of the geochemical patterns in figure 6 shows that the composition of the water in the Magothy aquifer (fig. 6F) most closely resembles precipitation, and it is markedly different in character from the comparatively highly mineralized water in the overlying upper glacial aquifer.

The observed large differences in the dissolved-solids content and in the concentrations of other constituents in the water in the two aquifers in the report area are due to some extent to natural factors related to differences in the mineralogy of the aquifer materials (see "Water-bearing units") and in the pattern of recharge and movement of ground water in the two aquifers (see "Hydrologic system"), but manmade contamination of the water in the upper glacial aquifer doubtless is the major cause of the large differences in the quality of the two waters.

According to analyses of uncontaminated ground water from other parts of Long Island, it is likely that under natural conditions the dissolved-solids content of water in the upper glacial aquifer in the South Farmingdale area was not more than 10–20 mg/l greater than that of water in the Magothy aquifer. In 1962, however, the dissolved-solids content of the water in the upper glacial aquifer at South Farmingdale was about 100–200 mg/l greater than that of water in the Magothy aquifer (table 5), and the concentration of individual constituents such as chloride, nitrate, and sulfate also were markedly higher in the shallow ground water. These large differences result mainly from the infiltration of dissolved constituents from industrial, domestic, and agricultural wastes and to a lesser extent from the dissolved constituents in precipitation, which entered the upper glacial aquifer as recharge within and upgradient from the South Farmingdale area.

No evidence was noted of widespread downward movement of these contaminants into the middle and deep water-bearing zones of the

underlying Magothy aquifer in the report area. Probably, this was largely because the natural direction of movement of most of the water in both aquifers was nearly horizontal. In one well, N4042 (pl. 1 and table 3) owned by the South Farmingdale Water District, which taps the upper part of the Magothy aquifer at a depth of 150 feet, contamination of the water was indicated by a nitrate content of about 24 mg/l and an MBAS content of about 0.2mg/l, which were determined by the U.S. Geological Survey in August 1967. The cortamination is believed to be local and probably came from the overlying upper glacial aquifer. (See "Effect on water use and developement" for further discussion of potential contamination of the Magothy aquifer.)

PLATING-WASTE CONTAMINATION

SOURCE, CHARACTER, AND DISPOSAL OF PLATING WASTES

The plating-waste contaminants in the water are derived from chemical solutions, which have been used chiefly in anodizing and in other metal-plating processes at the industrial park (pl. 1) since about 1941. Anodizing is used to inhibit corrosion and to prepare aluminum aircraft parts for painting (Davids and Lieber, 1951, p. 529). In the anodizing process the aluminum components are given an oxide coating by electrolytic treatment in a chromic acid bath. The chromium ions are not actually plated on the aluminum, and therefore they are readily removed by rinse water, which upon disposal in basins becomes a major source of ground-water contamination. Other processing and cleansing solutions used at the metal-plating plant also contain cadmium, copper, nickel, zinc, hydrochloric acid, nitric acid, sulfuric acid, silver cyanide, sodium hydroxide, sodium hypochlorite, alkali soap, and synthetic detergents. Only the occurrence of cadmium and chromium has been studied in detail, but a few determinations were made of several of the other constituents in the contaminated water (table 5).

During World War II and for several years afterward, large quantities of virtually untreated plating-waste effluent were recharged to ground water through disposal basins at the industrial park, but only scanty records were kept of the quantity so disposed. On the basis of a reported use of about 100 pounds of chromic acid per day, it is estimated that during the early 1940's, as much as 200,000 to 300,000 gallons of effluent, containing about 52 pounds of chromium and smaller amounts of other metals, was recharged daily into the upper glacial aquifer. Since the end of World War II, the amount of plating-waste effluent has been reduced substantially, the character of the wastes has changed to some extent, and at times metal-plating operations have been shut down completely.

In 1949, a chromium-removal unit was installed at the metal-plating plant (Lieber and others, 1964). Ferrous sulfate and sulfuric acid were used to reduce the hexavalent chromium to the trivalent state. After the reduction phase, the pH was raised with lime to precipitate the trivalent chromium, and cyanide was eliminated by alkaline chlorination. In 1962, the chromium-treatment procedure was modified slightly to prevent bypassing of part of the waste water, and sodium metabisulfite was substituted for ferrous sulfate as the reducing agent. The treatment process has not always been effective as shown by comparison of several analyses of raw plating wastes with the treated effluent in the disposal basins (table 5).

After treatment, the effluent was piped to the three nearby disposal basins (pl. 1)—two of the basins are about $65 \times 65 \times 15$ feet and one is about $54 \times 130 \times 15$ feet. Generally, one basin was used to receive the wastes, while the others were used for alternate disposal and for control of overflow. At present [1969], one of the basins is used to collect storm water in the industrial park and the other two receive plating-waste effluent. The depth of effluent observed in the basins during 1962–63 ranged from zero to as much as 10 feet. The high water levels probably coincided with periods when the bottoms and sides of the basins were covered with a thin layer of sludge that retards infiltration; therefore, the basins require periodic scraping.

The water table was about 1 to 2 feet below the bottom of the basins in December 1962, a seasonally low period, but in the spring, the water table may rise above the bottoms of the basins. During periods when the water table is low, plating-waste effluent from the basins moves slowly downward, and there is virtually no lateral spread in the unsaturated zone according to analyses of samples from test wells near the disposal basins (pl. 1D). This permits the contaminated effluent to reach the water table by percolation through only a few feet of sand and gravel. Under these conditions, there is probably little opportunity for reduction in the concentration of the wastes before they reach the water table and merge with the main body of ground water.

MOVEMENT AND SPREAD OF PLATING WASTES

CHANGES IN THE DIMENSIONS AND IN THE HEAVY-METALS CONTENT OF THE PLUME

Changes in the dimensions of the plume of plating wastes, chiefly during the period 1949–62, are shown on maps (pl. 1), and changes in the concentrations of cadmium and of hexavalent chromium during the same period are shown by isopleths (lines along which all points have the same concentration) on geochemical sections (pls. 2–4 and fig. 7).

By 1949, about 9 years after the start of disposal of the plating wastes, the contaminated plume had assumed a cigar shape in plan view, was about 3,900 feet long, and had a maximum width of about 850 feet (pl. 1A). No analyses were made of Massapequa Creek in 1949, and the position of the southern limit of the plume in that year was estimated. In later years, the plume apparently developed mainly by elongation and some widening at its southern end, and by 1958 the leading edge probably was a short distance west of Massapequa Creek. Movement of the contaminated water beneath the west bank and further slow elongation parallel to the stream was verified by test drilling in 1962. The plume was about 4,300 feet long and had a maximum transverse width of about 1,000 feet near Spielman Avenue in 1962 (pl. 1D). South of Spielman Avenue, the leading edge of the plume converged as it approached and moved beneath Massapequa Creek, where part of the contaminated water was discharged.

Plate 3 shows transverse sections of the plume arranged progressively downgradient, which illustrate the broadly elliptical outline of the body of contaminated water and of the isopleths of cadmium and of chromium. The concentration patterns are elongated parallel to the bedding in accordance with the gross horizontal stratification of the upper glacial aquifer and the horizontal flow pattern of the water.

Significant physical characteristics of the plume (from 1949–62) illustrated in plate 3 and in the more detailed transverse sections of plate 4 are summarized as follows:

1. The upper surface of the plume was generally within 10 feet of the water table.
2. The plume was thickest, about 70 feet maximum, along its longitudinal axis, which represented the principal path of flow from the basins. It was thinnest along its east and west boundaries.
3. The bottom of the plume apparently was entirely within the upper glacial aquifer in 1962.
4. An unusual major irregularity of the eastern boundary of the plume was the thin fingerlike easterly extension from the main body of contaminated water which is shown in nearly all the sections. In two sections (pl. 3, $C-C'$, $D-D'$) the finger contained a local zone of relatively high concentrations of chromium. No local heterogeneity of the deposits is known which could account for this feature. The finger probably was chiefly due to minor leakage of plating wastes from a processing building located east of the disposal basins. Wastes from both sources presumably merged downgradient to form the easterly part of the plume shown in the geochemical sections.

The marked difference in the depth of penetration of the upper glacial aquifer by the contaminants in the eastern finger and in the main body of the plume (see C-C', pl. 3, for example) was due to the small volume of leakage of wastes at or near land surface at the processing building mentioned previously, compared to the relatively large quantity of wastes which seeped down almost directly into the zone of saturation beneath the disposal basins. In contrast to the major irregularity observed at the eastern boundary, minor irregularities along the western and lower boundaries of the plume were probably due chiefly to small variations in permeability of the deposits of the upper glacial aquifer.

5. The relatively small changes in the overall shape and dimensions of both the cadmium and chromium isopleths in the plume south of Lambert Avenue (pl. 1), observed during successive surveys from 1949 to 1962, suggests a fairly consistent pattern of recharge and movement of the contaminants during that period.

Significant geochemical features of the plume from 1949–62 observed or inferred from data on plates 3 and 4 are summarized as follows:

1. Differences in the quality of the water in the plume downgradient from the disposal basins may be partly attributable to the differences in the age and history of the contaminated water in different parts of the plume. For example, water in the northern part of the plume is younger than the water in the southern part. Consequently, its character is influenced by comparatively recent conditions of inflow, waste treatment, and dilution from precipitation compared to the character of the plume further south which reflects different conditions in earlier years.

2. The concentration of chromium has decreased substantially in nearly all sections since the start of chromium treatment operations in 1949—peak concentrations decreased from an observed maximum of about 40 mg/l in 1949 (pl. 3, section E-E,) to an observed maximum of about 10 mg/l in 1962 (pl. 3, section C-C').

3. The principal path of flow from the disposal basins generally was marked by locally high concentrations of hexavalent chromium, whose centers were observed at progressively lower depths downgradient. An imaginary line connecting the centers of these local highs seemed to coincide with the direction of the hydraulic gradient and may be analogous to the "mean line of dispersion" described by Skibitzke (1964, p. 5–6). (See also "Dispersal mechanisms" and fig. 9.)

4. The smaller extent and lower concentrations of the chromium

distribution pattern compared to that of cadmium at Motor Avenue (pl. 3, section $B-B'$) suggests moderately effective removal of the chromium by treatment of the plating-waste effluent probably shortly before the period 1962–64.

5. Cadmium concentrations apparently decreased in some places and increased in others, and peak concentrations did not coincide everywhere with those of chromium. These variations in concentrations were probably due partly to changes in the chemical character of the treated effluent during different years and partly to the influence of the hydrological and geochemical factors discussed in "Dispersal mechanisms."

