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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

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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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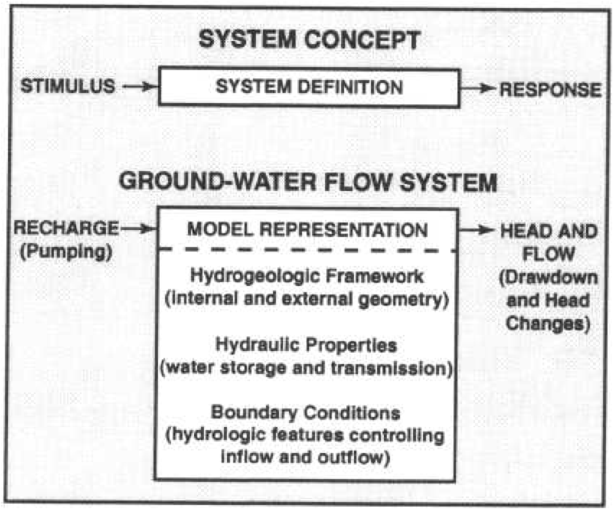



**Figure 2.** Conceptual approach to representation of ground-water flow systems. (Modified from Reilly and others, 1987, fig. 1).

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.

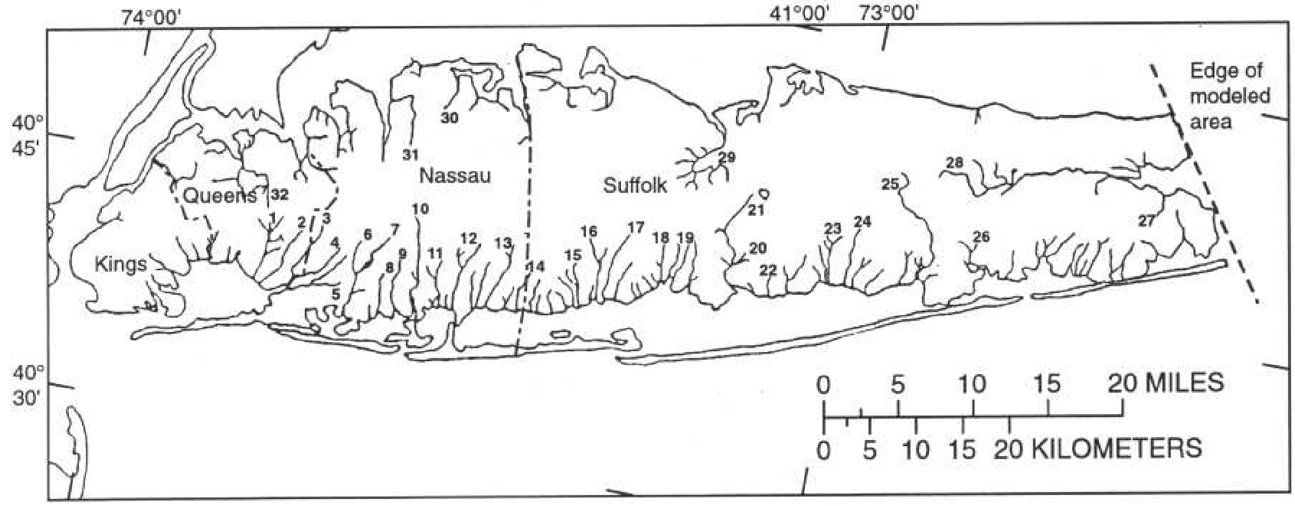
The basis of ground-water-flow simulation is the formulation of a series of mathematical equations (one for each model cell) that represent the balance of flow entering and exiting each cell. Together these equations represent the distribution of water entering, flowing through, and exiting the ground-water 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

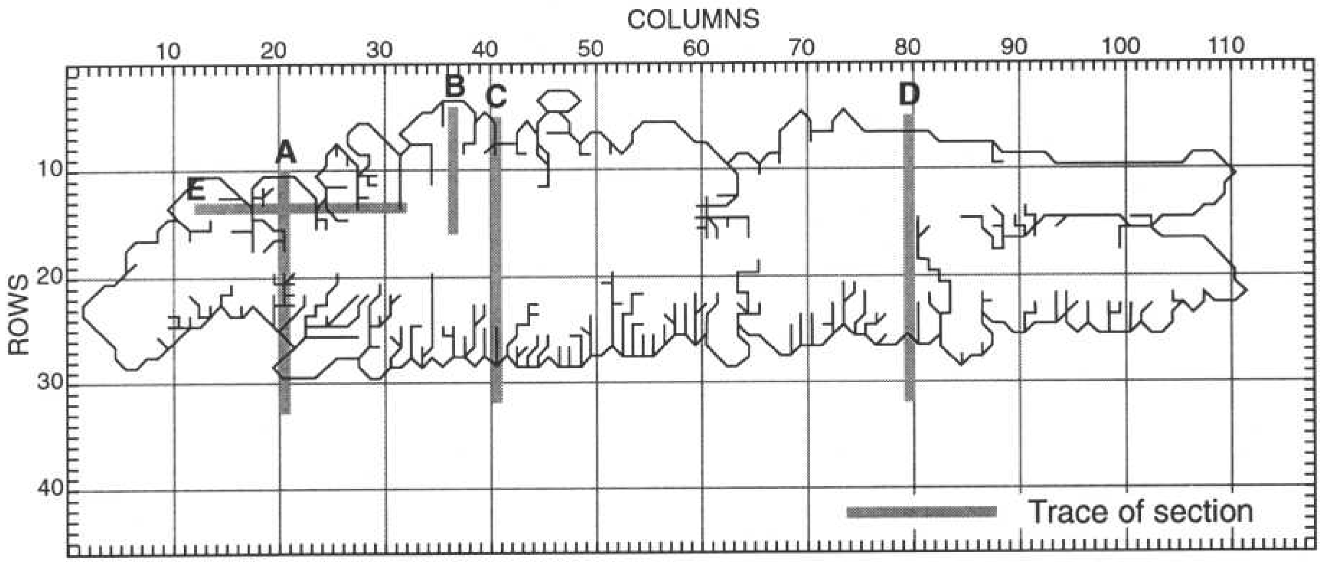
Long Island is underlain by a sequence of unconsolidated deposits of clay, silt, sand, and gravel that overlies southeastward-dipping igneous and metamorphic bedrock. The hydrogeologic structure that forms the framework for the aquifers and confining units within the Long Island ground-water system,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




