U.S. Department of the Interior
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SIMULATION OF THE EFFECTS OF DEVELOPMENT OF THE GROUND-WATER FLOW SYSTEM OF LONG ISLAND, NEW YORK

Water-Resources Investigations Report 98-4069

Prepared in cooperation with the
NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS,
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SUFFOLK COUNTY WATER AUTHORITY, and the
NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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Table 4. Ground-water budget for predevelopment conditions on Long Island

County	Recharge	Discharge		
	Precipitation	Stream	Shore	Subsea
Kings and Queens	160	58	96	10
Nassau	257	125	94	24
West Suffolk	273	140	137	28
East Suffolk	436	137	258	19
Total	1,126	460	585	81

Ground-water discharge decreases sharply with depth, as indicated by the small amount of subsea discharge in relation to stream and shore discharge. Progressively smaller amounts enter each successive model layer (aquifer) (table 5); only about 20 percent of the flow in the system enters the basal zone of the Magothy and Jameco aquifer (layer 3), and only about 3 percent enters the Lloyd aquifer (layer 4). A disproportionate amount of water enters the Lloyd in Nassau County (table 5), where the two holes in the confining units, (each represented by only a single model cell), together allow 2.2 Mgal/d to flow to the Lloyd aquifer. Much of the downward flow to each of layers 2, 3, and 4 (table 5) returns to the overlying aquifer, however, and continues flowing through the system. (See fig. 15.)

Findings that most ground-water flows in the shallowest part of the aquifer system and that progressively less water flows to each aquifer with depth suggests that water moves more slowly and has greater residence time in the deep confined aquifers. Results of Buxton and Modica (1992) indicate that under predevelopment conditions, ground-water travel-times in the water-table aquifer are on the scale of tens of years; in the Magothy aquifer are on the scale of hundreds of years; and in the Lloyd aquifer are on the scale of thousands of years.

Table 5. Distribution of ground-water flow with depth under predevelopment conditions as represented in model

County	Model layer[1]			
	1	2	3	4
	(water table)	(Magothy and Jameco)		(Lloyd)
Kings and Queens	160	28	16	3
Nassau	257	116	62	16
West Suffolk	273	141	75	9
East Suffolk	436	177	82	8
Total	1,126	462	235	36

[1]Flow into layer 1 is recharge from precipitation; flow into layers 2, 3, and 4 is leakage from the overlying layer.

EFFECTS OF DEVELOPMENT ON THE GROUND-WATER SYSTEM

Human activities affected the ground-water system on Long Island as early as the mid-17th century, when early European settlers withdrew water from streams or from shallow dug wells that intersected the water table. Most wastewater infiltrated back to the water table and affected water quality locally, but had negligible effect on the quantity or patterns of ground-water flow. Over the next 2 centuries, the population increased significantly, mainly in western Long Island. By the 19th century, local dug wells were being replaced by large-capacity but shallow public-supply wells that served population centers. The increased water use and attendant onsite wastewater disposal posed a major threat to the quality of shallow ground water. To minimize further contamination, the City of Brooklyn, in the mid-19th century, began construction of a combined storm- and sanitary-sewer system to carry wastewater to tidewater. Although these sewers slowed the rate of ground-water contamination, they also diverted a large quantity of water that would have recharged the ground-water system. From the earliest development of Long Island, diversion of recharge to tide water via increased runoff over developed land and storm and sanitary sewers became a major part of the stress of on the ground-water system.

By 1904, pumping for public supply on Long Island exceeded 50 Mgal/d (fig. 18). Most of the pumping was in Kings, Queens, and Nassau Counties, and much of the water pumped in Nassau was exported to Kings and Queens (by then part of New York City). Virtually all ground water used in Kings and Queens was discharged to the ocean through the sewer system. By 1915, islandwide ground-water withdrawals had increased to about 150 Mgal/d, but decreased rapidly thereafter when the first New York City water tunnel provided water from an upstate surface-water-reservoir system.

Although the increasing population prompted a continued increase in ground-water pumping throughout the island (fig. 18), imported surface water soon became a much larger source of supply than ground water in Kings and Queens Counties. By the 1930's, overpumping in the Kings had induced saltwater intrusion which prompted a continual shift eastward in pumping patterns; in 1947, all pumping for public supply in Kings County was stopped to prevent further saltwater intrusion. Meanwhile, other effects of development in Kings and Queens Counties had become severe. Extensive paving of land surface routed large amounts of stormwater to the combined sewer system and ultimately the ocean, and thereby decreased the amount of natural recharge. On the other hand, recharge was augmented by leakage from water-supply lines carrying three quarters of a billion gallons of water per day. Cessation of pumping in Kings allowed water levels to recover, causing subways and deep basements in Kings County to become flooded, which in turn required extensive dewatering. Large construction projects that entailed filling stream channels and tidal wetlands and altering the shoreline in some areas literally changed the shape of the ground-water system. A discussion of ground-water development in Kings and Queens Counties is given in Buxton and Shernoff (1995).

Eastward urban expansion from New York City after World War II resulted in rapid increases in public-supply pumping in Nassau County during 1945-65 and in Suffolk County during 1955-70 (fig. 18). The paving of land surface in Nassau and Suffolk Counties soon prevented infiltration of precipitation over large areas and decreased ground-water recharge. In shore areas, stormwater was routed directly to streams and the ocean; whereas inland stormwater was routed to infiltration (recharge) basins which were installed beginning in the 1950's to prevent flooding and maintain ground-water recharge. The infiltration-basin network may even increase recharge above predevelopment rates in areas (Ku and others, 1992).

Several small sanitary-sewer systems were installed in Nassau and Suffolk Counties before 1950. Their annual average discharge to the ocean then was less than 25 Mgal/d in Nassau County and only a few million gallons per day in Suffolk (fig. 19). After 1955 however, total sewer discharge to the ocean in Nassau County increased continuously as new sewer connections were made, and by 1960, the sewer system had been expanded to serve more than a half million inhabitants. Sewering in Suffolk County remained negligible through the 1960's and 1970's and discharged an average of less than 5 Mgal/d. Sewering continued in both counties with the installation of Nassau County Sewage Disposal District 3, which began new hookups in 1977, and then the installation of the Southwest Sewer District in Suffolk County, which began hookups in 1982.

