Effects of Urban Development on Direct Runoff to East Meadow Brook, Nassau County, Long Island, New York

GEOLOGICAL SURVEY PROFESSIONAL PAPER 627-B

Prepared in cooperation with the New York State Department of Conservation, Division of Water Resources; the Nassau County Department of Public Works; the Suffolk County Board of Supervisors; and the Suffolk County Water Authority

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By G. E. SEABURN

HYDROLOGY AND SOME EFFECTS OF URBANIZATION ON LONG ISLAND, NEW YORK

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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EFFECTS OF URBAN DEVELOPMENT ON DIRECT RUNOFF TO EAST MEADOW BROOK, NASSAU COUNTY, LONG ISLAND, NEW YORK

By G. E. Seaburn

ABSTRACT

The study described in this report is concerned with the effects of intensive urban development on direct runoff to East Meadow Brook, a southward-flowing stream in central Nassau County, N.Y., during the period 1937–66. The specific objectives of the study were (a) to relate indices of urban development to increases in the volume of annual direct runoff to the stream; (b) to compare hydrograph features at different periods during the transition of the drainage basin from rural to urban conditions; and (c) to compare the rainfall-runoff relations for periods before and after urban development.

Periods of housing and street construction in the drainage basin correspond to three distinct periods of increased direct runoff after the base period 1937–43—namely, 1944–51, 1952–59, and 1960–62. During each period, the average annual direct runoff increased because of an increase in the area served by storm sewers that discharged into East Meadow Brook. The amount of land served by sewers increased from about 570 acres in 1943 to about 3,600 acres in 1962, or about 530 percent. During this same period, the average annual direct runoff increased from about 920 acre-feet per year to about 3,400 acre-feet per year, or about 270 percent.

The shape of direct-runoff unit hydrographs of East Meadow Brook also changed during the period of study. The average peak discharge of a 1-hour-duration unit hydrograph increased from 313 cubic feet per second, for storms in 1937–43, to 776 cubic feet per second, for storms in 1960–62, or about 2.5 times. In addition, the widths of the unit hydrographs for 1960–62 at values of 50 and 75 percent of the peak discharge were 38 and 28 percent, respectively, the comparable widths of the unit hydrographs for 1937–43.

An analysis of the rainfall-runoff relations for both preurban and urban conditions indicates that the direct runoff for both periods increased with the magnitude of the storm. However, the direct runoff during a period of urbanized conditions (1964–66) was from 1.1 to 4.6 times greater than the corresponding runoff during the preurban period 1937–43, depending on the size of the individual storm.

The volume of direct runoff from the parts of the subarea equipped with storm sewers that discharged into East Meadow Brook is estimated to have been roughly 3,000 acre-feet per year in 1960–62, or about 20 percent of the precipitation on those parts of the area.

The increase in direct runoff probably represents a loss of ground-water recharge. However, because data changes in evapotranspiration are insufficient and because the effects of recharge basins are unknown, adequate quantitative estimates of ground-water recharge can not be made.

On the basis of the present zoning regulations and on assumption that an additional 320 acres in the Hempstead subarea will be serviced by storm sewers that discharge into East Meadow Brook, direct runoff from the subarea is expected to increase in the future to an estimated 4,000–4,500 acre-feet per year.

INTRODUCTION

Long Island, which extends northeastward from the the mainland of New York State about 120 miles into the Atlantic Ocean, has a total area of about 1,400 square miles (fig. 1). Two boroughs of New York City (Kings and Queens Counties) occupy slightly less than 200 square miles of the western part of the island and have a combined population of more than 4.5 million people. Nassau and Suffolk Counties have areas of about 300 and 900 square miles, respectively, and had a combined population of about 2.5 million people in 1965.

Although the New York City part of Long Island derives most of its water supply from upstate surface-water sources, the people of Nassau and Suffolk Counties derive their entire fresh-water supply from wells which tap the underlying ground-water reservoir. Because of present large demands on the local ground-water system and because of the prospect of increased demands, knowledge about the hydrologic system of Long Island—with special emphasis on water conservation and management—is of immediate concern to millions of people.

Much information is available about the water resources of Long Island as a result of studies made during the past 3 decades by the U.S. Geological Survey in cooperation with New York State and county agencies.

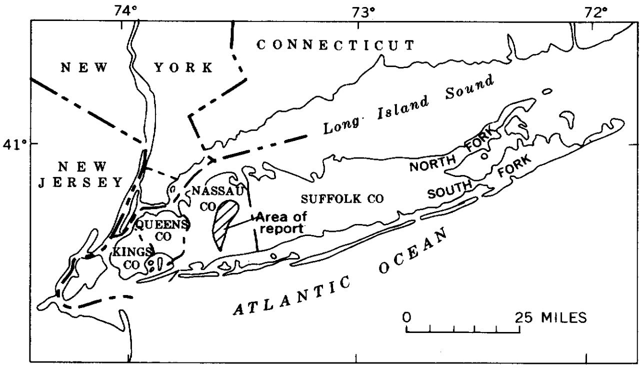

FIGURE 1.—Location of the East Meadow Brook drainage area.

Although those studies met many of the needs for information on specific problems and areas of Long Island, better quantitative information about the island-wide hydrologic system, and the relations between the various components of the system, is needed for water-management purposes. To provide that water information, a comprehensive water-budget study presently is being made by the U.S. Geological Survey in cooperation with the New York State Department of Conservation, Division of Water Resources; Nassau County Department of Public Works; Suffolk County Board of Supervisors; and the Suffolk County Water Authority. This report is one of a series resulting from the comprehensive water-budget study. The purpose and scope of the comprehensive study and of this report are discussed briefly below.

PURPOSE AND SCOPE OF THE WATER-BUDGET STUDY

The major objectives of the water-budget study are to summarize and interpret pertinent existing information about the hydrologic system of Long Island and also to fill several gaps in the knowledge of the hydrologic system. Some segments of this comprehensive study pertain to all of Long Island; other segments of the study, such as the one described in this report, pertain to only small areas of the island. However, the primary area of concern includes most of Nassau County and that part of Suffolk County west of the forks (fig. 1).

Separate reports that have been or will be prepared as a result of this study deal with (a) precipitation (Miller and Frederick, 1969), (b) streamflow, (c) transmissibility of aquifers (d) runoff to recharge basins, and (e) the increase in direct runoff to streams resulting from urban development (the present report). In addition, a final report is in preparation which will briefly summarize, the overall hydrologic situation on Long Island, with special reference to the water-management implications of the hydrologic analysis. The reports are being published as separate chapters of this publication series.

PURPOSE AND SCOPE OF THIS REPORT

This report deals with one aspect of the effect of man's activities on the hydrologic system—namely, increased direct runoff on Long Island resulting from urban development. The construction of impervious surfaces such as streets, parking lots, and buildings has been one of the major physical changes associated with urban development on Long Island, and the methods used to dispose of the large volumes of direct runoff from these impervious surfaces have had a significant impact on the hydrologic system of the island. Two major methods of storm-water disposal are employed in Nassau and Suffolk Counties: discharge through storm sewers directly into streams and ultimately into adjacent bays and the ocean; and discharge through storm sewers into nearby open pits (called recharge basins or sumps), from which most of the water infiltrates into the ground and ultimately recharges the ground-water reservoir. Direct runoff to recharge basins is the subject of another report in this report series (Seaburn, 1969).

