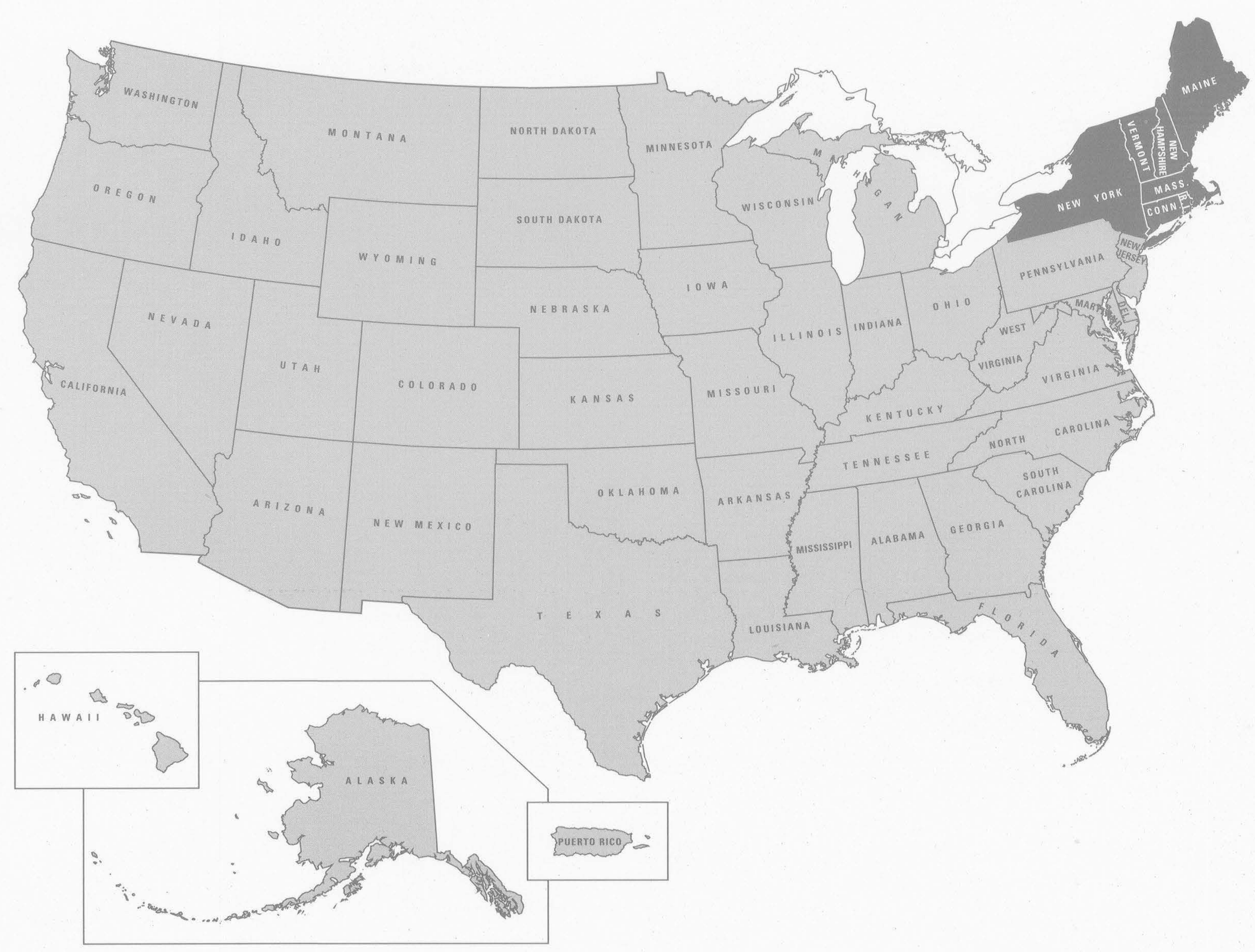
GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 12

Connecticut
Maine
Massachusetts
New Hampshire
New York
Rhode Island
Vermont



HYDROLOGIC INVESTIGATIONS ATLAS 730–M

U.S. Geological Survey

Reston, Virginia
1995

GROUND WATER ATLAS OF THE UNITED STATES
Hydrologic Investigations Atlas 730–M

FOREWORD

The Ground Water Atlas of the United States presents a comprehensive summary of the Nation's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas.

The Atlas, which is designed in a graphical format that is supported by descriptive discussions, includes 13 chapters, each representing regional areas that collectively cover the 50 States and Puerto Rico. Each chapter of the Atlas presents and describes hydrogeologic and hydrologic conditions for the major aquifers in each regional area. The scale of the Atlas does not allow portrayal of minor features of the geology or hydrology of each aquifer presented, nor does it include discussion of minor aquifers. Those readers that seek detailed, local information for the aquifers will find extensive lists of references at the end of each chapter.

An introductory chapter presents an overview of ground-water conditions Nationwide and discusses the effects of human activities on water resources, including saltwater encroachment and land subsidence.

Gordon P. Eaton

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, *Director*

CONVERSION FACTORS

For readers who prefer to use the International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound units	*By*	*To obtain metric units*
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
billion gallons per day (Bgal/d)	3.785	million cubic meters per day (Mm^3/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
	Temperature	
degree Fahrenheit (°F)	5/9(°F–32)=°C	degree Celsius (°C)

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

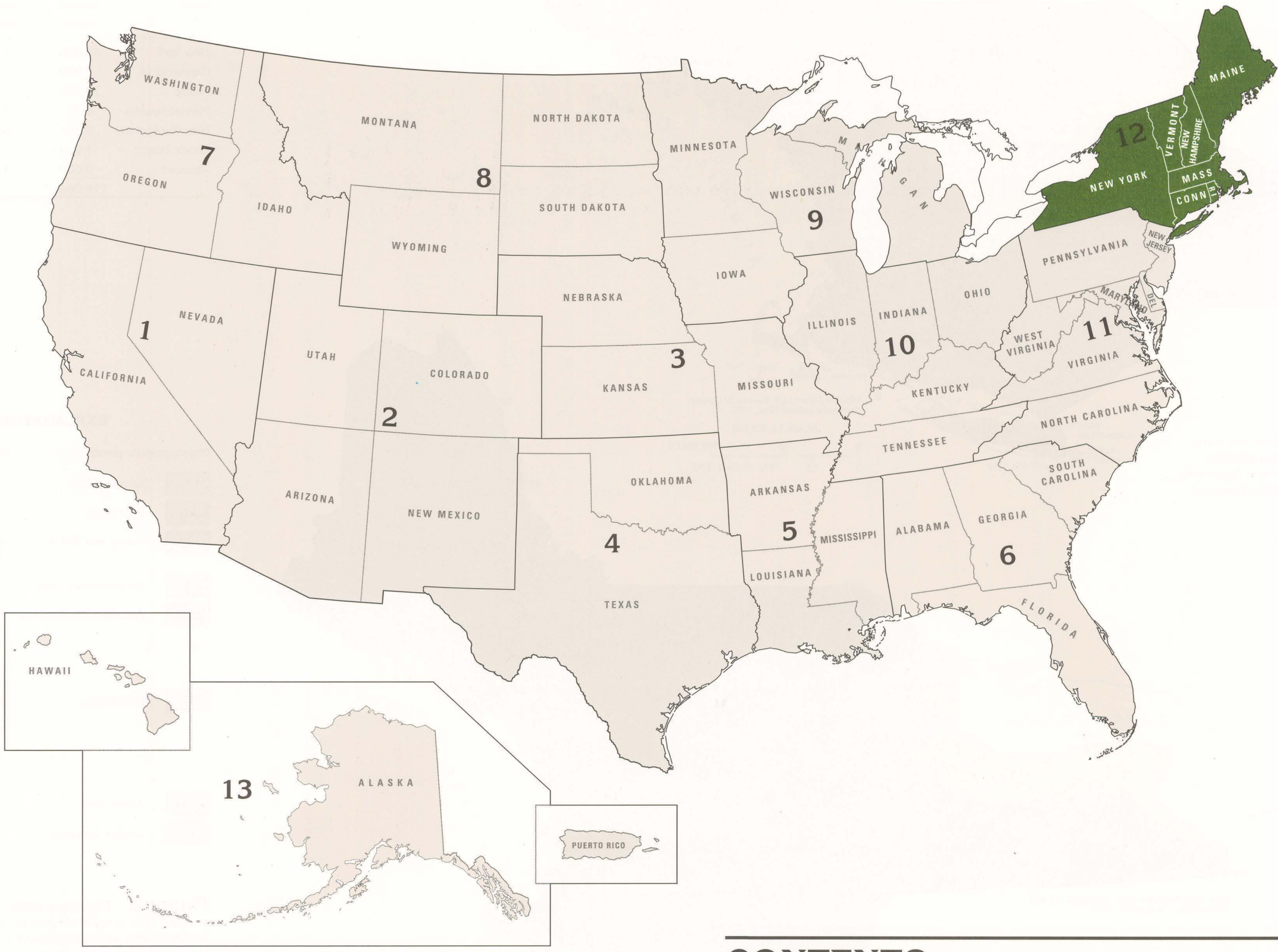
Segment Number	*Chapter content*	*Hydrologic Atlas Chapter*
—	Introductory material and nationwide summaries	730–A
1	California, Nevada	730–B
2	Arizona, Colorado, New Mexico, Utah	730–C
3	Kansas, Missouri, Nebraska	730–D
4	Oklahoma, Texas	730–E
5	Arkansas, Louisiana, Mississippi	730–F
6	Alabama, Florida, Georgia, South Carolina	730–G
7	Idaho, Oregon, Washington	730–H
8	Montana, North Dakota, South Dakota, Wyoming	730–I
9	Iowa, Michigan, Minnesota, Wisconsin	730–J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730–K
11	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	730–L
12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730–M
13	Alaska, Hawaii, Puerto Rico	730–N

Ground Water Atlas of the United States

Segment 12

Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont

By Perry G. Olcott



CONTENTS

Cartographic design and production by Caryl J. Wipperfurth and Steven M. Bolssen

Regional summary

INTRODUCTION

The State of New York and the six New England States of Maine, Vermont, New Hampshire, Massachusetts, Connecticut, and Rhode Island compose Segment 12 of this Atlas (**fig. 1**). The seven States have a total land area of about 116,000 square miles (**table 1**); all but a small area in southwestern New York has been glaciated.

Population in the States of Segment 12 totals about 30,408,000 (**table 1**) and is concentrated in southern and eastern Massachusetts, Connecticut, Rhode Island, and especially New York (**fig. 1**). The northern part of the segment and the mountainous areas of New York and much of New Hampshire, Vermont, and Maine are sparsely populated.

The percentage of population supplied from ground-water sources during 1980 was 54 to 60 percent in Maine, New Hampshire, and Vermont (**table 1**). Nearly all rural, domestic, and small-community water systems obtain water from wells that are, in comparison with other sources, the safest and the least expensive to install and maintain. Where water demand is great—in the urban areas of New York, Connecticut, Massachusetts, and Rhode Island—sophisticated reservoir, pipeline, and purification systems are economically feasible and are needed to meet demands. Surface water is the principal source of supply in these four States, and ground water was used to supply only 24 to 35 percent of their population during 1980 (**table 1**).

PHYSIOGRAPHY

The States in Segment 12 incorporate a variety of topographic features that range in altitude from more than 6,200 feet above sea level at Mount Washington in New Hampshire (**table 1**) to sea level along the Atlantic seaboard. The land of these States has been subdivided into physiographic provinces and sections (**fig. 2**) that range from mountainous areas, such as the White Mountains of New Hampshire and Maine, the Taconic and Green Mountains of New York, Massachusetts, and Vermont, and the Adirondack Mountains of New York, to lowland areas, such as the Central Lowland along Lakes Erie and Ontario and the Coastal Plain and Seaboard Lowland along the Atlantic coast. The Appalachian Plateaus and the New England Upland, which are of intermediate altitude between mountains and lowlands, dominate Segment 12 and extend from western New York through much of central New England.

The bedrock surface in the States of Segment 12 was deeply dissected by erosion before and during glaciation. A cover of glacial debris, however, moderates the relief of this erosional surface, resulting in rolling to flat topography in the lowland areas and flat-bottomed, partially filled valleys between highlands in the plateaus, uplands, and mountainous areas.

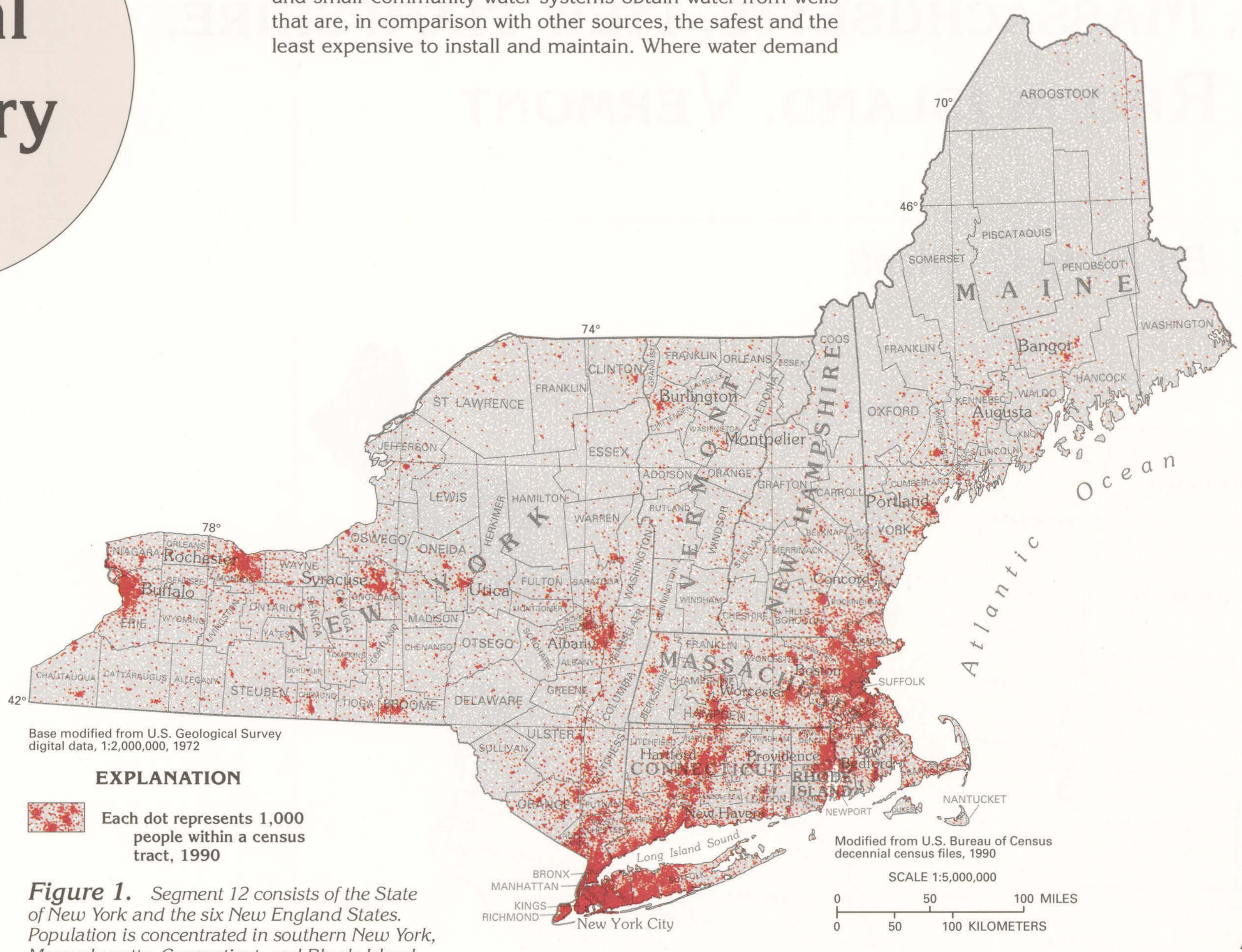


Figure 1. Segment 12 consists of the State of New York and the six New England States. Population is concentrated in southern New York, Massachusetts, Connecticut, and Rhode Island.

Table 1. The total land area in the seven States of Segment 12 is about 116,000 square miles. Altitudes in these States range from sea level to more than 6,000 feet above sea level. Nearly 30 million people live in the seven States

[Data from U.S. Bureau of the Census, 1990; and U.S. Geological Survey, 1985]

State	Land area (square miles)	Highest altitude (feet above sea level)	Estimated 1985 population	Population supplied by ground water, 1980 (percent)
New York	49,476	5,344	17,774,000	35
Connecticut	5,009	2,380	3,172,000	32
Maine	33,215	5,268	1,163,000	57
Massachusetts	8,257	3,491	5,819,000	33
New Hampshire	9,304	6,288	997,000	60
Rhode Island	1,214	812	948,000	24
Vermont	9,609	4,393	535,000	54
	116,084		30,408,000	

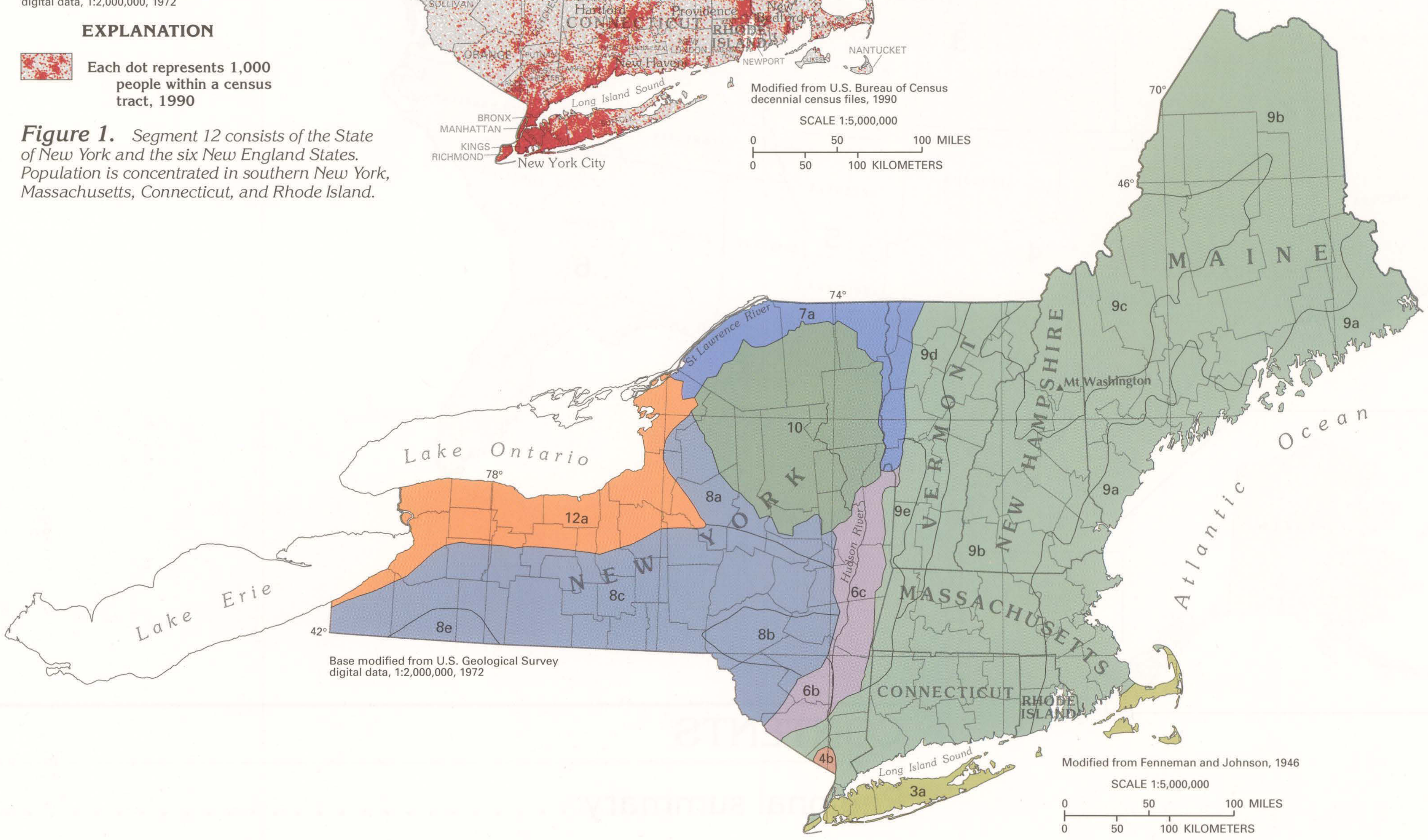


Figure 2. The Appalachian Plateaus Province and the New England Upland section dominate the segment and are interspersed with three mountainous areas and lowlands along the Atlantic coast, Lakes Erie and Ontario, and the Hudson and St. Lawrence River Valleys.

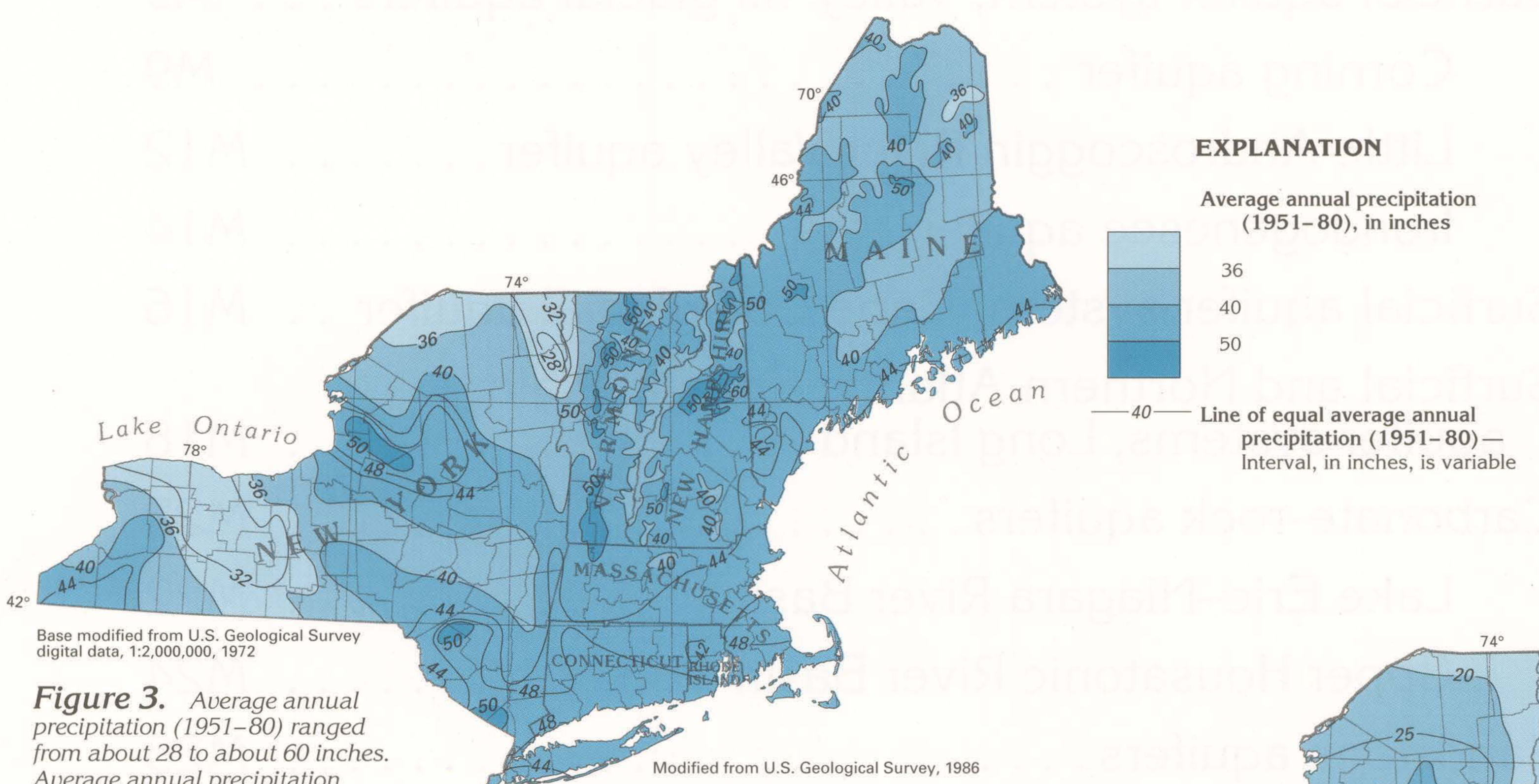


Figure 3. Average annual precipitation (1951–80) ranged from about 28 to about 60 inches. Average annual precipitation exceeds 50 inches mostly in mountainous areas and in an area east of Lake Ontario.

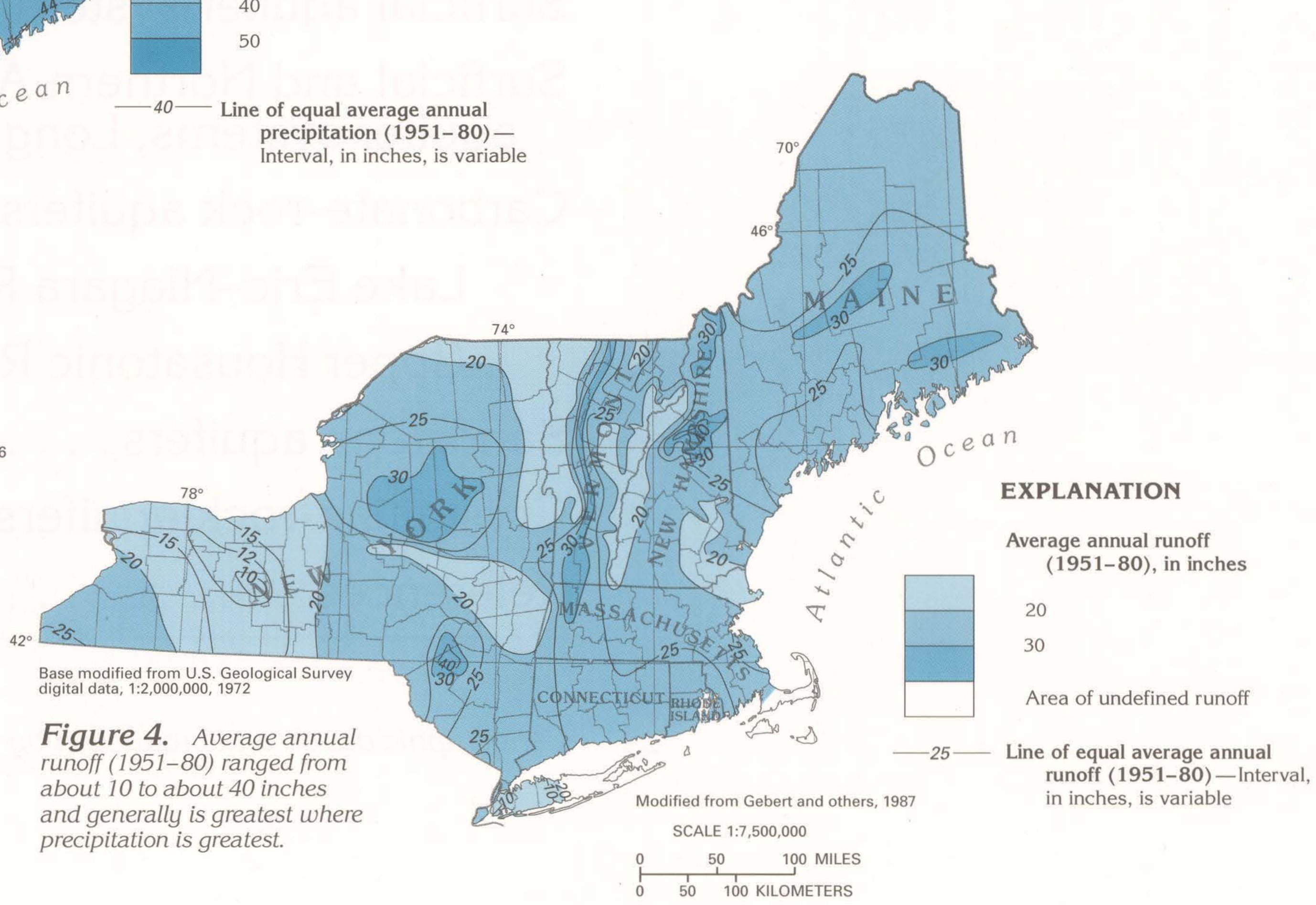


Figure 4. Average annual runoff (1951–80) ranged from about 10 to about 40 inches and generally is greatest where precipitation is greatest.

PRECIPITATION AND RUNOFF

Precipitation is the source of all freshwater in the seven States of Segment 12. Most of the precipitation runs directly off the land surface to streams or reaches streams after temporary storage in lakes, reservoirs, wetlands, soils, and aquifers. Water that leaves the area on its way to the ocean as streamflow is called surface runoff. Much of the remainder is returned to the atmosphere by evapotranspiration (evaporation from lakes, marshes, and other surface-water bodies coupled with transpiration from plants). A small part of the precipitation infiltrates the land surface and percolates downward to recharge aquifers.

Average annual precipitation in the seven-State area ranged from about 28 to about 60 inches from 1951 through 1980 (**fig. 3**). Precipitation was least (36 inches or less) in parts of New York, Vermont, and Maine. The greatest precipitation (50 to about 60 inches) fell in the mountainous areas of New York, Vermont, New Hampshire, Massachusetts, and Maine because of the orographic effect of the mountains, and in an area east of Lake Ontario, because of the effect of the lake. Average annual precipitation was greater than 40 inches in about two-thirds of Segment 12.

Average annual runoff from 1951 through 1980 ranged from about 10 to about 40 inches (**fig. 4**); however, runoff from much of the area from western New York to Maine was in the 20- to 30-inch range. Generally, the quantity of runoff is directly related to the quantity of precipitation throughout the seven-State area. Precipitation is about two times greater than runoff in most parts of the seven-State area (compare **fig. 3** with **fig. 4**).

GEOLOGY

The seven States of Segment 12 are underlain by consolidated rocks that vary from sedimentary rocks in the west to igneous, metamorphic, and sedimentary rocks in the east (**fig. 5**). The rocks range in age from Precambrian to early Mesozoic, but those of Cambrian through Devonian age are the most widespread. During Pleistocene time, most of the seven-State area was covered by continental glaciers that planed off soil and weathered bedrock and redeposited these materials as a thin mantle of glacial debris over the bedrock surface. Sheetlike Quaternary glacial outwash deposits mantle Cape Cod and overlie Cretaceous Northern Atlantic Coastal Plain sediments on Long Island, Block Island, Martha's Vineyard, and Nantucket Island.

In New York, Precambrian metamorphic and igneous rocks underlie the Adirondack Province in the north and small parts of the Valley and Ridge and the New England Provinces in the south. The Adirondack Precambrian rocks are surrounded by Cambrian and Ordovician sedimentary rocks (primarily carbonate rocks, sandstone, and shale) that underlie the St. Lawrence Valley and parts of the Valley and Ridge, the Central Lowland, and the Appalachian Plateaus Provinces. In the Valley and Ridge Province, these rocks extend southward into New Jersey. A small area of Cambrian and Ordovician igneous and metamorphic rocks (primarily volcanic and carbonate rocks) is present in southern New York. Silurian and Devonian sedimentary rocks (primarily carbonate rocks and shale with some sandstone) underlie part of the Central Lowland and the Appalachian Plateaus in south-central and southwestern New York. Here, the rocks are either flat-lying or dip gently to the south (**fig. 6**) and have been deeply eroded. A small area of lower Mesozoic sedimentary and igneous rocks (primarily sandstone and conglomerate interbedded with flows of trap rock) underlies the northern tip of the Piedmont Province in southern New York (**fig. 5**); these rocks extend southward into New Jersey. On Long Island, Cretaceous Coastal Plain sediments (primarily clay, sand, and gravel) overlie igneous and metamorphic rocks that crop out in Connecticut. The surface of these rocks slopes to the southeast, and the overlying Coastal Plain sediments slope and thicken in the same direction. Quaternary glacial deposits (primarily outwash sand and gravel) cover the Coastal Plain sediments on Long Island to depths of as much as 600 feet.

In New York, major faults that trend northeastward are concentrated in two areas in the eastern part of the State. In the northern area, major faults are concentrated in the southeastern part of the Adirondack Province. Some of these faults extend southwestward into the Albany–Utica area. In the southern area along the New Jersey State line, vertical displacement along the major faults has been substantial; for example, Precambrian metamorphic rocks are now adjacent to lower Mesozoic sedimentary and igneous rocks deposited in a downfaulted trough.

In New England, most consolidated rocks of Precambrian through early Mesozoic age are present in either north- or northeast-trending belts. Precambrian metamorphic rocks (primarily gneiss and mica schist) underlie parts of the Green Mountain Section in western New England; Precambrian igneous rocks (primarily granite) underlie parts of the Seaboard Lowland, the New England Upland, and the White Mountains Sections. Cambrian and Ordovician igneous and metamorphic rocks (primarily volcanic and carbonate rocks) are widespread and underlie much of the Green Mountain Section and parts of all other physiographic sections to the east. Cambrian and Ordovician sedimentary rocks (primarily carbonate rocks, sandstone, and shale) underlie most of the Taconic Section in western New England. Narrow bands of carbonate rocks (marble, dolomite, and limestone; **fig. 7**) are common in the valleys of the Green Mountain and the Taconic Sections. Ordovician, Silurian, and Devonian igneous and metamorphic rocks (primarily volcanic and intrusive granitic rocks, gneiss, marble, phyllite, schist, and slate; **fig. 8**) are present in northeast-trending belts throughout much of New England east of the Green Mountain and the Taconic Sections. Pennsylvanian sedimentary rocks (primarily sandstone, shale, and coal with some conglomerate) occupy two structural basins in the southern part of the Seaboard Lowland (**fig. 5**). In the Boston Basin, these sedimentary rocks are about 5,000 feet thick; in the Narragansett Basin, they are about 10,000 feet thick. In the Connecticut River Valley of Connecticut and Massachusetts, a thick sequence of lower Mesozoic sedimentary and igneous rocks (primarily sandstone and conglomerate interbedded with flows of trap rock) occupies a downfaulted trough, which is similar to the one in southern New York. Cretaceous Coastal Plain sediments (primarily clay, sand, and gravel) underlie Block Island, Martha's Vineyard, and Nantucket Island and are completely covered by Quaternary glacial deposits (primarily outwash sand and gravel). Similar Quaternary deposits, as much as 1,000 feet thick, mantle Cape Cod.

The geologic and hydrogeologic nomenclature used in this report differs from State to State because of independent geologic interpretations and varied distribution and lithology of rock units. A fairly consistent set of nomenclature, however, can be derived from the most commonly used rock names. Therefore, the nomenclature used in this report is basically a synthesis of that of the U.S. Geological Survey, the Connecticut Geological and Natural History Survey, the Maine Geological Survey, the Massachusetts Executive Office of Environmental Affairs, Massachusetts Coastal Zone Management, the New Hampshire Department of Environmental Services, the New York State Geological Survey, the Rhode Island Office of the State Geologist, and the Vermont Geological Survey. Individual sources for nomenclature are listed with each correlation chart prepared for this report.