By 1983, pumpage for public supply on Long Island had reached 398 Mgal/d, of which 57 Mgal/d was in Queens County, 194 Mgal/d was in Nassau County, and 147 Mgal/d was in Suffolk County (fig. 18). That year, sewers discharged 128 Mgal/d to the ocean from

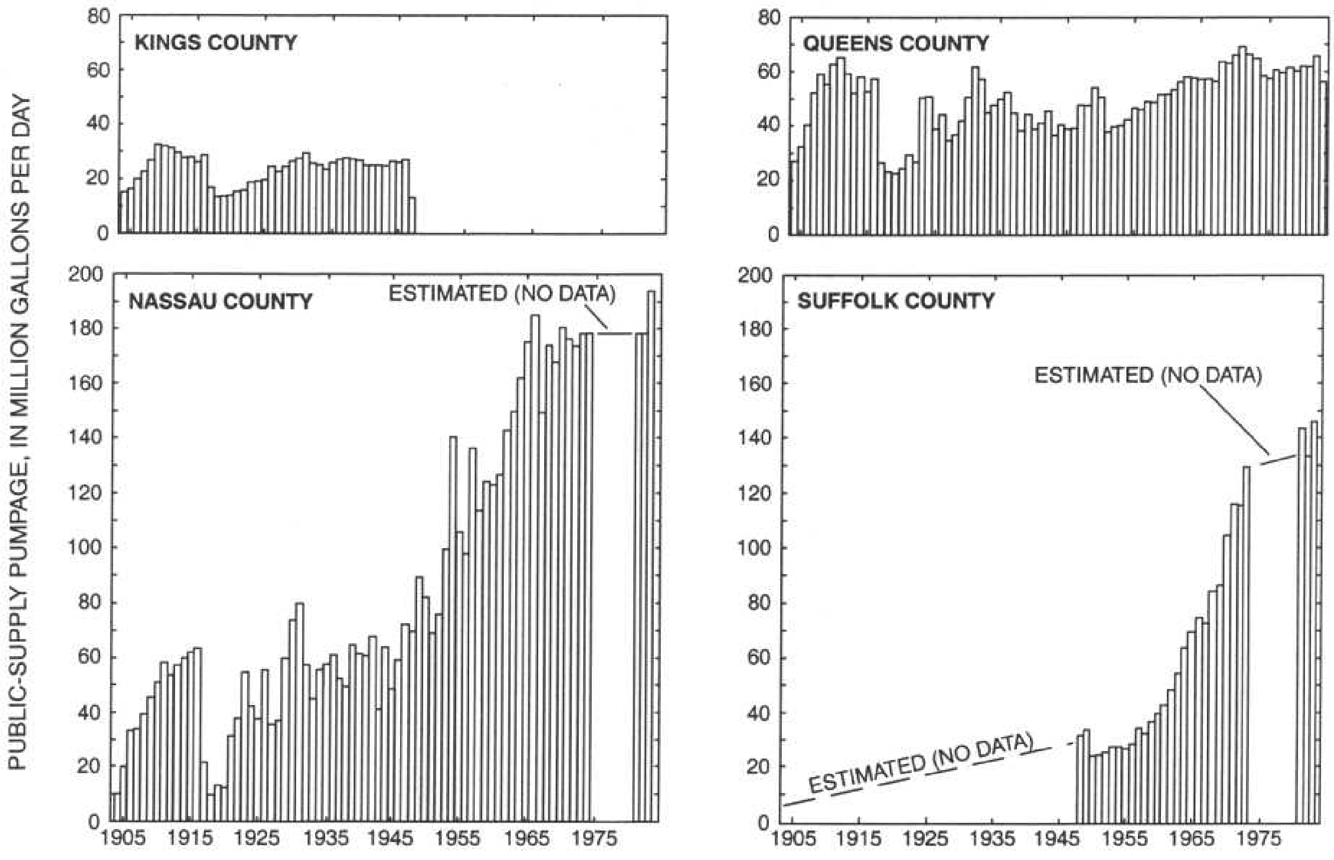


Figure 18. Annual average public-supply pumpage on Long Island, N.Y., 1904-83.

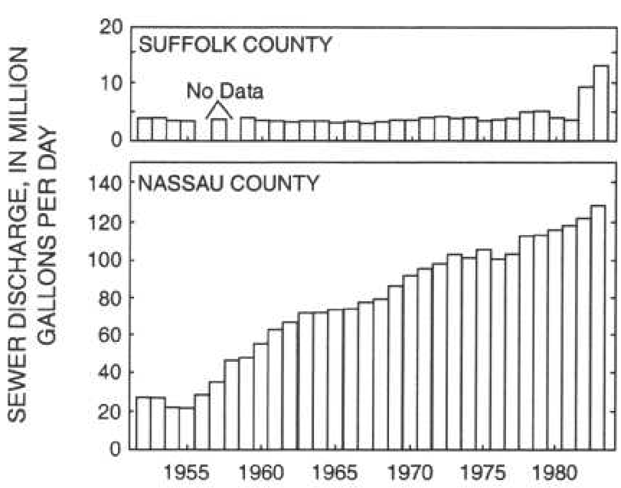


Figure 19. Annual average sewer discharge to tidewater, Suffolk and Nassau Counties, N.Y., 1952-83.

Nassau County and 13.4 Mgal/d from Suffolk (fig. 19). The total water supply in Kings and Queens Counties attained 750 Mgal/d, almost 700 Mgal of which was imported from upstate surface waters, and all wastewater was routed to the ocean by the combined sewer system.