The study described in the report was specifically concerned with the impact of urban development on direct runoff to East Meadow Brook in Nassau County during the past three decades (1937–66). The objectives of the study were: (a) to describe the urban development that has taken place in the East Meadow Brook drainage area (p. B4) during the last three decades and to relate this development to changes in the amount of annual direct runoff; (b) to evaluate changes in the runoff hydrographs of East Meadow Brook during this period; and (c) to study the relation between rainfall and runoff in the drainage area before and after significant urban development. Changes in the amount of direct runoff to streams is highly significant on Long Island inasmuch as part of the increased stream discharge associated with urban development represents a decrease in the amount of ground-water recharge.

LOCATION AND PERTINENT HYDROLOGIC FEATURES OF EAST MEADOW BROOK

East Meadow Brook, which is in south-central Nassau County about 8 miles from the Queens County–Nassau County border, is a southward-flowing stream which empties into a salt-water channel between Middle Bay and East Bay (fig. 2). The flow of the stream has been monitored continually since 1937 at a gaging station about 2 miles north of (upstream from) the salt-water channel (fig. 2). The control for the gaging station, a Columbus-type weir, and the gage house are immediately north of East Meadow Pond (pl. 1*B*). Water

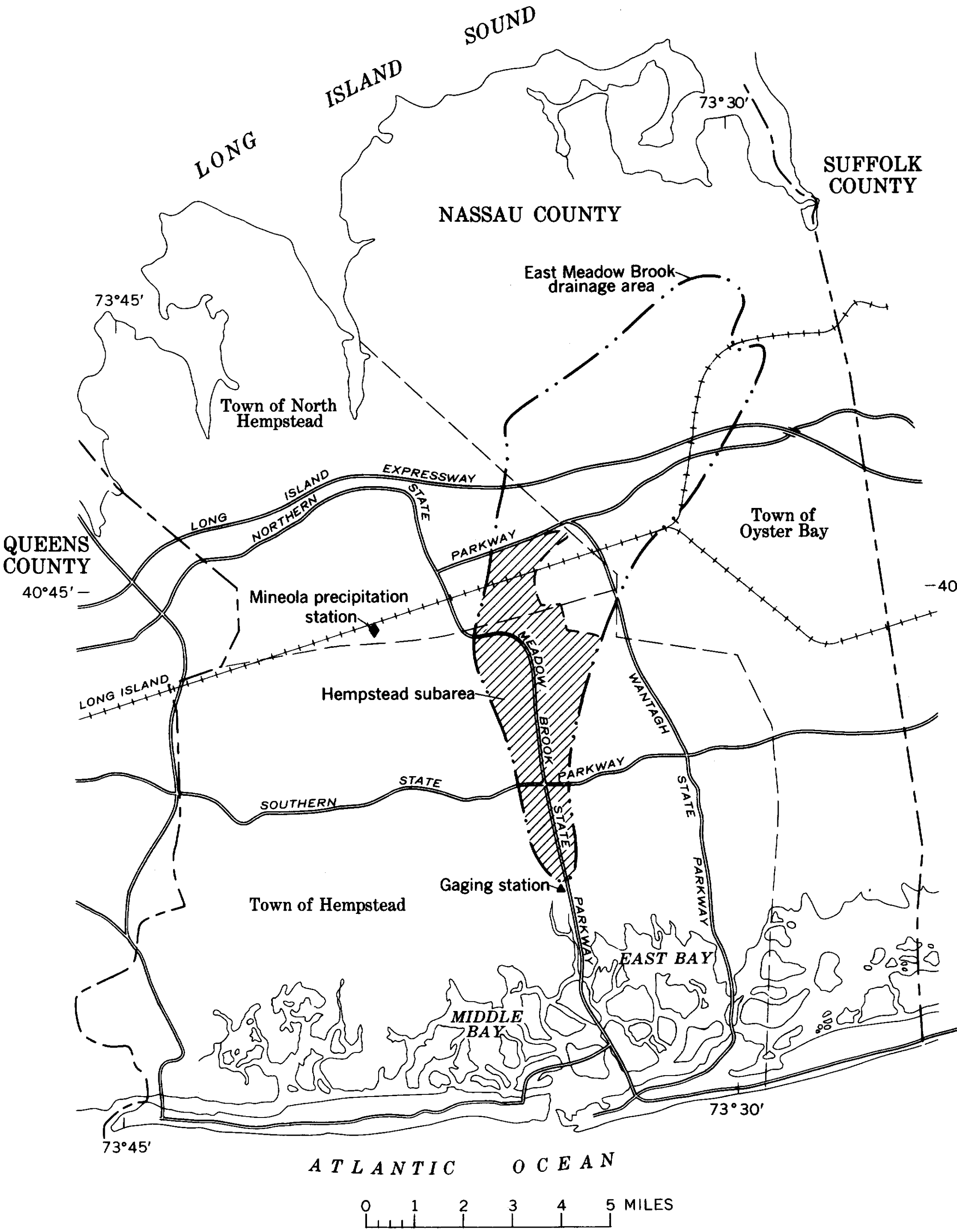

FIGURE 2.—Location of the East Meadow Brook drainage area and the Hempstead subarea.

flowing over the weir passes through the pond before discharging into other creeks and swampy areas between the gaging station and tidewater. The pond and the gaging-station control are unaffected by tides; however, during some storms high water levels in the pond have caused backwater at the control, thereby precluding the use of data for those periods in the present study.

The average discharge of East Meadow Brook for the period of record, water years[1] 1937–66, was about 17.5 cfs (cubic feet per second), or about 11.3 mgd (million gallons per day). Average monthly discharge for water years 1940–65 (fig. 3) ranged from a maximum of about

[1] The "water year" is defined as the 12-month period beginning October 1 and ending September 30.

21 cfs in April to a minimum of about 14 cfs in September. Information developed by Sawyer (1963) suggests that betwen 85 and 90 percent of the annual discharge in the past decade or so was derived from the ground-water reservoir, and direct runoff accounted for the remaining 10 to 15 percent.

The source of the stream is about 2.2 miles north of the gaging station. A well-defined channel (pl. 1*B*) extends about 2.4 miles above the source; however, this ephemeral channel carries water only during periods of storm runoff. The average slope of the stream channel is 12.4 feet per mile, and the average slope of the land surface is about the same. The stream has no tributaries of any consequence, but there are several artificial ponds on the perennial segment of the stream.

In accordance with the generally accepted meaning of the term "drainage area," the name "East Meadow Brook drainage area" (pl. 1) is used herein to designate the area upstream from the gaging station that is enclosed by the topographic drainage divide. (Langbein and Iseri, 1960, p. 8.) Because of several hydrogeologic features, most notably the highly permeable character of the surficial sand and gravel and the poorly developed drainage system in much of the drainage area, virtually all the direct runoff measured at the East Meadow Brook gaging station originates from roughly the southern one-third of the drainage area. Accordingly, urban development in the southern one-third of the drainage area, which is herein termed the "Hempstead subarea" (because it is located principally in the town of Hempstead) is emphasized in this report (pl. 1).

