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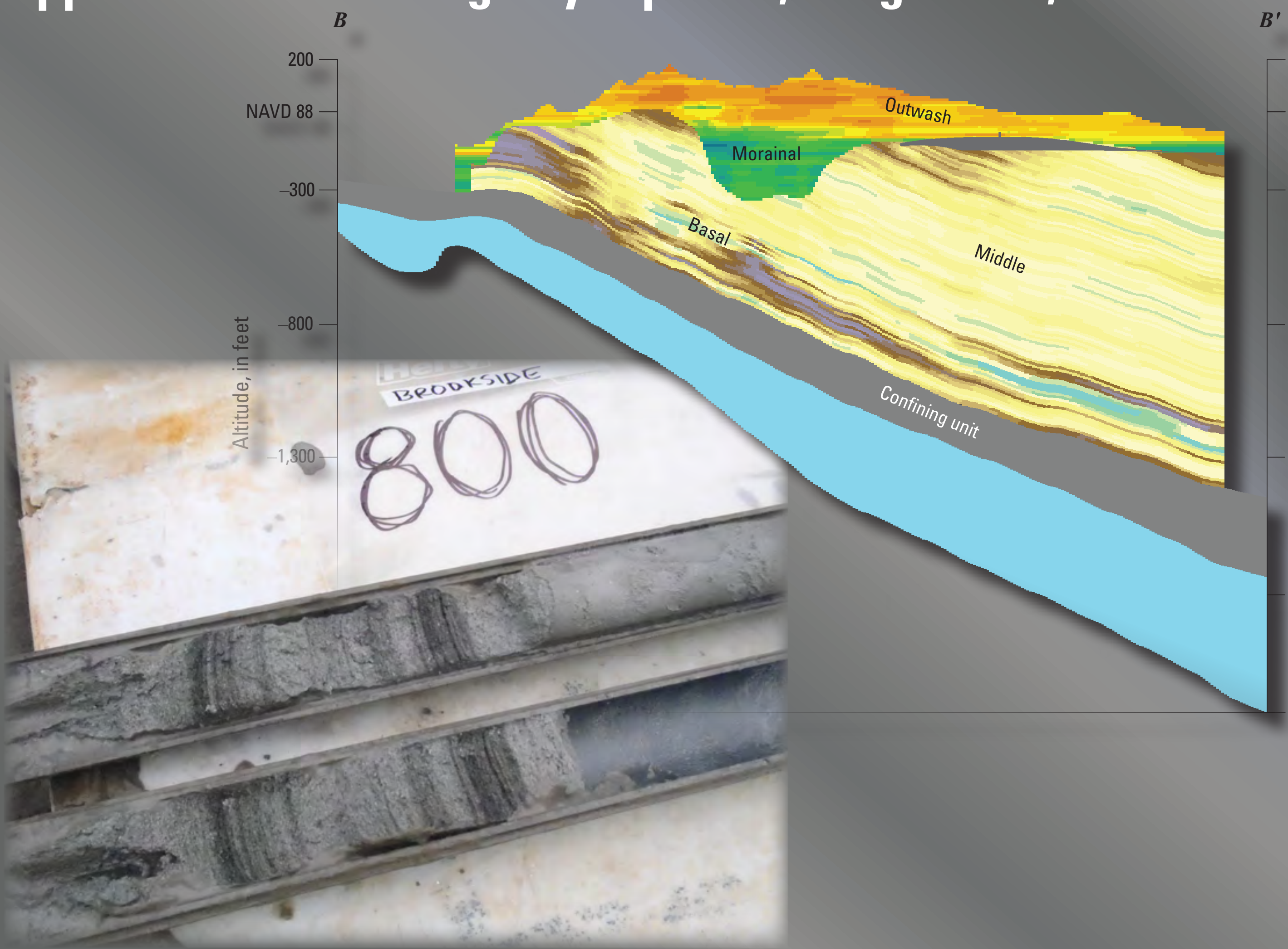
# Distribution of Selected Hydrogeologic Characteristics of the Upper Glacial and Magothy Aquifers, Long Island, New York




Scientific Investigations Report 2020–5023


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

**Cover.** (Left) Core samples from Nassau County, New York; photograph by Marie Zuck, U.S. Geological Survey. (Right) Vertical distribution of estimated horizontal hydraulic conductivity along north-south section *B*–*B*′ on Long Island, New York; from figure 10*A* of this report.

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**U.S. Department of the Interior**
DAVID BERNHARDT, Secretary

**U.S. Geological Survey**
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

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## Contents



## Figures

## Table



# Conversion Factors

U.S. customary units to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |

# Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NGVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

# Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

# Abbreviations

| | |
|---|---|
| GIS | geographic information system |
| GWSI | Ground-Water Site Inventory System |
| MSL | mean sea level |
| NAWQA | National Water-Quality Assessment Project |
| USGS | U.S. Geological Survey |

# Distribution of Selected Hydrogeologic Characteristics of the Upper Glacial and Magothy Aquifers, Long Island, New York

By Donald A. Walter and Jason S. Finkelstein


## Abstract

The Pleistocene- and Cretaceous-age sediments underlying Long Island, New York, compose an important sole-source aquifer system that is nearly 2,000 feet thick in some areas. Sediment characteristics of importance for water supply include water-transmitting properties—horizontal and vertical hydraulic conductivity—the presence of clay and silt and the distribution of lignite, which provides an important control on oxygen-reduction (redox) conditions and water quality, in Cretaceous-age aquifers. Several decades of urbanization and the associated need to meet water demand have generated abundant data on the lithology of the aquifer sediments and the potential for an improved regional-scale understanding of this aquifer system. There is a range in the source and quality of the information, but large amounts of data, even of lesser quality, can yield insight into important aquifer characteristics.

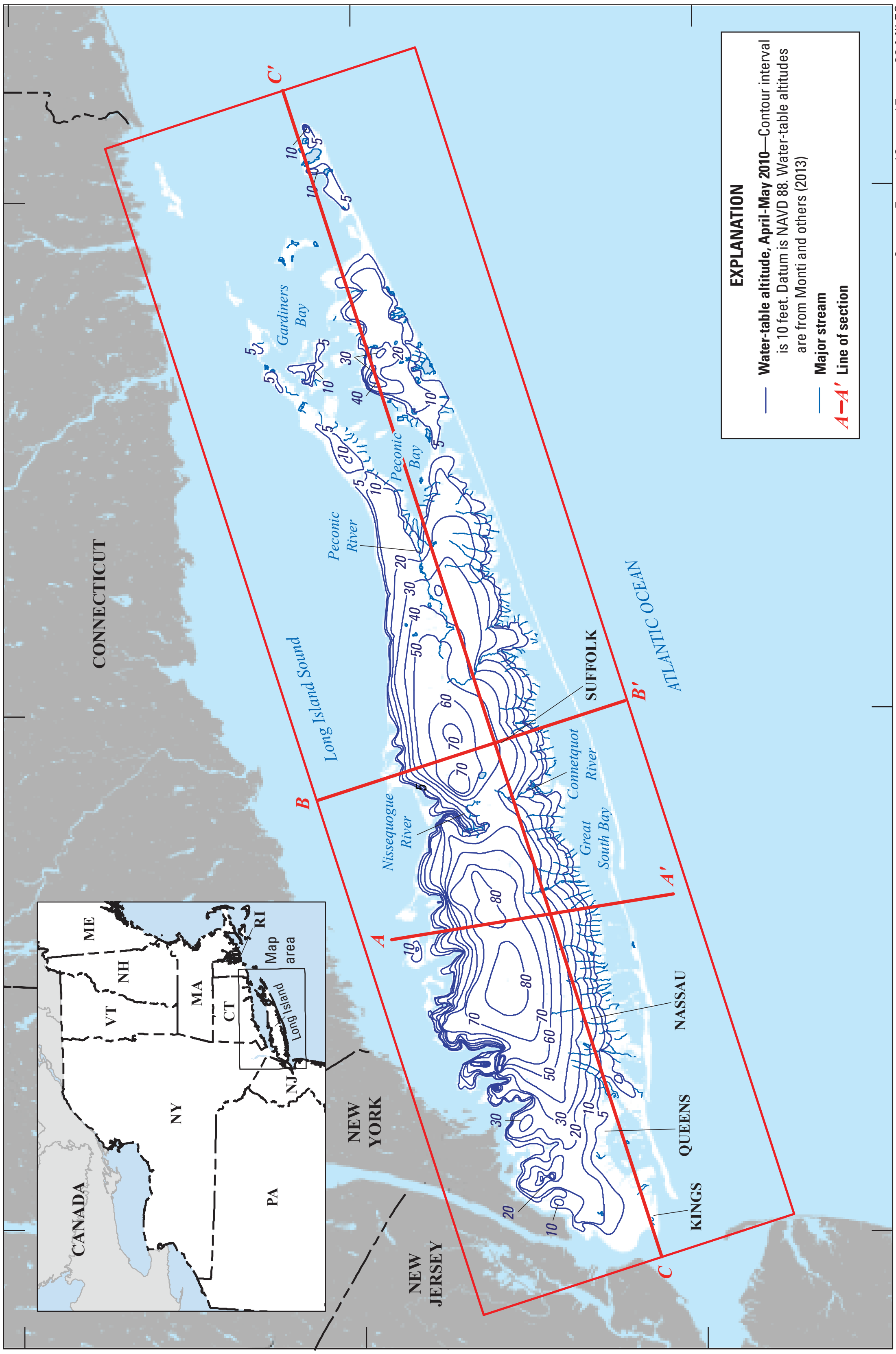
The distribution of horizontal and vertical hydraulic conductivity and the probability of occurrence of lignite and clay in the aquifer were developed for this study from a database of drilling records and geophysical logs. Lithologic descriptions were categorized into a set of standardized codes, which in turn, were aggregated into a set of general codes for the Pleistocene-age upper glacial and Cretaceous-age Magothy aquifers. General values of hydraulic conductivity were assigned to each code from published estimates on Long Island and analogous hydrogeologic environments on Cape Cod, Massachusetts. A binary value of 1 or 0 was assigned to each coded interval to indicate the presence or absence of clay and lignite based on keywords in the lithologic descriptions. This information was assembled into a geographic information system database that was queried sequentially and used to develop gridded values of each aquifer characteristic by use of ordinary kriging for a set of grids, each representing 10-foot-thick planar slices for the entire vertical thickness of each aquifer. These sets of grids, taken as a whole, represent a quasi-three-dimensional representation of each aquifer characteristic in both the upper glacial and Magothy aquifers.

The analysis of hydraulic conductivity shows patterns that generally reflect known depositional features of each unit and are consistent with the current understanding of the geology of the aquifers. Spatial patterns in the upper glacial aquifer show contrasts in estimated hydraulic conductivity: lower values occur in inland areas and are associated with glacial moraines; higher values generally occur to the south in association with glacial outwash. Higher values of hydraulic conductivity in the Magothy aquifer, which resulted from deltaic deposition, generally occur in the basal parts of the unit, likely are associated with channel-lag deposits and are found in parts of the aquifer known for large well yields. Lower values of hydraulic conductivity generally occur in middle parts of the aquifer associated with deposition in overbank and wetland environments. The probability of lignite occurrence is highest in this same vertical zone of the Magothy aquifer, consistent with deposition in wetland environments. The probability of lignite occurrence generally is highest along the southern shore of the island. Lignite occurrence generally is consistent with water-quality patterns; water quality in these same areas indicate chemically reducing conditions and redox-related iron biofouling commonly occurs.