HYDROLOGIC CONDITIONS DURING 1968-83

Hydrologic conditions during 1968-83 were analyzed to evaluate how development has affected the Long Island ground-water system. Although the total stress on the ground-water system generally increased throughout this century, the increase temporarily stopped during the 1970's. Public-supply pumping and sewer discharge (figs. 18 and 19) remained relatively stable during this period, and precipitation records from the Mineola and Setauket gages (fig. 1), which have the longest available records on Long Island, indicate that average precipitation during 1968-75 was 46.5 in/yr, comparable to the long-term average of 45.8 in/y). Therefore, the system is assumed to have achieved a steady-state condition during this period, and the observed changes from predevelopment conditions are attributed mostly to the effects of development.

Analysis of this stressed hydrologic condition entailed defining the average stress imposed on the system and evaluating the response of the system in terms of changes in ground-water levels, flow patterns, and water budget. Simulation results for conditions during 1968-83 and the predevelopment condition are compared to quantify the system response to development.

Hydrologic Stresses

Hydrologic stresses on the Long Island ground-water system occur when natural or human activities change the quantity of water entering or leaving the system. The net stress on the Long Island ground-water system during 1968-83 (table 6) is the sum of a number of components and will cause a corresponding net decrease in ground-water discharge to natural boundaries. The distribution of stress generally reflects the degree of urban development—it is greatest in the west and decreases eastward.

Pumping for public supply is the largest stress, but its net effect depends largely on water-use and wastewater-disposal practices. Pumped ground water is partly returned to the ground-water system through onsite septic systems, leaking water-supply or sewer lines, and infiltration in unpaved areas (such as during lawn watering). Even the withdrawal of water from shallow public-supply wells and its return to the water table by infiltration throughout the area of use causes a change in flow patterns.

In unsewered areas of Nassau and Suffolk Counties, 85 percent of the water pumped for public supply is estimated to infiltrate back to the ground-water system, whereas in sewered areas, only about 20 percent returns. The amount of public-supply water that returns to the ground-water system in Nassau and Suffolk Counties varies spatially; it is estimated that 50 percent of pumpage is returned in Nassau County and 80 percent in Suffolk County (table 6). These estimates were based on water-supply distribution, sewer-district infrastructure, and population information. The smaller percent returned in Nassau is due to the considerably larger sewered area (fig. 19). At the time of this study (1984-89), the effects of the Southwest Sewer District in Suffolk County and Sewage Disposal District 3 in Nassau County, which began operation in 1982 and 1977, respectively, were just beginning to appear in hydrologic records and, therefore, were not considered in the analysis of conditions during 1968-83.

Table 6. Components of stress on the Long Island ground-water system during 1968-83

Location	Components of stress				Net stress (sum of components)
	Public-supply pumpage	Returned water	Industrial-commercial/agricultural pumpage	Recharge loss through increased runoff	
Kings and Queens	-61	+58	-16/0	-82	-101
Nassau	-179	+89	-6/0	0	-96
Western Suffolk	-83	+66	-4/0	0	-21
Eastern Suffolk	-43	+36	-4/-11	0	-22
Total	-366	+249	-41	-82	-240

The distribution of ground-water pumping during 1968-83 as represented in the model is summarized in table 7. More of the pumping in western Long Island is from deeper aquifers than in eastern Long Island; most of the pumping in Nassau County is from the basal zone of the Magothy aquifer.

The combined effect of the pumping and the return of water in Kings and Queens differs substantially from that in Nassau and Suffolk.

Table 7. Distribution of ground-water pumping for public-supply, industrial-commercial, and agricultural uses during 1968-83, Long Island, as represented in model

County or area	Model layer[1]				Total
	1	2	3	4	
Kings and Queens	32	4	35	6	77
Nassau	10	9	155	11	185
Western Suffolk	26	0	61	0	87
Eastern Suffolk	41	0	17	0	58
Total	109	13	268	17	407

[1]Model layer 1 represents the water-table aquifer; model layers 2 and 3 generally represent the Magothy and Jameco aquifers; layer 4 represents the Lloyd aquifer. (See fig. 9.)

Virtually all of Kings and Queens has combined sewers, and the major source of returned water is leakage from water-supply and sewer lines, which carry 700 Mgal/d from upstate reservoirs. About 58 Mgal/d is estimated to enter the ground-water system through this leakage—almost as much as is pumped (61 Mgal/d). The leakage was estimated from the length of pipelines, number of connections, and standard engineering estimates of leakage (Buxton and Shernoff, 1995).

About 82 Mgal/d is lost as runoff from paved areas to the ocean in Kings and Queens Counties, unlike Nassau and Suffolk Counties, where recharge-basins maintain natural recharge rates. Only about 20 percent of precipitation reaches the aquifer in Kings County, and about 30 percent in Queens, as estimated from the percentage of land area that is paved. Under predevelopment conditions, 52 percent of precipitation reached the water table.

It is assumed that nearly all the water pumped for industrial-commercial and agricultural use returns to the ground-water system (table 6). Much of the industrial-commercial pumping in Kings and Queens is for dewatering of subways and deep basements that are flooded as a result of abandoned pumping and recovering ground-water levels in the far western parts of these counties. Agricultural pumping occurs only in eastern Suffolk County.

Each component of stress for conditions during 1968-83 is represented in the model so as to reproduce its actual effect on the ground-water flow system. Model pumpage is based on an inventory of wells pumping for public supply in 1981 (Philip Barbato, New York State Department of Environmental Conservation, written commun., 1984). More than 1,000 public-supply wells are represented in the model at the cells closest to their actual locations and screened intervals (fig. 20). Pumpage for public supply totaled 366 Mgal/d. The estimated amount of water that returns to the ground-water system is represented in the model as additional recharge at the water table, and is distributed in sewered and unsewered areas according to population and water-supply company distribution areas. Industrial-commercial pumping is distributed uniformly throughout each county because individual well records are unavailable. Agricultural pumpage was assigned to the water-table aquifer (model layer 1) within the agricultural areas shown in figure 21.

Ground-Water System Response

The response of the ground-water system to stress takes the form of changes in ground-water levels, and in the pattern and distribution of ground-water flow. Declines in the water table decrease discharge to streams and the shore; declines in head in the confined aquifers decrease subsea discharge and accelerate landward movement of the saltwater/freshwater interface. The pattern of water-level declines determines which areas are affected most severely.

