Influence of Recharge Basins on the Hydrology of Nassau and Suffolk Counties, Long Island, New York

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INFLUENCE OF RECHARGE BASINS ON THE HYDROLOGY OF NASSAU AND SUFFOLK COUNTIES, LONG ISLAND, NEW YORK

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ABSTRACT

An investigation of recharge basins on Long Island was made by the U S Geological Survey in cooperation with the New York State Department of Environmental Conservation, Nassau County Department of Public Works, Suffolk County Department of Environmental Control, and Suffolk County Water Authority The major objectives of the study were to (1) catalog basic physical data on the recharge basins in use on Long Island, (2) measure quality and quantity of precipitation and inflow, (3) measure infiltration rates at selected recharge basins, and (4) evaluate regional effects of recharge basins on the hydrologic system of Long Island The area of study consists of Nassau and Suffolk Counties — about 1,370 square miles — in eastern Long Island, N Y

Recharge basins, numbering more than 2,100 on Long Island in 1969, are open pits in moderately to highly permeable sand and gravel deposits These pits are used to dispose of storm runoff from residential, industrial, and commercial areas, and from highways, by infiltration of the water through the bottom and sides of the basins

The hydrology of three recharge basins on Long Island — Westbury, Syosset, and Deer Park basins — was studied The precipitation-inflow relation showed that the average percentages of precipitation flowing into each basin were roughly equivalent to the average percentages of impervious areas in the total drainage areas of the basins Average percentages of precipitation flowing into the basins as direct runoff were 12 percent at the Westbury basin, 10 percent at the Syosset basin, and 7 percent at the Deer Park basin Numerous open-bottomed storm-water catch basins at Syosset and Deer Park reduced the proportion of inflow to those basins, as compared with the Westbury basin, which has only a few open-bottomed catch basins

Inflow hydrographs for each basin typify the usual urban runoff hydrograph — steeply rising and falling limbs, sharp peaks, and short time bases Unit hydrographs for the Westbury and the Syosset basins are not expected to change, however, the unit hydrograph for the Deer Park basin is expected to broaden somewhat as a result of additional future house construction within the drainage area

Infiltration rates averaged 0 9 fph (feet per hour) for 63 storms between July 1967 and May 1970 at the Westbury recharge basin, 0 8 fph for 22 storms from July 1969 to September 1970 at the Syosset recharge basin, and 0 2 fph for 24 storms from March to September 1970 at the Deer Park recharge basin Low infiltration rates at Deer Park resulted mainly from (1) a high percentage of eroded silt, clay, and organic debris washed in from construction sites in the drainage area, which partly filled the interstices of the natural deposits, and (2) a lack of a well-developed plant-root system on the floor of the younger basin, which would have kept the soil zone more permeable

The apparent rate of movement of storm water through the unsaturated zone below each basin averaged 5 5 fph at Westbury, 3 7 fph at Syosset, and 3 1 fph at Deer Park The rates of movement for storms during the warm months (April through October) were slightly higher than average, probably because the recharging water was warmer than it was during the rest of the year, and therefore, was slightly less viscous

On the average, a 1-inch rainfall resulted in a peak rise of the water table directly below each basin of 0 5 foot, a 2-inch rainfall resulted in a peak rise of about 2 feet The mound commonly dissipated within 1 to 4 days at Westbury, 7 days to more than 15 days at Syosset, and 1 to 3 days at Deer Park, depending on the magnitude of the peak buildup

Average annual ground-water recharge was estimated to be 6 4 acre-feet at the Westbury recharge basin, 10 3 acre-feet at the Syosset recharge basin, and 29 6 acre-feet at the Deer Park recharge basin

Chemical composition of precipitation at Westbury, Syosset, and Deer Park drainage areas was similar hardness of water ranged from 6 to 56 mg/l (milligrams per liter as calcium and magnesium hardness), dissolved-solids content ranged from 21 to 124 mg/l, and pH ranged from 5 9 to 6 6 Calcium was the predominant cation, and sulfate and bicarbonate were the predominant anions Atmospheric dust and gaseous sulfur compounds associated with the Northeast urban environment mainly account for this combination of ions in precipitation

Chemical composition of the inflow to the basins was also similar in each of the three basins In general, hardness of the water samples collected at Westbury, Syosset, and Deer Park recharge basins in 1970 was less than 50 mg/l (as calcium and magnesium hardness), and dissolved-solids content was less than 100 mg/l The pH ranged from 6 1 to 7 4 The concentrations of most constituents in inflow were greater than those in precipitation, precipitation contributed 70 to 88 percent of the loads of dissolved constituents in the inflow

Only three of 11 pesticides sought by chemical analysis were detected A maximum DDT concentration of 0 08 μg/l (micrograms per liter) was determined for an inflow sample to Westbury recharge basin Concentrations of other pesticides were 0 02 μg/l or less

Total concentration of pesticides detected in the soil layers on the floors of each basin generally ranged from 0 4 to 40 mg/l The greater organic content of the soil layers, compared with that of the underlying natural deposits, suggests that pesticides as well as other organic material are effectively reduced or removed from the infiltrating water in the soil layer

Ground-water recharge from precipitation through the total area (73,000 acres) drained by 2,124 recharge basins in operation in 1969 was estimated to be 166,000 acre-feet per year, or about 148 million gallons per day Ground-water recharge in the areas where recharge basins are used is probably equivalent to or may slightly exceed recharge under natural conditions

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

In 1971, ground water was the sole source of fresh water for more than 2 5 million residents of Nassau and Suffolk Counties on Long Island, N Y (fig 1) Under natural conditions, the ground-water reservoir was recharged only by local precipitation Rapidly increasing demands for fresh water resulting from increased population and urbanization on the island and consequent increased discharge of waste water through cesspools and septic tanks threaten quantity and quality of the ground-water supply The growing problem is a matter of vital concern for local planners and water managers

Recharge basins have been used to dispose of storm runoff from urban and suburban areas on Long Island since 1935, in 1971, more than 2,100 recharge basins were in operation on Long Island The basins are generally considered a highly efficient means of disposing of storm water, and they are a major influence on the hydrologic system of the island

Because reliable information has been lacking on basin operation and on the effectiveness of basins in recharging the ground-water reservoir, a detailed study of recharge basins was made during 1965–71 to help assess

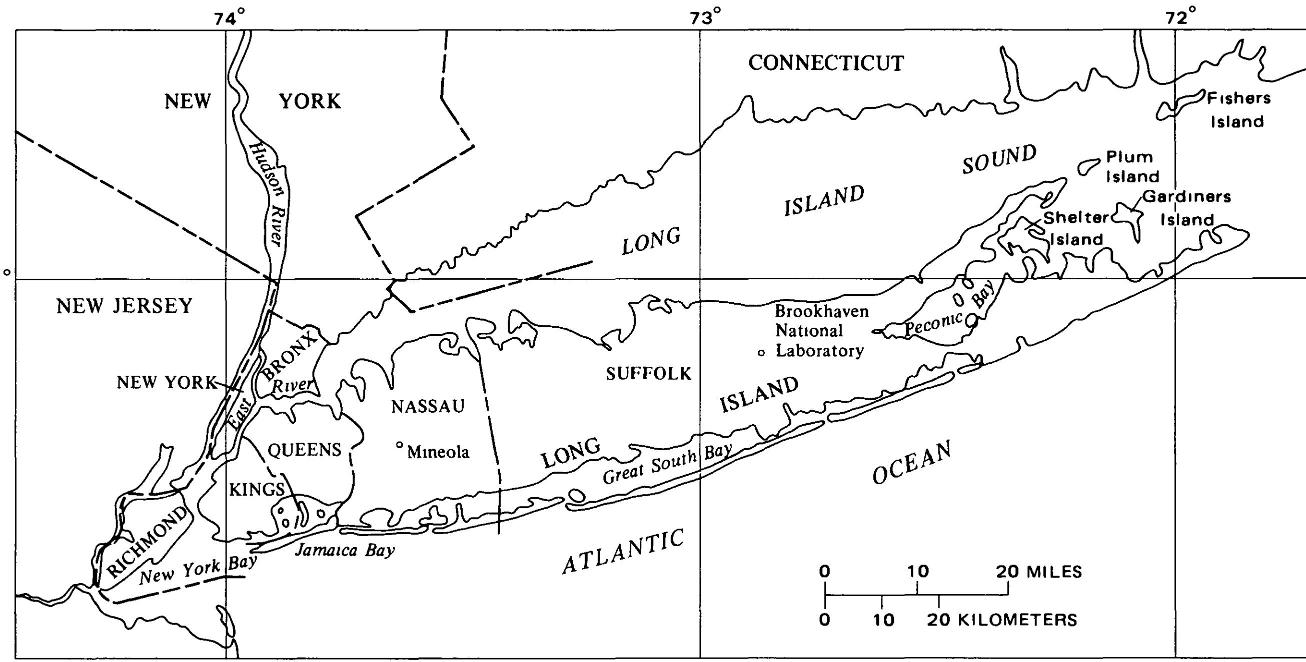

FIGURE 1 — Location and general geographic features of Long Island

the impact of recharge basins on the hydrologic system of Long Island The study was done by the U.S Geological Survey in cooperation with the New York State Department of Environmental Conservation (formerly the New York State Conservation Department, Division of Water Resources), the Nassau County Department of Public Works, the Suffolk County Department of Environmental Control, and the Suffolk County Water Authority One phase of the study mainly involved preliminary hydrologic studies at two recharge basins (Seaburn, 1970a) Those studies were expanded and incorporated into the studies described in this report This report summarizes precipitation-inflow relations, inflow-hydrograph features, infiltration rates, quality of water at three recharge basins, and present and future effects of recharge basins on the hydrology of Long Island

Two additional reports were prepared as part of this study A catalog of basic physical data on 2,124 recharge basins in operation on Long Island in 1969 (Seaburn and Aronson, 1971) lists detailed information on location and design data of each basin, including date of construction, type of drainage area, capacity, basin size, drainage area, altitudes of bottom, overflow, land surface, and water table, and geologic and soil environment The second report (Aronson and Seaburn, 1973) discusses results of a reconnaissance of the operating efficiency of recharge basins on Long Island in 1969 and describes possible causes of reduced infiltration rates at basins that hold water for 5 or more days after a runoff event, as well as the relation of these basins to selected physical parameters such as basin use, geology, and soil environment

LOCATION AND EXTENT OF STUDY AREA

Long Island, which extends from the mainland of New York State east-northeastward about 120 miles into the ocean, consists of four counties, has a total area of 1,550 square miles, and had 7 2 million residents in 1970 Recharge basins are used only in the two eastern counties — Nassau and Suffolk — which occupy 310 and 1,060 square miles, respectively (fig 1) The study was limited to this two county area

POPULATION AND INDUSTRY

Since World War II, the population of Nassau and Suffolk Counties has increased significantly (table 1) In 1971, the population was increasing more rapidly in Suffolk County than in Nassau County mainly because the open areas in the eastern part of the island were being converted to housing developments and industrial sites The population influx has been accompanied by large suburban housing developments consisting mainly of single-family units

TABLE 1 — *Population of Nassau and Suffolk Counties, 1920–70*

[From U S Bureau of the Census 1941, 1961, 1971, rounded to three significant figures]

	1920	1930	1940	1950	1960	1970
Nassau County	126,000	303 000	407,000	673,000	1,300,000	1,429 000
Suffolk County	110,000	161 000	197 000	276,000	667 000	1 127 000
Total	236,000	464,000	604,000	949,000	1,967,000	2,556 000

Industry in Nassau and Suffolk consists mainly of light manufacturing in many diversified fields It is concentrated mainly in the heavily populated areas of Nassau and western Suffolk Counties Agriculture, mostly truck farming, is concentrated mainly in the rural areas in eastern Suffolk County

CLIMATE

The generally mild and humid climate on Long Island is influenced largely by westerly winds, which cause most weather conditions to move from the continental landmass to the island Temperature extremes are moderated by the island's proximity to the ocean and Long Island Sound The average annual temperature at Mineola (fig 2) is about 11°C (Celsius), or 52°F (Fahrenheit), average monthly temperature ranges from a minimum of −1°C (30°F) in January to a maximum of 23°C (73°F) in July Average monthly temperatures and average monthly precipitation at Mineola are shown in figure 2

Average annual precipitation on Long Island from 1951 to 1965 was 43 inches, it ranged from 40 inches in the nearshore areas to 50 inches in the central part of the island (Miller and Frederick, 1969, p A13) Average monthly precipitation was fairly constant during the year and ranged from 3 inches to slightly more than 4 inches per month at Mineola Monthly precipitation is greatest during March and August and least during January, June, and October

PREVIOUS STUDIES

Several hydrologists (Leggette and Brashears, 1938, Brashears, 1941 and 1953, Johnson, 1948 and 1955, Parker and others, 1967, and Cohen and others, 1968) have studied the broad subject of artificial recharge on Long Island, with emphasis on recharge wells Only a few (Brashears, 1946, Welsch, 1949, Brice and others, 1956, Holzmacher and others, 1970) have discussed recharge basins in detail or have made estimates of recharge rates Seaburn (1970a) made preliminary hydrologic studies at two recharge basins

ACKNOWLEDGMENTS

The writers thank the many local officials of State, county, and town engineering and highway departments for providing basic physical data and design information about recharge basins on Long Island Especially helpful in providing detailed design information on the three recharge basins that were instrumented for this study were R A Hanington, Superintendent of Highways, Town of Babylon Highway Department, and F X Merklin, Chief (retired), and E W Bowker, Senior Civil Engineer, Drainage Design Section, Nassau County Department of Public Works

Aerial photographs were purchased from Lockwood, Kessler, and Bartlett, consulting engineers. B H Lowell, computer specialist, U S Geological Survey, contributed immeasurably in the compilation and analysis of the data A S Candela, J J Bachmore, A L Iorio, and J C Walsh contributed greatly to collection, compilation, and analysis of the data Their help is gratefully acknowledged

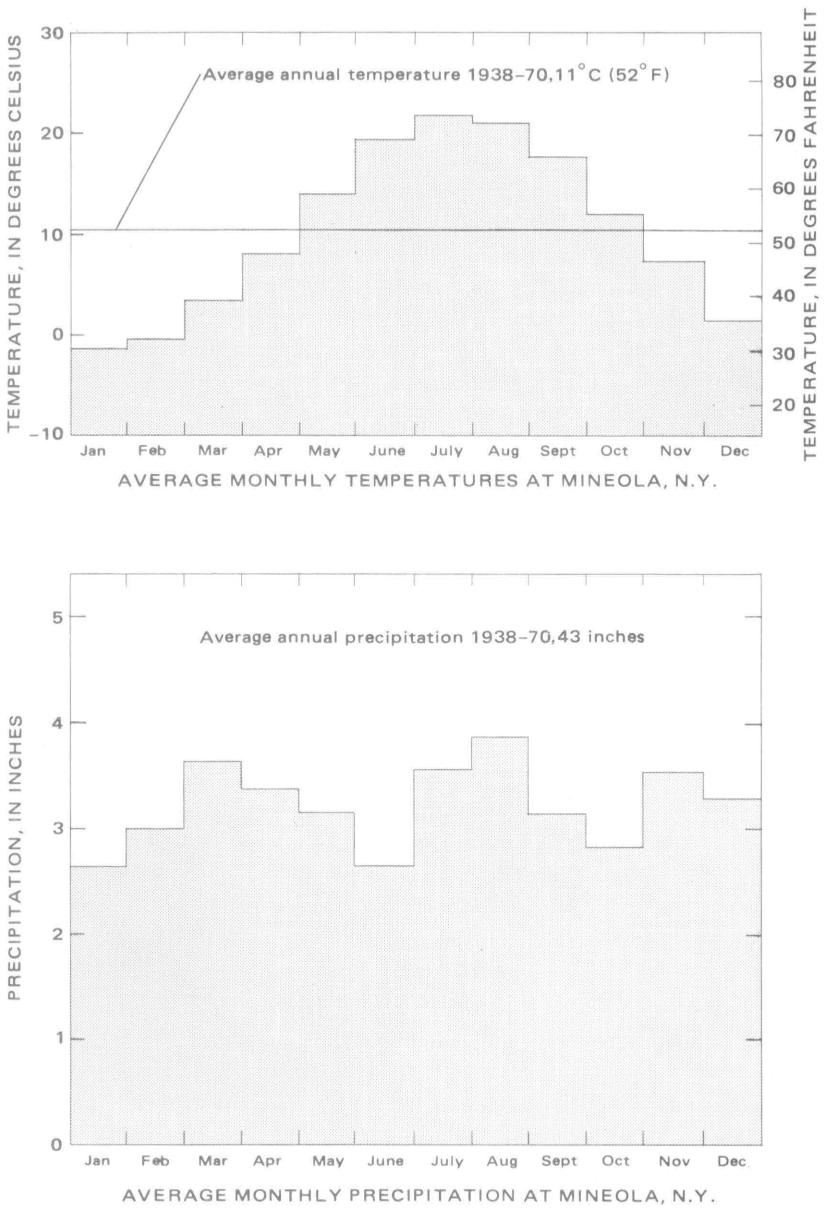

FIGURE 2. — Average monthly temperatures and precipitation at Mineola, 1938–70.

RECHARGE BASINS ON LONG ISLAND

Disposing of storm runoff in Nassau County by recharge basins was begun in 1935 by the Nassau County Sanitation Commission (Welsch, 1935) as part of a comprehensive drainage plan. The use of recharge basins not only satisfied the need to conserve storm runoff and to augment the fresh-water reservoir serving the residents of Long Island, but it also eliminated a costly alternative of building long trunk storm sewers to discharge into streams and to tidewater. The concept also was adopted throughout Suffolk County some years later. The use of basins developed slowly until after World War II, when the postwar building boom was accompanied by a large increase in the number of recharge basins throughout the island. In 1950 there were only 14 basins in Nassau and Suffolk Counties. By 1960 the number had increased to more than 700. In 1969 there were more than 2,100 basins in use in these two counties.

The location of recharge basins used for disposal of storm runoff in 1969 on Long Island is shown on plate 1. Most recharge basins are in areas where the water table is sufficiently deep to remain below the floor of the basin most of the time. The majority of future basins will be constructed in the suburban and rural areas of eastern Long Island, which were still relatively unpopulated in 1971, as the wave of urban growth advances eastward.

In general, recharge basins are open pits of various shapes and sizes excavated in moderately to highly permeable sand and gravel deposits of glacial origin. Principally, the basins dispose of storm runoff from residential, industrial, and commercial areas and from highways. About 30 basins are used for disposal of treated sewage, however, basins of that type were not included in this study. The area of each basin generally ranges from 0.1 to 30 acres and averages between 1 and 2 acres. Most extend 10 to 15 feet below land surface, but some are as deep as 40 feet. A typical recharge basin in Nassau County that drains a residential area is shown in figure 3. This basin is similar to basins draining industrial and commercial areas and highways.

Basins can be grouped into two general types. (1) those with and (2) those without overflow structures — that is, basins with or without pipes, flumes, or gutters to carry excess water from one basin to another or to a nearby stream.

Design criteria for recharge basins on Long Island have evolved for the most part on a trial-and-error basis during the last 30 years. Two major criteria are used to design a basin that has an overflow structure (or structures). First, the required capacity of the basin below the overflow altitude is estimated by multiplying the volume of water equivalent to 5 inches of rainfall (this "design storm" differs slightly among agencies) on the total drainage area of the basin by a factor ranging from 30 to 100 percent. The factor selected is based on conditions in the drainage area, such as land slope and percentage of area occupied by streets and parking lots. A runoff factor of 30 percent is used in most residential areas, and the factor used in industrial areas is as much as 100 percent to allow for the usually higher proportion of impervious surfaces. Second, the altitude of the overflow-structure outlet is not more than 10 feet above the floor of the basin. Infiltration into the floor and the sides of the basin is not considered as a fac-

FIGURE 3. — Typical recharge basin.

tor in calculating the design capacity, even though infiltration occurs during inflow and thereby provides an additional factor of safety.

Only a few basins are built without overflow structures; these are termed "dead-end basins." Because the operation of these dead-end basins varies widely, depending on local conditions, firm regulations on their size have not been established.

Many recharge basins on Long Island hold water for several days to several weeks after rainfall; some hold water perenially. A preliminary study of these basins (Aronson and Seaburn, 1973) revealed two major causes of water containment: (1) the basin intersects the regional water table or a perched water table overlying glacial deposits of low hydraulic conductivity, and (2) sediments and debris of low hydraulic conductivity, deposited on the basin floor by storm runoff, impede infiltration. In this study, basins were arbitrarily defined as water-containing if they held water for 5 days or longer after a 1-inch rainfall over the contributing drainage area. Study of aerial photographs and field inspections revealed that about 200 basins — less than 10 percent of all basins in operation in 1969 — were characterized as water-containing basins.