A. STREAMS AND SHORE




B. MODEL GRID

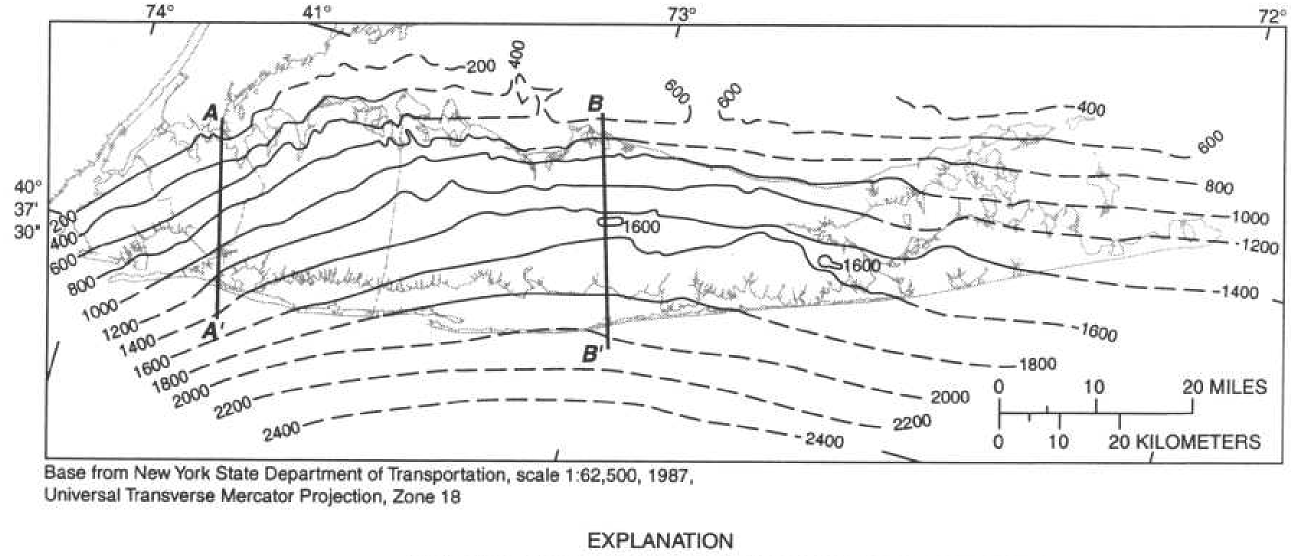
**Figure 3.** A. Long Island's streams and shore. B. Model grid and representation of streams and shore. (Names of major streams, numbered, are given in table 3. Vertical sections A through E are given in fig. 6.)

correlations interpreted from the depositional history of the unconsolidated materials that form the ground-water system. Hydrogeologic-unit surface maps were constructed as part of this project and are published in Smolensky and others (1989) at a scale of 1:250,000; correlations made from borehole data (from more than 3,100 wells) from which those maps were constructed are presented in Buxton and others (1989).

The unconsolidated deposits that form the Long Island aquifer system overlie a southward sloping bedrock surface. They are thinnest in the northwest, where bedrock crops out in a few areas of northern Queens, and thicken to the south and east, attaining a maximum thickness of 2,000 ft beneath the barrier island in southern Suffolk County (fig. 4).

This wedge-shaped mass of unconsolidated deposits consists of seven distinct geologic units that range in age from late Cretaceous to Pleistocene; some recent deposits are found near the shores and along streams. The units are differentiated by age, method of deposition, and lithology in table 1. The geologic units generally correspond to hydrogeologic units, which have specific water-transmitting properties (table 1). In order of deposition, the hydrogeologic units are the Lloyd aquifer, the Raritan confining unit, the Magothy aquifer, the Jameco aquifer, the Gardiners Clay (a confining unit), and the upper glacial aquifer. The Jameco aquifer is present only in western Long Island (fig. 5A). The Monmouth greensand is associated with the Gardiners Clay in eastern Long Island (fig. 5B). The irregular extent and surface configuration of these units, caused by extensive erosion of Cretaceous-age sediments and filling by subsequent deposition, has resulted in complex spatial relations between aquifers and confining units (fig. 5).

The depositional history (record of periods of deposition, erosion, and nondeposition) that characterize Long Island's geologic past is summarized in Smolensky and others (1989) and is essential to the interpretation of Long Island's hydrogeologic framework. Maps of the surface configuration of the hydrogeologic units and additional hydrogeologic sections




Base from New York State Department of Transportation, scale 1:62,500, 1987, Universal Transverse Mercator Projection, Zone 18

EXPLANATION

2400 — — LINE OF EQUAL THICKNESS OF UNCONSOLIDATED DEPOSITS– Dashed where approximately located. Contour interval 200 feet

A —— A' TRACE OF HYDROGEOLOGIC SECTION (see figure 5)