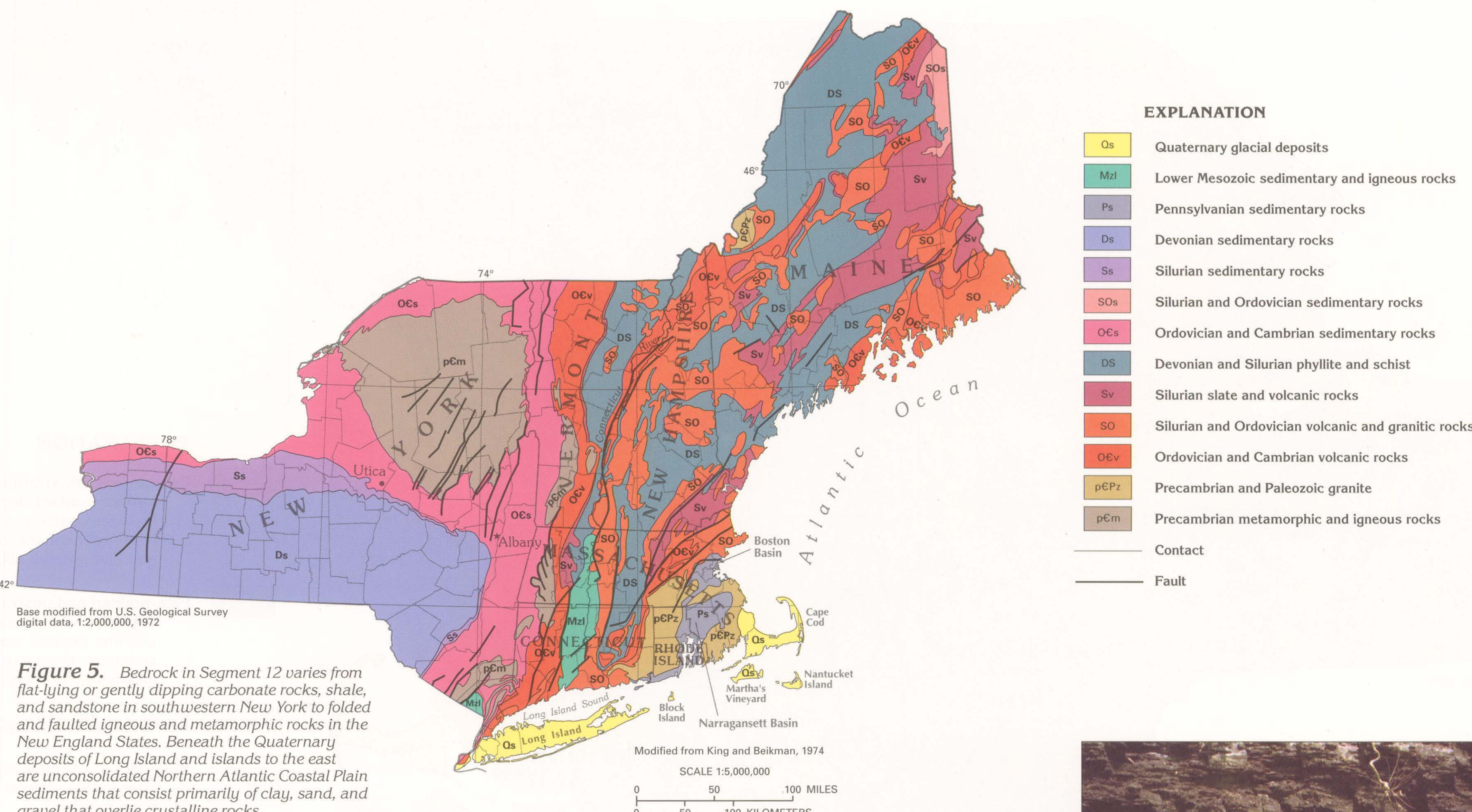


Figure 5. *Bedrock in Segment 12 varies from flat-lying or gently dipping carbonate rocks, shale, and sandstone in southwestern New York to folded and faulted igneous and metamorphic rocks in the New England States. Beneath the Quaternary deposits of Long Island and islands to the east are unconsolidated Northern Atlantic Coastal Plain sediments that consist primarily of clay, sand, and gravel that overlie crystalline rocks.*

Figure 6. *Flat-lying or gently dipping carbonate rocks and shale underlie most of the Appalachian Plateaus of New York.*

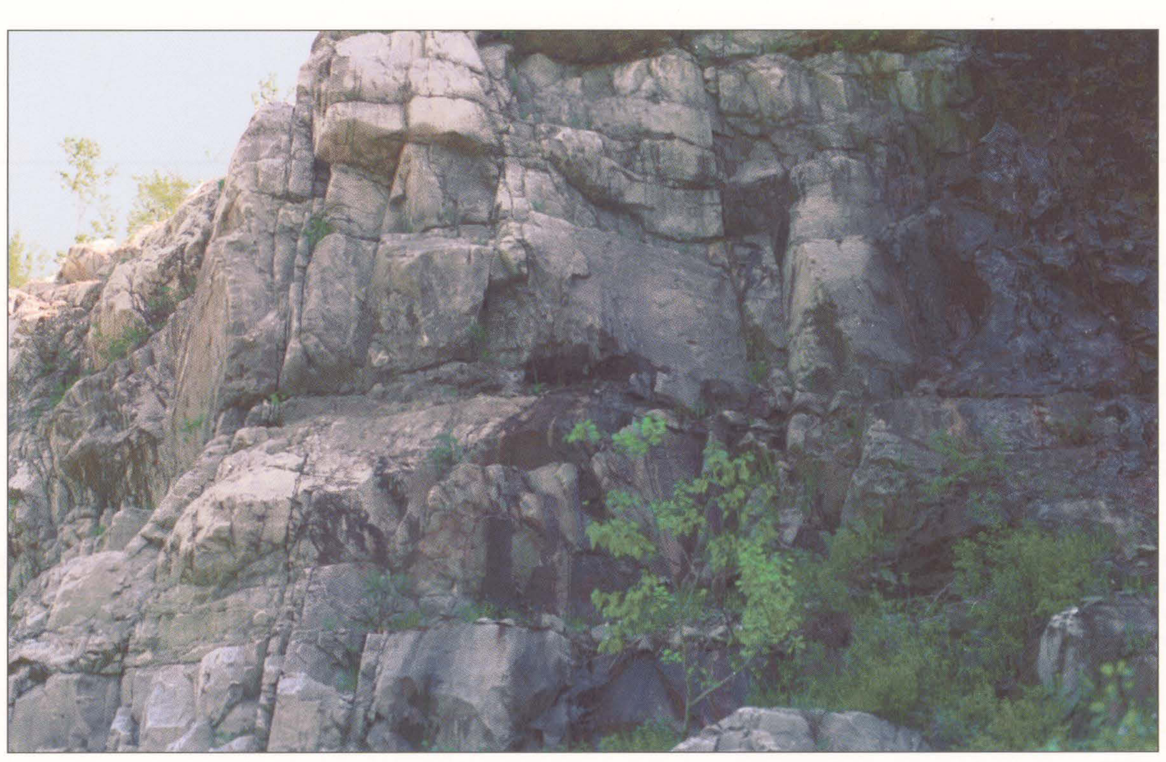


Figure 7. *Marble (shown here), dolomite, and limestone are exposed in valleys of the Green Mountain and the Taconic Sections.*

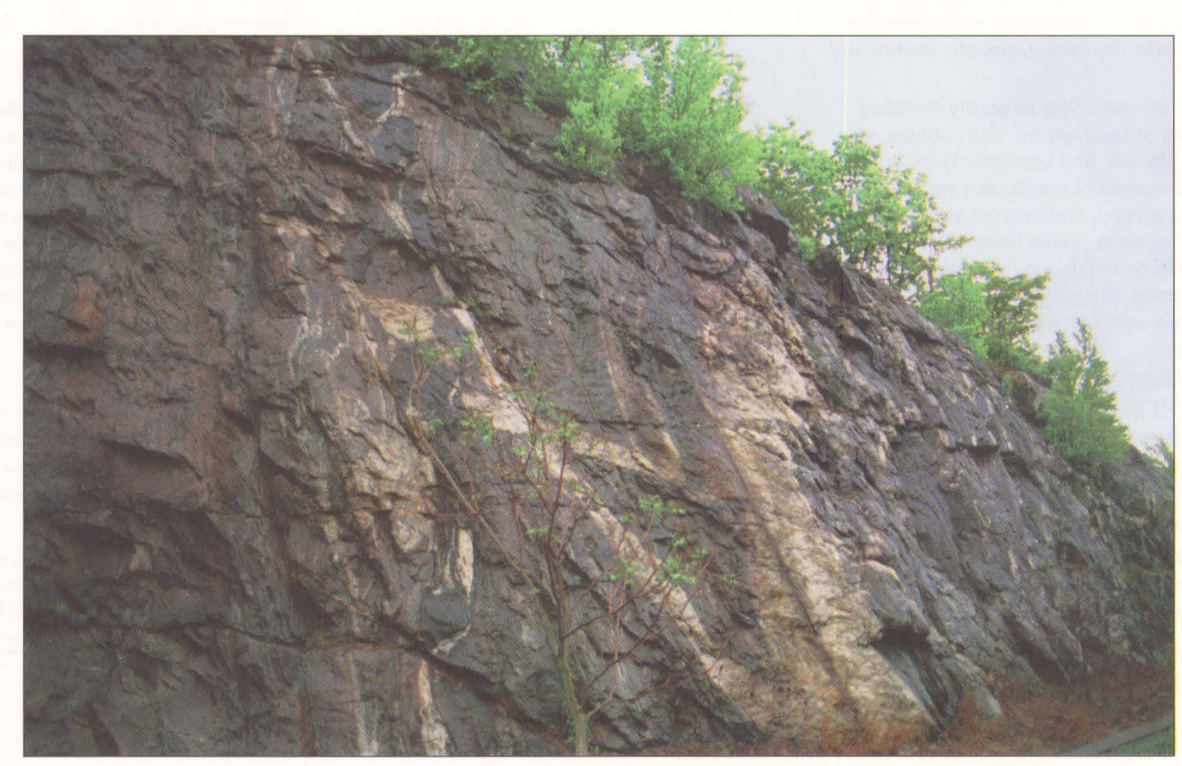


Figure 8. *Belts of igneous and metamorphic rocks trend northeast in the New England Upland section.*

MAJOR AQUIFERS

Aquifers (rock units that yield water to wells in usable quantities) are in three principal hydrogeologic environments in the seven States of Segment 12: unconsolidated glacial deposits, unconsolidated Coastal Plain sediments, and consolidated bedrock. These aquifers are grouped into principal aquifers or aquifer systems according to the characteristics of their ground-water flow systems and rock types. Two or more aquifers that are hydraulically connected or a set of individual aquifers that have common characteristics compose an aquifer system. Names and descriptions of the principal aquifers and aquifer systems in the segment, along with well characteristics and other information, are shown in **table 2**. The areas where the aquifers are exposed at or near land surface are shown in **figures 9 and 10**.

The most productive and widely used aquifers in Segment 12 are part of the surficial aquifer system (**fig. 9, table 2**). These aquifers primarily consist of deposits of sand and gravel which, for the most part, are individual valley-fill deposits of outwash and ice-contact materials laid down in numerous bedrock valleys by glacial meltwater. Principal exceptions are sheet-type outwash deposits of sand and gravel that compose the Cape Cod glacial aquifer and the upper glacial aquifer on Long Island. Minor aquifers of outwash sand and gravel are present on the islands of Nantucket, Martha's Vineyard, and Block Island.

The Northern Atlantic Coastal Plain aquifer system (**fig. 11, table 2**) consists of the Magothy aquifer and the underlying Lloyd aquifer, which are separated by a leaky confining unit, the upper clay member of the Raritan Formation. Both aquifers consist primarily of sand; gravel is more prevalent in the Magothy aquifer than in the Lloyd aquifer. The Magothy aquifer provides most of the water for public supply in Queens, Nassau, and western Suffolk Counties. The Lloyd aquifer provides most of the water for public supply for the northwest-shore area of Long Island. In Segment 12, this aquifer system only underlies Long Island. Although equivalent Coastal Plain sediments underlie the glacial aquifers on Block Island, Martha's Vineyard, and Nantucket Island, the sediments contain brackish water or saltwater and are not used as a source of supply. Because the Northern Atlantic Coastal Plain aquifer system extends southward into Segment 11 of this Atlas, it is discussed in greater detail in Chapter L.

Consolidated bedrock aquifers in the Central Lowland, the St. Lawrence Valley, the Adirondack, the New England, and the Appalachian Plateaus Physiographic Provinces consist of carbonate rocks, sandstone, and crystalline rocks (**fig. 10, table 2**). Although these aquifers are the least productive of the major aquifers, they are important sources of domestic water supplies in areas where the surficial and Northern Atlantic Coastal Plain aquifer systems are not present. Because of their limited areal extent in Segment 12, aquifers in the Piedmont and the Valley and Ridge Provinces are only minor aquifers in the segment. These aquifers extend southward into Segment 11 of this Atlas and are discussed in greater detail in Chapter L.

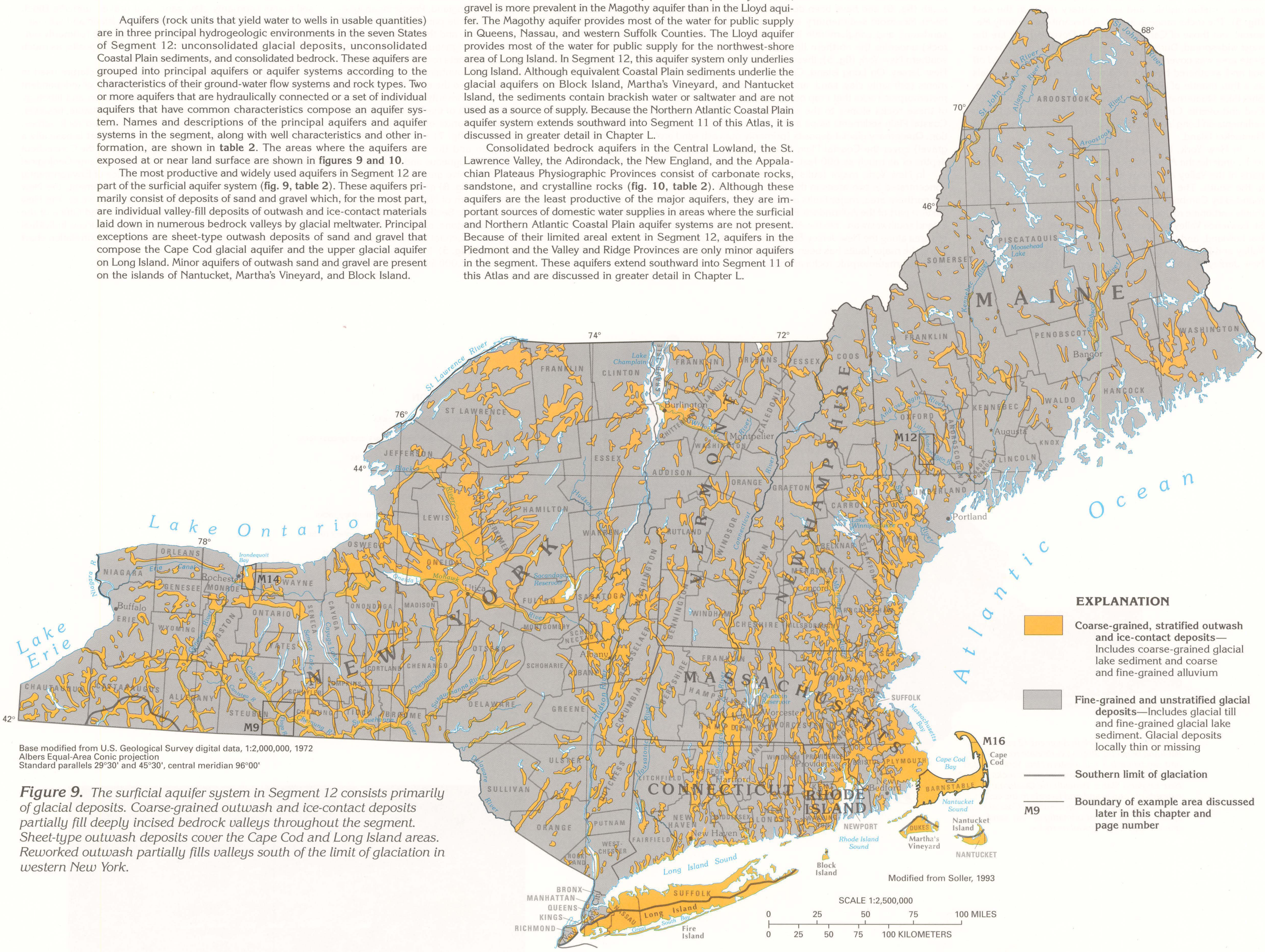


Figure 9. *The surficial aquifer system in Segment 12 consists primarily of glacial deposits. Coarse-grained outwash and ice-contact deposits partially fill deeply incised bedrock valleys throughout the segment. Sheet-type outwash deposits cover the Cape Cod and Long Island areas. Reworked outwash partially fills valleys south of the limit of glaciation in western New York.*

Table 2. *Major aquifers in Segment 12 consist of glacial deposits, Coastal Plain sediments, and carbonate rocks, sandstone, and crystalline rocks*

[Source: U.S. Geological Survey, 1985]

Aquifer name and description	Well characteristics: Depth (feet) Common range	Depth (feet) Might exceed	Yield (gallons per minute) Common range	Yield (gallons per minute) Might exceed	Remarks
SURFICIAL AQUIFER SYSTEM					
Valley-fill glacial aquifers					
Outwash deposits: Stratified sand and gravel deposits in valley trains, outwash plains, or deltas. Percentage of gravel is greatest near ice-contact deposits and decreases seaward. Deposits contain some clay, silt, and cobbles. Might overlie or interfinger with marine or glacial-lake deposits. Generally unconfined.	10–120	150	10–400	2,000	Yield depends on thickness and grain size of deposits; larger yields obtained where deposits are hydraulically connected with adjacent body of surface water. Quality of water generally adequate for most uses. Large concentrations of iron and manganese commonly reported.
Ice-contact deposits: Well to poorly stratified deposits of sand, gravel, and cobbles, with some clay, silt, and boulders. Deposited under a variety of conditions; variation in texture, sorting, and internal structure is great. Deposits overlie bedrock or glacial till. Might be overlain by younger unconsolidated units, principally marine deposits. Generally unconfined.	35–140	150	10–1,000	3,000	Generally, source of large supplies of ground water. Yields depend on thickness, sorting, and grain size of deposits. Larger yields obtained where deposits are hydraulically connected with adjacent body of surface water. Quality of water generally adequate for most uses. In some localities, concentrations of iron and manganese are large enough to limit use without treatment. Because of permeability and typically shallow water table, these deposits are susceptible to contamination from the land surface.
Cape Cod glacial aquifer					
Outwash and ice-contact deposits intermingled in places with glacial till or lacustrine silt and clay. Unconfined.	60–120	200	100–1,000	2,000	Main source of water for public supply on Cape Cod. Water contains large concentrations of iron and manganese in some places. Locally yields hydrogen sulfide from buried marsh deposits.
Upper glacial aquifer on Long Island					
Outwash deposits of fine to very coarse quartzose sand and pebbles to boulder-sized gravel. Unconfined.	50–500	600	50–1,000	1,500	Main source of water for public supply in central and eastern Suffolk County. Contains large concentrations of nitrate and organic compounds in western Long Island. Local saltwater-intrusion problems.
NORTHERN ATLANTIC COASTAL PLAIN AQUIFER SYSTEM					
Magothy aquifer					
Fine to medium sand, clayey in part; interbedded with lenses and layers of coarse sand, sandy clay, and clay. Gravel common in basal 50–200 feet. Generally unconfined.	150–1,000	1,500	50–1,200	2,000	Main source of water for public supply in Queens, Nassau, and western Suffolk Counties. Local saltwater-intrusion problems.
Lloyd aquifer					
Fine to coarse sand and some gravel, commonly in a clayey matrix. Some lenses and layers of clay and silty clay. Locally contains thin lignite layers and iron concretions. Confined.	50–1,100	1,500	50–1,000	1,200	Main source of water for public supply along northwest shore of Long Island and on barrier islands. Local saltwater-intrusion problems.
CONSOLIDATED BEDROCK AQUIFERS IN THE CENTRAL LOWLAND, ST. LAWRENCE VALLEY, ADIRONDACK, NEW ENGLAND, AND APPALACHIAN PLATEAUS PHYSIOGRAPHIC PROVINCES					
Carbonate-rock aquifers					
Limestone, dolomite, marble, calcareous shale, and calcareous siltstone. Generally unconfined in upper 200 feet; might be confined at depth.	20–500	800	10–30	1,000	Water contained primarily in secondary openings, such as cleavage or bedding planes, joints, fractures, or solution openings.
Sandstone aquifers					
Mostly sandstone and sandy dolomite in New York. Sandstone, shale, siltstone, and conglomerate, some with interbedded basalt flows and dikes in Connecticut and Massachusetts. Unconfined to partly confined in upper 200 feet; might be confined at depth.	100–300	950	2–100	600	Hydrologic characteristics poorly defined, particularly in zones deeper than 300 feet. Generally overlain by variable thicknesses of unconsolidated deposits. Moderately hard to hard water; locally contains large concentrations of dissolved chloride, sodium, and sulfate.
Crystalline-rock aquifers					
A variety of igneous and metamorphic rocks. Igneous rocks mainly granite, gabbro, diorite, granodiorite, and pegmatite. Metamorphic rocks mainly schist, gneiss, quartzite, slate, and argillite. Locally confined at depth.	20–600	1,000	2–10	500	Dense, almost impermeable, but contain recoverable water in secondary openings such as joints, fractures, and bedding or cleavage planes. Quality of water suitable for most uses. Acidity might cause corrosion of pipes and appliances. Concentrations of iron and manganese exceeding recommended Federal limits detected in water from some wells. Large concentrations of radon-222 have been detected in the water locally, primarily from wells finished in granite, pegmatite, and metamorphic rocks.

Figure 10. *Carbonate-rock, sandstone, and crystalline-rock aquifers underlie glacial deposits throughout most of Segment 12. In the Cape Cod area of southeastern Massachusetts and in parts of New York, these aquifers are saturated with saltwater; elsewhere, they yield freshwater primarily from joints, fractures, faults, and bedding planes. The Northern Atlantic Coastal Plain aquifer system that underlies Long Island consists of unconsolidated sand and gravel and yields water from intergranular porosity.*

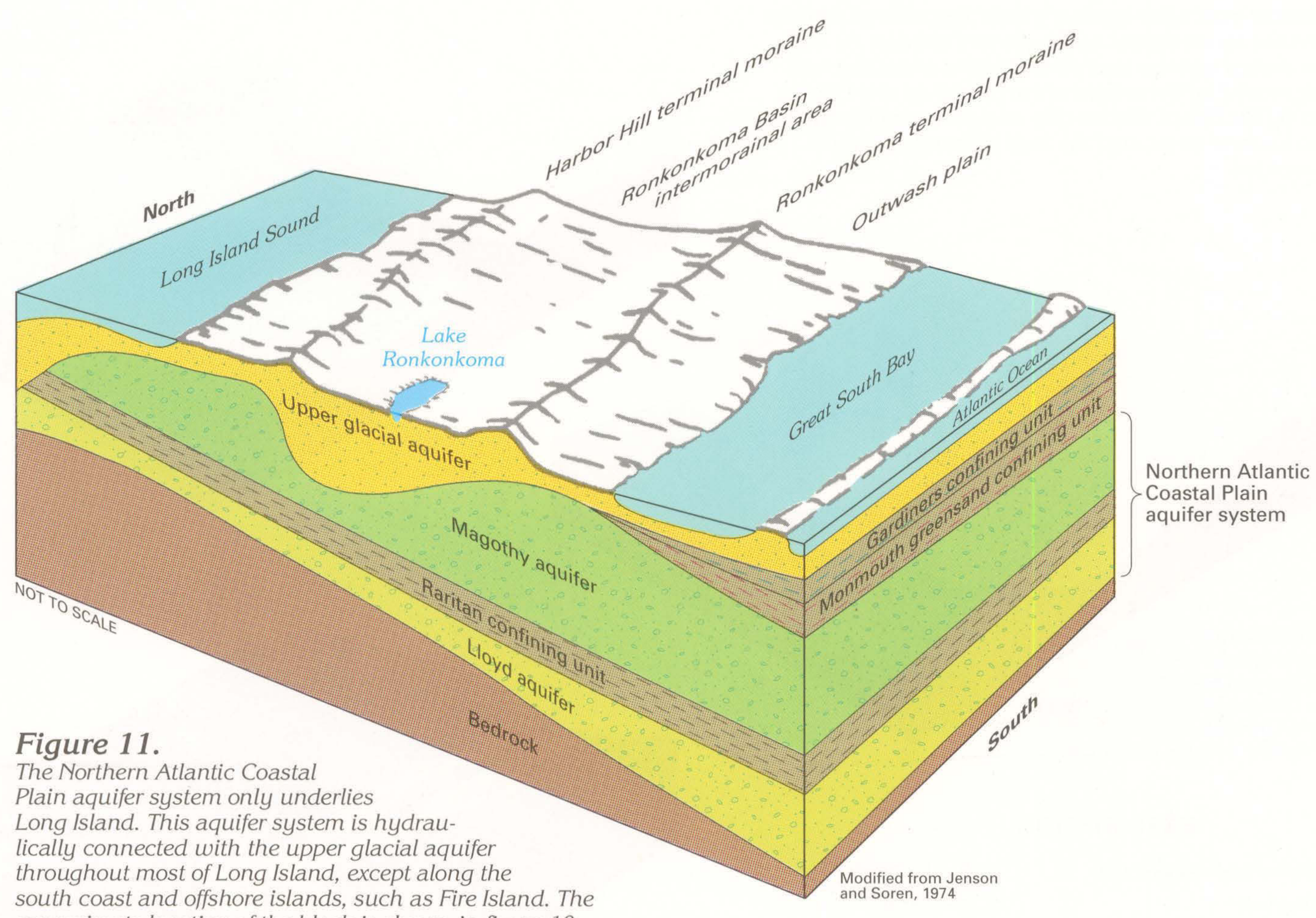


Figure 11. *The Northern Atlantic Coastal Plain aquifer system only underlies Long Island. This aquifer system is hydraulically connected with the upper glacial aquifer throughout most of Long Island, except along the south coast and offshore islands, such as Fire Island. The approximate location of the block is shown in figure 10.*

Surficial Aquifer System

The surficial aquifer system in Segment 12 consists of glacial deposits of sand and gravel that were laid down during several advances and retreats of continental glaciers that encroached from the north or northwest. The glacial stage between the most recent advance, which took place about 21,000 years ago, and final retreat, which occurred about 12,000 years ago, is termed Wisconsinan. During this stage, ice covered all of Segment 12, except for parts of Long Island, Martha's Vineyard, Nantucket Island, and southwestern New York (**fig. 12**). The glacial ice and meltwater derived from the ice laid down several characteristic deposits. Till, which consists of unsorted and unstratified material ranging in size from clay to boulders, was deposited directly from the ice. Meltwater laid down outwash, which consists mostly of stratified deposits of sand and gravel (**figs. 13, 14**); ice-contact deposits, which consist primarily of poorly stratified sand and gravel; and glacial-lake deposits, which consist of mostly clay, silt, and fine sand. These deposits are present in four types of areas within Segment 12 (**fig. 12**).

In all the areas shown in **figure 12**, till was plastered to the deeply eroded and glacially scoured bedrock surface under the advancing glacier. As the ice melted, the till generally remained in place, which left a relatively continuous sheet over the bedrock throughout Segment 12. Till yields little water because it generally is unsorted and unstratified and contains a large amount of fine-grained material. Before the development of deep well-drilling equipment, however, till was developed for domestic water supplies by constructing large-diameter dug wells that penetrated only a few feet below the water table. Yields from wells completed in till generally range from less than 1 to only a few gallons per minute; rarely, yields might be as much as 20 gallons per minute.

In areas where streams in most valleys drained away from the glacial ice (**fig. 12**), stratified glacial drift, including outwash, ice-contact, and glacial-lake deposits, was deposited mostly during stagnation or melting of the ice sheet. Abundant meltwater flowed down a steep gradient provided by the ice and transported rock fragments released from the melting ice (**fig. 15*A***) to the ice margins and beyond. Sand and gravel deposited at the face of the ice sheet or in cracks in the ice formed ice-contact deposits. Coarse-grained sand and gravel outwash was deposited by the swiftly moving, sediment-laden streams as they flowed across the land surface (**fig. 15*B***). Outwash was laid down in front of the ice as the streams deposited successively finer material farther and farther from the ice. As the glacial ice continued to melt and retreat, deposits of clay, silt, and fine to coarse sand were laid down toward the middle of the valleys and coarse-grained terrace deposits formed at the sides of the valleys (**fig. 15*C***). If a lake temporarily formed downvalley, then clay, silt, and fine sand were deposited on the lake bottom (**fig. 15*C***). After all the glacial ice in the valleys had melted, the land rebounded, base level was lowered, and streams began to erode the glacial deposits, which resulted in present-day conditions as shown in **figure 15*D***. The streams are now depositing alluvium that consists primarily of reworked glacial material. The coarse-grained outwash, ice-contact, and alluvial deposits form the productive valley-fill glacial aquifers of the surficial aquifer system. Where the valley-fill glacial aquifers consist primarily of ice-contact deposits, well yields commonly range from 10 to 1,000 gallons per minute and might be as much as about 3,000 gallons per minute. Where these aquifers consist primarily of outwash deposits, well yields commonly range from 10 to 400 gallons per minute and might be as much as 2,000 gallons per minute.

Broad lowland areas (**fig. 12**) were inundated by either the ocean or freshwater lakes during the melting and retreat of the glacial ice. Along parts of the Atlantic coast in Segment 12, the immense weight of the glacial ice temporarily depressed the land surface below sea level (**fig. 14**). As the glacial ice melted and retreated and before the land surface rebounded above sea level, broad lowlands were inundated by the ocean. Marine clay and silt were deposited over till and other fine- and coarse-grained glacial deposits in these lowlands. Along the ancestral Great Lakes and St. Lawrence River drainage system, large freshwater lakes formed south of the melting glacial ice and inundated broad lowlands. Mostly clay and silt were deposited in these lakes; however, some ice-contact and outwash deposits of sand and gravel were deposited locally.

In valleys where streams either drained toward the glacial ice (**fig. 12**) or drained away from the ice and were dammed by sediments, large lakes commonly formed. Sediments deposited in these lakes were primarily clay, silt, and very fine to fine sand that accumulated in places to a thickness of several hundred feet. Although sand and gravel of deltaic or alluvial origin also were deposited, these coarse-grained materials generally have limited saturated thickness and do not yield large quantities of water. In these valleys, therefore, valley-fill glacial aquifers are few and are not major sources of water.

Areas of low preglacial topography at the terminus of the glacier, such as the Cape Cod area and Long Island (**fig. 12**), were buried by extensive, thick glacial deposits—as much as 1,000 feet thick on Cape Cod and as much as 600 feet thick on Long Island. All types of glacial deposits are present in both locations. In the Cape Cod area, the predominant glacial deposits are ice-contact and outwash deposits that consist primarily of coarse sand and gravel. These deposits are intermingled in places with till from terminal moraines and layers of glacial-lake deposits that consist primarily of clay and silt. The sand and gravel form the productive Cape Cod glacial aquifer. The maximum thickness of the aquifer is about 200 feet and it is the only source of fresh ground water in the Cape Cod area. Well yields commonly range from 100 to 1,000 gallons per minute and might be as much as 2,000 gallons per minute. On Long Island, glacial deposits are sandy till that is present in two westward-coalescing terminal moraines and outwash deposits that are present north of, between, and south of the two moraines. The outwash and moraine deposits form the productive upper glacial aquifer on Long Island. A well-developed ground-water flow system, which is present throughout the aquifer, is hydraulically connected with that of the underlying Northern Atlantic Coastal Plain aquifer system in most places. Wells completed in the upper glacial aquifer commonly yield from 50 to 1,000 gallons per minute and might yield 1,500 gallons per minute.

Because of the diversity of aquifers within the surficial aquifer system, examples of typical aquifers (**figs. 9 and 12**) are listed here and described in detail later in the chapter:

- The Corning aquifer is typical of valley-fill glacial aquifers deposited by meltwater streams that flowed away from the glacial ice in upland valleys.
- The Little Androscoggin River Valley aquifer is typical of valley-fill glacial aquifers deposited by meltwater streams that flowed away from the glacial ice in lowland valleys that had been either partly or completely inundated by the ocean; the outwash that composes the aquifer was deposited, at least partly, over marine sediments.
- The Irondogenesee aquifer is typical of valley-fill glacial aquifers deposited by meltwater streams that flowed toward the glacial ice in lowland valleys that were either partly or completely inundated later by large freshwater lakes; fine-grained glacial-lake sediments were deposited, at least partly, over the coarse-grained outwash that composes the aquifers.
- The Cape Cod glacial aquifer and the upper glacial aquifer on Long Island are typical of aquifers in sheetlike glacial deposits that buried low-lying preglacial topography at the glacial terminus. The Northern Atlantic Coastal Plain aquifer system on Long Island and the upper glacial aquifer are described jointly because of the hydraulic connection between them.

An example of aquifers in valleys where streams drained toward the glacial ice (**fig. 12**) is not presented because most of these valleys contain fine-grained glacial-lake deposits that generally do not form productive aquifers. The Finger Lakes of western New York occupy some of these valleys that are partly filled with fine-grained deposits.