Several procedures are used to construct recharge basins and maintain their operating efficiency throughout Long Island; these procedures are: (1) Excavation of settling areas in the basin floor, (2) construction of retention basins, (3) installation of diffusion wells below basins, and (4) scarification of the basın floor The floors of many basıns are buılt on two or more levels The lower level acts as a settlıng area to collect ınflowıng sedıment and trash, and the hıgher level facılıtates ınfiltratıon of the overflowıng water because ıt remaıns relatıvely free of sedıments Retentıon basıns are sımılar to basıns wıth settlıng areas except that they are connected by pıpes or channels to adjacent or nearby basıns to whıch the clean overflow water ıs transported Basıns that operate poorly because of the low hydraulıc conductıvıty of underlyıng materıals are commonly equıpped wıth dıffusıon wells These wells are constructed of porous concrete rıngs that are 8 to 10 feet ın dıameter The rıngs, whıch are ınstalled below the floor of the recharge basın and are covered wıth a sand and gravel fılterpack, penetrate the ımpermeable strata and provıde access for water to deeper, more permeable strata Basın floors are also scarıfıed to expose the underlyıng, more permeable, natural deposıts

TEST BASINS

Three recharge basıns were chosen for detaıled study to provıde ınformatıon on the quantıty and the qualıty of water dıscharged ınto the basıns These basıns are ın the vıllages of Westbury, Syosset, and Deer Park (fig 4) For convenıence, each basın ıs referred to ın thıs paper by the name of the vıllage ın whıch ıt ıs located These three recharge basıns were chosen maınly because theır ınflow may be easıly and accurately measured Other factors were that each had a sıngle ınflow pıpe and a relatıvely sımple, well-defined draınage system

WESTBURY RECHARGE BASIN

The draınage area of the Westbury recharge basın ıs a fully suburban resıdentıal area of 15 acres ın central Nassau County (fig 4) ın whıch house constructıon and land development ıs complete Boundarıes of the Westbury recharge basın and draınage area are shown ın fıgure 5 The draınage area ıs rectangular and slopes about 13 feet per mıle to the south Addıtıonal ınformatıon about the Westbury draınage area ıs lısted ın tables 2 and 3

TABLE 2 — *Summary of data on the contrıbutıng draınage areas of Westbury, Syosset, and Deer Park recharge basıns*

	Westbury	Syosset	Deer Park
Date of constructıon	1954	1957	1967
Draınage area acres	15 0	28 8	118
Number of houses ın draınage area ın 1969[1]	52	90	257
Densıty of houses houses per acre	3 5	3 1	2 2
Impervıous area[2]			
Total acres	4 8	10 2	25 5
Percentage of draınage area	32	35	22
Area of streets			
Total acres	1 7	3 9	12 9
Percentage of draınage area	11	13	11
Dıstance from furthest point ın draınage area feet	1 200	2,700	3 400
Slope of draınage area feet per mıle	13	20	23

[1]The draınage areas of Westbury and Syosset basıns are fully developed suburban areas The Deer Park area ıs only a partly developed suburban area (1971)
[2]Impervıous area ıncludes streets, sıdewalks, drıveways, and roofs

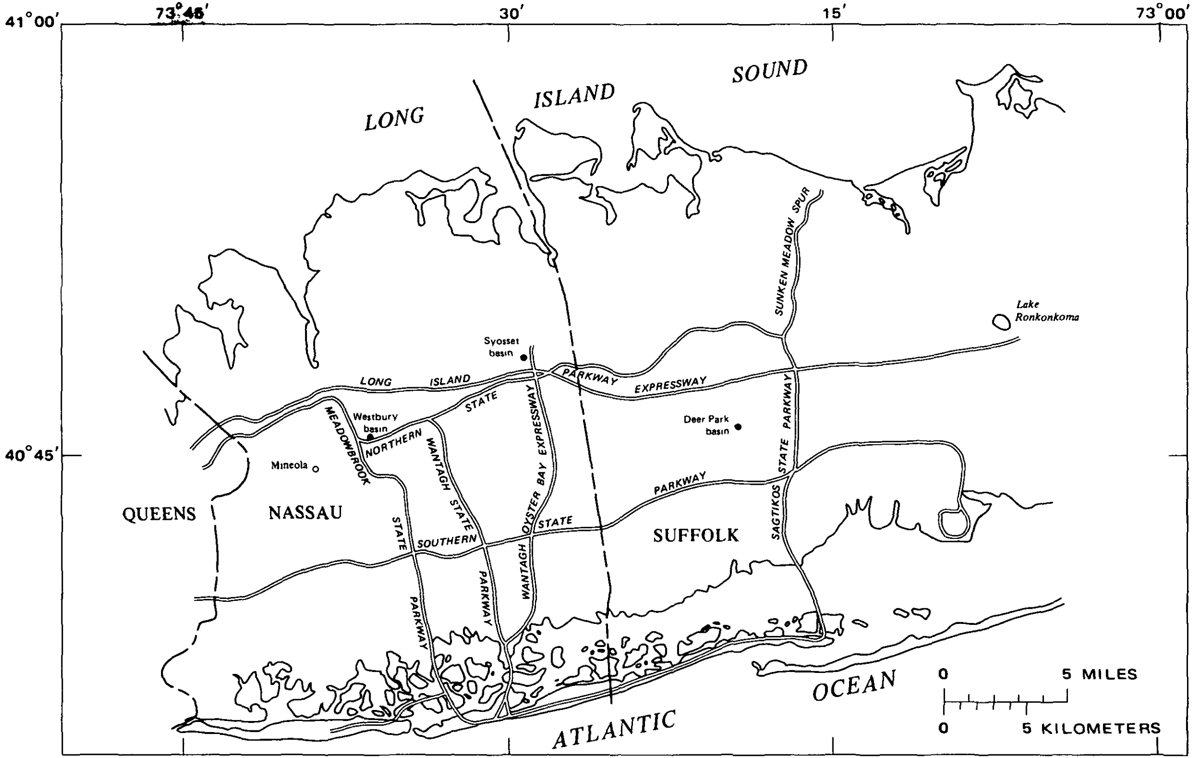

FIGURE 4 — Location of Westbury, Syosset, and Deer Park recharge basins

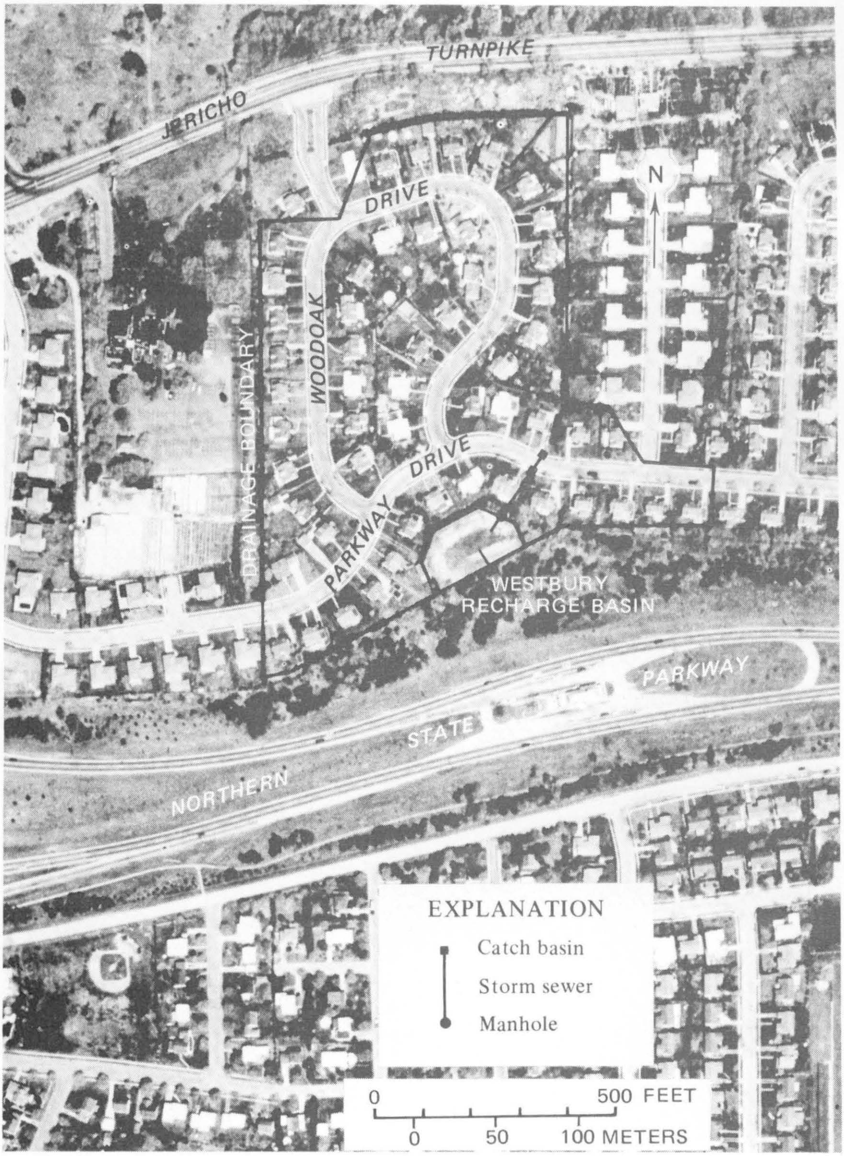

FIGURE 5. — Westbury recharge basin and its drainage area. (Photograph used through courtesy of Lockwood, Kessler, and Bartlett, Consulting Engineers.)

The Westbury recharge basin is a 0.5-acre rectangular area that has two levels. The lower level is 12 feet below land surface, covers about 3,000 square feet, and is generally at or below the altitude of the invert of the inflow pipe. The upper level, an additional 1,500 square feet, is about 2 feet above the lower level and is covered with water only during large storms.

TABLE 3. — *Summary of physical data on Westbury, Syosset, and Deer Park recharge basins*

Basin	Area of basin (acres)	Land-surface altitude (feet)	Depth below land surface (feet)	Capacity (million gallons)	Maximum infiltrating area[1] (sq ft)	Diameter of inflow pipe (inches)
Westbury	0.5	110	12	0.7	10,000	24
Syosset	1.0	205	14	2.1	25,000	30
Deer Park	1.4	85	12	2.8	48,000	36

[1]Maximum infiltrating area is the horizontal area at the overflow altitude.

The Westbury recharge basin and the location of hydrologic instruments are shown in figure 6. Additional information about the Westbury recharge basin is listed in tables 2 and 3.

Materials in the unsaturated zone beneath the Westbury basin are deposits of brown medium to very coarse sand and gravel and many thin lenses of silt and fine sand. The water table was about 35 feet below the floor of the lower level in September 1970.

FIGURE 6. — Location of hydrologic instruments used to collect data on precipitation, inflow, water storage, and water-table fluctuations at Westbury recharge basin. *a*, Inflow recorder, in manhole upstream from apron. *b*, Water-table observation well and recorder. *c*, Precipitation gage and recorder. *d*, Stage recorder, and observation well and recorder.

SYOSSET RECHARGE BASIN

The drainage area of the Syosset recharge basin is in Nassau County, about 7 miles northeast of the Westbury drainage area (fig. 4); it drains a fully developed suburban residential area. House construction in the 28.8-acre drainage area was completed in 1957. The Syosset recharge basin and its drainage-area boundaries are depicted in figure 7. The drainage area is

FIGURE 7. — Syosset recharge basin and its drainage area. (Photograph used through the courtesy of Lockwood, Kessler, and Bartlett, Consulting Engineers.)

rectangular and slopes about 20 feet per mile to the south. Additional information about the drainage area is listed in tables 2 and 3.

The Syosset recharge basin includes about 1 acre, is triangular, and extends about 14 feet below land surface. The floor of this basin is on two levels; the lower level has an area of about 10,000 square feet and is about 3 feet below the upper level, which has an area of about 4,000 square feet. The Syosset recharge basin and the location of hydrologic instruments are depicted in figure 8. Additional information about the recharge basin is listed in tables 2 and 3.

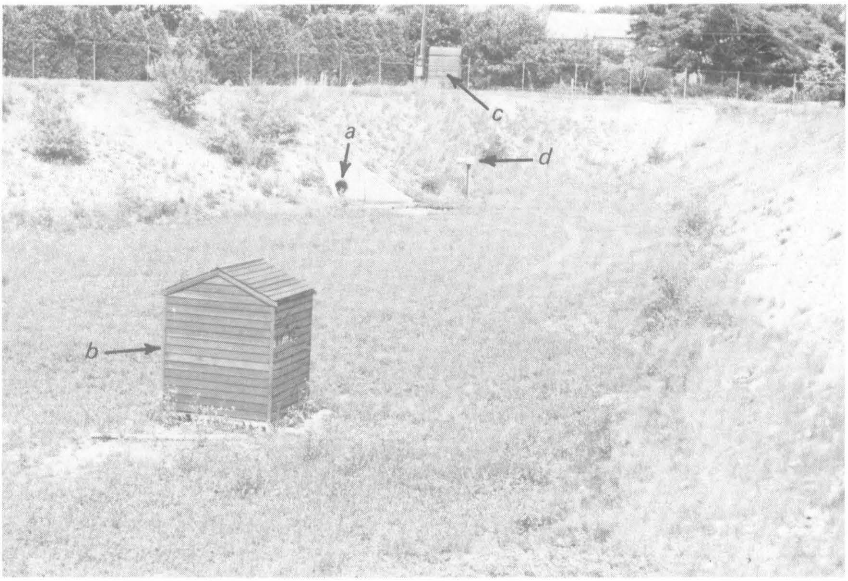

FIGURE 8. — Location of hydrologic instruments used to collect data on precipitation, inflow, water storage, and water-table fluctuations at Syosset recharge basin. *a*, Inflow recorder, in manhole upstream from apron. *b*, Stage recorder. *c*, Precipitation gage and recorder. *d*, Water-table observation well and recorder.

The materials in the unsaturated zone beneath the Syosset basin are similar to those beneath the Westbury basin; they consist of medium to very coarse sand and gravel and many thin lenses of silt and fine sand. These deposits are about 85 feet thick, and they overlie clay deposits that are about 80 feet thick. The water table was about 72 feet below the basin floor in September 1970.

DEER PARK RECHARGE BASIN

The drainage area of the Deer Park recharge basin in Suffolk County is about 6 miles east of the boundary between Nassau and Suffolk Counties and about 9 miles southeast of the Syosset recharge basin. (See figure 4.) The Deer Park recharge basin and its drainage system are shown in figure 9.

FIGURE 9. — Deer Park recharge basin and its drainage area. (Photograph used through courtesy of Lockwood, Kessler, and Bartlett, Consulting Engineers.)

Before July 13, 1970, the Deer Park drainage area totaled 96 acres. This area is shown in figure 9. In July 1970, an additional 22 acres was equipped with storm sewers that drain to the Deer Park recharge basin. The additional area is also shown in figure 9. The present 118-acre drainage area is generally triangular and slopes 23 feet per mile to the south. Additional information on the drainage area is listed in tables 2 and 3. Suburban land development in this area was still incomplete in 1971; several houses were built on scattered lots during the study.

The Deer Park recharge basin (fig. 10) covers 1.4 acres and is rectangular; its floor is 12 feet below land surface. Additional information on the Deer Park recharge basin is listed in tables 2 and 3.

The materials in the unsaturated zone beneath the Deer Park recharge basin are deposits of fine to medium sand and lenses of both silt and pebbles. The water table was about 18 feet below the floor of the basin in September 1970.

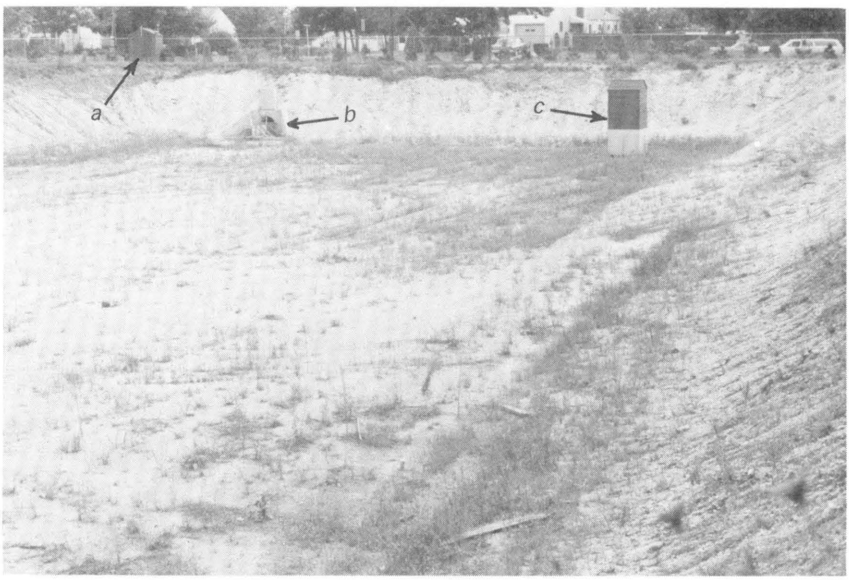

FIGURE 10. — Location of hydrologic instruments used to collect data on precipitation, inflow, water storage, and water-table fluctuations at Deer Park recharge basin. *a*, Precipitation gage and recorder. *b*, Inflow recorder, in manhole upstream from apron. *c*, Stage recorder, and observation well and recorder.

DRAINAGE SYSTEMS

Precipitation on the drainage areas of recharge basins is disposed of by evapotranspiration, infiltration through lawns, or overland runoff. Only the last item was investigated in this study. Runoff water collects in gutters and flows to nearby catch basins. Catch basins are commonly open-bottomed to permit some water to infiltrate from the bottom Most catch basins are about 3 by 3 by 5 feet and are connected with storm sewers that carry the water to the recharge basin for disposal The few catch basins which are not connected with storm sewers act as small recharge pits

The drainage systems leading to the Westbury, Syosset, and Deer Park recharge basins are depicted in figures 5, 7, and 9, respectively In the Westbury drainage area, water flows by street gutters into two catch basins that are sealed at the bottom, hence, all the water from these catch basins flows directly into the recharge basin

In the Syosset drainage area, water flows by street gutters into nine connected catch basins. None of these catch basins are sealed, therefore, some storm runoff is recharged directly from the catch basins, and the remainder overflows through storm sewers to the recharge basin

In the Deer Park drainage area there are 49 catch basins, 34 of which are connected by storm sewers to the recharge basin All these catch basins are open-bottomed They differ in size and, therefore, in quantity of water recharged For example, the larger catch basins are dry wells constructed of 8-foot diameter perforated concrete rings that permit the infiltration of water through the sides as well as through the bottoms. Other catch basins, generally not larger than 3 by 3 by 5 feet, have only open bottoms and clog easily

THE SOIL ZONE

All natural soils are stripped away during construction of recharge basins, and vegetal cover on the basin floors and sides is sparse for several years after construction A soil layer develops with time because of the gradual accumulation of fine-grained sediment and plant material eroded from the drainage area and because of the soil-forming processes within the basin

Analyses of particle-size distribution and of content of organic matter in samples from the bottoms of each recharge basin are shown in table 4 Two samples were collected at each basin Sample A represents material in the soil layers, which were 3–4 inches thick at the Westbury and Syosset basins and 1–2 inches thick at the Deer Park basin, sample B represents the deposits 3–4 inches below the bottoms of the soil layers

The data in table 4 show that the soil layer from each of the three basins contains significantly higher percentages of silt- and clay-size particles than the underlying deposits This suggests that substantial amounts of suspended material flushed into the basins by storm water are filtered out in the soil layer

The content of organic matter in each sample was determined by two procedures The results, expressed as a percentage of sample weight, are shown in table 4 Readily oxidizable organic matter in the soil was determined by a wet-combustion procedure modified by Walkley-Black (Jackson, 1958, p 219–221) It represents natural organic matter such as grass cuttings, leaves, and twigs washed in from the drainage area and

TABLE 4 — *Summary of particle-size distribution and content of organic matter in samples collected from the floors of Westbury, Syosset, and Deer Park recharge basins in July 1970*

[Analyses by U S Geological Survey, Harrisburg, Pa]

Basin and sample	Particle size (percentage by weight)				Organic matter (percentage by weight)	
	>2 mm	Sand 2–0 062 mm	Silt 0 062–0 004 mm	Clay <0 004 mm	Readily oxidizable	Total
Westbury						
A	4 3	37 9	42 5	15 3	20 0	23 1
B	57 0	39 4	1 9	1 7	7	1 6
Syosset						
A	10 2	55 3	25 5	9 0	11 3	13 3
B	46 5	46 4	4 0	3 2	1 3	3 5
Deer Park						
A	1 1	22 3	57 7	18 8	10 3	14 1
B	25 7	64 3	5 5	3 7	8	2 1

[1] Sample A represents the soil layer from the floor of the basin Sample B represents deposits 3–4 in below the soil layer

debris from plant growth in the basin. Total content of organic matter was determined as loss of weight as a result of dry combustion at 900°C for 2 hours. Total content of organic matter includes natural plant debris as well as manmade organic matter such as oil, grease, rubber, and asphaltic materials Therefore, the difference between the two percentages is an estimate of the amount of manmade organic matter in the sample

Natural soils on Long Island contain 1 to 5 percent organic matter, by weight (Warner, 1969, table 2) Total content of organic matter in the soils from the floors of Westbury, Syosset, and Deer Park recharge basins were 23 1, 13 3, and 14 1 percent, respectively (table 4) These high percentages of organic material largely represent organic material carried into the basin in the storm runoff A small part of the content of organic matter also represents accumulation of plant debris associated with vegetation growing in the basin.

Total content of organic matter in the three natural deposits ranges from 1 6 to 3 5 percent, which is much less than the content in the overlying soil layers Most of the total content of organic matter in the natural deposits is manmade organic matter that has leached down from the overlying soil layers The low total content of organic matter in the natural deposits compared with that of the soil layers further suggests that most of the organic material entering the basin in the storm runoff is filtered out in the uppermost few inches of the soil zone

The soil zone in the Westbury basin contains the greatest percentage of organic matter, presumably because it has been in operation longer than the other two basins The content of organic matter in the soil zone in the Deer Park basin is as much as that in the Syosset basin, despite the fact that the Deer Park basin has been in operation for a much shorter time than the Syosset basin Reasons for the approximate equality of organic matter in the soil zones of these two basins are unclear

INSTRUMENTATION AND DATA COLLECTION

Westbury, Syosset, and Deer Park recharge basins were instrumented to collect detailed data on precipitation, inflow to the basins, and fluctuations in the amounts of water stored in the basins Supplementary data on precipitation at nearby sites, specific conductance of the inflowing water, air temperature, and water-table fluctuations below each basin also were collected Selected samples of precipitation and inflow were obtained for chemical analyses, and samples of the deposits on and beneath the floors of the basins were collected and analyzed for particle-size distribution and chemical content

Instrumentation of the three basins is similar, therefore, subsequent comments apply equally to all three basins, unless stated otherwise Figure 11 is a generalized sketch of the instrumentation at the basins, and figures 6, 8, and 10 show the instruments at the Westbury, Syosset, and Deer Park basins, respectively, in more detail

Precipitation is measured continuously by a gage similar to that in figure 12, about 8 feet above land surface and within the fenced area of each recharge basin The gage consists of a 6 93-inch-diameter galvanized-sheet-metal funnel that catches the rain and delivers the water through a ½-inch-diameter tube to a 2-inch inside-diameter stilling well, which is about 4 feet long A float-operated digital recorder, above the stilling well, records water-level changes in the 2-inch pipe The ratio of the diameter of the funnel to that of the stilling well is such that the recorder measures directly in inches of rainfall The gage has a catch capacity of about 3 5 inches of precipitation

Inflow is recorded at a digital water-level recorder in the first manhole upstream from the basin (fig 13) The water level is recorded in a stilling well attached to the side of the manhole The water level in the stilling well is the same as that of the water ponded behind an artificial control in the inflow pipe to the manhole At the Deer Park recharge basin, the water level in the manhole itself is recorded (fig 14) Flow into each basin was calibrated to establish a stage-inflow relation, details on the rating of inflow at Westbury and Syosset basins were described by Seaburn (1970a) and at the Deer Park basin by Seaburn (1971)

The level of stored water in the basins also is recorded by digital recorder These float-operated recorders were installed several feet above the lowest altitudes on the floors of the basins Porous concrete stilling wells, sealed below ground level, were used to stabilize the recorder floats Water passed freely through the pipes, with no apparent lag in recorder response to water-level changes. The relations between stage (height of water above lowest altitude on the floor of the basin), water-surface area, and volume of storage above the floors of each basin, were determined by standard surveying methods.

