TRIP I: DEEP-WELL INJECTION OF TREATED WASTE WATER--AN EXPERIMENT IN RE-USE OF GROUND-WATER IN WESTERN LONG ISLAND, N. Y.

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INTRODUCTION

The thick unconsolidated deposits beneath Long Island, which contain many thousands of billions of gallons of fresh water, constitute one of the most productive ground-water reservoirs in the world. The average daily withdrawal from the reservoir in 1966 was about 440 million gallons. About 70 percent of the total pumpage was for public-supply commercial, and industrial use in the three western counties of Long Island--Kings, Queens, and Nassau Counties (Figure 1).

The fresh ground water is bordered by and is hydraulically connected with salty ground water which in turn is hydraulically connected with bodies of salty surface water in estuaries, bays, Long Island Sound, and the Atlantic Ocean. The salty ground water is a near-term local threat to the continued withdrawal of fresh ground water because of its proximity to and movement toward some existing public-supply well fields. It poses a long-term regional threat also, because of its slow migration inland and replacement of fresh ground water in substantial portions of the ground-water reservoir.

The salty ground water of chief significance is a locally encroaching body in the Jameco and Magothy aquifers in southwestern Long Island (Figure 1), and is referred to in this paper as the main salt-water wedge. The Magothy aquifer is the source of most of the ground water used for public-supply purposes on Long Island and, in all likelihood, will be the principal source for many years to come.

The immediate objective of the artificial-recharge experiments now in progress at Bay Park (Figure 1) in southwestern Nassau County is to obtain information on the hydraulic and geochemical problems involved in injecting treated sewage effluent into the Magothy aquifer through a deep injection well. The results of the present experiments may be used, along with additional geologic and hydrologic data, to evaluate the feasibility of injecting water into the Magothy aquifer to create and maintain a hydraulic pressure barrier in Southern Nassau County to stabilize the main salt-water wedge or possibly retard its movement inland.

A summary of the hydrogeologic environment of western Long Island and the characteristics of the main salt-water wedge are given below as background for understanding the design and operation of the injection study and its possible relation to the problem of regional salt-water encroachment.