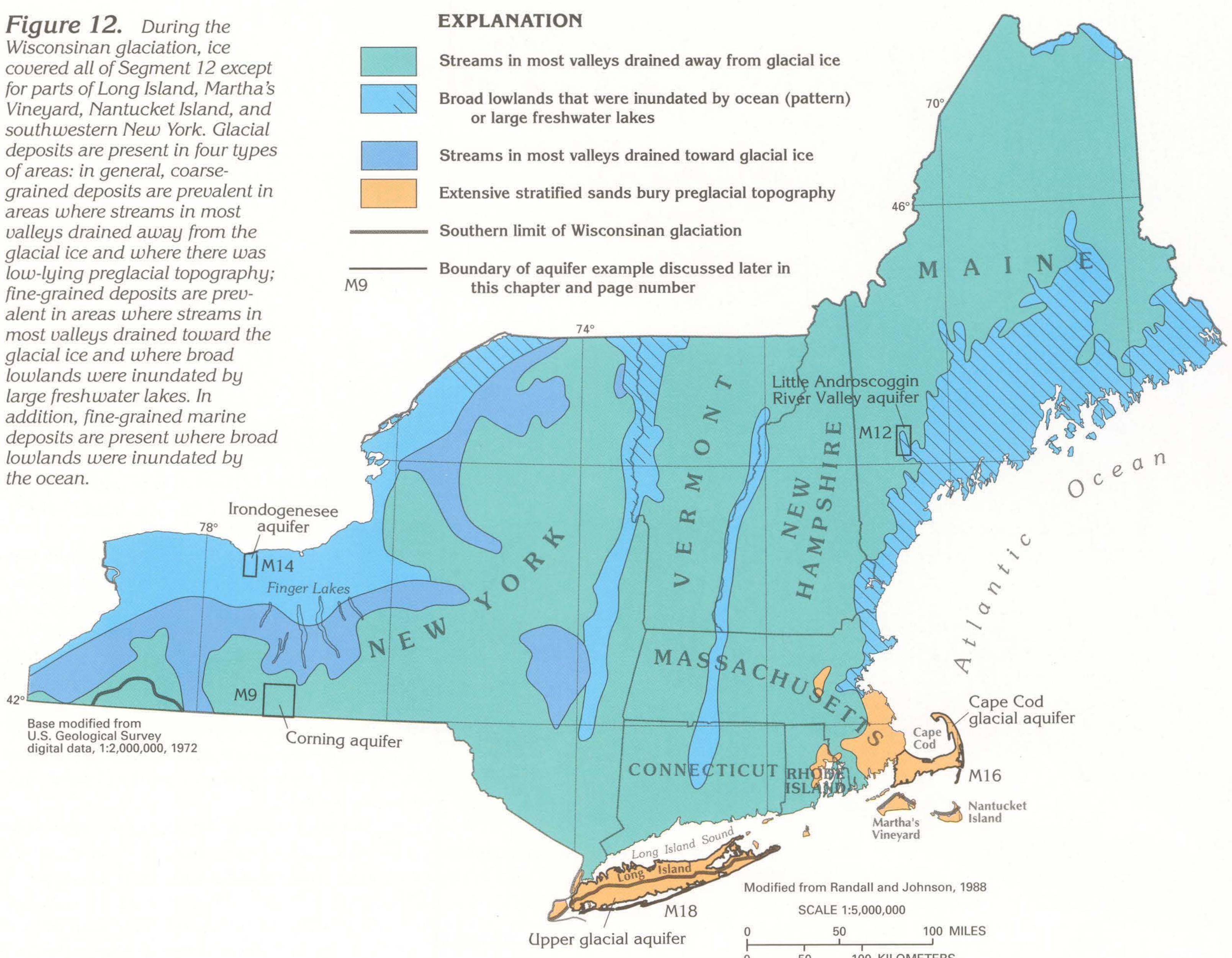


Figure 12. *During the Wisconsinan glaciation, ice covered all of Segment 12 except for parts of Long Island, Martha's Vineyard, Nantucket Island, and southwestern New York. Glacial deposits are present in four types of areas: in general, coarse-grained deposits are prevalent in areas where streams in most valleys drained away from the glacial ice and where there was low-lying preglacial topography; fine-grained deposits are prevalent in areas where streams in most valleys drained toward the glacial ice and where broad lowlands were inundated by large freshwater lakes. In addition, fine-grained marine deposits are present where broad lowlands were inundated by the ocean.*

Figure 13. *Outwash deposits, which consist of well sorted and stratified sand and gravel deposited primarily by streams during the melting and retreat of the glacial ice, form principal valley-fill glacial aquifers in much of Segment 12.*

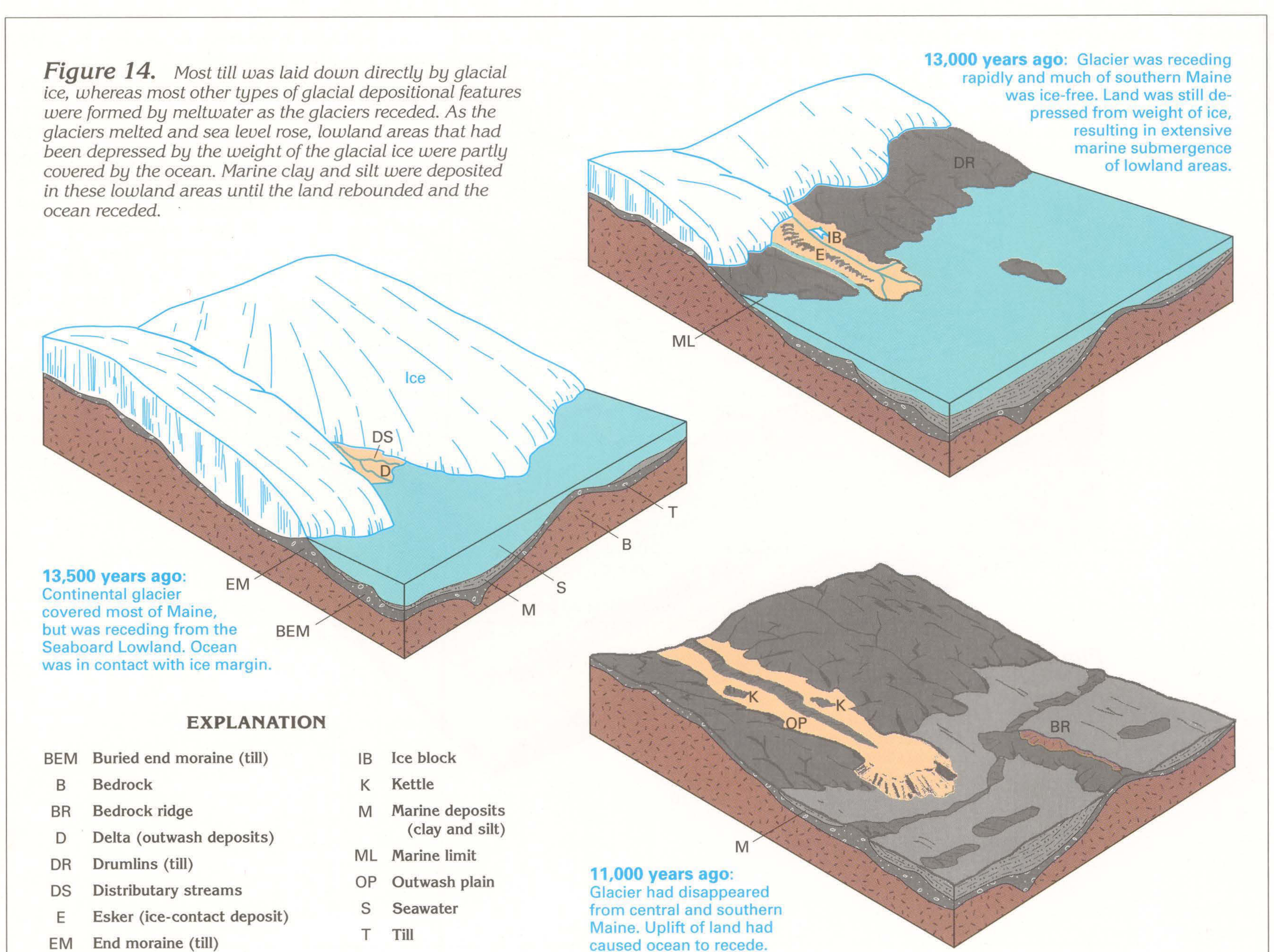


Figure 14. *Most till was laid down directly by glacial ice, whereas most other types of glacial depositional features were formed by meltwater as the glaciers receded. As the glaciers melted and sea level rose, lowland areas that had been depressed by the weight of the glacial ice were partly covered by the ocean. Marine clay and silt were deposited in these lowland areas until the land rebounded and the ocean receded.*

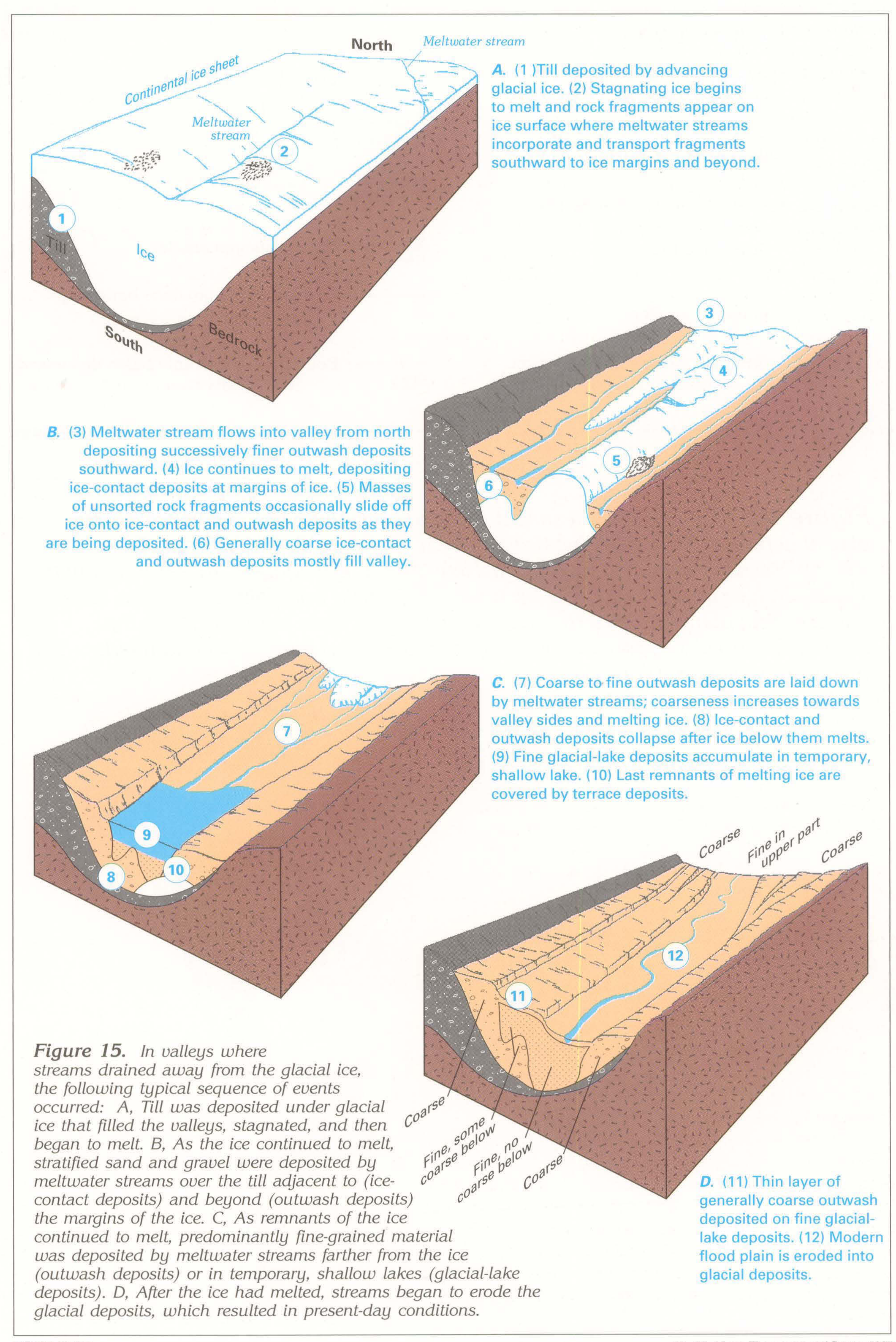


Figure 15. *In valleys where streams drained away from the glacial ice, the following typical sequence of events occurred: A, Till was deposited under glacial ice that filled the valleys, stagnated, and then began to melt. B, As the ice continued to melt, stratified sand and gravel were deposited by meltwater streams over the till adjacent to (ice-contact deposits) and beyond (outwash deposits) the margins of the ice. C, As remnants of the ice continued to melt, predominantly fine-grained material was deposited by meltwater streams farther from the ice (outwash deposits) or in temporary, shallow lakes (glacial-lake deposits). D, After the ice had melted, streams began to erode the glacial deposits, which resulted in present-day conditions.*

Northern Atlantic Coastal Plain Aquifer System

The Northern Atlantic Coastal Plain aquifer system, which underlies Long Island, overlies crystalline rocks that slope southeastward (**fig. 11**). The unconsolidated Coastal Plain sediments that compose the aquifer system slope and thicken in the same direction. The major water-yielding units are the Magothy Formation and the Lloyd Sand Member of the Raritan Formation.

The entire Magothy Formation forms the Magothy aquifer, which is a fine to medium sand with some clay and coarse sand and gravel. Near Great South Bay, the Magothy aquifer is overlain by a confining unit that consists of the Gardiners Clay and greensand of the Monmouth Group. Elsewhere, the Magothy aquifer is overlain by and hydraulically connected with the upper glacial aquifer. Yields of wells completed in the Magothy aquifer commonly range from 50 to 1,200 gallons per minute and might exceed 2,000 gallons per minute. The Magothy aquifer is the main source of water for public supply in Queens, Nassau, and western Suffolk Counties.

The Raritan Formation consists of an unnamed upper clay member, which is a leaky confining unit, and the lower Lloyd Sand Member that forms the Lloyd aquifer. The Lloyd aquifer consists of fine to coarse sand and gravel, commonly within a clayey matrix, interbedded with lenses and layers of clay and silty clay. Wells completed in the Lloyd aquifer commonly yield 50 to 1,000 gallons per minute and might yield as much as 1,200 gallons per minute. The Lloyd aquifer is the main source of water for public supply in the area along the northwestern shore of Long Island.

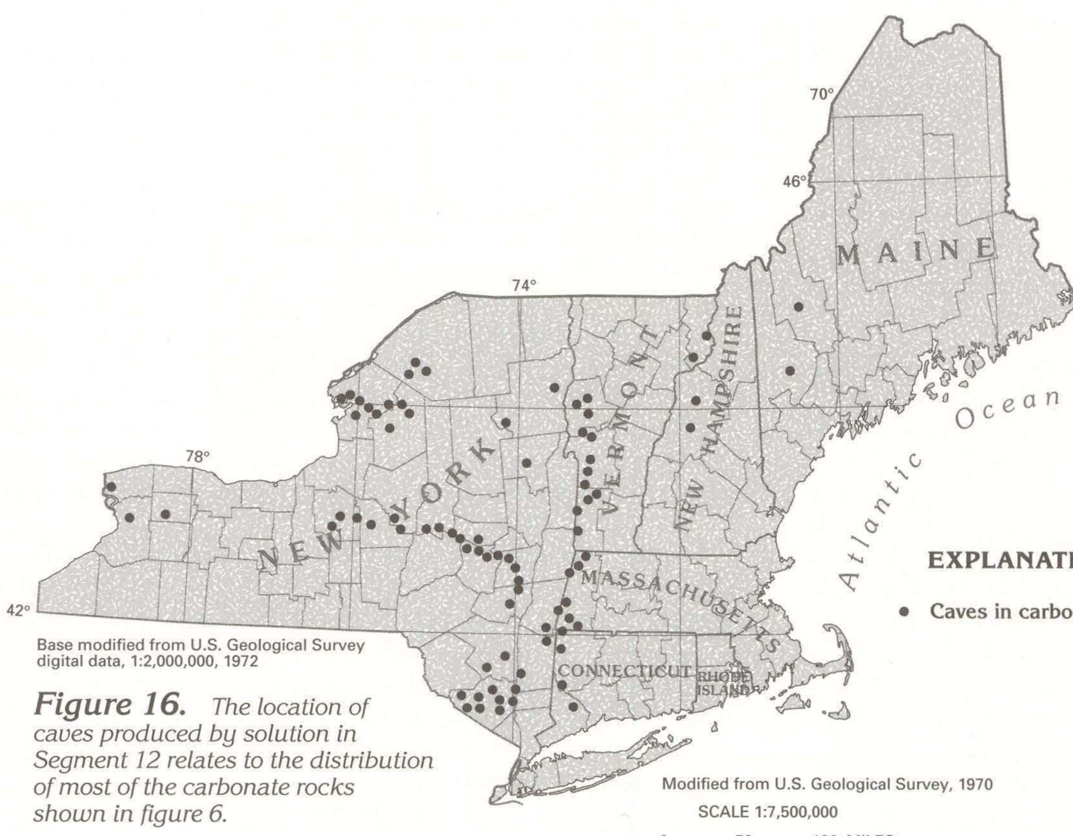


Figure 16. *The location of caves produced by solution in Segment 12 relates to the distribution of most of the carbonate rocks shown in figure 6.*

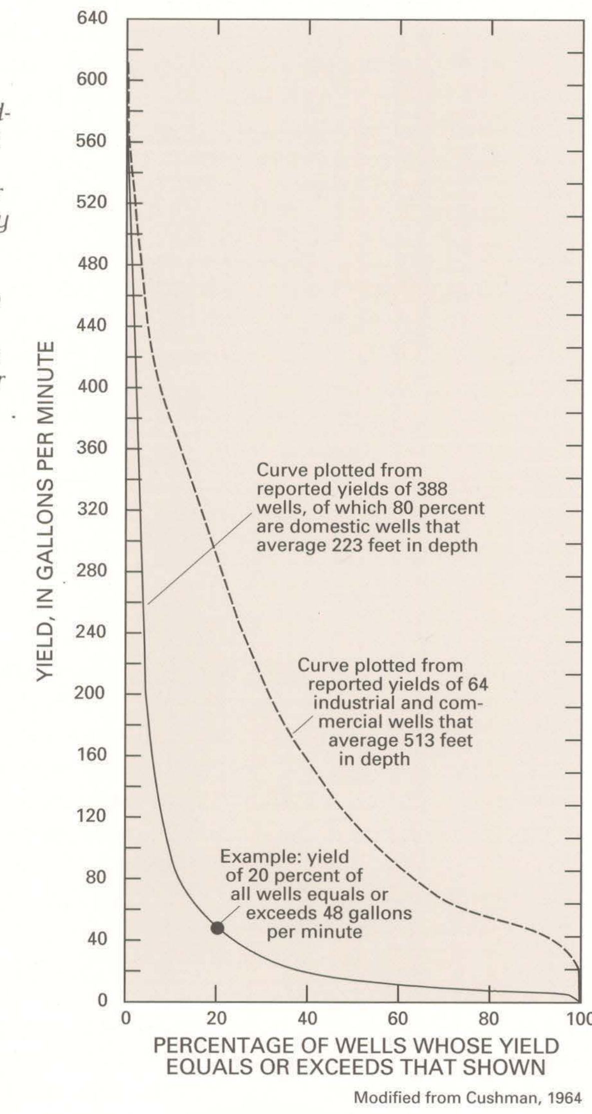


Figure 17. *Large-diameter, deep wells completed in the sandstone aquifer that underlies the Connecticut River Valley consistently yield more water than do small-diameter, shallow wells. Maximum yields of as much as 600 gallons per minute are obtained from only 1 to 2 percent of the wells.*

Carbonate-rock, Sandstone, and Crystalline-rock aquifers

Consolidated bedrock aquifers in the Central Lowland, the St. Lawrence Valley, the Adirondack, the New England, and the Appalachian Plateaus Physiographic Provinces in Segment 12 are in consolidated rocks of sedimentary, igneous, and metamorphic origin (**fig. 10**). Some of these aquifers consist of carbonate rocks (primarily limestone, dolomite, and marble) and sandstone (including some associated conglomerate, siltstone, and shale); others are crystalline rocks of igneous origin (pegmatite, granite, granodiorite, diorite, and gabbro), and still others are of metamorphic origin (argillite, slate, quartzite, schist, and gneiss). These consolidated rocks yield water primarily from bedding planes, fractures, joints, and faults, rather than from intergranular pores. Carbonate rocks generally yield more water than other types of consolidated rocks because carbonate rocks are subject to dissolution by slightly acidic ground water. Dissolution along openings, such as bedding planes, fractures, and joints, has enlarged these openings and increased the permeability of the carbonate rocks regardless of whether they are limestone and dolomite or have been metamorphosed to marble. Caves formed by the dissolution of carbonate rocks in Segment 12 are concentrated in northwestern and eastern New York, the western parts of Connecticut, Massachusetts, and Vermont (**fig. 16**), and along the outcrop bands of carbonate rock.

Carbonate-rock aquifers in Segment 12 are present mostly in New York and the western parts of Vermont, Massachusetts, and Connecticut (**fig. 10**). In New York, aquifers in carbonate rocks of Cambrian and Ordovician ages partially surround the Adirondack Mountains and crop out in the Central Lowland Physiographic Province and the valleys of the St. Lawrence and the Mohawk Rivers. Carbonate-rock aquifers also crop out along the escarpment that marks the northern and eastern edges of the Appalachian Plateaus Physiographic Province in western New York. A belt of limestone, dolomite, and marble that extends along the eastern edge of New York and the western edge of Connecticut, Massachusetts, and Vermont forms carbonate-rock aquifers. Carbonate rocks of Silurian age form an aquifer in northeastern Maine, where they supply about 4 million gallons per day, primarily for industrial and domestic uses.

Carbonate-rock aquifers in Segment 12 generally yield 10 to 30 gallons per minute to wells. Yields can be larger or smaller, however, depending on the degree of fracturing and the number and size of dissolution features in the rock; for example, yields of as much as 1,000 gallons per minute have been reported in some wells in carbonate-rock aquifers with numerous dissolution openings. Two examples of carbonate-rock aquifers are discussed in detail later in the chapter: the Lake Erie–Niagara River Basin in western New York and the Housatonic River Basin in western New England.

Sandstone aquifers in Segment 12 are present in New York and in the central parts of Massachusetts and Connecticut (**fig. 10**). Sandstone aquifers in New York include the Cambrian Potsdam Sandstone in the St. Lawrence Valley and sandstones of the Ordovician Medina Group in the Central Lowland Province and the Mohawk Valley. The sandstones in New York are productive aquifers which yield from 50 to 100 gallons per minute to wells. Water in these aquifers generally is confined.

Arkosic sandstone, conglomerate, shale, and interbedded trap rock form the lower Mesozoic Newark Supergroup, which occurs in fault-block basins that underlie the Connecticut River Valley in Connecticut and Massachusetts and a small area of southeastern New York. The sandstone in the Connecticut River Valley is very thick and dips toward a fault on the eastern side of the basin. In New York, rocks of the Newark Supergroup dip westward and are in fault contact with Precambrian crystalline rocks.

The yields of wells completed in the sandstone aquifer in the Connecticut River Valley (**fig. 17**) reflect the effects of well diameter, well depth, and use of the water. Yields of small-diameter, shallow, domestic wells commonly range from 2 to 50 gallons per minute, but yields of large-diameter, deep, industrial wells might exceed 600 gallons per minute. Water in this aquifer is unconfined to partly confined in the uppermost 200 feet but might be confined at depth.

Crystalline-rock aquifers are the least productive of the major aquifers in Segment 12 (**fig. 10**). Well yields commonly range from 2 to 10 gallons per minute, which generally are sufficient only for domestic and commercial and small public supplies. Some reported well yields, however, might exceed 500 gallons per minute. Crystalline-rock aquifers provide water for the majority of homes in rural New England. Water in these aquifers generally is unconfined but is locally confined at depth.

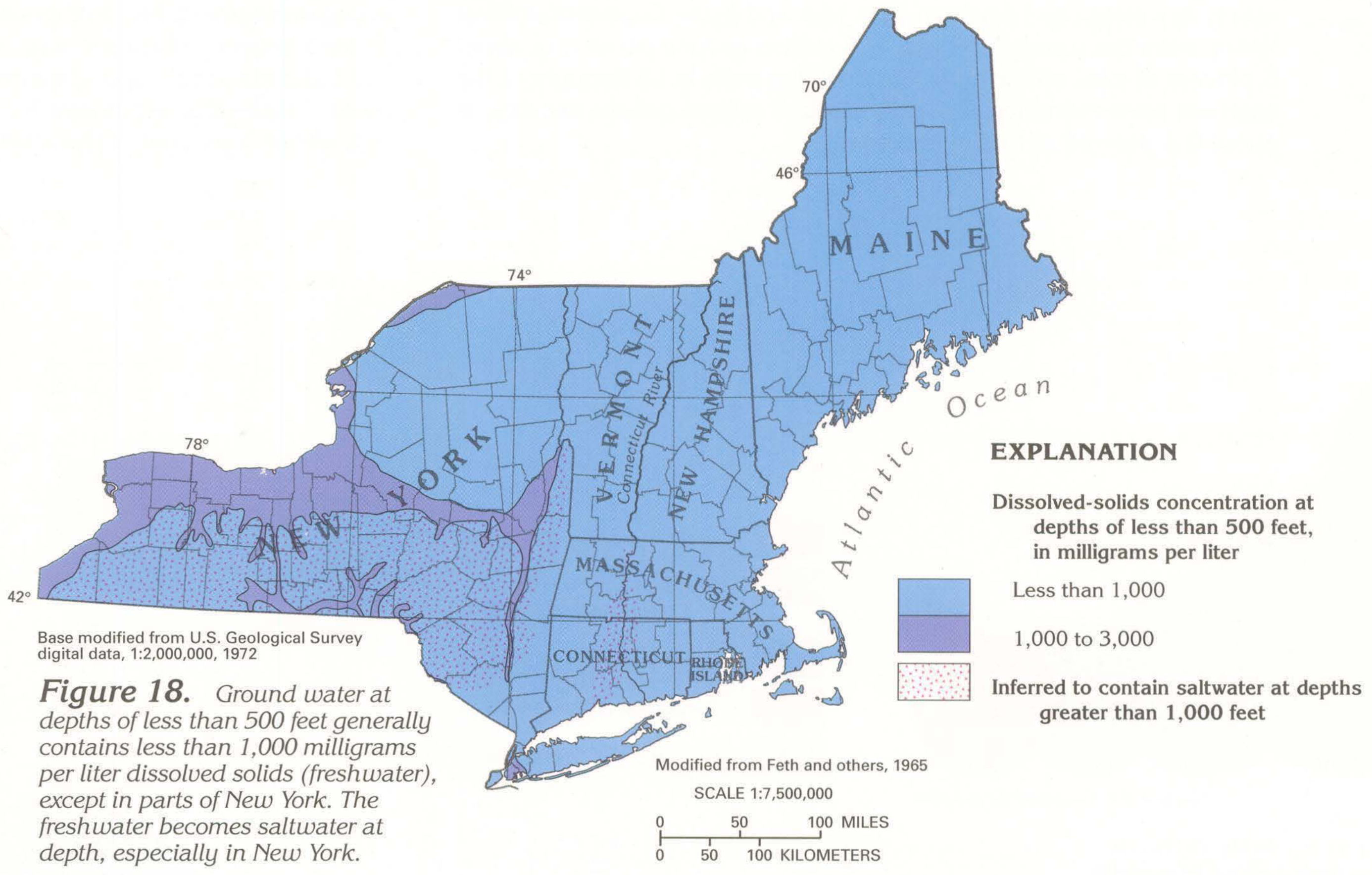


Figure 18. *Ground water at depths of less than 500 feet generally contains less than 1,000 milligrams per liter dissolved solids (freshwater), except in parts of New York. The freshwater becomes saltwater at depth, especially in New York.*

GROUND-WATER QUALITY

The chemical quality of the water in each of the major aquifers and aquifer systems of Segment 12 generally is suitable for most uses, including human consumption. Water quality, however, differs among the aquifers as a result of natural conditions and human activities that, locally, might prevent the use or require treatment of the water.

Ground-water quality is the result of dissolved material in the water and is primarily related to the (1) mineral composition and solubility of the rocks that make up the aquifer, (2) time that the water is in contact with the rock, (3) surface area of rock exposed to the water, (4) chemistry of water moving into the aquifer from other aquifers, and (5) introduction or induced movement of contaminants. In Segment 12, each of these factors influences ground-water quality. A summary, by aquifer type in each State, of the general chemical character of water in the aquifers and the aquifer systems of the segment is based on median concentrations of dissolved solids and is shown in **figure 18** and **table 3**. The concentration of dissolved solids in ground water generally increases with depth, and some aquifers contain saltwater or brine in their deeper parts.

Aquifers that are part of the surficial aquifer system in Segment 12 consist mainly of stratified drift. Generally, they are composed of unconsolidated layers of sand and gravel that are of small areal extent, less than 100 feet thick, and unconfined. Mineral composition of the sand and gravel is related to that of the parent bedrock eroded by the glaciers. The sand and gravel commonly are composed of more than 99 percent quartz and feldspar, minerals that are chemically stable, nonreactive, and almost insoluble in water. In places, however, the sand and gravel contain fragments of carbonate rocks, which are soluble in water. Although the sand and gravel has an extremely large surface area exposed to the water, the deposits are extremely permeable, and the water moves rapidly through them, generally along very short flow paths; therefore, the water is in contact with aquifer minerals for only a brief time. Because they are shallow, unconfined, and generally overlain by a highly permeable unsaturated zone through which they are recharged, the aquifers are susceptible to contamination. The quality of the water in the surficial aquifer system is determined by the chemistry of the minerals that comprise the aquifer and by the chemistry of the water that enters the aquifer system where bedrock aquifers discharge into it.

Median dissolved-solids concentrations in water from the surficial aquifer system in Segment 12 range from 75 to 200 milligrams per liter (**table 3**), which is substantially less than the 500-milligram-per-liter limit for public supply recommended by the U.S. Environmental Protection Agency. Median concentrations are least and range between 75 and 140 milligrams per liter in the New England States where these aquifers consist primarily of quartz and feldspar. Water in the extensive carbonate bedrock in New York commonly discharges into the surficial aquifer system, and the aquifers contain carbonate-rock fragments for several miles south of carbonate bedrock outcrops; these factors explain the median dissolved-solids concentrations of 200 milligrams per liter in some areas. Another factor that contributes to the large median concentrations in New York is the discharge of mineralized water from carbonate-rock aquifers along the margins of the Appalachian Plateaus Province and from gypsum-bearing shale in the Central Lowland Province into the surficial aquifer system.

Water from the surficial aquifer system in southern New York is hard and slightly alkaline because the aquifers contain fragments of carbonate rocks. Elsewhere in New York and in the New England States, water from the surficial aquifer system is acidic and soft. The acidity of the water makes it corrosive to metal and concrete pipes. Excessive iron and manganese concentrations in water from the surficial aquifer system is a segmentwide problem that, in many areas, requires treatment of the water to remove these metals. Saltwater is present locally in the surficial aquifer system as a consequence of excessive ground-water withdrawals, especially in coastal areas of western Long Island, Connecticut, and Massachusetts. The widespread use of deicing chemicals on roads in the segment also can introduce saltwater into the aquifer system. Other common sources of local contamination throughout the segment are effluent from septic systems and leaching of agricultural chemicals.

The sand and gravel aquifers of the Northern Atlantic Coastal Plain aquifer system have characteristics similar to those of the surficial aquifer system: (1) they are predominantly composed of quartz and feldspar, (2) a large aquifer-mineral surface area is exposed to the water, but the water moves along short flow paths, which results in brief water-mineral contact times, and (3) the upper aquifer (the Magothy aquifer) contains water generally under unconfined conditions. Median dissolved-solids concentrations in water from the Magothy aquifer and the underlying Lloyd aquifer are only about 40 milligrams per liter (**table 3**). The water is soft and slightly acidic. Locally, large iron and manganese concentrations from natural sources are a problem in water from the Magothy aquifer. There is a potential for saltwater intrusion into the aquifer system along most of the periphery of Long Island. Because the island is densely populated and the overlying upper glacial aquifer is extremely permeable in many places, local contamination of the Magothy aquifer from sources on the land surface is an increasing problem.

Carbonate-rock aquifers consist of limestone, dolomite, and marble and generally are the most soluble of the aquifers in Segment 12. For this reason, median dissolved-solids concentrations in water from carbonate-rock aquifers are among the largest—220 to 700 milligrams per liter—in the segment (**table 3**). Water from carbonate-rock aquifers is characteristically very hard and slightly alkaline. Sodium, fluoride, and sulfate concentrations typically are small. Water in the carbonate-rock aquifers at depth in the Appalachian Plateaus Physiographic Province is inferred to be saltwater (**fig. 18**) because of slow circulation along long flow paths and the leaching of evaporite deposits that contain gypsum in the bedrock. Elsewhere, circulation is faster along shorter flow paths. Where carbonate-rock aquifers are exposed at the land surface, they are susceptible to contamination from the land surface because of their solution-enhanced permeability.

Sandstone aquifers in New York are primarily in the northern one-half of the State, and are characterized by fracture rather than by intergranular permeability. The aquifers generally contain very hard water. The median dissolved-solids concentration is about 300 milligrams per liter (**table 3**), and the median chloride concentration is about 100 milligrams per liter. Dissolved-solids and chloride concentrations increase with depth, and saltwater is present at depths of less than 500 feet in some areas (**fig. 18**). The susceptibility of these aquifers to contamination from the land surface is greatest where they are exposed at the land surface.

The sandstone aquifer in the Connecticut River Valley is interbedded with shale, conglomerate, and trap rock. These rocks contain mineral sources of fluoride, sulfate, copper, lead, zinc, and uranium, and these ions occur as constituents in trace amounts in water from the aquifer. The aquifer is characterized by fracture rather than by intergranular permeability. Water in the upper 200 to 300 feet of the aquifer, where flow paths are shortest, is moderately hard and slightly alkaline; median dissolved-solids concentrations are 200 milligrams per liter in Connecticut and 360 milligrams per liter in Massachusetts (**table 3**). At depths of greater than 1,000 feet, the aquifer is inferred to contain saltwater (**fig. 18**). The susceptibility of the aquifer to contamination from the land surface is similar to that of sandstone aquifers in New York.

Crystalline-rock aquifers consist of almost insoluble igneous and metamorphic rock. These aquifers are characterized by shallow fracture systems that store and transmit water. The shallow fracture systems that have small surface areas and rapid water movement along short flow paths only allow minimal dissolution of the rocks. As a result, median dissolved-solids concentrations in water from these aquifers range from 110 to 150 milligrams per liter in Connecticut, Massachusetts, Maine, and New Hampshire (**table 3**). Water in crystalline-rock aquifers is similar in quality to water in aquifers of the surficial aquifer system. Locally, excessive concentrations of iron, manganese, and sulfate are present. Large concentrations of radon, a radioactive gas that is a decay product of the uranium minerals present in granite and some metamorphic rocks, have been reported in water from the crystalline-rock aquifers in all of the New England States except Vermont. The susceptibility of the crystalline-rock aquifers to contamination from the land surface is greatest where they are exposed at the land surface.

Table 3. *Median concentrations of dissolved solids in water from the major aquifers and aquifer systems underlying Segment 12 are substantially less than 500 milligrams per liter, except for carbonate-rock aquifers in New York*

[Source: U.S. Geological Survey, 1988. Dissolved-solids concentrations in milligrams per liter; —, no data available]

					Consolidated bedrock aquifers					
	Surficial aquifer system		Northern Atlantic Coastal Plain aquifer system		Carbonate-rock aquifers		Sandstone aquifers		Crystalline-rock aquifers	
State or area	Dissolved solids	Number of samples	Dissolved solids	Number of samples	Dissolved solids	Number of samples	Dissolved solids	Number of samples	Dissolved solids	Number of samples
New York	200	283	Absent		700	67	300	17	—	—
Long Island	120	195	40	378	Absent		Absent		Absent	
Connecticut	140	374	—	—	240	41	200	168	120	417
Maine	80	90	—	—	240	8	—	—	110	44
Massachusetts	88	697	—	—	220	15	360	15	120	35
New Hampshire	80	20	—	—	—	—	—	—	150	8
Rhode Island	75	209	—	—	—	—	—	—	—	—
Vermont	100	58	—	—	—	—	—	—	—	—

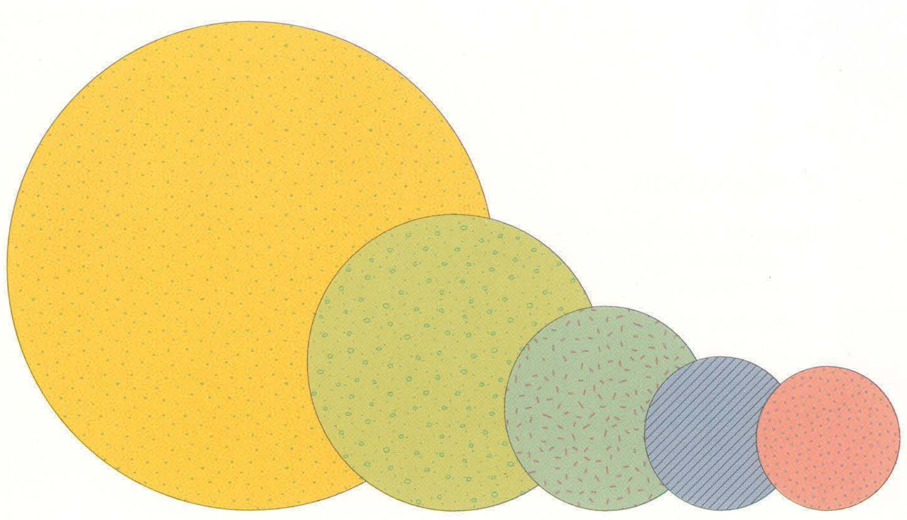
FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals in Segment 12 totaled about 1,675 million gallons per day during 1985. About 51 percent, or about 863 million gallons per day, was withdrawn from the surficial aquifer system (**fig. 19**) primarily on Long Island and Cape Cod and from numerous valley-fill glacial aquifers throughout the segment. The Magothy and the Lloyd aquifers that compose the Northern Atlantic Coastal Plain aquifer system underlying Long Island supplied about 23 percent of total withdrawals or about 387 million gallons per day. Withdrawals from bedrock aquifers in the Central Lowland, the St. Lawrence Valley, the Adirondack, the New England, and the Appalachian Plateaus Physiographic Provinces, totaled about 427 million gallons per day. Crystalline-rock aquifers in the New England States and the Adirondack Mountains of New York provided nearly 12 percent of total withdrawals, or about 199 million gallons per day. Carbonate-rock aquifers, primarily in western New York and in western Connecticut, Massachusetts, and Vermont, produced about 120 million gallons per day, or about 7 percent of total withdrawals. Sandstone aquifers, primarily in western and northern New York and in the Connecticut River Valley, were the source for about 106 million gallons per day, or about 6 percent of total withdrawals. Shallow dug wells in till throughout the segment were estimated to supply about 7 million gallons per day, or about 0.4 percent of total withdrawals.

