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,
SUFFOLK COUNTY DEPARTMENT OF HEALTH SERVICES,
SUFFOLK COUNTY WATER AUTHORITY, and the
NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

For additional information
write to:

Sub-District Chief
U.S Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report can be
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Branch of Information Services
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	square hectometer (hm^2)
gallon (gal)	3.785	cubic meter (m^3)
billion gallons	3,785,000	cubic meter (m^3)
foot per day (ft/d)	0.3048	meter per day (m/d)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Extensive development on Long Island since the late 19th century and projections of increased urbanization and ground-water use makes effective water-resource management essential for preservation of the island's hydrologic environment and maintenance of a reliable source of water supply. This report presents results of a ground-water flow simulation analysis of the effects of development on the Long Island ground-water system. It describes ground-water levels, streamflow, and the ground-water budget for the predevelopment period (pre-1900), the 1960's drought, and a more recent (1968-83) period with significant hydrologic stress. The report also presents estimated effects of a proposed water-supply strategy for the year 2020.

Long Island has three major aquifers—the upper glacial (water-table), the Magothy, and the Lloyd aquifers—that are separated to varying degrees by confining units. Before development, recharge from precipitation entered the ground-water system at a rate of more than 1.1 billion gallons per day. An equal amount discharged to streams (41 percent), the shore (52 percent), and subsea boundaries (7 percent). Urbanization and withdrawal of more than 400 Mgal/d (million gallons per day) from wells have resulted in local effects that include declines in ground-water levels, drying up and burial of streams and wetlands, reduction of ground-water recharge by increased overland flow to the ocean, a general decrease in ground-water discharge, and saltwater intrusion. In some areas, the reduction in recharge is mitigated by leakage from water-supply and wastewater disposal lines, and infiltration of stormwater through recharge basins. During 1968-83, a net loss of 240 Mgal/d from the ground-water system caused a decrease in ground-water discharge to streams (135 Mgal/d), to the shore (82 Mgal/d), and to subsea boundaries (23 Mgal/d). The greatest adverse effects have been in western Long Island, where the most severe development has occurred. This analysis shows stream base flow to be highly sensitive to water-table fluctuations, and long streams to be more sensitive than short ones.

A water-supply scenario for the year 2020 was simulated that employs redistribution of pumping centers to mitigate extreme local effects. Although the net stress on the ground-water system was projected to increase 57 Mgal/d (24 percent) above that of 1968-83, redistribution of ground-water withdrawals across the island would allow recovery of cones of depression in western Long Island, thereby reducing the threat of saltwater intrusion and increasing base flow of some streams. The increased stress would cause a net decrease in base flow islandwide of 44 Mgal/d; total base flow would be 281 Mgal/d—39 percent below predevelopment levels or 14 percent below 1968-83 levels. The most severe effects would be in Nassau and western Suffolk Counties.

INTRODUCTION

Long Island, N.Y., lies east of Manhattan and Staten Islands (fig. 1). It is 120 mi long, 25 mi wide at its widest point, and 1,400 mi^2 in total area. It is bordered by the Atlantic Ocean to the south and east, Long Island sound to the north, and tidal bays and narrows to the west. The island was formed largely during the Wisconsin glaciation, when periods of ice advance and retreat formed morainal ridges that trend east-west along the spine of the island. Long Island is bifurcated at the east end, where two morainal ridges separate to form the North and South Forks.

Long Island contains four counties, which, from west to east, are Kings, Queens, Nassau, and Suffolk (fig. 1). Kings and Queens Counties, the boroughs of Brooklyn and Queens, are part of New York City and are highly urbanized. Although Kings and Queens total only 76 mi^2 and 113 mi^2, respectively, their combined population reached 4.25 million in 1990 (2.3 million in Kings and 1.95 million in Queens). Nassau County ranges from highly industrialized and urbanized to residential and suburban. It encompasses 291 mi^2 and in 1992 had a population of about 1.29 million. Suffolk County has an area of 922 mi^2, and its population in 1992 was about 1.32 million. Suffolk County, the farthest from New York City, ranges from suburban, with commercial and industrial areas in the west to agricultural with extensive areas of open farmland in the east. The North and South Forks and selected locations along the south-shore barrier islands (fig. 1) are popular seasonal resort areas.

Ground water is the sole source of water supply for the entire population of Nassau and Suffolk Counties and for more than 500,000 people in eastern Queens County. Kings and Queens Counties import as much as 700 Mgal of water each day from a system of upstate reservoirs. Ground water also is used extensively for industrial, commercial, and agricultural uses. In 1981, 385 Mgal/d was pumped for public-supply; 100 Mgal/d was pumped at about 2,500 industrial-commercial installations across the island, and about 15 Mgal/d was pumped to irrigate about 40,000 acres of farmland.

Most surface-water bodies on Long Island are connected hydraulically to the ground-water system. These include (1) more than 100 streams, which are fed year round by ground-water discharge; (2) numerous lakes, which represent the intersection of the water table with glacial "kettles" or other topographic depressions; (3) extensive wetlands, where the water table intersects or lies just below land surface, and (4) brackish-water bays, whose salinity and shellfish population depend on a specific mix of sea water and fresh ground-water discharge.