## Introduction

Long Island, in southeastern New York, is bordered by bays and narrows to the east and west, the Atlantic Ocean to the south, and Long Island Sound to the north (fig. 1). The island is about 120 miles (mi) long and 25 mi wide at its widest point and covers about 1,400 square miles (mi$^2$) in total area. The island is densely populated and has an estimated population of about 7.9 million people (U.S. Census Bureau, 2018). Land use generally changes from west to east from urbanized to rural, with densely urbanized landscapes in Kings and Queens Counties and large areas of undeveloped or agricultural land in eastern Suffolk County.

Unconsolidated sediments underlying the island compose a sole-source aquifer system that supplies water to about 2.9 million people in Nassau and Suffolk Counties. The aquifer system also contributes groundwater discharge to freshwater and marine ecosystems throughout Long Island. Anthropogenic activities have affected the quantity and quality




Base from U.S. Geological Survey The National Atlas digital data, 1:1,000,000 scale
Long Island, New York, State Plane projection
North American Datum of 1988

**Figure 1.** Hydrography and water-table altitudes on Long Island, New York, in May 2010. NAVD 88, North American Vertical Datum of 1988.

of groundwater because of the island's large population, generally permeable sediments, and the unconfined conditions prevalent across the aquifer system.

In 2016, the U.S Geological Survey (USGS) National Water-Quality Assessment (NAWQA) project of the National Water Quality Program began an investigation into the distribution of groundwater age in the Long Island aquifer system and how age relates to contaminant susceptibility. Existing data were compiled and analyzed, and the results were used to support the development of a numerical model of the regional aquifer system. As part of this effort, lithologic descriptions, geophysical data, and ancillary well construction data were compiled from deep boreholes across the island. These data were assembled into a geographic information system (GIS) database and used to develop three-dimensional renderings of important aquifer characteristics, including horizontal and vertical hydraulic conductivity and the probability of occurrence of lignite and clay. These modeled distributions were used to inform development of groundwater-flow models and statistical models of water quality.

The topography of the island is characterized by high terrain in the interior associated with glacial moraines and gently sloping topography to the south associated with glaciofluvial outwash (fig. 2). The unconsolidated sediments are underlain by relatively impermeable bedrock, the altitude of which ranges from near sea level in the northwestern part of the island to about 2,000 feet (ft) below mean sea level (MSL) relative to the North American Vertical Datum of 1988 (NAVD 88) along the southern shore.

The bedrock is overlain by sediments of Cretaceous age that are part of the North Atlantic Coastal Plain regional aquifer system (Masterson and others, 2016), which in turn, are overlain by Pleistocene-age glacial sediments deposited largely during the Wisconsinan glaciation when periods of ice advance and retreat formed morainal ridges that trend east-west along the spine of Long Island (Cadwell and Muller, 1986). The Pleistocene-age glacial sediments and the underlying Cretaceous-age units compose a series of aquifers and confining units that are as much as 2,000 ft thick on the southeastern-dipping bedrock surface. The Cretaceous-age sediments are absent in some areas near the northern shore of the island (fig. 2); Wisconsinan glacial sediments in these areas are underlain by bedrock or by older (pre-Wisconsinan) Pleistocene-age glacial sediments.

The five major hydrogeologic units underlying Long Island, in ascending order, are the Lloyd aquifer (Lloyd Sand Member of the Raritan Formation), the Raritan confining unit (the clay member of the Raritan Formation), the Magothy aquifer (Magothy Formation and Matawan Group, undifferentiated), the Gardiners clay (Gardiners Clay unit)—all of Cretaceous age—and the upper glacial aquifer of Pleistocene age (fig. 3; Smolensky and others, 1989). In addition to these major units, the Pleistocene-age North Shore aquifer and North Shore confining unit underlie Wisconsinan glacial sediments in some areas where Cretaceous-age units are absent (Stumm, 2001; Stumm and others, 2002, 2004), and local confining units occur within the upper glacial aquifer (Doriski and Wilde-Katz, 1982; Krulikas and Koszalka, 1983; Schubert and others, 2003). The Magothy aquifer is contiguous with the Jameco aquifer and the Monmouth Greensand (Smolensky and others, 1989).

The upper glacial aquifer and the Magothy aquifer are the two principal aquifers used for water supply on Long Island. The upper glacial aquifer extends from land surface (fig. 2) to the top of the Magothy aquifer (figs. 3 and 4*A*) and is composed of sandy sediments deposited about 18,000 years ago in glaciofluvial and glaciolacustrine environments near the margin of the continental ice sheet during the Wisconsinan glaciation. The surface of the Magothy aquifer includes several elongated, northwest-southeast trending erosional channels that have been filled with glacial sediments (fig. 4*A*), which generally are permeable and consist of gravel, sand, silt, and clay. Glacial morainal deposits generally are less well sorted and less permeable than outwash, which generally consists of well-sorted and cross-bedded sand.

The lower extent of the underlying Magothy aquifer is the top of the Raritan confining unit (figs. 3 and 4*B*). The sediments that compose the Magothy aquifer are deltaic in origin and were deposited in a variety of depositional environments, including fluvial channels and overbank wetland deposits. The basal part of the unit generally is more permeable and is the primary source of water in many areas. The middle part of the aquifer generally is less permeable and contains silt and clay interbeds; lignite is common both interstitially and as extensive interbeds (Smolensky and others, 1989). The Lloyd aquifer is the deepest hydrologic unit in the aquifer system and is confined throughout its extent (fig. 3); the depositional history and lithologic composition of this unit is similar to that of the Magothy aquifer. Recharge from precipitation averages about 24 inches per year and is the sole source of freshwater to the aquifer system (Walter and others, in press). Groundwater flows away from regional groundwater divides towards discharge locations in streams, coastal waters, and pumping wells (fig. 3); some deep groundwater discharges offshore through overlying confining units by a process referred to as subsea discharge. The subsurface aquifers are bounded laterally by a freshwater/saltwater interface. Water-table altitudes exceed 60 ft in two areas, to the east and west of major surface-water drainages in the central part of the island (fig. 1).

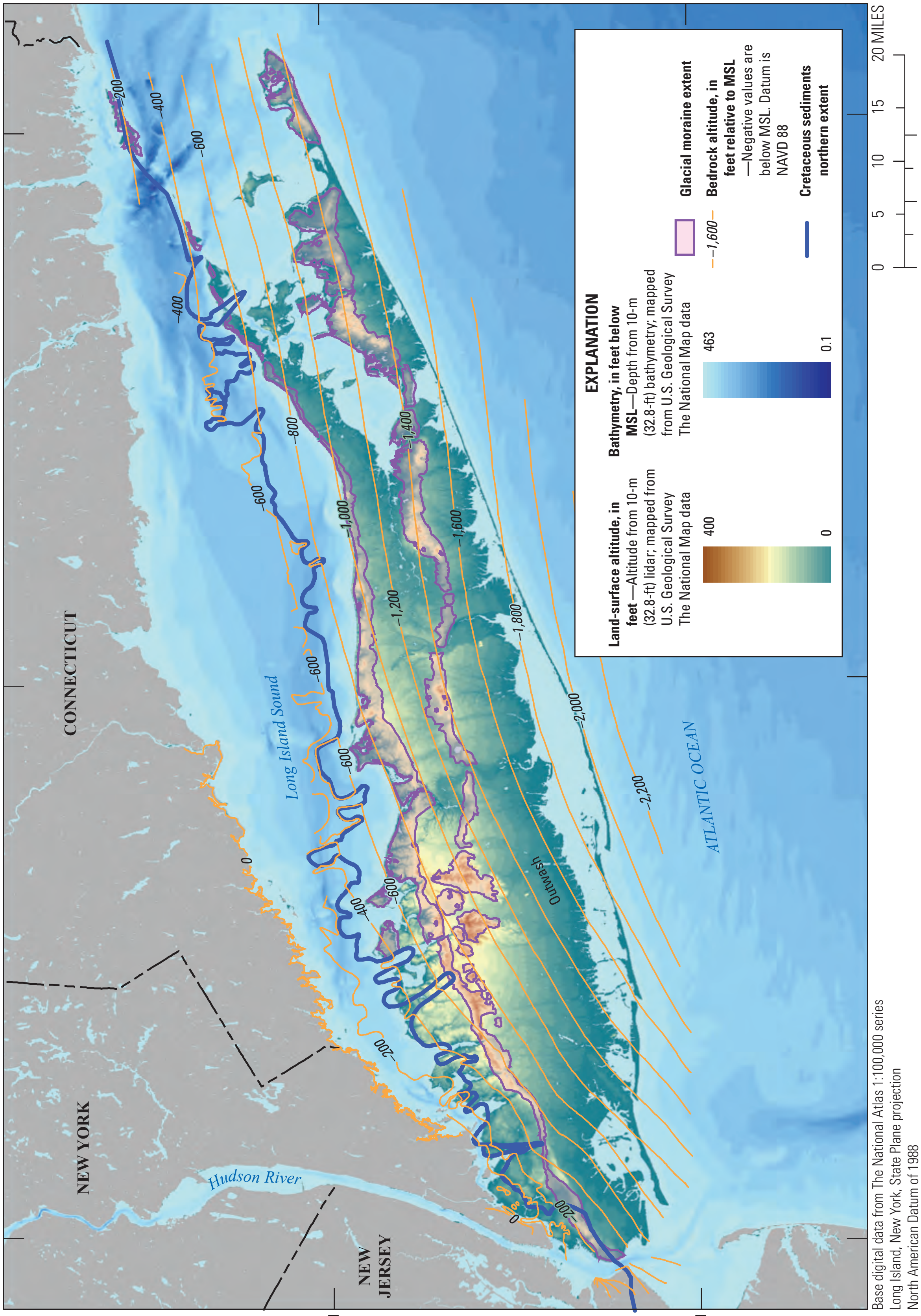



**Figure 2.** Land-surface altitude and bathymetry, northern extent of Cretaceous-age sediments, and altitude of the bedrock surface on Long Island, New York. m, meter; ft, foot; MSL, mean sea level; NAVD 88, North American Vertical Datum of 1988; lidar, light detection and ranging.

