Ground-Water Resource Evaluation on Long Island, New York, Using Flow Models and a Geographic Information System

U.S. Department of the Interior—U.S. Geological Survey

Introduction

The U.S. Geological Survey (USGS) has been conducting water-resources evaluations on Long Island (fig. 1) since the early 1900's in a continuing effort to assess the effects of natural and manmade stresses on the Island's ground-water-flow system, and to provide information that will permit the efficient management of its ground-water resources. Ground water is the sole source of drinking water to the residents of Nassau and Suffolk Counties and the southeastern part of Queens County (fig. 2A).

Ground water on Long Island is obtained from aquifers that consist of layers of gravel, sand, silt, and clay, that in places are more than 2,000 feet thick. The Island's ground-water-flow system has three major aquifers and two intervening confining units (fig. 3A), and is underlain by nearly impermeable bedrock. The major aquifers and confining units are, in descending order, the upper glacial (water-table) aquifer, the Gardiners Clay (a confining unit), the Magothy aquifer, the Raritan confining unit, and the Lloyd aquifer. Several other hydrogeologic units are present locally but are not discussed here; detailed information on the hydrogeologic units of Long Island is given in Smolensky and others (1989).

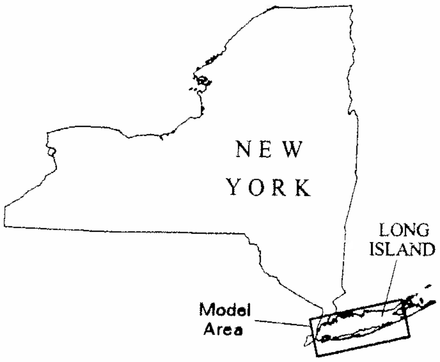

Figure 1. Location of model area on Long Island, N.Y.

Ground water flows continually within the aquifer system along the path of least resistance, from the point of entry (as recharge from precipitation) at the water table to the point of discharge at streams, lakes, wetlands, the shore, subsea-discharge areas, or pumped wells. Information on the Long Island ground-water-flow system is given in Franke and McClymonds (1972), and Buxton and Modica (1992).

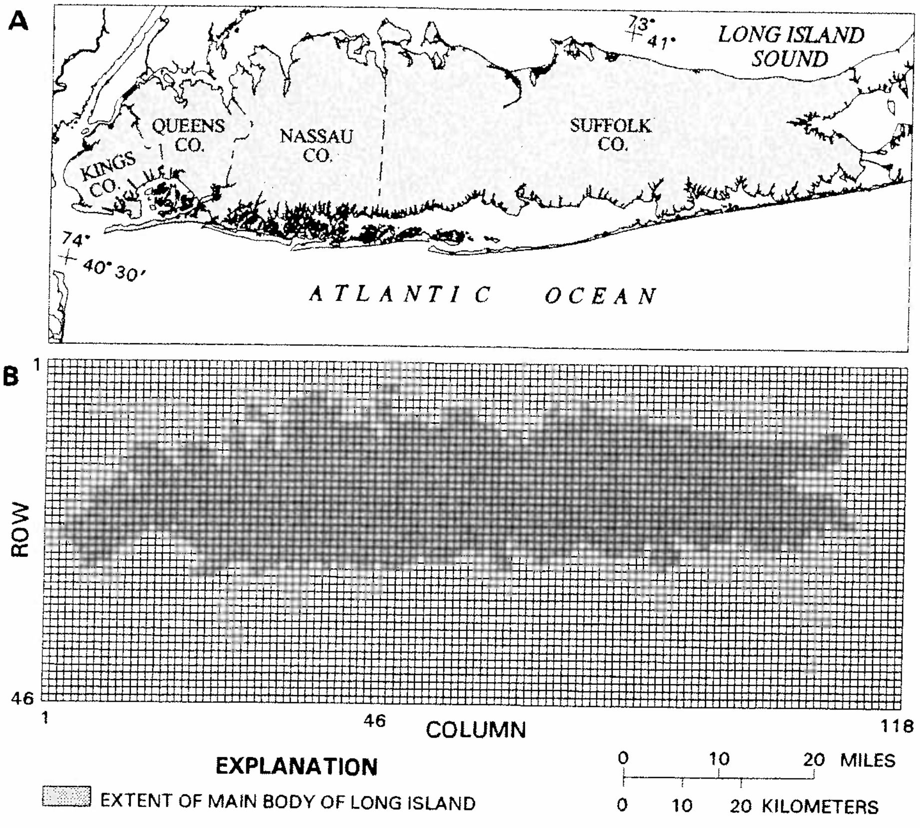

Figure 2. Location of main body of Long Island, N.Y.: (A) Model area. (B) Model grid. (Modified from Buxton and others, 1991, fig. 4.)