Base Flow

A streamflow data-collection program has been operated by the USGS on Long Island

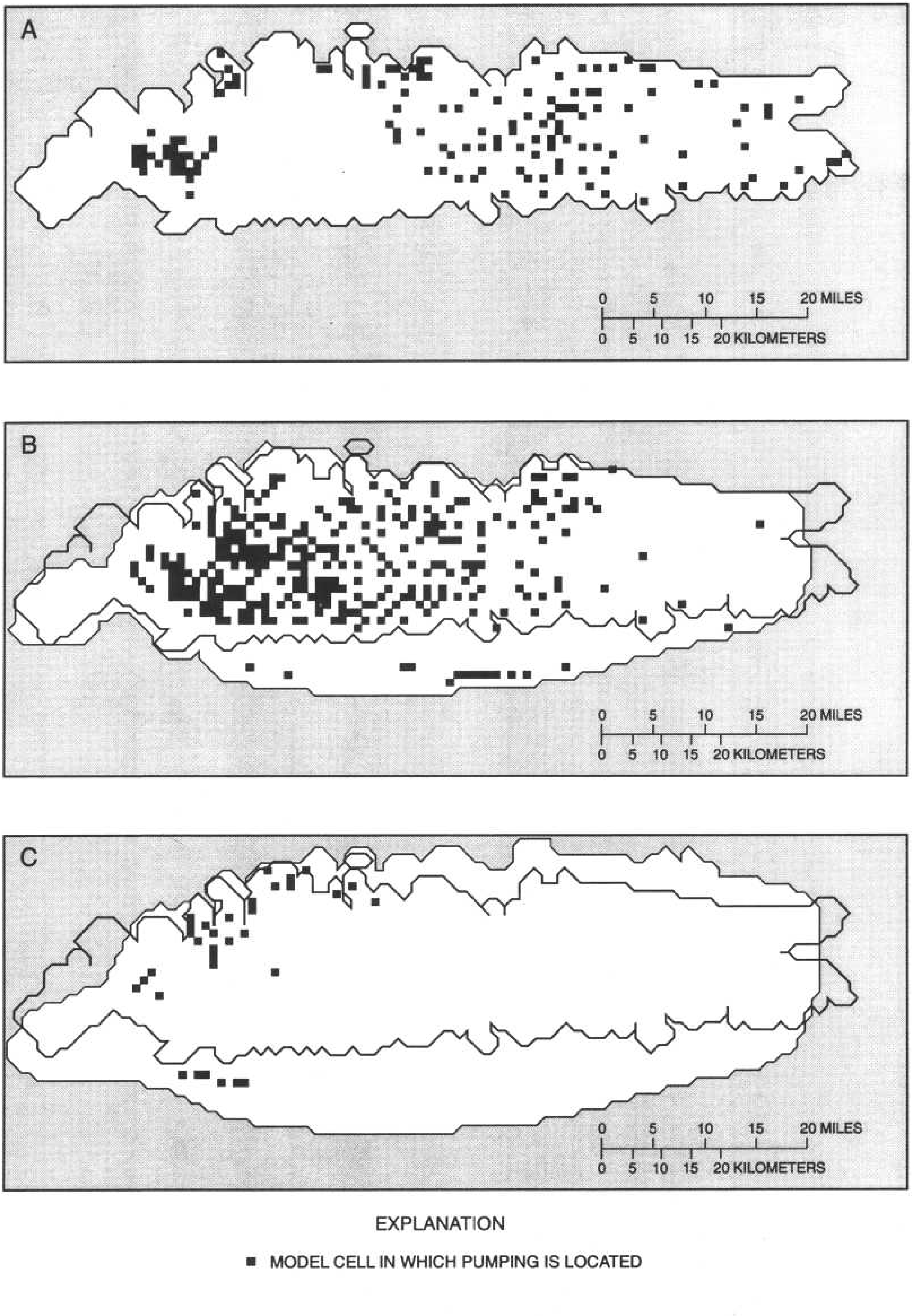
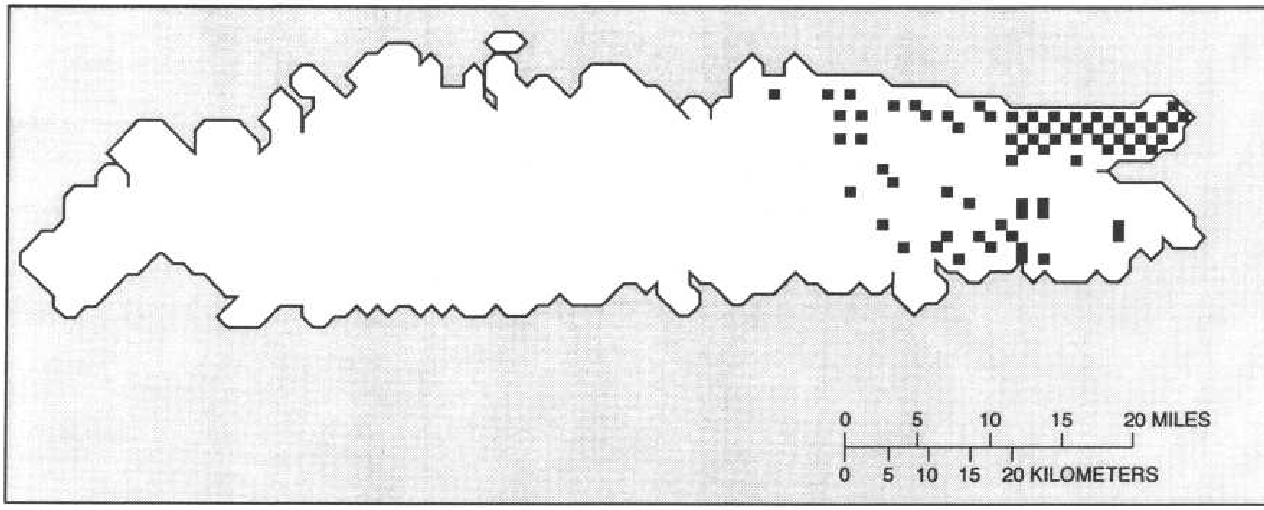


Figure 20. Location of public-supply and industrial-commerical pumpage as represented in model simulation of 1968-83 conditions. A., Water-table aquifer (model layer 1). B., Jameco and Magothy aquifer (model layers 2 and 3). C., Lloyd aquifer (model layer 4).