**Figure 4.** Thickness of unconsolidated deposits on Long Island, N.Y. (Modified from Buxton and others, 1989, fig. 2.)

**Table 1.** Hydrogeologic units of Long Island, N.Y.

| System | Series | Geologic unit | Hydrogeologic unit | Approximate maximum thickness (feet) | Geologic character | Water-transmitting character |
|---|---|---|---|---|---|---|
| Quaternary | Holocene | Recent deposits: Salt marsh deposits, stream alluvium, shoreline deposits, and fill | Recent deposits | 50 | Sand, gravel, clay, silt, organic mud, peat, loam, and shells. Colors are gray, brown, green, black, and yellow. | Beach deposits are highly permeable; marsh deposits poorly permeable. Locally hydraulically connected to underlying aquifers. |
| Quaternary | Pleistocene | Upper Pleistocene deposits<br>unconformity? | Upper glacial aquifer | 700 | Till composed of clay, sand, gravel, and boulders, forms Harbor Hill and Ronkonkoma terminal moraines. Outwash deposits consist of quartzose sand, fine to very coarse, and gravel, pebble to bounder sized. Also contains lacustrine, marine, and reworked deposits. Local units are Port Washington aquifer and confining unit, "20-foot" clay, and the "Smithtown clay". | Till is poorly permeable. Outwash deposits are moderately to highly permeable. Glaciolacustrine and marine clay deposits are mostly poorly permeable but locally have thin, moderately permeable layers of sand and gravel. |
| Quaternary | Pleistocene | Gardiners Clay<br>unconformity? | Gardiners Clay | 150 | Clay, silt, and few layers of sand. Colors are grayish green and brown. Contains marine shells and glauconite. | Poorly permeable; constitutes a confining layer for underlying aquifers. Some sand lenses may be permeable. |
| Quaternary | Pleistocene | Jameco Gravel<br>unconformity | Jameco aquifer | 200 | Sand, fine to very coarse, and gravel to large-pebble size; few layers of clay and silt. Gravel is composed of crystalline and sedimentary rocks. Color is mostly brown. | Moderately to highly permeable. Confined by overlying Gardiners Clay. |
| Cretaceous | Upper Cretaceous | Monmouth Group<br>unconformity | Monmouth greensand | 200 | Interbedded marine deposits of clay, silt, and sand, dark-greenish gray, greenish-black, greenish, dark-gray, and black, containing much glauconite. | Poorly permeable; primarily a confining unit for underlying Magothy aquifer. |
| Cretaceous | Upper Cretaceous | Matawan Group-Magothy Formation, undifferentiated<br>unconformity | Magothy aquifer | 1,100 | Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal zone. Sand and gravel are quartzose. Lignite, pyrite, and iron oxide concretions are common. Colors are gray, white, red, brown, and yellow. | Most layers are poorly to moderately permeable. Water is unconfined in uppermost parts, elsewhere is confined. Coarse basal zone has higher permeability than overlying sediments. |
| Cretaceous | Upper Cretaceous | Raritan Formation: Unnamed clay member | Raritan confining unit (Raritan clay) | 200 | Clay, solid and silty; few lenses and layers of sand. Lignite and pyrite are common. Colors are gray, red, and white, commonly variegated. | Poorly to very poorly permeable; constitutes confining layer for underlying Lloyd aquifer. |
| Cretaceous | Upper Cretaceous | Raritan Formation: Lloyd Sand Member<br>unconformity | Lloyd aquifer | 500 | Sand, fine to coarse, and gravel, commonly with clayey matrix; some lenses and layers of solid and silty clay; locally contains thin lignite layers. Sand and most of gravel are quartzose. Colors are yellow, gray, and white; clay is red locally. | Poorly to moderately permeable. Water is confined by overlying Raritan clay. |
| Precambrian and Paleozoic | -- | Bedrock | Bedrock | -- | Crystalline metamorphic and igneous rocks; muscovite-biotite schist, gneiss, and granite. A soft, clayey zone of weathered bedrock locally is more than 70 ft thick. | Poorly permeable to virtually impermeable; constitutes lower boundary of ground-water reservoir. Some hard freshwater is contained in joints and fractures but is impractical to develop at most places. |

provided in Smolensky and others (1989) provide a three-dimensional depiction of the ground-water system's hydrogeologic structure. Additional information on Long Island's geologic history is available in Soren (1971), Jensen and Soren (1974), Kilburn (1979), and Nemickas and Koszalka (1982).

The vertical sequence of aquifers and confining units that form the Long Island ground-water system was represented in the model in four layers that, as a general rule, correspond to the major aquifer units. The uppermost layer represents the water-table aquifer (which in most places is the upper glacial aquifer); the second and third layers represent the upper and lower zones of the Magothy aquifer; and the fourth (bottom) layer represents the Lloyd aquifer. The major confining units (Gardiners Clay and Raritan confining unit) are represented implicitly in the model (that is, where present, they affect only vertical flow between aquifers or model layers). In many places, local units are present, such as the Port Washington aquifer, Port Washington confining unit, "Smithtown clay", "20-foot" clay (a confining unit), and Monmouth greensand (a confining unit).

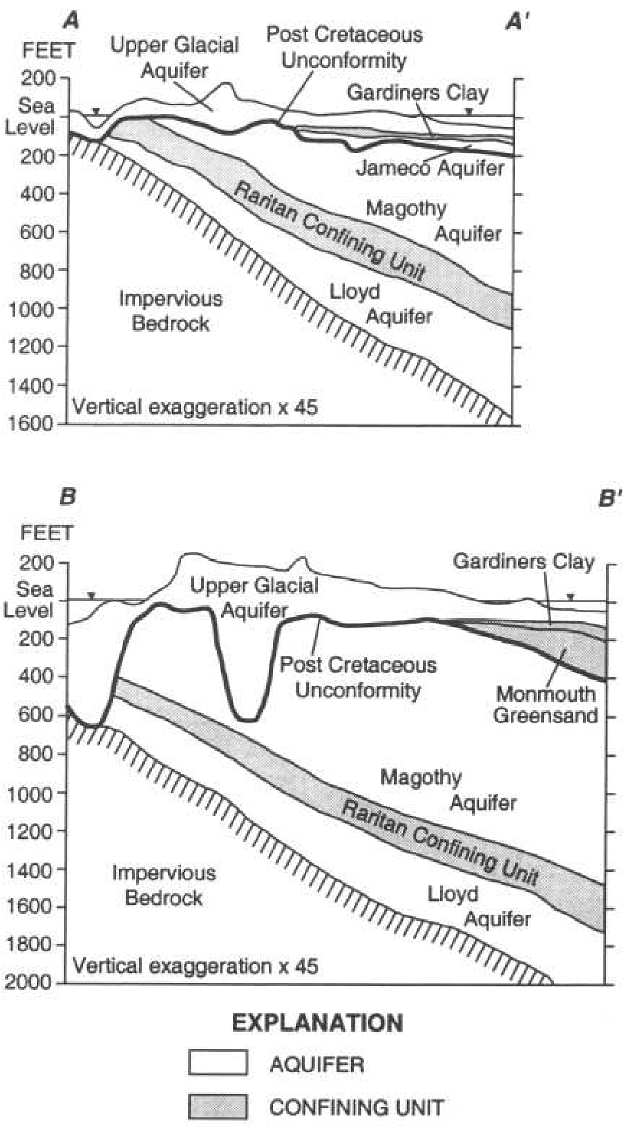



**Figure 5.** Hydrogeologic sections A-A' and B-B', Long Island, N.Y. (Trace of sections is shown in fig. 4.)

Selected sections that depict the model layering are shown in figure 6; maps showing the thickness and aquifers represented in each model layer, and the thickness of confining units, are presented in figure 7. These sections and maps illustrate the discrete model representation of Long Island's hydrogeologic framework.