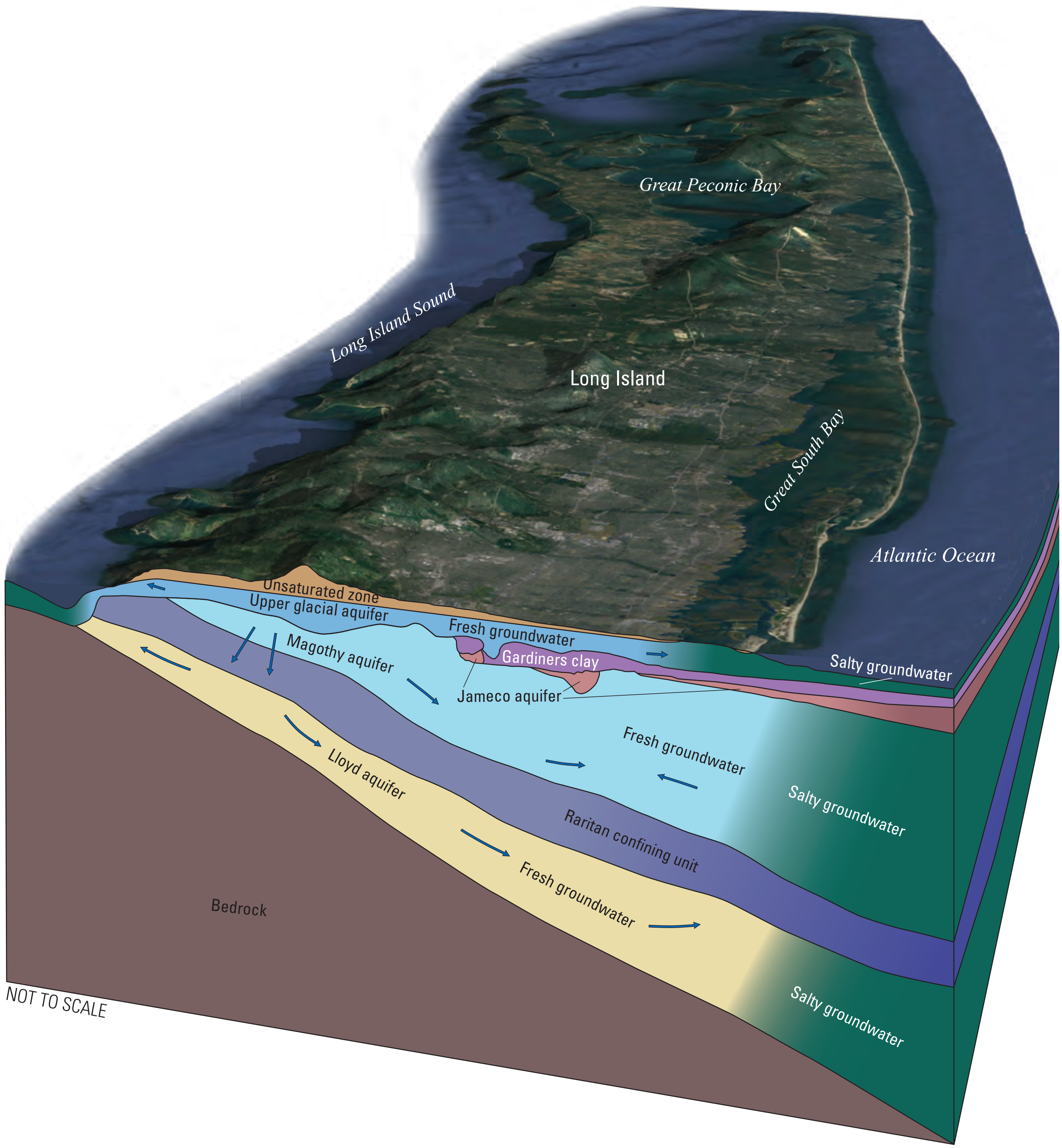



**Figure 3.** Major hydrologic units and position of freshwater/saltwater interface on western Long Island, New York. The direction of the groundwater flow is generalized. Line of section shown on figure 1. Modified from Masterson and Breault (2019). NAVD 88, North American Vertical Datum of 1988.

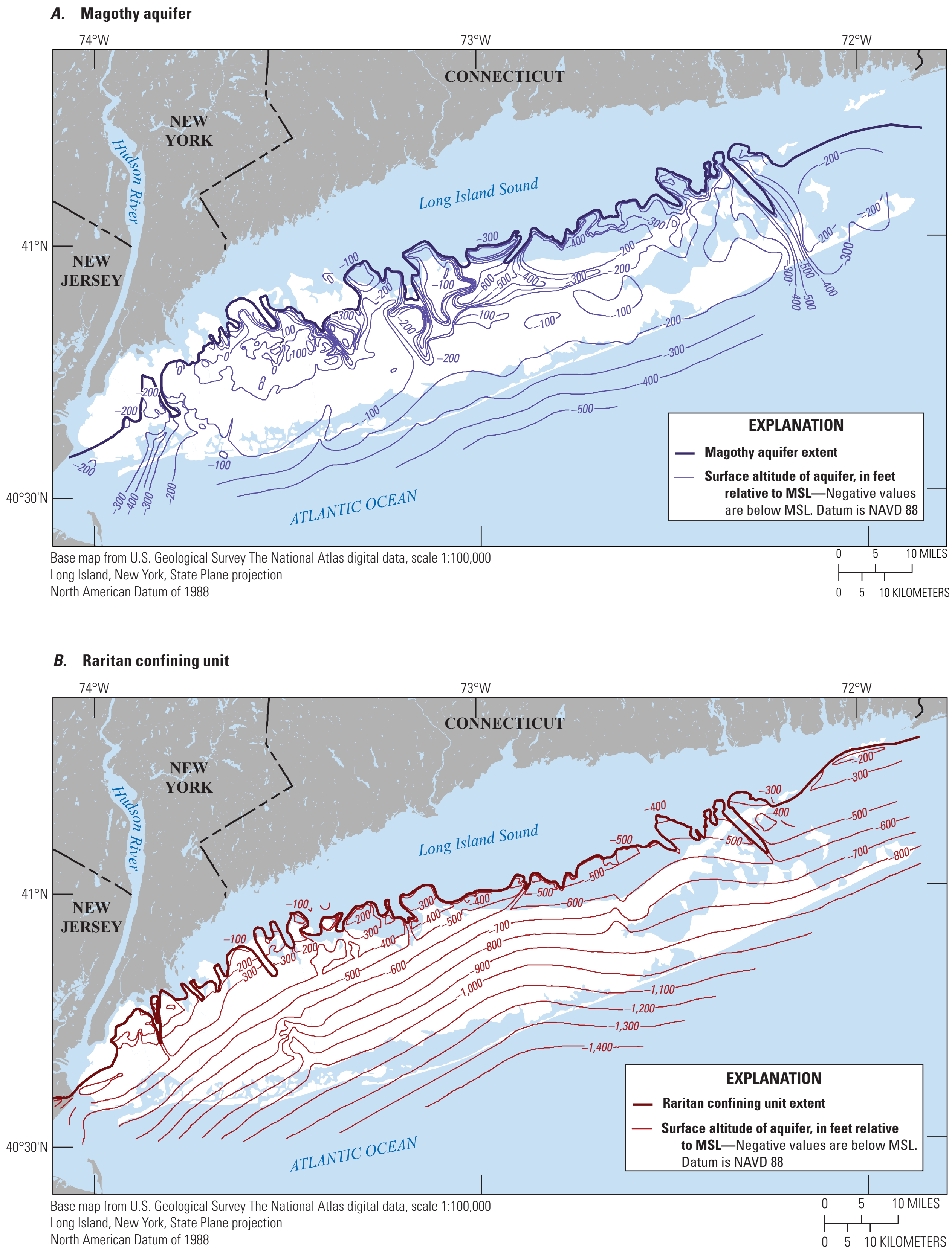



**Figure 4.** Extent and surface altitude of major Cretaceous hydrologic units in the *A*, Magothy aquifer and associated units and *B*, Raritan confining unit on Long Island, New York. NAVD 88, North American Vertical Datum of 1988.

# Methods of Analysis

A large volume of qualitative data regarding the lithology of the aquifer sediments underlying Long Island has been collected over several decades as part of water-supply exploration and remedial investigations. These data include drillers' descriptions of lithology, core samples, and borehole geophysical logs and range in source, type, and quality. Although the quality of some individual data points may be of lesser quality, when considered together with a sufficiently large sample size, the data may be used to characterize aquifer characteristics at a regional scale and in three dimensions. The analytical methods and application of those methods used in this analysis are similar to those documented in Arihood (2008), Faunt and others (2010), and Walter and others (2018).

Quasi-three-dimensional models of the distribution of horizontal and vertical hydraulic conductivity and the occurrence of clay were developed for the upper glacial aquifer and the underlying Magothy aquifer. The Monmouth Greensand and Jameco aquifers (Smolensky and others, 1989) are grouped with the Magothy aquifer in this analysis. The Lloyd aquifer, which is the deepest aquifer underlying the island, is not used for water supply and was not included in the analysis in this report because of the limited data available regarding that aquifer. The occurrence of lignite and associated pyrite was modeled in the Magothy aquifer, where it is known to occur; lignite was modeled because it provides an important control on oxygen-reduction (redox) conditions and water quality. Lignite is absent from glacial sediments.

## Data Compilation and Analysis

The compilation and analysis of the data underlying these models was a four-step process, as follows: (1) assignment of categorial codes at each specified depth interval in each borehole based on a lithologic description (fig. 5*A*–*C*); (2) further assignment of horizontal and vertical hydraulic conductivity to those depth intervals based on literature values associated with the assigned codes (fig. 5*D*; table 1); (3) subsequent calculation of thickness-weighted mean and geometric mean hydraulic conductivity values from those depth intervals to 10-ft regular intervals (fig. 5*E*); and (4) interpolation by ordinary kriging from those points within each 10-ft interval to a set of regular grids, with a 500-ft resolution.

Data collection at 1,769 boreholes across Long Island resulted in a total of 36,364 lithologic descriptions. Each borehole represented the deepest well within each 1-mi$^2$ cell of an island-wide grid (fig. 6). The lithologic descriptions were compiled and categorized into 45 separate codes. The lithologic codes are defined as part of the USGS Ground-Water Site Inventory (GWSI) System (U.S. Geological Survey, 2004). The 45 GWSI codes were further aggregated into 14 codes: 7 each for upper glacial and Magothy aquifer sediments (table 1). A small number of boreholes lacked lithologic records but had geophysical logs. These were included in the analysis by identifying intervals of coarse- and fine-grained sediments from the geophysical logs (both natural gamma and electromagnetic logs); intervals of coarse-grained sediments were assumed to be medium sand, and intervals of fine-grained sediments were assumed to be silt. Categorial classifications of the lithologic descriptions (table 1) were assigned estimated values of horizontal and vertical hydraulic conductivity based on published values for the Long Island aquifer system (McClymonds and Franke, 1972; Franke and Getzen, 1976; Lindner and Reilly, 1983; Prince and Schneider, 1987; Smolensky and others, 1989; Cartwright, 1996; Misut and Busciolano, 2010) and similar hydrogeologic environments on the coastal plain of Massachusetts (Guswa and Londquist, 1976; Guswa and LeBlanc, 1985; LeBlanc and others, 1986; Barlow, 1989; Barlow and Hess, 1993; Moench and others, 1996; Walter and others, 1996; Masterson and Barlow, 1997; Masterson and others, 1997).

The highest value of horizontal hydraulic conductivity in glacial sediments is about 350 feet per day (ft/d) in well-sorted coarse-grained sand and gravel. The anisotropy ratio in these sediments was assumed to be about 3:1, resulting in vertical hydraulic conductivity of about 100 ft/d (Moench and others, 1996). The lowest values of horizontal and vertical hydraulic conductivity for glacial silt and clay were 10 and 1 ft/d, respectively. Horizontal hydraulic conductivity values in the Cretaceous-age sediments, which generally are less well sorted and less permeable than glacial sediments, were assumed to range from 10 to 200 ft/d. Cretaceous-age sediments of the Magothy aquifer are assumed to be more anisotropic; vertical hydraulic conductivity ranged from 10 ft/d for coarse-grained sand and gravel to 1 ft/d for silt and clay, the same as that in glacial silt and clay.