The East Meadow Brook drainage area comprises about 31 square miles. The part north of the Hempstead subarea, about 21 square miles, consists largely of forested estates; and virtually all the direct runoff in that part, even during intense storms, infiltrates into the ground or flows into small ponds. Moreover, storm water from several small housing developments north of the Hempstead subarea presently drains into recharge basins (pl. 1).

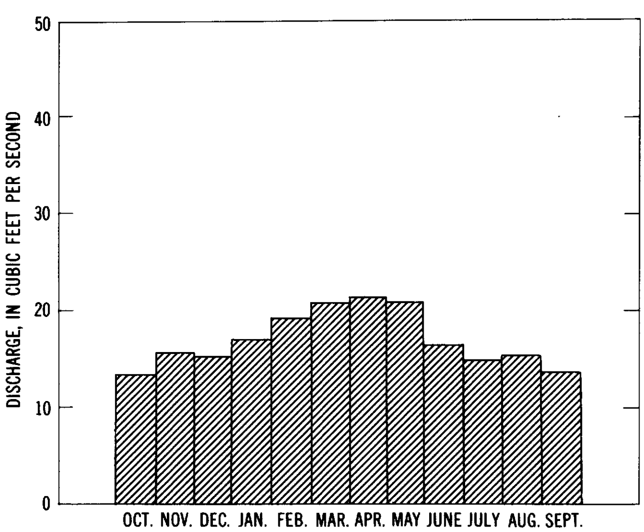

FIGURE 3.—Average monthly discharge of East Meadow Brook for water years 1940–65.

The total area of the Hempstead subarea, about 10 square miles in 1966, is south of the Northern State Parkway and is defined by a combination of topographic and storm-sewer boundaries. The shape and size of the subarea have changed from time to time because of the construction of recharge basins and the addition of new areas serviced by storm sewers. For the purposes of this study, however, the "effective drainage area" of the subarea (the area that drains directly into East Meadow Brook) has remained nearly constant since 1937.

DESCRIPTION AND SOURCES OF BASIC DATA

The basic data considered in this report are of two types: data pertaining to the hydrology of the area, and data pertaining to the degree of urban development. The types and sources of these data and other pertinent information are listed in table 1.

Continuous measurements of the flow of East Meadow Brook, recorded at the gaging station, are available since January 1937 except for a 13-month period from November 1962 to December 1963 when highway construction necessitated relocation of the station.

Precipitation data used in this report are from the Mineola precipitation station, which is about 3 miles west of the East Meadow Brook drainage basin. This is the closest station to East Meadow Brook for which reliable hourly precipitation data are available.

TABLE 1.—*Summary of types and sources of basic data*

Type of data	Source	Remarks
Hydrologic		
Precipitation (Mineola Station).	Nassau County Department of Public Works.	1937–40; original recorder charts.
	U.S. Weather Bureau	1941–66; published data.
Streamflow	U.S. Geological Survey	1937–66; original charts.
Urban development		
Population	U.S. Bureau of the Census	Published data by decade from 1920 to 1960, and a special census in 1965.
Maps or plans of storm sewers.	Town of Hempstead Engineering Department.	Complete record of sewer. drainage areas, outlets, and dates of installation.
	Nassau County Department of Public Works.	Record of sewered areas outside town of Hempstead.
Aerial photographs	National Archives and Records Service.	Flown in 1938.
	U.S. Department of Agriculture.	Flown in 1947.
	U.S. Geological Survey	Flown in 1953.
	Lockwood, Kessler and Bartlett, Engineers.	Flown in 1966.

RELATED INVESTIGATIONS

The geology and general hydrology of parts of Nassau County were studied intensively by Isbister (1966), Perlmutter and Geraghty (1963), and Swarzenski (1963). However, studies concerned with the effects of urbanization on the hydrologic system have been few, partly because the necessary data and methods of analysis have been available only for the last few years. Pluhowski and Kantrowitz (1964) studied the hydrology of part of southwestern Suffolk County and summarized the effects of urabanization on direct runoff to streams in that area. Sawyer (1963) compared direct runoff to East Meadow Brook and Mill Neck Creek, which drains a less developed area in northern Nassau County; he found that although the average annual precipitation between the periods 1938–51 and 1952–60 increased 9.4 percent, the average annual direct runoff to Mill Neck Creek increased only 7.2 percent whereas that to East Meadow Brook increased 15.8 percent. This large relative increase in direct runoff to East Meadow Brook was attributed to changes "in land surfaces from pervious to impervious as well as to the increase in precipitation" (Sawyer, 1963, p. C186).

Numerous investigators have studied the effects of urban development on different streamflow parameters in other areas. The investigations that were especially useful in the present study were those made by Waananen (1961), who studied changes in peak discharge and volume of runoff; Wiitala (1961), who studied the change in peak discharge, hydrograph shape, and total volume of runoff for two drainage areas; Harris and Rantz (1964), who compared the change in volume of runoff from an area affected by urbanization with that from an index or unaffected area; Crippen (1965), who studied the time lag between excess precipitation and runoff from a small drainage basin; and Carter (1961), who studied lag time as a function of basin characteristics.

ACKNOWLEDGMENTS

In this study, generous assistance and data were provided by several individuals and public agencies. In making available plans and data on the storm-drainage system of the town of Hempstead, Mr. Robert Plonsky, Civil Engineer, Department of Public Works, town of Hempstead, was especially helpful. Supplementary drainage data also were obtained from the Drainage Design Section, Nassau County Department of Public Works, which is under the direction of Chief Civil Engineer Francis X. Merklin, and under the supervision of Deputy Commissioner John H. Peters.

This report was prepared under the general direction of Garald G. Parker, district hydrologist, U.S. Geological Survey, Albany, N.Y., and under the immediate supervision of Bruce L. Foxworthy, hydrologist-in-charge, Long Island subdistrict.

HISTORY OF DEVELOPMENT IN THE EAST MEADOW BROOK DRAINAGE AREA

POPULATION

Although population data are not available specifically for the East Meadow Brook drainage area, the data listed in table 2 indicate the probable population trends in that area. The largest absolute increase in population occurred between 1950 and 1960, and, as is described subsequently, this was the period of most intense urban development in the East Meadow Brook drainage area.

Prior to and during World War II, urban growth in Nassau County was comparatively slow. After the war, a continuous wave of suburban development moved from west to east across Nassau County and into Suffolk County. This wave of development, which was manifested by the construction of single-family homes in large-scale housing developments, reached the East Meadow Brook drainage area about 1951. Building activity in the drainage area reached a peak in the mid-1950's but has continued to the present. Most of the urban development has centered in the Hempstead subarea of the drainage area—the area emphasized in this report.

AREA DRAINED BY STORM SEWERS

In the following paragraphs the history of urban development in the Hempstead subarea is considered in the context of four time periods—1937–43, 1944–51, 1952–59, and 1960–62—mainly because each of these periods is characterized by a different relationship between rainfall and runoff (p. B10). Aerial photographs that are reasonably representative of average conditions in each of these periods are shown on plate 1. The period

TABLE 2.—*Summary of population data for Nassau County, town of Hempstead, and the village of Westbury, 1920–65*

Year	Nassau County		Town of Hempstead		Village of Westbury	
	Number of people (thousands)	Percentage increase over previous entry	Number of people (thousands)	Percentage increase over previous entry	Number of people (thousands)	Percentage increase over previous entry
1920	126		71			
1930	303	140	187	164		
1940	407	34	259	39	4.5	
1950	673	65	432	67	7.1	58
1960	1,300	93	741	71	14.7	108
1965	1,393	7	813	10	14.6	−1

1937–43 is defined as the "base period," and subsequent changes in direct runoff associated with changes in urban development are related to that period.