The use of ground water on Long Island for supply is limited by local **availability** and **suitability**. Natural ground-water discharge sustains streams, lakes, wetlands, and salinity in estuaries. When water is withdrawn from the ground, however, the water table is depressed and the amount of ground water that discharges to the aforementioned surface-water bodies is diminished. Therefore, water-supply strategies must evaluate the **availability** of ground water by considering the corresponding effects of withdrawal on aquatic ecosystems. The **suitability** of ground water for human consumption is determined by (1) the quality of water that recharges the aquifer system, (2) the type of sediments with which the water is in contact, (3) the presence or absence of saltwater encroachment, and (4) the continual geochemical evolution of ground water along flow paths. Knowledge of the paths of ground-water flow from point of entry to point of exit is an essential step in predicting the suitability of water at a specified location and depth, especially in areas that are prone to contamination from spills, that contain certain types of land use, or that are subject to saltwater encroachment. Furthermore, definition of ground-water flow paths enables the evaluation of the migration of contaminants from known sources, and facilitates the protection of ground-water resources by source-area controls.

The USGS has developed computer programs that simulate the patterns and rates of ground-water movement, and has used these in water-resources evaluations throughout the United States. Flow models that simulate the Long Island ground-water-flow system have been used by the USGS since the late 1960's to evaluate the availability and suitability of the Island's ground-water resources. This fact sheet describes the technique of ground-water-flow simulation, and presents an evaluation of the ground-water resources of Long Island that uses a three-dimensional model (Buxton and others, 1991). The flow-model analysis uses a particle-tracking procedure to define flow paths and delineate the areas that contribute recharge to the major aquifers, and is coupled with a geographic information system (GIS) that can display, manipulate, and archive model input and output data and thereby increase the utility of the model.

model that represents Kings and Queens Counties, in cooperation with the New York City Department of Environmental Protection. Use of the GIS has facilitated the identification of areas from which additional data collection is warranted, and has enabled the prompt addition of newly collected field data.

Significance to Ground-Water Resource Management

The linkage of ground-water quantity and quality issues is increasingly affecting ground-water resource-management decisions. As development increases, the water-supply strategies of New York City and Nassau and Suffolk Counties will increasingly rely on coordinated islandwide evaluation of management alternatives to optimally meet demands. Knowledge of the recharge areas of aquifers, and especially the source areas of individual supply wells, will permit improved planning for the protection of the Island's water supply. Flow models coupled with particle tracking and a GIS provide a unique and effective tool to evaluate the availability and suitability of ground water for supply on Long Island. The USGS's archive of operational flow models, particle-tracking analyses, and GIS data bases are maintained to document the effects of natural and manmade stresses on the Long Island ground-water-flow system, and to support the efficient management of its ground-water resources.

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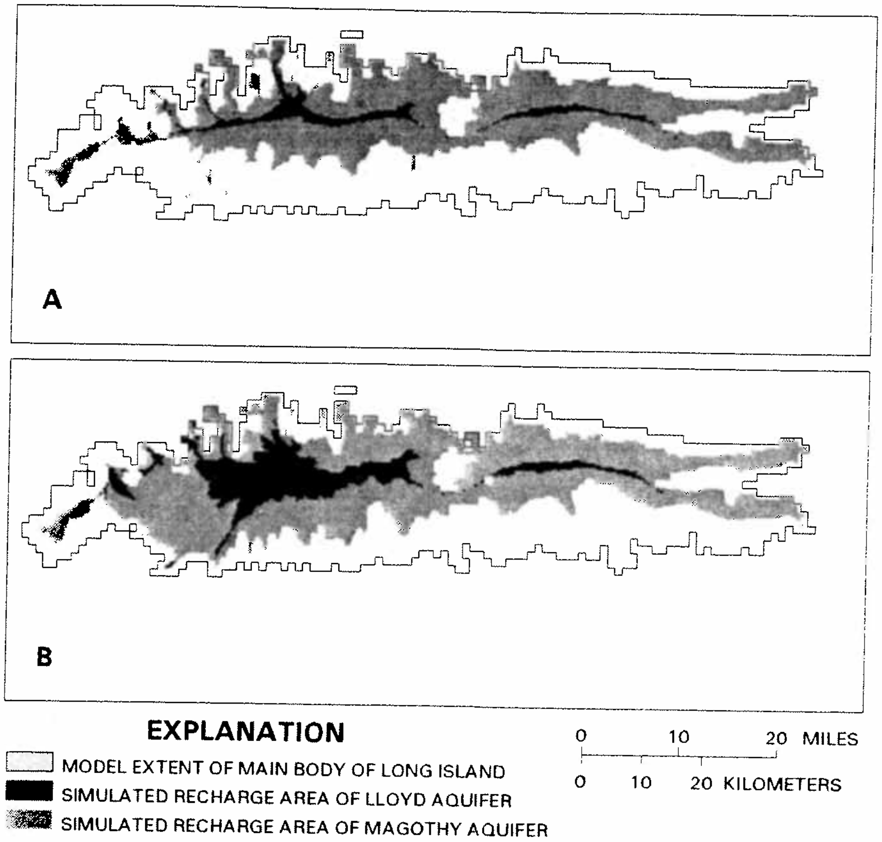