Measurements of precipitation accumulations, stage fluctuations of the inflowing water, and water-level fluctuations of the stored water above the floor of each recharge basin were recorded (punched) simultaneously by digital recorders on 16-channel paper tape at 5-minute intervals The data

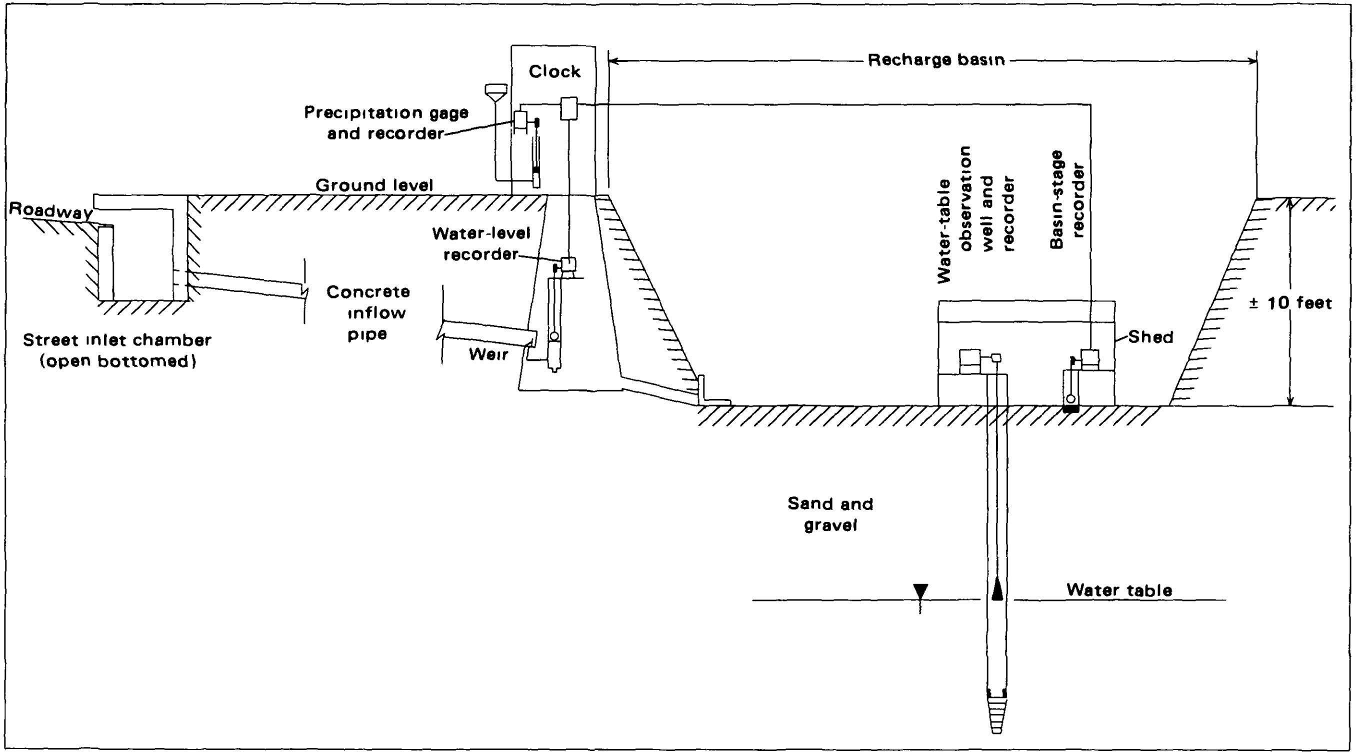

FIGURE 11 — Generalized sketch showing drainage system and location of measuring instruments at Westbury, Syosset, and Deer Park recharge basins

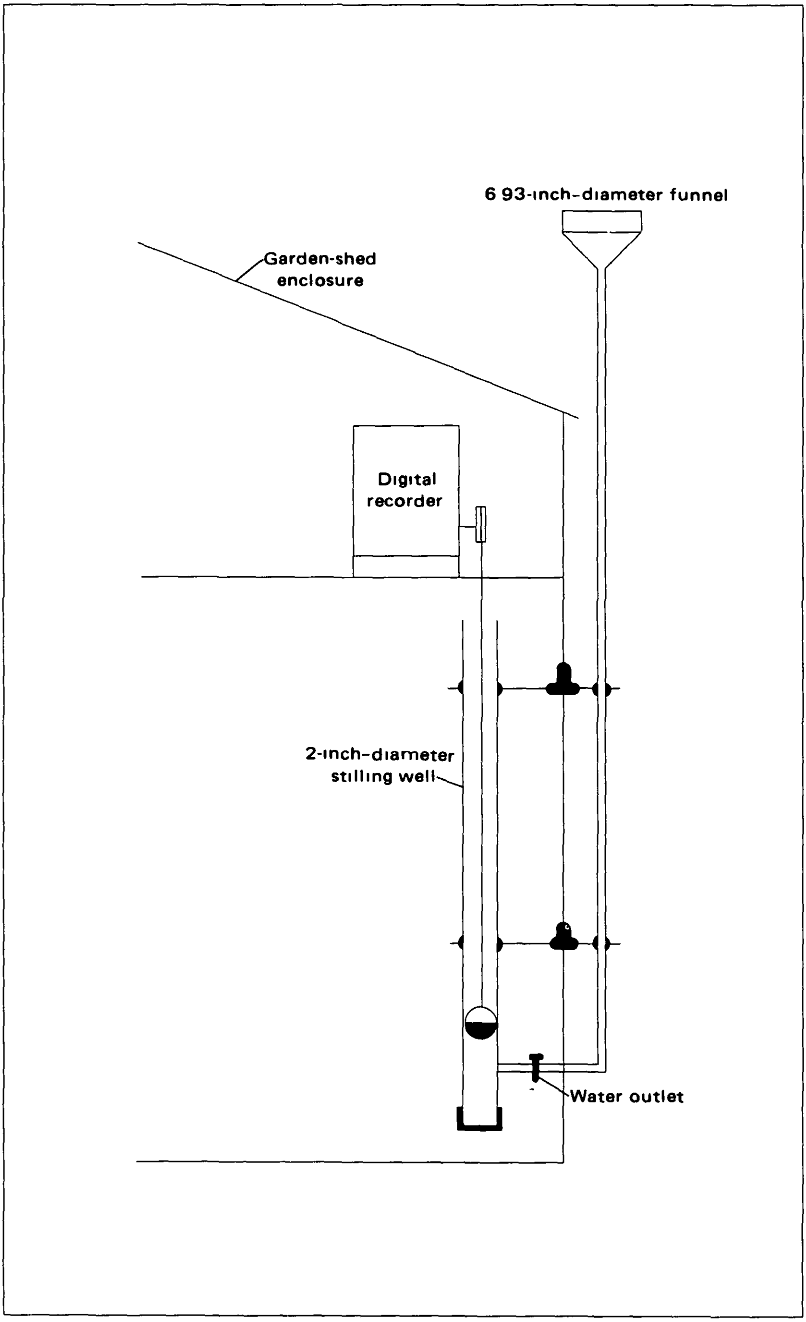

FIGURE 12 — Sketch of precipitation gage and recorder installation at Westbury, Syosset, and Deer Park recharge basins

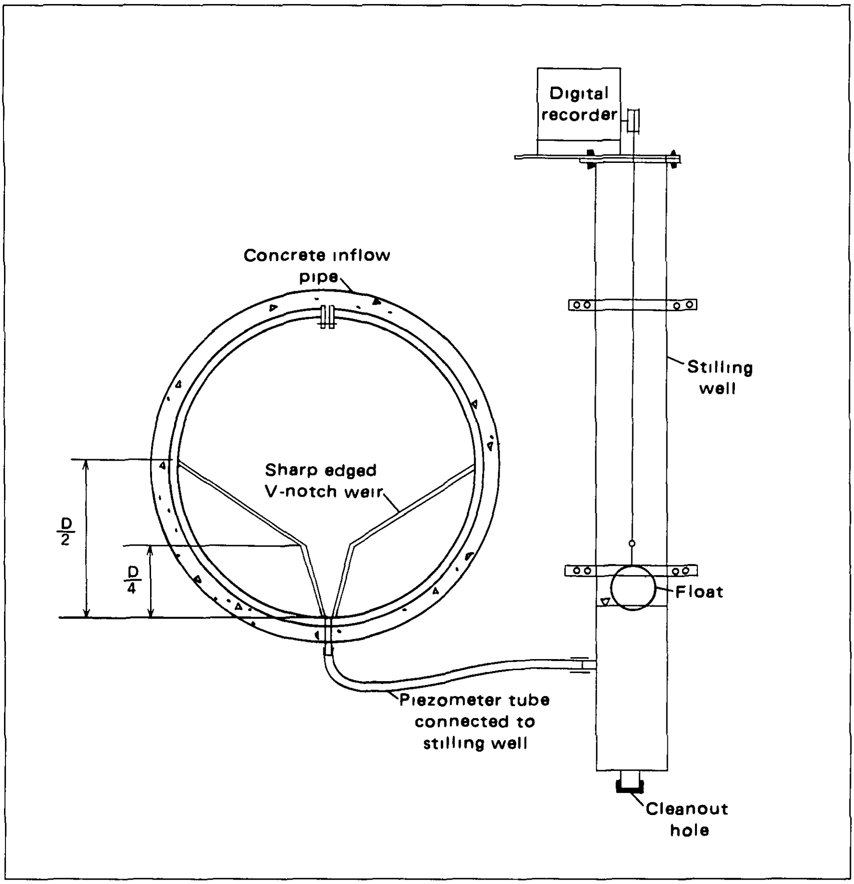

FIGURE 13 — Sketch of inflow-measuring apparatus in manhole nearest Westbury and Syosset recharge basins

recorded on the paper tapes, along with the corresponding rating curves for inflow, volume of storage, and water-surface area, were transformed by digital computer into tables and graphs Graphs of typical data collected during a storm on July 20, 1969, at Syosset are shown in figure 15 Additional computations included magnitude and distribution of precipitation, distribution of inflow, total inflow, incremental infiltration rates, and certain other summary data, such as percentage of precipitation entering the basin and average infiltration rate

RESULTS

Results of the computations on the recorded data are discussed under three categories — precipitation-inflow relation, inflow-hydrograph analysis of inflow distribution, and rates of infiltration. Results of chemical

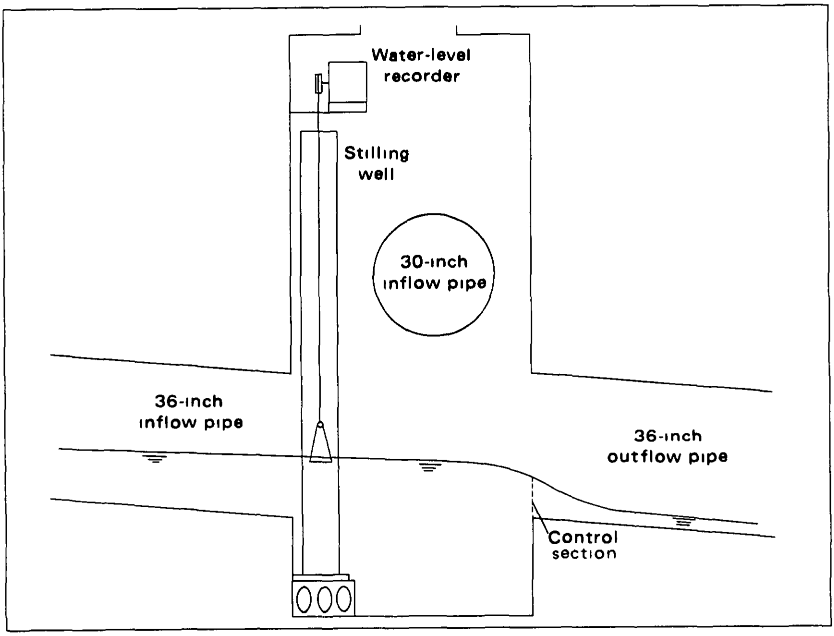

FIGURE 14 — Cross section of water level and water-level recorder through manhole and pipes at Deer Park recharge basin

analyses of selected samples of precipitation, inflow, and sediment from the basin floors are reported in the section "Chemical Quality of Water"

PRECIPITATION-INFLOW RELATION

The precipitation-inflow relation provides estimates of the total volume of water that enters each basin during a given storm The total volume of storm inflow is affected by two major groups of factors — those related to precipitation and those related to characteristics of the drainage area Major factors relating to precipitation include intensity, duration, and areal distribution of precipitation; direction of the storm travel; antecedent soil moisture, and the season of the year Major factors relating to characteristics of the drainage area include land use, soil type and ground cover, size, shape, and slope of the drainage area, and type and extent of sewering

The combined effect of these factors on the amount of inflow to a basin is complicated, is commonly nonlinear, and can best be assessed by relating precipitation and inflow directly. Data on precipitation and inflow were collected for 75 storms (from July 1966 to May 1970) at the Westbury recharge basin, for 73 storms (from July 1966 to September 1970) at the Syosset recharge basin, and for 24 storms (from March to September 1970) at the Deer Park recharge basin Recorded amounts of precipitation for in-

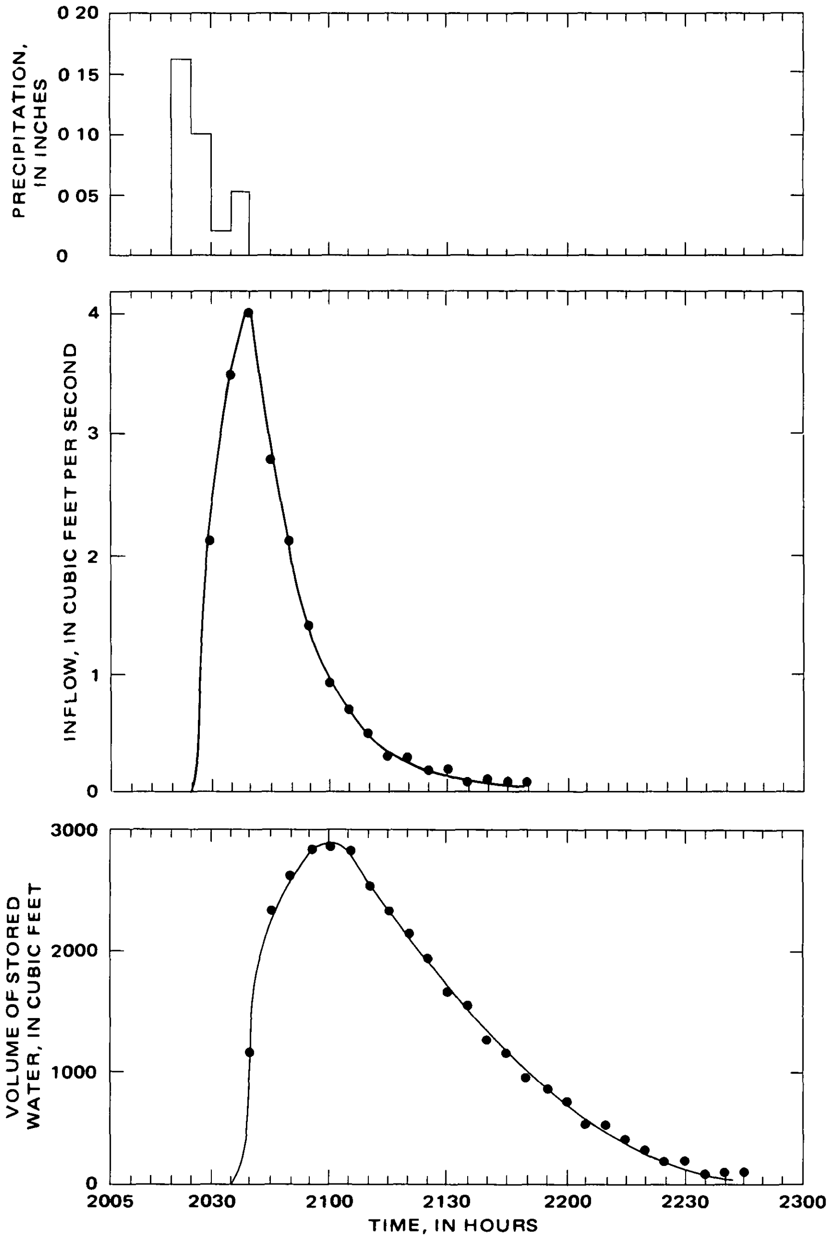

FIGURE 15 Precipitation, inflow, and water storage during the storm of July 20, 1969, between 2005 and 2300 hours (8 05 p m and 11 00 p m), at Syosset recharge basin

dividual storms generally ranged from 0 1 to 5 inches (at Syosset), and total inflow ranged from 0 002 to 0 76 inch (in inches of precipitation over the drainage area) Total precipitation and total inflow, for storms at the West-

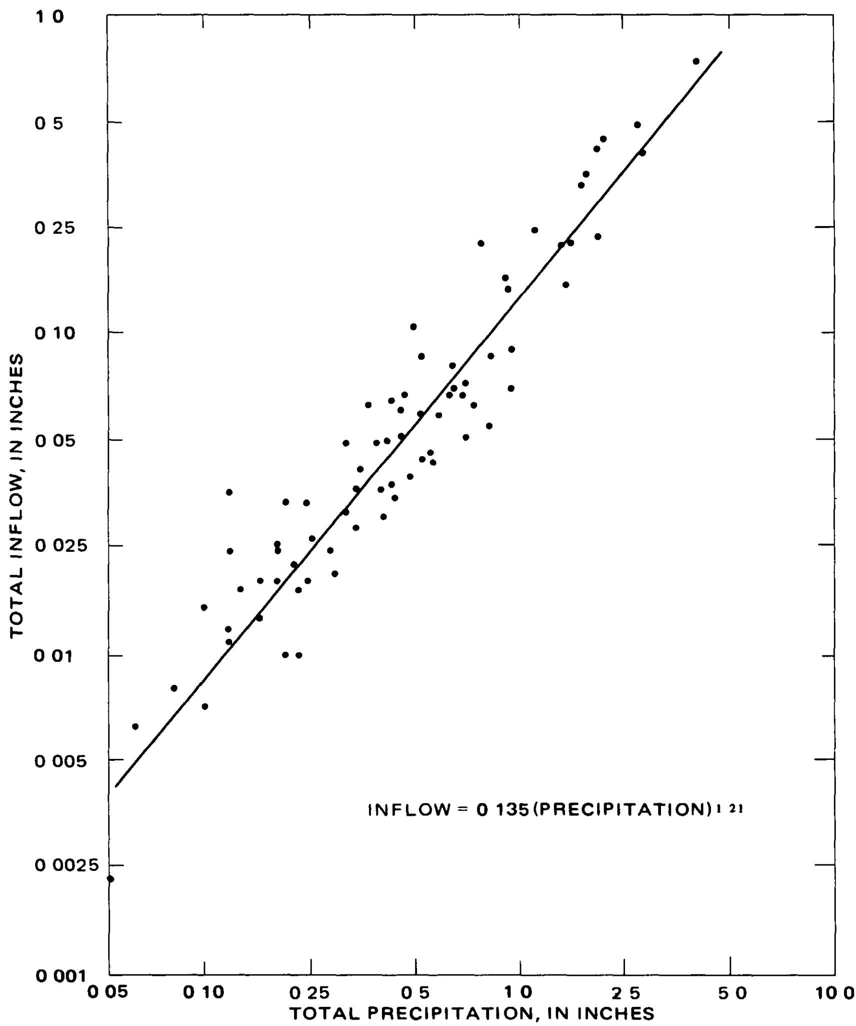

FIGURE 16 — Relation between total precipitation and total inflow to Westbury recharge basin for storms from July 1966 to May 1970

bury, Syosset, and Deer Park recharge basins, respectively, are shown in figures 16, 17, and 18 Trend lines determined by the method of least squares are drawn through the plotted data as solid lines in the figures

Average inflow and range in total inflow, expressed as a percentage at the three basins, are shown in table 5 The average percentage of precipitation entering each basin as inflow — 12 percent for Westbury, 10 percent for Syosset, and 7 percent for Deer Park — roughly approximates the percentage of street area in the drainage areas of each basin (11 percent for Westbury, 13 percent for Syosset, and 11 percent for Deer Park) This suggests