The distribution of ground-water withdrawals from all aquifers and aquifer systems during 1985 is shown by county in **figure 20**. The largest withdrawals, which ranged from 50 to 500 million gallons per day, were on Long Island, where ground water supplies a population of about 3.5 million people; in northeastern Massachusetts; and in Schenectady County, N.Y. The populous counties of southern and east-central New York, eastern and southwestern Massachusetts, and southern New Hampshire withdrew from 10 to 50 million gallons per day during 1985. Counties that surround large cities in western New York and southern Maine similarly withdrew from 10 to 50 million gallons per day during 1985.

In the sparsely populated areas of Segment 12, which include much of rural New York, Vermont, New Hampshire, and Maine, water demand is small, and withdrawals were less than 5 million gallons per day per county during 1985. Fresh ground-water withdrawals in Aroostook County, the northernmost county in Maine, were 5 to 10 million gallons per day during 1985, which reflects industrial, domestic, and agricultural use of water from carbonate-rock aquifers in the eastern part of the county.

The various uses of the fresh ground-water withdrawals in Segment 12 during 1985 are shown in **figure 21**. By far the largest use of freshwater, nearly one-half of the total, was for public supply in this populous segment. Much of the remaining one-half was approximately divided between domestic and commercial uses (about 27 percent) and industrial, mining, and thermoelectric power uses (about 21 percent). Freshwater withdrawn for agricultural purposes accounted for only about 3 percent of the total.



Data from U.S. Geological Survey, 1990

EXPLANATION

Fresh ground-water withdrawals during 1985, in million gallons per day

- Surficial aquifer system—863
- Northern Atlantic Coastal Plain aquifer system—387
- Carbonate-rock aquifers—120
- Sandstone aquifers—106
- Crystalline-rock aquifers—199

Figure 19. *The surficial aquifer system and the Northern Atlantic Coastal Plain aquifer system supplied about 75 percent of the 1,675 million gallons per day of ground water withdrawn in the segment during 1985.*

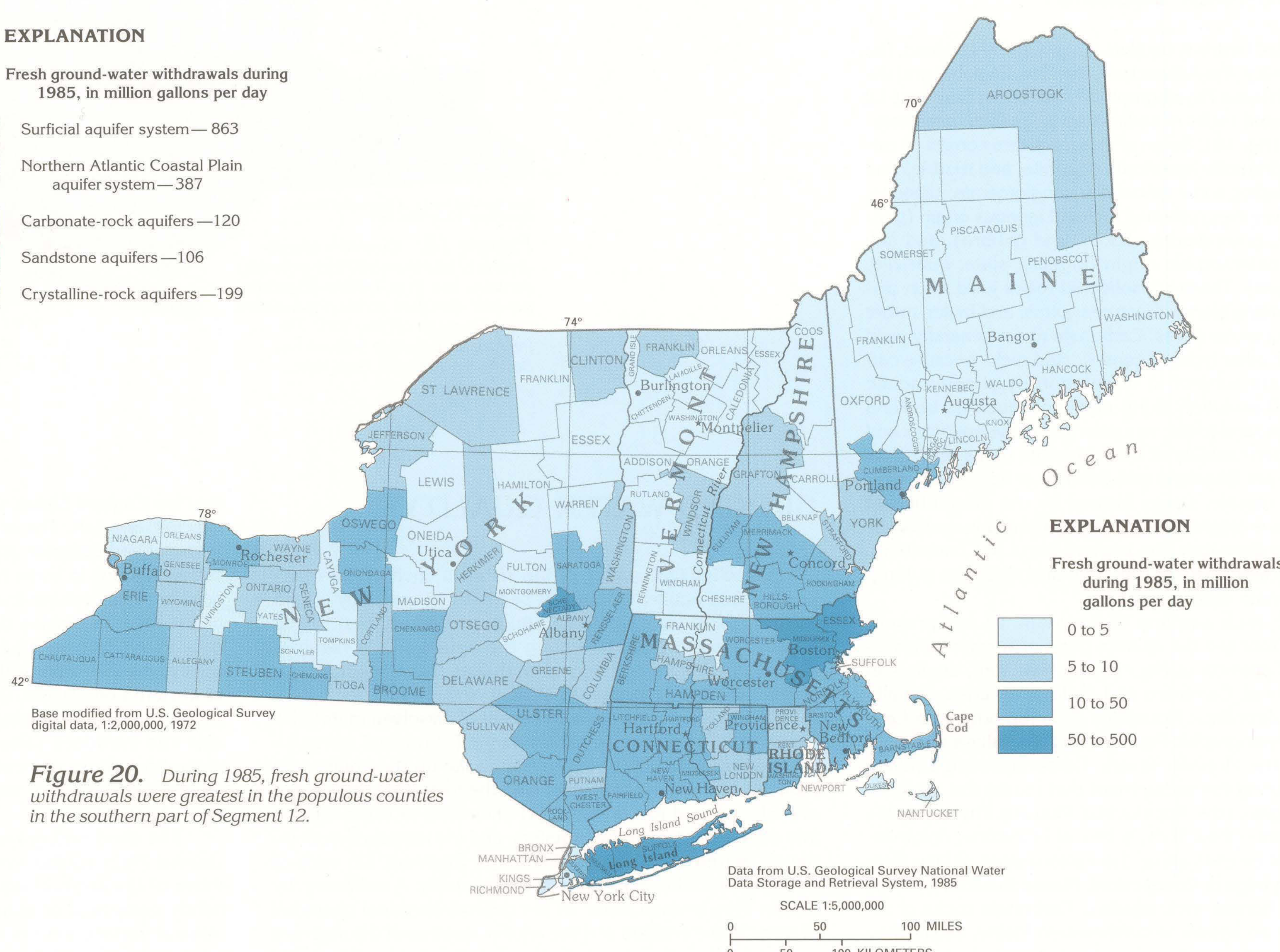
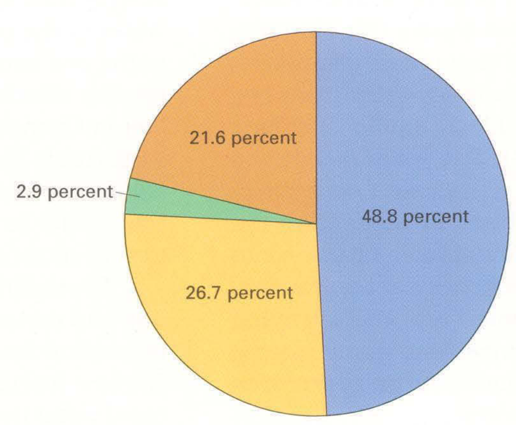


Figure 20. *During 1985, fresh ground-water withdrawals were greatest in the populous counties in the southern part of Segment 12.*



Total withdrawals
1,675 million gallons per day
Data from U.S. Geological Survey, 1990

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent

- 48.8 Public supply
- 26.7 Domestic and commercial
- 2.9 Agricultural
- 21.6 Industrial, mining, and thermoelectric power

Figure 21. *Fresh ground-water withdrawals during 1985 were used largely for public supply. Most of the remainder was used for either domestic and commercial purposes or industrial, mining, and thermoelectric-power purposes. Only a small percentage was used for agricultural purposes, primarily irrigation.*

CORNING AQUIFER

The Corning aquifer is an example of a valley-fill glacial aquifer deposited by meltwater streams that drained away from stagnated or melting glacial ice in upland valleys. It is characteristic of many such glacial-drift aquifers in the Appalachian Plateaus. The aquifer occupies four deeply incised bedrock valleys formed by the junction of the Chemung River and its principal tributaries, the Canisteo, the Tioga, and the Cohocton Rivers, in southeastern Steuben County, N.Y. (**fig. 22**). The valleys are incised deeply into flat-lying shaly carbonate bedrock. Valley walls rise steeply to rounded hill tops 800 feet or more above the valley floor (**fig. 23**) and about 1,800 feet above sea level.

The flat-lying valley floor is the site of the city of Corning and the villages of Addison, Painted Post, Riverside, and South Corning (**fig. 22**). Numerous homesites dot the rural landscape. About 31,000 people in the mapped area depend on ground water for water supplies. The city of Corning is the site of a major glass industry, which is a principal water user in the area.

The Corning aquifer extends over an area of about 28 square miles in valleys 0.5 to 1 mile wide. The maximum saturated thickness of the sand and gravel beds of the aquifer is slightly more than 60 feet and generally ranges between 20 and 60 feet (**fig. 24**). On the east, the aquifer is continuous with a similar valley-fill glacial aquifer.

GEOLOGY

The Corning area is located in the Appalachian Plateaus Province of southwestern New York. Bedrock underlying the area is flat-lying shale, limestone, siltstone, and sandstone that was deeply eroded by preglacial drainage. Preglacial erosion was enhanced by glacial scour that broadened and deepened the valleys and rounded off the hill tops (**fig. 23**). Till was deposited as a veneer on the hill tops and valley walls during advances of the glacial ice. When the glacial ice melted, the bedrock valleys became the resting place for stagnating ice and were the natural drainageways for meltwater that deposited ice-contact and outwash deposits, which consisted primarily of sand and gravel during peak ice-melting periods, and glacial-lake deposits, which consisted primarily of clay, silt, and very fine to fine sand during quiescent periods. Some of the till was eroded and carried as sediment into the valley where it formed alluvial fans as the tributary streams deposited sediment onto the valley floor. The last retreat of the glacial ice left the bedrock valleys partially filled with sand and gravel intermixed with fine grained glacial-lake deposits. Terraces, eskers, alluvial fans, and other features also were left on the land surface, as shown in **figure 25**.

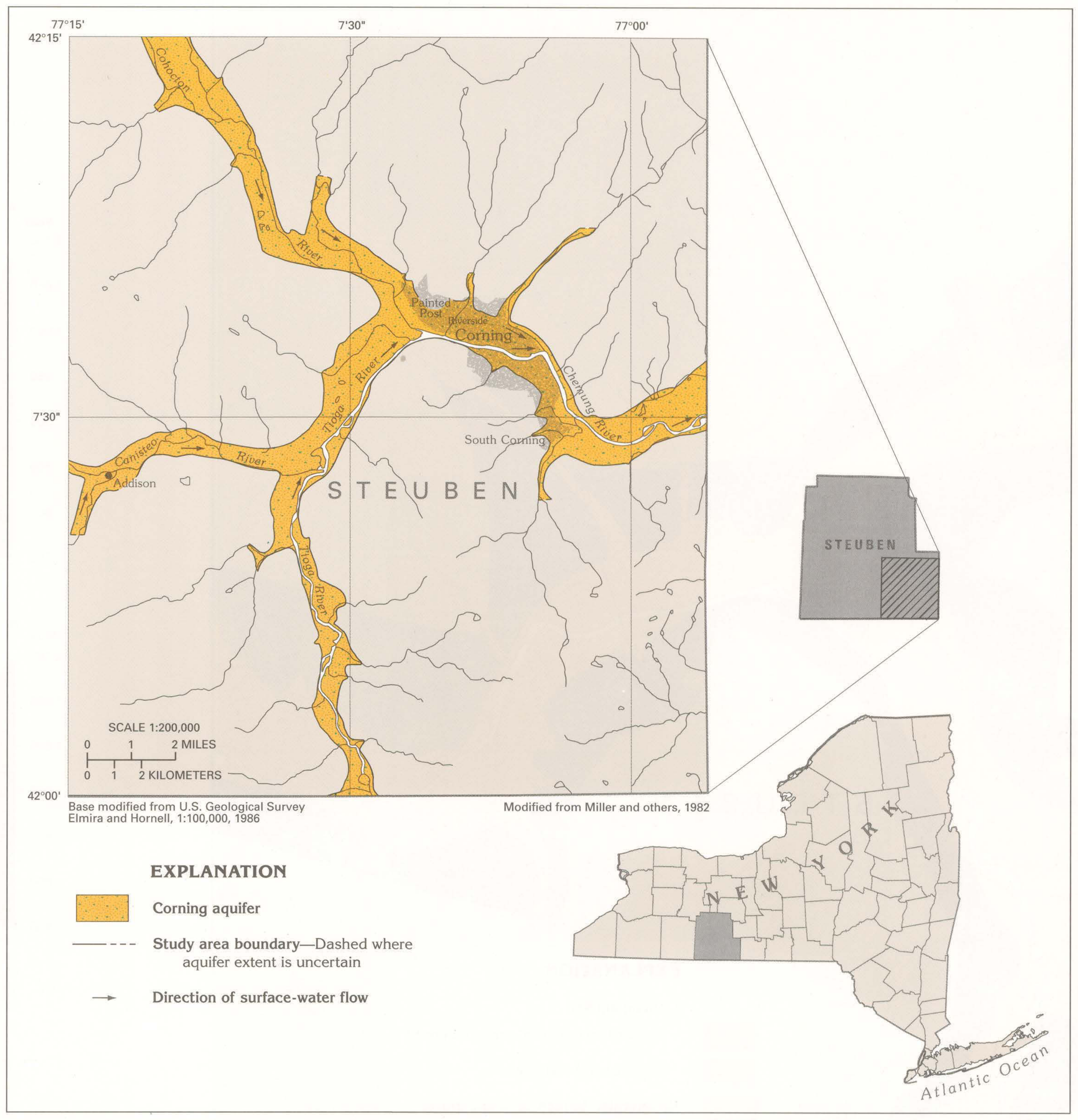


Figure 22. *The Corning aquifer occupies four deeply incised bedrock valleys drained by the Chemung, Canisteo, Tioga, and Cohocton Rivers.*

Figure 23. *Valley walls of bedrock rise steeply to the tops of rounded hills 800 feet or more above the glacial aquifer, which consists primarily of sand and gravel that form the valley floor.*

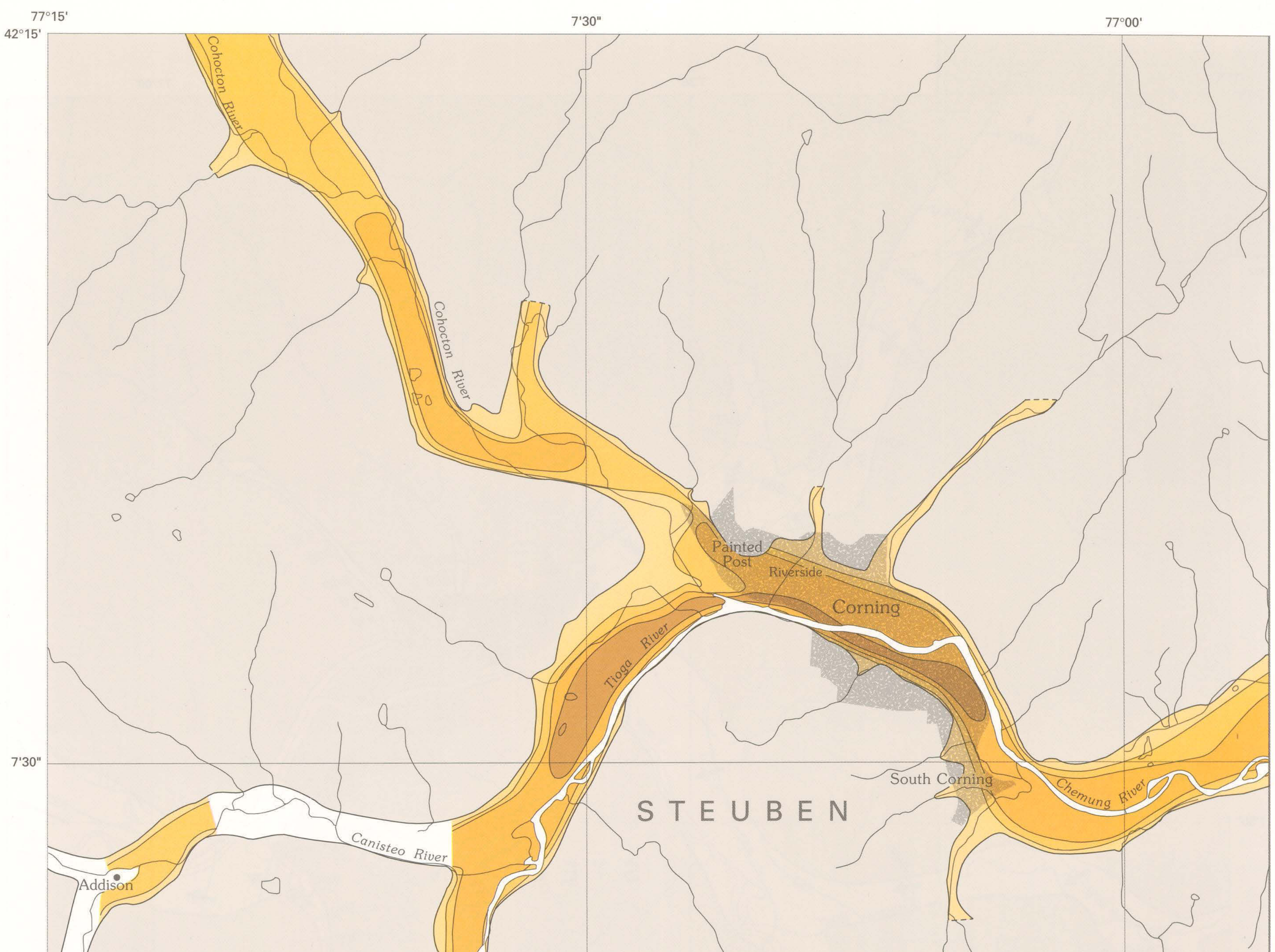


Figure 24. *The maximum saturated thickness of the sand and gravel beds that compose the aquifer is slightly more than 60 feet. The saturated thickness of these permeable beds generally is greatest near the center of the valleys and thins from 5 to 20 feet at the edges of the valleys.*

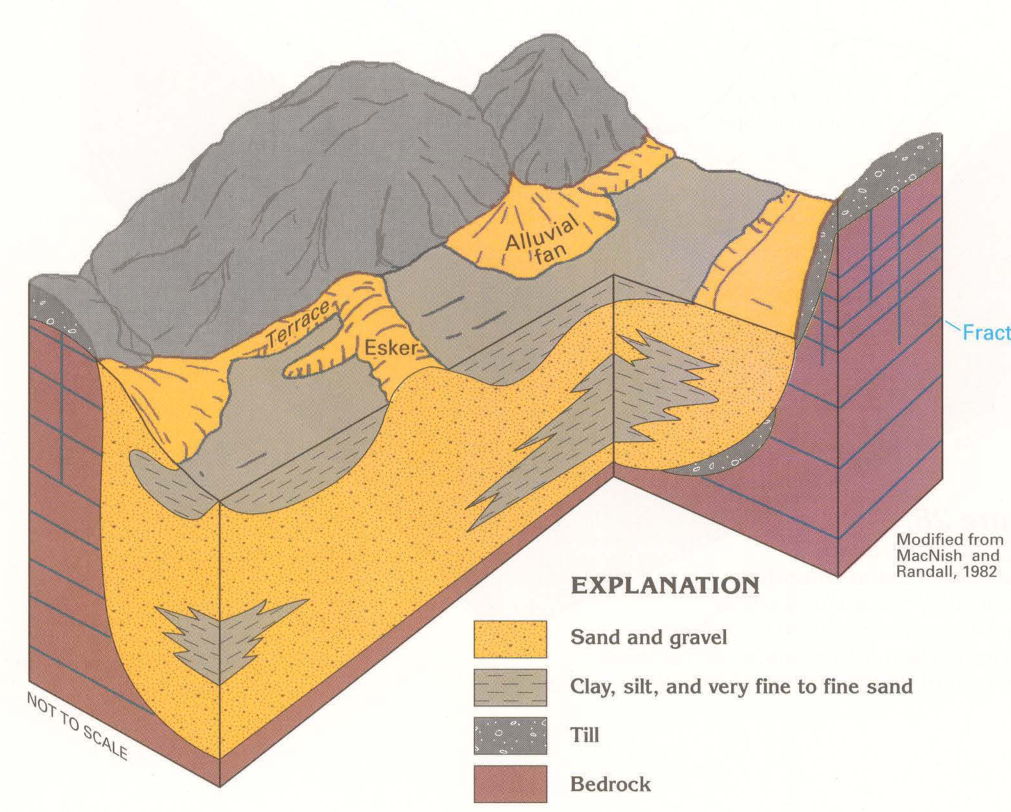
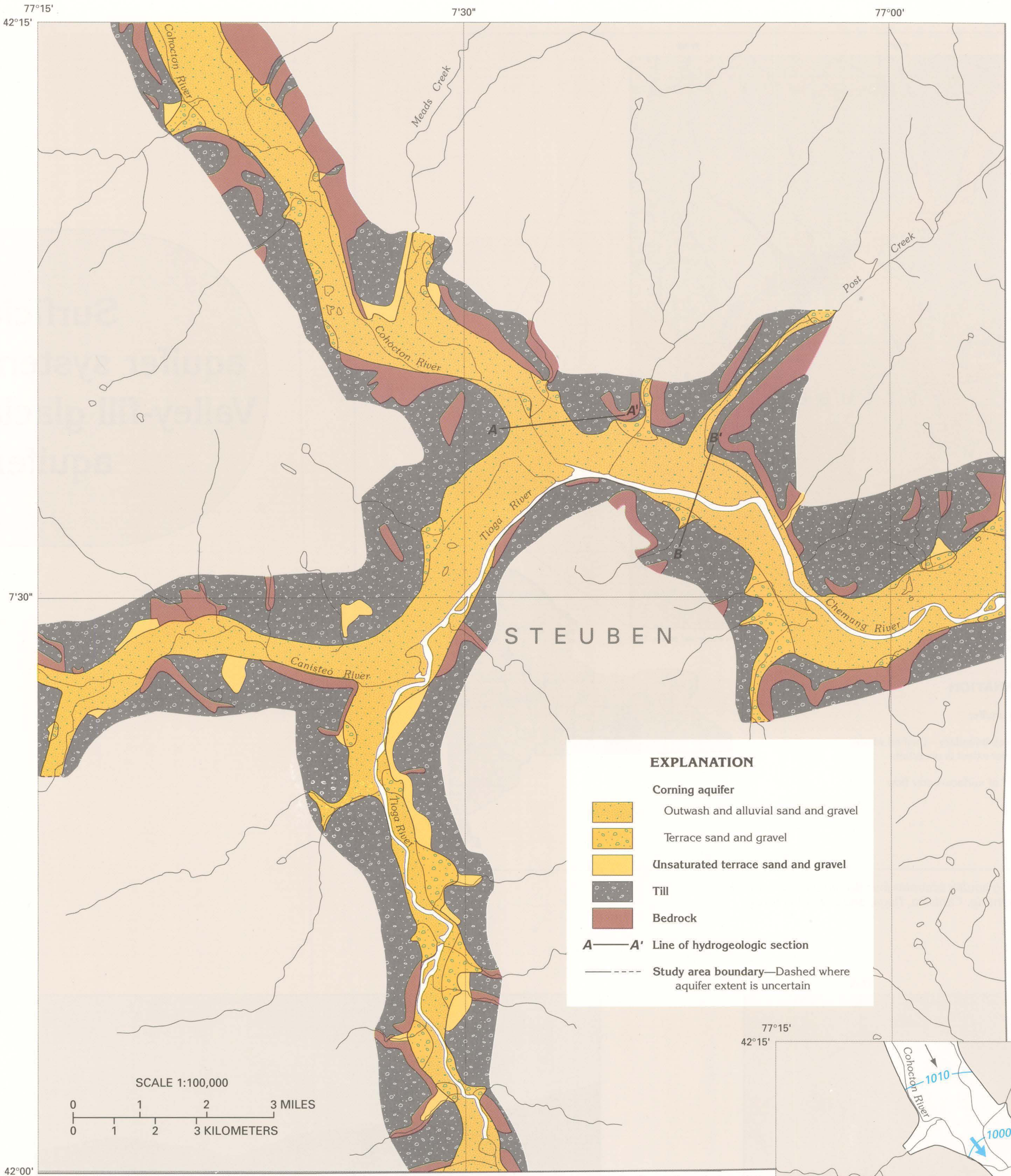


Figure 25. *Valley-fill glacial aquifers, like the Corning aquifer, were deposited by meltwater streams that drained away from the stagnating and melting glacial ice. Deposits typically are permeable, coarse-grained sand and gravel interbedded with layers and lenses of less permeable, fine-grained silt, clay, and very fine to fine sand. Terraces, eskers, and alluvial fans are common surface features on the valley floor.*



Base modified from U.S. Geological Survey, Elmira and Hornell, 1986

Modified from Miller and others, 1982

Figure 26. Outwash and alluvial sand and gravel form the Corning aquifer. Less permeable till and bedrock bound the aquifer. Remnants of terraces, which consist of kame sand and gravel, are present along the valley walls in some areas but are unsaturated and are not part of the Corning aquifer.

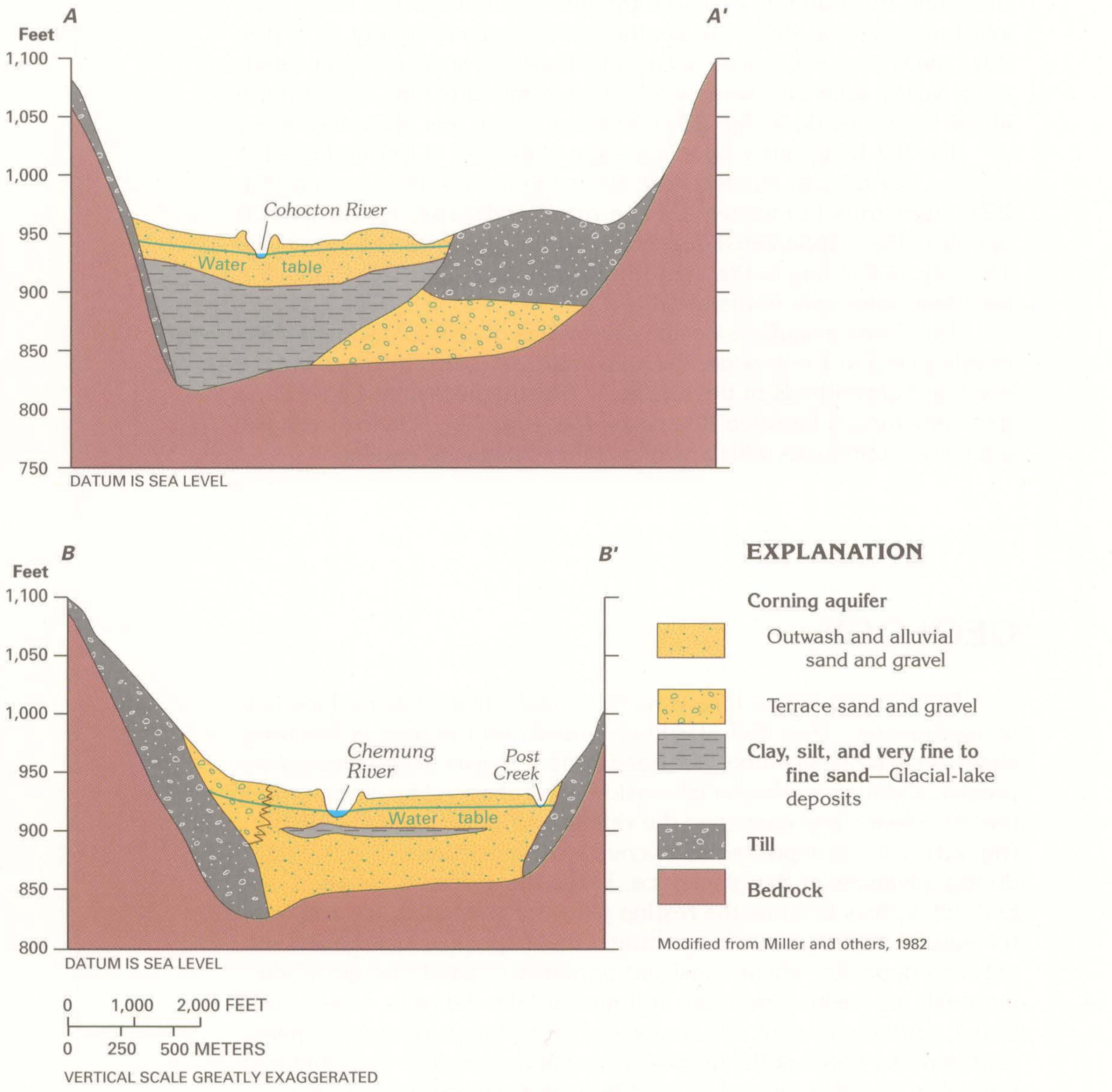


Figure 27. The Corning aquifer consists of sand and gravel interbedded with clay, silt, and very fine to fine sand. The lines of section are shown in figure 26.

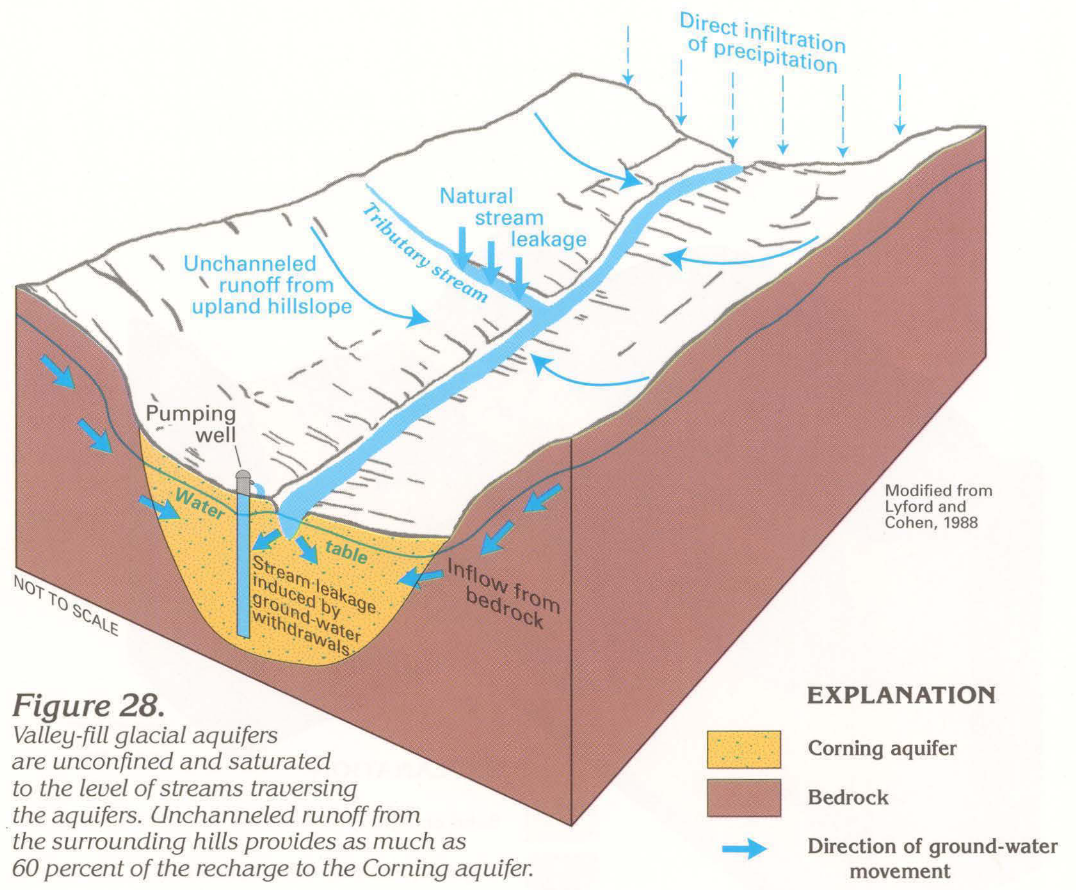


Figure 28. Valley-fill glacial aquifers are unconfined and saturated to the level of streams traversing the aquifers. Unchanneled runoff from the surrounding hills provides as much as 60 percent of the recharge to the Corning aquifer.

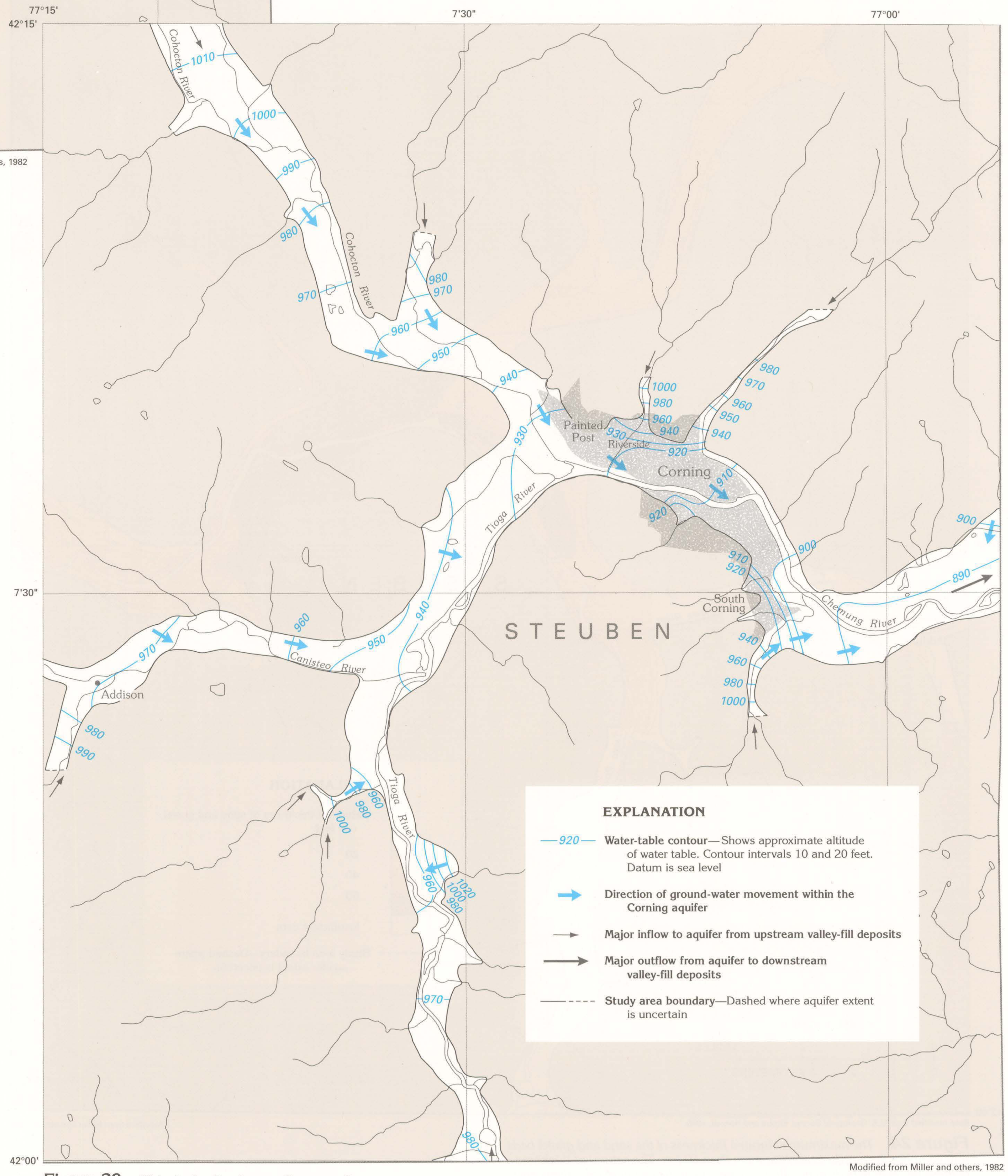


Figure 29. Water in the Corning aquifer generally moves downvalley and toward the principal streams.