Figure 5. Simulated recharge areas for the Lloyd and Magothy aquifers: (A) Predevelopment equilibrium conditions (before 1900). (B) Maximum recharge areas under recent equilibrium conditions (1968-83). (Modified from Buxton and others, 1991, figs. 8, 9.)

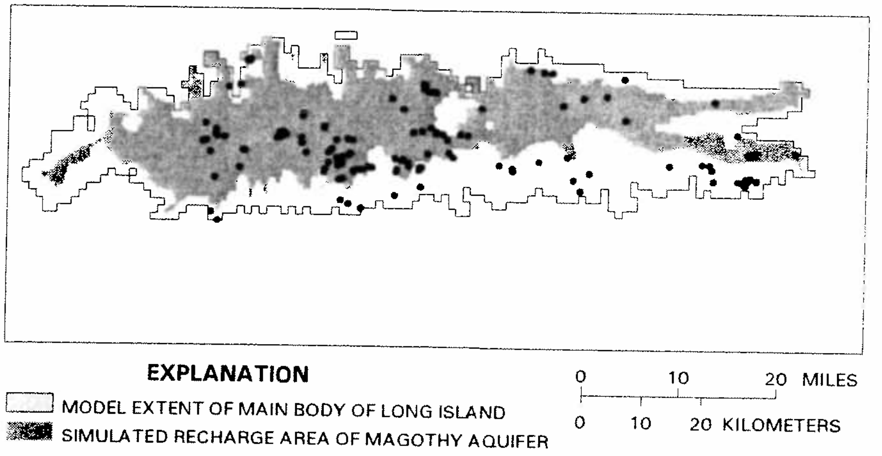

Figure 6. Simulated maximum recharge areas for the Magothy aquifer under recent equilibrium conditions (1968-83) and locations of inactive hazardous-waste sites in Nassau and Suffolk Counties, N.Y., in December 1987. (Inactive hazardous-waste site data from Brian Baker, New York State Department of Environmental Conservation, written commun., 1988.)

Additional Reading

Buxton, H.T., Reilly, T.E., Pollock, D.W., and Smolensky, D.A., 1991, Particle tracking analysis of recharge areas on Long Island, New York: Ground Water, v. 29, no. 1, p. 63-71.

Buxton, H.T., and Modica, Edward, 1992, Patterns and rates of ground-water flow on Long Island, New York: Ground Water, v. 30, no. 6, p. 857-866.

Franke, O.L., and McClymonds, N.E., 1972, Summary of the hydrologic situation on Long Island, New York, as a guide to water-management alternatives: U.S. Geological Survey Professional Paper 627-F, 59 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Pollock, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 89-381, 188 p.

Smolensky, D.A., Buxton, H.T., and Shernoff, P.K., 1989, Hydrologic framework of Long Island, New York: U.S. Geological Survey Hydrologic Investigations Atlas HA-709, 3 sheets, scale 1:250,000.

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Simulation of Ground-Water Flow

Simulation of ground-water flow through computer-modeling techniques provides an effective method of evaluating the response of ground-water-flow systems to natural and manmade stresses, and of predicting how potential future stresses may affect flow-system behavior. Simulation entails dividing the ground-water-flow system into numerous distinct parts, called cells (or blocks), each of which is assigned a set of hydraulic values inferred from hydrogeologic field data. This discrete version of the flow system is represented by a model grid, an example of which is shown for Long Island in figures 2B and 3B.