Horizontal and vertical hydraulic conductivity values were estimated for each of the 14 aggregated lithologic codes (table 1). The resulting horizontal and vertical hydraulic conductivity values were then assigned to each depth interval in each borehole. The probability of occurrence of clay, lignite, and pyrite was determined from binary variables assigned using keywords in the lithologic descriptions. Descriptions containing the appropriate keywords were assigned a probability of 1; a value of 0 was assigned to those without the keywords. The mean variable within the same 10-ft regular vertical intervals was estimated.

Each borehole was divided equally into 10-ft intervals along its length and the thickness-weighted mean horizontal and vertical hydraulic conductivity was computed for each interval (fig. 5*E*). An arithmetic mean was calculated for horizontal hydraulic conductivity and a geometric mean for vertical hydraulic conductivity. The mean probability of the occurrence of lignite and clay (represented as binary variables) also was computed for each 10-ft interval for each borehole. The X, Y, and Z coordinates, estimates of horizontal and vertical hydraulic conductivity and estimates of the probability of the occurrence of lignite and pyrite, respectively, were assembled into a database.

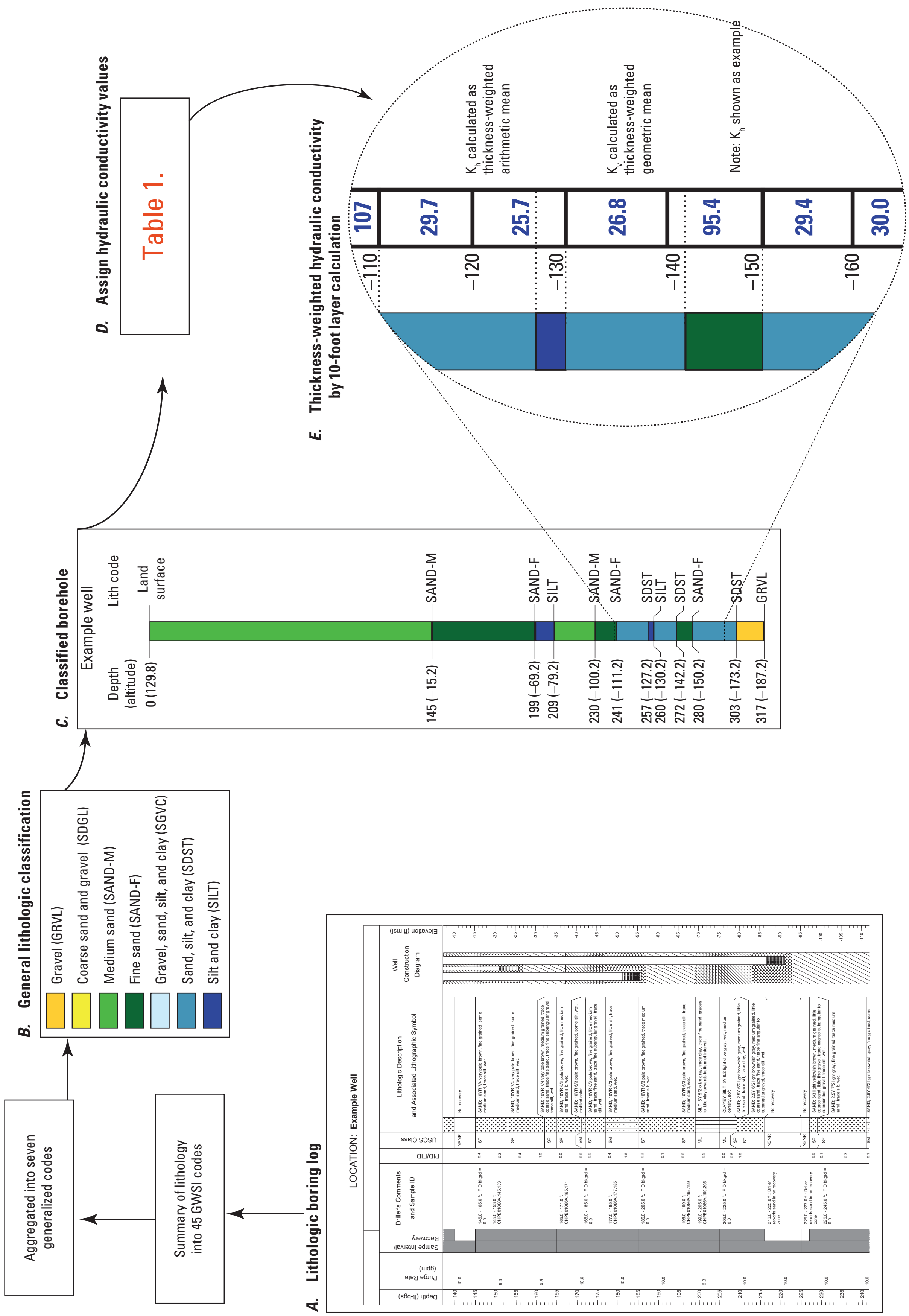



**Figure 5.** Three-dimensional lithologic analysis of the aquifer system of Long Island, New York. Kh, horizontal hydraulic conductivity; Kv, vertical hydraulic conductivity.

**Table 1.** Lithologic codes and associated values of horizontal and vertical hydraulic conductivity for lithologic descriptions in borehole logs on Long Island, New York.

[Kh, horizontal hydraulic conductivity; Kv, vertical hydraulic conductivity; GWSI, Ground-Water Site-Inventory System (U.S. Geological Survey, 2004)]

| Description | Upper glacial aquifer | | Magothy aquifer | | Assembled GWSI codes |
|---|---|---|---|---|---|
| | Kh | Kv | Kh | Kv | |
| Gravel | 350 | 100 | 200 | 10 | IGNS, COBB, GRVL, DIBS, GRGN, LMSH, SHLE, GNSS, SCST, GRCL, SLTE, ROCK, GRNT, QRTZ, MMPC, GRCM, BLDR |
| Coarse-grained sand and gravel | 300 | 60 | 150 | 5 | DRFT, SDGL, BLSD, COSD |
| Medium sand | 200 | 20 | 100 | 3 | SAND, OTSH |
| Fine-grained sand | 100 | 10 | 70 | 2 | OBDN, SOIL, SNDS, LOAM, LOSS |
| Gravel, sand, silt, and clay | 70 | 3 | 70 | 5 | BLSC, GRSC, GRDS, TILL, SGVC, COSC |
| Sand, silt, and clay | 30 | 2 | 30 | 1 | SNCL, SDCL, SDST |
| Silt and clay | 10 | 1 | 10 | 1 | CLSD, CLAY, HRDP, SILT, MUCK, MUD, PEAT, STCL |

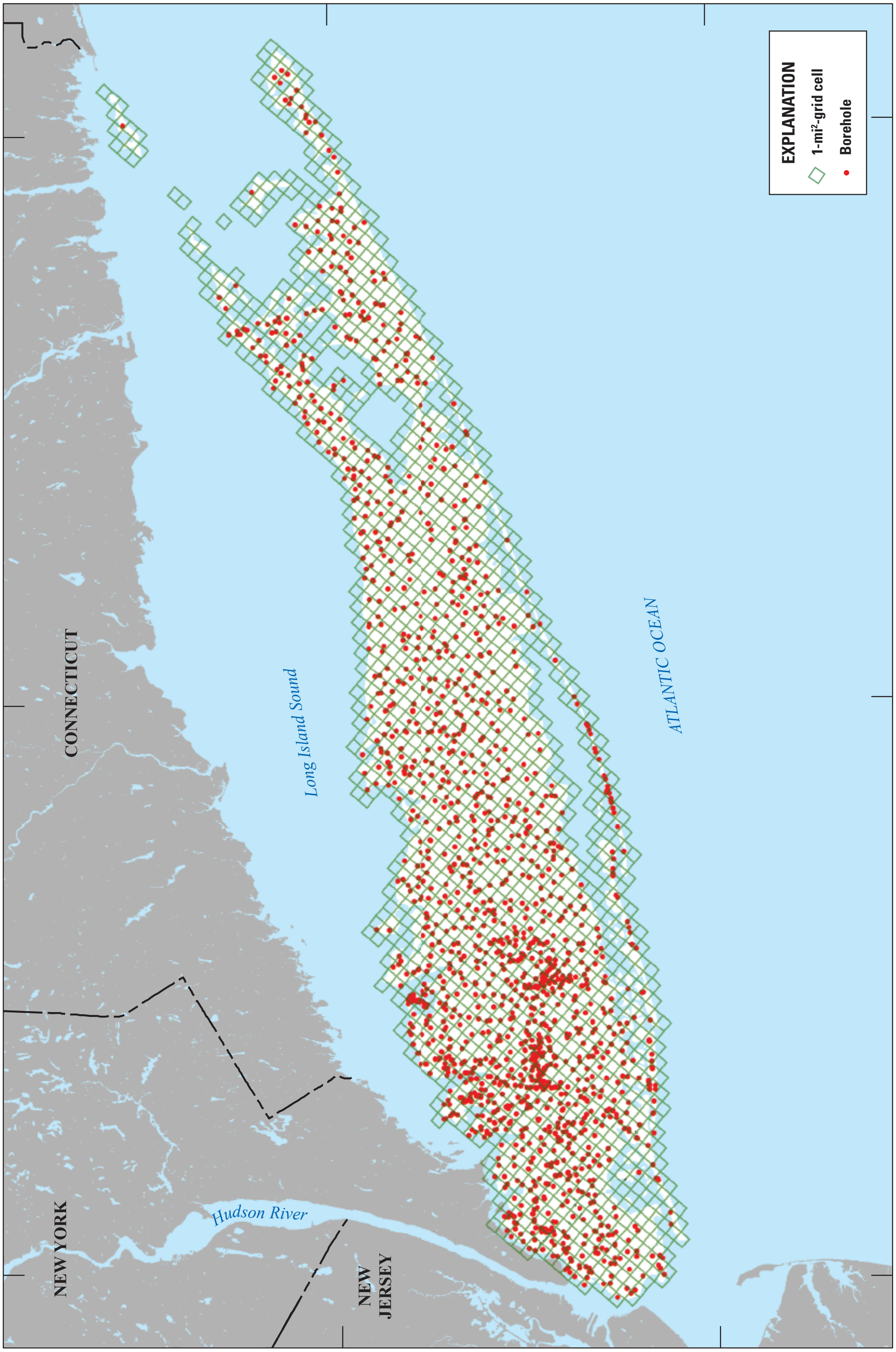
## Model Development

Quasi-three-dimensional models were developed that consist of stacks of individual two-dimensional grids with a uniform thickness of 10 ft. Two sets of quasi-three-dimensional models were produced: a set of grids each with a uniform altitude and a set of grids whose altitudes vary as determined by the surface altitude of the top of the underlying Raritan confining unit, which is considered to be the bottom of the principal aquifer system of Long Island (Smolensky and others, 1989). The first set, referred to as the “horizontal model,” is applied to the upper glacial aquifer and other Pleistocene-age sediments. The top of the horizontal model is land surface (fig. 2) and the bottom of the model is the top of the Magothy aquifer (fig. 4*A*). The second set, referred to as the “sloping model,” is applied to the underlying Cretaceous-age and contiguous units, including the Magothy and Jameco aquifers and the Monmouth Greensand. The top and bottom of the sloping model are the top of the Magothy aquifer (fig. 4*A*) and the top of the Raritan confining unit (fig. 4*B*), respectively.