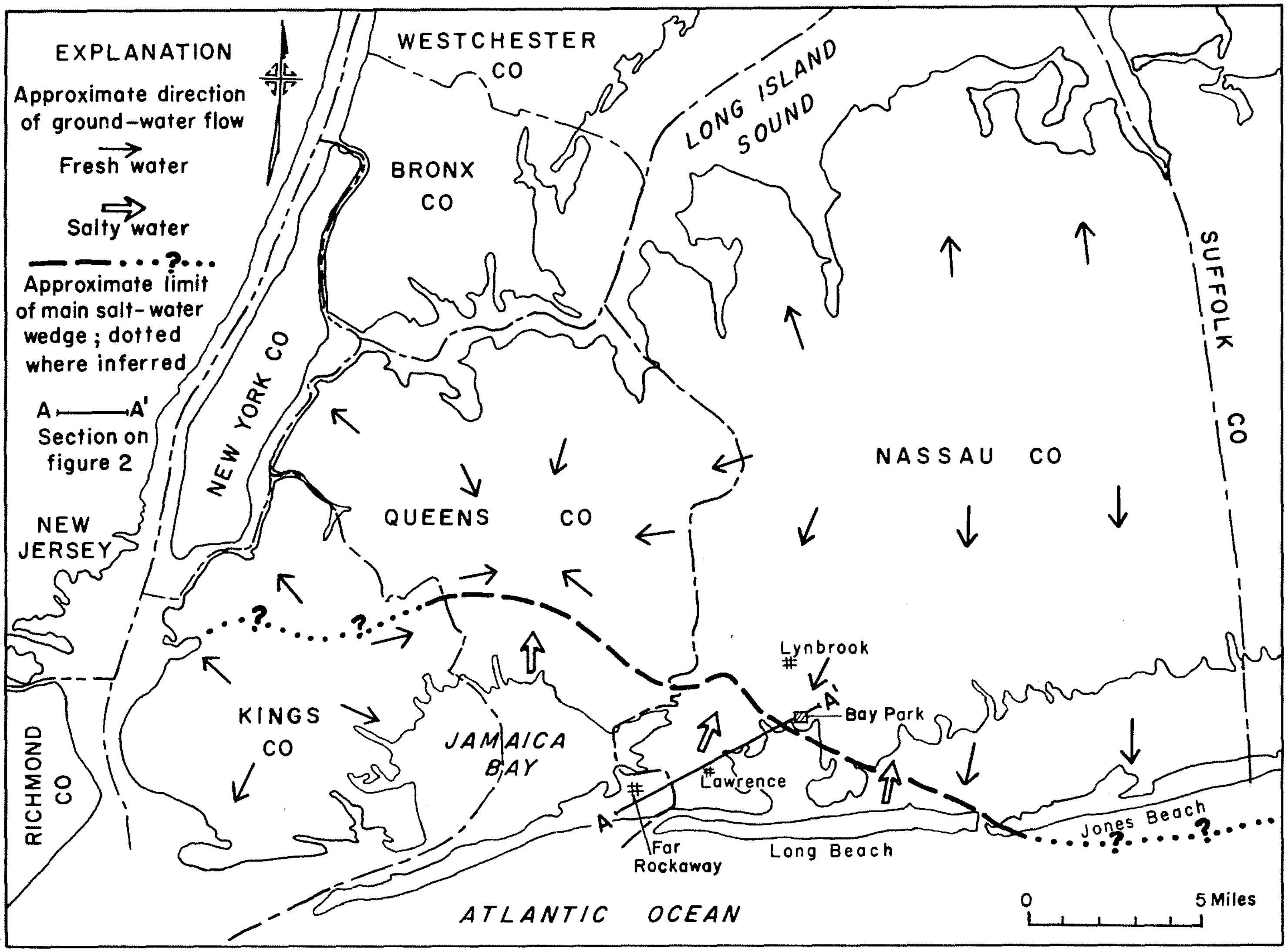

Figure 1. Approximate extent of salt-water encroachment in the Jameco and Magothy aquifers and the general direction of ground-water flow in western Long Island, N. Y.

HYDROGEOLOGIC FEATURES

The ground-water reservoir of Long Island is composed of unconsolidated deposits of gravel, sand, silt, and clay of Late Cretaceous, Pleistocene, and Recent age. These deposits, which constitute a thick wedge resting on a southeasterly sloping surface of crystalline basement rock of Precambrian(?) age, range in thickness from less than a foot in northwestern Queens County to about 1700 feet in southeastern Nassau County.

The geologic units in the area have been divided into the following major hydrologic units (see Figure 2, for sequence and lithology): (a) the upper glacial aquifer (Pleistocene and Recent), (b) the Jameco aquifer (Pleistocene), (c) the Magothy aquifer (Late Cretaceous), and (d) the Lloyd aquifer (Late Cretaceous). The Gardiners Clay (Pleistocene), a major confining unit, separates the upper two aquifers in much of Kings and Queens Counties and in southern Nassau County. The Raritan clay (Late Cretaceous), another major confining unit, generally separates the lower two aquifers. The "20-foot clay", a local discontinuous confining unit in the upper glacial aquifer, is found mostly in southern Nassau County. The upper surface of the relatively impermeable bedrock forms the bottom of the ground-water reservoir.

In some parts of western Long Island, particularly in Kings and Queens Counties, deep channels were eroded partly or completely through the confining clays and the aquifers. The channels were back-filled with more permeable material and now constitute conduits for inland and vertical movement of salty ground water.

Fresh ground water in Long Island is derived entirely from local precipitation. About half of the total precipitation is lost--mostly by evapotranspiration but partly by overland runoff. The remainder percolates down to the water table, which generally is in the upper glacial aquifer. The water table is about 90 feet above sea level in east-central Nassau County; its lowest point is about 10 feet below sea level in central Queens County as a result of intensive pumping. The highest point on the water table in Kings County is about 7 feet above sea level.

The Jameco, Magothy, and Lloyd aquifers, which are confined by overlying or interbedded silts and clays (Figure 2), contain water under artesian pressure. The first two aquifers are recharged mostly by downward leakage from the upper glacial aquifer, and the Lloyd aquifer is recharged mainly by downward leakage from the Jameco and Magothy aquifers.