The basis of ground-water-flow simulation is the formulation of a series of mathematical equations, one for each cell, that represent the balance of flow entering and exiting each cell in the model. Together these equations represent the distribution of water entering, flowing through, and exiting the simulated ground-water-flow system. A computer is used to solve the equations simultaneously, which provides an estimate of the distribution of ground-water levels and flow rates within the aquifer system under a given set of hydrologic conditions.

The number and size of cells used to represent the aquifer system is determined by the desired level of detail (resolution). Reliable simulation requires accurate representation of the hydrogeologic framework and its water-bearing properties, the hydrologic features that bound its extent, and the hydraulic stresses that control the rate at which water enters and exits the ground-water-flow system. The accuracy of the model is measured by how well the simulated ground-water levels and flow rates correspond to the values measured in the field.

The two most widely used classes of computer-model programs developed for the simulation of ground-water flow—based on slightly different mathematical theory—are those that use finite-difference methods and those that use finite-element methods. The USGS has selected the finite-difference MODFLOW model developed by McDonald and Harbaugh (1988) for its three-dimensional simulation of the Long Island ground-water-flow system because (1) its mathematical theory is more understandable from a conceptual standpoint, (2) it has particle (flow path)-tracking capabilities, (3) it is easily integrated with a GIS, and (4) it is used extensively across the Nation and is supported by the USGS.

The results generated from MODFLOW models can be used directly by a particle-tracking program (MODPATH, Pollock, 1989) to define the paths of ground-water flow. MODPATH calculates flow paths and traveltimes from any point, or to any point, in the ground-water-flow model. The coupling of ground-water-flow models to a particle-tracking technique provides an effective method of identifying the natural patterns and rates of ground-water movement in a given aquifer system, and the effects of manmade stresses, such as pumping, on these flow patterns and rates.