6. The highest concentration of cadmium determined prior to the latest test-drilling program was about 3 mg/l in 1953 (pl. 3, section $C-C'$). In 1964, samples from a test site on Motor Avenue showed as much as 10 mg/l of cadmium (pl. 3, section $B-B'$, well 95). This concentration, which was the highest recorded in the area, was determined in a zone near the center of the principal path of flow from the disposal basins, which had not been sampled previously.

7. The discontinuities in the distribution of cadmium in the southern part of the plume (pl. 3, sections $F-F'$ and $L-L'$) were probably caused chiefly by dilution of ground water containing low concentrations of cadmium. These discontinuities may have coincided in places with the contact zone between the main body of the plume and a smaller body resulting from leakage from a minor source referred to previously.

PATTERN AND RATES OF WASTE MOVEMENT

The general pattern of movement of the plating-waste effluent is largely vertically downward from the disposal basins, through the zone of aeration, and into the zone of saturation in the upper glacial aquifer directly beneath the basins. From there, most of the water moves nearly horizontally and southerly toward Massapequa Creek, where a small part seeps into the stream and the remainder of the contaminated water flows downgradient beneath and west of the stream. The horizontal components of flow of the ground water are indicated by arrows on the water-table map (pl. 1D). Components of flow in the vertical dimension along the longitudinal axis of the plume are shown in plate 2A.

It is likely that a local departure from the regional pattern of southerly flow occurs beneath the disposal basis as radial outflow from a small transient recharge mound on the water table which is superimposed on the regional field of parallel flow by downward seepage of

plating-waste effluent. The head buildup and the areal extent of the recharge mound is mainly a function of the volume and rate of seepage from the disposal basins and the permeability and storage characteristics of the upper glacial acquifer. The hydraulic gradient resulting from the head buildup influences the lateral and vertical movement of the contaminants in the immediate vicinity of the basins. Radial-flow components probably extend for a relatively short distance from the basins and ultimately merge with the dominant regional southerly flow components.

Except for downward components of flow in the recharge mound beneath the disposal basins and upward components from shallow depths beneath Massapequa Creek, most of the contaminated water in the plume moves nearly horizontally. The slight depression of the isopleths of hexavalent chromium downgradient (pl. 2) may be due in part to vertical displacement of the contaminated water in the plume by recharge from precipitation.

The average rate of movement of the plume was estimated by the distance-time method and by Darcy's law. The first method assumes that plating wastes began entering the ground water in 1941 and that the leading edge of the plume probably reached the vicinity of Massapequa Creek by December 1949 (pl. 1A). This implies that the wastes probably moved about 3,900 feet in 9 years or an average of about 430 feet per year (an average of slightly more than 1 foot per day).

By using a variation of Darcy's law and using reasonable estimates of the hydraulic parameters (see "Water-bearing units"), the velocity may also be calculated as shown below:

$$V = \frac{PI}{7.48p}$$

or

$$\frac{1600 \times \frac{7.5}{3000}}{7.48 \times 0.35} = \text{about 1.5 feet per day, or about 550 feet per year,}$$

where

V = velocity in feet per day,
P = coefficient of permeability, in gpd per sq ft,
I = hydraulic gradient, in feet per foot, within the plume,
p = porosity in percent, and
7.48 = number of gallons per cubic foot of water.

Allowing for variations in permeability, porosity, and hydraulic gradient within the plume, and the results of the time-distance method, the estimated average regional velocity of the contaminated

ground water north of Massapequa Creek probably is about 1 to 2 feet per day. Locally, beneath and immediately west of the stream, the rate of movement of the leading edge of the plume (1962) may be as low as 0.5 foot per day, owing to the smaller hydraulic gradient in that area.

There is no evidence to indicate, nor is it likely, that any of the dissolved constituents are moving at rates measureably different from the average rate of the water itself. See "Dispersal mechanisms" for further explanations of the variations in the concentration patterns of the contaminants in the plume.

AMOUNTS OF WASTE REACHING MASSAPEQUA CREEK

The general pattern of flow under which part of the ground water containing plating wastes seeps into Massapequa Creek and the remainder moves downgradient as underflow beneath and west of the creek is illustrated on plates 2 and 4 and in figure 7. Plate 2 (*A* through *C*) shows how the plume of plating wastes is cut by the shallow channel of Massapequa Creek. The interconnection between the contaminated ground water and the stream is shown in greater detail on plate 4 and in figure 7.

Figure 7, a longitudinal profile of the stream channel near the start of flow, shows that in 1962–63 the upper surface of the plume virtually coincided with the stream bottom in a 500-foot reach that extended from a short distance north of point C to a short distance south of point E. (See also pl. 1.) The results of chemical analyses of the stream (table 8) show that it was in this reach only that shallow ground water, containing plating wastes, seeped into the stream, whereas upstream and downstream from that reach, ground water seeping into the stream did not contain plating wastes.

In addition to the seepage of contaminated water into the stream, ground water moved laterally beneath and beyond the stream channel (pl. 4). The upper surface of the plume, as defined by the chromium concentrations, was below the stream bottom in section *I–I'* (pl. 4), and although the flow arrows suggest the presence of upward components of ground-water flow, chemical analyses of the stream did not indicate any actual movement of water contaminated by plating wastes into the stream at this point. Such upward movement did occur, however, a short distance downgradient (section *J–J'*, pl. 4), where high concentrations of chromium in the ground water near the center of the plume coincided roughly with the highest concentrations of chromium found in the stream. (See point D, pl. 1 and table 8.)
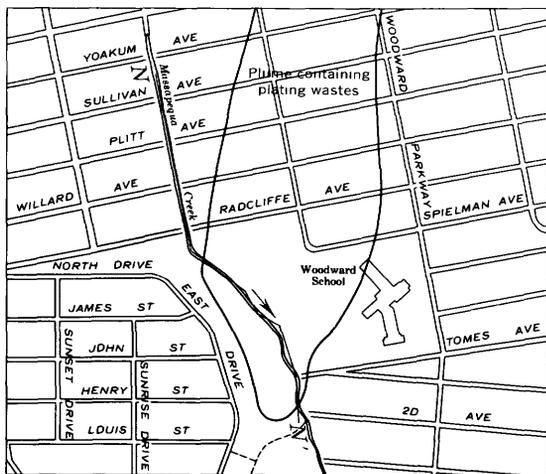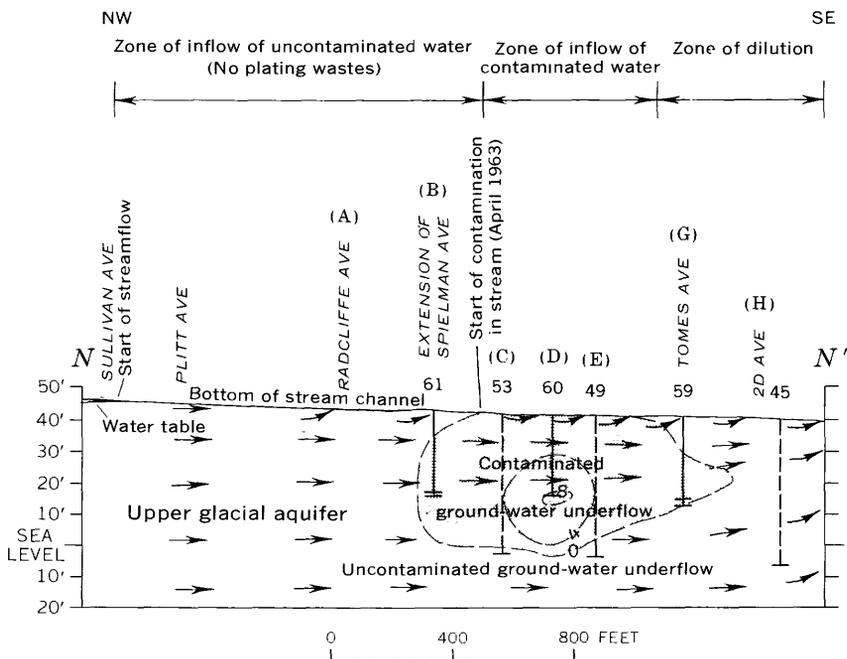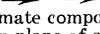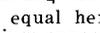
FIGURE 7.—Relation of the pattern of ground-water flow to the occurrence and dilution of plating wastes in Massapequa Creek.

TABLE 8.—*Discharge measurements and cadmium, hexavalent chromium, and MBAS contents of Massapequa Creek, South Farmingdale-Massapequa area, N.Y., 1962–64*

[Discharge measurements by U.S. Geological Survey; N, negligible; e, estimated. Chemical analyses by Nassau County Department of Health. See plate 1 for location of sampling points]