The regional pattern of movement of fresh water in the upper part of the ground-water reservoir is shown by the flow arrows in Figure 1. Ground water generally moves radially outward from interior areas of recharge, and discharges naturally at or near the shorelines by seepage into streams or as submarine outflow to adjacent bodies of salty surface water. A major distortion in the natural flow pattern occurs in central Queens County, however, where heavy pumping has created large cones of depression in the water table and in the piezometric surfaces of the deeper aquifers (J. Soren, U. S. Geological Survey, written communication). These depressions cause the ground water to flow radially inland toward the centers of pumping.

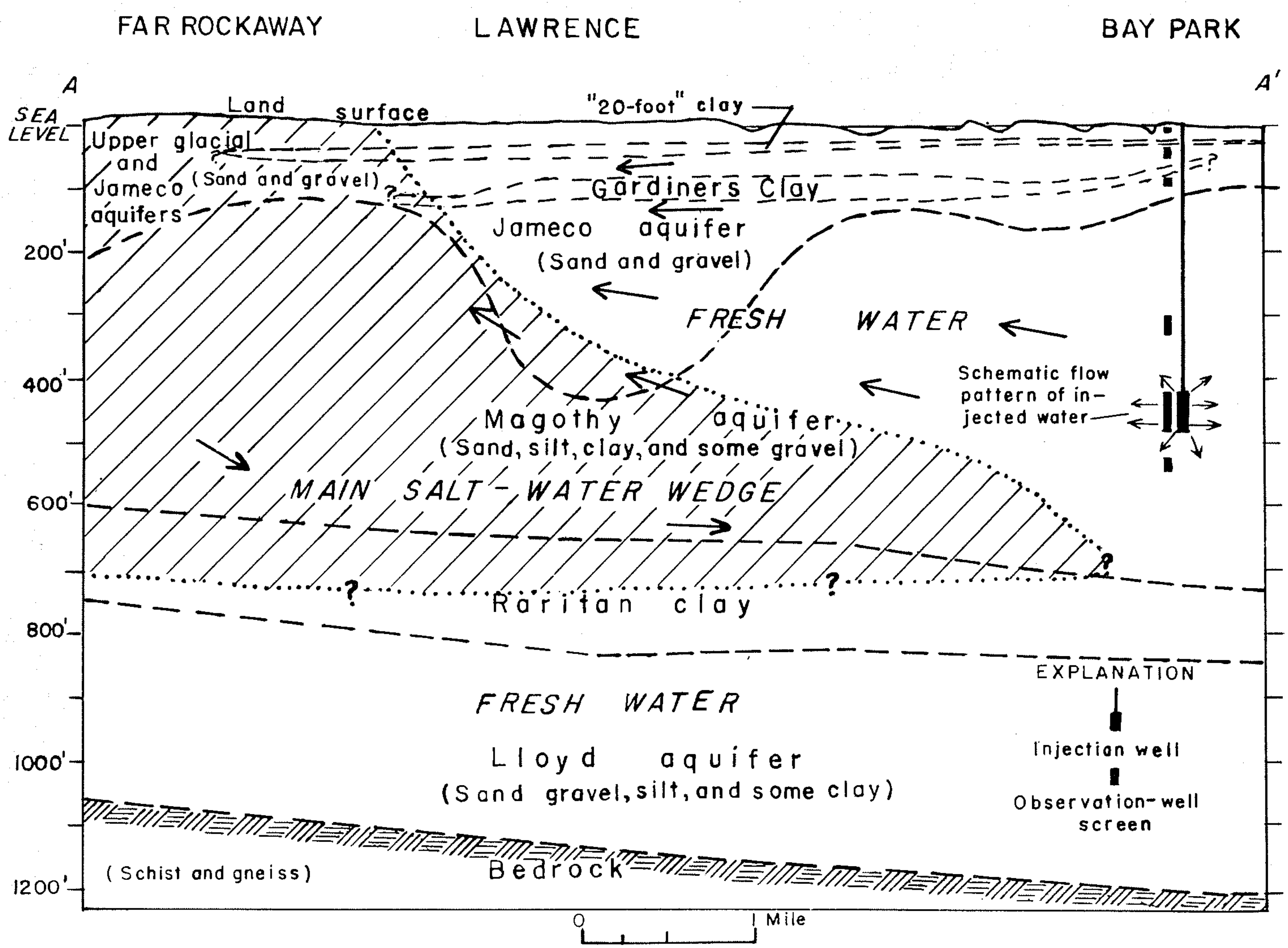

Figure 2. Hydrogeologic section showing the positions of the injection well at Bay Park and the main salt-water wedge. Arrows show component of flow in the plane of section. (Adapted in part from Lusczynski and Swarzenski, 1966, pl. 3A).

Another factor that has caused a regional lowering of the water table and artesian heads in Queens County and in southwestern Nassau County is the discharge of about 100 to 150 million gallons per day of used ground water to the sea through sewer systems (N. Y. State Water Resources Commission, 1966, written communication). This loss of natural fresh-water outflow has been a causative factor in the slow inland movement of the salty ground water described in the next section.

Water levels in wells tapping the upper glacial aquifer of eastern Nassau County, where most of the used water is returned to the ground-water reservoir by means of cesspools and seepage fields, generally have remained several feet higher than corresponding levels in the western area (Franke, 1968). It is likely, however, that the change in waste-water disposal planned for eastern Nassau County, from the use of cesspools to communal sewers, will cause some additional declines of water levels in the future, and consequently may accelerate salt-water encroachment in that area unless counter measures are taken.

DESCRIPTION OF THE MAIN SALT-WATER WEDGE

The experimental recharge site at Bay Park is near the landward limit of the main salt-water wedge whose leading edge (Figure 1) trends approximately from northwestern Kings County to Jones Beach in southeastern Nassau County. East of Jones Beach the leading edge extends offshore.

Detailed investigations of the extent and the hydraulic and chemical characteristics of the main salt-water wedge in southern Nassau and southeastern Queens County were made by the U. S. Geological Survey from 1952 to 1956 (Perlmutter and Geraghty, 1963) and from 1958 to 1961 (Lusczynski and Swarzenski, 1966). The extent of the salty ground water in Kings County and western Queens County is less well defined, and was inferred from various data obtained as a result of the long-term program of studies by the Geological Survey in cooperation with the New York State Water Resources Commission.