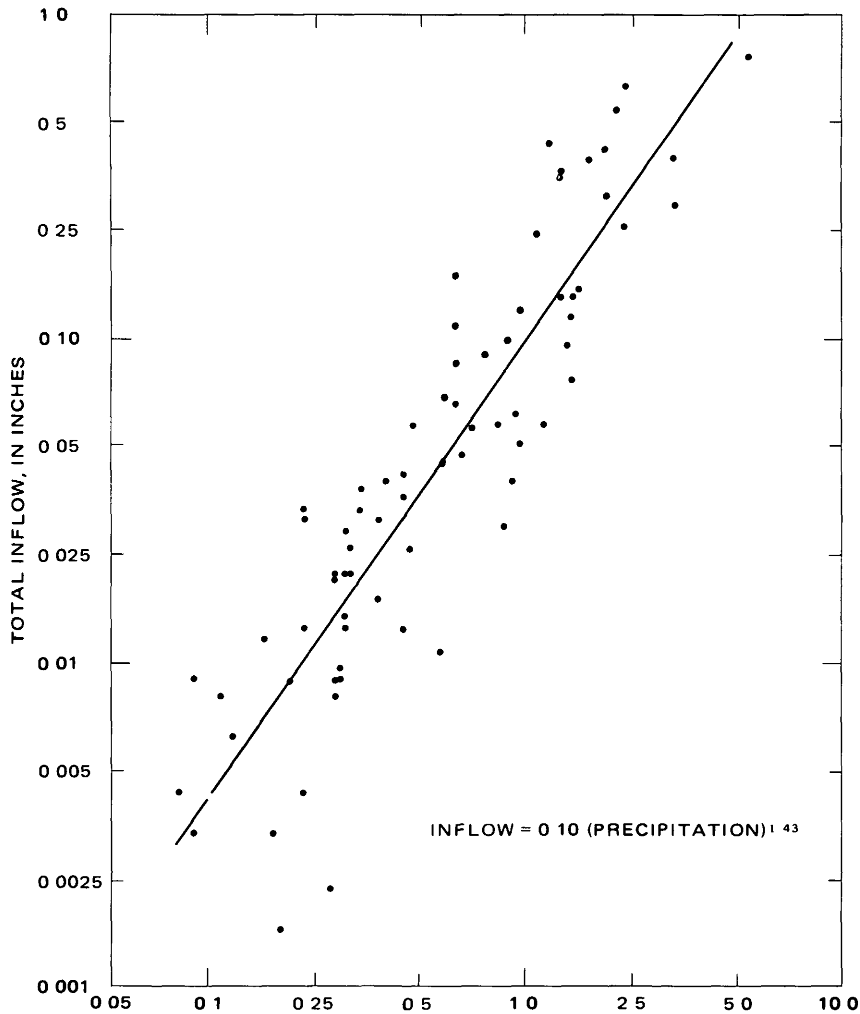

FIGURE 17 — Relation between total precipitation and total inflow to Syosset recharge basin for storms from July 1966 to September 1970

that for suburban areas of similar characteristics, the proportion of total inflow resulting from precipitation is about the same as the proportion of street area in the total drainage area For storms of large magnitude, a higher percentage of inflow is expected, as more runoff is contributed from lawns and sidewalks during these storms than during storms of less magnitude The ranges in percentages and presented in table 5

Table 6 lists precipitation and corresponding total inflow determined from the trend lines in figures 16, 17, and 18 These data show that as

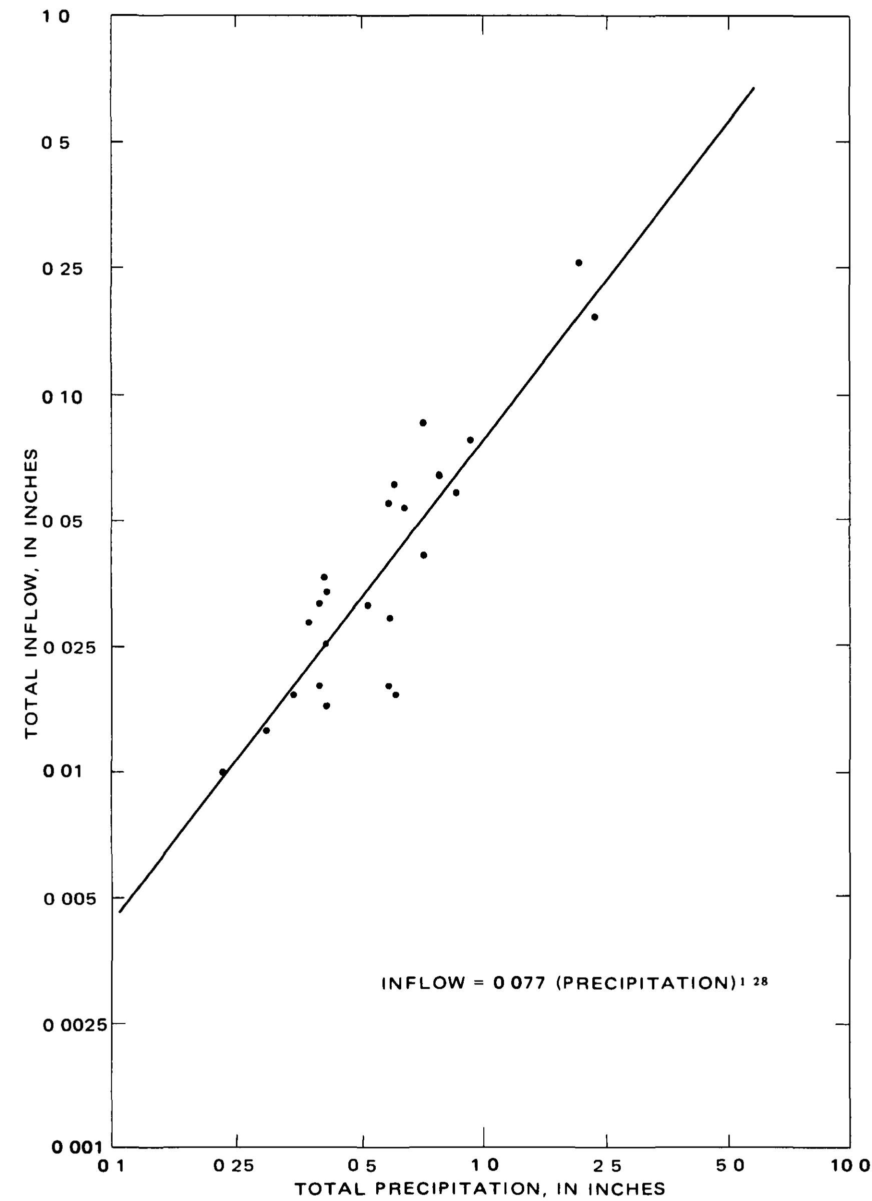

FIGURE 18 — Relation between total precipitation and total inflow to Deer Park recharge basin for storms from March to September 1970

precipitation increases from 0 5 inch to 4 inches, the proportion of inflow increases from 12 to 18 percent at Westbury, 8 to 18 percent at Syosset, and 6 to 11 percent at Deer Park

TABLE 5 —*Average inflow and range in total inflow expressed as a percentage of precipitation for Westbury, Syosset, and Deer Park recharge basins, based on data obtained from individual storms*

Basin	Number of storms	Total inflow as a percentage of precipitation	
		Average for all storms	Range
Westbury	75	12	4–27
Syosset	73	10	2–30
Deer Park	24	7	3–12

TABLE 6 — *Selected values of precipitation and inflow, for Westbury, Syosset, and Deer Park recharge basins, derived from trend lines in figures 16, 17, and 18, respectively*

	Westbury		Syosset		Deer Park	
Precipitation (inches)	Inflow (inches)	Percentage of precipitation	Inflow (inches)	Percentage of precipitation	Inflow (inches)	Percentage of precipitation
0 5	0 06	12	0 04	8	0 03	6
1 0	13	13	10	10	08	8
1 5	22	15	18	12	13	9
2 0	31	16	27	14	18	9
2 5	40	16	37	15	24	10
3 0	50	17	48	16	31	10
3 5	60	17	60	17	38	11
4 0	70	18	72	18	45	11

The three trend lines in figure 19 largely reflect differences in the contributing drainage areas, and only physical changes in the drainage areas will significantly change the curves For example, that the Syosset and the Deer Park trend lines have flatter slopes than the Westbury trend line is partly due to a loss of inflow to the recharge basins by storm water recharging through the bottoms of the many open-bottomed catch basins in the Syosset and the Deer Park drainage systems (See section on "Drainage Systems ") Estimates of recharge through the nine open-bottomed catch basins in the Syosset area, a fully developed suburban area as is the Westbury drainage area, range from 0 to 6 percent of the total inflow to the recharge basin The larger percentage of losses through catch basins does not occur during large storms, but during small storms, when the volume of street runoff to the catch basins is only slightly greater than the volume recharged through the bottoms of the catch basins

For large storms, the amounts of water recharged through the bottoms of the catch basins probably become relatively constant early in the storm period, and, thereafter, the amount of inflow to the recharge basin increases proportionately to precipitation As shown in figure 19, at about 3 5 inches precipitation, proportions of inflow to precipitation at the Westbury and Syosset basins are equal Precipitation in excess of 3 5 inches produces a larger proportion of inflow in the Syosset drainage area than in the Westbury area The larger proportion is attributed mainly to the slightly larger percentage of impervious cover in the Syosset drainage area than in the Westbury drainage area (See table 2)

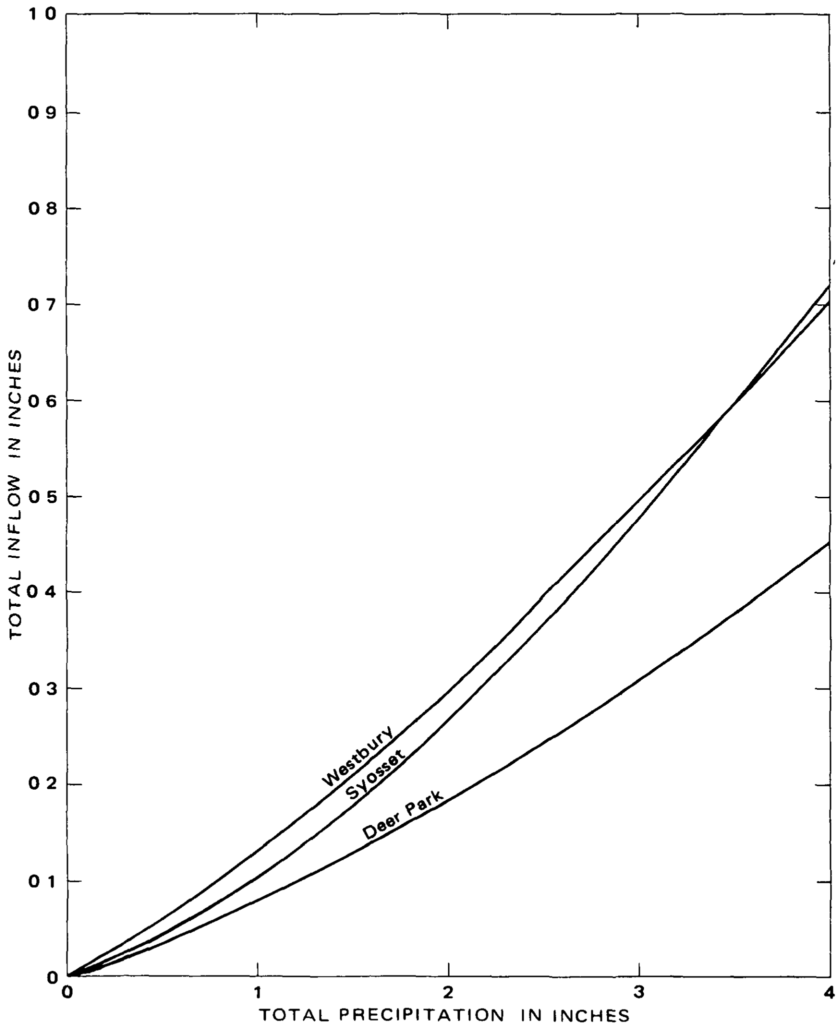

FIGURE 19 — Relation between trend lines of precipitation and inflow at Westbury, Syosset, and Deer Park recharge basins

The Deer Park drainage area, four and eight times larger than the Syosset and Westbury drainage areas, respectively, produces a much smaller proportion of inflow to precipitation This smaller proportion is the result of two factors (1) the drainage system has 49 open-bottomed catch basins, 15 of which do not overflow into storm sewers that lead to the recharge basin, and (2) the storm-drainage system is not fully developed over the area, so the outlying parts of the drainage area probably contribute little runoff to the recharge basin As more houses are built on scattered lots and more storm runoff is collected from the additional impervious areas, the precipitation-inflow relation for the Deer Park recharge basin will probably gradually approach that of the Westbury and Syosset recharge basins.

INFLOW-HYDROGRAPH ANALYSIS

Runoff hydrographs graphically depict distribution with time of flow past a certain point Shape and size of the runoff hydrograph reflect the combined effects of hydrology and physical characteristics of the drainage area These factors influence the magnitude of the resulting peak discharge as well as the length of time during which runoff occurs The purpose of this part of the report is to define certain hydrograph features of the inflow to each basin as they relate to characteristics of the drainage area

An effective method of analyzing the inflow hydrograph involves the use of the unit hydrograph, which standardizes hydrograph features by minimizing effects caused by variable parameters such as magnitude and intensity of precipitation The unit hydrograph was first introduced by Sherman (1942, p. 514) and was defined as a hydrograph of surface runoff resulting from an effective rain falling in a unit of time It was further defined by Chow (1964, p 14–13 to 14–14) as a hydrograph of direct runoff resulting from 1 inch of effective rainfall generated uniformly over the drainage area at a uniform rate during a specified period of time For this paper, the duration of effective rainfall is defined as the length of time that the rainfall intensity exceeded the average infiltration rate in the drainage area The average infiltration rate was computed by dividing the difference between total rainfall, in inches, and total inflow (in inches of precipitation on the total drainage area) by the duration of rainfall Evapotranspiration losses during the storm were assumed negligible

Representative recharge-basin inflow hydrographs for short intense storms were selected for unit-hydrograph analysis Of these, seven were for the Westbury basin, five for the Syosset basin, and six for the Deer Park basin. Duration of effective rainfall for these storms ranged from 5 to 15 minutes.

Unit hydrographs were constructed and converted to 10-minute-duration unit hydrographs by procedures described by Chow (1964, p 14–17 to 14–21). An average 10-minute-duration unit hydrograph was determined for each recharge basin by alining peak discharges and calculating the mean of the corresponding unit-hydrograph ordinates The resulting average unit hydrograph for each of the recharge basins in the study are shown in figure 20 Several hydrograph features determined from these average unit hydrographs are summarized in table 7

Although hydrograph widths are nearly equal for the three basins, peak inflow to the Deer Park basin is almost five and six times larger than peak inflows to the Syosset and Westbury basins, respectively The reason for this is that house construction in the Deer Park drainage area is still (1971) in progress, whereas house construction in the other two drainage areas has

TABLE 7 — *Summary of features of average 10-minute-duration unit hydrographs for Westbury, Syosset, and Deer Park recharge basins*

Basin	Number of storms used in unit hydrograph	Average peak (cfs[1] per inch of inflow)	Average peak (cfs per acre)	Average unit-hydrograph widths: Base[2] (min)	Average unit-hydrograph widths: W_{50}[3] (min)	Average unit-hydrograph widths: W_{75}[4] (min)	Average time lag[5] (min)
Westbury	7	38 5	2 6	96	19	11	21
Syosset	5	48 5	1 7	103	22	12	21
Deer Park	6	228 0	1 9	110	24	13	25

[1]Cubic feet per second
[2]Base width is the time lapse from the beginning to the end of inflow
[3]W_{50} is the unit hydrograph width at 50 percent of the peak discharge
[4]W_{75} is the unit-hydrograph width at 75 percent of the peak discharge
[5]Time lag is the difference in time between the center of mass of excess rainfall and the center of mass of the unit hydrograph

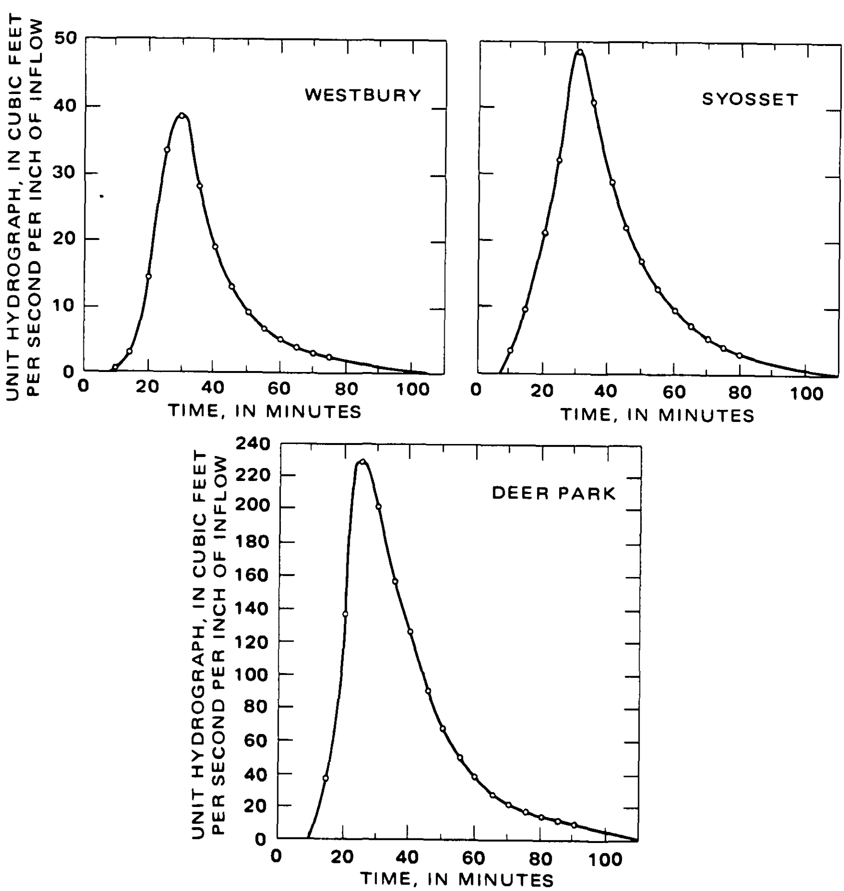

FIGURE 20 — Average 10-minute-duration unit hydrographs of inflow to Westbury, Syosset, and Deer Park recharge basins

been completed As construction in the Deer Park area approaches completion, additional impervious areas will necessitate storm-sewer extensions to the outlying parts of the drainage area As a result, unit-hydrograph base width will probably broaden because of longer traveltimes of storm runoff from the outlying areas to the basin as well as increased volumes of inflow from the additional impervious area The height of the unit-hydrograph peak may increase, decrease, or remain the same, depending on the combined effects of physical change resulting from additional construction in the drainage area

The 10-minute-duration unit hydrographs for Westbury and Syosset are similar in size and shape, the slight differences in shape of the hydrographs are attributed to differences in the shape of the drainage areas and the resulting flow patterns from the various parts of the drainage areas

Inflow unit hydrographs for each basin typify the urban-runoff hydrograph, characterized by steeply rising and falling limbs, sharp peaks, and short time bases These unit hydrographs are probably typical of most inflow hydrographs to recharge basins on Long Island, because most drainage areas have the same general characteristics as those used in this study

RATES OF INFILTRATION

Infiltration is the movement of water from the surface of the ground into the soil Quantitatively, infiltration rates can be expressed in terms of the volume of water entering a unit area of ground in a unit of time For this study, infiltration specifically refers to the rate of movement of storm water through the bottoms and the sides of the recharge basins Lithologic data indicate that infiltration rates from the three basins studied were controlled by the soil layer at the bottom and the sides of each basin That is, the hydraulic conductivity of the surface material of each basin was the major factor governing rates of movement of storm water into the soil

Factors affecting infiltration can be classified into two groups — characteristics of the soil and characteristics of the water Musgrave (1955) summarized the major factors affecting infiltration as follows (1) Surface conditions and the amount of protection against rainfall impact, (2) soil-mass characteristics, including pore size, thickness of permeable layer, degree of swelling of clays and colloids, content of organic matter, and degree of aggregation, (3) soil-moisture content and degree of saturation, (4) rainfall duration, (5) season of the year, and (6) soil and water temperature Suspended sediments and chemical and biological quality of the water commonly alter the infiltration capacity of soils

Rates of infiltration through the bottom and the sides of each recharge basin were computed for each 5-minute period throughout each storm from inflow and stage data recorded on 16-channel tape The following equation of continuity was used in the computations

$$\text{Infiltration} = \frac{\text{inflow} \pm \Delta\,\text{storage}}{\Delta\,\text{time} \times \text{infiltrating area}},$$

where infiltration is in feet per hour, inflow is the average volume of water entering the basin during Δ time, in cubic feet, Δ storage is the net change in the volume of water stored in the basin during each Δ time, in cubic feet, Δ time is the increment of time between each point of data, in hours, and infiltrating area is the average horizontal water-surface area of the water stored in the basin during Δ time, in square feet Because evapotranspiration was negligible for the short periods of time water remained in the basins after storms, nearly all the water that entered the basins infiltrated the ground

Infiltration rates were computed for each 5-minute period throughout an inflow event for which there was a measurable depth of stored water in the recharge basin Because of instrument inaccuracies, infiltration rates computed from data associated with small amounts of inflow and shallow depths of stored water were commonly unrealistic and physically impossible Therefore, only infiltration rates computed for periods when the volume of storage was greater than 100 cubic feet were used. An example of the fluctuation in the computed infiltration rates at the Syosset recharge basin during a storm on July 28–29, 1969, is shown in figure 21

Because of the wide variations in infiltration rate at each basin, an average infiltration rate was computed to characterize each storm Two methods were used in the computations First, the average incremental infiltration rate was computed by using only the values for increments where the volume of storage exceeded 100 cubic feet, and second, the average infiltration rate was computed by dividing the total storm inflow, in cubic feet, by the product of the duration of inflow, in hours, and the average infiltrating area, in square feet The second method represents the average infiltration rate for the entire period of inflow, including those periods for which there was no measurable depth of ponded water

Total precipitation, total inflow, and average infiltration rates determined by these methods at Westbury, Syosset, and Deer Park recharge basins, respectively, are summarized in tables 8, 9, and 10 In general, differences in the two values of average infiltration rate were insignificant, therefore, only the average values computed from the incremental infiltration rates are used subsequently in this report.