GEOLOGY—Continued

Since the last retreat of the glacial ice, the streams in the valleys have eroded and redeposited some of the glacial deposits; as a result, outwash and alluvial sand and gravel cover the floor of the main and the tributary valleys (**fig. 26**). Till lines the valley walls along much of the Canisteo and Chemung Rivers. Bedrock forms the valley walls along much of the Cohocton River and intermittently elsewhere. Remnants of terraces are present on the valley walls chiefly along the Canisteo and the Tioga Rivers and along Meads Creek. Although the terraces consist of sand and gravel, these deposits generally are unsaturated and not considered to be part of the Corning aquifer.

Sections ***A–A'*** and ***B–B'*** in **figure 27** show some of the many possible relations among the deposits that form the Corning aquifer. The sections also show the till plastered on the valley walls and its relation to the Corning aquifer.

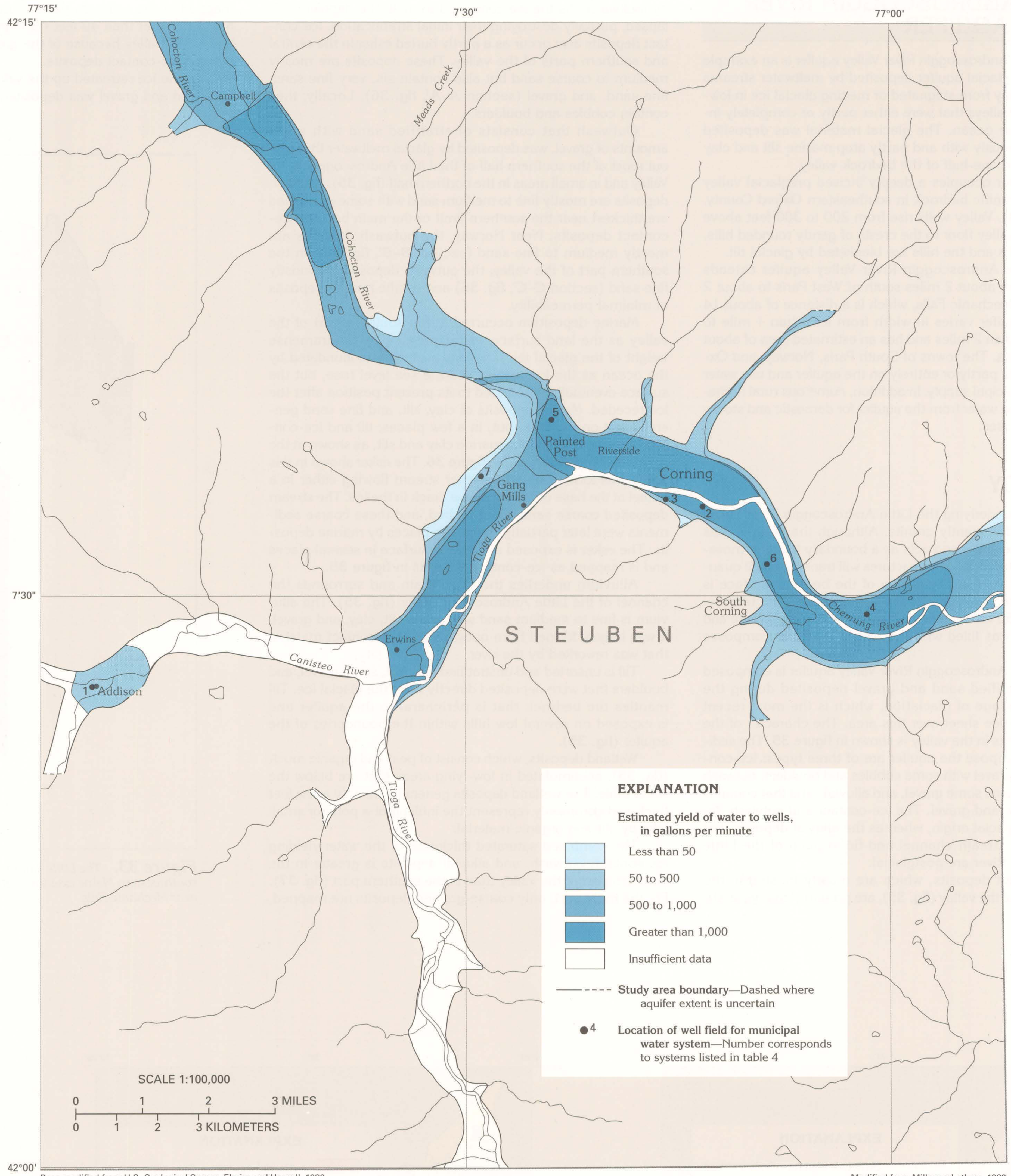
HYDROLOGY

Sand and gravel deposits of the Corning aquifer generally are unconfined and saturated to the level of the streams that traverse them; thus, in most places they are saturated nearly to land surface. Some recharge to the aquifer is by infiltration of precipitation that falls directly on the aquifer; however, about 50 percent of the precipitation is returned to the atmosphere by evapotranspiration. Recharge also takes place by inflow from the adjacent bedrock and by downvalley movement of water through the aquifer (**fig. 28**). Studies have concluded that as much as 60 percent of the recharge to the aquifer is from runoff of precipitation that falls on the surrounding hills that are underlain by low permeability till and bedrock. Unchanneled upland runoff recharges the aquifer by direct infiltration at the valley wall. Where tributary streams flowing in bedrock channels begin to flow over the alluvial fan and outwash deposits of the aquifer, the water level in the streams is commonly higher than that of the water table in the underlying aquifer, and water moves from the stream into the permeable sand and gravel. Withdrawal of water from the aquifer by wells lowers the water table locally and might induce additional leakage of water from streams to the aquifer, thus providing an additional source of recharge near well fields.

Water in the Corning aquifer generally moves downvalley and toward the principal streams, as shown in **figure 29**. However, near losing tributary streams, such as those north of Corning, ground-water movement is away from the tributary and into the aquifer.

Water discharges from the Corning aquifer to the principal streams throughout the length of the system as indicated by the shape of the water-table contours in **figure 29**. The ground-water discharge provides the base flow of the streams and sustains flow during periods of no precipitation. Much of this water can be captured by wells that intercept water that otherwise would move to the streams. Water also is discharged from the aquifer as underflow at the downgradient end of the valley (**fig. 28**).

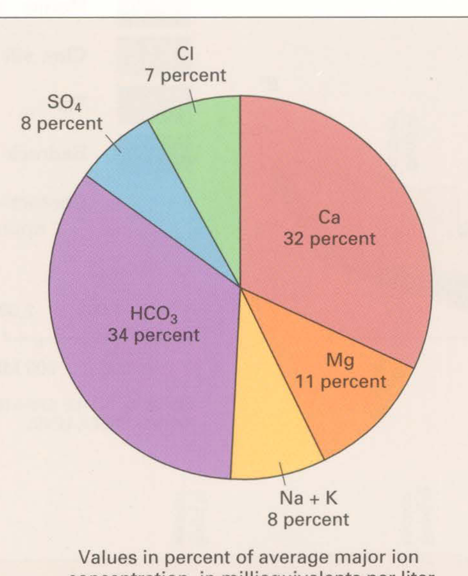
Estimated yields of wells completed in the Corning aquifer range from about 50 to about 1,000 gallons per minute (**fig. 30**). The largest yields can be expected in three areas: from Painted Post to east of South Corning in the Chemung River Valley, from near Erwins to near Gang Mills in the Tioga River Valley, and southeast of Campbell in the Cohocton River Valley. Large yields can be expected from outwash and alluvial deposits that consist largely of sand and gravel where the saturated thickness is more than 40 feet. In areas where the sand and gravel is thinner or where fine-grained glacial-lake deposits are present, yields are less. Little is known about the area east of Addison in the Canisteo River Valley and the area in the Tioga River Valley upstream from Erwins.



Base modified from U.S. Geological Survey, Elmira and Hornell, 1986

Modified from Miller and others, 1982

Figure 30. *Estimated yields of wells withdrawing water from the Corning aquifer range from about 50 to about 1,000 gallons per minute. Large yields can be expected where the saturated thickness of outwash and alluvial sand and gravel is largest.*



Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	7.1 to 8.2	7.8 (median)	13
Hardness ($CaCO_3$)	85 to 358	225	13
Calcium (Ca)	32 to 83	60	13
Magnesium (Mg)	1.2 to 18	12	13
Sodium (Na)	8.6 to 30	15	9
Potassium (K)	1 to 4.3	2	8
Bicarbonate (HCO_3)	110 to 268	192	13
Sulfate (SO_4)	12 to 54	37	13
Chloride (Cl)	13 to 48	24	14
Dissolved solids	146 to 282	212	5

Data from U.S. Geological Survey, 1980

Figure 31. *Water in the Corning aquifer is a calcium magnesium bicarbonate type. Generally, the water is of suitable quality for most uses.*

GROUND-WATER QUALITY

The chemical quality of water from the Corning aquifer generally is suitable for most uses. Dissolved-solids concentrations in five representative samples of the water averaged 212 milligrams per liter and ranged between 146 and 282 milligrams per liter (**fig. 31**). The water is a calcium magnesium bicarbonate type; these ions constitute 77 percent of the dissolved ions in the water. The water typically is alkaline (pH of greater than 7.0) and very hard (hardness as calcium carbonate, greater than 180 milligrams per liter); excessive iron and manganese concentrations are a nuisance in some areas, but the water can be easily treated to remedy these problems.

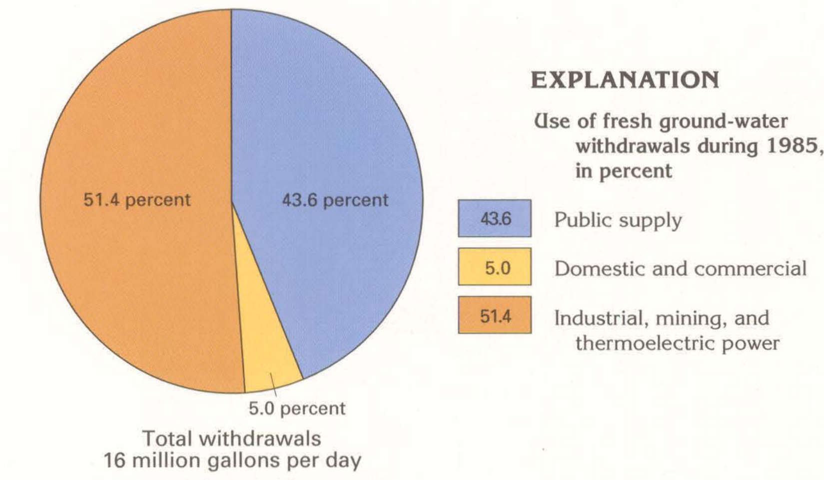
Table 4. *Fresh ground-water withdrawals from the Corning aquifer during 1985 were about 16 million gallons per day to supply a population of about 31,000 and industrial needs*

[Sources: New York State Department of Health, 1981; unpublished data from New York Department of Health, Southern Tier Central Regional Planning and Development Board, 1976; and unpublished data from the U.S. Geological Survey]

Source of ground-water supply	Population served	Average fresh ground-water withdrawals, 1985 (million gallons per day)
Municipal community water systems		
1. Addison	2,100	0.475
2. City of Corning	12,953	5.000
3. Corning Manor Water District	300	.020
4. Gibson Water District	500	.030
5. Painted Post and Riverside	2,878	.900
6. South Corning and Pinewoods Acres	3,535	.200
7. Morningside Heights Water District	1,351	.230
Subtotal	23,617	6.855
Other community water systems		
Trailer parks (17)	1,400	.178
Private water supplies		
Home use of 100 gallons per day per capita is assumed	6,000	.800
Industry	—	8.300
Total	31,017	16.133

FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the Corning aquifer during 1985 totaled about 16 million gallons per day to supply industrial needs and a population of about 31,000 (**table 4**). Industrial, mining, and thermoelectric power uses accounted for about 8.3 million gallons per day, or about 51 percent of the total use (**fig. 32**), which largely was used to supply industry in the city of Corning. Public supply for the city of Corning, 5 communities, 3 water districts, and 17 trailer parks, accounted for about 7 million gallons per day, or about 44 percent of the total use. Domestic and commercial withdrawals accounted for about 0.8 million gallons per day, or about 5 percent of the total use.



Data from U.S. Geological Survey, 1990

Figure 32. *Fresh ground-water withdrawals in the highly industrialized Corning area during 1985 were used primarily for public supply and industrial purposes.*

LITTLE ANDROSCOGGIN RIVER VALLEY AQUIFER

The Little Androscoggin River Valley aquifer is an example of a valley-fill glacial aquifer deposited by meltwater streams that flowed away from stagnated or melting glacial ice in lowland bedrock valleys that were either partly or completely inundated by the ocean. The glacial material was deposited contemporaneously with and partly atop marine silt and clay in the southern one-half of the bedrock valley.

The aquifer occupies a deeply incised preglacial valley eroded into granitic bedrock in southeastern Oxford County, Maine (**fig. 33**). Valley walls rise from 200 to 300 feet above the flat-lying valley floor to the crests of gently rounded hills. The valley walls and the hills are blanketed by glacial till.

The Little Androscoggin River Valley aquifer extends southward from about 2 miles south of West Paris to about 2 miles west of Mechanic Falls, which is a distance of about 14 miles. The aquifer varies in width from less than 1 mile to slightly more than 2 miles and has an estimated area of about 16 square miles. The towns of South Paris, Norway, and Oxford are located partly or entirely on the aquifer and use water from it for municipal supply. In addition, numerous rural homesteads withdraw water from the aquifer for domestic and stock-watering purposes.

GEOLOGY

Bedrock underlying the Little Androscoggin River Valley aquifer is predominantly granite. Although the bedrock has minimal permeability and acts as a boundary to water movement, it is fractured, and the fractures will transmit small quantities of water. The configuration of the bedrock surface is shown in **figure 34**. A southward-sloping valley with total relief of about 150 feet was eroded into the bedrock surface and subsequently was filled with the glacial drift that composes the aquifer.

The Little Androscoggin River Valley aquifer is composed mostly of stratified sand and gravel deposited during the Wisconsinan stage of glaciation, which is the most recent advance of an ice sheet over this area. The character of the surficial deposits in the valley is shown in **figure 35**. The sediments that compose the aquifer are of three types: ice-contact sand and gravel with some cobbles and boulders, outwash sand that contains some gravel, and alluvial sand that contains some silt, clay, and gravel. The ice-contact and outwash deposits are of glacial origin, whereas the alluvial deposits that are along the stream channel and flood plain of the Little Androscoggin River are postglacial.

Ice-contact deposits, which are mostly located in the northern part of the valley (**fig. 35**), are primarily coarse, stratified sand and gravel that was deposited against the glacial ice by meltwater. As the ice continued to melt, the deposits collapsed, partially destroying their initial stratification. Ice-contact deposits also occur as a partly buried esker in the central and southern parts of the valley. These deposits are mostly medium to coarse sand but also contain silt, very fine sand, fine sand, and gravel (section *A–A'*, **fig. 36**). Locally, they contain cobbles and boulders.

Outwash that consists of stratified sand with small amounts of gravel, was deposited by glacial meltwater throughout most of the southern half of the Little Androscoggin River Valley and in small areas in the northern half (**fig. 35**). Outwash deposits are mostly fine to medium sand with some gravel and are thickest near the southern limit of the main body of ice-contact deposits. Near Norway, the outwash deposits are mostly medium to fine sand (section *B–B'*, **fig. 36**). In the southern part of the valley, the outwash deposits are mostly fine sand (section *C–C'*, **fig. 36**) and overlie marine deposits of minimal permeability.

Marine deposition occurred in the southern part of the valley as the land surface was depressed by the immense weight of the glacial ice. The land surface was inundated by the ocean as the ice melted and the sea level rose, but the surface eventually rebounded to its present position after the ice receded. Marine deposits of clay, silt, and fine sand generally rest on bedrock, but, in a few places, till and ice-contact deposits underlie the marine clay and silt, as shown at the right side of section *C–C'* in **figure 36**. The esker shown in this figure was formed by a meltwater stream flowing either in a tunnel at the base of the ice or in a crack in the ice. The stream deposited coarse sand along its bed, and these coarse sediments were later partially covered in places by marine deposits. The esker is exposed at the land surface in several places and is mapped as ice-contact deposits in **figure 35**.

Alluvium underlies the flood plain and surrounds the channel of the Little Androscoggin River (**fig. 35**). The alluvium is fine to medium sand with some silt, clay, and gravel. It was largely formed from outwash and ice-contact material that was reworked by the river.

Till is unsorted and unstratified clay, silt, sand, gravel, and boulders that were deposited directly from the glacial ice. Till mantles the bedrock that is peripheral to the aquifer and is exposed on several low hills within the boundaries of the aquifer (**fig. 35**).

Wetland deposits, which consist of peat and organic muck (**fig. 35**), accumulated in low-lying areas that are below the water table. The wetland deposits generally are only a few feet thick and commonly represent the infilling of a pond or small lake by silt and organic material.

The combined saturated thickness of the water-yielding ice-contact, outwash, and alluvial deposits is greater in the northern part of the valley than in the southern part (**fig. 37**). For the most part, only coarse-grained deposits are mapped, but fine sands are included in the saturated thickness as mapped in the southern parts of the valley. Saturated thickness is greater than 40 feet throughout most of the northern half of the valley because of the greater thickness of coarse-grained ice-contact deposits.

As the ice retreated up the valley from Norway, ice-contact sand and gravel was deposited between the ice and the valley sides, and outwash was deposited in front of the ice by streams that were channeled down the valley. Although partially filled with sediments, the valley remained as a topographic low after the ice receded and formed a channel for the present-day stream that reworked sediments along its bed to produce the ribbon of alluvial material shown in **figure 35**.

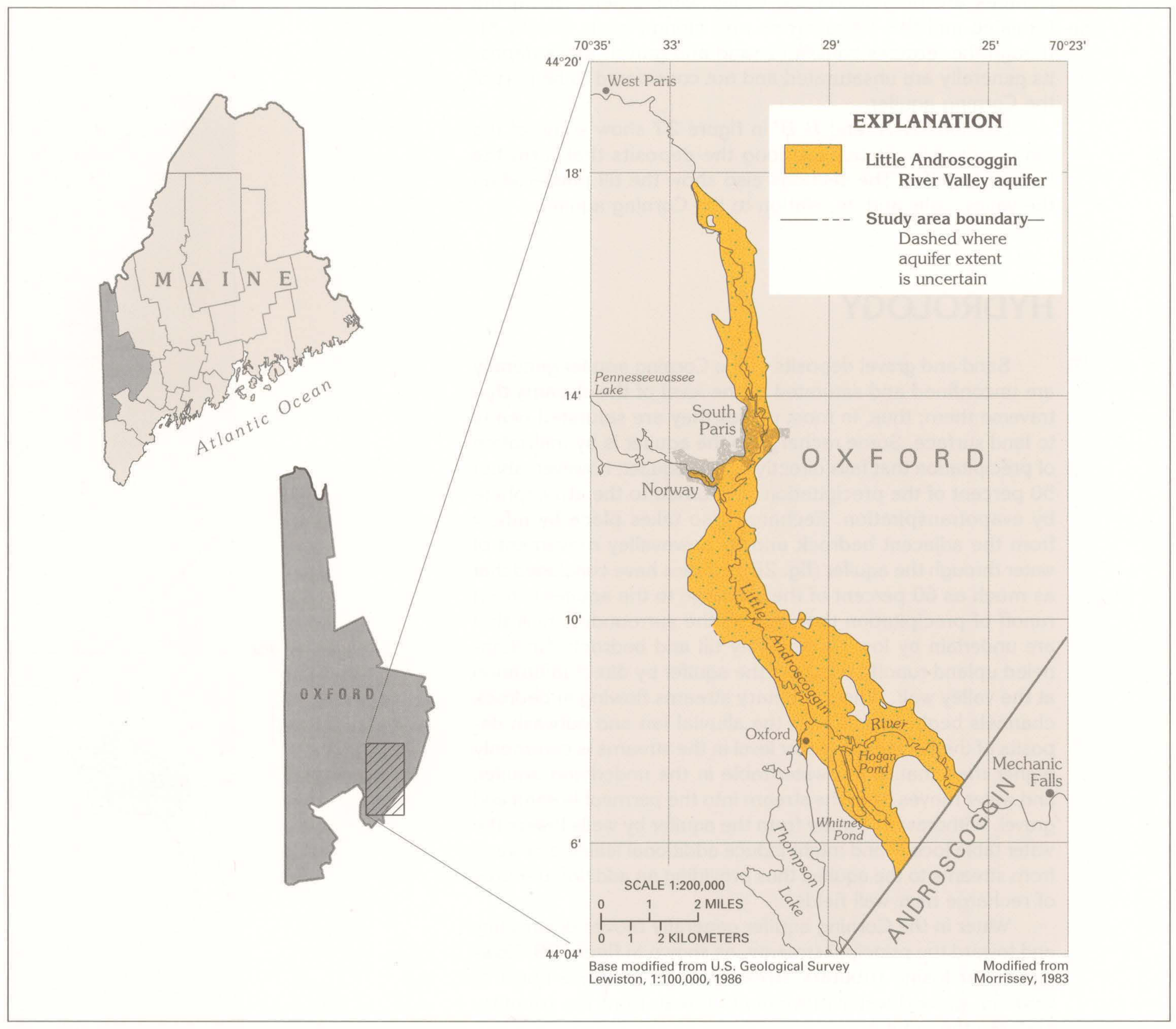


Figure 33. The Little Androscoggin River Valley aquifer in southwestern Maine extends southward from near West Paris to near Mechanic Falls.

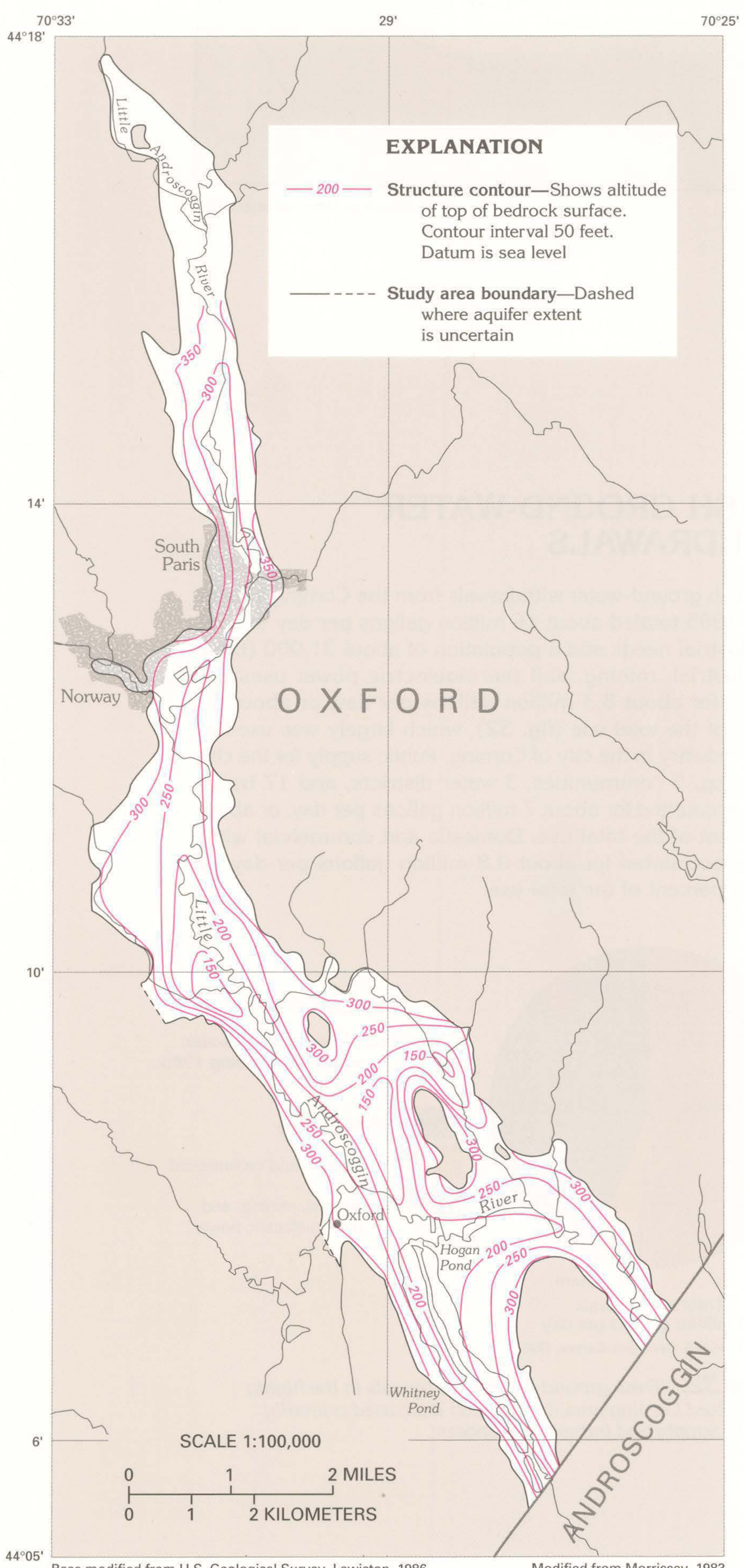


Figure 34. A southward-sloping valley with total relief of about 150 feet has been eroded into the bedrock surface that underlies the aquifer.

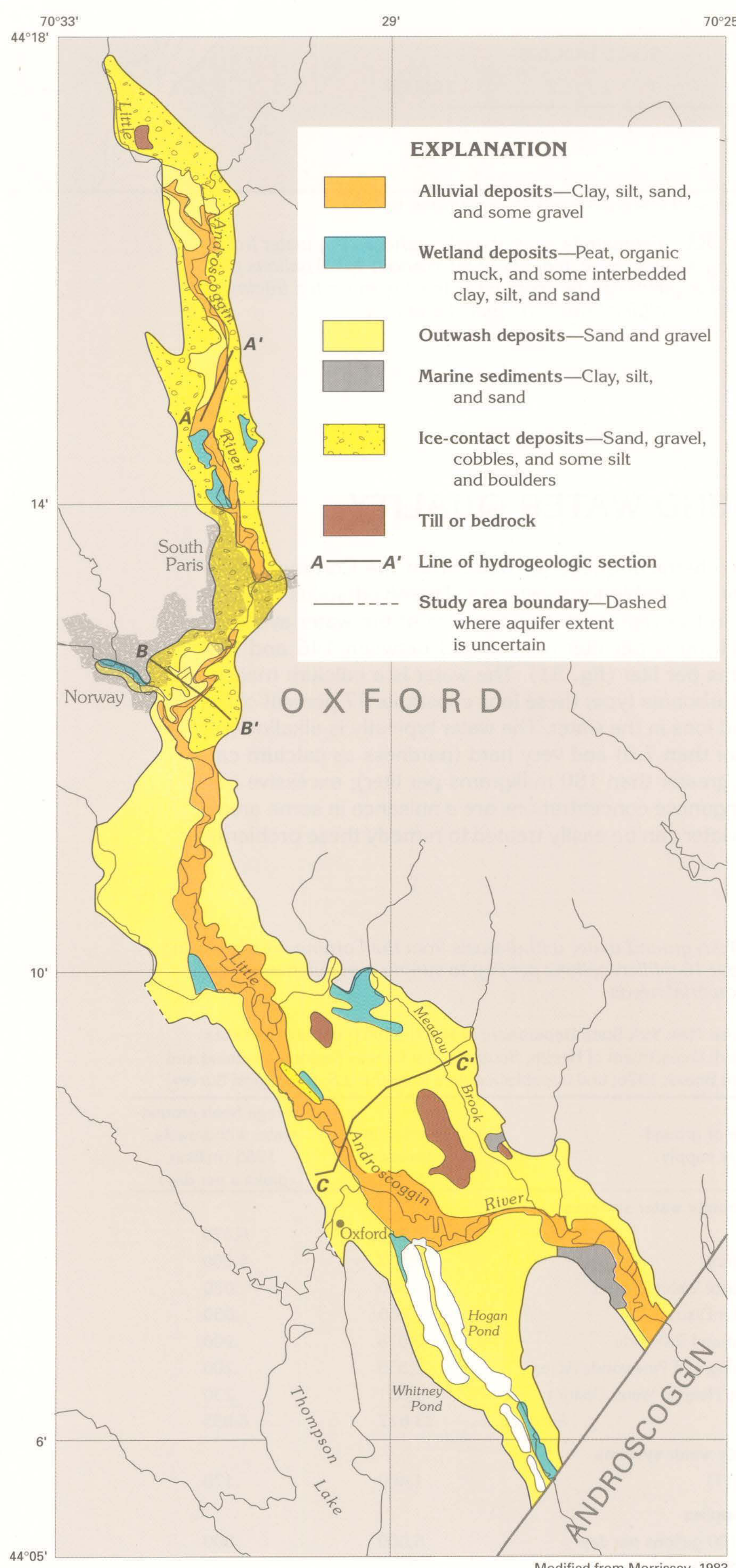


Figure 35. Sand and gravel of ice-contact, outwash, and alluvial origins compose surficial materials throughout most of the extent of the aquifer.

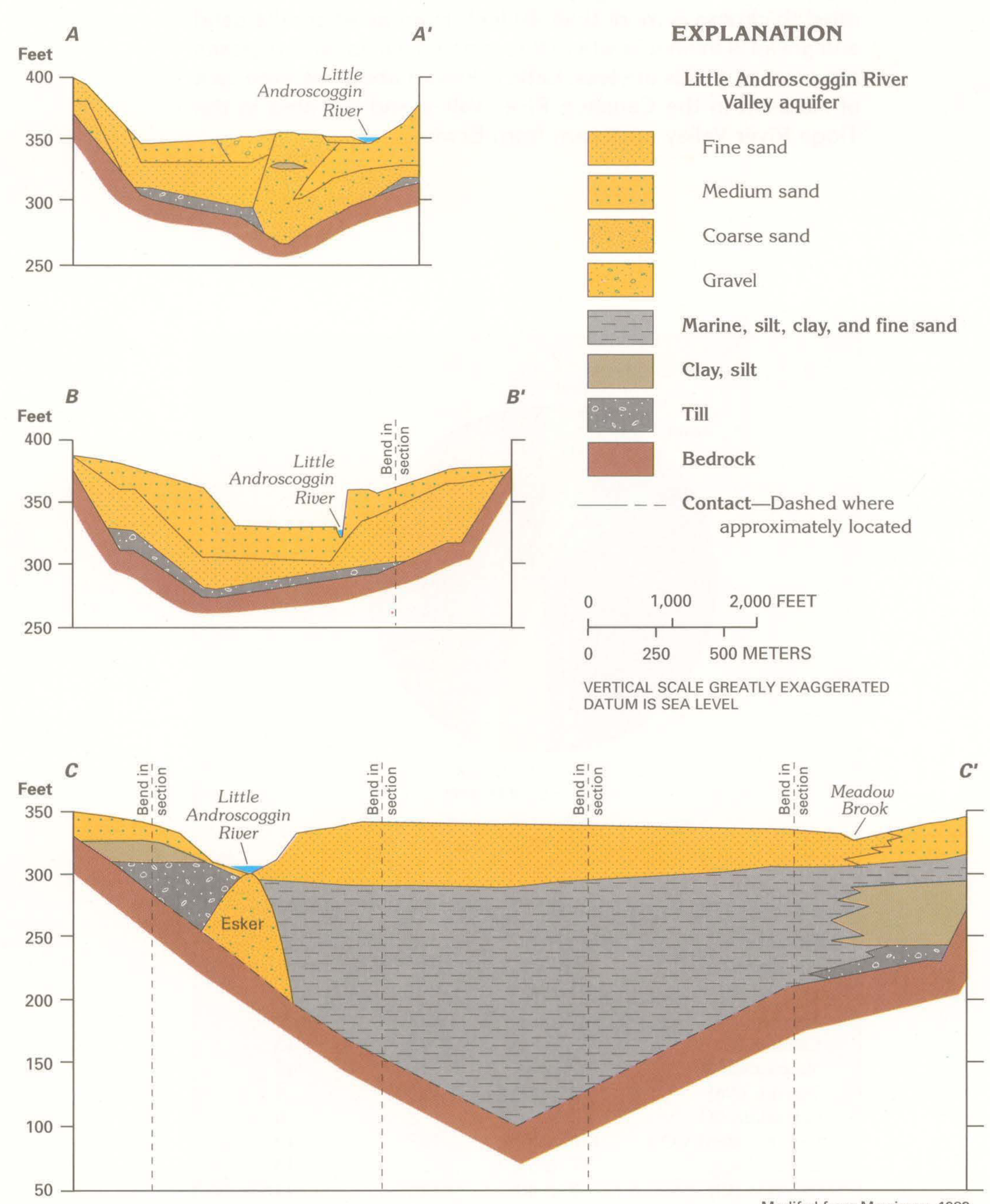


Figure 36. Much of the valley fill consists of fine to coarse sand. In the southern one-half of the valley, the aquifer overlies a thick section of marine sediments that consist of clay, silt, and sand. The lines of section are shown in figure 35.

HYDROLOGY

The Little Androscoggin River Valley aquifer is not hydraulically connected with valley-fill glacial aquifers in other valleys, and the aquifer does not extend past the drainage basin of the Little Androscoggin River. Thus, precipitation that falls on the Little Androscoggin River aquifer and the surrounding basin area is the source of all water in the basin. Long-term, average annual precipitation is about 43.2 inches of which 53 percent, or about 22.9 inches, is returned to the atmosphere by evaporation or is transpired by plants. The remaining 47 percent, or about 20.3 inches, leaves the basin as streamflow; some of this water runs off directly, and some is released more slowly from storage in lakes, marshes, or the aquifer.

The largest volume of water stored in the basin is in the Little Androscoggin River Valley aquifer; water enters the aquifer as recharge primarily from precipitation that falls directly on the aquifer. During water year 1981, direct recharge to the 16-square-mile aquifer was estimated to be at an average annual rate of 16.4 cubic feet per second (**table 5**).

Additional recharge is contributed by overland runoff from the 23 square miles of till-covered hills within the basin that surrounds the aquifer. Although some water undoubtedly moves in the till and in the marine sediments that underlie the aquifer, the extremely low hydraulic conductivity of these materials (**table 6**) precludes any appreciable quantity of water entering the aquifer as underflow. Inflow from the upland areas is considered to be totally from overland flow. Recharge from overland runoff during water year 1981 was estimated to be at an average annual rate of 11.2 cubic feet per second (**table 5**).