Sampling point	Location	Date collected	Discharge (cfs)	Discharge (mgd)	Cadmium Concentration (mg/l)	Cadmium Approximate load (lbs per day)	Hexavalent chromium Concentration (mg/l)	Hexavalent chromium Approximate load (lbs per day)	MBAS Concentration (mg/l)	MBAS Approximate load (lbs per day)	Remarks
A........	Near Radcliffe Ave.	9–11–62			<0.01	0	<0.01	0	1.7		
		10–23–62			<.01	0	<.01	0	1.7		pH, 6.4; Cl, 21 mg/l.
		2– 6–63			<.01	0	<.01	0	1		pH, 6.2.
		10– 9–63	0	0	0	0	0	0	0	0	
B........	Near well 29, extension of Spielman Ave.	8–30–62	0.19	0.12	<.01	0	<.01	0	1.1	1.1	
		9–10–62	.05e	.03e	<.01	0	<.01	0	1.2	.3	
		9–14–62	.05	.03	<.01	0	<.01	0	1.1	.3	—
		12–14–62	.12	.08	<.01	0	<.01	0	1.2	.8	
		4–22–63	.09	.06	<.01	0	<.01	0	1	.5	pH, 6.
		10– 9–63	0	0	0	0	0	0	0	0	Cl, 12 mg/l.
		8– 6–64	0	0	0	0	0	0	0	0	
C........	About 45 feet north of well 53.	9–10–62	.06e	.04e	.03	<.1			1.1	.4	
		12–13–62	.18	.12e			.05	<.1	1.2	1.2	
		4–22–63	.08	.05	<.01	0	.19	<.1	1.0	.4	pH, 6.2.
		10– 9–63	N	N	.005	N	<.01	0			
		8– 6–64	0	0	0	0	0	0	0	0	
D........	Near well 37.	9–10–62	.12e	.08e	.05	<.1	1.65	1	.9	.6	
		12–14–62	.26	.17	.06	<.1	2.10	3	.9	1.3	
		4–22–63	.19	.12	.08	<.1	2.88	2.9			pH, 5.8.
		10– 9–63	.04	.03	.10	<.1	1.20	3	1.2	.3	Cl, 19 mg/l.
		8– 6–64	N	N	.04		.48				pH, 7.1.
E........	Near well 49.	9–10–62	.22e	.14e	.06	<.1	2.15	2.5	.9	1	
		9–14–62	.21	.14	.06	<.1	2.00	2.3	.9	1	
		11– 8–62	.26	.17	.03	<.1	1.20	1.7	1.1	1.6	
		12–13–62	.30e	.19e	.05	<.1	1.95	3	1.0	1.6	
		2– 6–63	.30e	.19e	.09	.1	1.35	2	1.1	1.7	pH, 6.2.
		10– 9–63	.07e	.05e	.09	<.1	1.75	.7			
		8– 6–64	.01	.01	.17	<.1	1.05	<.1	1.1	.09	pH, 6.8.
F........	75 ft north of Tomes Ave.	8–30–62	.56	.36	.04	.12	1.55	4.7	.9	3	
		9–14–62	.31	.20	.04	<.1	1.80	3.0	.9	2	
		12–14–62	.38	.25	.07	.1	1.70	3.5	.8	2	
		4–22–63	.37	.24	.08	.2	1.90	3.8	.9	2	pH, 5.9.
		10– 9–63	.10	.06	.07	<.1	1.13	.6	1.2	.6	Cl, 19 mg/l.
		8– 6–64	.07	.05	.08	<.1	.85	.4	1.2	.5	pH, 6.9.
G........	Near well 34.	9–10–62	.31e	.20e	.05	<.1	1.55	2.6e	.8	1	
		12–13–62	.38e	.25e	<.01	0	1.55	3	.9	2	
		10– 9–63	.10e	.07e	.02	<.1	1.05	.6			
H........	Near well 51 at 2d Ave.	9–10–62	.35e	.23e	.03	<.1	1.20	2	.8	2	
		9–11–62	.35e	.23e	.05	.1	1.00	2	.8	2	
		12–14–62	.65	.42	<.01	0	1.25	4.4	.9	3	
		4–22–63	.52	.34	.05	.1	1.2	3.4	.8	2	pH, 6.1.
		10– 9–63	.13	.08	.01	<.1	.73	.5			
		8– 6–64	.10	.06	.07	<.1	.55	.3	1.1	.6	pH, 6.9.
I........	Near 3d Ave.	9–11–62	.42e	.27e	.03	<.1	1.05	2	.9	2	
J........	Near 4th Ave.	9–11–62	.50e	.32e	.03	<.1	.85	2	.8	2	
		9–14–62	.56	.36	.02	<.1	.8e	2	.9	2	
		4–22–63	.63	.41	.04	.1	.98	3.4	.8	3	pH, 6.1.
		10– 9–63	.15	.10	<.005	0	.33	.27			
		8– 6–64	.10	.06	.05	<.1	.28	.1	1.1	.6	pH, 7.1.
K........	Near 5th Ave.	9–11–62			.03		.85		.9		

TABLE 8.—*Discharge measurements and cadmium, hexavalent chromium, and MBAS contents of Massapequa Creek, South Farmingdale-Massapequa area, N.Y., 1962–64*—Continued

Sam-pling point	Location	Date collected	Discharge (cfs)	(mgd)	Cadmium Concen-tra-tion (mg/l)	Ap-proxi-mate load (lbs per day)	Hexavalent chromium Concen-tra-tion (mg/l)	Ap-proxi-mate load (lbs per day)	MBAS Concen-tra-tion (mg/l)	Ap-proxi-mate load (lbs per day)	Remarks
L_____	Near 6th Ave.	9-11-62	_____		0.03	_____	0.80	_____	0.7	_____	
M_____	Near 7th Ave.	9-11-62	0.64e	0.41e	.03	0.1	.75	2.6	.9	3	
		9-13-62	.66e	.43e	.03	.1	.73	2.6	.9	3	
		9-14-62	.68	.44	.01	<.1	.60	2.2	.8	2	
		4-22-63	1.0e	.65							
		10- 9-63	.19	.12	.02	<.1	.17	.17	.9	.9	Cl, 18 mg/l
		8- 6-64	.15	.10	.02	<.1	.18	.15	.9	.8	pH, 7.4.
N_____	Near 9th Ave.	9-13-62	_____		.03	_____	.60	_____	.8	_____	
O_____	North side of basin 1, near 11th Ave.	9-13-62	_____		.02	_____	.55	_____	.8	_____	
		12-13-62	_____		<.01	0	.50	_____	.8	_____	
		8- 6-64	.18	.12	<.005	0	.15	.2	.9	.9	pH, 7.9.
P_____	South side of basin 1.	9-14-62	1.47	.95	<.01	0	.26	2.1	.7	6	pH, 6.3.
		4-22-63	1.38	.89	<.01	0	.13	1	.9	7	Cl, 18 mg/l.
		10- 9-63	.87	.56	<.005	0	<.01	0	1	5	pH, 7.4.
		8- 6-64	.55	.36	<.005	0	<.01	0	1	3	
Q_____	West branch about 600 ft north of Southern State Parkway.	9-14-62	_____		<.01	0	<.01	0	.5	_____	
R_____	80 feet north of South-ern State Parkway.	9-13-62	_____		.02	_____	.10	_____	.7	_____	
		9-14-62	2.79e	1.80e	<.01	0	.09	1	.6	9	
		9-21-62	2.96	1.91							
		4-22-63	4.18	2.70	<.01	0	.06	1	.7	10	pH, 6.2.
		10- 9-63	1.39	.90	<.005	0	<.01	0	.9	7	Cl, 16 mg/l.
		8- 6-64	1.12	.72	<.005	0	<.01	0	.9	5	pH, 7.3.
S_____	Near Lin-den St.	9-14-62	3.0e	1.94e	<.01	0	.08	1	.6	10	
		9-21-62	3.2	2.07							
T_____	Near Franklin St.	9-14-62	4.2e	2.71e	<.01	_____	.05	1	.5	10	
		9-21-62	4.17	2.70							
		8- 6-64	2.17	1.40	<.005	0	<.01	0	.7	8	pH, 7.2.
U_____	Gaging Sta-tion near Garfield St.	9-14-62	7.7	4.95	<.01	_____	.02	.8	.5	20	
		9-21-62	7.2	4.65							
		12-14-62	10.1	6.53	_____		.01	.5	.5	30	
		4-22-63	9.5	6.14	<.01	_____	.02	1	.6	30	pH, 6.8.
		10- 9-63	4.6	2.97	<.005	0	<.01	0	.6	15	Cl, 16 mg/l.
		8- 6-64	4.6	2.97	<.005	0	<.01	0	.7	20	pH, 7.5.
V_____	Massapequa Pond near Clark Blvd.	9-14-62	9.1e	5.88e	<.01	0	<.01	0	.6	30	
		9-21-62	8.57	5.54							
		10- 9-63	5.5e	3.55e	<.005	0	<.01	0	.6	20	Cl, 15 mg/l.
		8- 6-64	_____		<.005	0	<.01	0	.8	_____	pH, 7.3.

Only a small amount of the plating wastes seeped into the stream near the southerly section $K-K'$ (pl. 4) because most of the plume was west of the stream in that area and was not in direct contact with the stream bottom as in section $J-J'$ noted previously.

The cadmium content of the stream in the reach betwen section $I-I'$ and $K-K'$ was generally less than 0.2 mg/l in contrast to concentrations of about 1–3 mg/l of hexavalent chromium (sampling points B through D, table 8). The low concentrations of cadmium in the stream are in accord with the low concentrations observed in the ground water at the leading edge of the plume (pl. 4) near the zone of natural discharge into the stream.

Because of dilution, cadmium generally was not detected in the stream south of point O (near 11th Avenue, pl. 1), whereas traces of chromium were found as far south as the gaging station at point U (Garfield Street), about 2 miles south of the first appearance of chromium in the stream and nearly 3 miles south of the disposal basins.

Although the concentrations of the contaminants in the ground water which seeped into the stream at any point were relatively constant, the concentrations in the stream fluctuated with changes in the stream discharge (fig. 8). Therefore, a more useful parameter for comparing the contamination of a stream from point to point is the change in the load of the contaminants.

The approximate relation between load and concentration is illustrated by the following calculation based on data collected at sampling point F on August 30, 1962 (table 8):

$$L = C \times Q \times 8.34$$

or

$$1.55 \times 0.36 \times 8.34 = 4.7 \text{ pounds per day,}$$

where

L = load in pounds per day,
C = concentration of hexavalent chromium in mg/l,
Q = discharge of the stream in mgd, and
8.34 = approximate weight of a gallon of water in pounds.