As shown in Figure 2, the main salt-water wedge is chiefly in the Jameco and Magothy aquifers. It thins and disappears along the top of the Raritan clay at depths as great as 600 feet below sea level. The wedge thickens seaward where it merges with other tongues and wedges of salty water that collectively occupy the entire ground-water reservoir. Chloride concentrations in the main salt-water wedge increase through a zone of diffusion from about 40 milligrams per liter (mg/l) at the fresh-water interface. The zone of diffusion which is as much as 500 feet thick and several miles wide is not shown in Figure 2.

The landward encroachment of the main salt-water wedge from its natural predevelopment position near the shoreline is believed to be due mainly to the activities of man, particularly large net withdrawals of ground water from the artesian aquifers in western Long Island, which have caused substantial declines in water levels and reduction in the amount of subsurface outflow of fresh water.

Following the cessation of heavy pumping for public supplies in Kings County in 1947 (Lusczynski, 1952), the formerly depressed water levels in that county recovered slowly from elevations as much as 35 feet below sea level to elevations above sea level in most of the area. Although active salt-water encroachment may have virtually ceased in most of Kings County, chloride data from scattered wells suggest, however, that residual salty water, containing up to several thousand milligrams per liter of chloride or more probably occupies parts of the shallow and deep aquifers in that county.

Salt-water encroachment in the Jameco and Magothy aquifers and in part of the upper glacial aquifer is occurring in southern Queens and southwestern Nassau Counties, as indicated by increases in chloride concentrations and by the decline in water levels in selected-wells. Estimates made in 1961 of the rates of movement of the main salt-water wedge (Lusczynski and Swarzenski, 1966, p. 71) are about 160 feet per year in southern Queens County, about 300 feet per year in southwestern Nassau County, and about 10 feet per year in southcentral and southeastern Nassau County. The higher figures are for small areas near the leading edge that are relatively close to centers of heavy pumping, and the lowest figure represents the rate of movement over a broad segment of the leading edge, which is influenced mainly by regional withdrawals in inland areas.