A third source of recharge to the aquifer is from the infiltration of water from the Little Androscoggin River and its tributary streams when and where the water level in the streams is higher than the hydraulic head in the aquifer; for example, this condition occurs in the vicinity of the South Paris well field where ground-water withdrawals have lowered the water table of the aquifer and induced recharge from the river. The contribution of water from the river to the aquifer during water year 1981 was estimated to be at a rate of 1.4 cubic feet per second (**table 5**). These several sources of water contribute a total of about 29 cubic feet per second of water to the aquifer as recharge.

As recharge water enters the soil overlying the aquifer, it moves downward through an unsaturated zone to the top of the saturated zone, which is the water table and the top of the aquifer. A contour map of the water-table altitude (**fig. 38**) indicates that the water table slopes from the edges of the aquifer toward the Little Androscoggin River and from north to south in a downstream direction. Thus, water that enters the aquifer flows horizontally through the aquifer in response to the hydraulic gradient toward the Little Androscoggin River (**figs. 38, 39**) where it is discharged and becomes part of the streamflow. Small local flow systems that discharge to tributary streams or marshes are superimposed on this larger system.

The rate of ground-water flow is dependent on the hydraulic gradient and the hydraulic conductivity of the aquifer material. Hydraulic-conductivity values listed in **table 6** indicate that under an equal hydraulic gradient, the rate of flow is largest in ice-contact deposits, much less in outwash deposits, and minimal in till and marine deposits.

Ground-water seepage into the Little Androscoggin River and its tributaries is the principal method of discharge from the Little Androscoggin River Valley aquifer. The rate of this seepage was about 26.7 cubic feet per second during water year 1981 (**table 5**). The other method of discharge, which diverts water that normally would discharge to streams, is ground-water withdrawals from the aquifer for municipal and domestic water supply. Water was withdrawn during water year 1981 at a rate of 2.3 cubic feet per second. Most of the withdrawals were for municipal supply for the towns of South Paris, Norway, and Oxford.

Total discharge (outflow) from the Little Androscoggin River Valley aquifer was about 29 cubic feet per second during water year 1981, which was equal to aquifer recharge (inflow) (**table 5**). Thus, the aquifer is in equilibrium, with recharge equal to discharge, and the volume of water in storage remains constant.

The principal hydrologic effect of the marine sediments associated with valley-fill glacial aquifers in Segment 12 (**fig. 40**) is to form a barrier to ground-water flow. The fine-grained sediments retard the movement of water between the glacial deposits and bedrock.

Wells completed in the Little Androscoggin River Valley aquifer yield from 6 to 1,300 gallons per minute. Yields are largest for wells completed in the coarse-grained ice-contact deposits and least for wells completed in outwash material. The average yield of eight large-diameter municipal wells completed in the aquifer is 650 gallons per minute. Chances of obtaining large well yields are greater north of Norway because the coarse-grained ice-contact deposits are thicker and more extensive.

GROUND-WATER QUALITY

The water from the Little Androscoggin River Valley aquifer has small dissolved-solids concentrations (**fig. 41**) and generally is suitable for most uses. The water is a calcium sodium bicarbonate type, which is not typical of water in most valley-fill glacial aquifers. Large concentrations of iron and manganese in the water are present locally; these constituents are not a hazard to health and can be easily removed from the water by treatment. The water typically is slightly acidic and soft.

Water in the bedrock surrounding the Little Androscoggin River Valley aquifer is similarly a calcium sodium bicarbonate type (**fig. 42**) but has a higher ratio of sodium to chloride than does water from the aquifer. Minimal circulation of water in the bedrock, which results in the water being in contact with aquifer minerals for a long time, might account for the relatively large concentrations of sodium.

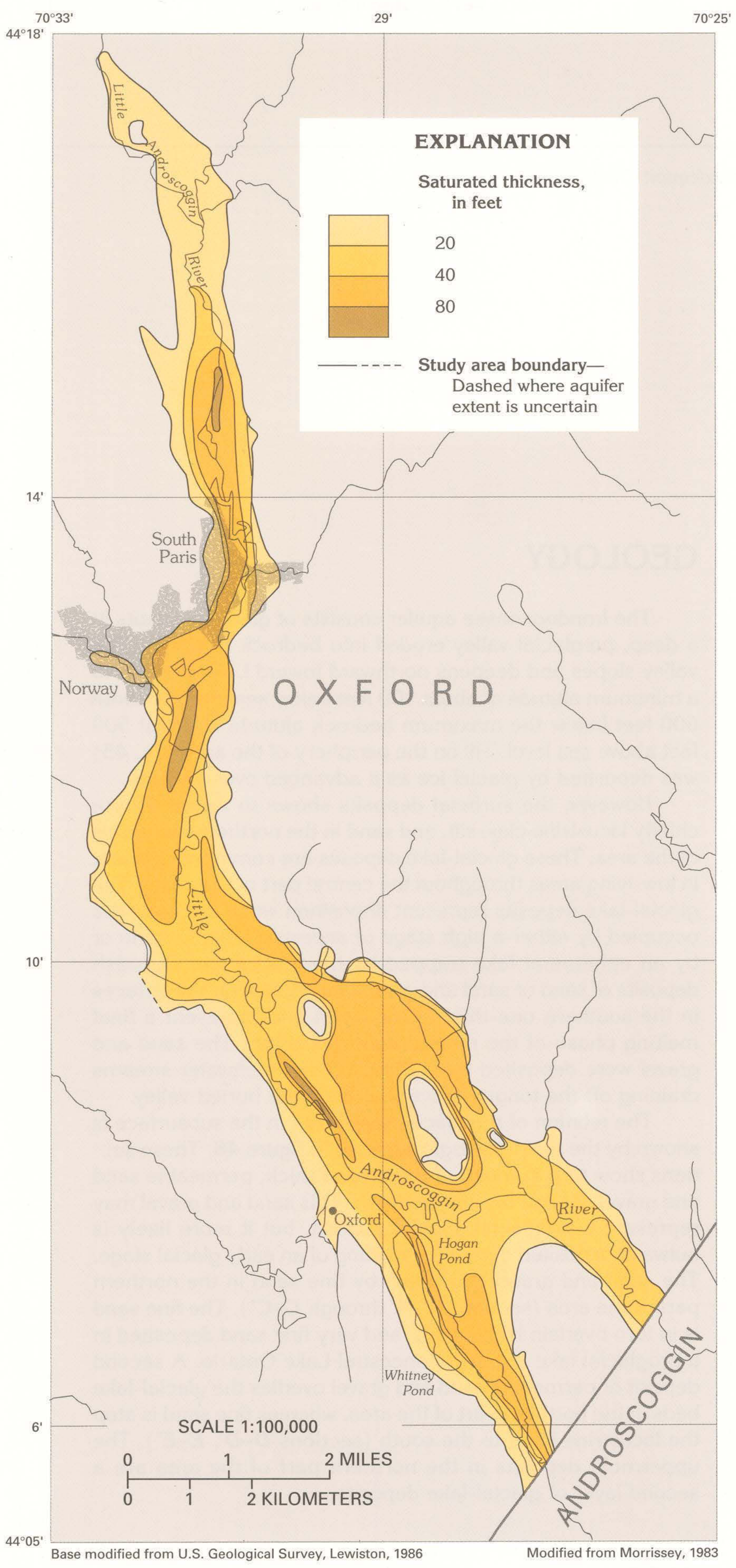


Figure 37. *The saturated thickness of the water-yielding, mostly coarse-grained deposits that form the Little Androscoggin River Valley aquifer ranges from 0 to more than 80 feet.*

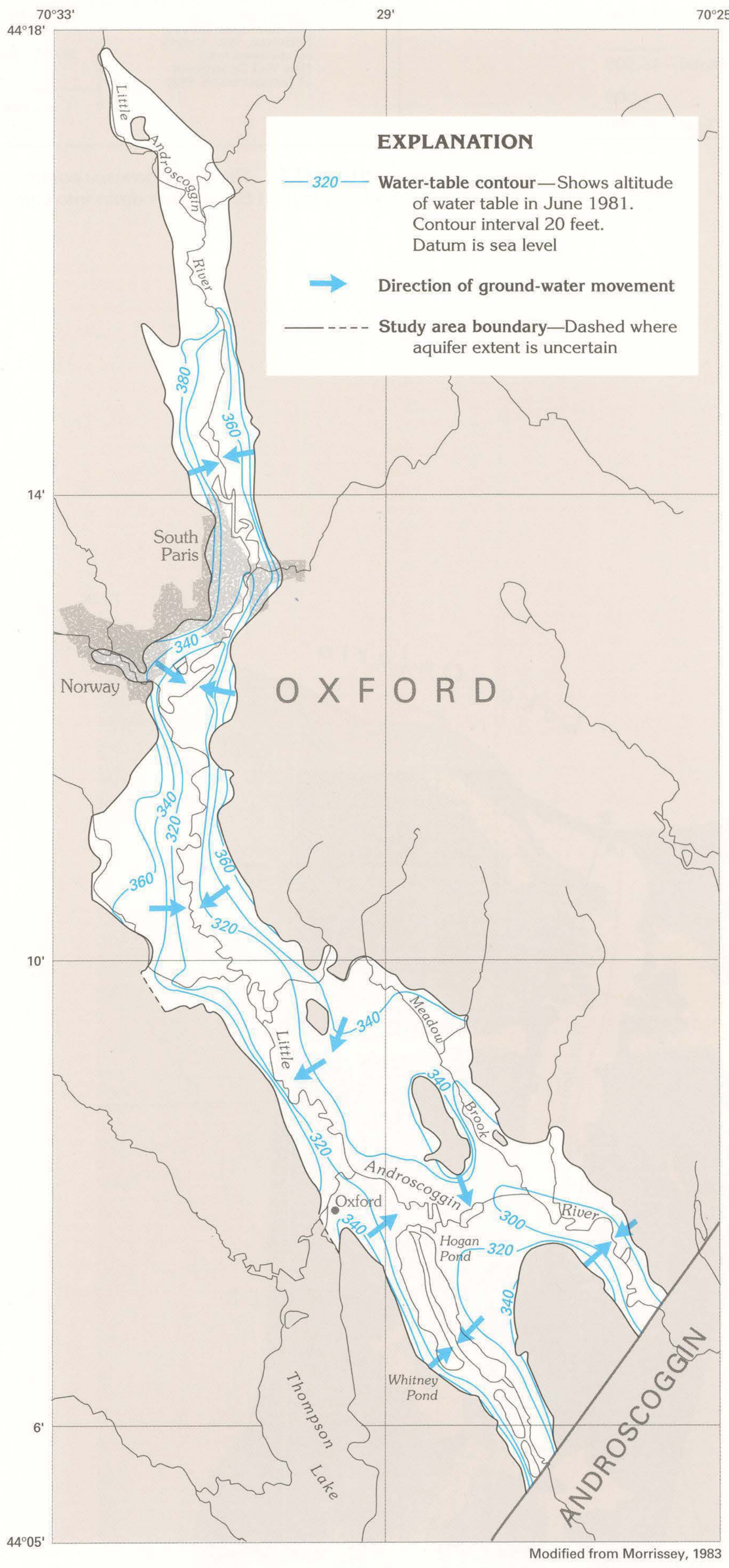


Figure 38. *Water in the aquifer moves from the edges of the aquifer toward the Little Androscoggin River and its tributaries and in a generally downstream direction.*

Table 5. *During water year 1981, water moved through the Little Androscoggin River Basin at a rate of about 29 cubic feet per second*

[Source: Morrissey, 1983]

Recharge (inflow)	Rate (cubic feet per second)	Discharge (outflow)	Rate (cubic feet per second)
Infiltration from precipitation	16.4	Ground-water seepage to streams	26.7
Overland runoff from surrounding till-covered hills	11.2	Ground-water withdrawals	2.3
Leakage from streams	1.4		
Total	29	Total	29

Table 6. *The estimated horizontal hydraulic conductivity of coarse grained ice-contact deposits is an order of magnitude greater than that of outwash deposits, which, in turn, have a hydraulic conductivity 4 to 20 times greater than that of till and marine sediments*

[Source: Morrissey, 1983]

Glacial material	Estimated hydraulic conductivity (feet per day)
Coarse grained ice-contact deposits	150–200
Outwash deposits	15–80
Till and marine sediments	4

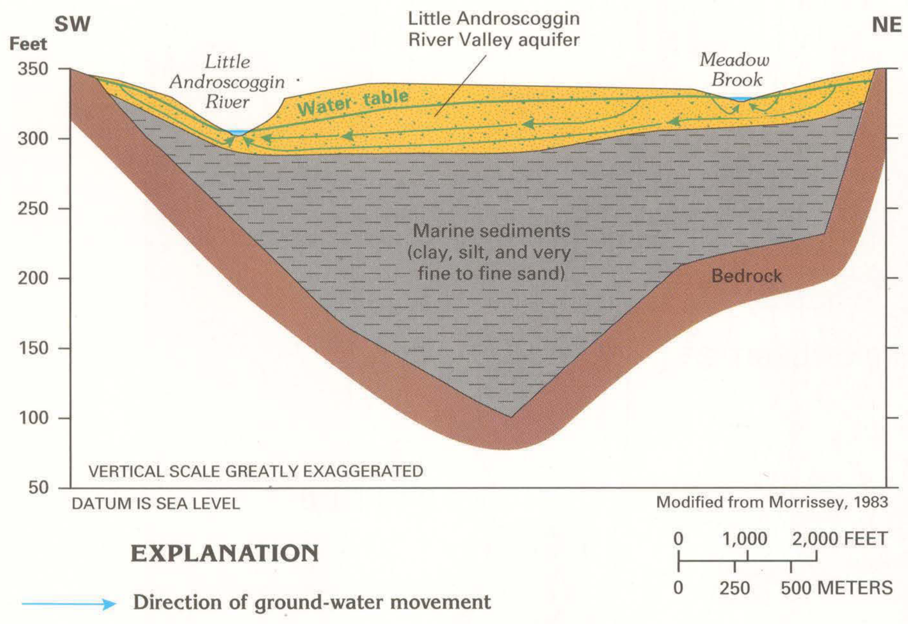
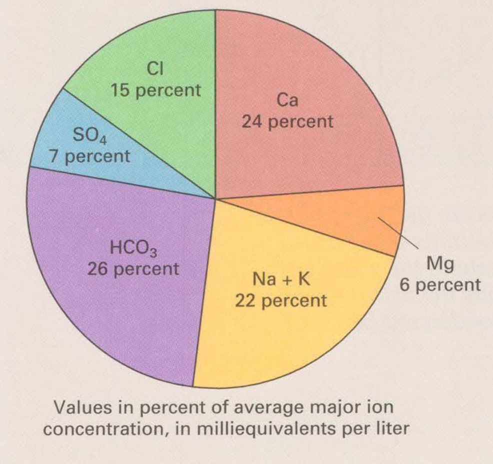


Figure 39. *A generalized hydrogeologic section shows that water in the aquifer flows downgradient toward the Little Androscoggin River where the water is discharged. Superimposed on this larger ground-water flow system are local flow systems through which recharge moves only short distances to tributary streams or small ponds or marshes where the water is discharged.*

Figure 40. *Marine sediments that consist of clay, silt, and very fine to fine sand underlie outwash deposits in the southern one-half of the Little Androscoggin River Valley aquifer.*

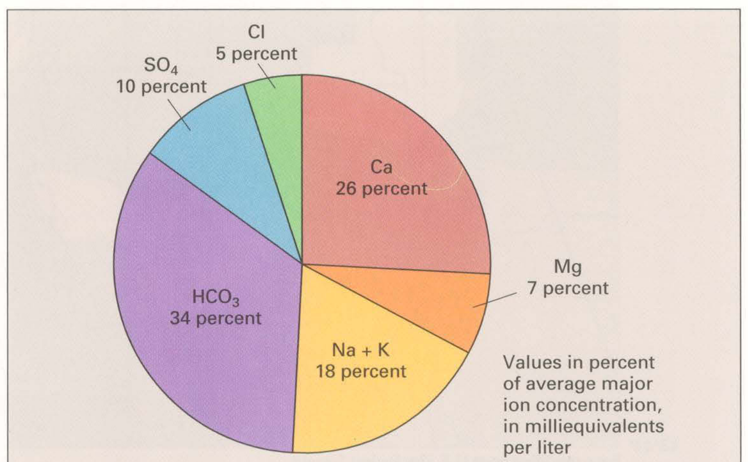


Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	4.4 to 7.4	6.5 (median)	35
Hardness ($CaCO_3$)	3 to 64	24	38
Calcium (Ca)	1.0 to 22	7.7	38
Magnesium (Mg)	0.2 to 3.9	1.3	38
Sodium (Na)	1.1 to 18	7	38
Potassium (K)	0.2 to 5.7	1.5	38
Bicarbonate (HCO_3)	3.6 to 71	25.6	37
Sulfate (SO_4)	1.3 to 13	6	38
Chloride (Cl)	0.7 to 31	8.8	38
Dissolved solids	20 to 139	67	37

Data from U.S. Geological Survey, 1990

Figure 41. *Water in the Little Androscoggin River Valley aquifer has small concentrations of dissolved solids and typically is slightly acidic and soft.*



Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	5.8 to 7.6	7.6 (median)	8
Hardness ($CaCO_3$)	24 to 150	68	8
Calcium (Ca)	8.1 to 47	21	8
Magnesium (Mg)	0.9 to 7.7	3.6	8
Sodium (Na)	3 to 49	16	8
Potassium (K)	1 to 5.2	2.3	8
Bicarbonate (HCO_3)	34 to 134	83	8
Sulfate (SO_4)	5.4 to 74	20	8
Chloride (Cl)	1.1 to 25	7.9	8
Dissolved solids	58 to 238	128	8

Data from U.S. Geological Survey, 1990

Figure 42. *Water in the bedrock that surrounds the Little Androscoggin River Valley aquifer is similar in chemical composition to that in the aquifer but is slightly more mineralized.*

IRONDOGENESEE AQUIFER

The Irondogenesee aquifer is an example of a glacial-drift aquifer deposited by meltwater streams in a broad lowland partly inundated by large freshwater lakes. The broad lowland was inundated by the glacial lake that was the predecessor of Lake Ontario when it was at a high stage during the glacial period. Soils and the underlying parent material partly consist of clay and silt laid down as lake sediments. As the glacier melted, northward drainage was blocked by the retreating ice; thus, ponding of meltwater occurred in the area with accompanying deposition of fine-grained glacial-lake sediments.

The Irondogenesee aquifer is in the Irondogenesee buried valley in eastern Monroe County, N.Y. (**fig. 43**), in the drainage basin of Irondequoit Creek. The valley is a deep, preglacial valley cut into bedrock by a stream that drained northward into the ancestral Lake Ontario basin. The bedrock valley underlies the present Irondequoit Creek and Irondequoit Bay; drainage is northward into Lake Ontario. The city of Rochester is at the western edge of the area, and the village of Webster is about 2 miles east of the area. The villages of East Rochester, Pittsford, Penfield, and West Webster are within the area. The area is heavily urbanized and has an estimated population of 200,000.

Irondequoit Creek and Bay are the dominant geographic features. The creek, which drains about 150 square miles of rolling glaciated topography to the south, has incised as much as 200 feet into fine-grained sediments on the relatively flat lake plain from East Rochester north to the bay. Irondequoit Bay covers about 2.6 square miles and has a maximum reported depth of 75 feet. The bay connects with Lake Ontario through a narrow inlet that is shielded by a sandbar. Steep, wooded bluffs about 100 feet high border the bay and are underlain by glacial and proglacial-lake sediments. Extensive wetlands are present along the southern part of the bay and the downstream reaches of Irondequoit Creek.

Water from the Irondogenesee aquifer supplies about 47,500 people, and about 11,500 of them are supplied by municipal water systems that serve the villages of East Rochester and Pittsford (**table 7**). The Sand Bar and Dewitt Road well fields (**fig. 43**) supply water to about 35,000 people in Webster. Private wells constructed for domestic use supply about 1,000 people. The remaining population is served by the Monroe County Water Authority, which gets water from Lake Ontario. Industrial ground-water use in the area is negligible; most industry is supplied from Lake Ontario. Some industries and towns have developed large-capacity wells but have not used them because of the ready access to lake water.

Table 7. *Municipal water systems supplied ground water to about 46,500 people in and near the Irondogenesee Valley area during 1980*

[Source: Waller and others, 1982]

Source of ground-water supply	Population served, 1980
Municipal water systems	
1. East Rochester (three wells)	8,000
2. Pittsford (two wells)	3,500
3. Webster (Sand Bar [SB] and Dewitt Road [DR] well fields)	35,000
Subtotal	46,500
Private wells	1,000
Total	47,500

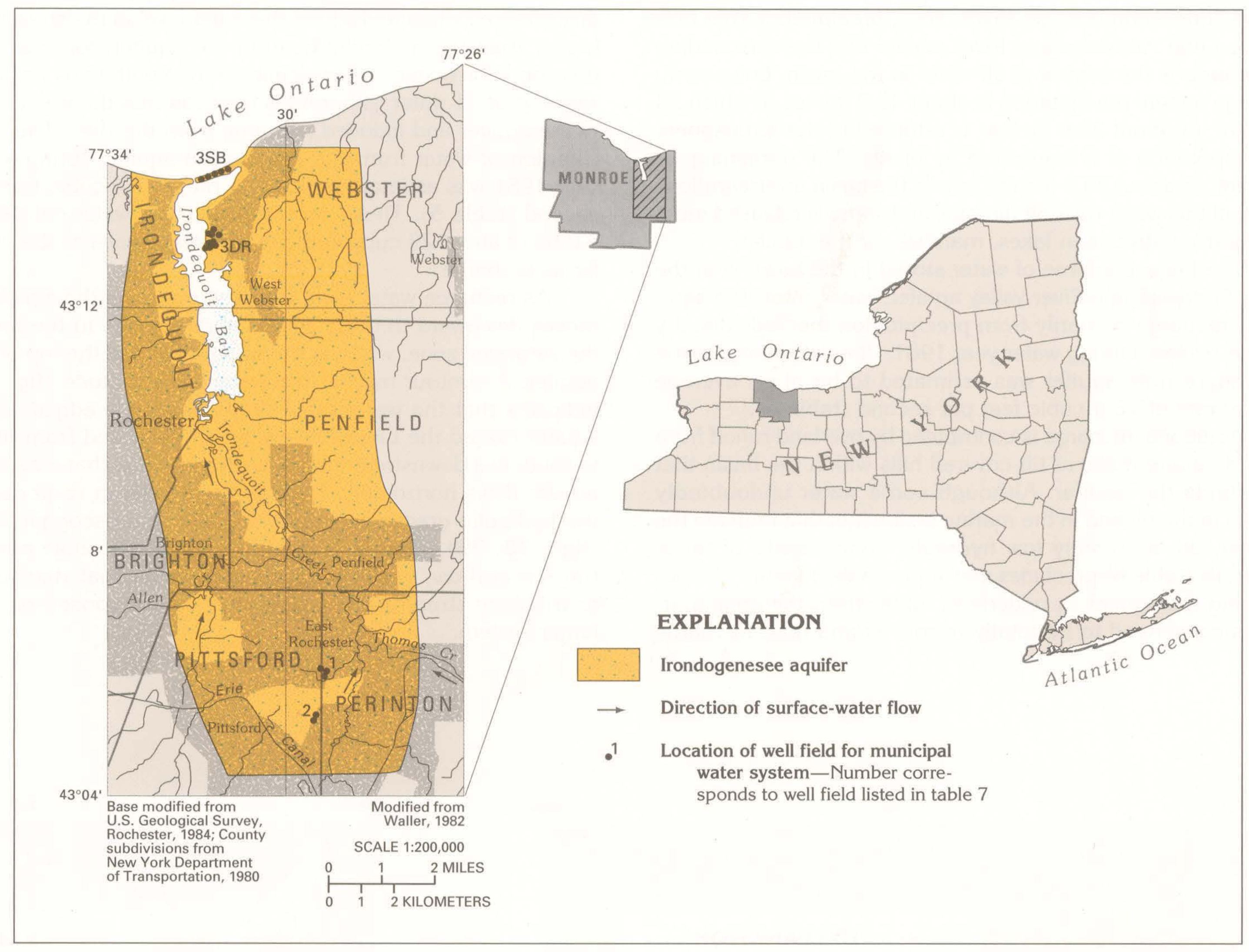


Figure 43. *The Irondogenesee aquifer underlies Irondequoit Creek and Irondequoit Bay, which drain into Lake Ontario.*

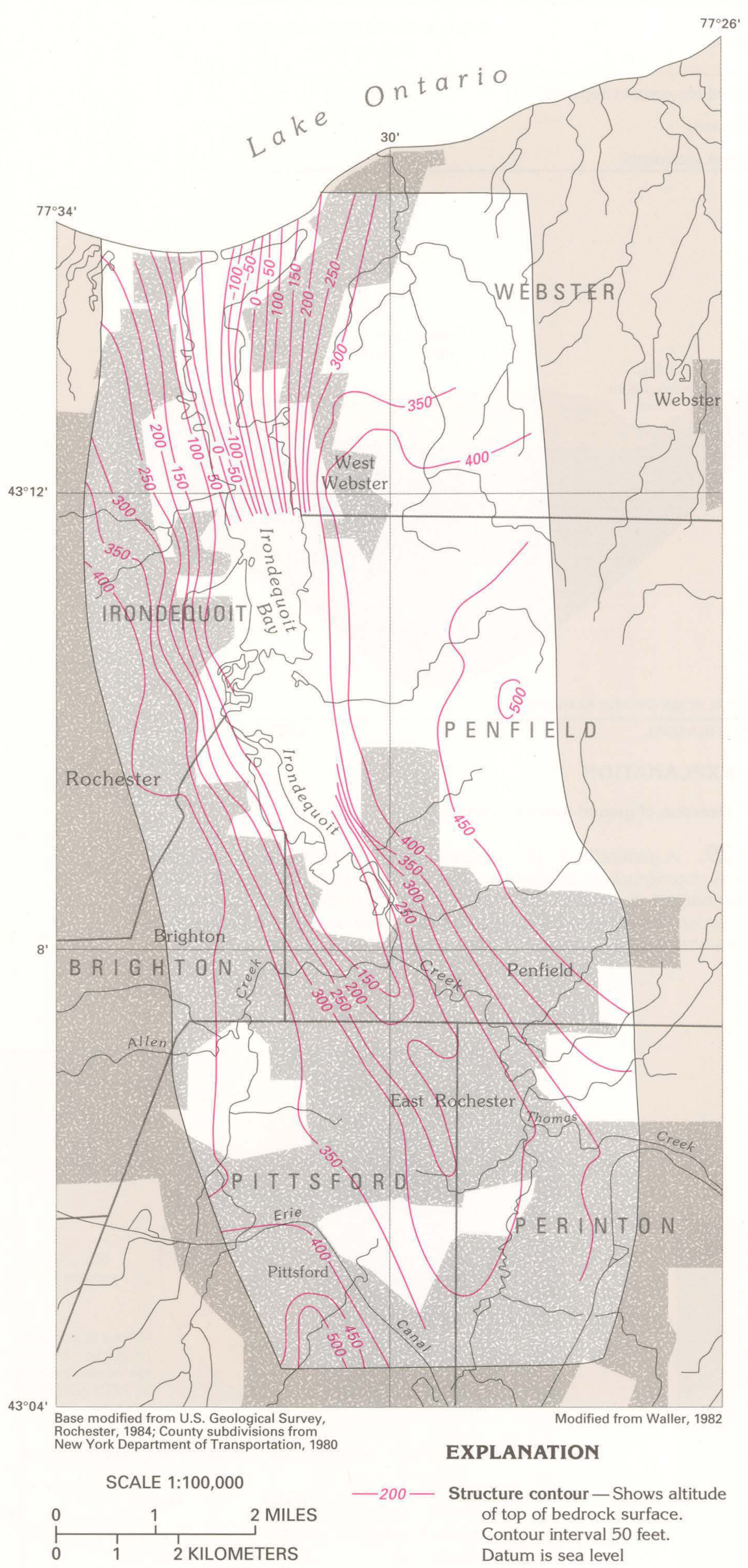


Figure 44. *A deep, preglacial valley eroded into the bedrock surface contains the Irondogenese aquifer.*

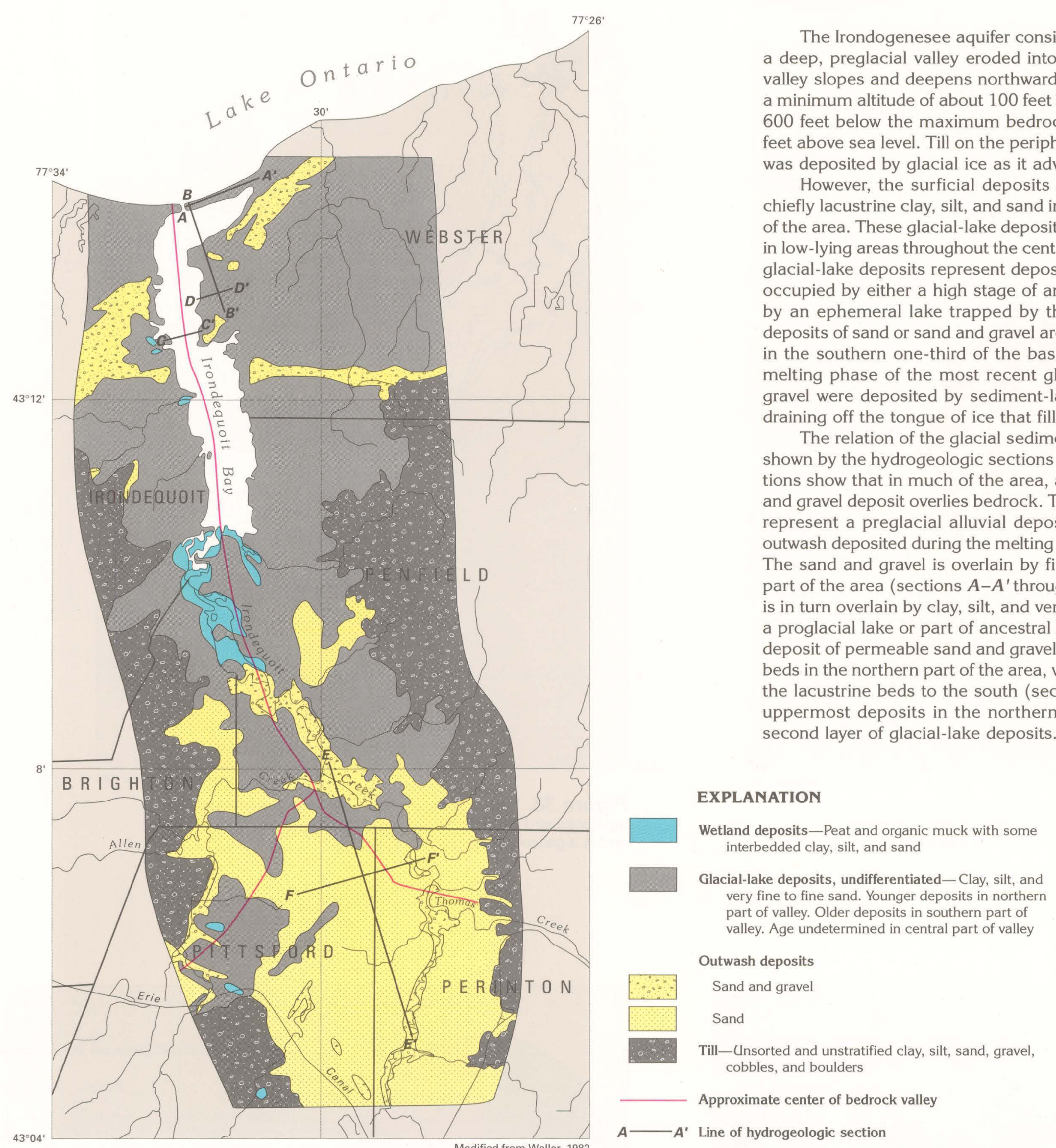


Figure 45. *Glacial-lake deposits are the predominant surficial deposits in the northern two-thirds of the area, and outwash deposits are predominant in the southern one-third. Extensive areas of till mantle the valley edges, and wetland deposits are south of Irondequoit Bay.*

GEOLOGY

The Irondogenesee aquifer consists of glacial deposits in a deep, preglacial valley eroded into bedrock (**fig. 44**). The valley slopes and deepens northward toward Lake Ontario to a minimum altitude of about 100 feet below sea level, or about 600 feet below the maximum bedrock altitude of about 500 feet above sea level. Till on the periphery of the area (**fig. 45**) was deposited by glacial ice as it advanced over the area.

However, the surficial deposits shown in **figure 45** are chiefly lacustrine clay, silt, and sand in the northern two-thirds of the area. These glacial-lake deposits are commonly present in low-lying areas throughout the central part of the valley. The glacial-lake deposits represent deposition when the area was occupied by either a high stage of ancestral Lake Ontario or by an ephemeral lake trapped by the glacial ice. Outwash deposits of sand or sand and gravel are present on the terraces in the southern one-third of the basin and represent a final melting phase of the most recent glaciation. The sand and gravel were deposited by sediment-laden meltwater streams draining off the tongue of ice that filled the buried valley.

The relation of the glacial sediments in the subsurface is shown by the hydrogeologic sections in **figure 46**. These sections show that in much of the area, a thick, permeable sand and gravel deposit overlies bedrock. This sand and gravel may represent a preglacial alluvial deposit, but it more likely is outwash deposited during the melting of an early glacial stage. The sand and gravel is overlain by fine sand in the northern part of the area (sections ***A–A'*** through ***C–C'***). The fine sand is in turn overlain by clay, silt, and very fine sand deposited in a proglacial lake or part of ancestral Lake Ontario. A second deposit of permeable sand and gravel overlies the glacial-lake beds in the northern part of the area, whereas fine sand is atop the lacustrine beds to the south (sections ***D–D'***, ***E–E'***). The uppermost deposits in the northern part of the area are a second layer of glacial-lake deposits.

AQUIFER THICKNESS AND EXTENT

The Irondogenesee aquifer consists of two thick, productive sand and gravel layers and lenses that are separated in most places by less permeable glacial-lake beds. Two well fields, the Dewitt Road and Sand Bar fields that supply the village of Webster, have been developed in the northern part of the aquifer. Wells in the Sand Bar field obtain water from the upper and lower permeable zones of the aquifer (sections *A–A′*, *B–B′*, **fig. 46**). Wells in the Dewitt Road field reportedly produce water from only the lower permeable zone (sections *C–C′*, *D–D′*, **fig. 46**), which is hydraulically connected to the lower permeable zone north of the well field (section *B–B′*, **fig. 46**). The lower permeable zone of the aquifer is from 60 to 85 feet thick and might extend as far west as the center of the Irondogenesee Valley; the zone extends northward under Lake Ontario. In the southern part of the area, the aquifer consists only of the lower permeable zone (sections *E–E′*, *F–F′*, **fig. 46**). Here, the lower permeable zone consists of sand and gravel, which is about 80 feet thick (section *F–F′*, **fig. 46**) and extends laterally at least 3 miles. Well fields that supply East Rochester and Pittsford obtain water from this zone. The northern extent of this sand and gravel is unknown, but it may connect with the lower permeable zone of the aquifer at the Dewitt Road well field.

HYDROLOGY

Water in the upper permeable zone is under water-table (unconfined) conditions where the sand and gravel of the zone are exposed at the land surface (**fig. 45**) or where the overlying glacial-lake deposits are extremely thin, such as in the vicinity of the Sand Bar well field (section *A–A′*, **fig. 46**). The water is under artesian (confined) conditions where the upper permeable zone is covered by thick glacial-lake deposits. Recharge to the upper permeable zone primarily is by infiltration of precipitation into the sand and gravel where it is exposed at the land surface. Water in the upper permeable zone moves toward natural discharge areas along the shores of Irondequoit Bay and Lake Ontario. When wells completed in the upper permeable zone at the Sand Bar well field are pumped, they intercept some of the water moving toward natural discharge areas, increasing sustained well yields. Pumping of these wells also probably causes some water to move from the bay and the lake into the upper permeable zone, further increasing sustained well yields.