In western Long Island (fig. 6A), the Jameco aquifer was deposited by glacial meltwaters that were at the same time eroding the Magothy (Cretaceous) surface. The Jameco is extensive throughout western Long Island (fig. 7B) and is represented in model layer 2 where Magothy deposits are thin, and in model layers 2 and 3 where Magothy deposits are absent (fig. 7C). Although the Jameco is thin in places, its high hydraulic conductivity makes it an important aquifer. The Jameco and Magothy aquifers (model layers 2 and 3) thin northwestward and eventually pinch out (fig. 6A).

A deep, north-south trending channel in central Queens County was eroded through the Cretaceous deposits (the Magothy aquifer, Raritan confining unit, and Lloyd aquifer) into bedrock (fig. 6E) (Smolensky and others, 1989, sheet 2). This channel is now filled with upper glacial aquifer material and provides a direct

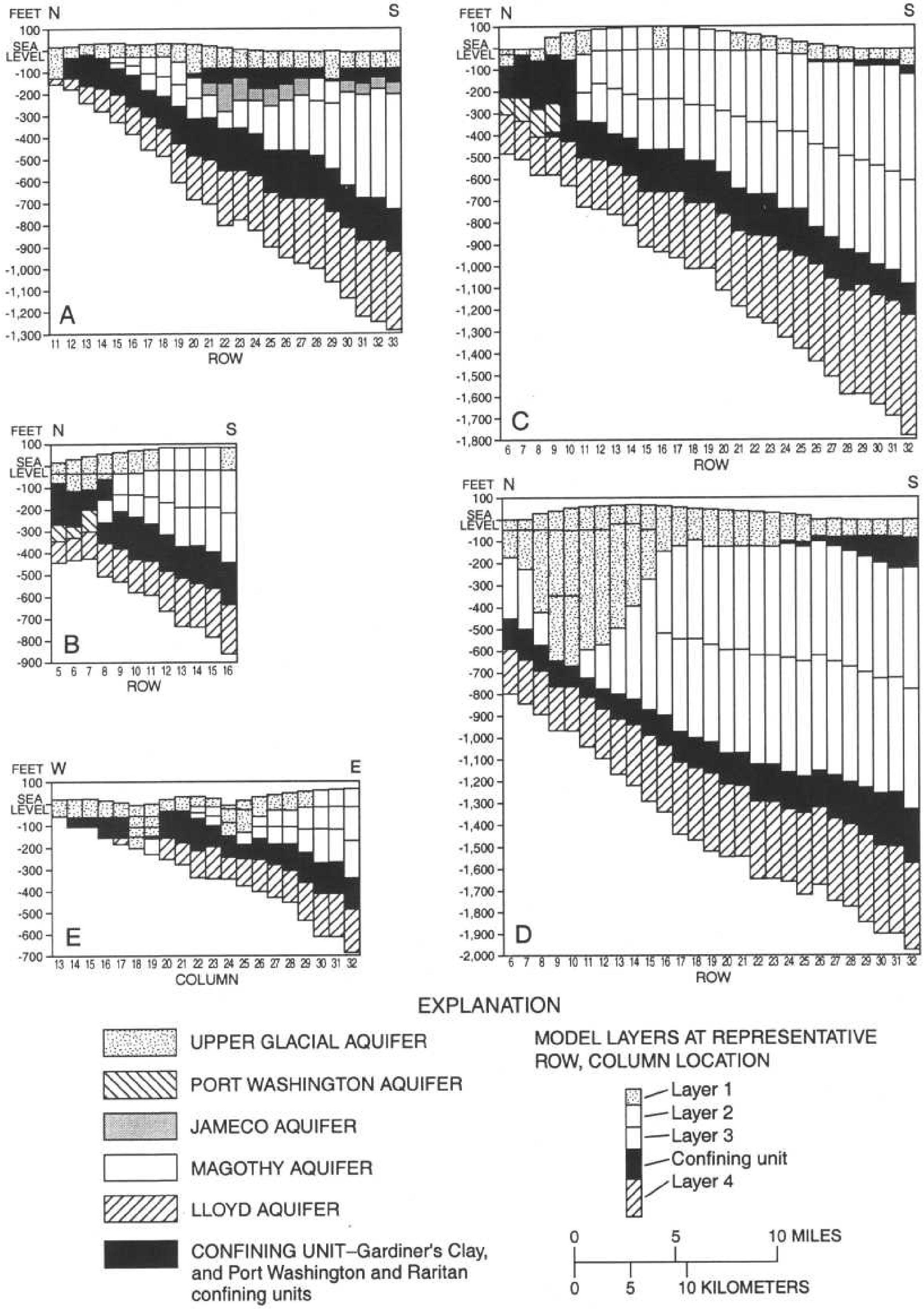



**Figure 6.** Selected sections showing model hydrogeologic geometry. A. Column 21. B. Column 37. C. Column 41 D. Column 80. E. Row 14. (Section locations are shown in fig 3B.)