EXPLANATION

■ MODEL CELL IN WHICH PUMPING IS LOCATED

Figure 21. Location of agricultural pumpage as represented in model simulation of 1968-83 conditions. Pumping is from the upper glacial aquifer (model layer 1).

since before 1950 (Sawyer, 1958). The program entails collection of continuous discharge records at gaged sites near the mouths of 17 large streams and partial records (periodic discharge measurements) at 74 sites. Most partial-record sites are on smaller streams; the rest are at upstream sites on streams with continuous records. These data allow estimation of average ground-water discharge to streams during 1968-83. Reynolds (1982) estimated the average 1968-75 base flow for all Long Island streams with a continuous record. Those data were used with regression analysis in this study to estimate average base flow at the partial-record stations. The methods of this analysis and data from some of these partial-record stations are discussed in Buxton (1985). The estimated average base flow of the 32 major streams (defined earlier in this report) on Long Island during 1968-83 are listed in table 8 along with base flow under predevelopment conditions.

The greatest depletion of base flow has been in western Long Island, where the effects of development have been most severe. Several streams in Kings and Queens Counties have disappeared through the lowering of the water table and the filling in of stream channels, and several streams in adjacent western Nassau County have all but dried up. Streams in easternmost Suffolk County are assumed to have the same base flow as under predevelopment conditions because development there is relatively small, and records do not indicate a decrease from predevelopment conditions.

For the simulation of conditions in 1968-83, base flow was distributed proportionally along stream length as was done in the simulation of predevelopment conditions. Significantly more data are available during 1968-83 permitting a more detailed estimate of the distribution of ground-water discharge along stream channels. Recent stream lengths were estimated from the channels indicated on

Table 8. Average base flow of major streams on Long Island, during 1968-83 and predevelopment conditions

Map number (fig. 3)	Stream name	Period: Predevelopment	Period: 1968-83	Map number (fig.3)	Stream name	Period: Predevelopment	Period: 1968-83
1	Jamaica Creek	17.9	0.0	17	Sampawams Creek	9.9	6.7
2	Springfield Stream	7.9	0.0	18	Penataquit Creek	6.8	6.5
3	Simonsons (Brookfield) Stream	9.6	0.3	19	Pardees and Orowoc Creeks	10.3	8.9
4	Valley Stream	14.3	0.3	20	Rattlesnake Brook	9.2	8.8
5	Motts Creek	6.4	2.1	21	Connetquot River	36.0	34.6
6	Pines Brook	13.0	0.5	22	Green Creek	6.5	6.5*
7	South Pond	20.0	0.4	23	Patchogue River	18.9	18.9*
8	Parsonage Creek	8.1	4.5	24	Swan River	13.3	13.3*
9	Milburn Creek	13.0	6.9	25	Carmans River	24.9	24.9*
10	East Meadow Brook	15.3	6.3	26	Forge River	9.6	9.6*
11	Cedar Swamp Creek	9.5	6.8	27	Little River	7.4	7.4*
12	Bellmore Creek	14.6	9.4	28	Peconic River	37.4	37.4*
13	Massapequa Creek	12.0	6.6	29	Nissequogue River	41.7	40.2
14	Carman Creek	6.8	6.7	30	Mill Neck Creek	7.0	5.6
15	Santapogue Creek	10.0	8.0	31	Glen Cove Creek	8.7	3.7
16	Carlls River	27.3	20.5	32	Flushing Creek	21.5	7.8

* Assumed to be the same as under predevelopment conditions because development is minimal, and records indicate no decrease in base flow from predevelopment conditions.

USGS 1:24,000 series topographic maps and observations of the point at which flow begins in stream channels (start-of-flow) during low-flow conditions in March and April 1978. Base flow in ungaged streams and in reaches downstream from gages were estimated from the base flow in nearby and similar gaged reaches. In all, 98 of the 108 streams represented in the predevelopment simulation are still flowing and were represented in the simulation of recent conditions. The model representation of the length of flowing channels is depicted on a map of the simulated water-table altitude in figure 24A (further on). The degree to which streams in western Long Island have dried up can be assessed through comparison with the stream lengths shown for predevelopment conditions in figure 17A.

Saltwater-Freshwater Interface

The position of the saltwater-freshwater interface in confined aquifers beneath Long Island is typically inferred from the concentration of chloride in pore fluid extracted from core materials and by analysis of borehole geophysical logs. Some wells have been screened in the zone of diffusion to enable periodic sampling and chloride analyses. Locations of wells in which the zone of diffusion in the confined aquifers was detected are shown in figure 22. The interface in the Magothy aquifer has been detected onshore in southern Queens and southwest Nassau County (Buxton and Shernoff, 1995) and in places along the northern shore and on the east end of the island. Many wells screened in the Magothy aquifer on the barrier islands from southeastern Nassau through most of southern Suffolk