Extensive development through the 20th century, and projections of increased urbanization and ground-water use, makes effective water-resource management essential for preservation of Long Island's hydrologic environment and maintenance of a reliable source of water supply for the future.

Purpose and Scope

This report describes the Long Island ground-water system and its response to water-supply and land development. It describes use of both hydrologic field measurements and a ground-water flow simulation model to quantify historic resources and implications of future development. The report describes the geologic structure that forms the framework of the Long Island ground-water system, and three historical hydrologic conditions—predevelopment conditions (before 1900), a more recent (1968-83) stressed condition, and a period of severe drought during the 1960's. The predevelopment and recent stressed conditions provide a basis for evaluation of the effects of

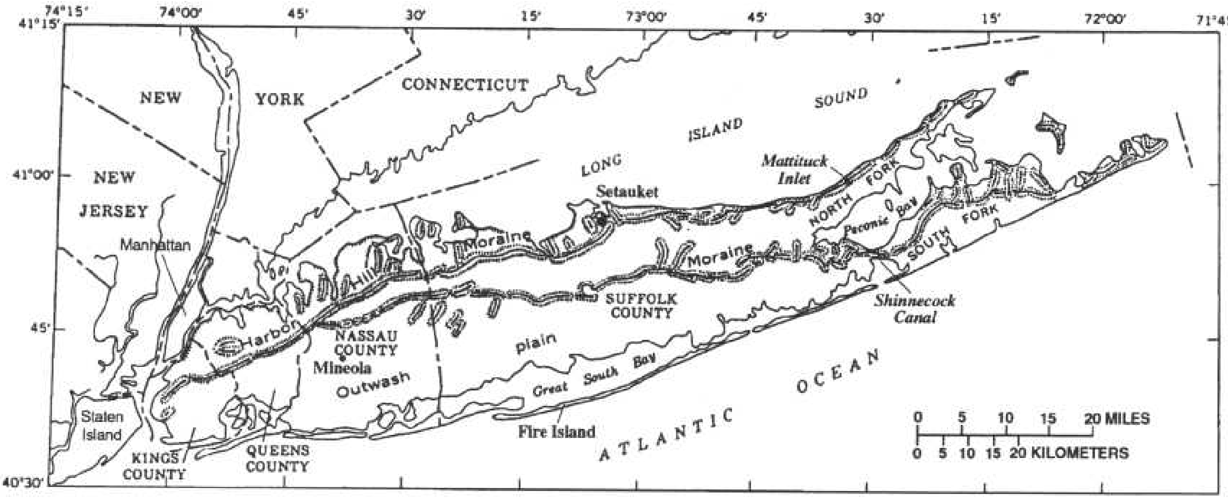

Figure 1. Location and pertinent geographic features of Long Island, N.Y. (Modified from McClymonds and Franke, 1972, fig. 2.)

future development. The drought, which caused a severe natural decrease in ground-water recharge, was analyzed to evaluate the transient response of the ground-water system to stresses (like ground-water withdrawals or reduced recharge), particularly the response of stream base flow. The model was used to estimate the hydrologic effects of proposed water-supply development strategies of Nassau and Suffolk Counties and New York City for the year 2020. The effects of historical and planned development are presented in terms of changes in ground-water levels, base flow, and the water budget of the Long Island ground-water system.

Previous Investigations

The earliest comprehensive discussion of the Long Island ground-water system was that by Veatch and others (1906); it presented hydrogeologic data and information on the source and movement of ground water and ground-water/surface-water interaction. Many early investigations were motivated by New York City's interest in Long Island as a source of water supply (Burr and others, 1904; Spear, 1912). Suter (1937) discussed the ramifications of overdevelopment of Long Island's ground-water resources and the concept of a "safe" level of development when (1) overpumping in Brooklyn was causing saltwater intrusion, and (2) development of Nassau and Suffolk Counties was expected to cause a significant draft on the remainder of Long Island's ground water.

Early attempts to manage Long Island's ground-water resources were handicapped by a poor understanding of the processes that control the system's operation. For example, Suter (1937, p. 37) states:

> "A theory has been advanced by many that the proper way to develop the underground resources of the Island to their maximum capacities is to place the wells close to salt water and in effect to intercept the fresh water that is flowing from the Island towards the sea."

This theory, if implemented, would have resulted in rapid encroachment of saltwater on these wells.