The Hempstead subarea can be divided conveniently into three parts: a northern, a middle, and a southern part. The northern part is a part of the village of Westbury (pl. 1*B*). The middle part is a tract of about 2.5 square miles which extends eastward across the subarea; it consists almost entirely of an airfield and a park. The southern part of the Hempstead subarea, the area south of Hempstead Turnpike (pl. 1*B*), was almost entirely open fields and forests in 1937. Since 1937, most of the urban development in the East Meadow Brook drainage area has been in the southern part of the Hempstead subarea. This development has been characterized mainly by the construction of roads and housing developments, including the construction of storm sewers. All storm sewers in the Hempstead subarea discharge either into recharge basins or directly into the channel of East Meadow Brook; thus, none of the runoff is diverted outside of the East Meadow Brook drainage area.

Virtually no additional urban development took place from 1937 to 1943 in the Hempstead subarea (pl. 1*A*, *B*, *C*). The total sewered area in the subarea in 1943 was about 570 acres, and most of this area was in the village of Westbury. During the period 1944–51 (pl. 1*E*, *F*, *G*), about 150 additional acres in the Hempstead subarea were sewered, mainly to provide storm drainage for several new highways. As is described subsequently (p. B9), even this small increase in sewered area caused a clearly defined increase in direct runoff to East Meadow Brook.

The period 1952–59 (pl. 1*H*, *I*, *J*) was the time of most rapid urban development in the Hempstead subarea. The area drained by storm sewers discharging into East Meadow Brook increased by about 2,560 acres. Most of this increase was related to the construction of housing developments and additional highways.

During the years 1960–62 (pl. 1*K*, *L*, *M*), storm sewers that emptied into East Meadow Brook were constructed in about 315 additional acres in the Hempstead subarea. The marked decrease in sewer construction, compared with construction during the previous period, largely reflected the fact that by 1960 most of the available land in the subarea was already developed. In 1962 only about 320 acres in the Hempstead subarea, excluding the aforementioned park and airfield in the middle part, remained undeveloped and unsewered.

Increases in the acreage served by storm sewers draining into East Meadow Brook from the Hempstead subarea are summarized in table 3.

TABLE 3.—*Additions to the part of the Hempstead subarea served by storm sewers draining to East Meadow Brook, 1937–66*

Year	Additional sewered area (acres)	Year	Additional sewered area (acres)
1937		1953	404
1938		1954	628
1939	128	1955	453
1940		1956	
1941		1957	285
1942		1958	212
1943		1959	195
1944		1960	94
1945		1961	142
1946		1962	79
1947	11	1963	54
1948	6	1964	40
1949		1965	[1]
1950	134	1966	[1]
1951			
1952	383	1937–64 total	3,248

[1] No information available.

DEVELOPMENT IN A SAMPLE AREA

Urban development in a sample area of about 0.41 square mile (pl. 1*D*) in the southern part of the Hempstead subarea is representative of the development in the entire subarea during the study period, and, accordingly, that development is summarized briefly in the following text. In this sample area, which was largely farmland and woodland in 1937, the number of houses increased from about 200 in 1938 to 350 in 1947, to 620 in 1953, and to 760 in 1966. The impervious cover (streets, highways, parking lots, rooftops, and other surfaces) increased from 6.0 percent in 1938 to 7.8 percent in 1947, to 12.2 percent in 1953, and to 27.6 percent in 1966. The large increase in impervious cover between 1953 and 1966 resulted partly from the construction of parking lots at a new school and at a small factory. In this sample area, construction of storm sewers draining to East Meadow Brook was not begun until 1954, and 170 acres (about 65 percent) of the area was draining to that stream through sewers by 1966.

RECHARGE BASINS

During the period of study 1937–66, the drainage pattern in the East Meadow Brook drainage area, especially in the Hempstead subarea, was markedly modified as a result of the construction of recharge basins. One of the two major design functions of recharge basins is to dispose of storm drainage from impervious surfaces in newly created urban developments (Parker and others, 1967). Consideration of the other major function of the basins, artificial augmentation of the natural ground-water recharge, is beyond the scope of this report.

Since 1935, most new housing subdivisions in Nassu County have been required to construct recharge basins (Welsch, 1935) to dispose of the storm runoff. Few builders have been permitted to construct storm sewers which discharge directly into streams. The operation and maintenance of most of the basins is assumed by the Nassau County Department of Public Works soon after the basins are constructed. The number of these basins acquired by Nassau County in a given year is, therefore, an index of recent building activity. In 1966, there were about 100 basins in the East Meadow Brook drainage area (table 4), of which 7 were in the Hempstead subarea; most of the other basins were in the part of the drainage area north of the Hempstead subarea. Eighty-two basins were constructed in the period 1952–59, the period of most intense urban development in the drainage area.

With respect to this study, an especially pertinent fact is that the parts of the area draining into the recharge basins have been effectively removed as sources of direct runoff to East Meadow Brook.

TABLE 4.—*Recharge-basin acquisitions by the Nassau County Department of Public Works in the East Meadow Brook drainage area*

Year	Recharge basins acquired	Year	Recharge basins acquired
1937	0	1953	7
1938	0	1954	8
1939	0	1955	18
1940	0	1956	20
1941	1	1957	9
1942	0	1958	7
1943	0	1959	4
1944	0	1960	2
1945	1	1961	5
1946	0	1962	3
1947	1	1963	2
1948	1	1964	1
1949	2	1965	(1)
1950	0	1966	(1)
1951	8		
1952	9	1937-64 total	100

[1] No information available.

CHANGES IN DIRECT RUNOFF, 1937–62

VOLUME OF DIRECT RUNOFF

Urban development in the East Meadow Brook drainage area has caused several major changes in the flow characteristics of East Meadow Brook, including changes in the volume of annual direct runoff. To determine the volume of annual direct runoff, hydrographs of average-daily discharge for each water year were prepared. Daily values of base flow were estimated by using a procedure described by Chow (1964, p. 14–11). The daily values of base flow were then subtracted from corresponding values of total flow, and these differences were summed to obtain the annual volume of direct runoff.

Figure 4 shows a cumulative (mass) curve of annual direct runoff to East Meadow Brook and a cumulative curve of annual precipitation at Mineola for water years 1937–62. Neither of the curves shown in the figure was extended to 1966 because of the aforementioned 13-month break in the streamflow record of East Meadow Brook. Marked changes in the slope of the direct-runoff curve occurred in 1943, 1951, and 1959. These years divide the runoff record into four periods, each having similar rainfall-runoff relations. Moreover, each subsequent period had a larger volume of annual direct runoff than the preceding period.

As is shown by the following data, average annual precipitation at Mineola in the periods 1952–59 and 1960–62 was somewhat more than that in the periods 1937–43 and 1944–51.