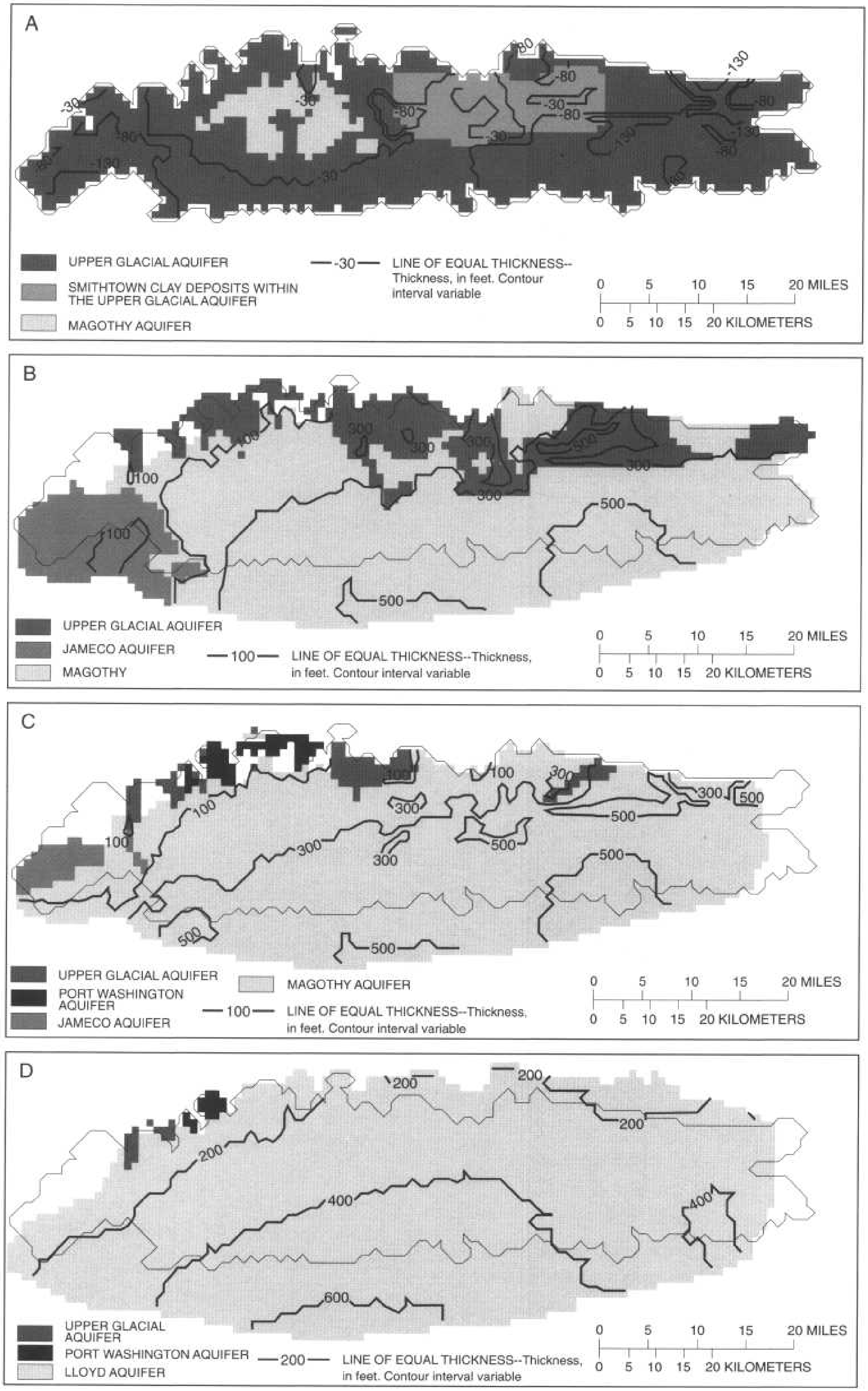
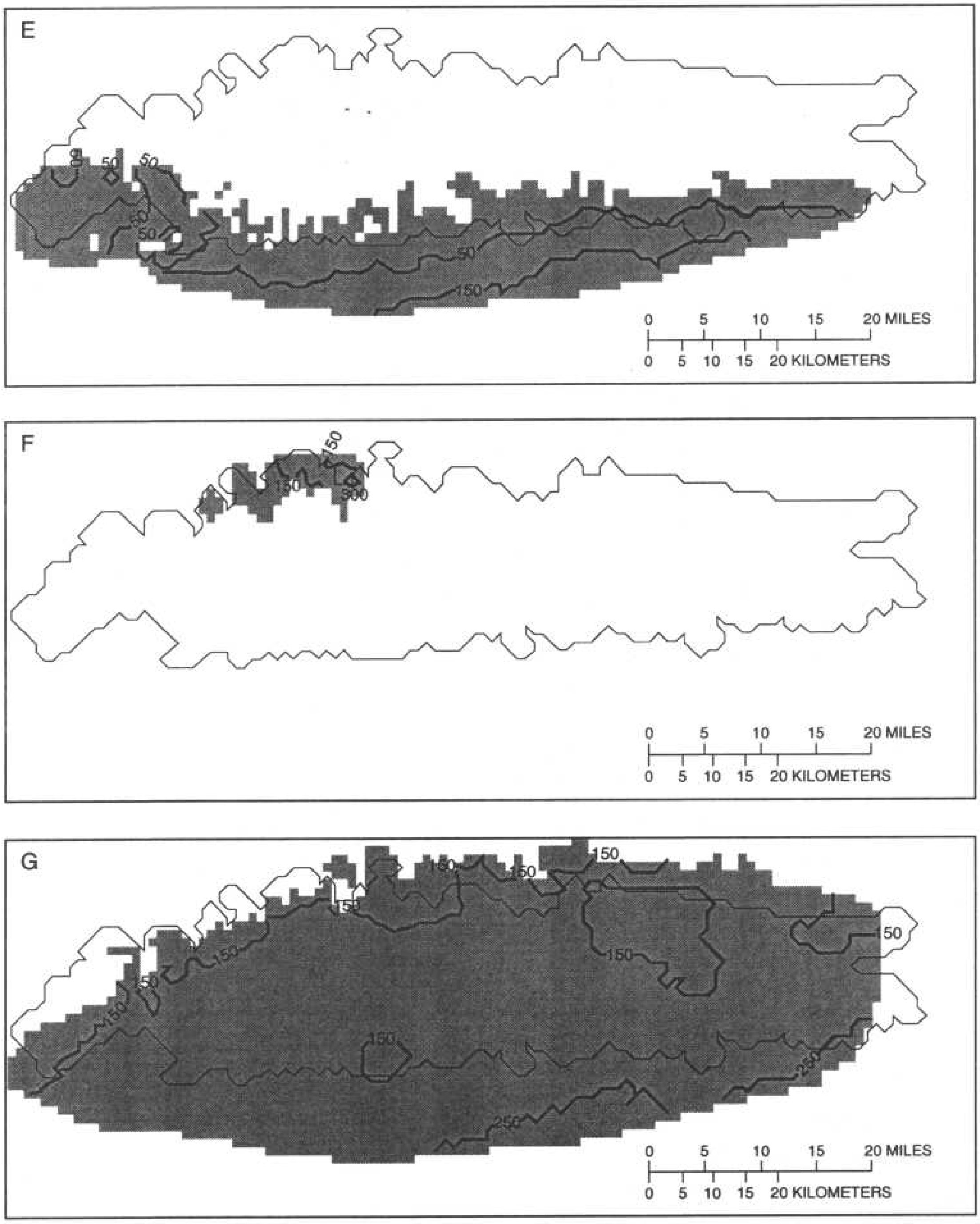