By similar calculations, the approximate loads of cadmium and hexavalent chromium at selected points in Massapequa Creek, between the start of flow and Massapequa Pond (pl. 1), were determined for the period 1962–64 (table 8). In calculating the load it was assumed that owing to the generally uniform rate of base flow of Massapequa Creek during an average 24-hour period, it was reasonable to use a miscellaneous discharge measurement as an approximation of the daily average discharge at a sampling point. Similarly, concentrations based on analyses of instantaneous samples of the stream were considered to be representative of the daily average concentrations of the contaminants.
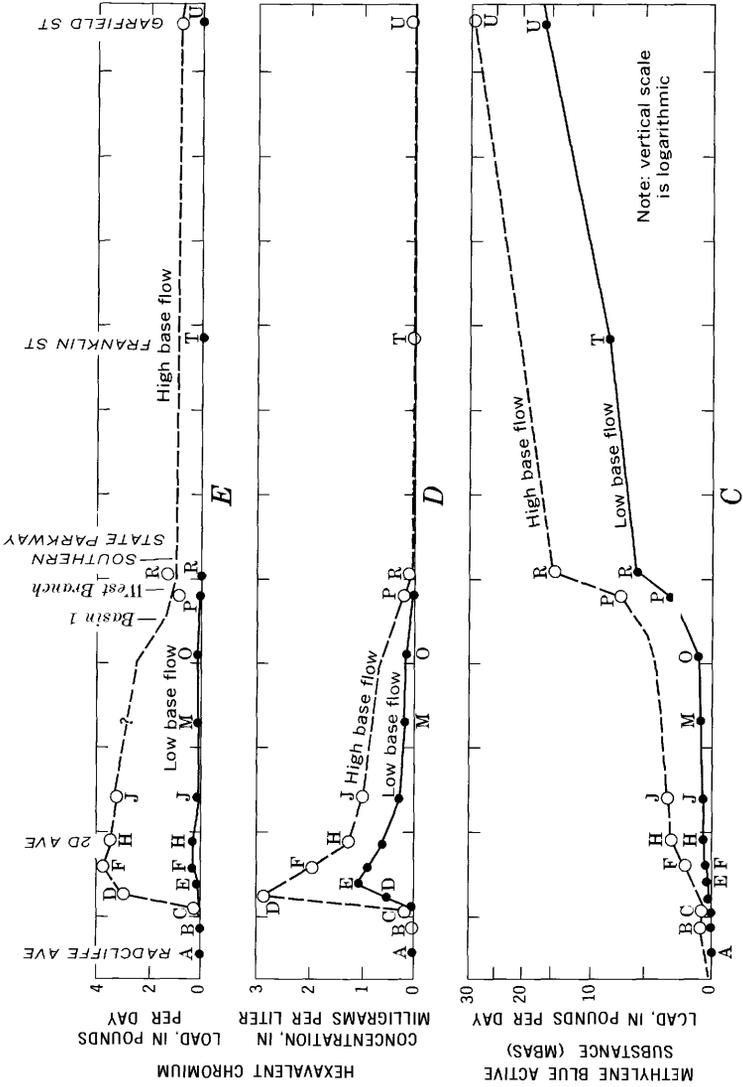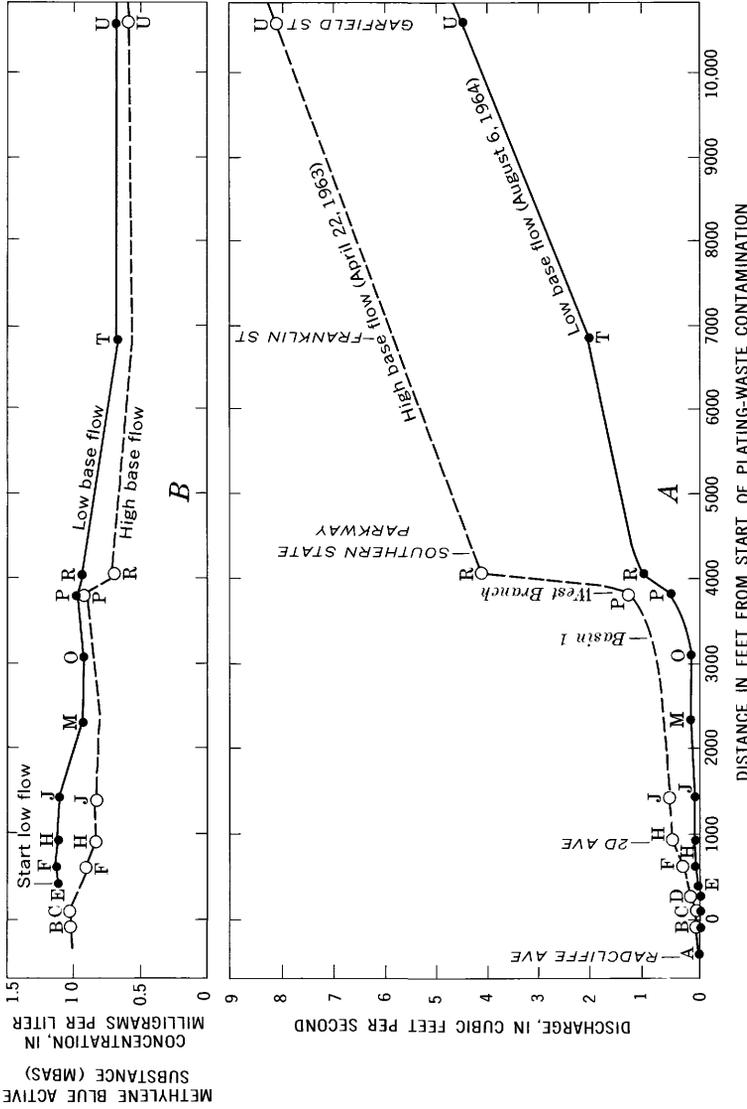
FIGURE 8.—Discharge and hexavalent chromium and MBAS content of Massapequa Creek at selected sampling points, 1963–64. Locations of sampling points designated by letters shown on plate 1.

As shown on the graphs in figure 8, no chromium was found near the start of flow at points A and B, but south of point B the concentration and load of heavy metals generally increased to about the vicinity of points D and E. The maximum observed concentrations cf cadmium and chromium in the stream during the period of high base flow in 1963, about 0.1 mg/l and 2.9 mg/l respectively, were determined at point D near the longitudinal axis of the plume (pl. 1). Dilution of the contaminants by seepage of ground water uncontaminated by plating wastes and by inflow from a tributary between points P and R accounts for the substantial decline in the concentration of chromium (fig. 8D) downstream from the plume. The maximum loads of cadmium and hexavalent chromium determined in the stream (table 8) were about 0.2 pound per day in April 1963 and nearly 5 pounds per day in August 1962, respectively, at point F, near the leading edge of the plume (pl. 1).

The unusual fluctuations in the load of chromium (fig. 8E) may be explained as follows: Theoretically, the load of chromium in the stream, after reaching a peak near the leading edge of the plume (pl. 1D), should have stabilized south of that point, provided that no chromium ions were lost by adsorption or by other geochemical processes, because no further seepage of water contaminated by plating wastes occurred downstream from the plume (pl. 1). The results of analyses (table 8 and fig. 8E) show, however, that a moderate decline occurred in the load of chromium between points F and O, and a steeper decline occurred between points O and P, where the stream moved through the first of several detention basins (pl. 1). Interpretation of the load graph south of point P is impractical owing to large dilution of the chromium content of the stream by tributary inflow.

Possible explanations for the decrease in the load of chromium downgradient are: (1) Adsorption of the heavy metal ions by small amounts of silt and organic particles in the streambed material between points F and O; (2) increased adsorption by silt, grass, and algae in basin 1, between points O and P; and (3) possible reduction of hexavalent chromium to trivalent chromium by hydrogen sulphide, which may be produced by bacterial action and decay of vegetation in basin 1. Such a reduction in valence would suggest an apparent loss of chromium from the stream as only the hexavalent ion was determined by chemical analysis.

During a period of below-normal precipitation corresponding with low-base flow in August 1964, both the concentration and the load of hexavalent chromium were reduced significantly below that of the seasonally high base flow in April 1963 (fig. 8D and 8E). The decrease in both characteristics is attributed to a decline of the water table, which resulted in: (1) Reduction in the length of the reach receiving seepage

of ground water contaminated by plating wastes and (2) seepage from a less contaminated part of the plume. These factors, in turn, resulted in a decrease in the quantity of contaminated ground water that seeped into the stream (fig. 7).

Under extreme conditions of water-table decline, the length of the reach of the stream within which seepage from the plume occurs could be reduced to zero. This unusual situation actually occurred in 1965 and 1966 when, as a result of a regional drought, the flow of Massapequa Creek started about half a mile downgradient from the plume of contaminated ground water which was observed in 1962 (pl. 1 and fig. 7). Consequently, no chromium was found in the stream samples during this period. The contaminated water probably moved downgradient virtually entirely as subsurface flow beneath and west of the stream. It seemed reasonable to infer that chromium and associated plating-waste contaminants would reappear in the stream when the water table rose to its former level and hydrologic conditions were restored to those prevailing in 1962. Subsequent sampling of Massapequa Creek in April 1968 at the start of flow near Second Avenue (pl. 1) showed no indication of plating-wastes, but in May 1969, 0.13 mg/l of hexavalent chromium was detected further north in the stream at Tomes Avenue (pl. 1). This suggests at least a partial return to predrought conditions.

DISPERSAL MECHANISMS

The downgradient spread or dispersal of the heavy-metal ions is a result of a complex history of three-dimensional flow, displacement, and mixing of the plating-waste effluent and the native ground water in the upper glacial aquifer in the report area. Many hydraulic, geologic, and geochemical factors have contributed to the distribution of the metals in the ground water—a distribution which is characterized by a longitudinal spread of ions in the direction of flow three to four times greater than the lateral spread transverse to the direction of flow. (See maps, pl. 1.) In sharp contrast, the spread of the ions in the vertical direction (pl. 2) is about 15 to 60 times smaller than that observed in the lateral and longitudinal directions, respectively.

Most of the dispersal mechanisms operating in the report area have been evaluated in general terms only. Quantitative estimates of the influence of the various mechanisms could not be made owing to the complexity of field conditions and the inadequacy of the available data and equations.

Present knowledge of dispersal mechanisms is based mainly on laboratory studies using simplified and idealized hydraulic models and on mathematical analyses (Perkins and Johnston, 1963; Harleman

and Rumer, 1962; Hoopes and Harleman, 1965; Ogata, 1963; and others). Except for Skibitzke's analysis of heterogeneous environments and influences (Skibitzke and Robinson, 1963, and Skibitzke 1964), most dispersion studies generally assume or simulate ideal conditions which are not commonly found in the field. Common simplifying assumptions are: (1) The porous medium is homogeneous—that is, physical properties such as porosity and permeability are constant throughout the medium; (2) the medium is isotropic—properties are the same in all directions from a point; (3) injection is made at a point and is either instantaneous (a single slug) or at a steady rate (continuous injection); (4) no disturbance of the natural flow field occurs at the point of injection; (5) the flow is laminar, consisting of streamlines in a one- or two-dimensional field of flow; and (6) density and viscosity differences between the injected and native waters are insignificant.

The term hydrodynamic dispersion as applied to the study of fluid displacement in hydraulic and mathematical models generally refers to the small-scale spreading of the boundary or zone of contact between two miscible fluids, which is caused by the intermingling of the ions of the fluids as they move through a porous medium. Hydrodynamic dispersion is commonly divided into two components: (1) Longitudinal dispersion, and (2) lateral dispersion. In longitudinal dispersion the ions are spread mainly by microscopic variations in flow direction, velocity, and length of flow paths, which reflect mostly the pore geometry of the aquifer. In lateral dispersion, the ions are thought to be spread mainly by the meandering of streamlines around sand grains and by the diffusion of ions between adjoining streamlines within individual pore spaces. Scientists do not agree, however, on the relative importance of these two possible mechanisms.

Field examples of large-scale spreading of tagged contaminants are rare. Therefore, despite the nonuniformity of the hydrologic properties of the upper glacial aquifer, a comparison between dispersion observed under field conditions in the report area and that which might be predicted from theory based on idealized laboratory models and mathematical analyses may be helpful in evaluating the dispersal mechanisms which govern the present and future extent of the plume.

An initial attempt to explain the distribution pattern of the heavy metals in the South Farmingdale area was made by the application of classical dispersion formulas and coefficients. The calculated values of longitudinal and lateral dispersion based on the theoretical formulas were not more than a few tens of feet, in contrast to the large observed spread of the plume of plating wastes (pl. 1D). This discrepancy suggests that the dispersal of the ions in the report area was

influenced by a variety of local hydraulic, geologic, and geochemical factors which were incompatible with the idealized assumptions of existing dispersion formulas.