The horizontal model composes 100 horizontal layers of a uniform thickness of 10 ft. The model extends from land surface down to −700 ft MSL (fig. 7*A*). Only aquifer characteristics for cells within the upper glacial aquifer are considered to be active cells in the model; underlying cells within the Cretaceous-age sediments are not used. The sloping model consists of 152 layers, each with a uniform thickness of 10 ft. The altitude of each layer is determined by the top of the Raritan confining unit. The bottom of layer 152 is the top of the Raritan confining unit and all layers above are increased by multiples of 10 ft from that bottom layer (fig. 7*B*). Only aquifer characteristics for cells within Cretaceous aquifers are considered; overlying cells within the glacial sediments are not used (fig. 7*B*).

The database of point locations and values was imported into a GIS and queried to extract the X,Y locations of boreholes of sufficient depth that extend to or beyond each layer in the models (fig. 8). The subset of data points and the locations and values present in each 10-ft layer was used to populate each two-dimensional grid for each characteristic of interest by use of ordinary kriging (fig. 8). The number of points available for interpolation decreases monotonically with depth. As an example, there are 1,645 points within layer 32 of the horizontal model, corresponding to an altitude of 0 to −10 ft MSL NAVD 88 (fig. 8*A*) and 288 points within layer 141 of the sloping model (fig. 8*B*), which is in the basal part of the Magothy aquifer and has an average altitude of −740 ft MSL NAVD 88. The density of points in the sloping model generally decreases to the southeast owing in part to the southeast dip of each layer manifesting the top of the Raritan confining unit and, possibly, to the existence of fewer wells than in the more urbanized areas to the west. The horizontal and sloping models, when combined and included with codes delineating the three-dimensional definition of the sedimentary units—glacial or Cretaceous-age—fully define the estimated aquifer characteristics for the principal aquifer system of Long Island.

The set of data points within each layer was used to populate that layer with interpolated values by use of ordinary, spherical kriging (Oliver and Webster, 1990). Kriging is a stochastic, weighted-average method of interpolation that predicts spatially distributed values based on the structure and spatial correlations among data points. The method is a Gaussian process that uses a model of spatial correlation known as a variogram. Spherical kriging assumes that dependence and correlation becomes asymptotic at a specified distance and requires a set of parameters to apply the modeled variogram to estimate values across the grid. These parameters were determined for each layer from each set of data points using an optimization process included with the Geostatistical Analyst toolbox of ArcGIS (Esri, 2019).




Base map from U.S. Geological Survey The National Atlas digital data, scale 1:100,000
Long Island, New York, State Plane projection
North American Datum of 1988

**Figure 6.** Design of 1-square-mile ($mi^2$) sampling grid and deep boreholes used in the lithologic-log analysis of the aquifer sediments underlying Long Island, New York.

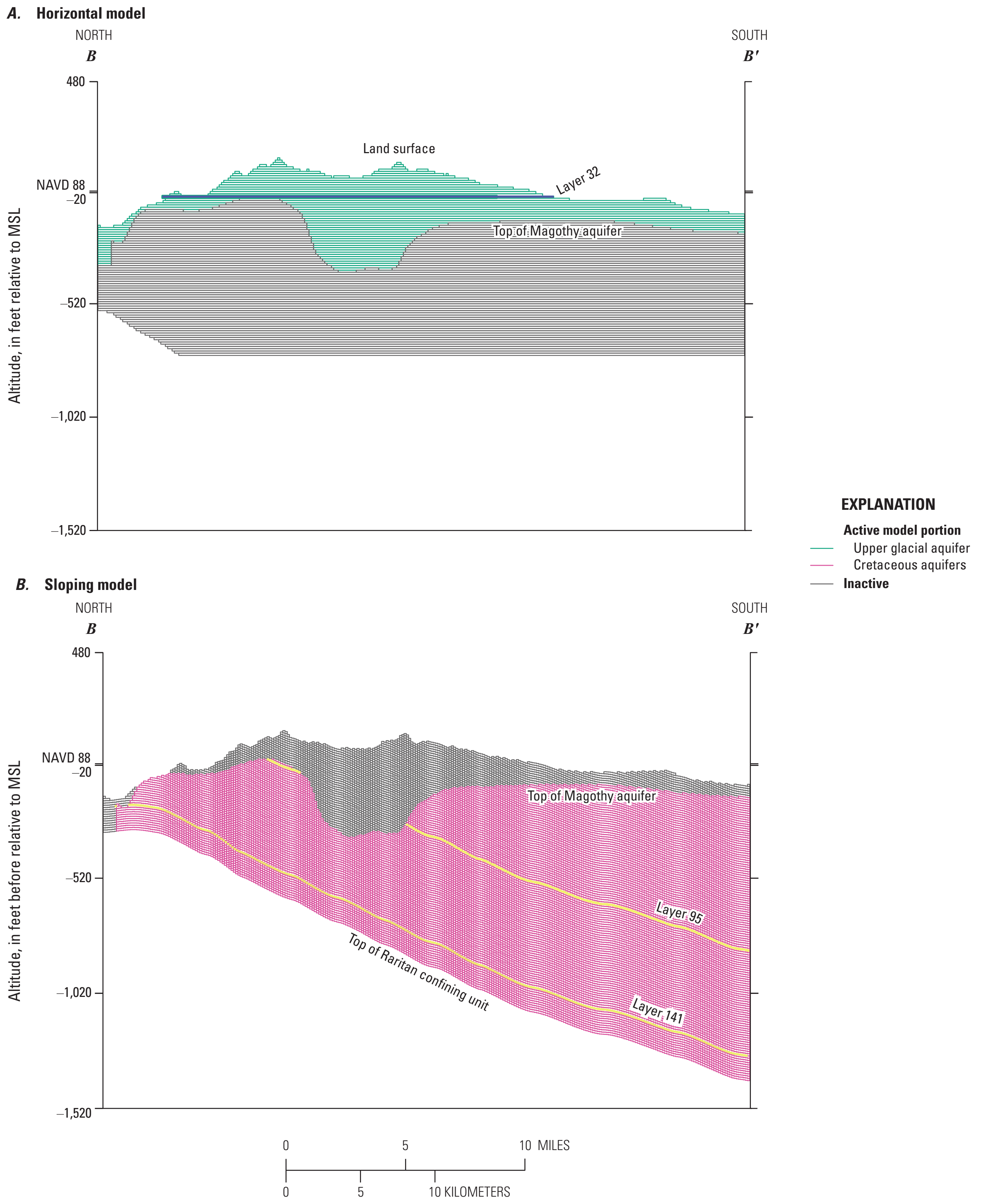
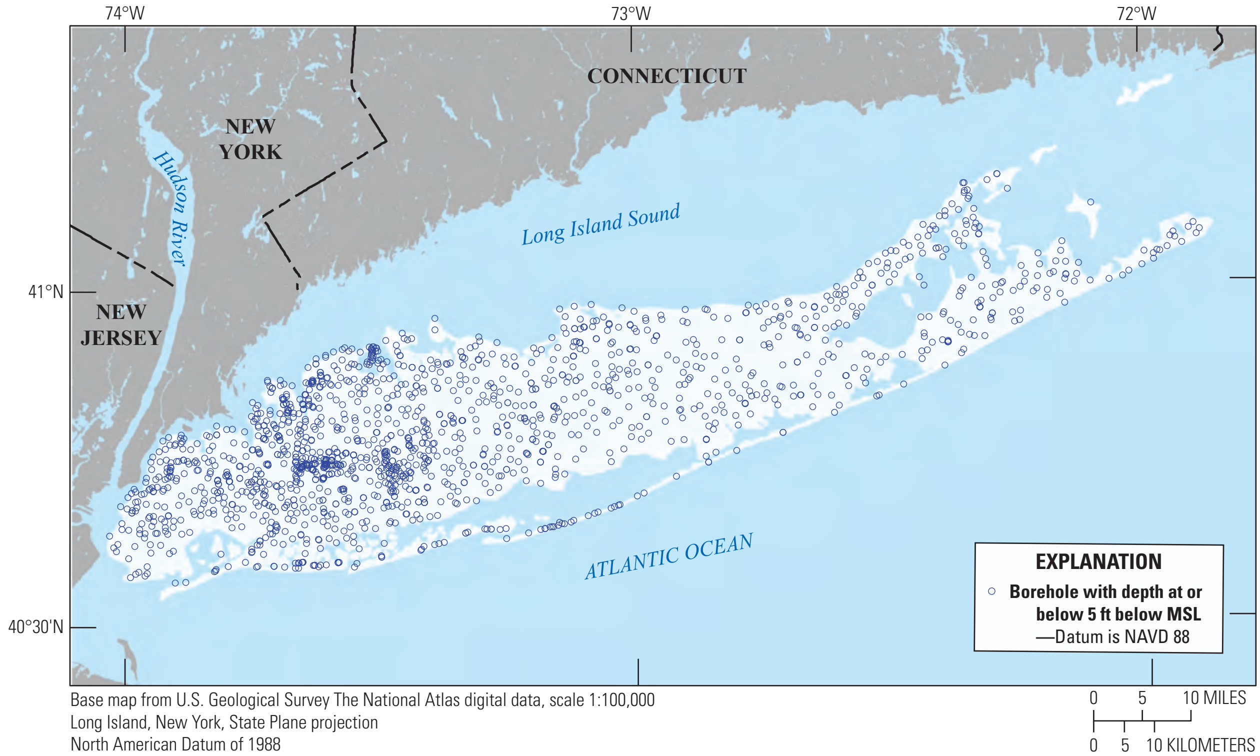



**Figure 7.** Vertical design of quasi-three-dimensional grids for the *A*, horizontal and *B*, sloping models along north-south section *B*–*B*′ on Long Island, New York. Location of line of section shown on figure 1. MSL, mean sea level; NAVD 88, North American Vertical Datum of 1988.