With the advance of analytical and numerical techniques for analyzing ground-water systems in the 1970's, investigations of Long Island's ground water evolved toward a "system concept" approach, based on increasing knowledge of the processes that affect the quantity and movement of water within the system and the response to stress. Franke and McClymonds (1972) and Cohen and others (1968) define the hydrologic boundaries of the entire Long Island ground-water system and all components of its water budget. The first three-dimensional model of the Long Island ground-water flow system was constructed in the early 1970's (Getzen, 1974; Getzen, 1977). This model was an electric analog model that used an extensive electrical resistor network to represent the system of aquifers and confining units, and the flow of electricity (electrical current) to represent the flow of ground water. The model omitted the deepest confined (Lloyd) aquifer. Gupta and Pinder (1978) and Reilly and Harbaugh (1980) used the finite-element and finite-difference computer-model programs, respectively, to convert the analog model to the first digital-numerical models of the Long Island ground-water system. The analog model developed by Getzen (1977) and the finite-difference model of Reilly and Harbaugh (1980) were used extensively in the 1970's and early 1980's to estimate the effects of proposed water-resource management strategies (Aronson and others, 1979; Harbaugh and Reilly, 1976 and 1977; Kimmel and Harbaugh, 1975 and 1976; Kimmel and others, 1977). The Reilly and Harbaugh (1980) model was used to calculate boundary conditions for fine-scaled subregional models to evaluate the local effects of sewer networks (Reilly and others, 1983; Buxton and Reilly, 1985; Reilly and Buxton, 1985; Buxton and Reilly, 1987). The modeling analysis presented herein includes a finer-scale representation of the Long Island ground-water flow system than previous models, and includes the Lloyd aquifer (not previously included in islandwide models); it also includes improvements based on significant hydrogeologic data collected since 1970.

Acknowledgments

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PRINCIPLES OF SIMULATION ANALYSIS

A simplified conceptual approach is used herein to describe the structure and operation of the Long Island ground-water system (fig. 2). The structure of the system is defined by the distribution of water transmitting and storing properties within the aquifers and confining units, and the geometry and nature of its external boundaries. The operation of the system reflects the system's response to specific stimuli or stress. Ground-water systems can be viewed as being driven by recharge (the stimulus), and the response is defined in terms of the distribution of hydraulic head (water levels) and of ground-water flow within, and entering and leaving, the system. Natural or human-induced changes in recharge or discharge (considered stresses), such as pumping (fig. 2),

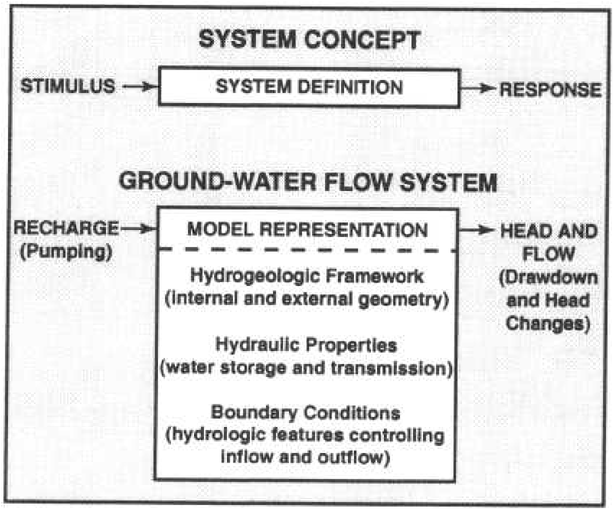

Figure 2. Conceptual approach to representation of ground-water flow systems. (Modified from Reilly and others, 1987, fig. 1).

similarly drive changes in ground-water levels and flows. A conceptual model of the system is developed from hydrogeologic data on the hydrogeologic geometry, water-storing and transmitting properties, hydrologic boundaries, the distribution of ground-water levels within the system, and ground-water discharge to streams (base flow). This system concept is represented in the model in a discrete form—represented as a grid of discrete blocks or cells, each with uniform properties.

A finite-difference ground-water flow model was used in this analysis (McDonald and Harbaugh, 1988). Finite-difference models employ rectangular grids with a series of cells aligned in rows and columns. This model was defined to represent the main ground-water flow system uniformly, and with enough cells to incorporate local hydrogeologic features and provide the desired level of resolution of ground-water levels and flow (fig. 3). The model did not include the North and South Forks, which have local flow systems that are not integrally connected to the island's main ground-water flow system. In plan view, the grid cells are square and represent 4,000 ft on a side. The grid extends offshore to include the entire fresh ground-water system. The model has 4 layers representing the island's vertical sequence of aquifers and confining units.

The basis of ground-water-flow simulation is the formulation of a series of mathematical equations (one for each model cell) that represent the balance of flow entering and exiting each cell. Together these equations represent the distribution of water entering, flowing through, and exiting the ground-water system. A computer is used to solve the equations simultaneously and thereby provides an estimate of the ground-water level within, and the rates of flow through each face of each cell in the model for a specified hydrologic condition. The model analysis includes calibration, a quantitative test of the model representation of the ground-water system through comparison of simulated and measured values of system response (ground-water levels and flows), and use of the model for prediction of the system response to possible future conditions. Within this report, information and interpretations based on field data and model results are presented concurrently to provide a unified concept of the ground-water system.

HYDROGEOLOGIC FRAMEWORK

Long Island is underlain by a sequence of unconsolidated deposits of clay, silt, sand, and gravel that overlies southeastward-dipping igneous and metamorphic bedrock. The hydrogeologic structure that forms the framework for the aquifers and confining units within the Long Island ground-water system, and the distribution of hydraulic properties within that framework are described below.

Hydrogeologic Structure

The hydrogeologic structure of sediments beneath Long Island is inferred from borehole data, offshore seismic surveys, and geologic