**Figure 7.** Model representation of hydrogeologic units. A. Surface altitude of bottom of water-table layer (layer 1) and distribution of aquifers. B., C., D. Thickness and distribution of aquifers model layers 2, 3 and 4.




EXPLANATION

AREA OF CONFINING UNIT

—50— LINE OF EQUAL THICKNESS--Thickness, in feet. Contour interval variable

**Figure 7.** Model representation of hydrogeologic units (continued), thickness of confining units. E. Composite of Gardiner's Clay and Monmouth greensand (between layers 1 and 2). F. Port Washington confining unit (between layers 2 and 3). G. Raritan confining unit (between layers 3 and 4)--Continued.

hydraulic connection between the shallow aquifer and the Lloyd without interference by the Raritan confining unit (fig. 6E). The channel extends southward into central Queens County (fig. 7G and 7D).

Two Pleistocene hydrogeologic units —the Port Washington aquifer and overlying Port Washington confining unit (Kilburn and Krulikas, 1987; and Kilburn, 1979) (fig. 8)— were deposited on the severely eroded, northward sloping surface of Cretaceous deposits in northern Nassau County. The Port Washington aquifer is represented in model layer 3 (fig. 7C), and the overlying Port Washington confining unit (fig. 7F) restricts vertical flow between layers 2 and 3. The Port Washington confining unit overlaps the underlying Port Washington aquifer throughout its southern extent but has been eroded completely in a channel through Manhasset Bay (fig. 8B). The Port Washington confining unit overlaps and acts as an extension of the Raritan confining unit where both the Magothy and Port Washington aquifers are absent (fig. 6C). This does not apply in two areas where the Port Washington aquifer overlaps the Magothy aquifer, forming a hydraulic connection between these two aquifers (fig. 6B, rows 7 and 8).

The surface of the Magothy aquifer in central Nassau and west-central Suffolk County is above sea level, and the water table lies within Magothy deposits, represented in model layer 1 in this area (figs. 6C and 7A). Cretaceous deposits are eroded more extensively in Suffolk County than in Nassau County (fig. 5B, and Smolensky and others, 1989, sheet 1), where the upper glacial aquifer attains a thickness greater than 800 ft in deep erosional channels (figs. 6D, 7B, and 7C) and is represented in layers 2 and 3. The "Smithtown clay", found mainly in the intermorainal areas in west-central Suffolk County (fig. 8), was deposited in a glacial lake during recession of