Infiltration rates computed from data collected during 63 storms at the Westbury recharge basin between July 1967 and May 1970 ranged from 0 3 to 1 7 fph (feet per hour) and averaged about 0 9 fph

Infiltration rates computed from data collected during 22 storms from July 1969 to September 1970 at the Syosset recharge basin ranged from 0 3 to 1 8 fph and averaged 0 8 fph

Infiltration rates computed from data collected during 24 storms from March to September 1970 at the Deer Park recharge basin generally ranged from 0 1 to 0 5 fph and averaged 0 2 fph

Infiltration rates reported in tables 8, 9, and 10 were measured under a wide range of meteorologic conditions Precipitation generally ranged from

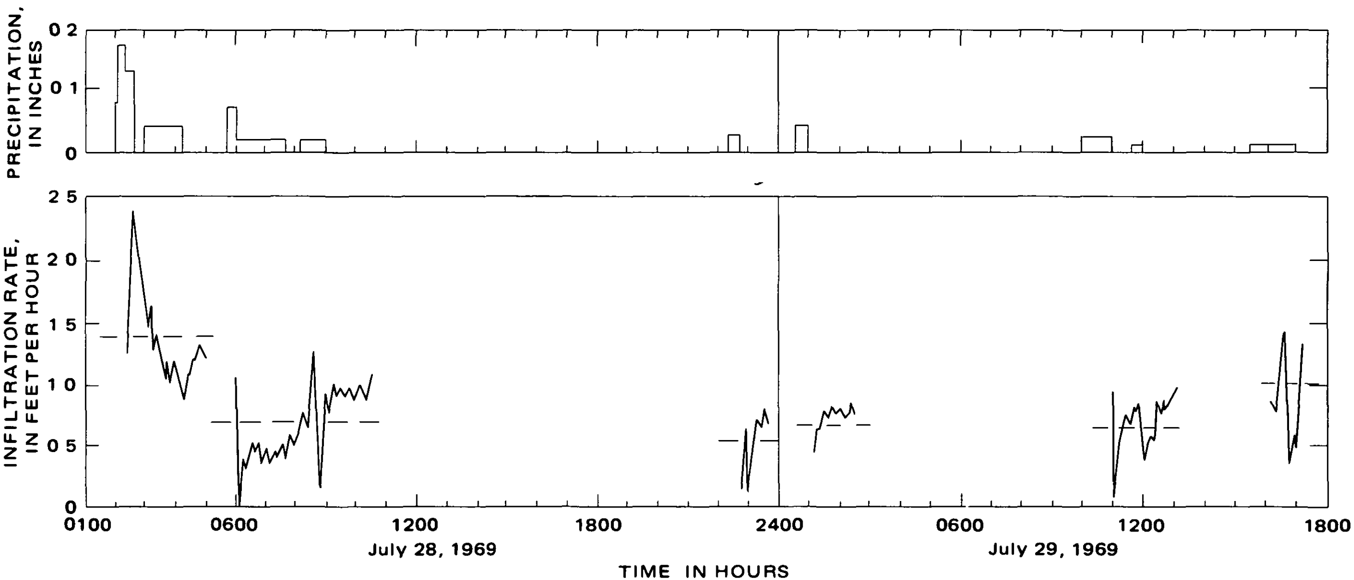

FIGURE 21 — Distribution of precipitation and fluctuation of infiltration rates during the storms on July 28–29, 1969, at Syosset recharge basin

TABLE 8 — *Summary of precipitation, inflow, and average infiltration rate at the Westbury recharge basin from July 23, 1967, to May 26, 1970*

[Average infiltration rate first value represents the average of the 5 minute incremental rates of infiltration computed during periods when the volume of stored water was greater than 100 cubic feet, the value in parentheses represents the average rate of infiltration computed from total inflow divided by the product of the time of inflow and the average infiltrating area]

Date[1]	Precipitation (inches)	Inflow		Average infiltration rate (feet per hour)
		Inches per acre of drainage area	Cubic feet	
1967				
July 23	0 18	0 03	1 600	1 4 (1 4)
July 25	42	05	2,700	8
July 28	66	08	4,100	5 (6)
Aug 9	42	06	3 200	9
Aug 10	15	02	900	1 0
Aug 25 A	1 77	20	11,000	5 (5)
Aug 25 B	71	06	3,300	9 (1 2)
Aug 26	37	03	1,500	7
Aug 27	33	06	3,300	9 (1 1)
Sept 16	55	06	3,000	1 5 (1 5)
Oct 18	1 45	19	10 600	1 3 (1 3)
Oct 25	60	06	3,500	9 (9)
Dec 3	1 75	38	2,100	1 0 (1 2)
1968				
March 23	67	05	2 600	3 (3)
March 29	12	03	1,700	1 1
April 30	49	04	2,200	9 (9)
May 28 A	18	01	500	1 1
May 28 B	3 60	71	38,800	1 2 (1 2)
Aug 1	90	14	7 700	1 5 (2 3)
1969				
March 25	2 38	45	24 600	9 (1 0)
April 22	1 57	29	15,900	8 (8)
April 24	35	05	2 500	5 (6)
May 20	1 34	19	10 500	1 1 (1 2)
June 25	22	02	1 300	1 2 (1 7)
July 3	49	09	4,700	1 3 (1 3)
July 7	67	07	3 900	5 (1 0)
July 12 A	31	04	2 100	1 1 (1 3)
July 12 B	17	02	900	6 (7)
July 12 C	10	01	400	1 1 (1 2)
July 18	39	06	3 400	1 4 (1 4)
July 20	12	02	1,100	1 2 (1 4)
July 26	12	01	600	1 1 (1 6)
July 28 A	1 13	21	11,500	1 4 (1 4)
July 28 B	92	14	7,600	7 (7)
July 28 C	17	02	1 200	6 (6)
July 29 A	28	05	2,500	7 (6)
July 29 B	38	05	2 600	6 (6)
July 29 C	19	02	1,000	1 0 (1 0)
Aug 8	21	03	1 600	1 0 (1 4)
Aug 15 A	61	08	4,400	1 0 (1 0)
Aug 15 B	15	01	700	5 (7)
Aug 15 C	21	02	900	1 0 (1 3)
Sept 3	48	06	3 100	1 5 (1 9)
Sept 4 A	2 46	37	20 100	1 2 (1 1)
Sept 4 B	36	03	1,800	1 0 (1 5)
Sept 9	25	02	1,100	9 (1 0)
Sept 28	39	03	1,900	1 7 (2 2)
Nov 5 6	98	13	7 300	8 (1 0)
Dec 8	92	07	3,800	4 (6)
Dec 10 A	45	04	2,000	6 (6)
Dec 10–11 B	94	09	4 900	4 (4)
Dec 22	1 40	14	7,700	4 (4)
1970				
March 4–5	52	04	2 300	5 (5)
March 12–13	53	04	2 200	6 (8)
March 26	43	06	3 500	1 0 (9)
March 29	46	10	5 700	6 (6)
March 30	80	05	2 800	4 (5)
March 31	26	02	1,000	5 (5)
April 2	1 63	32	17 200	5 (5)
April 20	75	19	10 500	8 (8)
April 24	20	01	500	-- (1 4)
May 22	10	01	800	1 6 (1 5)
May 26	30	03	1 800	1 0 (1 2)
Average	---	---	---	0 9 (1 0)
Range	0 10–3 60	0 01–0 71	---	0 3–1 7 (0 3–2 3)

[1]Capital letters represent the chronological order of two or more distinct storms occurring on the same day

TABLE 9 — *Summary of precipitation, inflow, and average infiltration rate at the Syosset recharge basin from July 12, 1969, to September 27, 1970*

[Average infiltration rate first value represents the average of the 5-minute incremental rates of infiltration computed during periods when the volume of stored water was greater than 100 cubic feet, the value in parentheses represents the average rate of infiltration computed from total inflow divided by the product of the time of inflow and the average infiltrating area]

Date[1]	Precipitation (inches)	Inflow		Average infiltration rate (feet per hour)
		Inches per acre of drainage area	Cubic feet	
1969				
July 12	0 28	0 02	2,000	1 4 (1 4)
July 20	44	06	5,800	5 (6)
Sept 3	92	06	6,300	8 (7)
Sept 4	1 94	52	54,800	6 (8)
Oct 2–3	1 80	28	29,600	6 (8)
Oct 3	60	11	11,800	4 (6)
Nov 5	1 28	14	14,300	4 (3)
Dec 8	95	12	13,100	6 (4)
Dec 10–11	1 18	41	43,000	5 (5)
Dec 22	1 60	37	38,300	5 (4)
1970				
March 24	96	05	5,100	3 (4)
March 29	1 14	06	5 900	3 (2)
April 2	2 05	62	64 600	1 0 (1 1)
April 20	75	09	9,400	4 (3)
April 24	41	03	3 100	4 (3)
May 26	30	04	3 600	1 0
June 18	41	04	4 100	1 0 (2 3)
June 21	27	03	2,700	1 8 (2 2)
July 31	60	09	9 000	1 0 (1 0)
Sept 10	55	07	7 000	1 3 (1 4)
Sept 18	82	06	5,900	8 (1 0)
Sept 27	85	03	2,800	1 2 (1 0)
Average	---	----	-----	0 8 (0 8)
Range	0 28–2 05	0 02–0 62		0 3–1 8 (0 2–2 3)

TABLE 10 — *Summary of precipitation, inflow, and average infiltration rate at Deer Park recharge basin from March 12 to September 27, 1970*

[Average infiltration rate first value represents the average of the 5-minute incremental rates of infiltration computed during periods when the volume of stored water was greater than 100 cubic feet, the value in parentheses represents the average rate of infiltration computed from total inflow divided by the product of the time of inflow and the average infiltrating area]

Date[1]	Precipitation (inches)	Inflow		Average infiltration rate (feet per hour)
		Inches per acre of drainage area	Cubic feet	
1970				
March 12–13	0 49	0 03	9,800	0 2 (0 2)
March 18–19	38	02	7,700	4 (2)
March 20–21	55	05	18,100	2 (2)
March 22–23	37	03	11,800	1 (1)
March 26–27	31	02	5,600	3 (4)
March 29	58	06	20,600	3 (3)
March 31	34	02	8 700	2 (3)
April 2	1 82	23	79,500	3 (2)
April 20	77	06	21,600	4 (2)
April 24	69	08	29,600	1 (1)
May 17–18	92	08	26,800	2 (4)
May 18–19	36	03	9 800	1 (4)
May 26	61	05	17,800	1 (1)
June 12	26	01	4,500	3 (3)
June 26–27	58	02	5,600	5 (5)
July 4	36	02	6,000	2 (3)
July 16	84	06	23 900	2 (2)
Aug 17	38	03	12,800	1 (1)
Aug 20	36	03	11,100	1 (1)
Aug 23	2 01	16	69,200	1 (2)
Aug 31	38	02	6 400	1 (1)
Sept 10 A	20	01	4,300	1 (2)
Sept 10 B	56	02	7,300	1 (1)
Sept 27	69	04	16 200	1 (1)
Average	---	---	----	2 (2)
Range	0 20–2 01	0 01–0 23	----	0 1–0 5 (0 1–0 5)

[1]Capital letters represent the chronological order of two or more distinct storms occurring on the same day

0 1 to 2 ınches (one storm at Westbury was 3 6 ın) and generally ranged from 10 mınutes to 17 hours ın duratıon The perıod between raınfall also varıed wıdely, from a few hours to many days No data were collected for storms ın January and February because most precıpıtatıon was snow and because the recorder malfunctıoned at freezıng temperatures ın these months Inflow resultıng from snowmelt was not studıed

Comparatıvely low ınfiltratıon rates at the Deer Park basın result from (1) a hıgh percentage of sılt, clay, and organıc debrıs (table 4) whıch washes ın from the draınage area and fills the ınterstıces of the natural deposıts and (2) a lack of plant growth on the floor of the basın Plant growth on the floor of Westbury and Syosset recharge basıns (figs 6 and 8) ıs abundant compared wıth that ın Deer Park recharge basın (fig 10) The plant root system keeps the soıl layer loose and permeable and provıdes channels for ınfiltratıng water

Infiltratıon rates decreased at the Deer Park recharge basın after ınstallatıon of addıtıonal storm sewers ın July 1970 Runoff from constructıon areas produced a sıgnıficant ıncrease ın sedıment load enterıng the recharge basın and apparently was largely responsıble for the subsequent decrease ın ınfiltratıon rates The average ınfiltratıon rate for 16 storms before ınstallatıon of addıtıonal storm sewers was 0 2 fph, whereas the average ınfiltratıon rate for eıght storms after ınstallatıon of addıtıonal storm sewers was 0 1 fph

EFFECTS OF SELECTED FACTORS ON INFILTRATION

Although ıt ıs beyond the scope of thıs study to evaluate all factors that affect ınfiltratıon, the ınfluence of temperature and depth of stored water ın a basın are dıscussed ın the followıng paragraphs

Temperature affects the rate of ınfiltratıon by changıng the vıscosıty of the water Water vıscosıty ıs related ınversely to temperature As temperature of water rıses, vıscosıty of water decreases, at the same tıme, the abılıty of water to ınfiltrate ıncreases Conversely, as temperature of water falls, vıscosıty of water ıncreases, and the abılıty of water to ınfiltrate decreases

The effect of temperature dıfference on the rate of ınfiltratıon at the Westbury, Syosset, and Deer Park recharge basıns ıs ıllustrated by two methods (1) seasonal varıatıons of the average rate of ınfiltratıon at each basın and (2) dırect relatıon between aır temperature and the average rate of ınfiltratıon

Seasonal varıatıons ın ınfiltratıon rates at each basın and varıatıon ın mean monthly aır temperature at Mıneola N Y , are shown ın figure 22 The trend lınes, shown as dashed lınes ın figure 22, were drawn through the average ınfiltratıon rate computed from the data plotted ın each monthly ıncrement At the Westbury and Syosset recharge basıns, ınfiltratıon varıed, ın general, dırectly wıth temperature Deer Park data ındıcate a declıne ın ınfiltratıon rate for the perıod shown as a result of the ıncreased sedıment

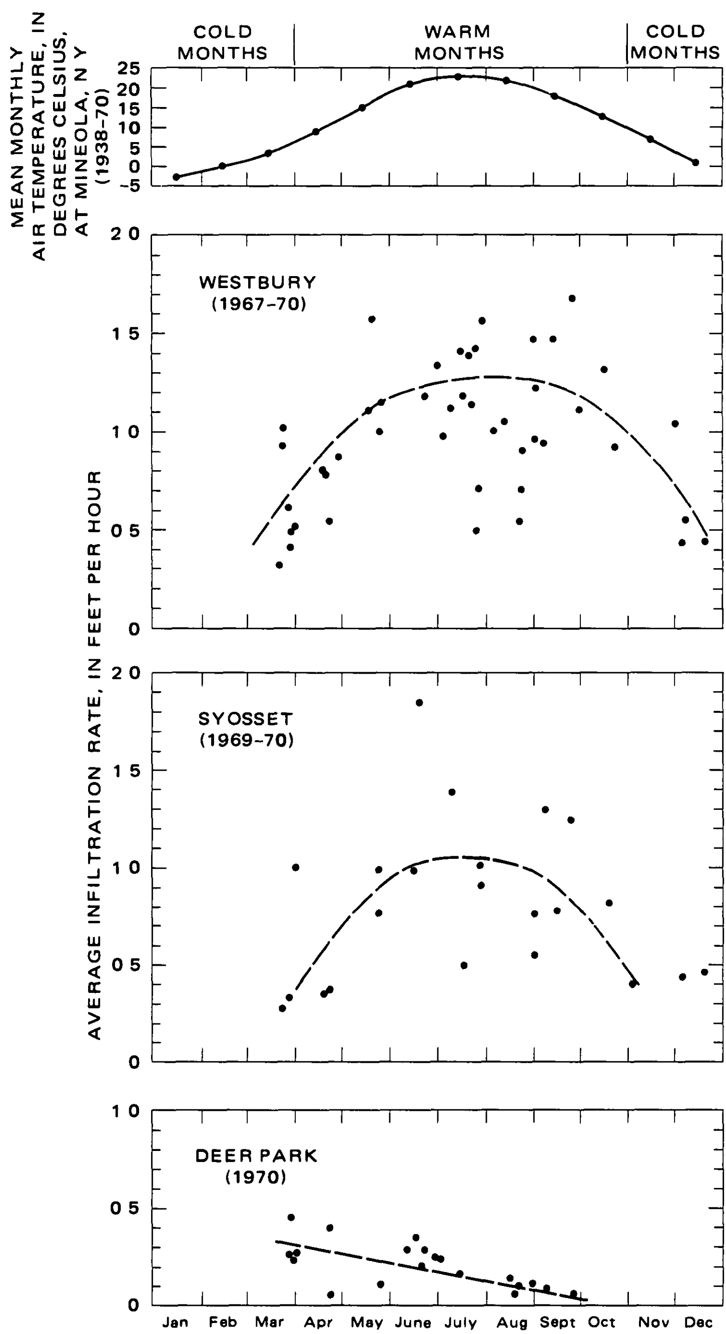

FIGURE 22 — Seasonal variations in mean monthly air temperature at Mineola, N Y , and average infiltration rates at Westbury, Syosset, and Deer Park recharge basins

loads in the inflow, therefore, the effects of temperature increases are not apparent. The average rate of infiltration for storms during warm months, defined as April through October, when air temperatures are generally above 10°C (50°F), was 1.0 fph at Westbury, 0.9 fph at Syosset, and 0.2 fph at Deer Park. The average rate of infiltration for storms during cold months, defined as November through March, when air temperatures are generally below 10°C (50°F), was 0.6 fph at Westbury, 0.4 fph at Syosset, and 0.2 fph at Deer Park.

The relation between average air temperature during a storm and the corresponding rate of infiltration is shown in figure 23. Continuous air temperatures were recorded at Mineola, N.Y., and were assumed to represent water temperatures during a storm. Dashed lines in figure 23 represent the regression lines determined by the method of least squares. The infiltration rate increased substantially as temperatures increased at Westbury and Syosset. The effect of temperature on the infiltration rate at the Deer Park basin is not apparent because of the previously described increased sediment loads. For this reason and because of the short period of record, a regression line was not determined for the Deer Park data.

The viscosity of water at 0°C (32°F) is about twice that at 30°C (86°F). In the same temperature range, infiltration rates at Westbury and Syosset shown in figure 23 increase two and three times, respectively. This indicates that viscosity accounts for a large part of the increase in infiltration rates. These increased infiltration rates may also be affected by the plant-root growth during the warmer seasons.

Effect of depth of stored water (the hydraulic head at the land surface) above the floor of the recharge basin on the infiltration rate was also studied. At the Westbury and Syosset basins, the area of ponding did not change appreciably for depths of water between 0.5 and 2.0 feet. Thus, data associated with this depth interval provide a basis for showing the effect of depth of stored water on the infiltration rate. At the Deer Park basin, the area of ponding increased from 3,000 to 23,000 square feet as the water level in the basin increased from 0.5 to 2.0 feet. Because infiltration rates vary throughout the basin, data from Deer Park are not conclusive.

Data for all storms that produced a depth of water in storage greater than 1.5 feet in the Westbury, Syosset, and Deer Park basins were compiled, and the average infiltration rate for the 0.5- to 1.0-, 1.0- to 1.5-, and 1.5- to 2.0-foot depth increments were computed. These selected values, as well as the average infiltration rate for each increment of depth of stored water for all storms in the compilation, are reported in table 11. Also, average rates for all storms in the compilation are plotted against depth of storage in figure 24.

Westbury data showed that the average infiltration rate nearly doubled between the 0.5- to 1.0-foot increment and the 1.5- to 2.0-foot increment, whereas the average infiltration rate at Syosset increased 1.5 times in the

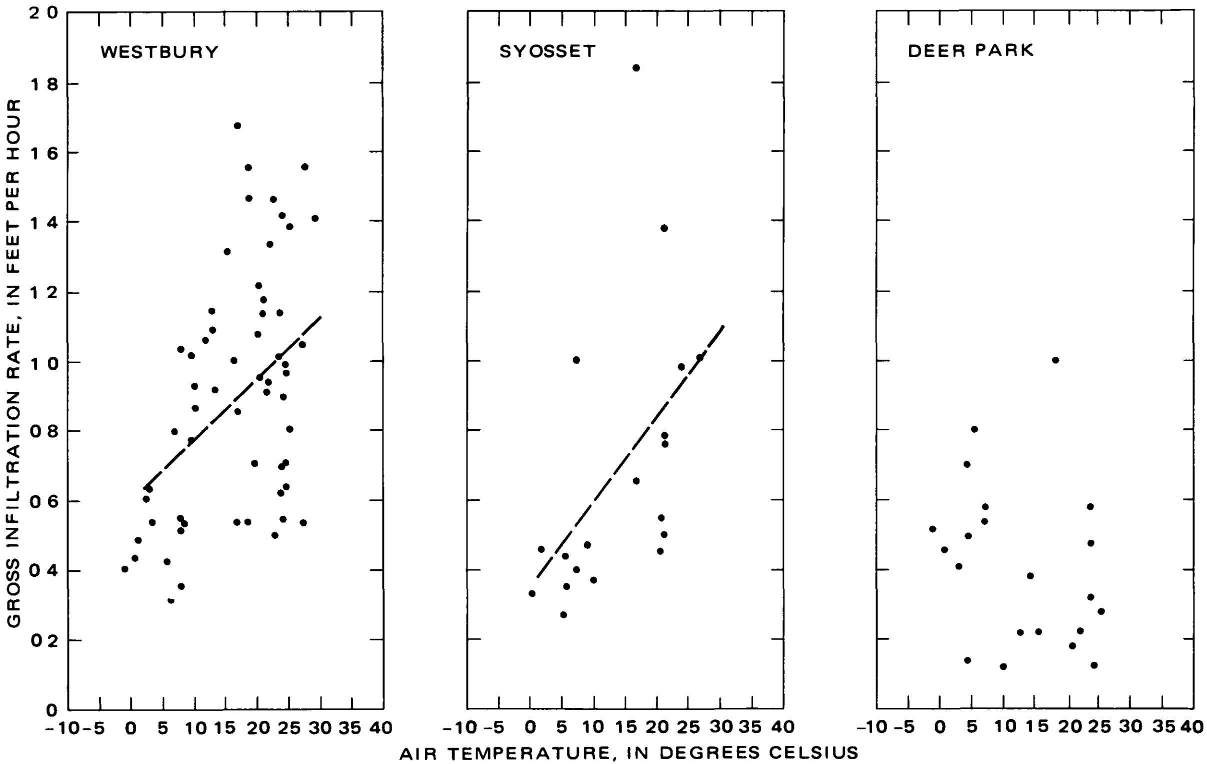

FIGURE 23 — Relation between average infiltration rate at Westbury, Syosset, and Deer Park recharge basins and air temperature at Mineola, N Y