Although the principal dispersal mechanisms are discussed separately in the following sections, with emphasis on the role of convection, disposal-basin hydraulics, and heterogeneity of the aquifer as the dominant mechanisms, all or some combination of these controls were operating simultaneously in different parts of the plume, and some exerted more influence on dispersion in one direction than in another.

HYDRAULIC CONTROLS

CONVECTION

The longitudinal extent of the plume is principally due to convection or bulk movement of the water and its dissolved constituents in the horizontal direction. The average rate and direction of such movement is controlled chiefly by natural velocities and flow patterns. Convection is fairly uniform throughout most of the plume, and no significant hydraulic barriers to longitudinal growth were observed except for the discharge zone at Massapequa Creek.

Both the cadmium and chromium ions have about the same longitudinal extent in the plume. No evidence was obtained of significant measurably different rates of movement of the two metals with respect to each other or to any other dissolved constituents in the water. The concentration distribution in the longitudinal direction is influenced also by other dispersal mechanisms, such as dilution and heterogeneity of the aquifer (discussed in later sections), and by changes in the chemical quality and degree of treatment of the plating-waste effluent injected since 1941.

PATTERN AND RATE OF INJECTION OF PLATING-WASTE EFFLUENT

Lateral or transverse spread of the plume, from a width of a few hundred feet at the disposal basins to an apparent width of about 1,000 feet near Plitt Avenue (pl. 1D), is attributed chiefly to the influence of three factors: (1) Hydraulic conditions associated with the disposal of the wastes by means of the basins, (2) heterogeneity of the upper glacial aquifer, and (3) secondary seepage of wastes from a minor source, possibly a processing building east of the disposal basins. The secondary seepage probably is due to accidental leakage which causes contaminated fluids to penetrate to relatively shallow depths below the water table on the east side of the plume. This seepage may account for about 200 to 250 feet of the observed lateral spread of the plume, according to the results shown in the geochemical sections.

Estimation of the influence of the disposal-basin hydraulics on the lateral dispersal of the plating wastes was based largely or a theoretical analysis of the problem. According to Ogata (1963, p. 201), when a fluid tracer or contaminant is injected continuously into a homogeneous aquifer by means of a circular cylindrical source, such as a fully penetrating well, at an assumed velocity of zero or at a negligible head relative to the natural flow field, a band of contamination develops downgradient that ultimately spreads laterally to a maximum width of about twice the diameter of the source. (See A–A', fig. 9.) This type of lateral dispersal may result solely from the hydraulic discontinuity created in the flow field by the presence of a hydraulic source of finite diameter through which contaminated fluids are being injected under idealized head relations.

In actual practice, injection is generally at a rate sufficient to produce a local recharge mound on the natural regional field of parallel flow. The resultant radial components of flow cause additional lateral spread of a contaminant in proportion to the hydraulic strength of the source. That is, the greater the head buildup and, consequently, the greater the velocity of the injected fluid relative to the velocity in the natural field of flow, the greater the lateral spread (Ogata, 1963, p. 201). Ogata also suggested that the spread due to the hydraulic strength of a source of injection may be very large compared to that resulting from hydrodynamic dispersion.

Although, as previously noted, the data and field conditions in the report area do not conform in all respects to the assumptions and restrictions of existing dispersion and hydraulics theories, these theories afford at least a limited frame of reference for appraising several of the principal factors accounting for the observed maximum lateral spread of nearly 1,000 feet. For example, by using Cgata's concepts (1963), if we assume that the recharge-basin complex is equivalent to a hypothetical, fully penetrating well having a diameter of about 200 feet (fig. 9), then, theoretically, injection of contaminated water with a negligible head buildup in the basins could produce a lateral spread of about 400 feet downgradient from the point of injection.

Intermittent head buildup in the disposal basins, however, probably has contributed in part to the increased lateral spread of the contaminants beyond that which might be attributed solely to the diameter of the source (fig. 9). The influence of the head buildup cannot be evaluated quantitatively owing to the lack of data on past injection rates and water levels. Also, adequate equations dealing with the case of partly penetrating basins were not available to make a more precise analysis of the effects of head buildup and basin diameter on lateral dispersion in the study area.
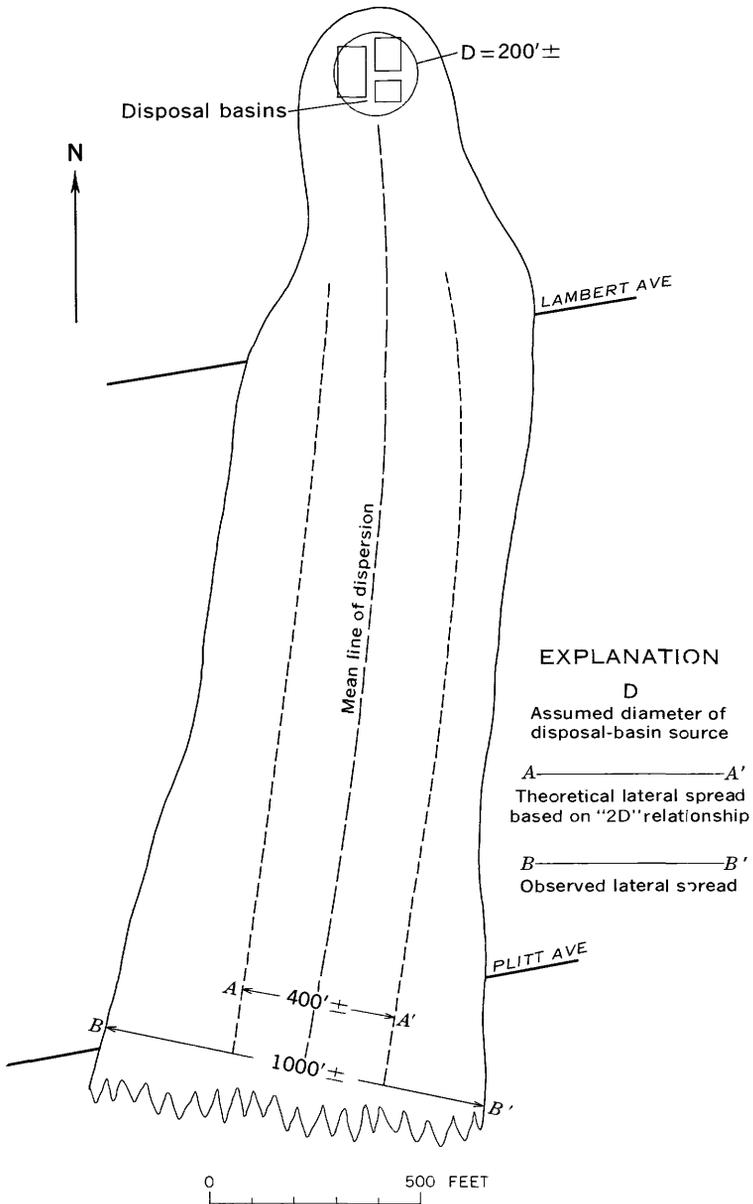
FIGURE 9.—Plume containing plating wastes. Sketch shows the theoretical relation between the diameter of the source and the calculated and observed lateral spread.

Dispersal of the contaminants due to the heterogeneity of the aquifer and to the influence of several minor dispersal mechanisms is discussed in the sections which follow.

GEOLOGIC CONTROLS

HETEROGENEITY OF THE UPPER GLACIAL AQUIFER

Heterogeneity or nonuniformity of aquifer materials can influence dispersion of ions both in the horizontal and vertical directions. Virtually all natural aquifers have some degree of heterogeneity which is indicated by variations in grain size and shape, sorting, permeability, porosity, and cementation. Laboratory studies and theoretical analyses indicate that large variations in these properties can cause significant dispersion for example by refraction or bending of flow lines across contacts marking abrupt changes in permeability and by preferential diversion of flow lines through relatively permeable channels (Hubbert, 1940, p. 844–47, and Skibitzke and Robinson, 1963, p. 1–3).

The heterogeneity of the upper glacial aquifer in the report area cannot be described in sufficient detail from available data to determine its influence quantitatively on dispersal of the heavy-metal ions. To obtain such data would require collection of a substantial number of detailed well logs and samples of material at closely spaced intervals which was not considered feasible during this investigation.

Although in gross aspect the upper glacial aquifer seems to behave as a relatively homogeneous conduit in transmitting water horizontally, especially when viewed on a regional basis (see generally smooth outlines of the plume and the character of the water-table contours, pl. 1D), there are indications that the aquifer is moderately to significantly heterogeneous in both the horizontal and vertical directions. Moreover, because of this heterogeneity, the actual flow pattern in the aquifer on a microscopic scale probably is far more complex than is apparent from examination of small-scale water-level contour maps and flow sections.

For example, a wide range in sorting and in grain size, and the lenticular character of the aquifer are indicated by the data in table 1 and by the columnar sections on plate 2A. These variations in the character of the medium probably were responsible for some feathering of the lines of equal concentration noted along the margins of the plume and also for the occurrence of several local anomalous zones of high concentrations of heavy metals observed in parts of the plume (pl. 3).

Of greater significance may be the effect of the overall heterogeneous character of the aquifer on lateral dispersal of the ions. It is suggested that possibly as much as several hundred feet or more of the lateral

spread may have been caused by the meandering or intertwining of the flow lines owing to the heterogeneity of the aquifer.

The average vertical permeability of the upper glacial aquifer is estimated to be at least several or more orders of magnitude lower than the average horizontal permeability owing to stratification of the aquifer materials. Consequently, heterogeneity of the aquifer in the vertical direction has doubtless influenced the depth of occurrence and the distribution of the contaminants not only beneath the disposal basins but also at other locations downgradient.

Data from the latest investigation suggest that in some places the bottom of the plume terminated in permeable material, and elsewhere it may have terminated on material of low permeability in the upper glacial aquifer. Plate 2 shows that the contaminated water moved down to about its maximum depth of occurrence in the upper glacial aquifer beneath the disposal basins. The depth penetrated was chiefly a function of the head buildup in the basin and the vertical permeability of the aquifer. Presumably, if the head buildup were greater, the contaminants might have penetrated somewhat deeper into the ground-water reservoir, possibly into the upper part of the Magothy aquifer. Downgradient from the basins where the water was generally moving horizontally, abrupt reductions in the concentrations of chromium were noted in short vertical distances near the bottom of the aquifer (pls. 2 and 3), which may indicate the presence of local lenses of material of low permeability.

GEOCHEMICAL CONTROLS

ADSORPTION, ION EXCHANGE, AND DENSITY

Adsorption and ion exchange may retard the movement of selected ions. Under certain conditions, delays of sufficient magnitude could significantly effect the concentration of a contaminant downgradient from its source. As shown below, however, both phenomena are believed to have little influence on dispersion in the upper glacial aquifer.