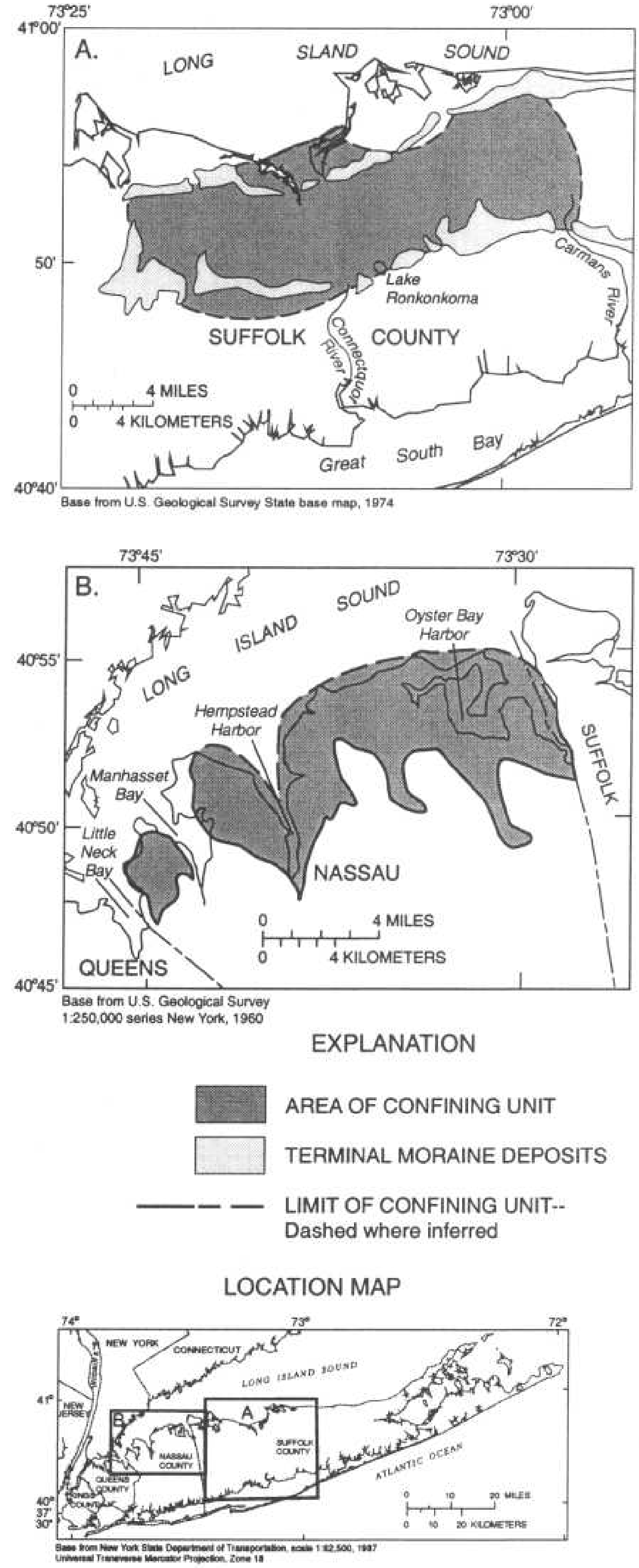



**Figure 8.** Extent of A., "Smithtown clay" (modified from Krulikas and Koszalka, 1983, fig. 3) and B., Port Washington confining unit (modified from Kilburn and Krulikas, 1987, plate 4B, and Kilburn, 1979, fig. 12).

the ice advance that formed the Ronkonkoma moraine (Krulikas and Koszalka, 1983). Its upper surface altitude ranges from sea level to 90 ft above sea level, and its maximum thickness is 170 ft. It is represented in layer 1 of the model (fig. 7A).

The "20-foot" clay and other upper Pleistocene shallow marine clays (Doriski and Wilde-Katz, 1983) have been identified locally. These clay units also behave much as the Gardiners Clay and were incorporated with the Gardiners Clay in the model.

The Monmouth greensand underlies the Gardiners Clay in Suffolk County (Smolensky and others, 1989, sheet 3) and probably has hydraulic properties similar to those of the Gardiners Clay. Therefore, it is incorporated with the Gardiners Clay and represented as part of the confining unit that restricts vertical flow between the upper glacial and Magothy aquifers (model layers 1 and 2). As a result, the total thickness of the confining unit is considerably greater in southern Suffolk County than elsewhere (fig. 7E).

Erosion of the Cretaceous deposits along most of the north shore (figs. 7D and 7G) provides a direct contact between the Lloyd and shallow aquifers (figs. 6A, 6B, and 7D). The Raritan confining unit overlaps the Lloyd in Kings and western Queens (fig. 6E; compare fig. 7D with 7G).

### Water-Transmitting Properties

Values of water-transmitting properties presented in this section represent a best estimate at the islandwide (model) scale of this analysis. Initial values taken from field estimates and previous model analyses were adjusted through model calibration. Field estimates include those made by McClymonds and Franke (1972), Prince and Schneider (1989), and Lindner and Reilly (1983). Estimates made in numerical model investigations include Franke and Getzen (1976), Getzen (1977) and Reilly and others (1983). Values of water-transmitting properties of the aquifers and confining units are assigned on a cell-by-cell basis in the model. Values of vertical to horizontal anisotropy of aquifers and vertical hydraulic conductivity of confining units were assumed constant for each hydrogeologic unit. Final model values of the water-transmitting properties of Long Island's major units are presented in figure 9 and summarized in table 2.

The upper glacial aquifer has horizontal hydraulic conductivity ranging from 20 to 270 ft/d (fig. 9A). Hydraulic conductivity changes abruptly at the line that corresponds to the Ronkonkoma terminal moraine; values for the outwash deposits south of the moraines generally range from 200 to 270 ft/d; that for the moraine deposits is less than 135 ft/d. Where the "Smithtown clay" is present, the average hydraulic conductivity of the upper glacial aquifer is less than 25 ft/d. The anisotropy (ratio of horizontal to vertical hydraulic conductivity) of the upper glacial aquifer is estimated to be 10:1; undoubtedly, local values could be as low as 3:1.

Horizontal conductivity of the Jameco aquifer ranges from 200 ft/d to 300 ft/d (fig. 9B), and its anisotropy is estimated to be 10:1. The Jameco aquifer attains the highest

**Table 2.** Estimated average values of hydraulic conductivity, anisotropy, and storage of major aquifers, Long Island

| Aquifer | Hydraulic conductivity (feet per day) | Anisotropy (vertical to horizontal) | Specific yield |
|---|---|---|---|
| Upper glacial | | | |
| Moraine | 50 | 10:1 | 0.25 |
| Outwash | 240 | 10:1 | .30 |
| Jameco | 250 | 10:1 | -- |
| Magothy | | | |
| Upper part | 50 | 100:1 | .15 |
| Basal part | 75 | 100:1 | -- |
| Lloyd | 50 | 100:1 | -- |