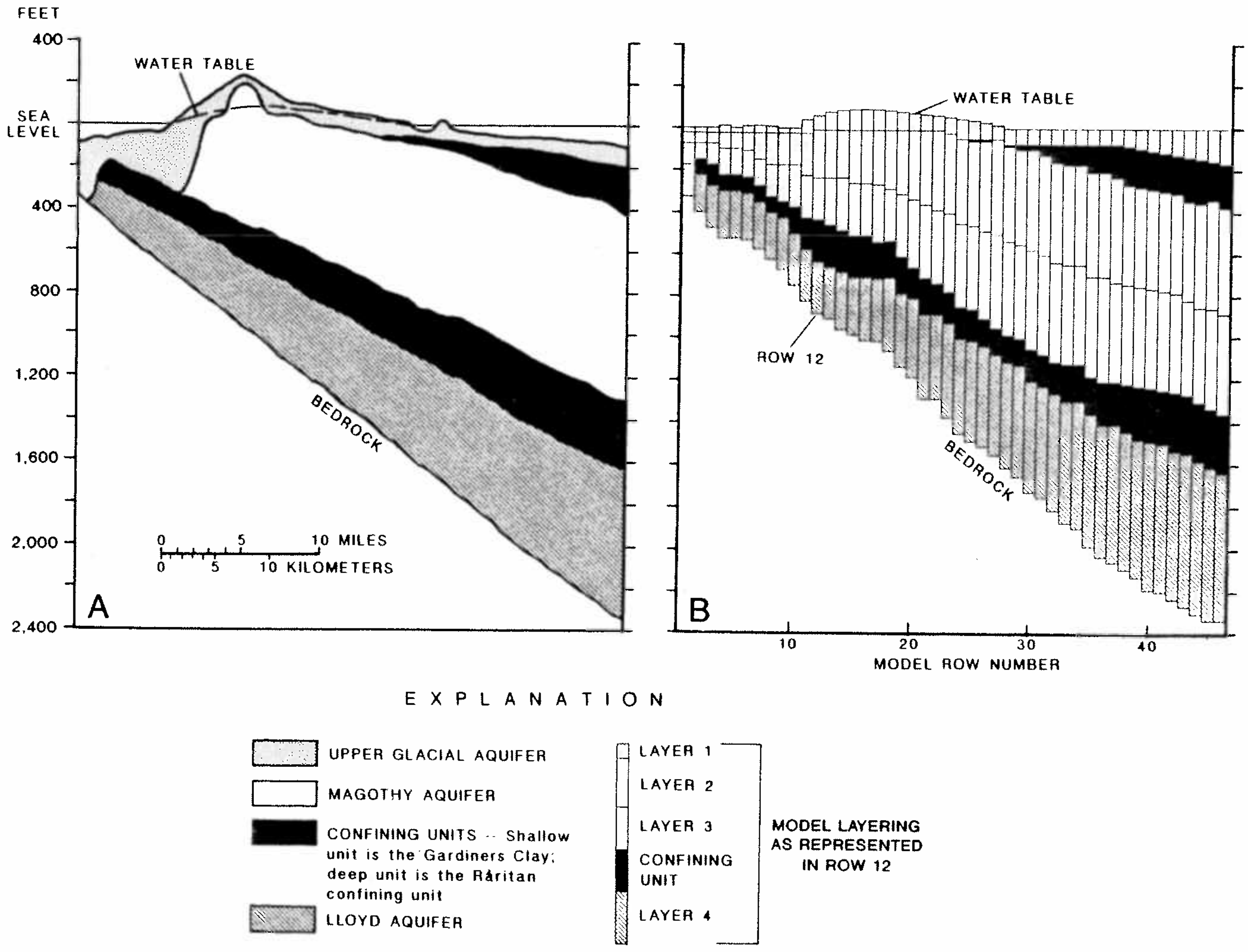

Figure 3. North-south hydrogeologic section through central Long Island, N.Y.: (A) Generalized hydrogeologic units. (B) Model representation of hydrogeologic units. (Section is near column 46 in fig. 2B.) (From Buxton and others, 1991, fig. 5.)

Simulation of the Long Island Ground-Water-Flow System

The USGS has developed a model of the islandwide ground-water-flow system in cooperation with the Nassau County Department of Public Works, the Suffolk County Department of Health Services, the Suffolk County Water Authority, and the New York City Department of Environmental Protection (Buxton and others, 1991). The model grid (figs. 2B, 3B) contains 21,712 cells, each of which represents an area 4,000 feet on a side, and four layers that represent the major aquifers and confining units; each layer has 46 rows and 118 columns. The model uses the MODFLOW program and is described in more detail in Buxton and others (1991).

The accuracy of the islandwide model has been measured by comparison of its results to measured ground-water levels and stream discharges corresponding to predevelopment equilibrium conditions (before 1900), recent equilibrium conditions (1968-83), and the drought (nonequilibrium) conditions of the mid-1960's. The model was then used to predict a hypothetical future condition in the year 2020. The resulting simulated water table for the upper glacial aquifer and the potentiometric surfaces for the Magothy and Lloyd aquifers under recent equilibrium conditions are shown in figure 4.

The results of the islandwide model were used with the MODPATH program to calculate recharge areas for the major aquifers (the source area of water that ultimately enters each aquifer) (Buxton and others, 1991). Water that entered the Magothy and Lloyd aquifers was tracked back to its point of origin to define the corresponding recharge area under the given set of hydrologic conditions. The simulated recharge areas for the Magothy and Lloyd aquifers under predevelopment and recent equilibrium conditions are shown in figure 5. Under recent equilibrium conditions, the source areas for all water that enters the Magothy and Lloyd aquifers is included within the maximum recharge areas, however, some water is intercepted by shallow wells before entering these aquifers. Recharge in areas not identified as part of the Magothy or Lloyd aquifer recharge areas stays within the upper glacial (water-table) aquifer and discharges to simulated streams, the shore, and pumped wells screened in the upper glacial aquifer. These results illustrate graphically how increased withdrawals from the Magothy and Lloyd aquifers (1) induce greater amounts of flow to the deeper aquifers, (2) reduce shallow flow and discharge to streams, and (3) broaden the potential source area of water to these aquifers, which complicates recharge-area protection strategies.

Incorporation of Flow Model into a GIS

Model data that represent the hydrogeologic framework, hydrologic boundaries, and hydraulic stresses for islandwide ground-water-flow simulations have been assembled into a GIS, in cooperation with the Suffolk County Water Authority. These digital spatial data sets (coverages) incorporate data on (1) dimensions and hydraulic properties of major aquifers and confining units, (2) boundaries of the fresh ground-water-flow system, (3) distribution of recharge, and (4) characteristics of streams and pumped wells simulated in the model. Coverages have also been created for model output data that include ground-water levels and flows, and particle-tracking results that delineate aquifer recharge areas.