Adsorption is caused by attraction between the surface molecules and ions of the aquifer materials and those in the water. The fine to coarse predominantly quartzose mineral grains comprising most of the upper glacial aquifer have low adsorbent characteristics according to the results of experiments by Wayman, Page, and Robertson (1965, p. 79), who demonstrated that such material had an adsorptive capacity of only 0.05–0.1 gram of ABS per gram of sand. It is likely that the adsorptive capacity of the deposits for cadmium and chromium is also low. Furthermore, the materials of the upper glacial aquifer probably reach their adsorptive capacity very quickly, although

desorption or removal of ions may occur from time to time when the character of the inflowing water changes.

The ion-exchange capacity of the materials of the upper glacial aquifer—that is, their ability to exchange selected ions with those in the ground water—was not determined specifically for this report. However, on the basis of experiments by Faust (1963, p. 27) and by E. A. Jenne (U.S. Geological Survey, written commun., 1964), who reported exchange capacities of only 0.1 to 0.6 milliequivalent per 100 grams for typical glacial sand from Suffolk County, it was inferred that the removal of cadmium and chromium by ion exchange during movement through the predominantly sandy beds of the upper glacial aquifer in the report area was negligible.

Consideration was given to the possibility that differences in density between the native ground water and ground water containing plating wastes might influence the flow pattern and concentration distribution of the contaminants. Accordingly, density determinations were made of contaminated samples of water from a disposal basin and from a well downgradient from the basin (well 77), both of which contained 5 mg/l of hexavalent chromium. A similar determination was made of a sample from well 65 which did not contain plating wastes. The densities of the waters ranged from 0.998 to 0.999 g/l (gram per liter), virtually the same as that of distilled water. These results suggest that differences in density among the waters studied were too small to effect the distribution of the contaminants significantly and were probably largely overshadowed by the effects of other dispersal mechanisms.

DILUTION AND DIFFUSION

Dilution of the plume, which had an estimated volume of about 200 million gallons in 1962, occurred chiefly by direct overhead recharge from precipitation and from cesspool wastes (about 0.15 mgd) and by lateral subsurface inflow (about 0.1 mgd). Significant dilution of the concentration of heavy metals mainly in the interior of the plume probably occurred also as a result of intermittent disposal of less concentrated plating-waste effluent and of storm water collected in the industrial park and piped to the disposal basins. From a gross viewpoint, dilution probably had a greater influence on local concentration distributions of cadmium and chromium than on the overall shape and extent of the plume of contaminated water. Because of the large variations in precipitation and scantiness of data on changes in the concentration and volume of plating wastes recharged since 1941, however, it was difficult to quantitatively assess the influence of the individual factors contributing to dilution of the plume.

Diffusion is the slow intermingling of ions between two fluids that were initially in sharp contact. Movement of the ions results in the development of a zone of transitional concentrations (zone of diffusion) between the two fluids. Because of the low concentration gradients and the moderate ground-water temperatures which exist in the plume, ionic diffusion must be extremely slow, possibly on the order of a few thousandths of a foot per year according to a rough calculation. Consequently, diffusion as an independent mechanism could not account for the extensive dispersal of the heavy metals in the ground water. The possible role of diffusion as a supplementary mechanism in lateral dispersion was noted previously.

More fundamental research, particularly in heterogeneous ground-water environments, is needed before the influences of individual dispersal mechanisms can be sorted out more precisely in situations such as the plume of plating wastes at South Farmingdale.

DETERGENT CONTAMINATION

Detergents now constitute the principal washing compound for domestic and industrial use in the United States. These compounds contribute to water-quality problems when they percolate into the ground water as part of the effluent from individual domestic waste-disposal systems or are discharged into streams in the effluent from sewage-treatment plants. Detergents in a water supply may also indicate the presence of other sewage constituents such as nitrate and chloride, and in some places they may indicate the presence of bacteria and viruses as well.

COMPOSITION OF DETERGENTS

Synthetic detergents consist of about 20–40 percent of surfactants (surface-active agents, which loosen soil particles) about 30–50 percent of complex sodium phosphate salts, and about 10–30 percent of miscellaneous builders and minor additives (California State Water Quality Board and others, 1965, p. 14). The surfactant used chiefly from 1946–65 was ABS (alkylbenzenesulfonate), an organic compound manufactured from petroleum or natural gas (Soap and Detergent Association, 1962, p. 9). ABS, which is used at concentrations as high as 200–600 ppm in laundry machines, generally causes foaming when dispersed in stream and well waters at concentrations as low as 1–2 ppm.

In 1964, the soap and detergent industry began production of a so-called soft detergent containing a new surfactant, LAS (linear alkylsulfonate), which reportedly is about 95 percent removed after passage through sewage-treatment plants utilizing activated sludge

(California State Water Quality Board and others, 1965, p. 40–41), but there is no evidence to date of comparable removal in the Long Island ground-water reservoir. Both surfactants are referred to by the term "MBAS" in this report. (See "Laboratory Techniques.")

Except for phosphate salts which act as nutrients for algae in surface water, the other constituents in detergents are not considered to be significant contaminants in ground water.

DISPOSAL AND DEGRADATION OF DOMESTIC SEWAGE

An estimated 0.3 to 0.4 million gallons of household sewage containing various concentrations of detergents and other domestic-waste constituents are added daily to the upper glacial aquifer in the principal study area (pl. 1) as effluent from sanitary disposal systems. The wastes are discharged through individual cesspools and through combined systems composed of a septic tank and a cesspool or a septic tank and a seepage field (fig. 10).

A cesspool is an open-bottom cylindrical structure composed of slotted concrete blocks or reinforced rings. A typical pool in the report area is about 8 feet in diameter and about 10 feet deep. The top of the pool is generally 1–2 feet below ground level and the bottom terminates above the water table. In a cesspool system, solid, largely nitrogenous, wastes are decomposed in the pool by natural biochemical processes. Partly decomposed solids accumulate as sludge on the bottom of the pool while most of the liquid wastes seep out through the slotted walls of the pool and some may seep out through the sludge-covered bottom.

Septic tank-seepage field systems are commonly constructed where the water table is at shallow depths. The septic tank is a closed-bottom concrete cylinder or box in which the partly decomposed solid sewage remains as sludge while the liquid wastes pass into a nearby seepage field or cesspool and ultimately seep down into the ground water. The seepage field usually consists of several parallel or radial lines of perforated or loosely jointed pipes installed in a bed of gravel.

Degradation of organic material in cesspools results in the production of end products such as ammonia, nitrate, nitrite, chloride, carbon dioxide, and hydrogen sulphide. Degradation requires and is accompanied by abundant growth of bacteria. Some wastes are adsorbed temporarily by the sludge on the bottom of the cesspools, but most of the dissolved constituents seep down to the water table.

Concentrations of MBAS were substantially diluted by mixing with waste water in cesspools and septic tanks, but apparently the surfactants were not completely degraded as indicated by their wide distribution in ground water downgradient from the disposal systems.
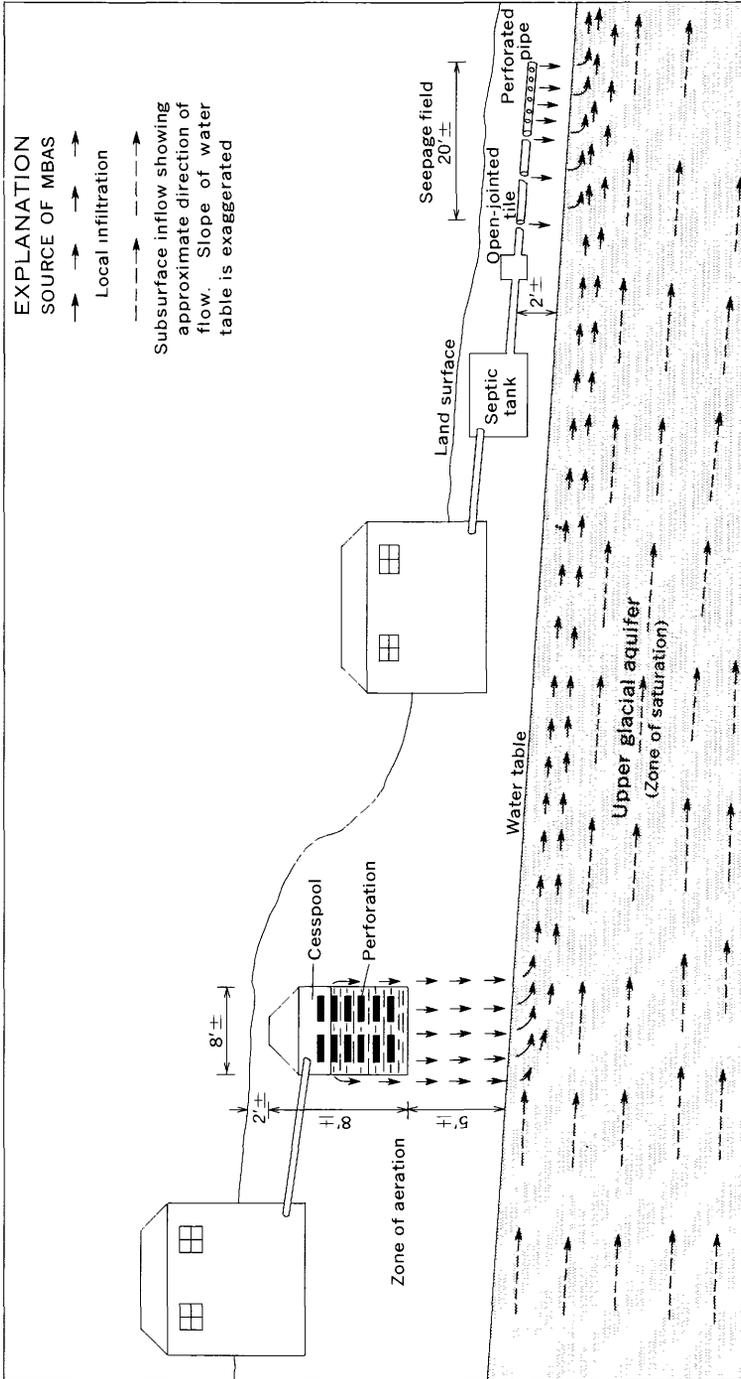
FIGURE 10.—Pattern of contamination of shallow ground water by effluent from typical domestic waste-disposal systems in the South Farmingdale-Massapequa area (not to scale). Contaminated water is shaded.