TABLE 11 — *Relation between depth of stored water and average rate of infiltration at Westbury, Syosset, and Deer Park recharge basins*

[Rate of infiltration in feet per hour]

Basin and date of storm for which rate of infiltration was calculated	Depth of stored water above basin floor (feet)				
	0 5–1 0	1 0–1 5	1 5–2 0	2 0–2 5	2 5–3 0
Westbury					
1967					
Aug 25	1 08	1 42	1 67	----	----
Dec 3	86	1 61	1 69	----	----
1969					
Mar 24–25	81	98	1 78	----	----
Apr 22	61	1 07	----	----	----
May 20	1 05	1 48	----	----	----
May 28–29	1 04	1 34	1 69	----	----
June 3	1 36	1 31	----	----	----
June 28 A[1]	1 10	1 40	----	----	----
June 28 B	64	83	----	----	----
Aug 15	1 10	1 07	----	----	----
Sept 4	1 01	1 05	----	----	----
Dec 10–11	40	36	----	----	----
Average rate of infiltration for all storms	92	1 16	1 71	----	----
Syosset					
1967					
Dec 22	30	37	52	87	----
1969					
Sept 4	63	85	1 07	----	----
Oct 2	61	66	----	----	----
Oct 3	36	55	75	----	----
Dec 11	36	53	1 12	----	----
1970					
Apr 2	98	90	----	----	----
July 31	99	1 67	----	----	----
Average rate of infiltration for all storms	60	79	86	87	----
Deer Park					
1970					
Apr 2	67	15	16	----	----
June 12	34	28	----	----	----
June 23	27	29	----	----	----
July 16	40	14	18	----	----
Aug 17	----	14	16	----	----
Aug 20	----	09	08	----	----
Aug 23	----	----	17	14	13
Aug 31	32	13	----	----	----
Average rate of infiltration for all storms	40	17	15	14	13

[1] Two storms occurred on June 28, 1969, and are identified in chronological order by the letters A and B

same range Large changes in infiltration rates associated with a small change in hydraulic head at the land surface indicate that infiltration capacity of the basins is markedly affected by the soil layer

Change in infiltration rates with time is illustrated in figure 21 Infiltration rates are highest during the early period of wetting and decrease to a constant rate as wetting of soil and sediments continues

WATER MOVEMENT THROUGH THE UNSATURATED ZONE AND ITS EFFECTS ON THE WATER TABLE

Movement of water through the unsaturated zone beneath each recharge basin was evaluated by recording the water-table rise associated with a particular storm The data, recorded in an observation well screened in the water table beneath each basin, were used to study the time of travel of storm water through the unsaturated zone and the resulting rise and fall of the water table The apparent rate of movement of water through the unsaturated zone was computed by dividing the depth to the underlying water

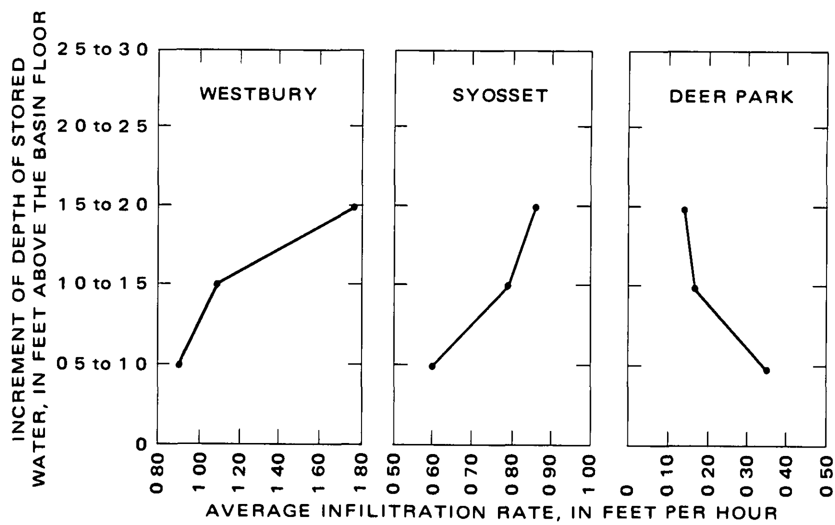

FIGURE 24 — Average infiltration rate associated with selected increments of depth of stored water at Westbury, Syosset, and Deer Park recharge basins

table by the difference in time between the beginning of inflow to the basin and the beginning of water-table rise, herein called traveltime The water-table rise associated with a particular storm was assumed to have been caused by the downward movement to the water table of inflow associated with that storm (Seaburn, 1970b, p B197)

A summary of traveltimes and apparent rates of movement of water through the unsaturated zone beneath each recharge basin is shown in table 12 The time required for water to arrive at the water table depends on numerous factors, including infiltration rates, antecedent moisture conditions, depth to the water table, and the period of ponding at land surface The wide range in traveltimes reported in table 12, therefore, is to be anticipated

From 1967 to 1968, the apparent rates of movement of storm water through the unsaturated zone beneath the Westbury recharge basin averaged about 5 fph for 38 storms (Seaburn, 1970b) These rates ranged from an average of 3 fph during November through March to 6 fph during April through October Similar data obtained since 1968 at the Westbury basin (table 12) averaged 5 5 fph for 70 storms and ranged from an average of 3 3 fph during the winter to 6 8 fph during the summer Data from the Syosset and Deer Park basins indicate apparent average rates of movement slightly less than those observed at Westbury — 3 7 fph for four storms at Syosset and 3 1 fph for 17 storms at Deer Park

Although the exact shapes of water-table mounds caused by recharging storm water were not defined in this study, they were assumed to have approached spherical or conical mounds similar to those described by Haskell

TABLE 12 — *Summary of traveltimes and apparent rates of movement of storm water through the unsaturated zone beneath Westbury, Syosset, and Deer Park recharge basins*

[Average depth to water table below basin floor, in feet Westbury, 35, Syosset, 72 Deer Park, 14]

	Westbury	Syosset	Deer Park
Total			
Number of storms recorded	70	4	17
Traveltime between beginning of inflow to basin and initial rise in water table			
Range hours	3 5–24 0	13 5–33 5	2 0–11 5
Average[1] hours	8 4	21 8	6 2
Apparent rate of movement through the unsaturated zone beneath the recharge basin			
Range feet per hour	1 5–10 0	2 1–5 3	1 2–7 0
Average[2] feet per hour	5 5	3 7	3 1
Data for storms occurring during warm months (April through October)			
Number of storms recorded	45	2	14
Traveltime between beginning of inflow to basin and initial rise in water table			
Range hours	3 5–24 0	13 5–18 0	2 0–11 5
Average hours	6 7	15 8	6 6
Apparent rate of movement through the unsaturated zone beneath the recharge basin			
Range feet per hour	1 5–10 0	4 0–5 3	1 2–7 0
Average feet per hour	6 8	4 7	2 9
Data for storms occurring during cold months (November through March)			
Number of storms recorded	25	2	3
Traveltime between beginning of inflow to basin and initial rise in water table			
Range hours	7 0–24 0	22 5–33 5	2 25–5 0
Average hours	11 5	28 0	3 9
Apparent rate of movement through the unsaturated zone beneath the recharge basin			
Range feet per hour	1 5–5 0	2 1–3 2	2 8–6 2
Average feet per hour	3 3	2 7	4 0

[1]The average traveltime was computed by averaging the mean traveltime for each storm recorded
[2]The average apparent rate of movement was computed by averaging the mean rate of movement for each storm recorded

and Bianchi (1965) Moreover, observation wells in the basins were assumed to have been drilled near the apexes of the water-table mounds, and their peak measurements were assumed to have represented mound peaks

Observations of the peak water-table rises associated with selected storms were made at the three study basins Data indicate that the water-table mounding had no apparent effect on the infiltration rates at the basins Total precipitation and associated peak water-table rises above prestorm levels are plotted in figure 25 for Westbury and Deer Park basins Presumably, the scatter of points was caused by the effects of precipitation magnitude and intensity, antecedent soil-moisture conditions, and many other complex factors associated with flow through the soil layer and the unsaturated zone. Trend lines, determined by the method of least squares and drawn as solid lines through Westbury and Deer Park data, indicate that, on the average, a 1-inch rainfall resulted in a water-table rise of 0 5 foot, and a 2-inch rainfall resulted in a rise of about 2 feet A trend line was not determined for data from the Syosset basin because of an insufficient amount of data, but the magnitude of water-table mounding at that basin apparently is about the same as that under Westbury and Deer Park basins

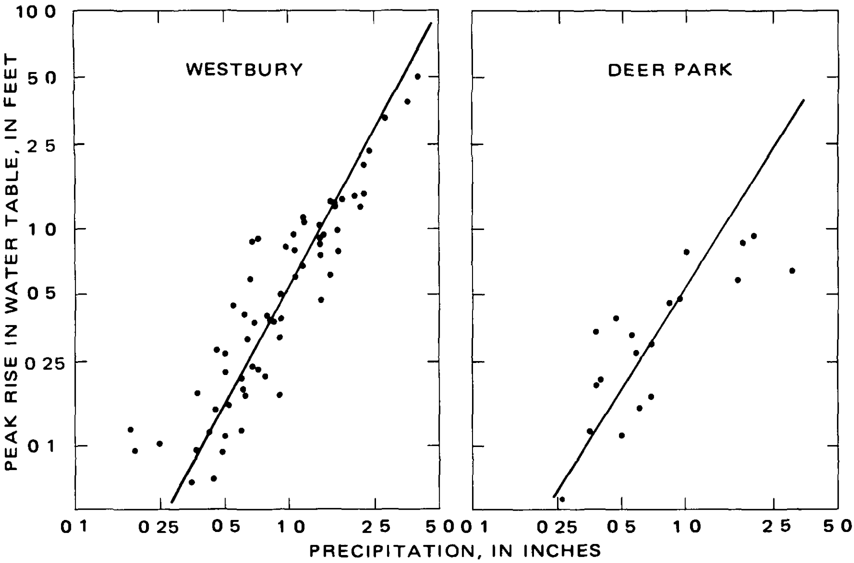

FIGURE 25 — Relation between amounts of precipitation and peak rises in the water table beneath Westbury and Deer Park recharge basins

The water-table mounds commonly dissipated in 1 to 4 days at Westbury, 7 days to more than 15 days at Syosset, and 1 to 3 days at Deer Park, depending at least partly on the relative magnitude of the peaks

GROUND-WATER RECHARGE THROUGH WESTBURY, SYOSSET, AND DEER PARK RECHARGE BASINS

Estimates made of the average annual ground-water recharge at each of the study basins were based on the assumptions that (1) the average volume of inflow to each basin (table 5) is proportional to the average-annual precipitation on the drainage areas of each basin, and (2) all, or nearly all, the inflow to the basins recharges the ground-water reservoir Virtually all the storm water collected in Westbury and Syosset recharge basins infiltrated the basin floors within a few hours after a storm, in the Deer Park basin, within 2–3 days Evaporation losses were negligible Some water is consumed by evapotranspiration from the soil layers on the basin floors between storms, but the amounts are probably negligible compared with amounts of inflow to the basins during storms

Miller and Frederick (1969, p A13) reported that the average annual precipitation on Long Island from 1951 to 1965 was 43 inches As previously noted (table 5), the estimated percentages of average annual precipitation flowing into the three study basins are Westbury, 12, Syosset, 10, and Deer Park, 7 The estimated average annual ground-water recharge is 6 4 acre-feet (5,700 gpd, gallons per day) at the Westbury basin, 10 3 acre-feet (9,200 gpd) at the Syosset basin, and 29 6 acre-feet (26,000 gpd) at the Deer Park basin

CHEMICAL QUALITY OF WATER

The preceding parts of the report dealt primarily with amount and disposition of storm water entering Westbury, Syosset, and Deer Park recharge basins Chemical quality of the infiltrating water is also highly significant to local water managers Samples of precipitation and inflow were collected periodically and analyzed for dissolved constituents to help provide a preliminary evaluation of the quality of the inflow Samples of deposits from the floor of each basin also were collected and analyzed for pesticide content

PRECIPITATION

Chemical quality of precipitation, which partly reflects the chemical characteristics of dust and other particles in the air, differs greatly from storm to storm and from place to place on Long Island (U S Geological Survey, 1970, p 132) Major sources of particulate matter in the air on Long Island are salt spray from the sea, factories, internal combustion engines, and coal- and oil-burning furnaces Other sources are also related to the heavily urbanized and industrialized areas in New Jersey, New York City, and Nassau and Suffolk Counties

Monthly composite samples of bulk precipitation were collected from October 1969 to June 1970 at the Westbury recharge basin, from October 1969 to May 1970 at the Syosset recharge basin, and from March to June 1970 at the Deer Park recharge basin Analysis of these samples included determination of major inorganic constituents, dissolved-solids content, hardness of water, specific conductance, pH, and color (table 13) Estimated average loads of selected chemical constituents in precipitation at each recharge basin during the sampling period are shown in table 14 These loads were computed by multiplying the concentration of the chemical constituent by the total monthly precipitation and converting the results to pounds

Precipitation on the drainage areas of Westbury, Syosset, and Deer Park recharge basins generally was of similar chemical quality Dissolved-solids content averaged 50 mg/l (milligrams per liter) at Westbury, 50 mg/l at Syosset, and 40 mg/l at Deer Park Average monthly load of dissolved solids deposited on the drainage area was 650 lb (pounds), or 43 lb per acre, at Westbury, 1,100 lb, or 38 lb per acre, at Syosset; and 2,400 lb, or 25 lb per acre, at Deer Park The pH of precipitation at the three basins ranged from 5 9 to 6 6 Hardness of the precipitation ranged from 6 to 56 mg/l, which characterizes the precipitation water as soft (Hem, 1970, p 225) Calcium, the predominant cation in solution, averaged 79 to 86 percent of the weight of determined cations Sulfate, the predominant anion in solution, averaged 47 to 64 percent of the weight of the determined anions, bicarbonate averaged 22 to 31 percent Atmospheric dust of terrestrial origin and gaseous sulfur compounds associated with the Northeast urban environment largely account for this combination of ions in precipitation

TABLE 13 — *Chemical analyses of monthly composite samples of precipitation at Westbury, Syosset, and Deer Park recharge basins*

[Chemical analyses in milligrams per liter, analyses by U S Geological Survey]

Composite period	Precipitation (inches)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonium (NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Phosphate (PO_4), total	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$ (Ca, Mg)	Specific conductance (micromhos per cm at 25°C)	pH	Color
Westbury																
1969																
October	2 39	7 0	0 2	1 2	0 8	0 11	10	13	4 0	1 3	0 12	50	18	57	6 4	16
November	3 47	2 3	3	1 2	3 6	10	10	26	2 9	7	05	61	6	74	6 1	12
December	6 54	9 2	2	1 0	5	12	7	14	1 7	1 4	17	[1]32	24	53	6 0	--
1970																
February	3 70	8 8	3	1 2	2	14	6	16	5 5	1 1	14	56	23	56	6 1	4
March	4 11	14	3	7	0	06	7	24	2 5	3 0	09	60	36	85	6 1	4
April	3 30	10	2	6	2	15	9	16	2 4	2 6	07	44	26	63	6 4	14
May	2 38	10	4	7	--	--	11	18	2 4	1	42	49	26	65	6 4	40
June	3 23	13	3	1 6	8	79	12	21	4 4	6 8	--	64	34	92	6 3	19
Weighted average	---	9 4	3	1 0	--	--	9	18	3 1	2 1	--	50	24	67	--	--
Syosset																
1969																
October	2 84	8 0	0 4	1 1	1 8	--	12	13	2 8	2 2	0 56	48	22	62	6 5	14
November	3 58	2 4	1	11	1 4	0 19	11	21	2 5	9	06	49	6	68	6 6	15
December	5 08	5 2	2	8	0	08	5	10	1 4	4	16	[1]21	14	36	6 1	--
1970																
January	50	22	3	2 6	1	38	6	54	7 1	6	19	124	56	148	6 3	5
February	3 79	7 8	1	8	0	12	8	13	3 0	1	05	37	20	49	5 9	3
March	4 30	16	2	1 0	0	52	6	31	2 8	3 7	06	70	41	100	6 2	2
April	3 10	15	2	8	1	32	11	25	3 0	3 2	32	68	38	90	6 4	6
May	2 51	11	3	6	6	50	12	19	3 0	3 5	63	56	28	73	6 4	11
Weighted average	---	9 4	2	2 3	5	--	9	19	2 6	1 8	22	50	24	68	--	--
Deer Park																
1970																
March	3 02	7 0	0 3	1 1	0 1	0 15	4	12	2 8	2 2	0 01	30	18	49	6 2	4
April	3 59	8 5	2	7	0	22	8	15	3 0	3 0	07	42	22	60	6 3	9
May	1 32	12	7	9	2	43	16	16	3 1	2	58	54	33	67	6 3	19
June	1 97	8 0	3	6	1	22	8	14	2 3	3 3	04	44	22	58	6 5	24
Weighted average	---	8 4	3	8	1	23	8	14	2 8	2 4	11	40	22	57	--	--

[1]Calculated from sum of determined constituents

TABLE 14 — *Loads, in pounds, of dissolved constituents and dissolved solids in precipitation at Westbury, Syosset, and Deer Park recharge basins*

Composite period	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonium (NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Phosphate (PO_4), total	Dissolved solids (residue at 180°C)
Westbury											
1969											
October	57	1.6	9.8	6.5	0.9	81	110	32	11	1.0	410
November	27	3.5	14	42	1.2	120	310	34	8.3	6	720
December	200	4.4	22	11	2.7	160	310	38	31	3.8	710
1970											
February	110	3.8	15	2.5	1.8	75	200	69	14	1.8	700
March	200	4.2	9.8	0	.8	98	340	35	42	1.3	840
April	110	2.2	6.7	2.2	1.7	100	180	27	29	.8	490
May	81	3.2	5.7	--	--	89	150	19	.8	3.4	400
June	140	3.3	18	8.8	8.7	130	230	48	75	--	700
Weighted average	130	3.5	14	9.6	2.3	110	250	39	28	1.8	650
Load per acre of drainage area	8.6	2	9	6	2	7.6	16	2.6	1.9	1	43
Syosset											
1969											
October	159	7.4	20	33	--	220	240	52	41	10	890
November	56	2.3	260	33	4.4	260	490	58	21	1.4	1 100
December	170	6.6	26	0	2.7	170	330	46	13	5.3	700
1970											
January	72	.9	8.5	.3	1.2	20	180	23	2.0	.6	400
February	190	2.5	20	0	3.0	200	320	74	2.5	1.2	920
March	450	5.6	28	0	15	170	870	79	100	1.7	2,000
April	300	4.0	16	2.0	6.5	220	510	61	65	6.5	1,400
May	180	4.9	9.8	9.8	8.2	200	310	49	57	10	920
Weighted average	220	4.7	54	9.4	5.7	200	450	60	41	4.6	1,100
Load per acre of drainage area	7.6	2	1.9	3	2	6.9	16	2.1	1.4	2	38
Deer Park											
1970											
March	460	20	72	6.6	9.9	260	790	180	140	0.7	2 000
April	660	16	55	0	17	620	1 200	230	230	5.5	3 300
May	340	20	26	5.7	12	460	460	89	5.7	17	1 600
June	340	13	26	4.3	9.4	340	600	99	140	1.7	1 900
Weighted average	490	17	51	3.7	13	430	860	170	150	4.8	2 400
Load per acre of drainage area	5.1	2	5	.04	1	4.5	8.9	1.8	1.6	.05	25

(Gambel and Fisher, 1966, and F J Pearson and D W Fisher, written commun , 1971)

INFLOW

Inflow to the recharge basins is composed of the chemical constituents in precipitation modified by numerous factors, mainly by the addition of dissolved and suspended constituents acquired during runoff Some of the major sources of additional dissolved solids include dissolved minerals from natural sediments, plant fertilizers, pesticides, deicing salts, and dry fallout Sources of suspended material include eroded sediments and plant debris, grease, tar, oil, rubber, and other bulk debris, such as paper, wood, and metal products related to man's activities

Composite precipitation samples and a series of inflow samples were collected during selected storms to compare concentrations and loads of dissolved constituents in the precipitation and the resulting inflow Determinations in the analysis of each sample included major chemical constituents, and the properties of dissolved-solids content, pH, color, hardness of water, and specific conductance Inorganic- and organic-carbon content of several samples were also determined Results of these analyses are shown in table 15 Samples of the inflow were collected at 5- or 10-minute intervals from the beginning of flow until after peak inflow This procedure provided a sampling of 70 to 95 percent of the total inflow of the storms at Westbury, Syosset, and Deer Park basins The part of the inflow hydrograph for the times samples were selected is shown in figure 26

The sanitary quality of inflow was not determined One source of biological constituents would result from exercising of pets along the streets and sidewalks in the drainage area This contribution, presumably, is small

Generally, the data indicate

1 Chemical composition of inflow was similar at each of the three recharge basins
2 Concentration of most constituents in the inflow exceeded their concentration in precipitation
3 Fluctuation of the specific conductance during three successive rainfalls at the Syosset recharge basin from July 31 to August 2, 1970, and the effect of antecedent inflow on the specific conductance are illustrated in figure 27 The first rainfall washed dust and gasses from the atmosphere and flushed a large part of the soluble material on the surface of the drainage area The lower specific conductance of the two inflows of August 1, 1970, resulted from lesser amounts of material available for solution This variation in the specific conductance of inflow during a rainfall is typical of all except winter storms, when the specific conductance of inflow is commonly high and reflects solution of deicing salts spread on the streets Maximum and minimum specific conductances of inflow during selected storms at Westbury, Syosset, and Deer Park are listed in table 16
4 Chemical quality of inflow was generally satisfactory for most domestic

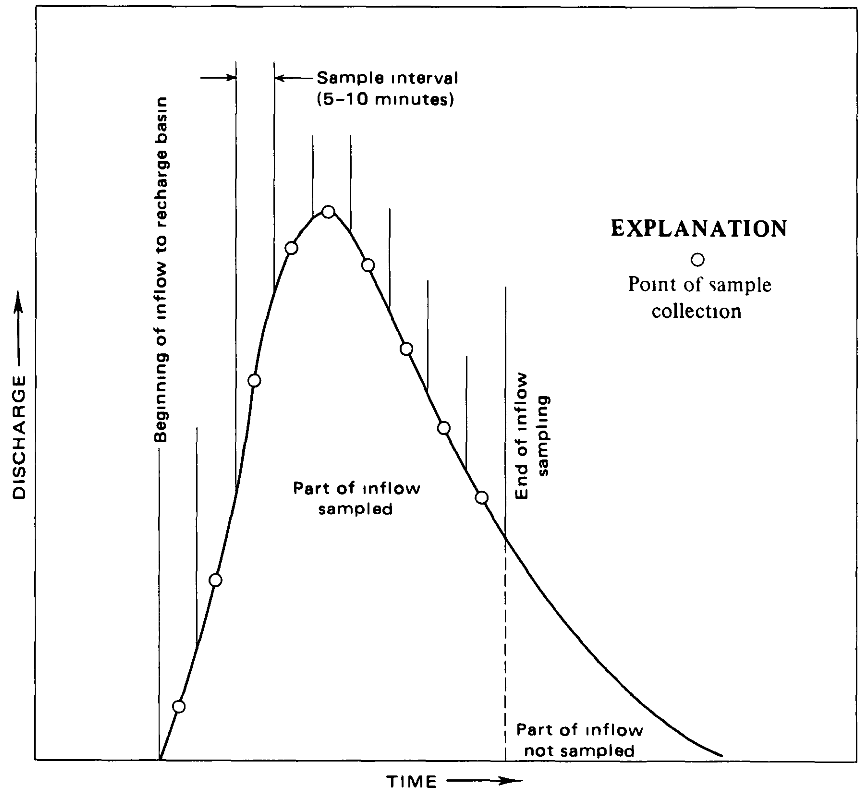

FIGURE 26 — Sketch of inflow hydrograph for the time when water samples were collected

and industrial uses Concentrations of constituents are well below the limits recommended for drinking water by the U S Public Health Service (1962).