Incorporation of islandwide model input, output, and particle-tracking data sets into the GIS provides the ability to relate these coverages to the cultural, demographic, and geographic features of Long Island, such as relating the quality of ground water in aquifers to the land uses within the corresponding aquifer recharge areas. This ability is illustrated in figure 6, which shows the maximum recharge area for the Magothy aquifer under recent equilibrium conditions, and the locations of inactive hazardous-waste sites in Nassau and Suffolk Counties registered with the New York State Department of Environmental Conservation in December 1987 (Brian Baker, written commun., 1988).

The GIS facilitates the development of local ground-water-flow models coupled to the islandwide model, which enables detailed evaluation of local problems while preserving accurate representation of regional flow patterns. Currently, the USGS is using a GIS to update and refine the part of the islandwide

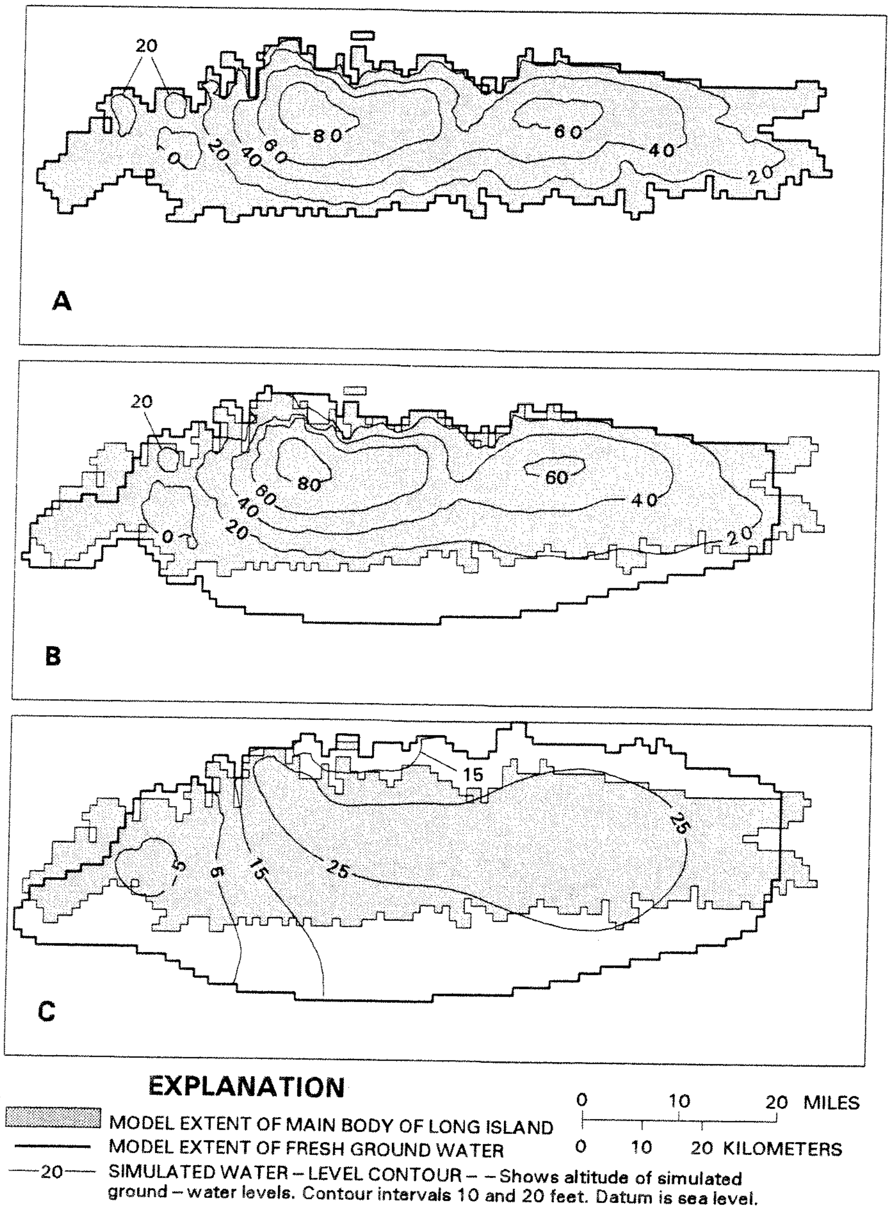

Figure 4. Simulated ground-water levels under recent equilibrium conditions (1968-83): (A) Upper glacial (water-table) aquifer. (B) Magothy aquifer. (C) Lloyd aquifer.