Period	*Average annual precipitation (inches)*	*Percentage increase over 1937–43 average*
1937–43	43.7	----------
1944–51	43.9	0.6
1952–59	46.1	5.7
1960–62	46.7	7.0

However, a comparison of the two curves in figure 4 shows that the percentage increases in average annual precipitation are very small in relation to the percentage increases in average annual direct runoff for the same period (table 5). Therefore, increased precipitation can be disregarded as a major cause of the increased direct runoff.

Summary figures of average annual direct runoff for the four periods listed in the previous table, and the percentage increase in direct runoff for each period (compared with the base-period average for 1937–43), are listed in table 5. Also shown in table 5 are the total areas served by storm sewers that drained to East Meadow Brook at the end of each period, and the percentage increases in the sewered area for each period compared with the area at the end of the base period. The large increases in average annual direct runoff are clearly related to the increases in the total area serviced by storm sewers draining to East Meadow Brook. The major increases in 1952–59 reflect the rapid land and housing development that was taking place in the Hempstead subarea during that time.

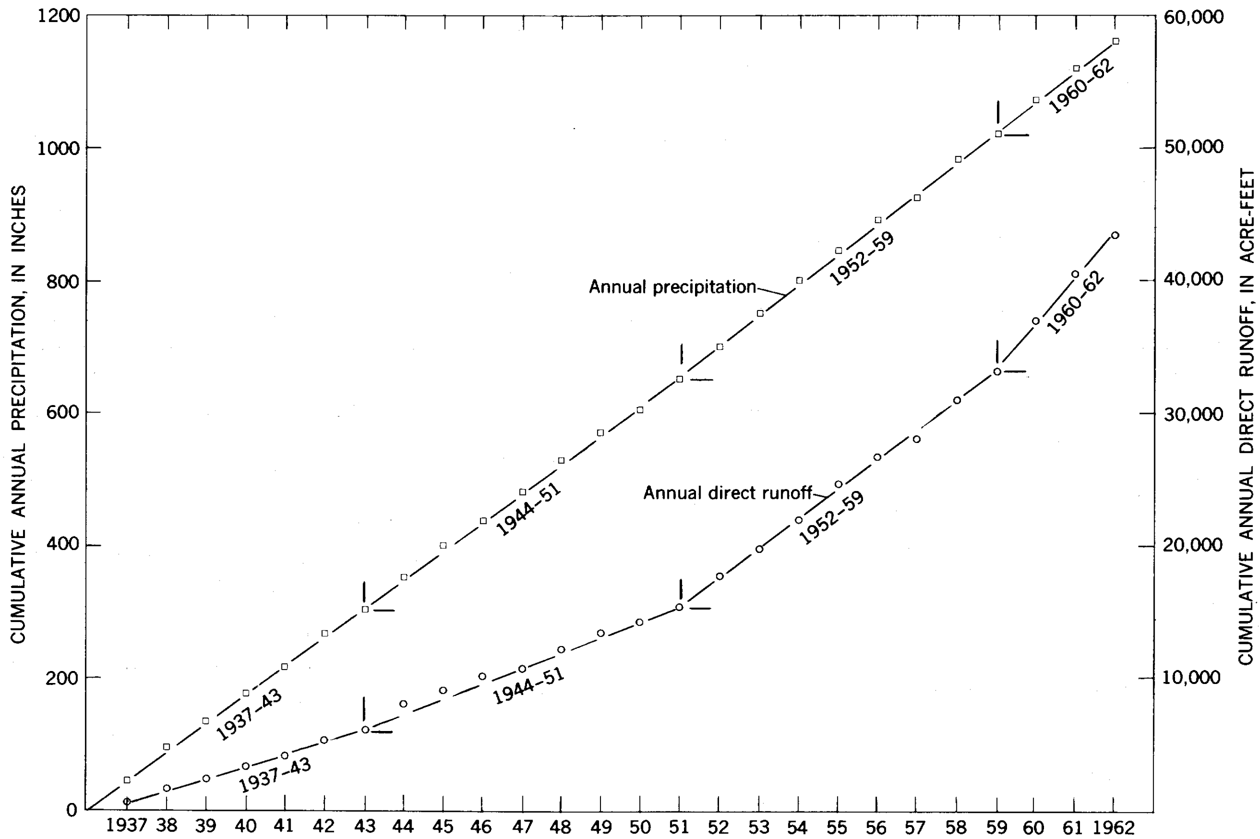

FIGURE 4.—Cumulative curves of annual direct runoff in East Meadow Brook, and annual precipitation at Mineola.

TABLE 5.—*Relation between the areas drained by storm sewers discharging into East Meadow Brook and direct runoff to the stream in the Hempstead subarea, 1937–62*

Period	Size of Hempstead subarea [1] (acres)	Area drained by storm sewers discharging into East Meadow Brook		Direct runoff	
		Total (acres)	Percentage increase from base-period area (1937–43)	Average annual (acre-ft)	Percentage increase from base-period amount (1937–43)
1937–43	5,700	570		920	
1944–51	5,700	720	27	1,170	27
1952–59	5,500	3,280	480	2,200	140
1960–62	6,400	3,600	530	3,400	270

[1] Size of subarea has changed over the years owing to the addition of sewered area and the deletion of area draining to recharge basins.

TIME DISTRIBUTION OF DIRECT RUNOFF

Urban development in the East Meadow Brook drainage area affected not only the volume of direct runoff but also caused marked changes in the shape of the direct-runoff hydrograph. Changes in the hydrograph were evaluated by developing 1-hour unit hydrographs for specific storms occurring within the four time periods referred to in the previous section. A unit hydrograph is defined as a hydrograph of direct runoff resulting from 1 inch of effective rainfall generated uniformly over the basin area at a uniform rate for a specified duration (Chow, 1964, p. 14–13). The duration of effective rainfall is defined in this study as the time that rainfall intensity exceeded the average infiltration rate. The average infiltration rate was determined by dividing the difference between rainfall and runoff by the duration of the rainfall (Chow, 1964, p. 12–17). The assumptions used in the present study for choosing storms appropriate for unit-hydrograph analysis and the procedures used to derive unit hydrograph were outline by Chow (1964, p. 14–15 to 14–24).

Storms suitable for unit-hydrograph analysis were selected for each of the years 1938, 1947, 1953, and 1962. These specific years were chosen to correspond, insofar as possible, with years for which aerial photographs of the basin were available. Photographs were not available for 1962. However, changes in the basin between 1962 and 1966 (a year for which an aerial photograph was available) were slight. When a sufficient number of appropriate storms needed for the analyses were not available for the above years, storms in the preceding or following years were used. Five to ten storms, all meeting the qualifying assumption for unit-hydrograph analysis and each exceeding 0.5 inch of precipitation, were studied for each of the years noted above. A unit hydrograph of 1-hour effective-rainfall duration was derived for each storm. Pertinent features of these hydrographs are considered in the following paragraphs.

Plate 1*C* shows a typical unit-hydrograph for a high-intensity storm in the spring of 1939. The hydrograph shows a double peak, which is characteristic of all runoff hydrographs for East Meadow Brook prior to 1951. This feature complicates the analysis and comparison of hydrographs from this period with hydrographs from later periods. The first peak resulted from runoff originating in the rural areas adjacent to the stream channel, and the second peak was caused by runoff from areas serviced by storm sewers in the village of Westbury.