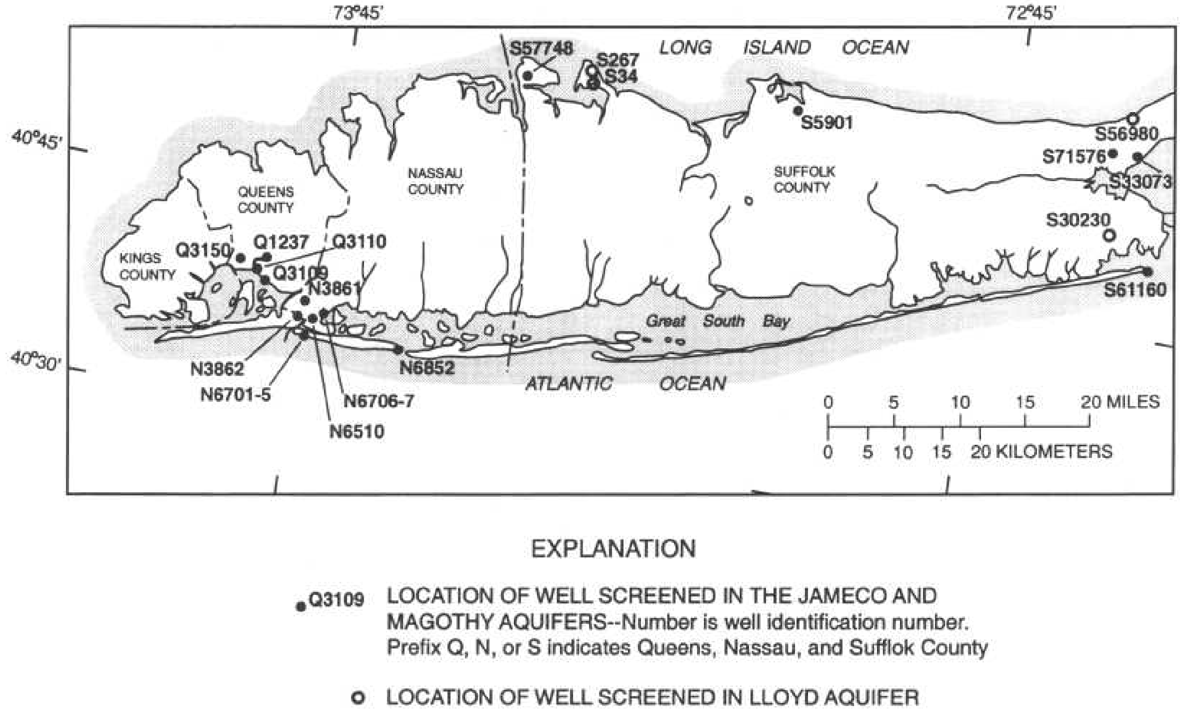


Figure 22. Location of wells that intersect the saltwater-freshwater interface in the confined aquifers of Long Island, New York.

County do not tap saline water, indicating that the saltwater interface is offshore in this aquifer throughout most of southern Long Island. The interface in the Lloyd aquifer has been detected only on the eastern end of Long Island and along the northern shore, although evidence indicates that it is just offshore south of Kings County (Buxton and Shernoff, 1995). Wells screened in the Lloyd aquifer on the barrier islands in southern Nassau County provide the sole source of water supply.

The estimated configuration of the saltwater-freshwater interface in the Magothy and Lloyd aquifers is indicated in the maps of the simulated head distribution within the Magothy and Lloyd aquifers (fig. 24, further on). Since predevelopment times, the interface in both the Magothy and Lloyd aquifers in western Long Island is assumed to have migrated several miles landward. This movement decreases eastward in both aquifers, and its movement over the past 100 years from about the Nassau-Suffolk County border eastward is assumed to have been negligible.

Ground-Water Levels and Flow Patterns

Synoptic water-level measurements in observation wells were made several times during the late 1960's and 1970's and were used to construct maps of the water table and the potentiometric surfaces in the Magothy and Lloyd aquifers. These maps represent the water table in 1966, 1970, 1971, 1972, 1974, 1975, and 1979; the potentiometric surface in the Magothy aquifer in 1966, 1972, 1975, and 1979; and the potentiometric surface in the Lloyd aquifer in 1971, 1975, and 1979. The sources of these maps are indexed in Smolensky (1984). Maps that were selected for this study were those that best represent average conditions during 1968-83. These were the water-table and Magothy maps for March 1972 (Vaupel and others, 1977) and the Lloyd map for January 1971 (Kimmel, 1973) (fig. 23). These maps can be compared with corresponding predevelopment water-level maps (figs. 15 and 17) to indicate changes resulting from development.

The water table in western Long Island has been drawn down considerably (compare fig. 23A with 15B, and 17A); pumping in Queens County has caused the water table to decline below sea level. The greatest water-table declines in Nassau County are in the west and probably exceed 30 ft near the ground-water divide at the Queens-Nassau County border. The maximum water-table altitude in central Nassau County has probably declined more than 15 ft below its predevelopment level. The decline at the ground-water divide near the Nassau-Suffolk County line is about 10 ft. Water-table declines in eastern Suffolk County appear negligible.

The potentiometric surface of the Magothy aquifer under recent conditions shows significant drawdown in western Long Island which decreases eastward (compare fig. 23B with 17B). Drawdown in the Lloyd aquifer in western Long Island is greater than that in the overlying aquifers even though pumpage is substantially less, because (1) only a small fraction of the flow in this system enters the Lloyd aquifer (table 5), and (2) pumping induces even lower ground-water levels in the Lloyd than in the overlying aquifers to increase downward flow to the Lloyd and satisfy the withdrawals.

The simulated distribution of head in the three major aquifers under recent conditions is shown in figure 24. These maps closely resemble those drawn from measured water levels (fig. 23). In a sense, the simulated results give a more complete representation of system operation than the maps of measured values because they (1) extend to the system's hydrologic boundaries, and (2) were calculated in accordance with the physical laws that represent the distribution of flow within the ground-water system. The model-generated maps indicate the lengths of flowing stream channels and the extent of the fresh ground-water system (to either the saltwater-freshwater interface or the pinchout of the aquifer). Locations of pumping wells are shown in figures 20 and 21. The simulated results are still only an approximation of the actual system, however, and as such could omit important but unknown details.

Accurate representation of the holes in the overlying Raritan confining unit is essential for accurate reproduction of water levels in the Lloyd aquifer. The high head in the Lloyd aquifer in extreme north-central Nassau County (fig. 24C) is caused by downward flow from the Magothy aquifer through the holes in the confining unit and into the Lloyd. Also, the shape of the cone of depression in central Queens indicates that the eroded channel through the Raritan confining unit forms a pathway through which water from overlying aquifers flows toward pumping in the Lloyd.