It is significant to note that the position of the main salt-water wedge in southwestern Nassau County was established largely prior to the construction of sewers in that area from 1952 to 1964. The full impact of that construction on the position and movement of the main salt-water wedge in southern Nassau County may not be evident for some time to come, but several proposals to retard landward movement are under investigation now. One of these proposals is the subsurface injection of treated waste water described in the next section.

INJECTION STUDIES AND INSTRUMENTATION AT BAY PARK

The experimental recharge facility completed early in 1967 at the Bay Park Sewage Treatment Plant in southwestern Nassau County (Figure 1), was constructed cooperatively by the Nassau County Department of Public Works, the U. S. Geological Survey, and the Federal Water Pollution Control Administration. A series of injection experiments are in progress at the site under the direction of U. S. Geological Survey personnel to collect and evaluate information on techniques and problems connected with injecting treated sewage effluent into the Magothy aquifer through a deep recharge well. This information ultimately will be used to help evaluate the feasibility, and possibly the design, of a proposed line of recharge wells along the south shore of Nassau County to return about 30 million gallons per day or more of treated waste water to the Magothy aquifer. It has been conjectured that such recharge may permit increased withdrawals of fresh ground water and retard the rate of salt-water encroachment in southern Nassau County by maintaining submarine outflow at or above its present rate.

The primary features of the recharge facility are: (a) A tertiary sewage-treatment plant designed by private consultants that is capable of renovating about 400 gpm of effluent from the secondary sewage-treatment plant at Bay Park so that it meets drinking-water standards of the U. S. Public Health Service (1962), and (b) an injection plant (Figure 3). The injection plant includes: (a) a 50,000-gallon storage tank, for temporary retention of the treated water; (b) a vacuum-degasification tower, in which dissolved gases can be removed from the water prior to injection; (c) a supplementary chemical-treatment unit, now being used to adjust the pH of the water and to reduce residual oxidizing agents; (d) pumping and control equipment for maintaining injection either at a constant rate or under a constant