Water in the lower permeable zone is under artesian conditions throughout most of the area, especially in the northern part. The water is under unconfined conditions where the sand and gravel of the lower permeable zone are exposed at the land surface north of East Rochester (**fig. 45**; left side of section *E–E′*, **fig. 46**).

In the southern part of the area, most recharge to the lower permeable zone probably is by leakage through the beds of streams, such as Irondequoit Creek, that have eroded channels into the zone in their upstream reaches. Fractures in the underlying bedrock also contribute some recharge to the lower permeable zone. Water in the lower permeable zone generally moves toward Iron-dequoit Creek and downgradient to the north. Most discharge from the lower permeable zone is either to Irondequoit Creek, especially in its middle reach north of East Rochester (left side of section *E–E′*, **fig. 46**), or by wells in the East Rochester, Pittsford, and Dewitt Road well fields (**fig. 43**). Some water might continue to move downgradient to the north to "recharge" the lower permeable zone in the northern part of the area if the lower permeable zone is continuous through the central part of the area.

In the northern part of the area, possible sources of recharge to the lower permeable zone are underflow from the south, inflow from fractured bedrock, and downward percolation of water from the upper permeable zone through the leaky confining unit between the two zones. The downward percolation of water from the upper permeable zone, at least in the vicinity of the Sand Bar and the Dewitt Road well fields, appears to be negligible because withdrawals from wells completed in the lower permeable zone at these well fields have had no effect on water levels in the upper permeable zone. The natural hydraulic gradient in the lower permeable zone is to the north toward Lake Ontario. Withdrawals by wells, which is the principal form of discharge from the lower permeable zone, at the Sand Bar and Dewitt Road well fields, however, have disrupted the natural hydraulic gradient. Withdrawals at the two well fields have lowered water levels about 70 feet near the well fields and reversed the natural hydraulic gradient. The wells are capturing water that formerly discharged into Lake Ontario, thus increasing sustained well yields. The reversal in hydraulic gradient also has caused water from Lake Ontario to flow into the lower permeable zone, further increasing well yields.

Yields of wells completed in the Irondogenesee aquifer generally are several hundred gallons per minute. Wells in the Sand Bar well field can yield 2.8 million gallons per day from the upper permeable zone and as much as 10 million gallons per day from the lower permeable zone. Withdrawals from the Dewitt Road well field are as much as 13 million gallons per day. The potential volume of water available from the southern well fields is unknown, but withdrawals of 0.4 million gallons per day from only two wells caused little drawdown; this indicates that the fields can produce at least a few million gallons per day.

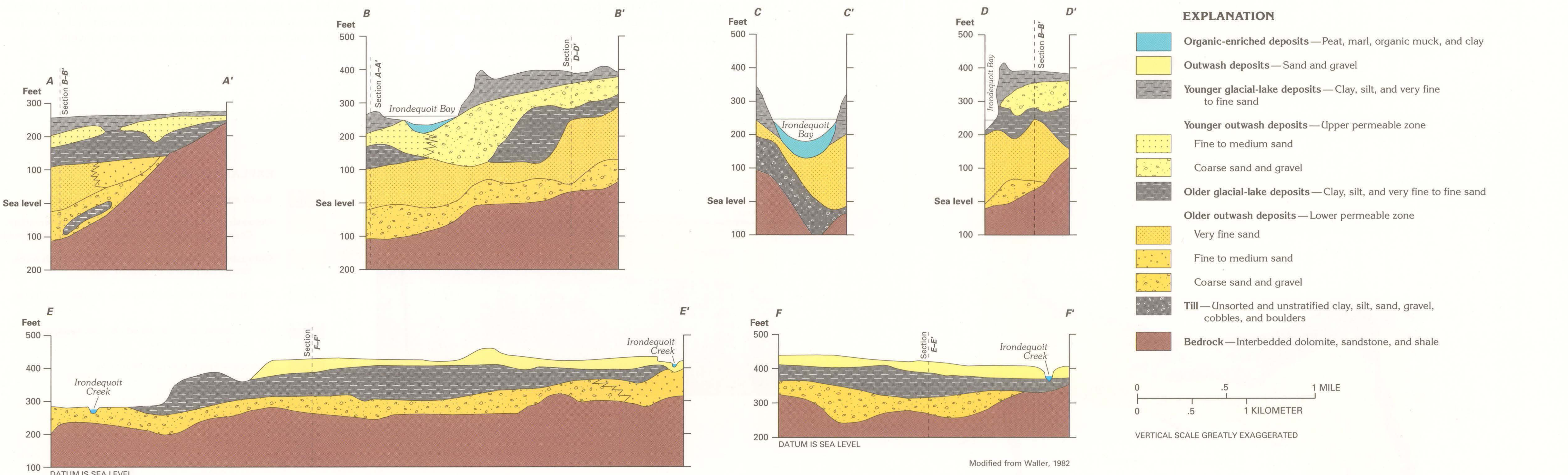
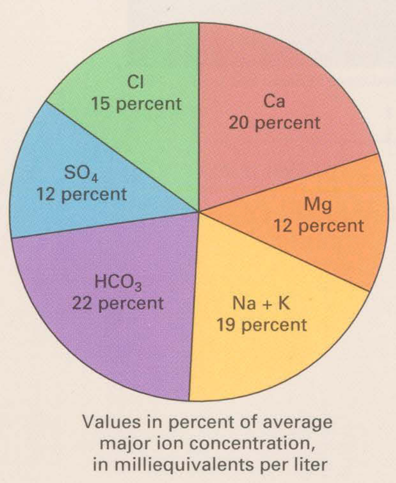


Figure 46. *Two thick and productive water-yielding zones that consist of fine to coarse sand and gravel (outwash deposits) that are separated by clay, silt, and very fine to fine sand (glacial-lake and outwash deposits) form the Irondogenesee aquifer. The areal extent of the lower water-yielding zone is greater than that of the upper water-yielding zone. The lines of section are shown in figure 45.*



Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	7.0 to 8.0	7.4 (median)	8
Hardness ($CaCO_3$)	110 to 490	373	8
Calcium (Ca)	27 to 130	95	8
Magnesium (Mg)	9.4 to 44	33	8
Sodium (Na)	32 to 250	101	7
Potassium (K)	1.6 to 2.7	2.3	7
Bicarbonate (HCO_3)	235 to 683	312	8
Sulfate (SO_4)	100 to 150	141	8
Chloride (Cl)	24 to 230	129	8
Dissolved solids	465 to 1,010	665	7
Nitrate (NO_3)	0 to 0.14	0.06	5
Iron (Fe)	0.05 to 0.42	0.18	7

Data from U.S. Geological Survey, 1980

Figure 47. *Water in the Irondogenesee aquifer has large concentrations of calcium, sodium, bicarbonate, chloride, and sulfate. The water typically is alkaline and very hard.*

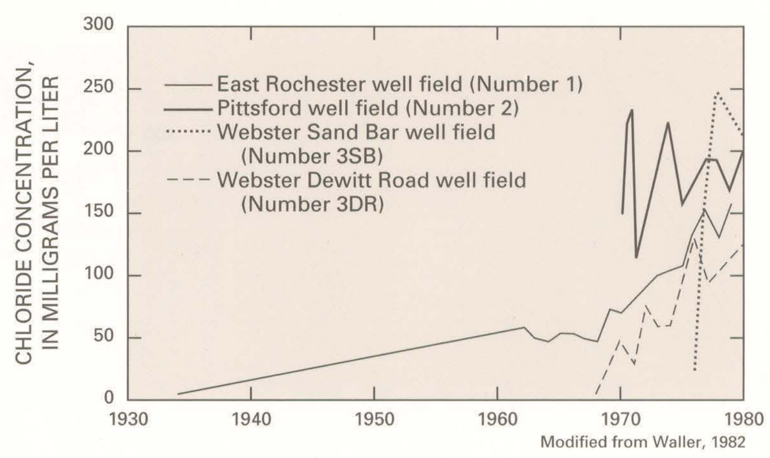


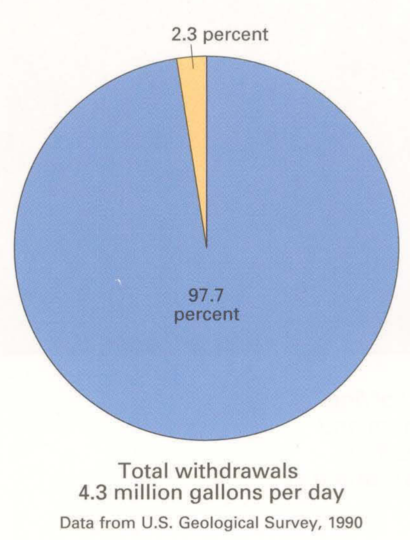
Figure 48. *Chloride concentrations in water from selected wells completed in the Irondogenesee aquifer show an increasing trend with time as cumulative withdrawals increased. This trend might result from either the migration of saltwater into the aquifer from the underlying bedrock or contamination of the aquifer by road-deicing chemicals. The locations of the well fields are shown in figure 43.*

GROUND-WATER QUALITY

Water in the Irondogenesee aquifer is a mixed-ion type and has large dissolved-solids concentrations, as indicated by data for eight representative chemical analyses shown in **figure 47**. The water typically is alkaline and very hard. As expected, calcium concentrations are large, because of carbonate-rock fragments in the aquifer. The large calcium concentrations result in increased dissolved-solids concentrations, alkalinity, and hardness.

Chloride is a problem in water from some wells, as indicated by the large average concentration and the upper range of concentrations (**fig. 47**). Chloride concentrations appear to be increasing in water from several municipal wells with time (**fig. 48**) as cumulative withdrawals increased. Because these wells are completed in the aquifer just above the bedrock surface, saltwater from the bedrock might be migrating toward the pumping wells. These increased chloride concentrations also might be an indication of contamination of the aquifer by road-deicing chemicals.

Although concentrations of many constituents in water from the Irondogenesee aquifer are large compared to concentrations in water from other valley-fill glacial aquifers, the water from the Irondogenesee aquifer generally is suitable for most uses. Locally, the water contains objectionable concentrations of manganese and iron, or is excessively hard; however, the water is easily treated.



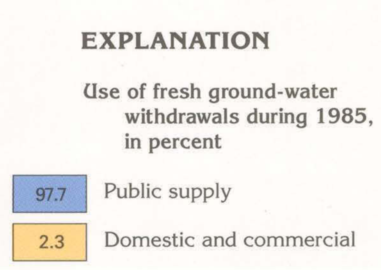


Figure 49. *Nearly all the freshwater withdrawn from the Irondogenesee aquifer during 1985 was used for public supply.*

Table 8. *Fresh ground-water withdrawals from the Irondogenesee aquifer during 1985 totaled about 4.3 million gallons per day*

[Source: New York State Department of Health,1981; unpublished data from New York State Department of Health and U.S. Geological Survey]

Source of ground-water supply	Fresh ground-water withdrawals (million gallons per day)
Municipal water systems	
1. East Rochester (three wells)	0.7
2. Pittsford (two wells)	.4
3. Webster (Sand Bar [SB] and Dewitt Road [DR] well fields)	3.1
Private wells	
Home use of 100 gallons per person per day is assumed	.1
Total	4.3

FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the Irondogenesee aquifer totaled about 4.3 million gallons per day during 1985 (**fig. 49**). Nearly all the water was withdrawn for public supply by three municipalities (**table 8**). Only about 2 percent of the water, or 0.1 million gallons per day, was withdrawn for domestic supply.

Surficial aquifer system, Cape Cod glacial aquifer

INTRODUCTION

The Cape Cod glacial aquifer is an example of an aquifer that consists of extensive outwash sheets that buried preglacial topography. The outwash deposits consist largely of fine to coarse sand and gravel. Glacial-lake clay, silt, and very fine to fine sand, as well as unsorted till, are interbedded as layers and lenses in the thick outwash deposits.

The Cape Cod glacial aquifer underlies Cape Cod, Mass., which is a hook-shaped peninsula that extends about 40 miles into the Atlantic Ocean from the southeastern part of the State and has a north-trending extremity about 25 miles in length (**fig. 50**). The peninsula has an area of about 440 square miles and a maximum altitude of 309 feet above sea level. The cape is surrounded by seawater, even on the west where saltwater in the Cape Cod Canal separates the peninsula from the mainland. The resident population was estimated to be about 168,000 in 1985; in the summer, the influx of tourists swells the population to almost three times that number. Residents and tourists get freshwater from the glacial aquifer, which is recharged solely from precipitation.

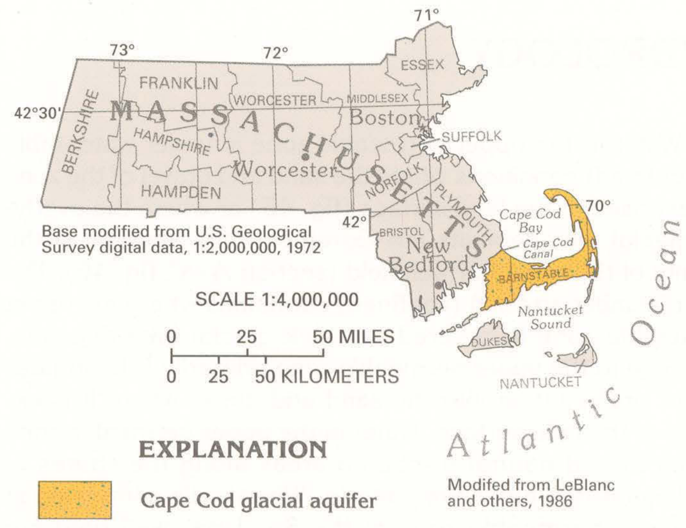


Figure 50. The Cape Cod glacial aquifer is located on the Cape Cod peninsula in southeastern Massachusetts.

GEOLOGY

The sediments on Cape Cod were deposited at or near the terminus of an ice sheet and consist of sandy terminal moraines (**fig. 51**) and an assortment of associated thick, sandy till, ice-contact, outwash, and glacial-lake deposits resting on crystalline bedrock. The bedrock surface slopes eastward from 80 to about 900 feet below sea level. The overlying glacial deposits range in thickness from 100 feet along the Cape Cod Canal to about 1,000 feet at Truro near the northern end of the peninsula. The wetland deposits and the beach and dune deposits shown in **figure 51** are postglacial deposits.

Coarse sand and gravel outwash, including local ice-contact deposits, is by far the most extensive type of glacial deposit at the land surface (**fig. 51**) and in the subsurface (**fig. 52**). The outwash consists predominantly of coarse sand and gravel (**fig. 53**) but contains fine sand in places. The outwash ranges in thickness from 50 to 200 feet and locally is interbedded with or overlies fine-grained glacial-lake deposits or till, as indicated in section *B–B'* of **figure 52**. Outwash sand and gravel generally has moderate to high permeability and forms the most productive aquifer on the cape.

Beach and dune deposits, which consist of fine to coarse sand (**figs. 51, 54**), are dispersed around the periphery of the peninsula but have only small areal extent and, although permeable, tend to be thin and largely unsaturated; accordingly, these deposits have virtually no potential for development of ground-water supplies. Glacial-lake and wetland deposits extend along the south shore of Cape Cod Bay (**fig. 51**). The glacial-lake deposits formed in a temporary lake, which was associated with retreat of the glacial ice, and consist of clay, silt, and very fine sand with some interbedded outwash sand and gravel. Generally, these deposits have minimal to moderate permeability. A terminal moraine that consists of till (poorly sorted sand and gravel with lenses of clay and silt) extends parallel to, but slightly inland from, Buzzards Bay and part of Cape Cod Bay. The hydrogeologic sections in **figure 52** show that till and lacustrine clay and silt are common at depth. These fine-grained materials tend to have minimal permeability and yield only small quantities of water to wells.

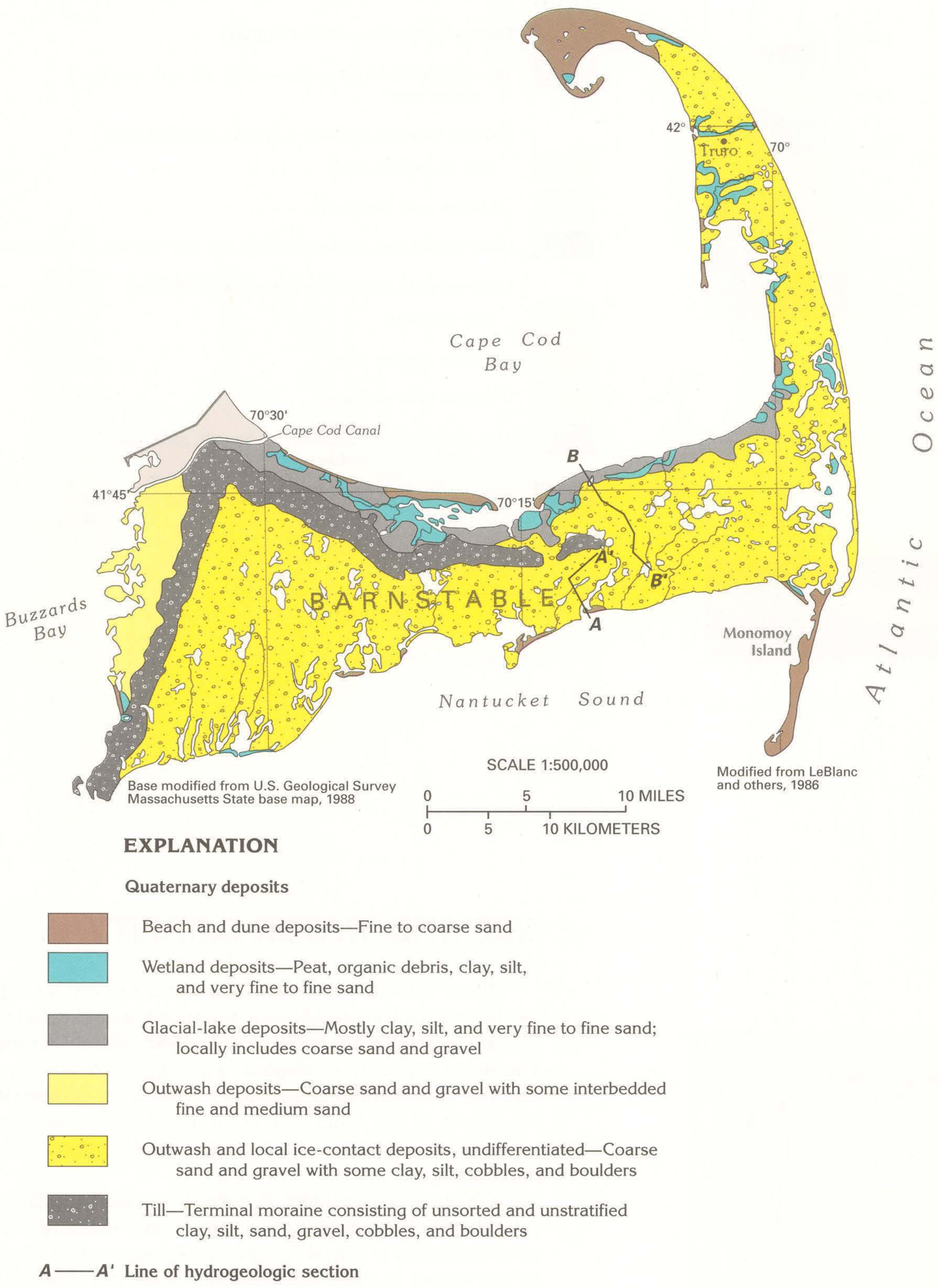


Figure 51. Outwash and local ice-contact sand and gravel are the most widespread surficial materials on Cape Cod. Wetland deposits and glacial-lake beds border much of Cape Cod Bay.

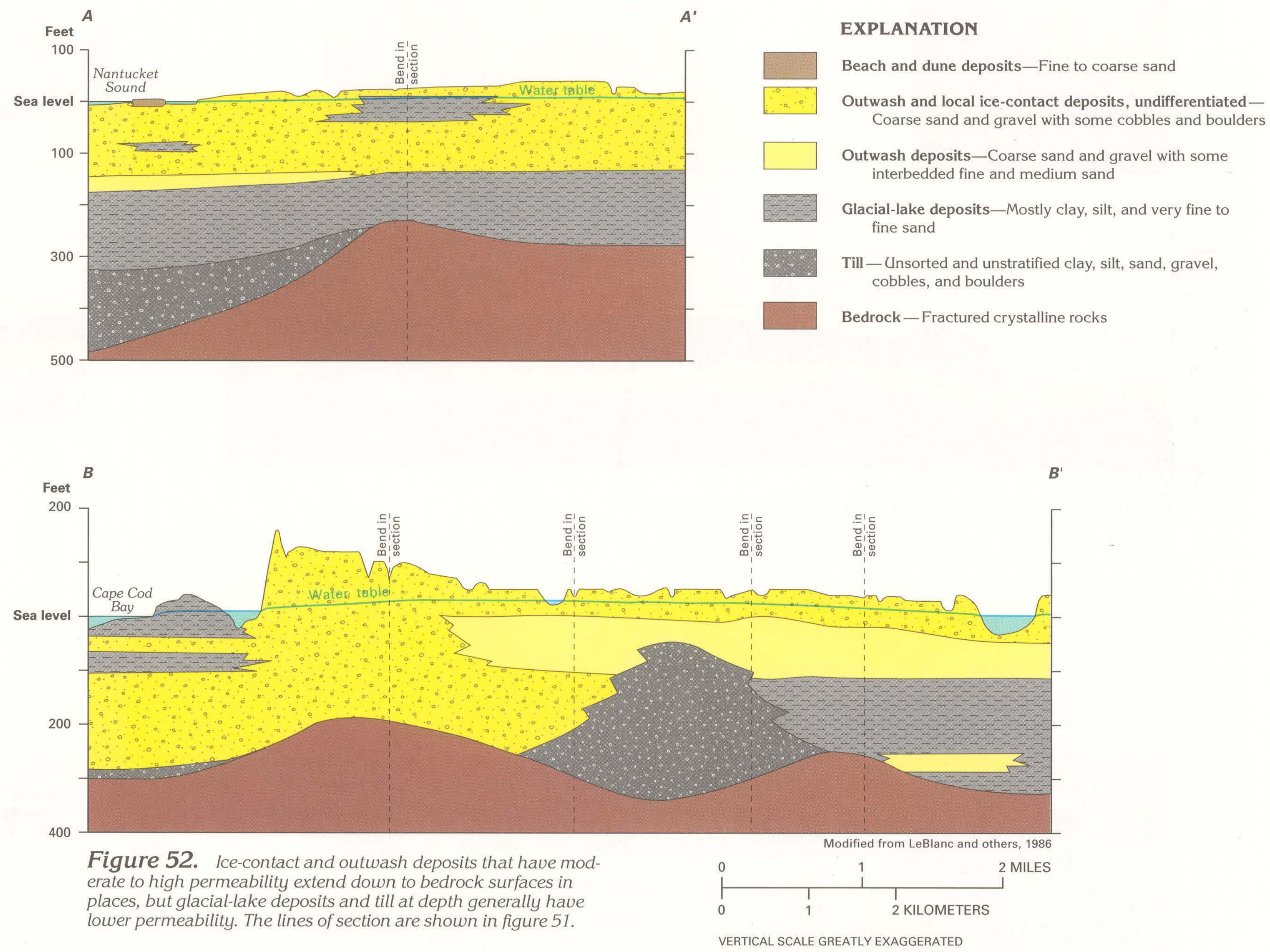


Figure 52. Ice-contact and outwash deposits that have moderate to high permeability extend down to bedrock surfaces in places, but glacial-lake deposits and till at depth generally have lower permeability. The lines of section are shown in figure 51.

Figure 53. Outwash deposits, such as those shown here, form the most widespread lithology on Cape Cod and consist predominantly of coarse sand and gravel.

Figure 54. Beach and dune deposits that consist of fine to coarse sand are located mostly at the extreme northern and southeastern ends of Cape Cod and along the southwestern shore of Cape Cod Bay. These deposits generally are unsaturated and have restricted extent.

HYDROLOGY

The Cape Cod glacial aquifer is recharged by the part of the water from precipitation that is not returned to the atmosphere by evapotranspiration or that does not run off directly to streams or other surface-water bodies. Because of the permeable nature of the soils on the cape, an estimated 45 percent of the average annual precipitation of 40 inches rapidly soaks into the soil and becomes ground-water recharge. An estimated 55 percent of the precipitation is evapotranspired, and less than 1 percent runs off directly to streams, ponds and lakes, or saltwater bodies.

Water that enters the soil percolates downward through an unsaturated zone until it reaches the water table. The water table of the Cape Cod glacial aquifer (**fig. 55**) is not a flat surface, but is dominated by six low mounds, which are highest at the greatest distance from the coastline. Thus, there is a hydraulic gradient on the ground-water reservoir reflected by differences in elevation of the water table. Water moves in response to this hydraulic gradient, from high areas to low areas, where it is discharged from the aquifer back to the land surface or directly to the ocean. The six mounds, or cells, are separated by ocean inlets or narrows, similar to the one shown in **figure 56**, that act as discharge areas. Under natural conditions, the cells are hydraulically independent ground-water flow systems. Ground-water flow in each of the six cells is steady because of a long-term balance between ground-water recharge and discharge. The configuration of the flow cells remains approximately the same from year to year. A computer analysis of the aquifer estimated that the total flow through the six systems is about 270 million gallons per day.

Thus, water movement through the aquifer, as indicated by the arrows in **figure 55**, is radially outward from the center of the mounds toward ocean inlets and to Buzzards Bay, the Cape Cod Canal, Nantucket Sound, Cape Cod Bay, and the Atlantic Ocean.

Ground-water flow in the vertical dimension is illustrated by the hydrogeologic section through the cape shown in **figure 57**. Flow is nearly horizontal in much of the aquifer. Vertical flow occurs mainly at recharge areas near water-table highs and at major discharge areas, such as the coast.

The lower boundary of the ground-water flow system is bedrock or slightly permeable glacial deposits, such as silt and very fine sand, or the transition, or mixing, zone between freshwater and saltwater in the aquifer. In the northern part of the cape, freshwater is underlain everywhere by saltwater. At Truro, the freshwater zone is about 200 feet thick and it might be thicker elsewhere on the outer cape. In the inner- and mid-cape areas, the freshwater zone extends to bedrock. In places near the ocean, fine-grained sediments mark the lower boundary of freshwater (**fig. 57**).

Freshwater and saltwater in the aquifer are separated by a narrow transition zone where mixing occurs. In this zone, freshwater that is moving seaward mixes by hydrodynamic dispersion and diffusion with saltwater that is moving landward. Freshwater and saltwater remain separated because flow in the transition zone is not turbulent and because of the difference in density between freshwater and saltwater. The transition zone is easily identified on electric logs from wells that penetrate the zone, as shown in **figure 58**.

The transition zone can move landward or seaward depending on the steepness of the hydraulic gradient in the water-table mounds. For example, during a drought, when the height of the water-table mounds is lowered and the hydraulic gradient becomes flatter, decreased seaward flow of freshwater would allow the transition zone to move landward. Because of the long-term steady-state conditions of the flow system on the cape, however, the location of the transition zone generally remains stable.

The transition zone also can move in response to ground-water withdrawals. Withdrawals decrease the seaward flow of freshwater by capturing the freshwater that would move toward the ocean. Thus, the transition zone moves toward pumping wells; this results in an increase in salinity, as indicated by an increase in chloride concentrations in freshwater at the well. The increase of chloride concentrations in water from an observation well located 300 feet from a pumping well is shown in **figure 59*A***. Withdrawals caused upconing (movement of the transition zone upward toward the pumping well) with a resulting increase in chloride concentrations in water from the nearby observation well (**fig. 59*B***). Note that with cessation of pumping, the transition zone nearly returned to its prepumping position with a resulting decrease in chloride concentrations in water from the observation well.

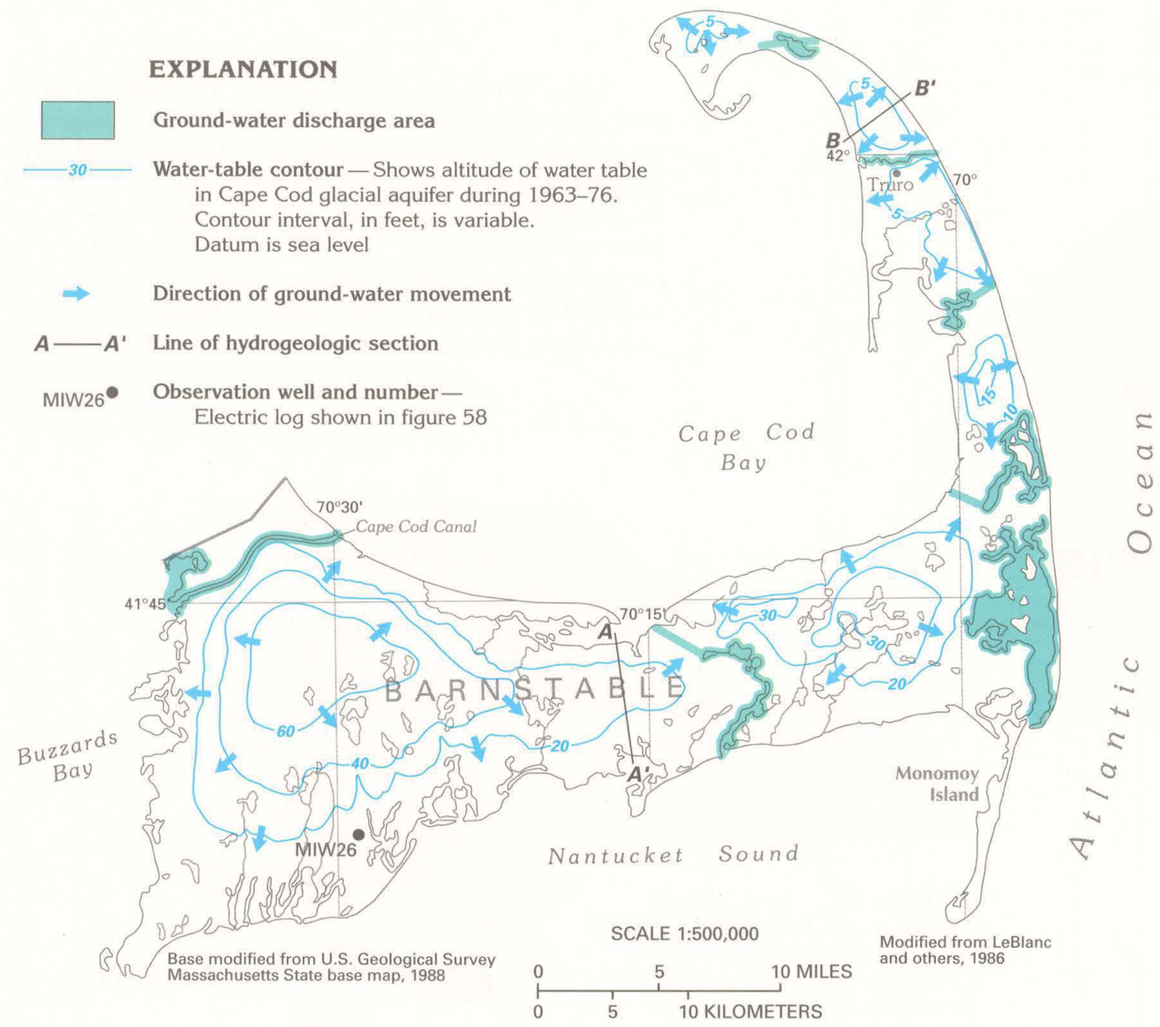


Figure 55. *The water table on Cape Cod is dominated by six mounds. Water moves radially from these mounds toward ocean inlets or narrows that are discharge areas.*

Figure 56. *Ocean inlets are discharge areas for the ground-water flow system.*

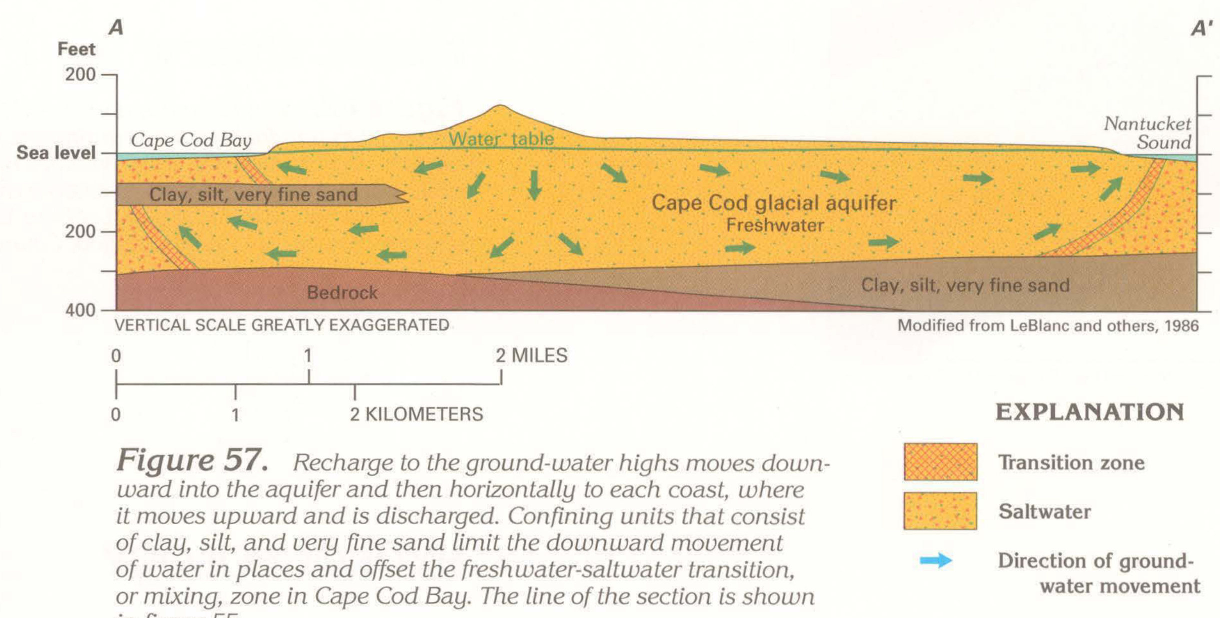


Figure 57. *Recharge to the ground-water highs moves downward into the aquifer and then horizontally to each coast, where it moves upward and is discharged. Confining units that consist of clay, silt, and very fine sand limit the downward movement of water in places and offset the freshwater-saltwater transition, or mixing, zone in Cape Cod Bay. The line of the section is shown in figure 55.*

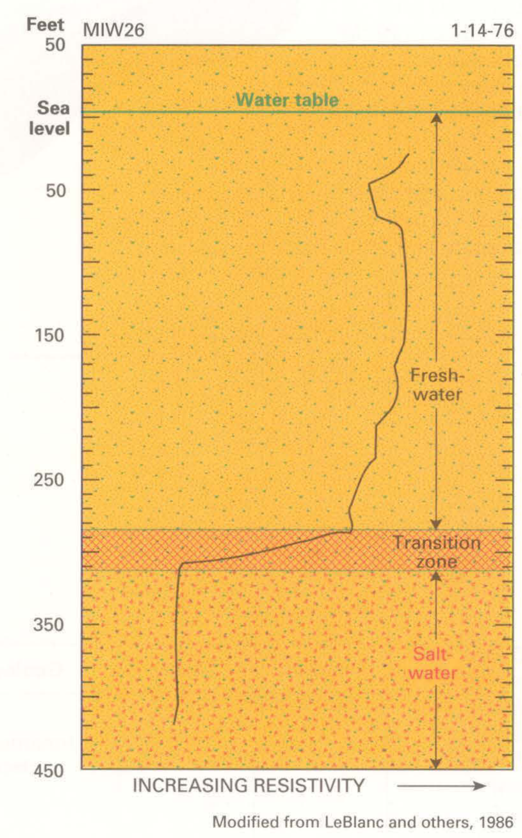


Figure 58. *Electric logs from boreholes, such as observation well MIW26, that completely penetrate the freshwater column show a decrease in electrical resistivity in the freshwater-saltwater transition, or mixing, zone. The resistivity decreases still further in lower parts of the aquifer that contain saltwater. The location of the observation well is shown in figure 55.*

Figure 59. *Ground-water withdrawals caused upconing of the freshwater-saltwater transition zone below the well screen of a pumping well (A). The upconing, in turn, caused increased concentrations of chloride in water from a nearby observation well (B). With cessation of pumping, the transition zone nearly returned to its original position, and chloride concentrations decreased nearly to prepumping concentrations. The line of the section is shown in figure 55.*

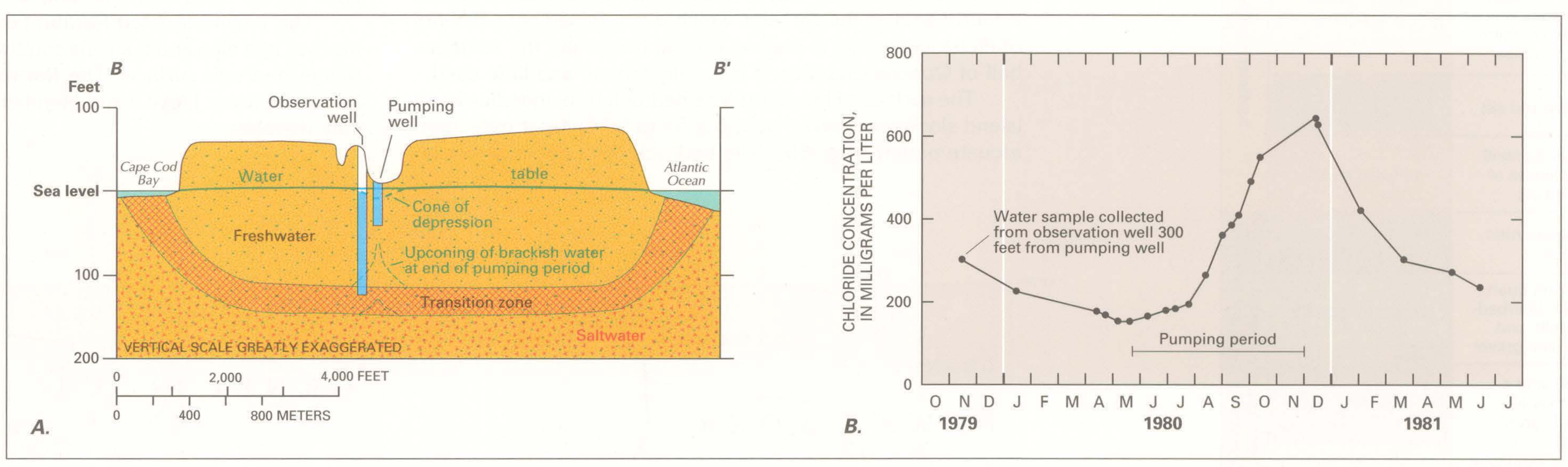


Table 9. *Median anion and cation concentrations in ground water on Cape Cod indicate the water is soft and contains only small amounts of dissolved minerals*

[Modified from Frimpter and Gay, 1979; Concentrations in milligrams per liter unless otherwise specified; µg/L, micrograms per liter]

	Median concentration	Number of analyses
pH (standard units)	6.1	202
Hardness as $CaCO_3$	20	202
Calcium (Ca)	3.6	202
Magnesium (Mg)	2.4	202
Sodium (Na)	13.2	112
Potassium (K)	.9	112
Bicarbonate (HCO_3)	11	202
Sulfate (SO_4)	6.6	202
Chloride (Cl)	19	202
Dissolved solids	70	196
Nitrate (NO_3)	.12	84
Iron (Fe)	.04	75
Manganese (Mn)	.01	83

GROUND-WATER QUALITY

The chemical quality of water in the Cape Cod glacial aquifer generally is suitable for most uses, including human consumption. The rapid rate of recharge, short ground-water flow paths, chemically inert character of the quartz and feldspar sand that comprise the aquifer, and the unconfined conditions all contribute to minimal mineralization of the water. For example, a median dissolved-solids concentration of 70 milligrams per liter was reported for 196 samples of water from the Cape Cod glacial aquifer (**table 9**).