Ground-Water Budget

Under predevelopment conditions, recharge was balanced by discharge to streams, to the shore, and to subsea boundaries. Under more recent conditions, however, the ground-water system is stressed by (1) pumping, (2) decreases in recharge, and (3) returned water (table 6), all of which cause changes in discharge to natural boundaries and the distribution of flow within the system. Comparison of discharges under recent conditions (table 9) with those under predevelopment conditions (table 4) indicates that the net stress of 240 Mgal/d has caused corresponding decreases of 135 Mgal/d (29 percent) in base flow, of 82 Mgal/d (14 percent) in shore discharge, and of 23 Mgal/d (28 percent) in subsea discharge. The most severe decreases in

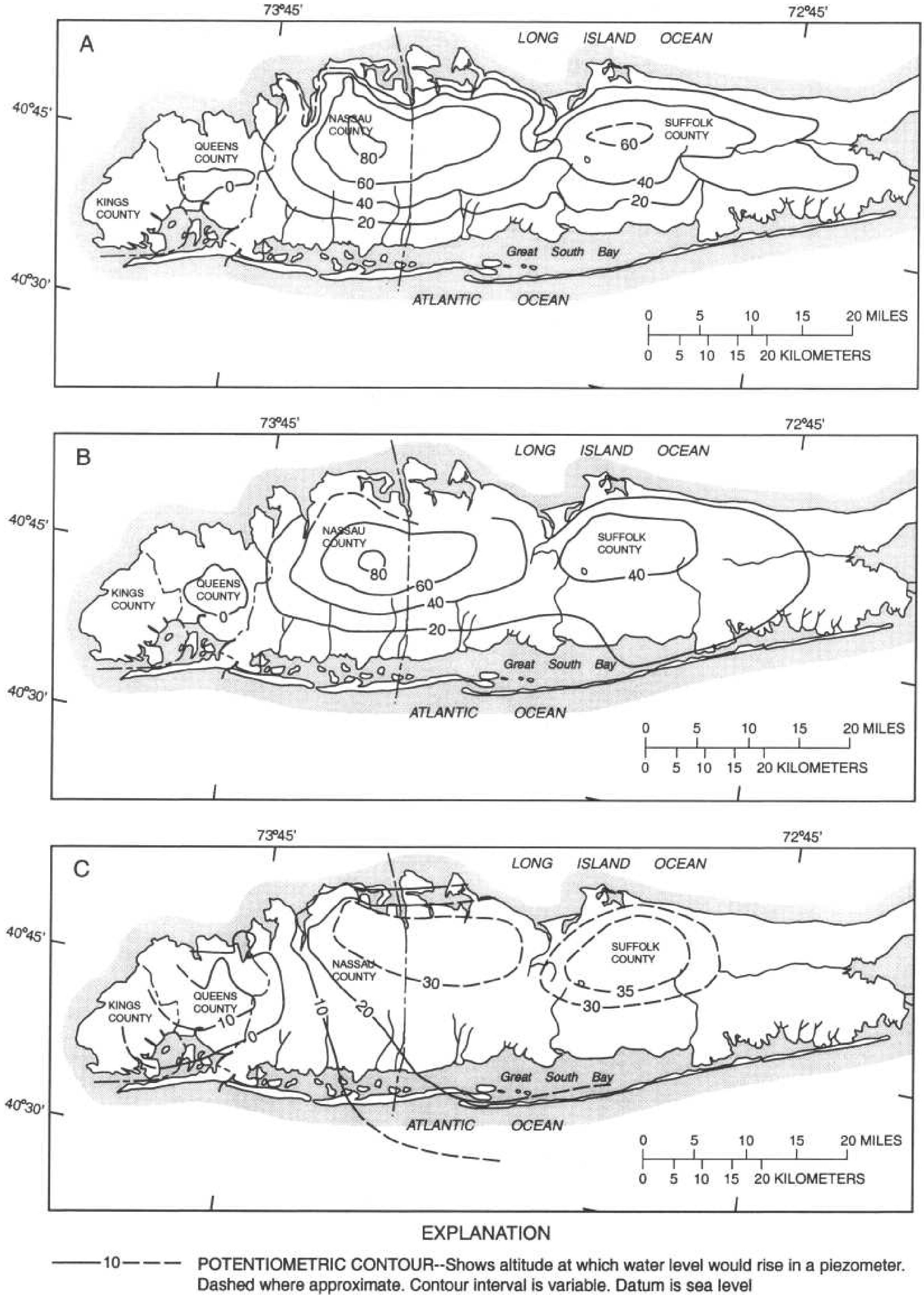
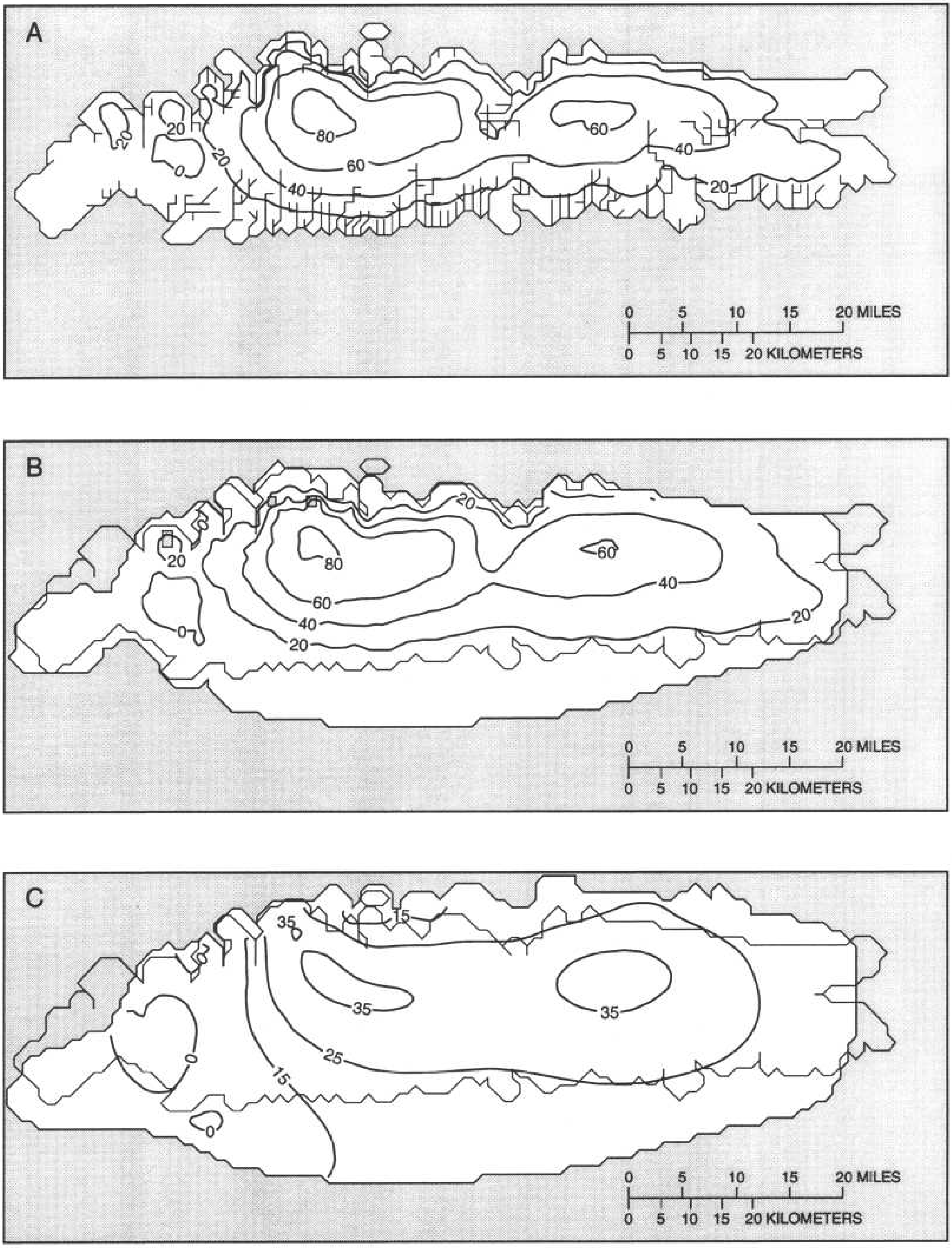