COMPARISON OF LOADS FROM PRECIPITATION AND INFLOW

Most of the total load of dissolved constituents in inflow to the three recharge basins was derived from solution of gases and aerosols in the atmosphere rather than from solution of material from the land surface A comparison of the loads of dissolved constituents in the precipitation and in the sampled inflow at the Westbury and Syosset basins for the storm of April 24, 1970, and at the Deer Park basin for the storm of April 17, 1970, is shown graphically in figures 28, 29, and 30 The comparison of the total load of dissolved solids at each basin is summarized in table 17

At the Westbury basin there was a general increase in all constituents, particularly in the sodium, bicarbonate, chloride, and nitrate contents of the inflow water There was a loss of calcium and sulfate in the inflow water at the Syosset basin and a loss of calcium and chloride at the Deer Park basin, other constituents increased in the inflow water

TABLE 15 — *Chemical analyses of precipitation and resulting inflow at Westbury, Syosset, and Deer Park recharge basins*

[Chemical analyses in milligrams per liter Analyses by U S Geological Survey]

Collection date and sample	Time	Precipitation (inches)	Discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Phosphate (PO_4), total	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$ (Ca, Mg)	Specific conductance (micromhos per cm at 25°C)	pH	Color	Total organic carbon (C)	Inorganic carbon (C)
Westbury																				
April 24, 1970																				
Precipitation	--	0 20	--	0 3	10	0 4	0 7	--	11	18	2 4	0 1	0 42	49	26	65	6 4	40	--	--
Inflow ---	1155	---	0 07	2 4	28	2 9	7 3	--	63	29	11	1	87	107	82	195	6 7	21	--	--
	1200	---	13	2 3	22	2 9	7 0	--	51	28	10	1 7	83	106	67	160	6 6	18	--	--
	1205	---	23	1 8	19	3 1	5 6	--	55	24	8 6	1	99	88	60	156	6 5	14	--	--
	1210	---	30	1 1	16	2 4	4 6	--	36	23	6 6	2 9	1 50	86	50	128	6 4	11	--	--
	1220	---	23	1 2	16	2 1	5 4	--	28	27	6 9	6 7	77	78	48	140	6 4	9	--	--
	1230	---	12	1 1	15	1 7	5 1	--	25	25	6 0	6 4	64	69	44	130	6 5	11	--	--
	1240	---	06	1 1	15	1 5	5 0	--	23	24	5 7	6 2	53	66	44	124	6 4	12	--	--
July 10, 1970																				
Precipitation	--	28	--	2	10	3	0 5	0 4	13	16	4 5	3 6	47	40	26	61	6 8	--	12	1
Inflow ---	0905	---	--	6	5 0	6	2 6	2 1	8	3 0	--	3 6	1 2	30	15	43	7 1	--	14	2
	0915	---	--	6	5 0	7	1 6	1 1	17	4 0	1 5	1	2 9	32	16	42	7 4	--	14	2
	0925	---	--	7	4 9	6	1 7	1 1	15	4 0	0	1	2 8	35	14	46	7 2	--	14	2
	0935	---	--	6	7 0	6	1 7	1 1	22	3 5	2 0	1	1 4	29	20	46	6 8	--	15	1
	0945	---	--	7	6 0	6	1 7	1 1	20	4 0	1 0	1	3 0	44	18	50	6 6	--	16	2
	0955	---	--	8	6 0	6	1 8	1 1	18	3 0	2 0	8	3 0	36	18	50	7 2	--	14	2
	1005	---	--	8	5 4	6	1 8	1 1	17	5 0	1 0	1	3 0	40	16	52	7 4	--	16	2
	1015	---	--	8	7 0	6	1 8	1 2	23	4 5	1 0	2	3 2	30	20	52	6 8	--	19	2
	1025	---	--	9	6 1	6	1 9	1 2	17	5 0	1 0	4	3 1	38	18	52	7 2	--	14	2

Syosset

April 24 1970																				
Precipitation	--	0 41	--	0 1	11	0 3	0 6	0 6	12	19	3 0	3 5	0 63	56	28	73	6 4	11	--	--
Inflow ---	1220	---	0 03	8	7 6	1 0	1 2	7	20	8 2	2 5	2 8	82	40	23	62	6 8	5	--	--
	1225	---	41	1 3	13	1 0	1 2	7	33	7 5	2 3	1 9	1 1	48	36	80	6 9	5	--	--
	1230	---	1 44	1 7	17	1 4	1 7	9	44	8 6	2 5	2 7	1 1	52	48	102	7 0	4	--	--
	1240	---	1 16	1 7	16	2 3	3 9	1 3	27	20	7 5	6 6	1 8	90	50	131	6 6	14	--	--
	1250	---	90	1 7	16	2 9	4 4	1 4	26	24	9 8	11	2 7	118	52	145	6 6	14	--	--
	1300	---	57	1 7	17	2 8	4 2	1 4	27	25	9 6	9 8	2 8	101	54	140	6 6	9	--	--

Deer Park

March 12, 1970																				
Inflow ---	1955	---	0 13	1 6	10	1 3	12	2 0	27	19	17	3 5	--	81	30	130	7 1	33	--	--
	2010	---	13	1 0	12	2 1	11	1 9	23	28	16	4 6	--	97	38	142	6 7	36	--	--
	2025	---	41	1 2	12	2 3	8 7	1 6	21	30	12	4 4	--	88	40	128	6 7	33	--	--
	2035	---	47	1 6	11	1 9	7 2	1 3	21	25	10	3 9	--	73	36	112	6 7	34	--	--
	2045	---	53	1 8	9 9	1 7	6 4	1 2	10	21	8 4	3 4	--	73	32	98	6 8	36	--	--
	2055	---	50	1 8	9 0	1 5	5 8	1 0	20	19	7 0	3 0	--	63	28	88	6 8	29	--	--
March 13, 1970																				
Inflow ---	1315	---	00	1 0	5 9	9	5 0	6	14	12	6 0	3 1	--	44	18	66	6 5	14	--	--
June 26 1970																				
Precipitation	--	0 58	--	2	8 0	1	5	5	8 0	12	1 5	3 0	0 23	44	20	58	6 4	18	--	--
Inflow ---	--	---	--	4 8	14	1 6	4 0	1 9	40	12	13	5	36	73	42	116	7 3	49	--	--
	--	---	--	5 6	15	1 2	4 3	1 9	36	13	10	2	52	70	42	119	7 4	42	--	--
	--	---	--	6 8	17	7	4 0	1 6	40	7 5	11	2 2	44	72	46	116	7 4	37	--	--
	--	---	--	6 4	18	9	4 1	1 9	36	9 5	20	1 3	46	81	48	127	7 2	46	--	--
	--	---	--	6 4	18	9	4 2	1 8	40	9 5	12	1	35	74	48	121	7 3	39	--	--
	--	---	--	6 2	16	1 0	4 3	2 0	44	9 5	12	4	50	74	44	125	7 3	41	--	--
August 17 1970																				
Precipitation	--	39	--	4	13	7	2	1	12	18	3 6	5 4	28	60	36	91	6 5	14	7	2
Inflow ---	1630	---	5 01	2 2	20	5 2	4 0	4 5	70	20	4 5	7 6	2 2	136	72	132	6 5	33	13	4
	1635	---	4 90	1 4	12	4 3	1 2	2 5	46	10	2 0	7 2	3 3	82	48	79	6 6	25	11	4
	1640	---	5 23	1 5	9 8	3 3	1 1	2 2	34	15	2 3	6	4 3	66	38	82	6 5	21	25	8
	1650	---	4 40	1 2	7 0	1 8	1 0	2 3	18	26	2 2	6 9	6 6	64	30	75	6 4	8	6	3
	1700	---	4 80	1 2	5 0	1 4	1 5	1 9	10	13	3 3	7 4	5 2	35	18	64	6 5	7	5	2
	1710	---	1 62	1 4	5 0	1 4	1 3	2 0	4	27	3 0	6 3	7 3	47	18	66	6 2	11	5	2
	1720	---	81	1 2	9 0	1 3	1 5	2 1	4	26	4 5	1	5 2	48	28	62	6 2	10	5	2
	1730	---	42	1 0	5 0	1 3	1 6	2 1	4	15	3 2	7 4	3 4	46	18	65	6 1	38	6	2
	1740	---	29	9	4 8	1 2	1 7	2 1	4	15	3 2	7 6	2 8	41	17	63	6 3	22	5	2
	1750	---	21	1 0	4 5	1 2	1 7	2 3	4	14	2 9	7 2	2 0	44	16	64	6 1	18	5	2
	1800	---	17	9	5 0	1 2	1 7	2 2	4	11	3 1	7 5	1 4	45	18	64	6 4	11	5	2

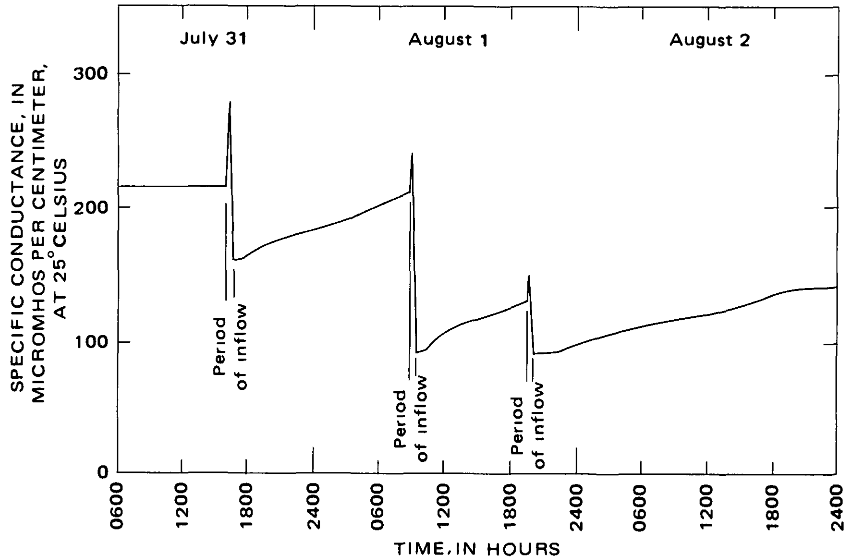

FIGURE 27 — Fluctuation in the specific conductance of inflow, during three successive rainfalls at Syosset recharge basin, July 31 to August 2, 1970

TABLE 16 — *Maximum and minimum specific conductance of inflow to Westbury, Syosset, and Deer Park recharge basins during selected storms in 1970*

Basin	Date[1]		Specific conductance (micromhos per cm at 25°C) Maximum	Minimum
Westbury	Oct	3	115	60
		15	105	25
		21	175	50
		22	145	95
	Nov	3	125	90
		13	155	25
		15	90	10
		19	130	110
	Dec	16	120	15
		18	270	115
Syosset	July	16	190	50
		31	290	160
	Aug	1	250	90
		1	145	90
	Sept	27	150	35
	Oct	3	140	85
		15	145	25
		22	130	85
		22	130	95
	Nov	4	170	30
	Dec	11	175	30
Deer Park	Sept	27	160	45
	Oct	3	125	115
		15	215	70
		22	165	130

[1]Duplicate dates for Syosset recharge basin indicate that two separate storms occurred on the same day

The total load of dissolved solids, estimated from analyses of the sampled inflow, was 2 4 lb at the Westbury basin, 16 2 lb at the Syosset basin, and 46 7 lb at the Deer Park basin The dissolved constituents in the precipitation accounted for 70 percent of the total inflow load at the Westbury basin, 88 percent at the Syosset basin, and 86 percent at the Deer Park basin

TABLE 17 — *Load of dissolved solids from precipitation and inflow at Westbury, Syosset, and Deer Park recharge basins during selected storms in 1970*

	Westbury April 24	Syosset April 24	Deer Park August 17
Precipitation ------ inches --	0 20	0 41	0 38
Total inflow			
Cubic feet ------	530	3 460	12,800
Percentage of precipitation ------	5 0	8 0	7 9
Inflow sampled			
Cubic feet ------	480	2 450	12,200
Percentage of total inflow ------	90 1	70 8	95 3
Load in precipitation ------ pounds --	1 67	14 2	40 2
Load in inflow			
Sampled ------ pounds --	2 2	11 9	46 5
Estimated total ------ pounds --	2 4	16 2	46 7
Percentage of precipitation load to total load ------	70	88	86

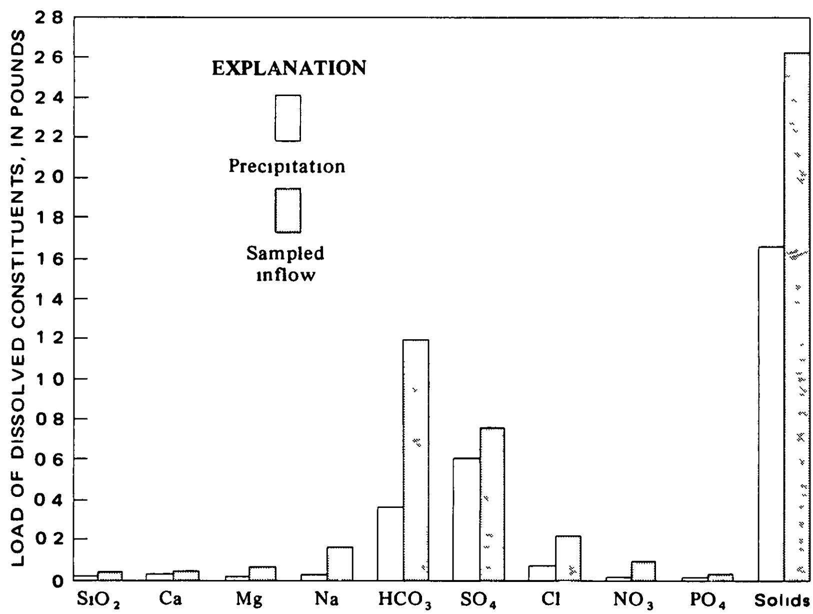

FIGURE 28 — Comparison of the load of dissolved constituents in precipitation and sampled inflow for the storm on April 24, 1970, at Westbury recharge basin

RELATION OF INFLOW QUALITY TO GROUND-WATER QUALITY

Quality of ground water in parts of Nassau and Suffolk Counties has deteriorated substantially because of domestic and industrial wastes entering the system through cesspools, septic tanks, and recharge basins (Heath and others, 1966, Perlmutter and Lieber, 1970) In 1971, the dissolved-solids content of shallow ground water ranged from 30 to 1,100 mg/l in selected areas of Nassau County but was commonly about 200 mg/l (N M Perlmutter and Ellis Koch, written commun , 1971)

Chemical quality of ground water of Long Island under natural conditions was determined from analysis of about 200 water samples collected during 1948–53 from wells tapping the shallow aquifer near the

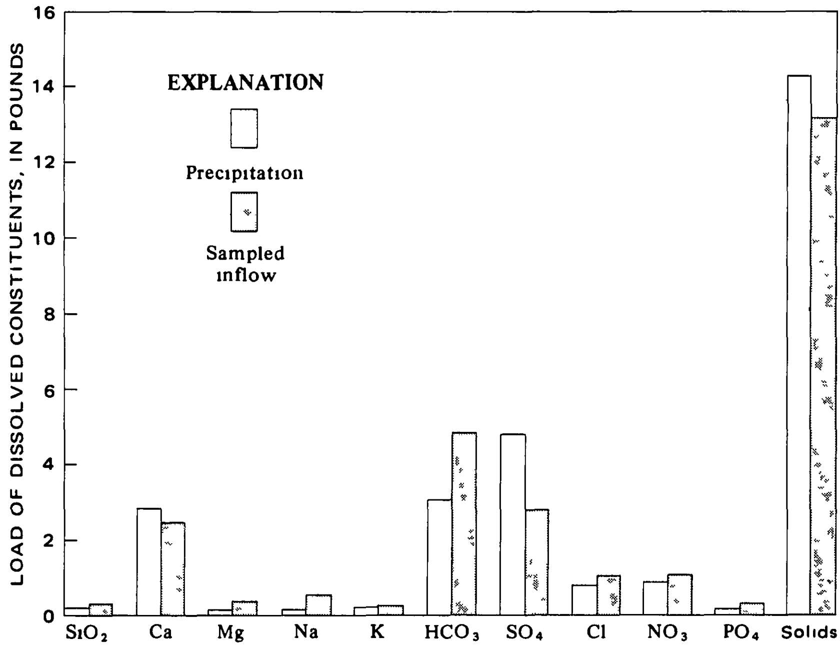

FIGURE 29 — Comparison of the load of dissolved constituents in precipitation and sampled inflow for the storm on April 24, 1970, at Syosset recharge basin

Brookhaven National Laboratory — an area still (1971) relatively rural (See fig 1) The dissolved-solids content of those samples ranged from 26 to 59 mg/l (de Laguna, 1964, p D23)

The dissolved-solids content of recharge water at Westbury, Syosset, and Deer Park recharge basins generally ranged from 30 to 150 mg/l Concentrations of chloride, nitrate (as NO_3), and total phosphate (as PO_4) of the water samples listed in table 14 are generally less than 10 mg/l; the samples represent precipitation and runoff from lawns and gardens in the drainage area Sulfate content, which is derived mainly from precipitation, ranged from 3 to 29 mg/1 but was generally about 20 mg/1 Other constituents in the water entering the three recharge basins are described in the following text

TOTAL ORGANIC CARBON

Dissolved organic material in inflow to recharge basins, reported in table 15 as total organic carbon, is derived mainly from asphalt, oil, grease, insecticides, and plant and animal debris Some organic aerosols may be washed from the atmosphere by precipitation Excepting highly polluted or strongly colored water, the organic-carbon content of ordinary river or lake water is about 10 mg/l (Hem, 1970, p. 215) Total organic carbon and inorganic carbon determined for samples of precipitation and inflow collected during two storms (table 15) show that the total organic-carbon content ranged

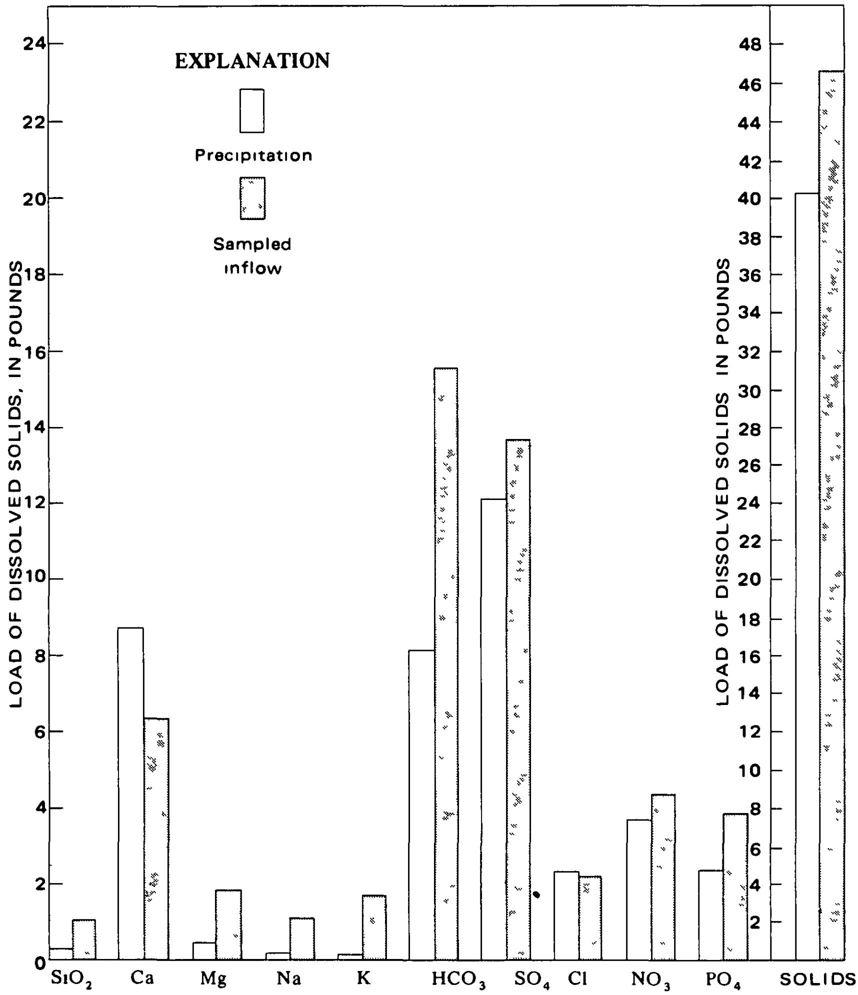

FIGURE 30 — Comparison of the load of dissolved constituents in precipitation and sampled inflow for the storm on August 17, 1970, at Deer Park recharge basin

from 5 to 25 mg/l These analyses also indicate that the total organic-carbon content is greater at the beginning of a storm than at the end, because precipitation flushes the atmosphere and the drainage area