***A.*** **Horizontal model, layer 32**




***B.*** **Sloping model, layer 141**

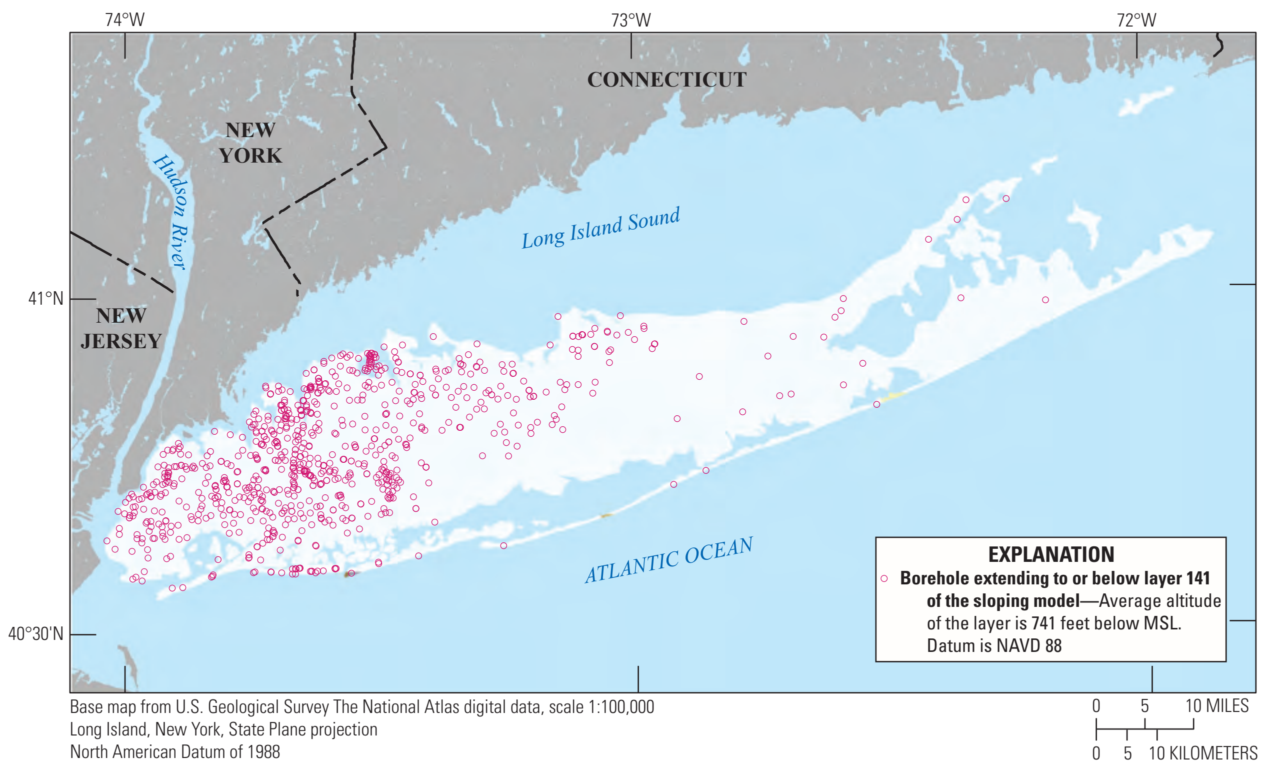



**Figure 8.** Boreholes providing data points for *A*, layer 32 (5 feet [ft] below mean sea level [MSL]) of the horizontal model and *B*, layer 141 (741 ft below MSL) of the sloping model for Long Island, New York. NAVD 88, North American Vertical Datum of 1988.

## Limitations of Analysis

This report presents the results of an analysis of lithologic descriptions and the conversion of these qualitative data to more quantitative measures of important hydrogeologic characteristics of the upper glacial and Magothy aquifers. The principal limitations of the analysis include classification of individual lithologic descriptions into categorial data, the assignment of hydraulic conductivity values to those lithologic categories, and the use of the resulting point data to estimate intermediate values by use of kriging.

The lithologic descriptions underlying the analysis are qualitative and likely do not represent actual lithology with complete accuracy. More than 36,000 lithologic descriptions, each with a unique combination of keywords, were classified into a total of 14 lithologic codes. The generalization of a large amount of data results in some loss of detailed information and it is likely that the 14 codes do not fully capture the regional distribution of these aquifer characteristics. Values of horizontal and vertical hydraulic conductivity assigned to each code are based on published values and are assumed to be reasonable but are, to an extent, arbitrary. Assigning a different set of values would result in a different estimated distribution of hydraulic conductivity. The analysis presented in this report is therefore considered an example of how these methods can be used to estimate the distribution of hydraulic conductivity in the aquifer for a given set of assigned hydraulic conductivity values.

Another set of considerations is the resolution of the analysis and the methods of interpolation used to convert point data into a three-dimensional rendering of these characteristics. The spatial resolution of the analysis, which is intended to be regional in scale, is 1 $mi^2$, and only the deepest well within a 1-$mi^2$ grid cell was included in the analysis. This data-sampling approach results in many other wells, and the associated information, being excluded from the analysis. Use of a denser network of wells would, therefore, result in a more detailed representation of the distribution of these characteristics. The spatial resolution of the interpolation used to convert point data to the quasi-three-dimensional distributions was 500 ft, and interpolated properties are uniform within that distance. Interpolation of the data at a smaller resolution also would result in a more detailed field of interpolated values.

The use of modeled interpolation, such as kriging, introduces some model error and can affect final interpolated values. Optimized kriging parameters were determined for the subset of points used for interpolation at each 10-ft layer to minimize the effects of model error on the estimated values.

# Distribution of Selected Aquifer Characteristics

Hydrogeologic characteristics of importance to understanding the Long Island aquifer system are those affecting groundwater flow and the geochemistry of the aquifer. Hydraulic conductivity is an intrinsic aquifer property that controls the ability of water to flow through the sediments and, in this analysis, is expressed as feet per day. Hydraulic conductivity is a function of permeability and is affected by sediment characteristics, such as grain size and the degree of sorting.

Lignite is a form of fossilized wood that results from the compression of buried peat and organic plant material and is commonly present in Cretaceous-age sediments. Lignite is a source of organic carbon in the aquifer, and the oxidation of that carbon can result in anoxic and chemically reducing conditions in parts of the Cretaceous aquifers; pyrite is commonly present in association with lignite indicating iron- and sulfur-reducing redox conditions.

## Horizontal Hydraulic Conductivity and Clay

Glacial sediments show patterns generally reflecting the surficial geology and depositional history of the upper glacial aquifer. The hydraulic conductivity of glacial sediments at an altitude of 5 ft below MSL generally are lowest in inland areas of eastern Nassau and western Suffolk County (figs. 1 and 9*A*). These sediments underlie hummocky terrain, suggesting an association with glacial moraines (fig. 2); this association also is consistent with the mapped surficial geology (fig. 2; Cadwell and Muller, 1986). Areas of low hydraulic conductivity in the north-central part of the island also may represent glaciolacustrine sediments, which are deposited in proglacial lakes between moraines. Extensive glacial clays, likely glaciolacustrine in origin, have been mapped in north-central Suffolk County (Krulikas and Koszalka, 1983). Hydraulic conductivity to the south, within outwash sediments, is substantially higher than in the north-central part of the island (fig. 9*A*). Morainal and glaciolacustrine sediments generally are lower in hydraulic conductivity than are outwash sediments owing to a generally finer grain size and a lesser degree of sorting.

Hydraulic conductivity values in the basal part of the Magothy aquifer show more spatial variability than those in glacial sediments (fig. 9*B*). The Cretaceous sediments are deltaic in origin and were deposited in a variety of depositional environments. Coarse-grained sandy sediments likely were deposited in high-energy, fluvial environments, such as stream channels. Fine-grained sediments generally were deposited in low-energy environments, such as overbank lakes and wetlands. Deposition in a variety of depositional environments results in highly heterogenous hydraulic conductivity patterns.

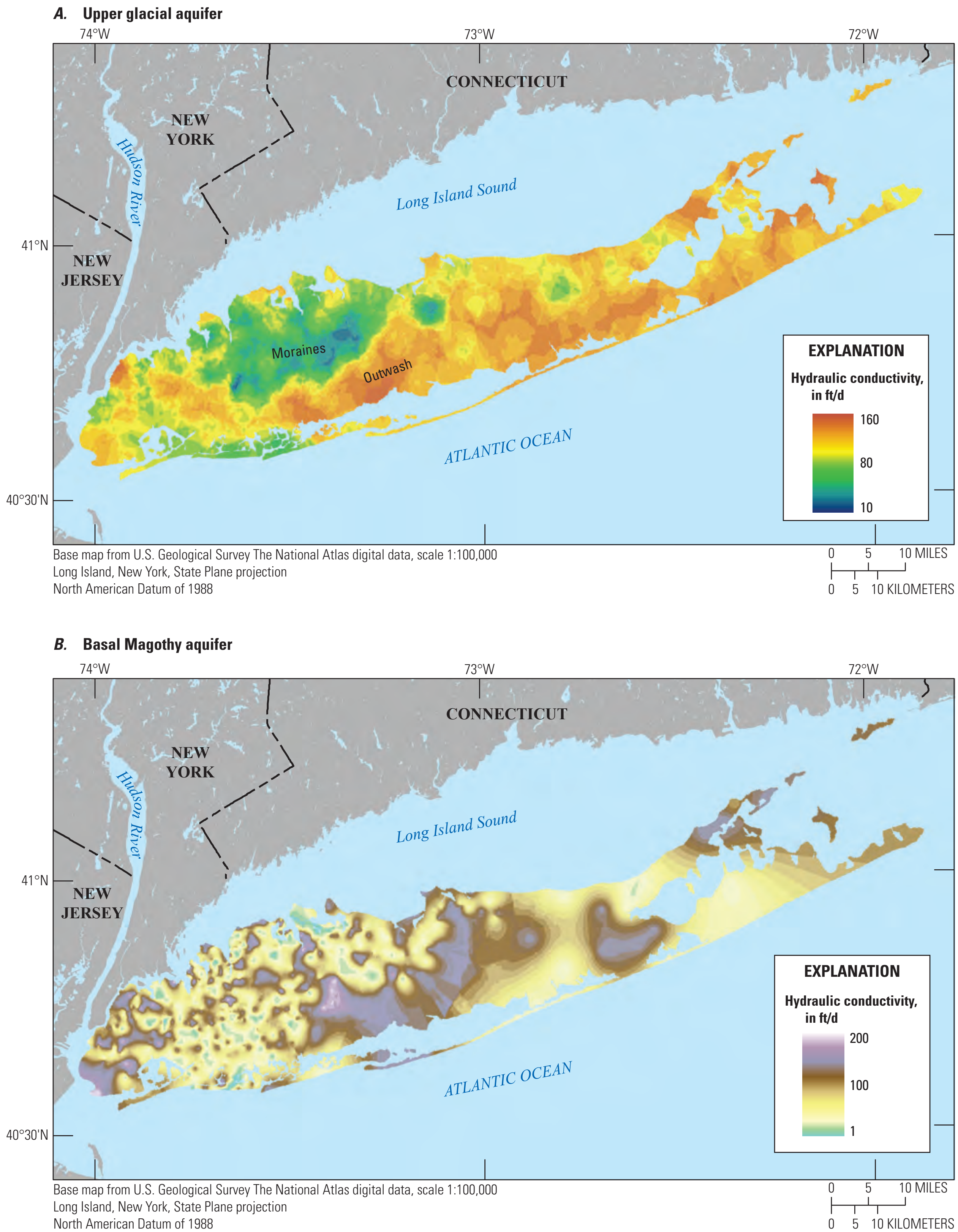



**Figure 9.** Interpolated horizontal hydraulic conductivity for *A,* the upper glacial (horizontal) model at an altitude of 5 feet below mean sea level (MSL) and *B,* the Magothy (sloping) model at a mean altitude of 741 feet below MSL on Long Island, New York. Hydraulic conductivity data are from Finkelstein and Walter (2020). ft/d, foot per day; NAVD 88, North American Vertical Datum of 1988.