Adsorption and other geochemical processes probably were also ineffective in removing significant amounts of MBAS during movement of the wastes through the relatively thin zone of aeration in the report area. It was indicated in an earlier section that the adsorptive capacity of the beds of glacial sand and gravel for MBAS was negligible. (See "Dispersal mechanisms.") It is likely, therefore, that reduction of MBAS in the zone of saturation from initially high concentrations of about 30–60 mg/l in and near cesspools to concentrations of a few milligrams per liter or less downgradient chiefly occurred as a result of dilution of the wastes by mixing with recharge from precipitation and with less contaminated ground water.

CONCENTRATION AND MOVEMENT OF MBAS IN THE GROUND WATER

Upon reaching the water table, the effluent from hundreds of relatively closely spaced cesspools and septic tanks in the report area form individual plumes of contaminated water which move slowly downgradient. The individual plumes are fairly discrete initially, but probably within a short distance from their sources, they tend to lose their identity by dilution and by merging with nearby plumes. Ultimately, the merged plumes become part of a broad zone of contaminated water in the upper glacial aquifer.

The distribution and concentration of MBAS in the upper glacial aquifer are shown in sections parallel (pl. 2) and oblique (pl. 5) to the direction of ground-water flow. The flow pattern shown on plate 2 suggests that most of the contaminated water moves nearly horizontally. The lower limit of MBAS contamination in the principal study area in 1962 apparently was in the upper glacial aquifer at depths as much as 10 feet or more above the underlying Magothy aquifer.

The zone of contaminated water in the upper glacial aquifer was as much as 70 feet thick in places and was fairly continuous both laterally and vertically throughout the report area. Concentrations of MBAS at depths of less than 5 feet below the water table were not determined at most test well sites, and they may be greater or lower than those shown in the sections.

The greatest concentrations of MBAS were commonly observed in the upper 20 feet of the zone of saturation, where they ranged generally from about 1 to 5 mg/l (pl. 5, $C-C'$). At one location (pl. 5, section $F-F'$) a concentration of 30 mg/l of MBAS suggests proximity to the center of a plume of sewage effluent from a nearby cesspool. The downward sag of the isopleths of MBAS at the east and west ends of section $B-B'$ (pl. 5) probably was due to the small amount of cesspool wastes percolating into the ground water in the relatively undeveloped area immediately upgradient from the sampling wells.

Another significant feature of the concentration distribution of MBAS was the decrease in concentration of the contaminants beneath the undeveloped flood plain of Massapequa Creek (pl. 5, sections G–G' and H–H') compared with the higher concentrations observed beneath the adjoining residential area. Section M–M' (pl. 5) illustrates the relatively uniform pattern of nearly horizontal stratification of the MBAS concentrations in an undeveloped area on the west side of Massapequa Creek in contrast to the more irregular patterns observed in sections B–B' to F–F' which represent conditions in largely inhabited areas.

AMOUNTS OF DETERGENT REACHING MASSAPEQUA CREEK

Analyses of samples of water collected between 1962 and 1964 from Massapequa Creek at 22 sites between the start of flow and Massapequa Pond at Sunrise Highway, a distance of about 15,000 feet (pl. 1), indicate that ground water containing MBAS seeped into the stream along its entire course. The results (table 8) showed that the MBAS content ranged from 1.7 mg/l at the headwaters to about 0.9 mg/l near the mouth of the stream. Graphs comparing MBAS concentrations and the discharge of the stream in 1963 and 1964 (fig. 8A and fig. 8B) show that the concentration between the start of flow and point P (pl. 1) averaged about 1 mg/l. From point P to point U, the concentration of MBAS decreased to about 0.6 mg/l.

The load of MBAS (fig. 8C and table 8) increased from less than 1 pound per day at the headwaters of Massapequa Creek to about 30 pounds per day at Massapequa Pond. The sharp rise in the load of MBAS at point R (fig. 8C) was caused by a large increase in the discharge of Massapequa Creek due to inflow of contaminated water from a major tributary, which enters the creek north of Southern State Parkway. The load increased more slowly south of point R; this increase reflects a gradual pickup of MBAS from small increments of slightly contaminated ground water.

The high base-flow curve shown in figure 8B indicates that, while the concentration of MBAS decreased about 50 percent by dilution within the reach sampled, the load (fig. 8C) increased about thirtyfold as a result of the additional MBAS contributed to the stream by inflow of contaminated water downgradient. The load of MBAS at low flow was substantially below that at high flow because of reduction in the volume of contaminated ground-water seepage and tributary inflow. In contrast, the concentration of MBAS during low flow was only slightly greater than that during high flow.

The graphs in figures 8B and 8D show that the concentrations of MBAS during low flow increased slightly above the concentrations at high flow, whereas the concentrations of chromium at comparable

stages showed a reverse trend. These opposing trends were probably due to differences in the pattern of inflow under which the contaminants entered the stream and also the influence of dilution. For example, ground water contaminated by MBAS seeped into the stream along its entire course, whereas ground water containing hexavalent chromium seeped into the stream only in the small reach which intersected the plume (fig. 7). Furthermore, at low flow, a smaller part of the plume was intersected by the stream than at high flow, which resulted in reduced seepage of plating-waste contaminants into the stream. As previously noted, at an extremely low-flow stage in 1966, the top of the plume was entirely below the streambed; consequently, no heavy metal ions entered the stream during that period.

EVALUATION OF CONTAMINATION EFFECTS
POSSIBLE HEALTH HAZARDS
PLATING WASTES

The principal concern over the presence of plating-waste and detergent constituents in the ground water are: (1) Possible health hazards due to toxicity, and (2) threats to usefulness of existing or potential supplies. The evaluation of the toxicity of the heavy metals given in this section is largely adapted from a report by the U.S. Public Health Service (1962, p. 29–31, 36–38). The Public Health Service recommends limits for cadmium and hexavalent chromium in drinking water of 0.01 mg/l and 0.05 mg/l, respectively.

Cadmium is not known to be biologically essential or beneficial to humans, but it has a high potential toxicity, based on human case histories of food and beverage poisoning and on laboratory tests on animals. The results of these studies, which suggest that excessive intake of cadmium by humans may interfere with metabolism and cause kidney damage, are the basis for the low limit of concentration recommended in drinking water (U.S. Public Health Service, 1962, p. 30).

Chromium also is not known to be essential to human metabolism. The hexavalent form is believed to be toxic, whereas low concentrations of trivalent chromium are not considered to be toxic nor are they grounds for rejection of a supply for drinking-water use. Of interest in this investigation was the case history of a family in the South Farmingdale area, which used ground water containing from 1 to 25 mg/l of hexavalent chromium for about 3 years without any apparent ill effects (Davids and Lieber, 1951, p. 532). No information on the health status of the family has been obtained since this 1951 report. Because the tolerance of hexavalent chromium over a normal life span is unknown, the limit in drinking water recommended by the U.S. Pub-

lic Health Service, 1962, p. 36) has been set at about the lowest amount
that can be determined analytically by standard methods. (See "Laboratory techniques.")

DETERGENTS

The recommended limit for MBAS in drinking water is 0.5 mg/l
(U.S. Public Health Service, 1962, p. 24). This relatively low concentration was established primarily because MBAS causes foaming in
water at concentrations of only a few milligrams per liter, and even a
trace of MBAS generally indicates that the water is partly of sewage
origin. Various studies on the toxicity of MBAS (U.S. Public Health
Service, 1962, p. 24–25) have shown that no pathological effects or
intolerance was noted in humans who drank the equivalent of 2 liters
of water containing 50 mg/l of MBAS daily for about 4 months, which
is far in excess of known concentrations in the ground water. Furthermore, Walton (1960) reports that people generally do not taste or
smell pure MBAS until the concentration exceeds about 16 mg/l and
1,000 mg/l, respectively. Consequently, many investigators believe that
the most obnoxious tastes and odors in water are probably caused by
waste constituents other than MBAS.

EFFECT ON WATER USE AND DEVELOPMENT

PLATING WASTES

As shown previously (see "Character of inflowing water"), the
concentrations of cadmium and hexavalent chromium in most of the
plume of contaminated ground water (pl. 1D) and in Massapequa
Creek, from a point just north of Tomes Avenue to about the vicinity
of Southern State Parkway (pl. 1), exceeded the recommended limits
for drinking water (U.S. Public Health Service, 1962). Consequently,
development of the upper glacial aquifer in these areas for either
domestic or public-water supplies would not under current conditions
be desirable.

A small number of privately owned shallow wells are operated for
lawn sprinkling in the area underlain by the plume of plating wastes.
The water from most of these wells is contaminated and should not
be used for drinking. Small-capacity wells used for lawn sprinkling
that are several hundred feet or more from the present boundaries of
the plume probably will not induce significant lateral movement of
water from the plume toward them during intermittent pumping.

All the public-supply wells in the report area were offset laterally
at least 2,000 feet or more from the actual or predicted path of the
plume (pl. 1), and they drew water from zones in the Magothy aquifer
(table 3) that were several hundred feet deeper than the contaminated

zone in the upper glacial aquifer. Under the hydrologic conditions prevailing during this investigation, it did not appear likely that the contaminated water of the plume would move toward the screens of the public-supply wells serving the report area.

Conceivably, some heavy-metal contaminants could move down into the upper part of the Magothy aquifer beneath the plume if the rate of recharge of plating wastes were increased substantially at the disposal basins, or if heavy withdrawals from the Magothy aquifer in the future caused the development of downward gradients and subsequent downward percolation of contaminated water from the upper glacial aquifer. Under such conditions, the low permeability of the silt and clay beds of the Magothy would tend to retard but probably would not prevent downward movement of the contaminated water.

It has been conjectured that certain geochemical processes such as ion exchange and adsorption might help reduce the concentration of the heavy metals if they reached the Magothy aquifer. However, the few determinations which have been made to date do not suggest that the Magothy sediments are particularly suitable for such purposes. Furthermore, persistent movement of the contaminants along the same flow paths probably would cause the sediments to quickly reach their absorptive capacity and, thus, lose their effectiveness as natural "filters."

Several parts of New York City's Ridgewood system in Massapequa, about 2.5 miles downgradient from the leading edge of the plume (pl. 1), are subject to potential contamination. These include Massapequa Pond, an infiltration gallery, and a well field (pl. 1). Plating-waste contaminants might reach these installations by three possible methods: (1) Direct flow of contaminated water from Massapequa Creek into Massapequa Pond, (2) induced infiltration of contaminated water from the creek and pond into the gallery and the well field during pumping, and (3) movement of the plume progressively downgradient as underflow to the gallery and well field.

The following statements summarize the potential risks of contamination of the Ridgewood system facilities by plating wastes:

1. Point U (pl. 1), about a mile north of the infiltration gallery, was the most southerly point in Massapequa Creek at which a trace of chromium (about 0.02 mg/l) was detected. Further dilution of the stream water by inflow of uncontaminated ground water downgradient from point U should reduce the content of heavy metals in the extreme southerly reach of the stream to nontoxic trace concentrations or less.