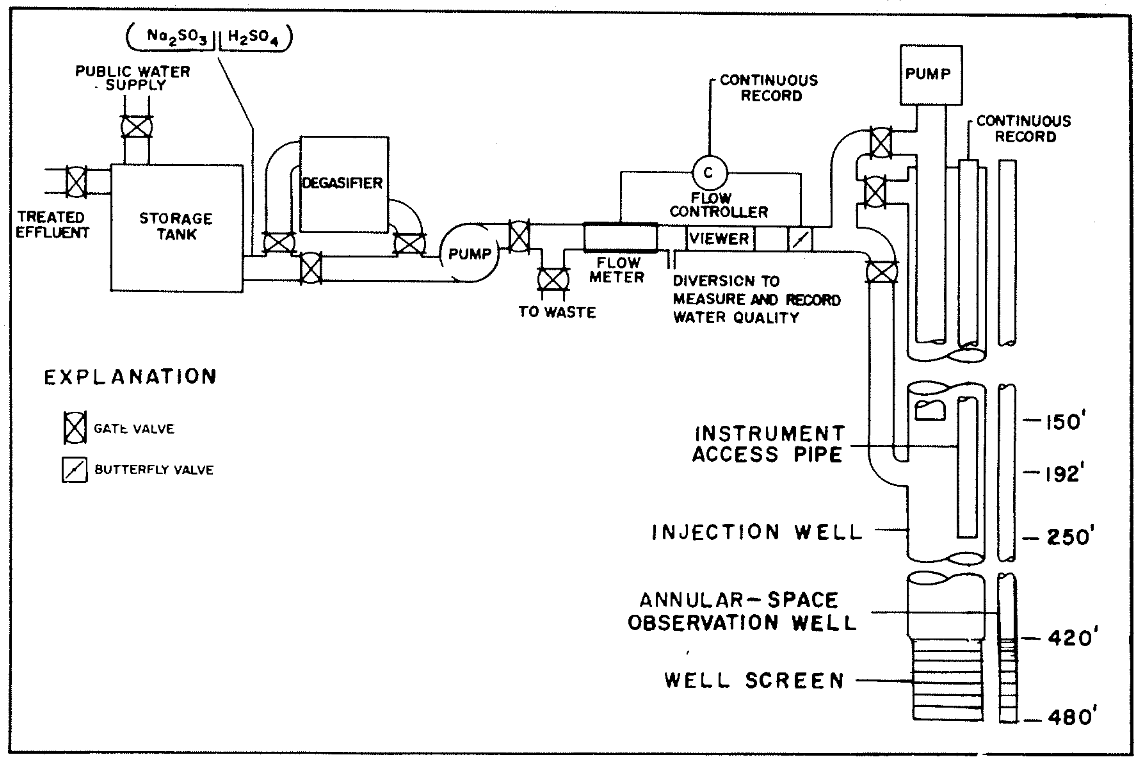

Figure 3. Schematic drawing of the injection plant at Bay Park. (Adapted from Cohen and Durfor, 1966b, fig. 4, p. 198).

pressure; (e) instrumentation for measuring and recording the injection rate, pressure and volume, and the pH, conductivity, residual chlorine content, oxidation-reduction potential, temperature, and turbidity of the injected water; (f) the main injection well; (g) an array of observation wells, at which the hydraulic and chemical effects of the recharge operation may be monitored; (h) pumping equipment for testing the main injection well and redeveloping it in the event of clogging; and (i) a small field laboratory for making partial chemical analyses of water samples.

The injection well is cased with 18-inch diameter non-corrosive fiber-glass pipe to a depth of 420 feet and a 16-inch diameter stainless-steel well screen is attached to the bottom of the casing from 420 feet to 480 feet. The well has been pumped at rates as high as 2,500 gallons per minute and has a specific capacity of about 35 gallons per minute per foot of draw-down (Cohen, and Durfor, 1966a, p. 257). Piezometer taps have been installed to permit head measurements within the injection well at land surface and at the top of the screen. The water to be injected enters the injection well under pressure and may be piped into the well either near the top, or may be routed through an injection pipe entering the main casing at a depth of 190 feet, or may be injected through the pump column and bowls of the redevelopment turbine pump (Figure 3).

An observation well has been installed in the same borehole as the injection well, and is screened in the filter pack surrounding the screen of the injection well to monitor potential clogging effects. Twelve other observation wells are installed at distances of 20 to 200 feet from the injection well at depths ranging from about 10 to 726 feet, to monitor changes in the head and quality of the water with time and distance from the injection zone. The vertical position of some of the nearby observation well screens are shown on Figure 2.

A number of injection experiments have begun starting with the injection of fresh ground water from a nearby public water-supply system at a rate of about 200-300 gallons per minute. Initially, this public-supply water was degasified and modified slightly for chemical compatibility. In later experiments, the injected water will receive progressively less treatment. Following the tests with public-supply water, a series of injection experiments will be made with the effluent from the tertiary sewage-treatment plant. Here again, the degree of treatment prior to injection will be progressively reduced in successive experiments. Throughout the experiments, the effects on the condition and performance of the injection well, and changes in the hydraulic head and in the chemical quality of the water at different depths in the Magothy aquifer will be studied. The results of these studies will be reported in appropriate technical publications at a later date.

GEOCHEMICAL ASPECTS OF THE INJECTION

The principal concern in regard to the geochemical aspects of the injection experiments are those that relate to potential clogging of the screen of the injection well and the adjacent aquifer materials. Such clogging would be indicated by a rise in pressure or head in the injection well for a constant rate of injection (equivalent to a decrease in the specific capacity of the well). Although clogging of other injection wells has been caused by several factors, including sediment accumulation and bacterial growth, the most likely potential causes of clogging in these experiments are: (1) the release of dissolved gases in the injected water, and (2) the formation of precipitates due to incompatibility of the native and injected waters (see Table 1 for comparative chemical