The vertical distribution of horizontal hydraulic conductivity generally reflects geologic trends in the depositional history of the upper glacial aquifer sediments (fig. 10*A* and *C*). Glacial moraine and glaciolacustrine sediments generally fine with depth and are associated with lower hydraulic conductivity values in interior parts of the island. Hydraulic conductivity generally is higher in the shallow parts of the upper glacial aquifer, in association with outwash sediment (fig. 10*A*). Lower values of hydraulic conductivity generally are in parts of the upper glacial aquifer that contain silt and clay (fig. 10*B*). Silt and clay generally indicate deposition in lacustrine environments in proglacial lakes. Silt and clay lenses generally are absent in outwash sediments, which were deposited in fluvial environments.

The vertical distribution of hydraulic conductivity in the Magothy aquifer also shows patterns consistent with depositional history. Hydraulic conductivity generally is lower in the middle part of the aquifer (fig. 10*A* and *C*) where fine-grained sediments commonly are present, in association with silt and clay interbeds (fig. 10*B* and *D*). This suggests deposition in low-energy overbank lake and wetland environments. Hydraulic conductivity values generally are higher in the basal part of the aquifer (fig. 10*A* and *C*). These sediments likely were deposited in high-energy fluvial environments and this part of the aquifer is commonly used for water supply. The occurrence of silt and clay generally is limited in the basal part of the Magothy aquifer (fig. 10*B* and *D*), consistent with fluvial deposition.

## Occurrence of Lignite and Pyrite

Lignite is common in Cretaceous-age sediments as an interstitial component of the sediments and as discrete lenses and interbeds. Pyrite commonly occurs in association with lignite, indicating locally reducing conditions. Lignite occurs primarily in the middle part of the Magothy aquifer (fig. 11*A* and *C*) and is correlated with lower values of hydraulic conductivity (fig. 10*A* and *C*) and the occurrence of silt and clay (fig. 10*B* and *D*). This co-occurrence is consistent with sediment deposition in low-energy overbank lake and wetland environments. This would coincide with the presence of peat and plant material and deposition with fine-grained sediments necessary for the formation of lignite. The occurrence of lignite in the basal part of the Magothy aquifer is limited (fig. 11*A* and *C*), consistent with deposition in fluvial environments as indicated by the higher hydraulic conductivity of coarse-grained sediments in that part of the unit (fig. 10*A* and *C*).

Lignite in the middle part of the Magothy aquifer generally occurs along the southern shore, in the central part of the island (fig. 12*A*). The spatial distribution of lignite is similar to the distribution of indicators of chemically reducing conditions, such as dissolved iron. Dissolved iron and iron-related biofouling of water-supply wells generally have the same spatial distribution as the occurrence of lignite (fig. 12*A*; Walter, 1997). Lignite in the basal part of the Magothy aquifer generally is limited and occurs primarily in the southwestern part of the island (fig. 12*B*). The occurrence of lignite in this area generally correlates to areas of low hydraulic conductivity in the basal part of the Magothy aquifer (fig. 9*B*).

The occurrence of pyrite (fig. 11*B* and *D*) is closely associated with the occurrence of lignite (fig. 11*A* and *C*). The oxidation of the organic carbon present in lignite can result in iron and sulfur reduction and the precipitation of pyrite. The presence of pyrite indicates highly reducing conditions, which is an important control on water quality. The elevated concentrations of ferrous iron in highly reducing geochemical environments indicates the potential for iron-related well biofouling (Walter, 1997).

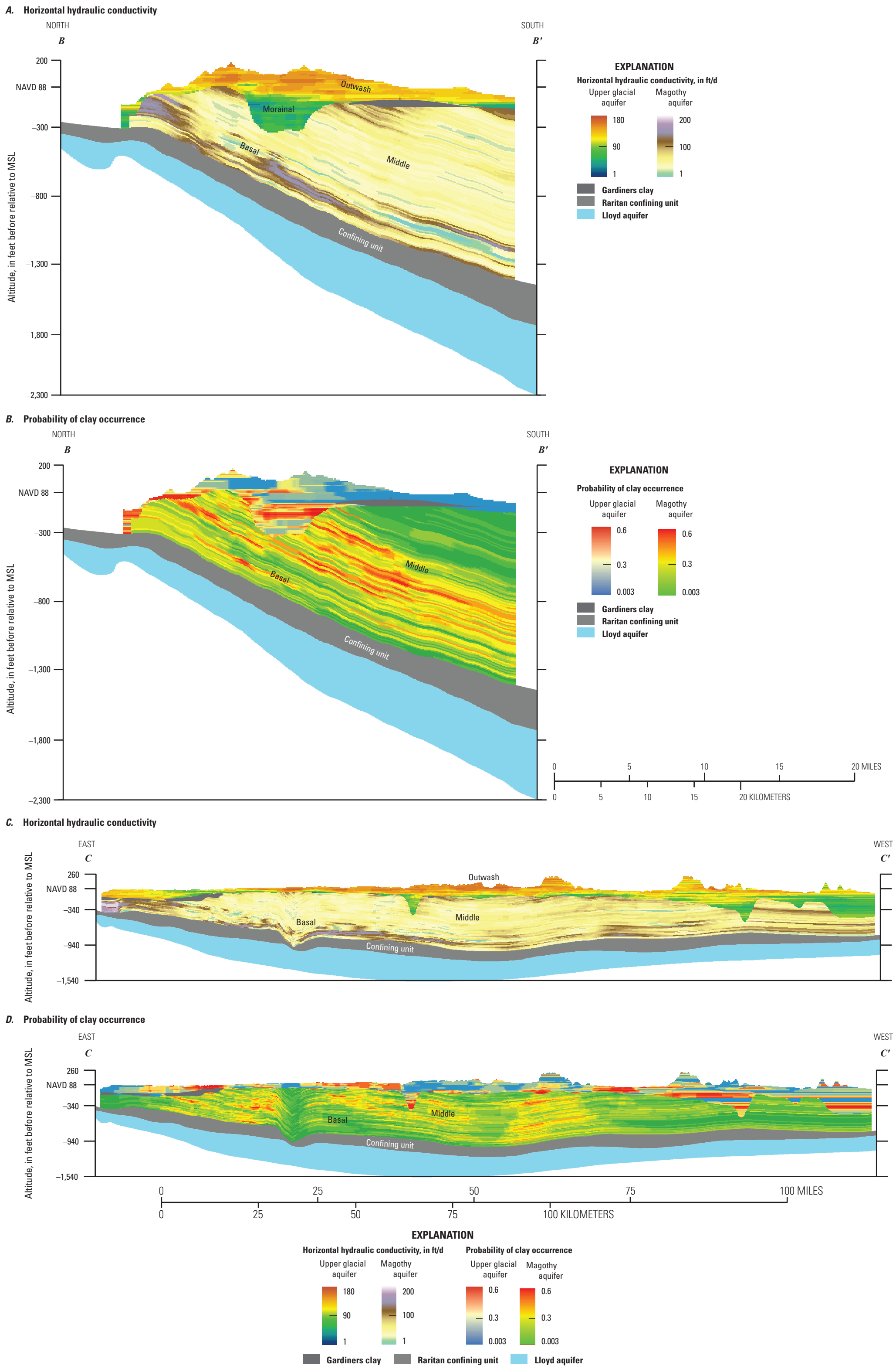



**Figure 10.** Vertical distribution of *A*, estimated horizontal hydraulic conductivity and *B*, probability (unitless) of clay occurrence along north-south section *B*–*B*′ and *C*, estimated horizontal hydraulic conductivity and *D*, probability of clay occurrence along east-west section *C*–*C*′ on Long Island, New York. Locations of lines of section shown on figure 1. Hydraulic conductivity and probability data are from Finkelstein and Walter (2020). NAVD 88, North American Vertical Datum of 1988. A larger version of this figure is available at https://doi.org/10.3133/sir20205023.

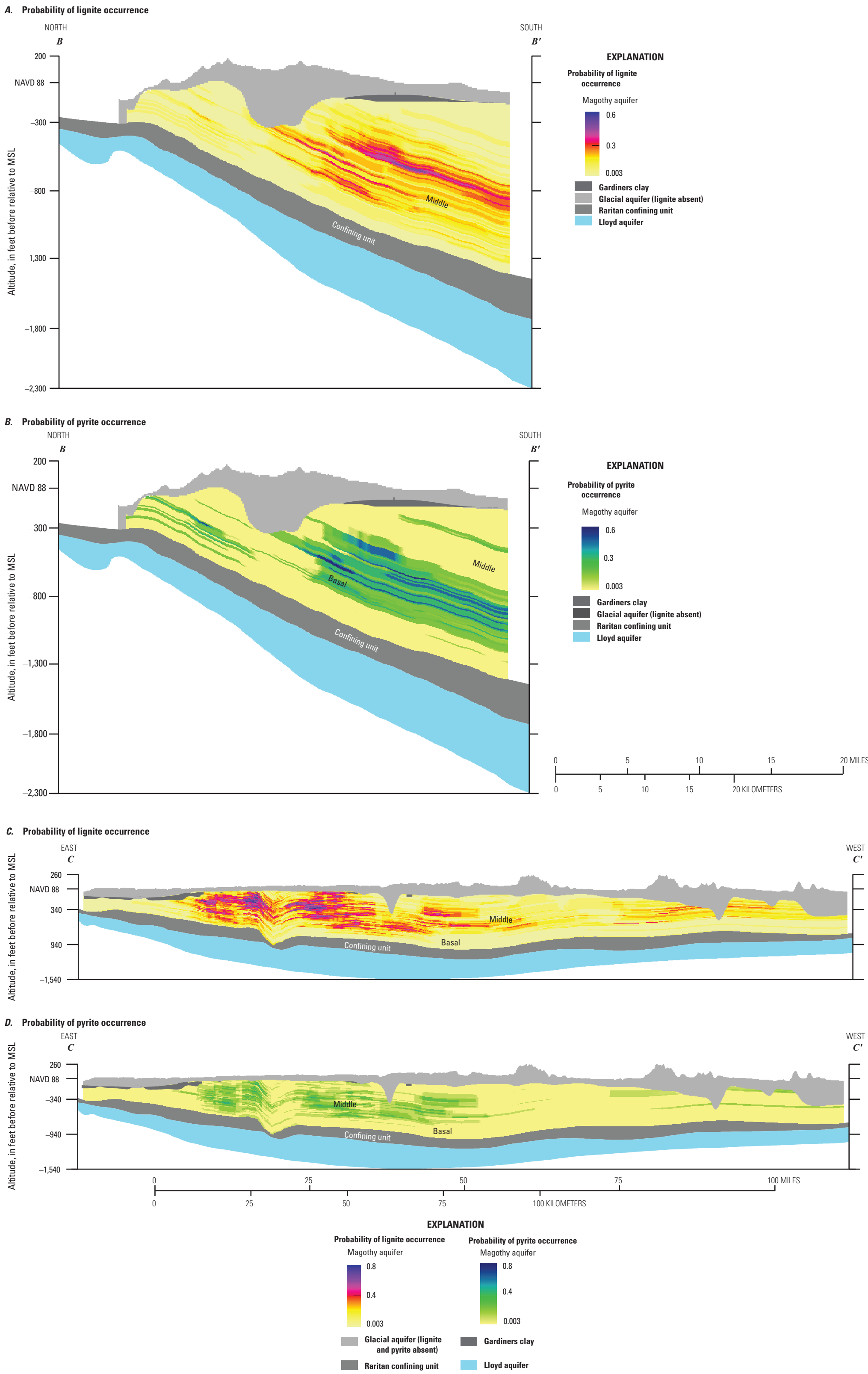
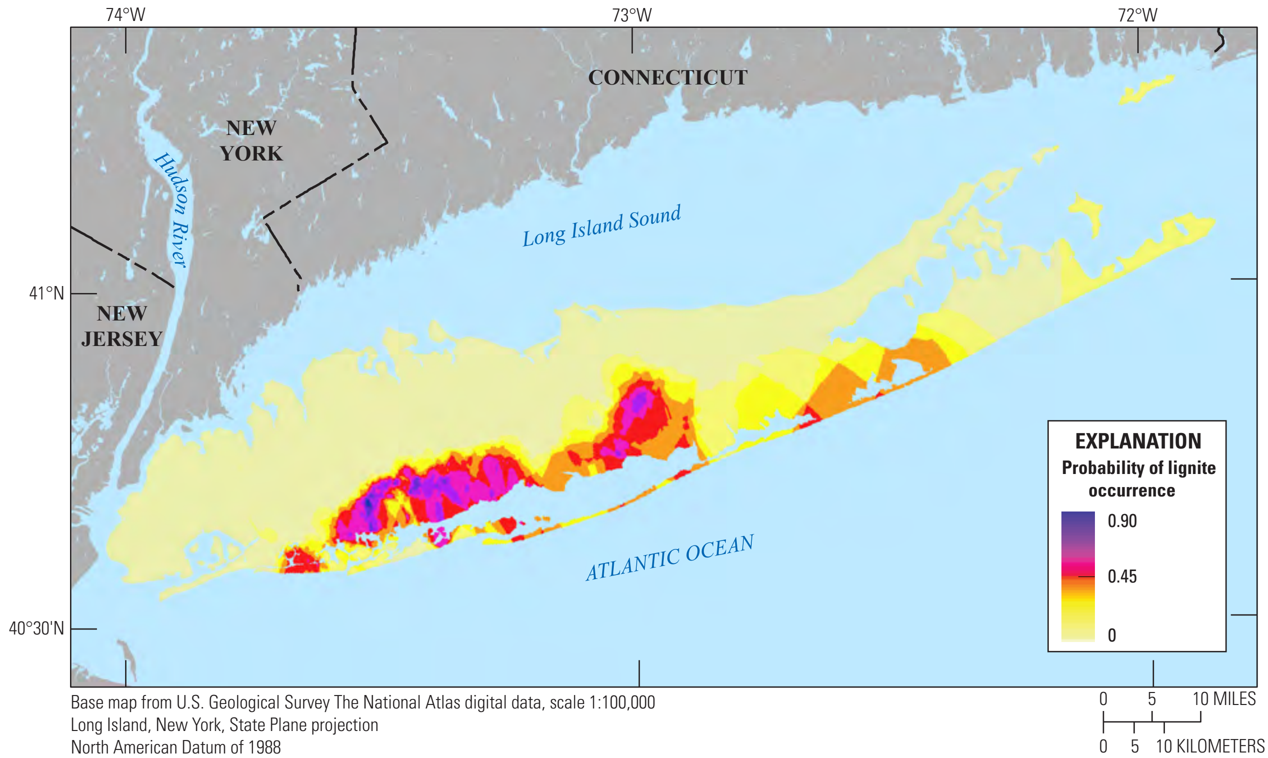