The peak discharge of 1-hour unit hydrographs for six storms during the base period 1937–43 averaged 313 cfs and ranged from 280 to 350 cfs. Generally, the two peak discharges on each hydrograph differed by not more than 10–20 cfs. The average lag time between the two peaks was about 8 hours. Analysis of selected hydrographs for this period indicates that 60–70 percent of the total runoff represented by these hydrographs was derived from the nonsewered area in the Hempstead subarea and that 30–40 percent was derived from the sewered area in the village of Westbury.

Peak discharges of the 1-hour unit hydrographs for seven storms in 1947 averaged 430 cfs and ranged from 320 to 490 cfs. Two peaks also occurred in the unit hydrographs for these storms; however, on the average the second peak was about 120 cfs more than the first. The average time lag between the two peaks decreased slightly from about 8 hours in 1939 to about 7 hours in 1947. A typical unit hydrograph for a storm in 1947 is shown on plate 1*G*. Despite the relatively small changes in urban development from 1939 to 1947, the unit hydrograph for the storm in 1947 was considerably different from the unit hydrograph for the storm in 1939. Apparently, these marked changes in the unit hydrographs were primarily related to the construction of several new highways and associated storm sewers that drained to East Meadow Brook and to some house construction. (See table 5 and compare pl. 1 *B* and *F*.)

The peak discharge of 1-hour unit hydrographs for five storms in 1953–54 averaged 492 cfs and ranged from 460 to 500 cfs. This average was about 1.6 times greater than the average maximum peak discharge in the base period (1937–43). A typical unit hydrograph for a storm in 1954 is shown on plate 1*J*. The change from the double to a single peak is one of the most obvious changes in this hydrograph as compared with those for 1939 and 1947.

The peak discharge of the 1-hour unit hydrographs for 10 storms in 1961–62 averaged 776 cfs and ranged from 500 to 990 cfs. The average peak discharge was 2.5 times greater than the average peak discharge of the unit hydrographs for the base period. A typical unit hydrograph for a storm in 1962 is shown on plate 1*M*. This hydrograph has a high, sharp peak and a short time base, both of which are characteristics of the direct-runoff hydrographs from urban areas reported by other investigators (Waananen, 1961; Wiitala, 1961).

Several quantitative features of all the unit hydrographs developed in this study are summarized in table 6, including the average peak discharges and the average widths of the hydrographs at 50-percent and 75-percent values of the peak discharges.

As shown in table 6, the average peak discharge of the 1962 unit hydrograph was about 2.5 times the average peak discharge of the 1939 unit hydrograph. Wiitala (1961) and other investigators have found that the limit of the ratio of peak discharge from an urbanized area to peak discharge from the same area under rural conditions is about 3. Furthermore, in 1962 the width of the unit hydrograph at values equivalent to 50 percent and 75 percent of the peak discharge was 38 and 28 percent, respectively, the width of the unit hydrograph in 1939. This decrease in unit-hydrograph width indicates the increased efficiency of the drainage system to

TABLE 6.—*Summary of features of 1-hour unit hydrographs of East Meadow Brook for selected years*

Year	Number of storms for which unit hydrographs were constructed	Peak discharges of unit hydrograph		Widths of unit hydrographs			
				At W_{50} [1]		At W_{75} [2]	
		Average (cfs)	Ratio of average for year shown to average for 1939	Average width (minutes)	Ratio of average width in year shown to average width in 1939	Average width (minutes)	Ratio of average width in year shown to average width in 1939
1939	6	313	----------	1,014	----------	804	----------
1947	7	430	1.4	804	0.76	414	0.53
1954	5	492	1.6	504	.50	288	.36
1962	10	776	2.5	384	.38	222	.28

[1] W_{50} is the width of the unit hydrograph at the 50-percent value of the peak discharge. (See examples on pl. 1*C*, *G*, *J*, and *M*.)

[2] W_{75} is the width of the unit hydrograph at the 75-percent value of the peak discharge.

quickly convey large quantities of direct runoff from the area.

Espey, Morgan, and Masch (1966) determined that the widths of unit hydrographs were related to the peak discharge and to the area of the drainage basin by the empirical formulas:

$$W_{50}=3.88\times10^4\left(\frac{Q_{max}}{A}\right)^{-1.025}, \qquad (1)$$

and

$$W_{75}=1.00\times10^4\left(\frac{Q_{max}}{A}\right)^{-0.89}, \qquad (2)$$

where W_{50} and W_{75} are the hydrograph widths, in minutes, at the percentage values of peak discharge described above; Q_{max} is the peak discharge, in cubic feet per second per inch of runoff; and A is the area of the drainage basin, in square miles. Values of W_{50} and W_{75} calculated from these equations are listed in columns 8 and 9 of table 7. Q_{max} was obtained from the data in table 6, and the value of A was taken as the area of the Hempstead subarea (10 sq mi).

The U.S. Army Corps of Engineers (1963) developed a set of curves relating the widths of unit hydrographs to peak discharges and to drainage area. Values for selected parameters relating to the unit hydrographs of East Meadow Brook obtained from those curves are listed in columns 2, 3, 6, and 7 of table 7. As shown in the table, values calculated from the data in table 6 (cols. 1, 4, and 5 in table 7) agree fairly closely with the empirically derived values based on equations 1 and 2, and with the values obtained from the curves developed by the Corps of Engineers.

TABLE 7.—*Comparison of unit-hydrograph widths and peak discharges from East Meadow Brook data, U.S. Army Corps of Engineers curves, and equations 1 and 2*

Year	Peak discharge of unit hydrograph (cfs per sq mi)			Width of unit hydrograph (hours)					
	Determined from unit hydrographs for East Meadow Brook	Determined from curves developed by the U.S. Army Corps of Engineers (1963)		Determined from unit hydrographs for East Meadow Brook		Determined from curves developed by the U.S. Army Corps of Engineers (1963)		From equation 1	From equation 2
		W_{50} curve	W_{75} curve	W_{50}	W_{75}	W_{50}	W_{75}	W_{50}	W_{75}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1939	35.2	35	27	16.9	13.4	17.0	9.5	16.8	6.9
1947	48.3	43	47	13.4	6.9	12.5	7.0	12.0	5.3
1954	77.6	66	67	8.4	4.8	7.1	4.2	7.6	3.5
1962	80.8	85	85	6.4	3.7	6.8	3.8	7.2	3.3

RAINFALL-RUNOFF RELATIONSHIP

The marked effect of urban development on the rainfall-runoff relationship in the Hempstead subarea of the East Meadow Brook drainage area is evident from figure 5. The trend lines (determined by the method of least squares) in the figure show that a given amount of precipitation during the period 1937–43 resulted in less runoff than in 1964–66. The large scatter of points is due to the complex relations between the factors that affect the rainfall-runoff relationship, including the relations between the intensity, duration, areal distribution, and direction of storms; antecedent precipitation and soil-moisture conditions; climatic conditions that affect evaporation and transpiration; and the physical characteristics of the drainage area. Despite the large scatter of points, however, the trend line of the points representing the period 1937–43 clearly is below the trend line for the period 1964–66. The scatter of points is greatest for the smaller storms (those yielding between 0.5 and 1.5 in. of rainfall). Even for smaller storms, however, the maximum values of direct runoff for the period 1964–66 are consistently greater than the maximum values for the earlier period.