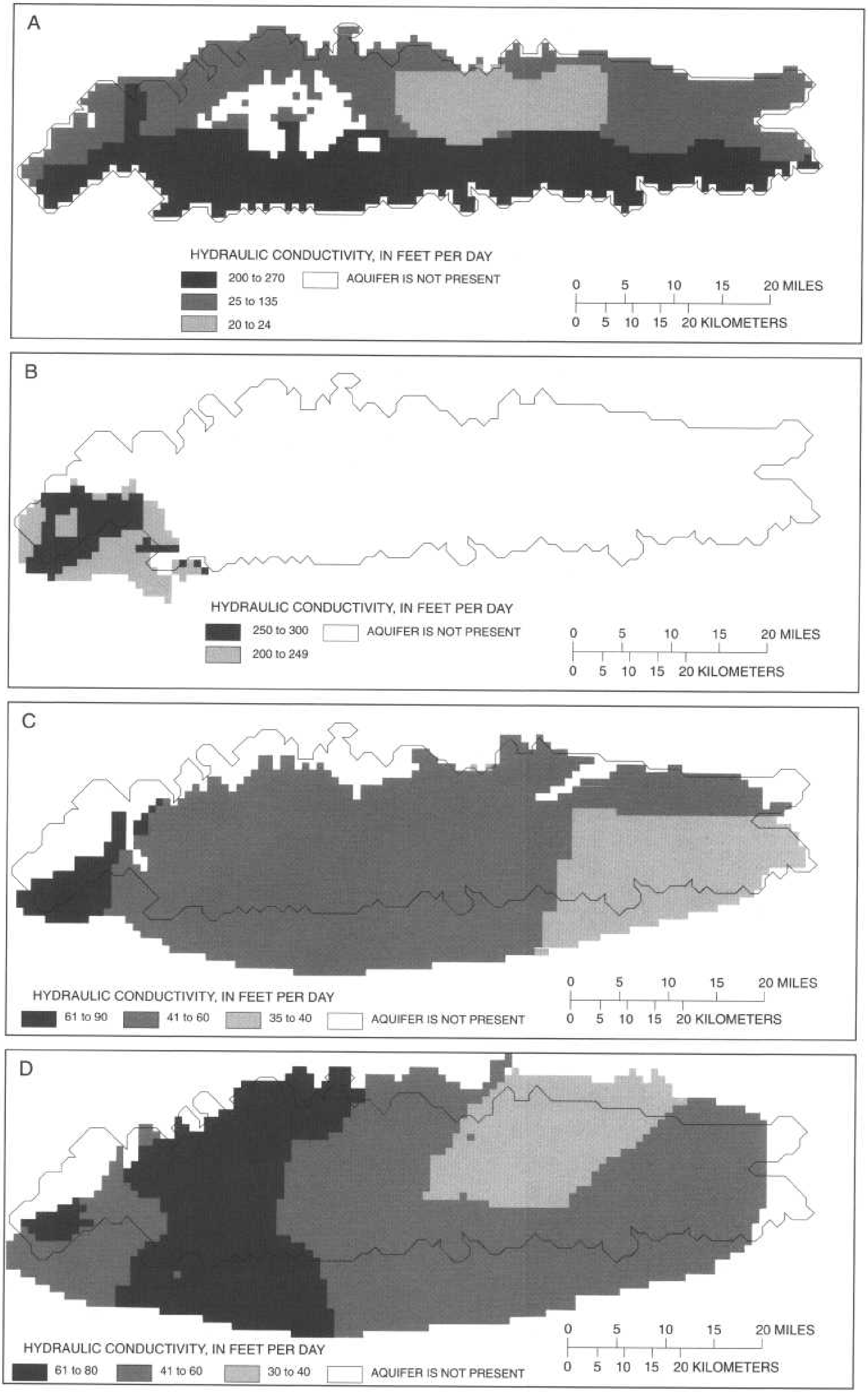



**Figure 9.** Model representation of hydraulic conductivity of four major aquifers. A. Upper glacial aquifer. B. Jameco aquifer. C. Magothy aquifer. D. Lloyd aquifer.

hydraulic conductivity of any aquifer on Long Island. The hydraulic conductivity of the Magothy aquifer varies with depth; values for the upper part range from 35 ft/d to 90 ft/d; values for the coarser, basal zone were estimated to be about 50 percent higher. Hydraulic conductivity of the Lloyd aquifer ranges from 30 ft/d to 80 ft/d and generally is greatest in Nassau County. The anisotropy of these aquifers is estimated to be 100:1 because of their highly stratified character.

Although data on hydraulic conductivity of the confining units are scant, the high clay and silt content indicates values several orders of magnitude lower than those of adjacent aquifers. Franke and Cohen (1972) estimated the average vertical hydraulic conductivity of the confining units to be 0.001 ft/d; Reilly and others (1983) estimated a value of 0.0029 ft/d for the Gardiners Clay. The vertical hydraulic conductivity values of the major confining units used in this analysis are Gardiners Clay, 0.004 ft/d, Port Washington confining unit, 0.0015 ft/d, and Raritan confining unit, 0.0012 ft/d.

Estimates of specific yield for the glacial outwash deposits are 0.18 (Getzen, 1977), 0.22 (Reilly and Buxton, 1985), 0.24 (Warren and others, 1968), 0.24 (Perlmutter and Geraghty, 1963), and 0.30 (Franke and Cohen, 1972). Estimates as low as 0.10 have been proposed for morainal deposits (Getzen, 1977), and estimates for unconfined parts of the Magothy aquifer have been as low as 0.10 (Getzen, 1977; Reilly and Buxton, 1985). Specific yield values for the water-table model layer are shown in figure 10. Specific yield of the upper glacial outwash is 0.30; of the moraine deposits is 0.25; and of the Magothy deposits is 0.15. Storage coefficients for confined aquifers were calculated from aquifer thickness and a specific storage of $6.0 \times 10^{-7}$/ft (Getzen, 1977). This value of specific storage is at the minimum extreme; the authors suggest that future analyses use values close to $1.3 \times 10^{-6}$/ft, as calculated by Jacob (1941).

## PREDEVELOPMENT HYDROLOGIC CONDITIONS (PRE-1900)

Before development, the Long Island ground-water system was in a state of dynamic equilibrium. Ground-water levels and rates of discharge to the ocean, streams, and springs, underwent natural fluctuations in response to natural fluctuations in recharge from precipitation. Despite short-term fluctuations in recharge and discharge, these budget components were in balance over the long term.

This section describes an average predevelopment (pre-1900) hydrologic condition that forms a basis for comparison with subsequent conditions. The predevelopment condition is based on the earliest available hydrologic data, and on results of a steady-state simulation made with the islandwide model. This section also describes (1) the natural hydrologic boundaries and their operation; (2) the system's ground-water budget, as estimated from field measurements and model-generated flow rates, and (3) general patterns of ground-water movement, as indicated by measured and simulated ground-water levels.

### Hydrologic Boundaries

The body of fresh ground water beneath Long Island is enclosed by natural hydrologic boundaries (fig. 11). The upper boundary is the water table and the many surface water bodies that intersect it. The lower boundary is consolidated bedrock. The lateral boundaries consist of the saline ground water and saline surface-water bodies that surround the island. Under natural (non-pumping) conditions, all water enters and leaves the system through these boundaries; therefore, the system's water budget and, ultimately, the amount of ground water available for development, is affected by the characteristics of these boundaries.