**Figure 11.** Vertical distribution of the probability (unitless) of the occurrence of *A*, lignite and *B*, pyrite along north-south section *B–B′* and *C*, lignite and *D*, pyrite along east-west section *C–C′* on Long Island, New York. Locations of lines of section shown on figure 1. Probability data are from Finkelstein and Walter (2020). NAVD 88, North American Vertical Datum of 1988. A larger version of this figure is available at https://doi.org/10.3133/sir20205023.

***A.*** **Middle part of Magothy aquifer**




***B.*** **Basal part of Magothy aquifer**

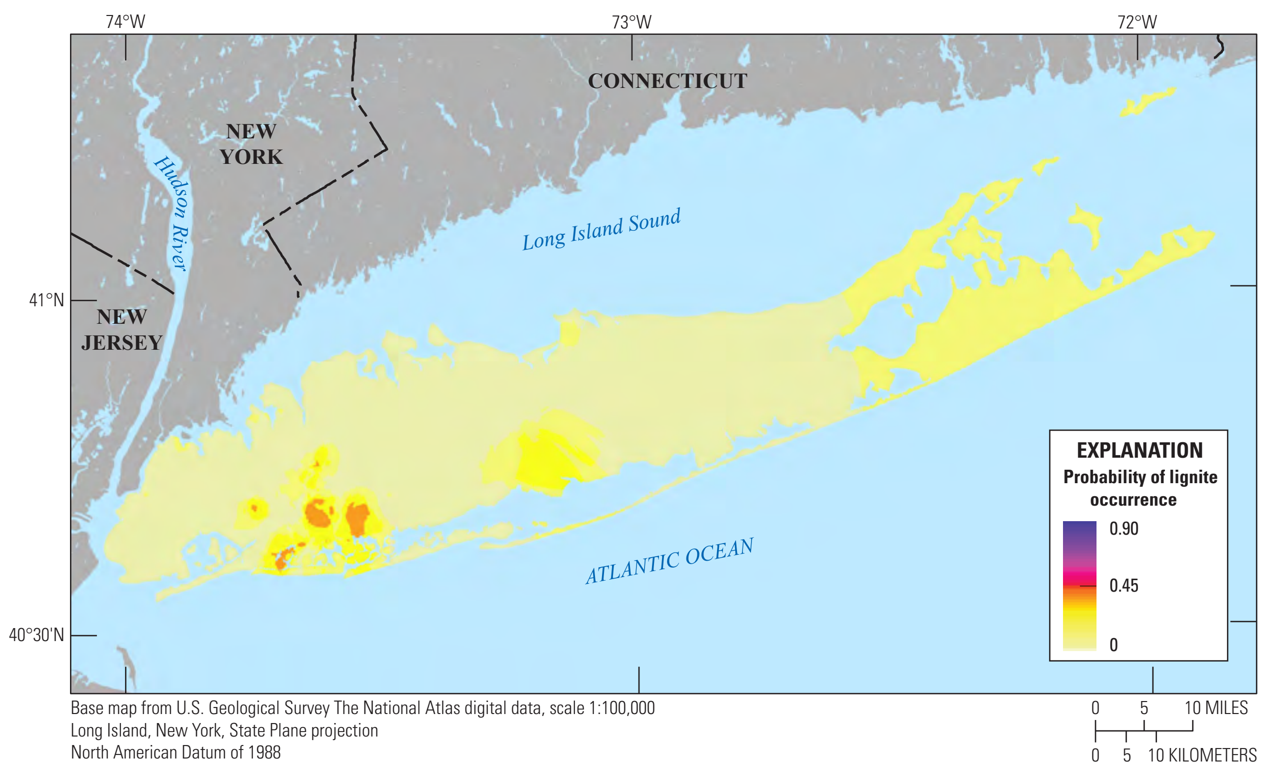



**Figure 12.** Estimated probability (unitless) of lignite occurrence for the *A*, middle and *B*, basal parts of the Magothy aquifer on Long Island, New York. Probability data are from Finkelstein and Walter (2020).

## Summary

Long Island, New York, is underlain by a sequence of unconsolidated glacial and Cretaceous-age sediments that are nearly 2,000 feet (ft) thick and compose a sole-source aquifer system that provides water to nearly 3 million people. The principal aquifers are the upper glacial aquifer and the underlying Magothy aquifer. Glacial sediments consist of gravel, sand, silt, and clay that were deposited in glaciofluvial and glaciolacustrine environments along the margin of retreating ice sheets during the late Wisconsinan glaciation. Glacial sediments are underlain by Cretaceous-age sediments that generally are more fine-grained and heterogenous than are the glacial sediments. These sediments compose the Magothy aquifer and were deposited in deltaic depositional environments, including fluvial channels and overbank lakes and wetlands. A large amount of lithologic data has been collected as part of water-supply exploration and remedial investigations. The quality of these data varies, but when considered together and in sufficient numbers, these data can be used to gain insight into the distribution of important aquifer characteristics, such as hydraulic conductivity and the occurrence of lignite.

An analytical approach was developed in which more than 36,000 lithologic descriptions from nearly 1,800 boreholes were used to define standard lithologic codes for each vertical interval in each borehole. These coded intervals were assigned values of horizontal and vertical hydraulic conductivity from previous investigations and were assigned a binary variable representing the presence or absence of lignite, pyrite, and clay. Each borehole was divided into 10-ft lengths and mean values of each quantity were computed for each interval. These borehole descriptions were assembled into a geographic information system database containing location, altitude, and the value of each computed mean.

A set of stacked three-dimensional grids was created, each 10 ft in thickness, that spanned the thicknesses of the upper glacial and Magothy aquifers. Grids representing the upper glacial aquifer were horizontal and in 10-ft increments of an equal altitude. Grids representing the Magothy aquifer were draped onto a surface representing the bottom of the unit and had altitudes that manifested that surface ascending in 10-ft intervals. The database was queried to extract those boreholes that extended to or beyond each successive grid. These subsets of data points were used to populate each grid with interpolated values of each aquifer characteristic by use of ordinary, spherical kriging. The vertical stack of grids, when combined, represent quasi-three-dimensional models of each unit. Those two models, when combined, represent a model of the principal aquifer system of the island.

Two modeled characteristics of importance are horizontal hydraulic conductivity (an important control on groundwater flow) and the occurrence of lignite (an important control on geochemical conditions and water quality). The spatial and vertical patterns in hydraulic conductivity generally are consistent with the depositional history of the regional aquifer system. Lower values of hydraulic conductivity in the upper glacial aquifer generally occur in interior parts of the island and are associated with glacial moraines and glaciolacustrine sediments. Hydraulic conductivity is highest in outwash sediments south of the moraine. Outwash sediments consist largely of well-sorted sand; moraine sediments generally consist of fine-grained and poorly sorted sediments. In addition, the glacial sediments generally become finer with depth. The Magothy aquifer is more heterogenous, with fewer broad spatial patterns. Hydraulic conductivity in the basal part of the Magothy aquifer, where sediments likely were deposited in fluvial depositional environments, generally is higher than in overlying parts of the unit. The basal part of the Magothy aquifer is considered productive for water supplies. The hydraulic conductivity generally is lowest in the middle part of the Magothy aquifer where sediments are fine-grained sands and silts with interbedded clay lenses and likely were deposited in overbank lake and wetland environments.

Lignite, which is formed from the compression of buried peat and plant material, occurs primarily in the middle part of the Magothy aquifer and is associated with fine-grained sediments, as indicated by the lower hydraulic conductivity values in that part of the unit. This occurrence is consistent with fine-grained sediment deposition in overbank lake and wetland deposits. Lignite occurrence generally is found in the south-central part of the island. Lignite is a source of organic carbon that causes chemically reducing conditions and elevated concentrations of reduced species, such as dissolved ferrous iron. The observed distribution of dissolved iron and iron biofouling in water-supply wells coincides with the occurrence of lignite.

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For more information about this report, contact:
Director, New England Water Science Center
U.S. Geological Survey
10 Bearfoot Road
Northborough, MA 01532
dc_nweng@usgs.gov
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