Theoretical considerations and observations suggest that the two trend lines shown in figure 5 should ultimately converge. These lines diverge for the range of values shown in figure 5 probably because of the very permeable nature and, therefore, the high infiltration capacity of the sand-and-gravel type soils in the East Meadow Brook drainage area.

The trend lines in figure 5 were used to compute the values in table 8, which show that larger storms yield proportionally larger quantities of direct runoff. For example, the 1964–66 curve in figure 5 indicates that about 0.09 inch of direct runoff (about 9 percent of the total rainfall) would occur, on the average, from a 1-inch rain; however, about 1.08 inches of direct runoff (22 percent of the total rainfall) would occur, on the average, from a 5-inch rain. The corresponding values for a 1-inch rainfall during the 1937–43 period were 0.06 inch (about 6 percent of the total rainfall) and, 0.28 inch (about 6 percent), respectively. As shown by the right-hand column in table 8, direct runoff in the more recent period 1964–66 was 1.1 to 4.6 times larger than the direct runoff during the earlier period 1937–43—the larger differences corresponding to larger storms.

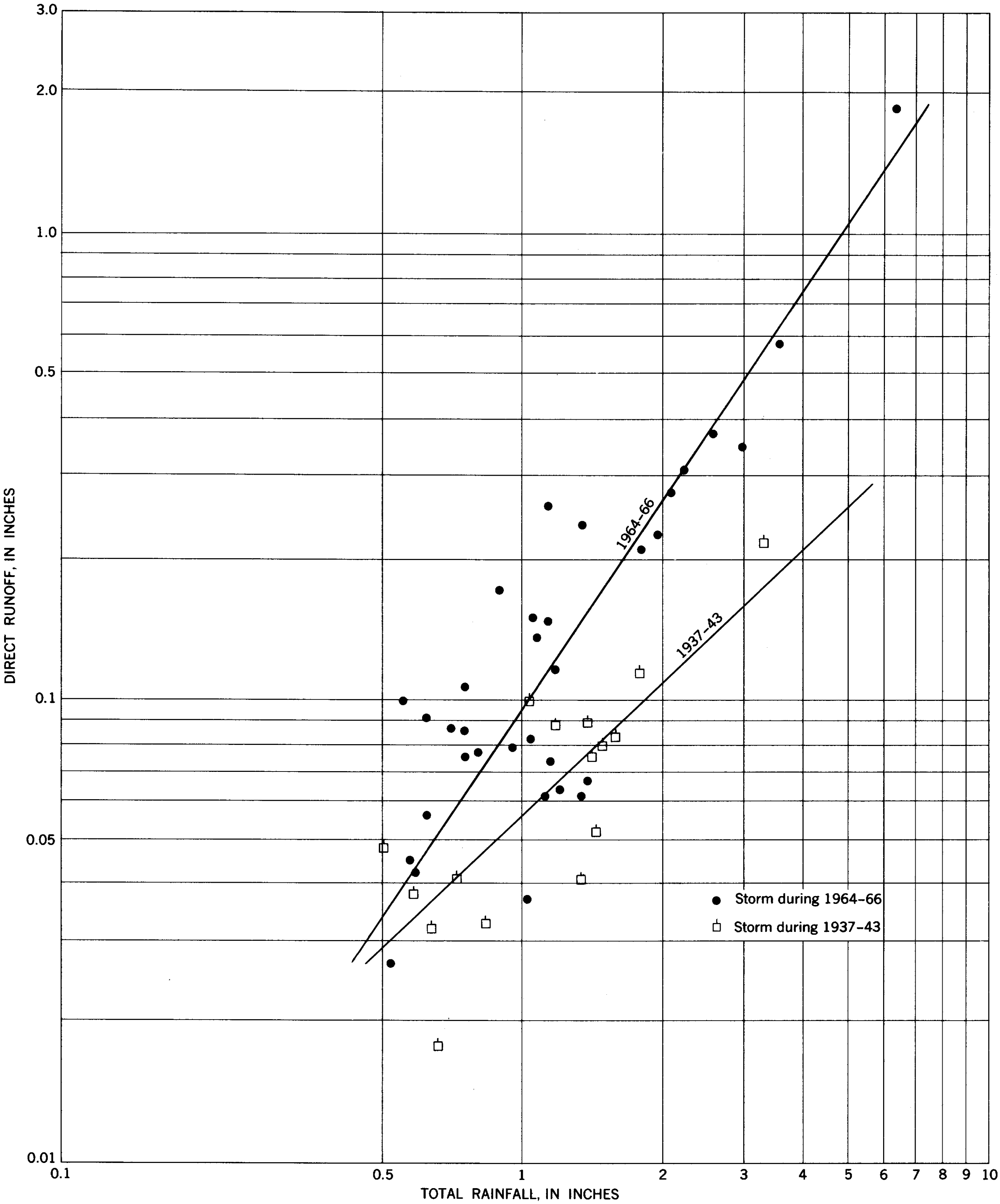

FIGURE 5.—Rainfall-runoff relationship for individual storms in the Hempstead subarea for urban (1964–66) and preurban (1937–43) conditions.

TABLE 8.—*Relationship between rainfall and direct runoff in the Hempstead subarea for urban and preurban conditions, derived from the trend lines in figure 5*

Rainfall (inches)	Urban period (1964–66)		Preurban period (1937–43)		Ratio of runoff in 1964–66 to runoff in 1937–43
	Direct runoff (inches)	Ratio of runoff to rainfall	Direct runoff (inches)	Ratio of runoff to rainfall	
0.5	0. 03	0. 07	0. 03	0. 06	1. 1
1.0	. 09	. 09	. 06	. 06	1. 5
2.0	. 27	. 13	. 11	. 06	2. 2
3.0	. 50	. 17	. 17	. 06	2. 8
4.0	. 76	. 19	. 23	. 06	3. 2
5.0	1. 08	. 22	. 28	. 06	3. 7
6.0	1. 40	. 23	. 32	. 05	4. 6

Comparisons of runoff volumes and peak discharges for specific storms of similar duration in each of the two periods 1937–43 and 1964–66 are given in the following table:

Date	Total precipitation (inches)	Duration of storm (hours)	Runoff (acre-feet)	Peak discharge of 1-hour unit hydrograph (cfs)
August 19, 1939	3. 3	16	97. 5	355
March 12, 1962	2. 4	18	260. 0	890

These data show that the 1962 storm, although it yielded only about two-thirds the rainfall, resulted in a runoff volume about 2.7 times greater, and a peak discharge on the 1-hour unit hydrograph about 2.5 times greater, than the corresponding quantities for the 1939 storm.

VOLUME OF DIRECT RUNOFF FROM THE SEWERED PARTS OF THE SUBAREA, 1960–62

As previously noted, the area of the Hempstead subarea was about 6,400 acres in 1962 (table 5). Of this total, about 3,600 acres was serviced by storm sewers that discharged into East Meadow Brook; the rest of the area either was not served by storm sewers or had storm sewers that discharged into recharge basins. Average annual rainfall for the period 1960–62 was 46.7 inches, which is equal to about 25,000 acre-feet of water on the entire Hempstead subarea, or about 14,000 acre-feet on the part of the subarea with storm sewers discharging directly into East Meadow Brook.