MBAS

The MBAS (methylene blue active substance, commonly used as a measure of the surfactants ABS, alkyl benzene sulfonate, and LAS, linear alkylate sulfonate) content of precipitation collected at the three recharge basins ranged from 0 08 to 0 29 mg/l The MBAS content of inflow to the basins ranged from 0 08 to 0 61 mg/l and averaged 0 29 mg/l at Westbury, 0 17 mg/l at Syosset, and 0 25 mg/l at Deer park In comparison, the

MBAS content of ground water from the upper glacial aquifer in the sewered area of Nassau County averaged 0 16 mg/l, and in the unsewered area it averaged 0 36 mg/l (Perlmutter and Koch, 1971) However, because of interfering substances in the precipitation (American Public Health Association, 1971, p 340), it is not certain that the indicated MBAS content is due to surfactants

PESTICIDES

The term "pesticides" refers, in general, to all herbicides, insecticides, and fungicides In this study, analysis was limited to eight chlorinated hydrocarbon insecticides (aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, and lindane) and three herbicides (silvex, 2, 4—D, and 2, 4, 5—T) Local residents and professional exterminators use these materials in the form of dusts, wettable powders, or solutions to control house and garden pests Pesticides are generally insoluble in water but moderately to freely soluble in organic solvents such as alcohol, oil, or acetone (Pressman, 1963, p 367—371) The persistence, or time required for total decomposition of pesticides in soils and water ranges widely from days to many years (Pressman, 1963, Van Middelem, 1966, and U S Public Health Service, 1970) Breakdown and mechanical dispersion of these compounds depend on factors such as temperature, light, humidity, air movement, volatility of the compounds, and microbiologic activity (Van Middelem, 1966) Of these, microbiologic activity is the most important and complex because it involves chemical breakdown of compounds as well as concentration and accumulation of compounds in plant and animal tissues Estimates of the amounts of pesticides applied differ widely and are difficult to make because of the wide variety of products used The general public's lack of knowledge about the effectiveness of each product commonly results in gross overapplication of certain products by many users Spring and early summer are the periods of most intensive use

Pesticides carried into the recharge basin from the drainage area by storm runoff are mixed with water, dissolved in organic solvents, or are sorbed on sediment particles Wilson (1970, p 132) and Tarrant and Tatton (1968, p 725—727) have shown that pesticide dusts are transported through the atmosphere and are deposited on drainage areas by precipitation or as dry fallout In the present study, no attempt was made to determine pesticide contribution from these separate sources

A composite sample of inflow was collected at each recharge basin during selected storms Concentrations of various pesticides in unfiltered samples were determined Data in table 18 show that DDT was present in each sample DDD and silvex were present in the sample collected at the Westbury basin but were not present in the samples collected at Syosset and Deer Park basins All the samples were collected in late summer Presumably, inflow water would contain higher concentrations in spring and early summer than in late summer

TABLE 18 — *Pesticides in inflow to Westbury, Syosset, and Deer Park recharge basins during selected storms in 1970*

[Analyses, in micrograms per liter, by U S Geological Survey]

		Westbury September 27	Syosset August 23	Deer Park August 17
Time[1]	hours	1245	1355	1720
Precipitation	inches	85	1 10	38
Pesticides				
Aldrin		0	0	0
DDD		02	0	0
DDE		0	0	0
DDT		08	01	01
Dieldrin		0	0	0
Endrin		0	0	0
Heptachlor		0	0	0
Lindane		0	0	0
2,4,-D		0	0	0
2,4,5-T		0	0	0
Silvex		01	0	0

[1]Samples were collected near peak inflow from storm inflow stored in recharge basin

TABLE 19 — *Pesticides in deposits collected from the floors of Westbury, Syosset, and Deer Park recharge basins in 1970*

[Analyses in micrograms per liter, by U S Geological Survey]

	Westbury November 12	Syosset November 12	Deer Park August 17
Aldrin	0	0	0
DDD	2,800	6,400	140
DDE	5,000	14 000	30
DDT	24,000	19,000	180
Dieldrin	56	129	39
Endrin	7 5	16	0
Heptachlor	300	250	0
Lindane	0	87	0

The concentration of each of several chlorinated hydrocarbon insecticides (aldrin, DDD, DDE, DDT, dieldrin, endrin, heptachlor, and lindane) in samples of material from the soil zone in each recharge basin was determined (table 19) Concentrations of DDD, DDE, and DDT in all three soil samples are several orders of magnitude higher than those in inflow samples For example, the DDT content of soil samples from each of the three basins ranges from 18,000 to 300,000 times the concentration of sampled inflow water to the basins These compounds are especially persistent and degrade slowly in nature (Pressman, 1963, p 367–371)

The translocation of pesticides in recharge basins is beyond the scope of this preliminary study, however, several observations can be made from the data reported here

1 The only known sources of pesticide contamination in recharge basins are storm-water inflow from the contributing drainage area and dry fallout Representative samples of inflow water showed low concentrations of certain pesticides Presumably, higher concentrations of pesticides are flushed into the recharge basin during spring and early summer, the periods of most frequent pesticide use, than during fall and winter
2 Large amounts of pesticides in bottom deposits suggest that pesticides concentrate in the soil layer, which is rich in organic matter

3 The quantity of pesticides infiltrating the soil layer and percolating through the underlying deposits to the water table seemingly is negligible Because of manmade organic material in the soil layer of each recharge basin (table 4), pesticides are probably sorbed or filtered out in the soil layer and effectively removed from the infiltrating water N M Perlmutter (written commun , 1971) found virtually no pesticides in water from shallow wells on Long Island Similarly, little or no pesticides were found in shallow wells in Kansas (Knutson and others, 1971), reportedly also because the pesticides were retained on organic material in the soil zone

4 All the pesticides reported except endrin and heptachlor persist in soils for about the same length of time as DDT (Pressman, 1963, p 368–377) As a result, the relative concentrations probably indicate preferential use of certain compounds Endrin and heptachlor reportedly disappear rapidly in soils, and their detection in the soil layer at Westbury and Syosset suggests that they may be used just as much as the other pesticides

5 Concentrations of DDT in each basin correlate well with the relative age of each basin That is, the older basins, Westbury and Syosset (17 and 14 yr old in 1971, respectively), contain much higher concentrations of DDT than the Deer Park basin (4 yr old in 1971)

EFFECTS OF RECHARGE BASINS ON THE HYDROLOGY OF LONG ISLAND

Basic physical data pertaining to recharge basins in operation on Long Island in 1969 (Seaburn and Aronson, 1971) and the information developed here will help in an evaluation of present and future effects of recharge basins on the hydrology on Long Island (See tables 20 and 21)

Data were obtained for 2,124 basins, about 95 percent of the basins on Long Island in 1969 Of these, 1,704 basins drained residential areas, 366 drained highways, and 54 drained commercial and industrial areas

The average drainage area of all recharge basins is estimated to be 34 4 acres Therefore, the total area of Long Island that drains to recharge basins is estimated to be 73,000 acres This area amounts to about 114 square miles, or about 10 percent of the total land area of Nassau and Suffolk Counties

Distribution of recharge basins on Long Island is shown on plate 1 Density of recharge basins generally ranges from 0 1 basin per square mile in the eastern towns of Suffolk County to 4 basins per square mile in the town of Smithtown For Nassau and Suffolk Counties, the average is 1 6 basins per square mile

In the future, most basins will be built on presently undeveloped land in the two counties and primarily on agricultural and forested areas in eastern Suffolk County Ultimately, the total number of recharge basins on Long

TABLE 20 — *Recharge basins classified by type of drainage area*

Town (fig 2) or governing agency	Residential	Highway	Commercial	Industrial
Town of				
Babylon	94	2	1	1
Brookhaven	425	42	4	6
East Hampton	3	0	0	0
Huntington	287	10	7	1
Islip	187	7	0	0
Nassau County	481	46	20	10
Riverhead	12	0	0	0
Smithtown	193	3	2	2
Southold	5	0	0	0
Southampton	17	0	0	0
New York State Parkway Commission	0	41	0	0
New York State Department of Transportation	0	215	0	0
Total	1,704	366	34	20

Island will probably be about 5,000, more than double the present number This estimate was based on the assumptions that (1) current zoning laws governing the use of recharge basins will not be changed and (2) maximum density of recharge basins in Nassau and Suffolk Counties will approach the present maximum density of about four basins per square mile

GROUND-WATER RECHARGE

NATURAL CONDITIONS

Under natural conditions, precipitation, the ultimate source of all ground-water recharge on Long Island, was consumed by evapotranspiration, infiltration, and percolation to the water table, or runoff to nearby streams or tidewater The areas now draining to recharge basins are mainly underlain by surficial deposits of moderate to high hydraulic conductivity, therefore, under natural conditions, the amount of direct runoff to streams from these areas would have been small — about 5 percent of the total streamflow (Pluhowski and Kantrowitz, 1964, p 34–35) Evapotranspiration was estimated to have been 45 to 50 percent of the annual precipitation (Pluhowski and Kantrowitz, 1964, p 38) Thus, under natural conditions, roughly 50 percent of the average annual precipitation recharged the ground-water reservoir

The average annual precipitation between 1951 and 1965 was about 43 inches (Miller and Frederick, 1969, p A13) Therefore, under natural conditions the average annual recharge resulting from infiltration of precipitation on the 73,000 acres that presently drain to recharge basins would have been about 131,000 acre-feet per year, or about 117 mgd (million gallons per day)

URBANIZED CONDITIONS

At present, ground-water recharge in the areas drained by recharge basins results mainly from the infiltration of precipitation on areas such as lawns and other open spaces and by the infiltration of the inflow to the recharge basins Additional recharge results from the recycling of water used for domestic and industrial purposes through cesspools, septic tanks, and recharge wells, and from the infiltration of some of the water used to irrigate lawns (Heath and others, 1966, p 4–10)

TABLE 21 — *Miscellaneous physical data on recharge basins in Nassau*

Town (fig 2) or governing agency	Number of basins cataloged	Density (basins per sq mi)	Basin capacity		
			Total (cu ft)	Number of basins	Average (cu ft)
Town of					
Babylon	98	1 38	--	--	--
Brookhaven	477	1 46	71,488,000	231	309,500
East Hampton	3	04	--	--	--
Huntington	305	3 25	44,150 000	167	264,400
Islip	194	1 42	30,118,000	113	266,500
Nassau County	557	1 77	172,938,000	454	380,900
Riverhead	12	18	--	--	--
Smithtown	200	3 71	49,413,000	156	316,800
Southold	5	09	--	--	--
Southampton	17	10	--	--	--
New York State Parkway Commission	41	--	--	--	--
New York State Department of Transportation	215	--	--	--	--
Totals	2,124	(1)	368,107,000	1,121	328,400

[1]Basin density throughout Nassau and Suffolk Counties is 1 6 basins per square mile
[2]This is assumed to be the average number of acres of each of the 2,124 basins on Long Island

A rough preliminary estimate of the total net groundwater recharge from precipitation in the areas draining to recharge basins was based on the assumption that the average percentage of precipitation resulting in inflow to recharge basins is roughly equivalent to the percentage of street area in the drainage area For residential areas, 15 percent of the precipitation was assumed to result in inflow to recharge basins This assumed percentage is slightly higher than the percentages reported in table 5, because the reported percentage of street area in most residential areas on Long Island ranges from 10 to 20 percent (Nassau-Suffolk Regional Planning Board, 1968) For highways and commercial and industrial areas, 70 percent of precipitation was assumed to result in inflow to recharge basins. This percentage was based on design information from local agencies and on the fact that the percentage of streets and parking areas in these areas ranges from 50 to 100 percent It was further assumed that 50 percent of the remaining precipitation is consumed by evapotranspiration and 50 percent infiltrates the ground and eventually recharges the ground-water reservoir

Using these qualifying assumptions, separate estimates were made of the amount of water recharged through basins (table 22) and the amount of water recharged through lawns and other open areas (table 23) for the total areas draining to recharge basins in 1969

TABLE 22 — *Estimated ground-water recharge through recharge basins in 1969*

	Number of basins	Average drainage area (acres)	Percentage of precipitation collected in basins	Average annual precipitation (feet)	Estimated ground water recharge (acre feet)
Residential	1,704	34 4	0 15	3 6	31,700
Highway	366	34 4	70	3 6	31,700
Commercial	34	34 4	70	3 6	3 000
Industrial	20	34 4	70	3 6	1,700
Total					68,100 (60 8 mgd)

and Suffolk Counties, Long Island, classified by town or governing agency

Basin area			Maximum infiltration area			Drainage area		
Total (sq ft)	Number of basins	Average (sq ft)	Total (sq ft)	Number of basins	Average (sq ft)	Total (acres)	Number of basins	Average (acres)
2,652,000	92	28,800	--	--	--	--	--	--
10,962,000	250	43,800	6,730,000	231	29,100	5,500	145	37 9
--	--	--	--	--	--	--	--	--
8,097,000	210	38,600	4,114,000	168	24 500	3,100	95	21 6
4 532,000	129	35,100	2,969,000	114	26,000	1,900	84	22 6
31 238 000	333	93 800	29,756,000	523	56 900	9 000	238	37 8
--	--	--	--	--	--	--	--	--
7 208 000	164	44,000	4 978 000	156	31 900	2 800	86	32 6
--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--
22 939,000	170	134,900	--	--	--	--	--	--
87 628 000	1 348	65,000	48 547,000	1,192	40 700	22 300	648	[2]34 4

The ground-water recharge resulting from precipitation on the area drained by 2,124 recharge basins in 1969 is estimated to be 166,000 acre-feet, or about 148 mgd These computations are necessarily rough, but, in areas where recharge basins are used to dispose of storm water, they suggest that ground-water recharge from precipitation is probably equal to and may slightly exceed recharge under natural conditions

Total ground-water recharge in the areas drained by recharge basins also includes domestic and industrial waste effluent from leaching ponds, cesspools, septic tanks, and recharge wells, as well as some of the water used to irrigate lawns and gardens This component of the total recharge represents a return of pumped water to the ground-water reservoir Insufficient data are available to estimate the volume of water recharged in this manner, but it is probably 40 to 70 percent of total pumpage in Nassau and Suffolk Counties Pumpage in 1969 was estimated to be 300 mgd Therefore, recharge of pumped water was 120 to 210 mgd, in 1969

TABLE 23 — *Estimated ground-water recharge through lawns and open spaces in the drainage areas of recharge basins in 1969*

	Number of basins	Average drainage area (acres)	Percentage precipitation not collected in basins	Estimated percentage of water recharged	Average annual precipitation (feet)	Estimated ground water recharge (acre feet)
Residential	1,704	34 4	0 85	0 50	3 6	89,700
Highway	366	34 4	30	50	3 6	6 800
Commercial	34	34 4	30	50	3 6	600
Industrial	20	34 4	30	50	3 6	400
Total						97 500 (87 1 mgd)

SUMMARY

Three recharge basins, selected as representative of more than 2,100 recharge basins in operation on Long Island in 1971, were instrumented for detailed study to define (1) Precipitation-inflow relations, (2) inflow-hydrograph features, (3) rates of infiltration, and (4) water quality of precipitation and inflow to each recharge basin

Two basins are in Nassau County, and one is in Suffolk County They drain suburban residential areas. The drainage areas of Westbury and Syosset recharge basins, 15 0 and 28 8 acres, respectively, are fully developed, that is, house construction and land development are complete The drainage area of Deer Park recharge basin is 118 acres and in 1971 was not yet completely developed with houses.

Particle-size distribution and organic-carbon content of deposits from the floors of the three recharge basins indicate that large quantities of silt or finer-sized material and organic matter are filtered out of the water in the soil layer. This accumulation of material in the soil layer governs the infiltration characteristics of the basins, inasmuch as the underlying natural deposits are highly permeable sand and gravel

The average percentage of precipitation resulting in inflow to each basin was 12 percent for the Westbury basin, 10 percent for the Syosset basin, and 7 percent for the Deer Park basin These values approximate the percentage of street area in the drainage areas of each basin, that is, 11 for Westbury, 13 for Syosset, and 11 for Deer Park

Inflow to Syosset and Deer Park recharge basins was proportionately less than inflow to Westbury recharge basin because of the many open-bottomed catch basins in the drainage systems of Syosset and Deer Park basins These catch basins act as small recharge pits that individually recharge some storm runoff through their bottoms Inflow to Deer Park recharge basin was proportionately less than inflow to Westbury or Syosset recharge basins because house construction in the Deer Park drainage area was not completed, and the outlying parts of the drainage area were contributing little runoff to the basin

The inflow unit hydrograph for each recharge basin is typical of the runoff hydrograph for an urban area — steeply rising and falling limbs, sharp peaks, and short time bases. Because construction of houses is complete in the Westbury and Syosset drainage areas, shapes and sizes of the unit hydrographs for those basins should not change However, shape and size of the unit hydrograph for the Deer Park basin may be expected to change because of future house construction At the Deer Park basin, the width of the base of the unit hydrograph will broaden as a result of longer traveltimes of storm runoff from the outlying areas and because of increased volumes of inflow from the additional impervious areas The peak of the unit hydrograph may increase, decrease, or remain the same, depending on the combined effects of physical changes in the drainage area resulting from additional construction

Westbury, Syosset, and Deer Park basins are typical of most recharge basins on Long Island They effectively dispose of storm water Infiltration rates computed from data collected during 63 storms at the Westbury recharge basin between July 1967 and May 1970 ranged from 0 3 to 1 7 fph and averaged 0 9 fph Infiltration rates computed from data collected during 22 storms from July 1969 to September 1970 at the Syosset recharge basin ranged from 0 3 to 1 8 fph and averaged 0 8 fph At the Deer Park recharge basin, infiltration rates computed from data collected during 24 storms from March to September 1970 ranged from 0 1 to 0 5 fph and averaged 0 2 fph The comparatively low infiltration rates computed from the Deer Park data are caused by (1) the large amount of eroded silt, clay, and organic debris that has been washed into the recharge basin from the drainage area and that tends to fill the interstices of the natural deposits, and (2) a lack of a well developed root system from plant growth on the floor of the basin that would keep the soil zone loose and permeable

The infiltration rates at Westbury and Syosset basins increased in direct relation to increases in temperature and hydraulic head (or depth of stored water in the basin) Similar relations were not apparent from the Deer Park data because the infiltration rates were influenced by increased sediment loads during the period of data collection

The apparent rate of movement of storm water through the unsaturated zone below each basin averaged 5 5 fph at Westbury, 3 7 fph at Syosset, and 3 1 fph at Deer Park The rates of movement were slightly higher than average for storms from April through October, probably because of the lower viscosity of recharging water, which was warmer then than during the rest of the year

Observations of peak water-table rises associated with particular storms at Westbury, Syosset, and Deer Park showed that the relation is complex and is affected by many factors. On the average, a 1-inch rainfall caused a peak mound on the water table of about 0 5 foot, but a 2-inch rainfall caused a peak rise of about 2 feet The mound commonly dissipated within 1 to 4 days at Westbury, 7 days to more than 15 days at Syosset, and 1 to 3 days at Deer Park, depending on the relative magnitude of the peak buildup

Average annual ground-water recharge is estimated to be 6 4 acre-feet at Westbury recharge basin, 10 3 acre-feet at Syosset recharge basin, and 29 6 acre-feet at Deer Park recharge basin

Chemical composition of precipitation at Westbury, Syosset, and Deer Park drainage areas was similar hardness of water (as calcium and magnesium hardness) ranged from 6 to 56 mg/l, dissolved-solids content ranged from 21 to 124 mg/l and was generally less than 70 mg/l, and pH ranged from 5 9 to 6 6 Calcium was the predominant cation, and sulfate and bicarbonate were the predominant anions Atmospheric dust and gaseous sulfur compounds associated with the Northeast urban environment mainly account for this combination of ions in precipitation

Chemical composition of the inflow to the basin was also similar at each of the three basins In general, hardness of the water samples collected at Westbury, Syosset, and Deer Park recharge basins in 1970 was less than 50 mg/l (as calcium and magnesium hardness), and dissolved-solids content was less than 100 mg/l The pH ranged from 6.1 to 7 4 Most chemical constituents in inflow were slightly to moderately more abundant as compared with those in precipitation Precipitation contributed from 70 to 88 percent of the dissolved-solids load in the inflow of the sampled storm events

A maximum DDT concentration of 0 08 μg/l (micrograms per liter) was determined for an inflow sample to Westbury recharge basin; concentrations of DDT in the inflow to the Syosset and Deer Park recharge basins during one storm in late summer were 0.01 μg/l or less Higher concentrations of pesticides are expected in inflow during spring and early summer — the periods of most frequent pesticide use.

Total concentration of pesticides in the deposits on the floors of each basin generally ranged from 0 4 to 40 mg/l, or from 40,000 to 4 million times the concentration of pesticides in runoff to the basins Because of the high percentage of manmade organic material and silt and clay in the soil layer of each basin compared with the percentage in the underlying natural deposits (table 4), pesticides are probably sorbed or filtered out in the soil layer and effectively removed from the infiltrating water

The total area draining to recharge basins in 1969 was about 73,000 acres, or 114 square miles, or 10 percent of the land area of Nassau and Suffolk Counties Under natural conditions, the average annual recharge in that area was about 131,000 acre-feet, or about 117 mgd Average annual ground-water recharge resulting from inflow to the 2,124 recharge basins on Long Island in 1969 was estimated to be 68,100 acre-feet, or 61 mgd The recharge through the remaining lawns and open spaces of the areas drained by recharge basins was estimated to be 97,500 acre-feet per year, or about 87 mgd Total recharge from precipitation on the 73,000 acres drained by recharge basins is about 166,000 acre-feet per year, or 148 mgd Ground-water recharge from precipitation in the areas where recharge basins are used is probably equal to or slightly more than the amount of recharge that occurred in the same area under natural conditions

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