2. If, in rare instances, Massapequa Creek contained excessive concentrations of heavy metals as it moved past the gallery and well

field at Sunrise Highway, a small amount of contaminated stream water might enter these installations by infiltration into and movement through the shallow aquifer during pumping. However, the volume of such induced inflow doubtless would be a small percentage of the total flow of the Ridgewood system. Therefore, it is likely that normal mixing of water from all sources would reduce the heavy-metals content below the limit of detection.

3. The possibility of the plume reaching the infiltration gallery at Sunrise Highway as underflow is remote. Under conditions in 1962, the plume was elongating extremely slowly at its southern extremity—the leading edge had progressed southward less than 500 feet from 1949 to 1962. This slow rate of elongation is due to the low hydraulic gradients near the leading edge and to natural discharge of part of the contaminated water into the stream. At the present average rate of movement of 1 foot per day, the plume would require about 12,000 days or about 30 years to reach the vicinity of the infiltration gallery as underflow. Furthermore, the contaminants would undergo substantial dilution during such movement. Moreover, additional significant southerly movement of the leading edge of the plume may be largely retarded by discharge of the contaminated ground water into Massapequa Creek.

The danger of contamination downgradient from the plume might be reduced or eliminated by removing the contaminated water from the aquifer. The volume of contaminated water in the plume is estimated to be 26 million cubic feet (about 195 million gallons). From an engineering viewpoint, it is possible to pump out most of this water by means of shallow wells and to dispose of it elsewhere (into the southshore bays, for example), but cost and time factors probably would make this procedure impractical. If recharge of plating wastes were stopped completely now, the plume would begin to decay by dilution from natural and artificial recharge. The rate of such dilution might be increased substantially by diverting additional quantities of storm water into the disposal basins at or near the origin of the plume.

DETERGENTS

The principal limitation on the usefulness of water contaminated by detergents is the tendency of surfactants to cause foaming at low concentrations, which, from an esthetic viewpoint, can render a water supply unsuitable for drinking. Foaming of water is undesirable also for certain industrial uses of water.

In the period 1962–64, about 75 percent of the water in the upper glacial aquifer in the report area contained at least a trace of MBAS,

although concentrations greater than the recommended limit of 0.5 mg/l were restricted mainly to about the upper 20 feet of the aquifer.

The effect of detergents on plants was studied at the New York State University Agricultural and Technical Institute at Farmingdale, Long Island, by Bing and Bradley (1964), who showed that the application of water containing concentrations of the surfactant ABS as high as 200 mg/l to several types of flowering plants and radishes resulted in no visible adverse effects on their growth. The investigators concluded that the low concentrations of ABS normally found in ground water are probably not harmful to most plants, particularly those grown in well-fertilized soil.

Because of the wide distribution of MBAS and other sewage constituents in the upper glacial aquifer, it presently might not be desirable to construct shallow public-supply wells in the report area. Nearly all the wells supplying water for public use in the report area, however, tap deep zones in the Magothy aquifer which generally yields water of excellent quality.

The only shallow public-supply installations in the overall report area that showed significant MBAS contamination were New York City's infiltration gallery and well field at Massapequa (pl. 1). Samples of water from the Massapequa infiltration gallery, which taps the upper glacial aquifer, contained 0.9 to 1.7 mg/l of MBAS in 1965. The character of the ground water available for inflow into the gallery was indicated by the results of the analyses of samples of water pumped at different depths from a shallow well driven at Brooklyn Avenue and Parkside Boulevard, a short distance north of the gallery (table 9). Nearly all the water contained excessive concentrations of MBAS, and one sample, at a depth of 27 feet, had a nitrate concentration which was only a few milligrams per liter below the recommended limit of 45 mg/l for drinking water.

A sample of water from the Massapequa well field (table 5) contained about 0.04 mg/l of MBAS in 1965. The water probably represented a composite sample from wells tapping both the upper glacial

TABLE 9.—*Chemical analyses of water from well N7950, Massapequa, N.Y.*

[Analyses by the Nassau County Department of Health. Date sampled, October 1, 1965. Depth to water about 10 feet]

Depth of sample (feet)	Chloride (mg/l)	Nitrate as NO₃ (mg/l)	MBAS (mg/l)
12.5	55	2?	0. 02
17.5	32	----------	1. 5
22.5	29	25	1. 5
27.5	23	42	1. 0
32.5	18	3?	1. 2

and the Magothy aquifers. Presumably the MBAS content was largely if not entirely from the upper glacial aquifer.

No evidence of detergent contamination was found in the water from the middle and lower zones of the Magothy aquifer in the report area. As noted previously (see "Chemical quality of the inflowing water"), however, one public supply well, N4042, screened in the upper part of the Magothy aquifer showed evidence of some MBAS contamination presumably of local origin.

The general lack of contamination in the Magothy aquifer in the report area was attributed to three factors: (1) The natural flow pattern of most of the contaminated water in the upper glacial aquifer was nearly horizontal, consequently, most of the contaminated water flows laterally through the upper glacial aquifer to areas of discharge such as streams and bays; (2) the heads in the Magothy aquifer at the southern end of the overall report area generally were slightly higher than the water table (Perlmutter and Geraghty, 1963, pl. 7), therefore little or no downward movement of MBAS from the upper glacial aquifer could occur except possibly in the immediate vicinity of heavily pumped wells; and (3) lenses of silt and clay in the Magothy aquifer have low permeabilities, but the lenses are not extensive enough to prevent some downward movement of MBAS and associated contaminants such as nitrate and chloride.

Long-term intensive pumping of the Magothy aquifer without some counter measures such as artificial recharge could result ultimately in the development of sizable and extensive declines of artesian pressures, which might ultimately induce downward leakage of significant quantities of contaminated water from the shallow aquifer. Such downward movement on a large scale, however, was not an imminent danger in the report area at the time of this investigation.

Slow deterioration of the chemical quality of the water in the upper glacial aquifer will continue until cesspools and similar waste-disposal systems have been eliminated by the construction and use of public sewers. Even after sewer construction, a period of many years may elapse before the major contaminants are substantially flushed out of the upper glacial aquifer by natural recharge, according to a preliminary study of ground water in the sewered area of southwestern Nassau County by the senior author (investigation in progress, 1969).

SUMMARY AND CONCLUSIONS

The uppermost aquifer in the South Farmingdale-Massapequa area consists chiefly of permeable deposits of sand and gravel having saturated thicknesses ranging from 60 to 140 feet. These deposits constitute the unconfined upper glacial aquifer, a major, but largely untapped,

water-bearing unit. Beneath the upper glacial aquifer are less permeable lenticular deposits of fine sand, silt, clay, and some gravel of Late Cretaceous age, having a total thickness of about 700 feet. These deposits contain water under confined, or artesian, conditions and comprise the Magothy aquifer, the principal water-bearing unit in the area.

Precipitation and subsurface inflow are the chief sources of natural recharge. Artificial recharge consisting of seepage from industrial disposal basins and domestic cesspools was the chief source of plating-waste and detergent contaminants in the ground water and in Massapequa Creek, whose flow is sustained mainly by seepage from the upper glacial aquifer. Water for public supply is provided generally by deep wells which tap the Magothy aquifer at depth° that are presently free of contamination.

Percolation of partly treated metal-plating solutions intc the upper glacial aquifer has produced a plume of contaminated ground water, whose changes in dimensions and in hexavalent chromium and cadmium content were monitored by test drilling and sampling mainly between 1949 and 1964. The plume is elongating very slowly downgradient, in the direction of the regional ground-water flow, and has moved beneath the west bank of Massapequa Creek. In 1962, the plume was about 4,300 feet long, as much as 1,000 feet wide, and from a few feet to about 70 feet thick. Maximum concentrations of chromium determined during successive investigations ranged from about 40 mg/l in 1949 to about 10 mg/l in 1962. Cadmium concentrations ranged from 0.01 to 10 mg/l, but in most places, they were less than 1 mg/l. Maximum observed concentrations of cadmium and chromium in Massapequa Creek were 0.1 and 2.9 mg/l, respectively. Concentrations of both cadmium and hexavalent chromium in most of the plume and in part of Massapequa Creek exceed the limits of 0.01 and 0.05 mg/l, respectively, recommended in the drinking-water standards of the U.S. Public Health Service.

Theoretical dispersion formulas were inadequate to explain the wide dispersal of the heavy-metal ions. The pattern and rate of injection of the plating-waste effluent, the heterogeneity of the beds and lenses, and the resultant distortion of the flow paths of the ground water, probably account for most of the longitudinal and lateral spread of the plume of plating wastes.

Another major contaminant, MBAS, consisting chiefly of ABS (alkylbenzenesulfonate), a surfactant contained in household detergents, was found in at least trace quantities in the upper three-fourths of the upper glacial aquifer. The highest concentrations of MBAS, generally 1 to 5 mg/l, were found in about the upper 20 feet of the

aquifer. Concentrations of MBAS in Massapequa Creek ranged from about 0.5 to 2.0 mg/l. These low concentrations of MBAS reportedly are not toxic, but they may cause foaming locally.

The principal conclusions of this report are:

1. A substantial plume of water contaminated by plating wastes occupies part of the upper glacial aquifer at South Farmingdale. Although the concentrations of the contaminants have been reduced since 1949, the residual concentrations greatly exceed the U.S. Public Health Service standards for drinking water.

2. No public-supply wells in the report area were contaminated by metal-plating wastes nor is such contamination imminent. The only public-supply installations in the direct path of the plume are New York City's well field and infiltration gallery at Massapequa (part of the Ridgewood system), about 2.5 miles south of the plume. Theoretically, at the present rate of movement, it would take about 30 years for the plume to reach the gallery, but the contaminated water may never reach that point owing to dilution of the wastes as they move downgradient.

3. Plating-waste contaminants in Massapequa Creek were diluted below concentrations detectable by standard methods before they reached the vicinity of the Ridgewood system at Massapequa.

4. Most of the water in the upper glacial aquifer in the overall report area was not entirely suitable for public-supply use, owing to detergent contamination, but it may be useable if diluted with uncontaminated water from other sources.

5. No evidence was obtained of downward movement of the plating wastes into the Magothy aquifer in the report area and, except at one well, water from the Magothy apparently was not contaminated by MBAS. This does not exclude the possibility of downward movement of these contaminants in the future if hydrologic conditions are changed substantially from those determined during this investigation.

6. Contamination of the upper glacial aquifer by detergents and by other sewage constituents probably will continue in those areas where individual waste-disposal systems are used. Construction of public sewers (now in progress, 1968) and advanced treatment of industrial wastes before disposal to the ground, however, should help reduce the present widespread contamination of the shallow ground water.

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