Much of the 3,400 acre-feet of average annual direct runoff during the period 1960–62 (table 5) undoubtedly was derived from the 3,600 acres having storm sewers that discharged to East Meadow Brook. However, a small amount of direct runoff also came from the nonsewered area. Calculations based on information derived for undeveloped drainage basins on Long Island (for example, see Pluhowski and Kantrowitz, 1964, p. 34–35) suggest that direct runoff to East Meadow Brook under natural conditions may have averaged about 400–500 acre-feet per year. The order of magnitude of this estimate is consistent with that of the independently derived estimate (p. B9) that 60–70 percent of the direct runoff to East Meadow Brook, or about 550–640 acre-feet per year, was derived from the nonsewered area in 1937–43. Therefore, direct runoff from the nonsewered area, including the stream channel itself and an undeveloped strip of land on both sides of the channel in the Hempstead subarea, probably was no more than about 400 acre-feet per year in 1960–62. Accordingly, direct runoff from the part of the area having storm sewers that discharged into East Meadow Brook is estimated to have been roughly 3,000 acre-feet per year in 1960–62, or about 20 percent of the precipitation on that part of the area.

EFFECTS OF URBAN DEVELOPMENT ON GROUND-WATER RECHARGE

In addition to increased direct runoff to East Meadow Brook, urban development has caused other changes in the hydrologic regimen of the Hempstead subarea. One of the changes that is of great concern to the water managers on Long Island is possible decreased ground-water recharge.

Other investigators (Pluhowski and Kantrowitz, 1964, p. 38) have estimated that an average of about 50 percent of the precipitation recharges the ground-water reservoir of Long Island under natural conditions. The remainder of the precipitation is consumed by evapotranspiration (directly from the land surface or from the soil zone) or enters the streams as direct runoff. Sufficient data are not available to allow evaluation of changes in evapotranspiration resulting from urban development in the Hempstead subarea. However, if evapotranspiration is assumed not to have changed as a result of urban development, then the increased direct runoff presumably represents a loss of ground-water recharge.

Urban development in the Hempstead subarea has also produced other changes in the hydrologic regimen that directly or indirectly affect ground-water recharge—for example, by the use of cesspools and septic tanks and the use of recharge basins. Unfortunately, the quantitative impact of these changes on ground-water recharge in the study area is not precisely known. Accordingly, because of insufficient data on changes in evapotranspiration and because the effects of other pertinent factors have not as yet been evaluated, it is not possible to determine the net quantitative effect of changes in direct runoff on ground-water recharge in the East Meadow Brook drainage area. Despite the present lack of a quantitative estimate of changes in ground-water recharge resulting from increased direct runoff, such changes may have a significant future effect on the hydrologic system of Long Island and should be carefully considered in future water-management proposals.

POSSIBLE FUTURE INCREASES IN DIRECT RUNOFF

The average annual volume of direct runoff that may discharge into East Meadow Brook in the future can be estimated by making the following qualifying assumptions: (a) The remaining 320 acres of land available for development in the Hempstead subarea ultimately will be serviced by storm sewers that discharge into East Meadow Brook; (b) the boundaries of the Hempstead subarea will remain unchanged; (c) virtually all the direct runoff to East Meadow Brook will continue to be derived from the Hempstead subarea; (d) the degree of urban development in the developed area, as reflected in part by zoning regulations, will remain unchanged from the precent conditions; and (e) climatological conditions will not change.

By 1966 approximately 3,600 acres equipped with storm sewers were contributing, on the average, about 3,000 acre-feet per year of direct runoff to East Meadow Brook (p. B12). If the ratio between the sewered area and the resulting direct runoff remains constant, the sewering of 320 additional acres under the conditions assumed above would add, on the average, slightly less than 300 acre-feet per year of direct runoff.

A more detailed analysis of the relation between sewered area and direct runoff indicates that for several years after an area has been sewered the proportion of direct runoff from that area continues to increase. This undoubtedly happens because the construction of storm sewers is one of the first steps in development of a new area, and construction of new houses, driveways, sidewalks, and other impervious surfaces continues for several years thereafter. Therefore, although little opportunity now exists for new construction in the 3,600 acres having sewers that contribute runoff to East Meadow Brook, some additional contribution of direct runoff from this part of the area can be expected in the future. Considering the uncertainties involved and the qualifying assumptions listed above, the writer estimates that the annual volume of direct runoff to East Meadow Brook will increase from the present average of 3,400 acre-feet per year (table 5) to about 4,000–4,500 acre-feet per year in the future. If, on the other hand, zoning regulations change and the sewered area drained by East Meadow Brook becomes much more urbanized, the resulting future direct runoff from this area could be as much as two or three times greater than the above estimate.

SUMMARY

Urban development in the Hempstead subarea of the East Meadow Brook drainage area in Nassau County, Long Island, N.Y., has greatly affected peak discharges, as well as the total volume and time of arrival, of direct runoff to East Meadow Brook during the 30-year period 1937–66. The area that contributed virtually all the runoff to East Meadow Brook (about 10 sq mi in 1966) consisted mostly of open fields in 1937, except for the village of Westbury, which is in the northern part of the Hempstead subarea. Scattered house construction in the Hempstead subarea in the 1940's was followed by extremely rapid urban development in the 1950's, after which further construction decreased markedly.

An increase in the volume of direct runoff closely corresponded to an increase in the area having storm sewers that drained directly to East Meadow Brook. This sewered area increased from about 570 acres in 1943 to about 3,600 acres in 1962, or about 530 percent. During the same period, average annual direct runoff to East Meadow Brook increased about 270 percent, from about 920 acre-feet per year in 1937–43 to about 3,400 acre-feet per year in 1960–62. (See table 5.)

One-hour-duration unit hydrographs of storms on the Hempstead subarea were derived for various stages of urban development in the basin. As shown by these hydrographs, the average peak discharge increased from 313 cfs in 1939 to about 776 cfs in 1962. Also, in 1962 the unit-hydrograph widths at discharge values of 50 percent and 75 percent of the peak discharge had decreased by 38 and 28 percent, respectively, the unit-hydrograph widths for storms in 1939.

To show the effect of urban development on direct runoff from individual storms, rainfall-runoff relationships (fig. 5) were plotted for storms during the pre-urban period (1937–43) and during the urban period (1964–66). Average trend lines through the widely scattered points indicate that during both periods the proportion of direct runoff increased with larger rainfalls, and also that the amount of direct runoff in 1964–66 ranged from 1.1 to 4.6 times larger than the direct runoff during the earlier period, depending on storm size.

The volume of direct runoff from the parts of the subarea equipped with storm sewers that discharged into East Meadow Brook is estimated to have been roughly 3,000 acre-feet per year in 1960–62, or about 20 percent of the precipitation on those parts of the area.

The increase in direct runoff probably represents a loss of ground-water recharge. However, because data on changes in evapotranspiration are insufficient and because the effects of recharge basins are unknown, ade-

quate quantitative estimates of ground-water recharge can not be made.

In 1966 the Hempstead subarea still contained small undeveloped sections. If these areas were equipped with sewers draining to East Meadow Brook, the average annual volume of direct runoff to East Meadow Brook might increase to 4,000–4,500 acre-feet per year.

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U.S. GOVERNMENT PRINTING OFFICE: 1969 O—353–973