Table 1. --Anticipated quality of the native and injected water at Bay Park, 1965-67

	Dissolved material in milligrams per liter (mg/1)														
	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total nitrogen as N	Total phosphate (PO_4)	MBAS 1/	Residue on evaporation at 180°C	pH
Composition of native water in the Magothy aquifer within 100 ft. vertically and 200 ft. horizontally of the injection well (average of 8 samples)	7.4	0.2	0.03	1.8	0.3	3.8	0.7	8	4.8	4.	0.1	0.01	<0.02	29	5.9
Composition of public-supply water at the injection plant (average of 2 samples)	8.3	.2	.03	16	.6	3.8	.4	47	6.2	4.2	.1	.07	<.02	64	8.0
Anticipated composition of sewage effluent after tertiary treatment 2/	15	.1	.04	19	3	44	13	158	63	97	23	14	<.02	339	7.4

1/ Methylene blue-active substances which indicate the presence of detergent compounds.

2/ Preliminary data from experimental treatment unit of Nassau County Department of Public Works.

characteristics).

Dissolved Gases.

After the sewage effluent receives tertiary treatment including coagulation, filtration, carbon adsorption, and chlorination, residual gases such as carbon dioxide, chlorine, and oxygen may remain in the renovated water. Also, air may be picked up as a result of leaks in the system. The dissolved gases may be released from solution at bends in the piping, at valves, and at other places where the velocity increases abruptly during injection. The bubbles of the gases can partly block openings in the well screen or the pores in the filter pack around the screen and in the adjacent aquifer materials, and reduce their capacity to transmit water. The chief measure against the release of gases in the injection well is passage of the effluent through a vacuum degasifier (Figure 3).

Precipitated and Suspended Solids.

The second major potential cause of clogging of the injection well may be the formation of precipitates on the well screen or in the adjacent aquifer materials due to chemical reactions between the native and injected waters (Table 1).

In general, the water in the Magothy aquifer and the more mineralized renovated water (Table 1) appear to be reasonably compatible chemically. The remarkably low dissolved-solids content of the water in the Magothy aquifer is related in part to the quality of its source water, precipitation, and in part to the scarcity of soluble materials in the aquifer which consists chiefly of quartz and a small percentage of heavy minerals, muscovite, pyrite, and lignite. Feldspars and carbonates are rare to absent.

The precipitates most likely to develop during injection are compounds of iron such as hydroxides, oxides, or sulfides. Dissolved iron may be present in the formation water, in the injected water, or may be derived from the materials used in well construction. Regardless of the source of iron, changes in the pH or in the oxidation-reduction potential during the injection and mixing of the renovated and native waters may cause the iron to precipitate. The reduction in velocity as the injected water enters the aquifer from the well tends to encourage clogging by precipitates that form in and near the well, and by other suspended matter in the injected water.

Most of the wells in the Bay Park experiment were constructed with fiberglass and plastic casings and stainless-steel screens which should yield virtually no iron. Also, the aquifer and the injection waters contain only small quantities of iron in solution (Table 1). In the early experiments, however, the pH of the injected public-supply water will be reduced to that of the formation water by the addition of sulfuric acid, and any oxidizing substances which may be present such as dissolved oxygen or residual chlorine should be reduced by the addition of sodium sulfite. Thus, hopefully, iron precipitation can be prevented or subdued. In later experiments, the amount of chemical treatment will be reduced deliberately to determine the minimum chemical adjustment, required for satisfactory injection operations.

The composition of the renovated water to be injected in later experiments is not as similar to the native ground water as is the public-supply water (Table 1), but the renovated water will receive similar chemical adjustments. Another problem in regard to the composition of the renovated water could be suspended sediment. The tertiary treatment is designed, however, to sharply reduce or eliminate this sediment, as well as to bring the sanitary quality of the water (Table 1) up to drinking-water standards (U. S. Public Health Service, 1962).

CONCLUDING STATEMENT

It is hoped that the results of the present experiments at Bay Park will supplement the findings of similar recharge studies elsewhere in the United States, and will provide water managers with part of the data needed to formulate plans for deep-well injection not only in shoreline environment but in inland areas as well.

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