Figure 23. Measured ground-water levels representative of 1968-83.
A. Water-table aquifer, measured in March 1972 (from Vaupel and others, 1977, plate 7).
B. Magothy aquifer, measured in March 1972 (from Vaupel and others, 1977, plate 8).
C. Lloyd aquifer, measured in January, 1971 (from Kimmel, 1973, fig. 4).



EXPLANATION

AREA OUTSIDE EXTENT OF FRESH GROUND-WATER SYSTEM

—— 20 —— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would rise in a piezometer. Contour interval, in feet, is variable. Datum is sea level

Figure 24. Simulated ground-water levels representative of 1968-83. A. Water-table aquifer (model layer 1). B. Magothy aquifer (model layer 3). C. Lloyd aquifer (model layer 4).

Table 9. Ground-water budget for conditions during 1968-83 on Long Island

County	Recharge: Precipitation and returned water[1]	Discharge: Pumpage[2]	Discharge: Stream	Discharge: Shore	Discharge: Subsea
Kings and Queens	136	77	12	56	2
Nassau	346	185	55	82	14
Western Suffolk	339	87	123	126	25
Eastern Suffolk	472	58	135	239	17
Total	1,293	407	325	503	58

[1]Total recharge at the water table, includes (1) water returned to the ground-water system after use, and (2) decreases in recharge that result from diversion of runoff in Kings and Queens Counties. (See table 6.)

[2]Includes total public-supply, industrial-commercial, and agricultural pumping.

boundary discharge were in Kings, Queens, and Nassau Counties, where discharge to streams was reduced by more than 60 percent, but these effects diminish rapidly eastward through Suffolk County.

The patterns of ground-water flow have been considerably altered, even in areas where most of the pumped water is returned to the system, because much of the pumping is from the basal zone of the Magothy aquifer (model layer 3) and induces increased flow downward into the confined aquifers from above (compare table 10 and table 5). Table 10 indicates that downward flow to the Magothy aquifer (layers 2 and 3) has increased significantly from predevelopment conditions, which is consistent with pumping (table 7) and the attendant drawdown (figs. 23 and 24). The amount of flow entering model layer 2 has increased by 40 percent, and the amount entering layer 3 has increased by nearly 100 percent. Increased rates of ground-water movement to deep aquifers increases the possibility of contamination from land-surface sources in these aquifers which were once considered insulated from such contamination.

Table 10. Distribution of ground-water flow with depth during 1968-83 as represented in model

County	Model layer[1]: 1 (water table)	2 (Magothy and Jameco)	3	4 (Lloyd)
Kings and Queens	136	50	44	4
Nassau	346	236	191	5
Western Suffolk	339	179	119	17
Eastern Suffolk	472	183	92	8
Total	1,293	648	446	34

[1]Flow into layer 1 is recharge from precipitation and returned water; flow into layers 2, 3, and 4 is leakage from the overlying layer.

1960'S DROUGHT CONDITIONS

Long Island experienced a prolonged drought during 1962-66. The decrease in recharge from precipitation over this period caused many streams to reach their lowest recorded flows and ground-water levels to decline by as much as 10 ft below the norm (Cohen and others, 1968). Detailed records of streamflow and ground-water levels during the drought allow an evaluation of the response of base flow to this stress. The following section describes the response of the ground-water system to the 1960's drought, and the model representation of the exchange of water between streams and the ground-water system that enables simulation of the response of base flow to changing ground-water levels.

Hydrologic Stress

For the purposes of this analysis, the only stress on the ground-water system during the drought period is assumed to be the loss of recharge through the natural decrease in precipitation during the drought. The precipitation measured at the Mineola and Setauket stations (fig. 1) during the drought is shown in figure 25. The 1962-66 period has the lowest 5-year average precipitation for the 100 years of record at the Setauket station.