Water-quality problems do, however, occur on the cape. Excessive concentrations of iron, manganese, and hydrogen sulfide might be detected in the water where dune deposits overlie wetland deposits. Large concentrations of iron deep in the aquifer inhibit development of water supplies from deep wells. Contamination of the aquifer by nitrogen from land disposal of municipal sewage, septic-tank effluent, fuel spills and fertilizers is a problem locally, and contamination by road salt and saltwater spray might be a problem in coastal areas. Landfills and lagoons used for disposal of sewage by septic-tank pumpers also are sources of ground-water contamination. Large-scale withdrawal of water near the periphery of the cape might induce saltwater to move into the aquifer either laterally or by upconing from depth.

FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the Cape Cod aquifer amounted to 16 million gallons per day during 1985 (**fig. 60**). Nondomestic water use, which was mostly for public supply, accounted for 14.8 percent of withdrawals, and withdrawals for agricultural use were 1.6 percent. The remainder and majority of the withdrawals, 83.6 percent, was for domestic and commercial use.

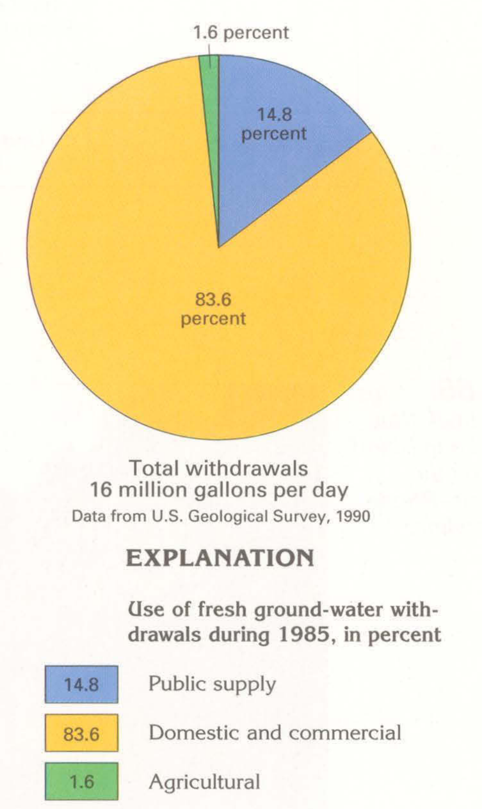


Figure 60. *Fresh ground-water withdrawals from the Cape Cod glacial aquifer were 16 million gallons per day during 1985. Nearly all the withdrawals were for public supply or domestic and commercial use.*

Surficial and Northern Atlantic Coastal Plain aquifer systems, Long Island

INTRODUCTION

Long Island, in southeastern New York, extends east-northeast about 120 miles into the Atlantic Ocean parallel to the Connecticut coastline (**fig. 61**). The island is surrounded by saltwater—Long Island Sound on the north, the Atlantic Ocean on the east and south, and the Hudson estuary and East River on the west (**fig. 62**). The western end of the island is part of New York City (Kings and Queens Counties), which is bounded on the east by the populous Nassau County. The less populous Suffolk County includes the remainder of the island.

About 2.8 million people lived on Long Island during 1985 and depended on ground water for drinking and most other uses. Ground water is virtually the only source of supply on the island. During 1985, about 470 million gallons per day of fresh ground water was withdrawn largely for public supply and industrial purposes.

Topographically, Long Island is dominated by two subparallel ridges that are terminal moraines—the Harbor Hill Terminal Moraine and the Ronkonkoma Terminal Moraine (**fig. 62**)—which were deposited during the Wisconsinan glacial stage. The moraines merge in the west but separate in central Nassau County and trend eastward the length of the island. They form the North and South Forks of the eastern end of the island. The land surface generally slopes both to the north and to the south from the two moraines; gently to the south and more abruptly to the north. Barrier beaches form the south edge of the island and enclose Great South Bay.

The moraines on Long Island mark the terminus of glaciation. The sandy morainal material is mingled with outwash sand and gravel that covers much of the remainder of the island and forms a thick and permeable aquifer similar to the Cape Cod glacial aquifer.

Long Island also is underlain by Coastal Plain sediments of Cretaceous and Pleistocene ages (**fig. 63**) that are hydraulically connected with the glacial aquifer. Because the glacial and Coastal Plain deposits cannot be hydraulically separated and generally function as a hydrologic unit, they are discussed together in this chapter.

Figure 61. Long Island is located in southeastern New York and extends into the Atlantic Ocean approximately parallel to the Connecticut coastline. The island is surrounded by saltwater.

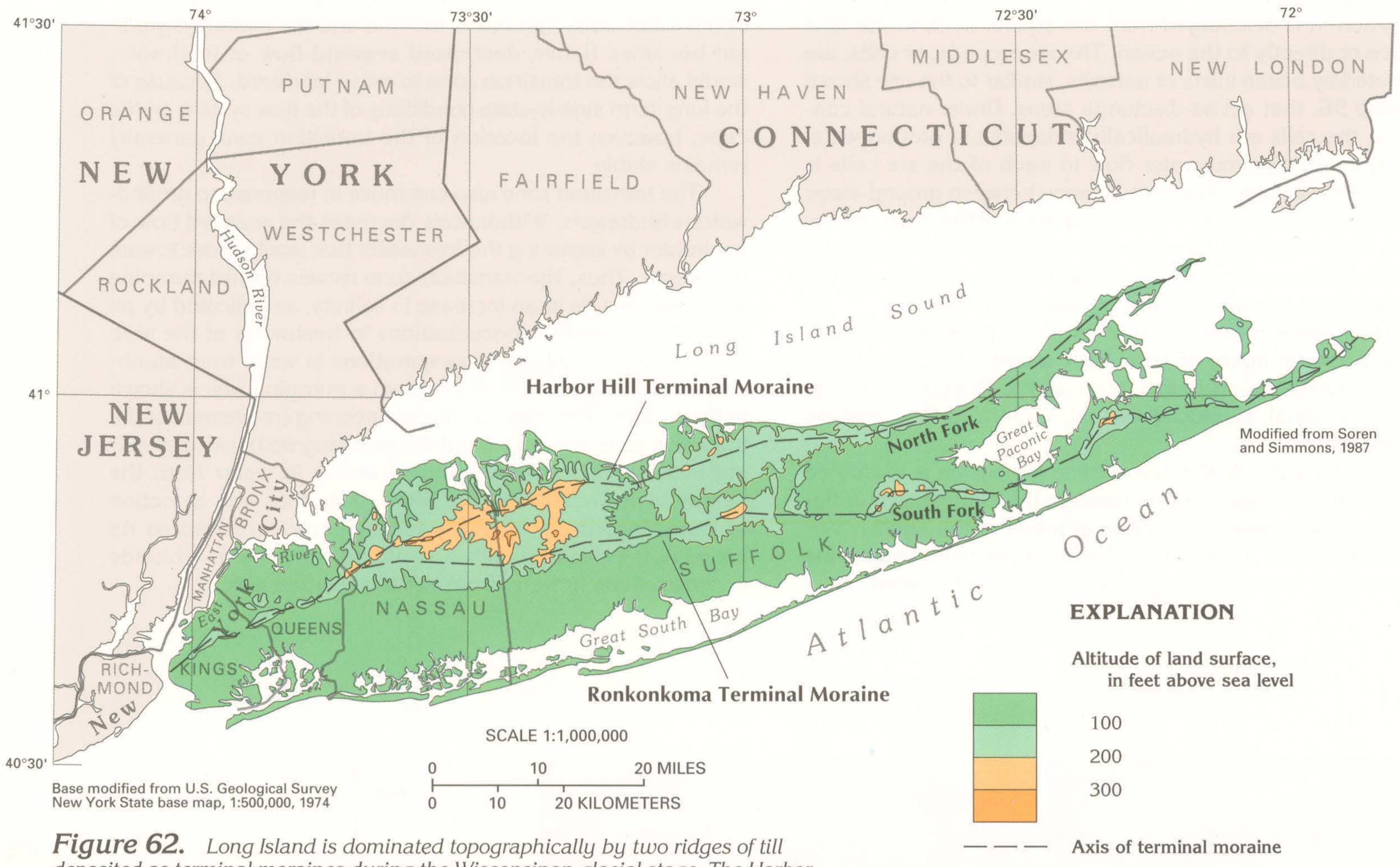


Figure 62. Long Island is dominated topographically by two ridges of till deposited as terminal moraines during the Wisconsinan glacial stage. The Harbor Hill and Ronkonkoma Terminal Moraines traverse the length of the island and form the North and South Forks on its eastern end. Kings and Queens Counties on the western end of the island are part of New York City. They are bounded on the east by populous Nassau County; Suffolk County includes the remainder of the island.

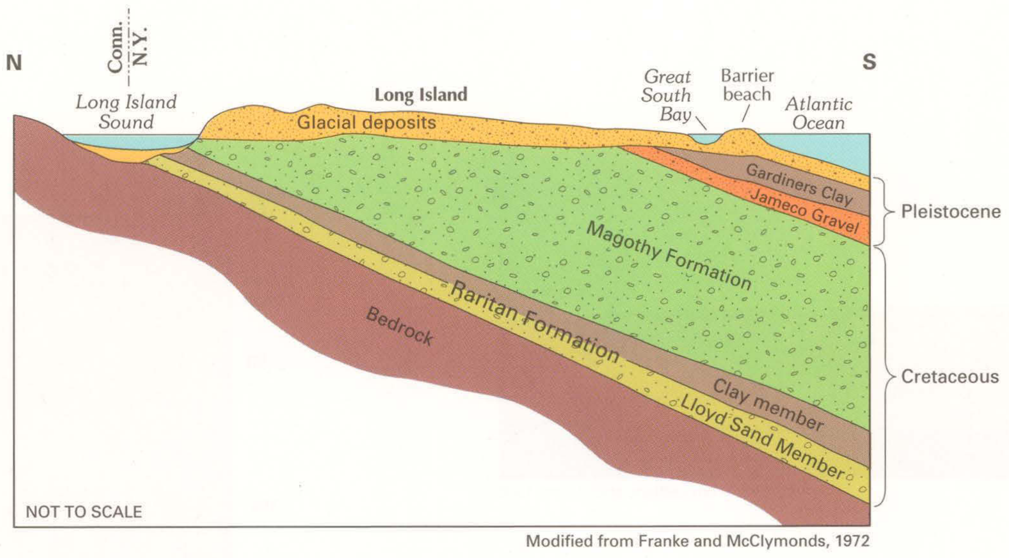


Figure 63. Coastal Plain sediments, which are of Cretaceous and Pleistocene ages, underlie glacial deposits on Long Island as shown by this idealized section of eastern Queens County. The Magothy Formation and the Lloyd Sand Member of the Raritan Formation form productive aquifers.

HYDROGEOLOGY

Three principal aquifers underlie Long Island. They are unconsolidated deposits of Pleistocene age, referred to as the upper glacial aquifer (**fig. 64**), and unconsolidated deposits of Cretaceous age, which include the Magothy aquifer above and the Lloyd aquifer below. The three aquifers are bounded above by the water table and below by the crystalline bedrock surface. Laterally, usable freshwater in the aquifers is bounded by a freshwater-saltwater transition zone that surrounds the island. A fourth aquifer, the Jameco, which is composed of sediments of Pleistocene age, is present only in Kings and the southern half of Queens Counties. It is areally limited and little used.

The surface of the crystalline bedrock that underlies Long Island slopes southward at about 55 to 60 feet per mile in an arcuate pattern (**fig. 65**). The bedrock does not crop out on Long Island, but is exposed at the Connecticut–Rhode Island shoreline north of Long Island Sound (**fig. 66**) and on Manhattan Island across the East River from the western end of Long Island. The crystalline-bedrock surface is nearly 2,000 feet below sea level along the central part of the south coast of Long Island (**fig. 65**). This bedrock foundation has negligible permeability and functions as a hydrologic boundary or base for the Long Island ground-water flow system.

The unconsolidated Raritan Formation (**fig. 64**) of Cretaceous age dips and thickens southward and overlies the crystalline-bedrock surface. The Raritan consists of two members—the lower Lloyd Sand Member and an upper, unnamed clay member.

Figure 64. Unconsolidated Coastal Plain sediments of Cretaceous age and glacial deposits of Pleistocene age compose the principal aquifers that underlie Long Island.

System	Series	Geologic unit		Principal lithology	Hydrogeologic unit	
Quaternary	Holocene	Unnamed surficial deposits		Sand, silt, clay, organic mud and shells	Confining unit in some areas. Beach sands locally yield water	Surficial aquifer system
Quaternary	Pleistocene	Upper Pleistocene deposits		Till, outwash, and glacial-lake deposits. Clay, sand, gravel, and boulders. Extensive marine clay in Queens and southern Nassau Counties	Upper glacial aquifer	Surficial aquifer system
Quaternary	Pleistocene	Gardiners Clay		Marine clay and silt	Gardiners confining unit	Surficial aquifer system
Quaternary	Pleistocene	Jameco Gravel		Fine sand and gravel with some lenses of clay and silt	Jameco aquifer	Surficial aquifer system
Cretaceous	Upper	Monmouth Group		Clayey, glauconitic sand	Monmouth greensand confining unit	
Cretaceous	Upper	Magothy Formation		Fine to medium quartzose sand with interbedded clay, silt, and coarse sand and gravel	Magothy aquifer	Northern Atlantic Coastal Plain aquifer system
Cretaceous	Upper	Raritan Formation	Unnamed clay member	Silty clay with a few lenses of sand and lignite	Raritan confining unit	Northern Atlantic Coastal Plain aquifer system
Cretaceous	Upper	Raritan Formation	Lloyd Sand Member	Fine to coarse sand with some gravel, commonly within a clayey matrix	Lloyd aquifer	Northern Atlantic Coastal Plain aquifer system
Precambrian		Undifferentiated bedrock		Metamorphic rocks and granite	Bedrock confining unit	

Modified from Reilly and others, 1983

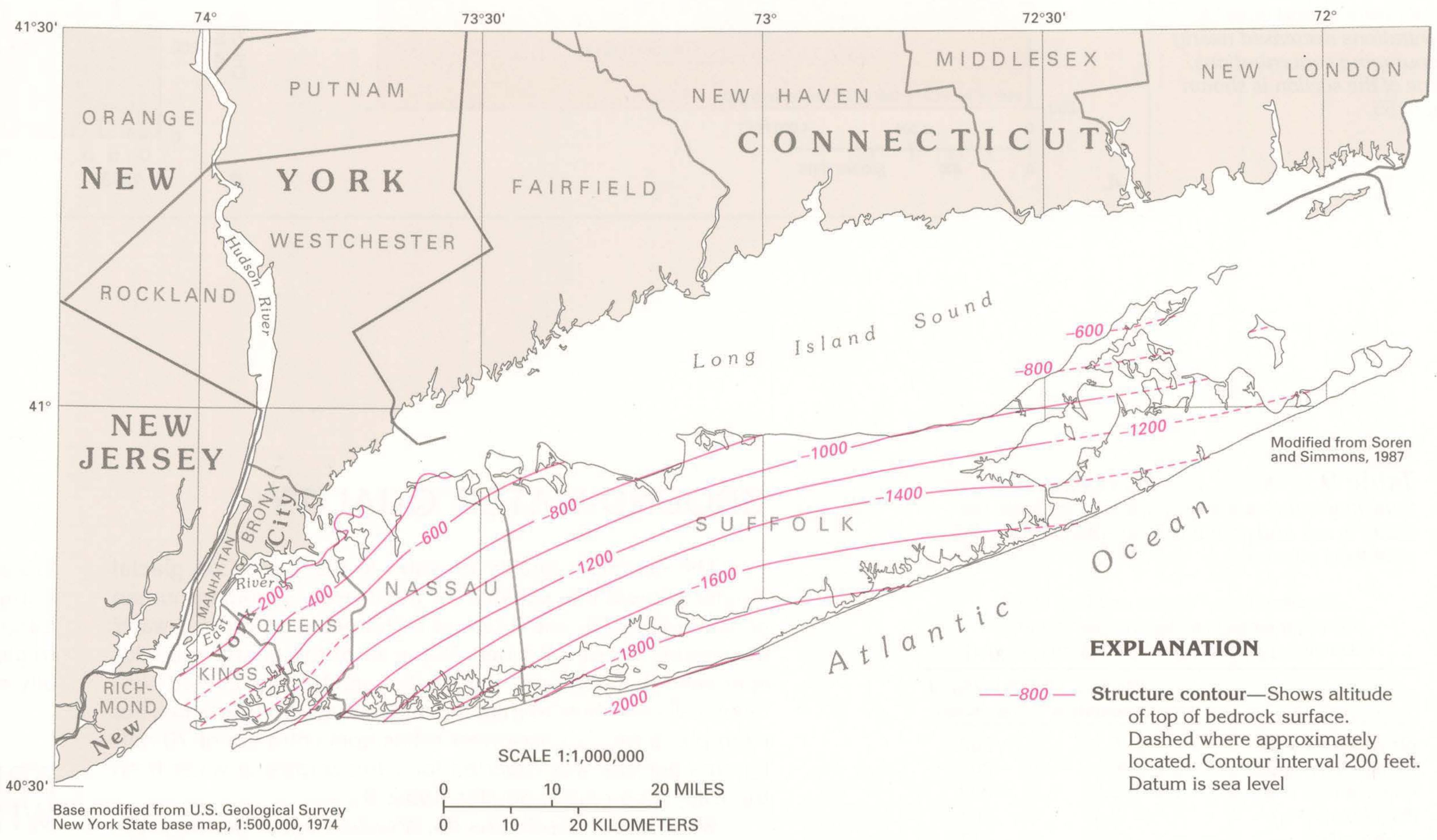
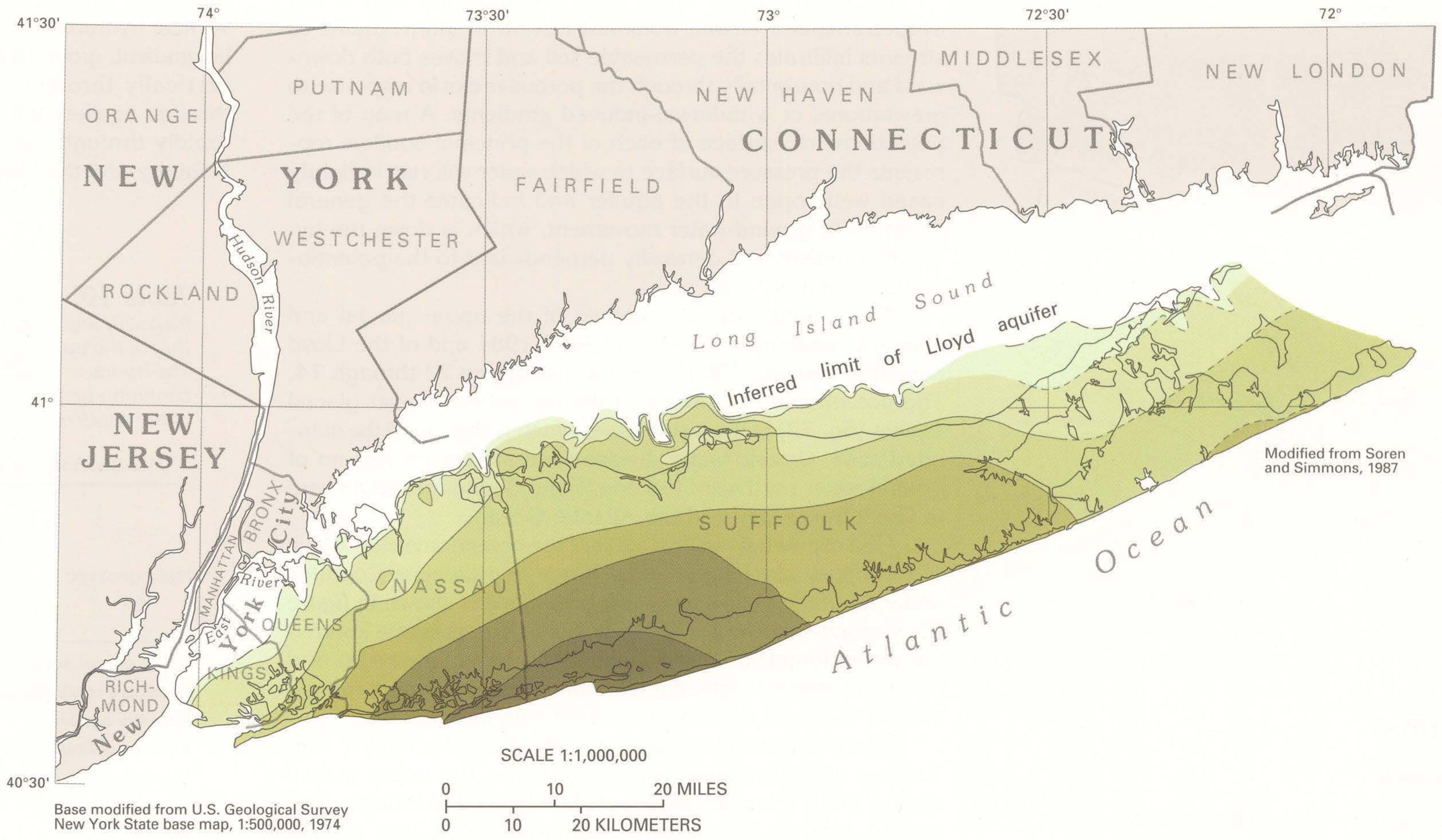


Figure 65. The crystalline-bedrock surface that underlies Long Island is at land surface in Connecticut but is about 2,000 feet below sea level along the central part of the southern coast of the island.

Figure 66. Crystalline bedrock that underlies Long Island crops out on the Connecticut–Rhode Island shoreline.

Figure 67. *The thickness of the Lloyd aquifer ranges from a featheredge in places on the northern side of Long Island to about 500 feet in southeastern Nassau County and southwestern Suffolk County on the southern side.*

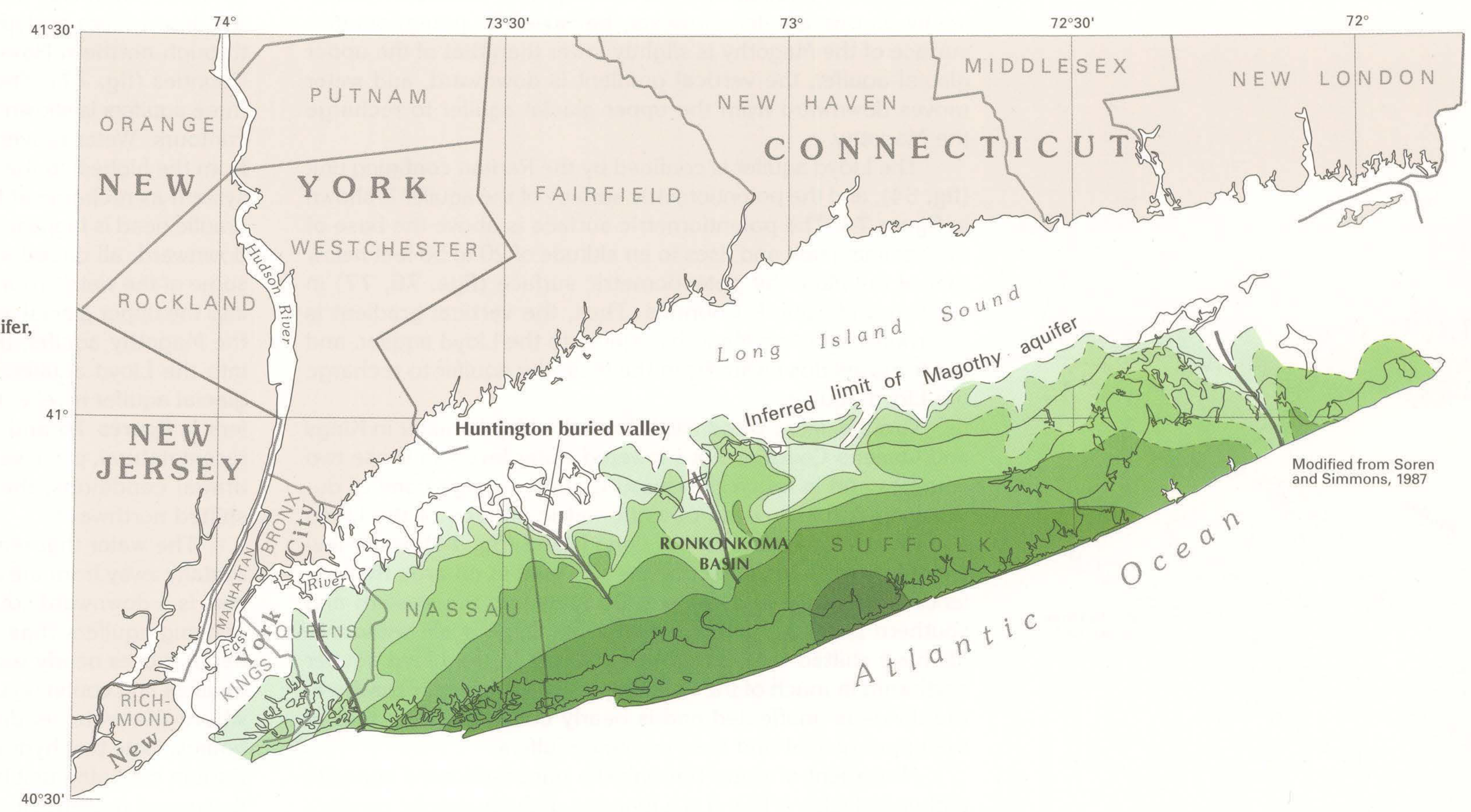


EXPLANATION

Thickness of Lloyd aquifer, in feet. Dashed where approximately located

- 100
- 200
- 300
- 400
- 500

Figure 68. *The Magothy aquifer on Long Island ranges in thickness from a featheredge in places on the northern side of Long Island to about 1,000 feet in an area of southwestern Suffolk County on the south shore.*



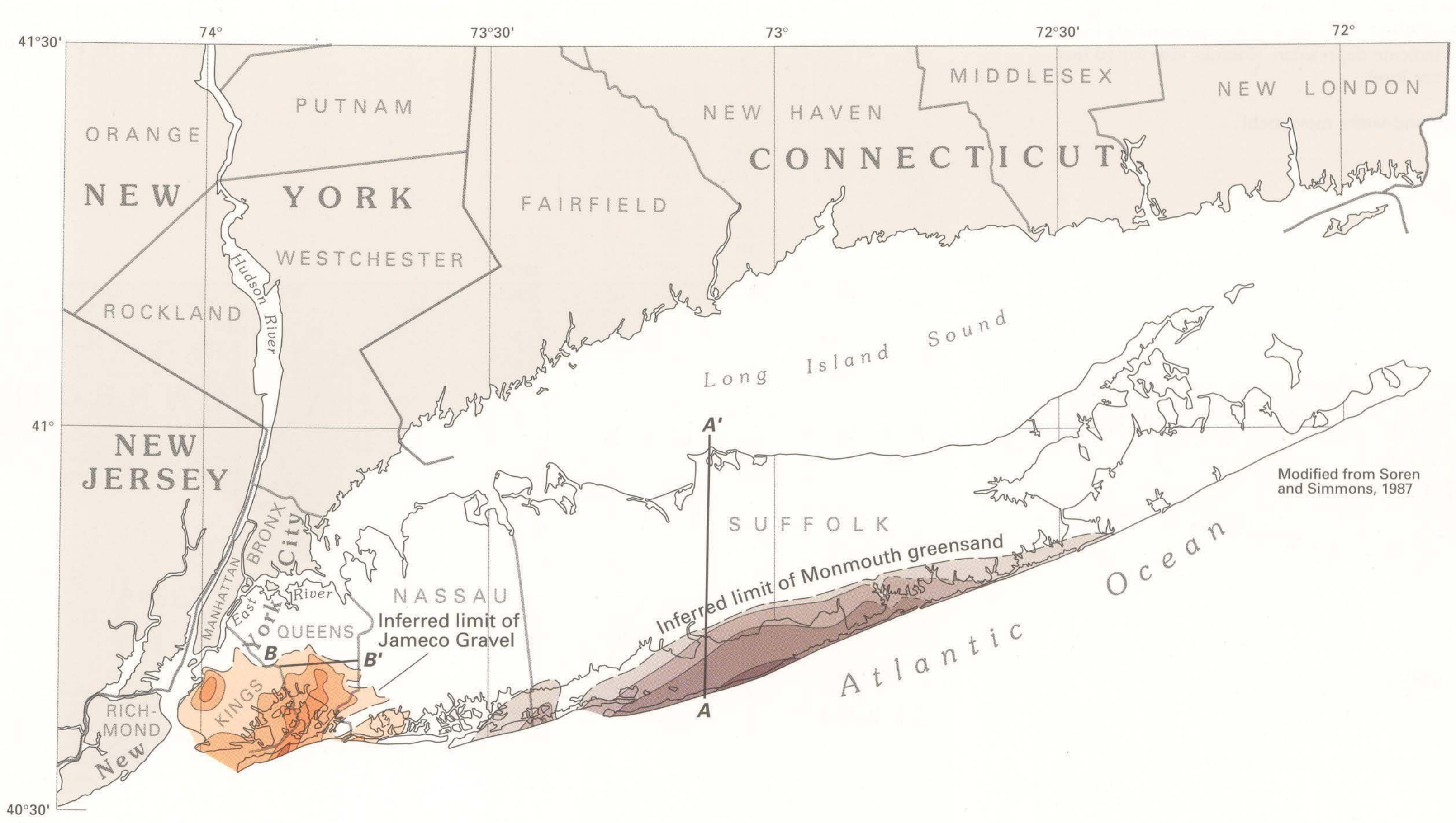
EXPLANATION

Thickness of Magothy aquifer, in feet. Dashed where approximately located

- 200
- 400
- 600
- 800
- 1,000

Approximate axis of pre-Pleistocene channel

Figure 69. *The Monmouth greensand is a confining unit that ranges in thickness from a featheredge on its northern edge to about 150 feet on the south shore of Long Island. The Jameco Gravel forms a minor aquifer that ranges in thickness from 0 to about 200 feet in the southwestern part of Long Island.*



EXPLANATION

Thickness of Monmouth greensand, in feet. Dashed where approximately located

- 50
- 100
- 150

Thickness of Jameco Gravel, in feet

- 50
- 100
- 200

A——A' Line of hydrogeologic section

The Lloyd Sand Member of the Raritan Formation consists of fine to coarse sand and gravel commonly within a clayey matrix and forms the Lloyd aquifer, which is the lowermost principal aquifer on Long Island. The Lloyd aquifer is missing in the northwestern part of the island where the Lloyd Sand Member was extensively eroded prior to glaciation. The Lloyd aquifer ranges in thickness from a featheredge in places on the north side of the island to about 500 feet in southeastern Nassau County and southwestern Suffolk County on the south side (**fig. 67**). The depth to the top of the aquifer ranges from about 200 to about 1,500 feet below sea level.

The clay member of the Raritan Formation has a maximum thickness of about 300 feet and consists of massive silty clay with a few lenses of sand and lignite. The clay member forms a leaky confining unit.

The Magothy Formation, which unconformably overlies the Raritan Formation, is composed of unconsolidated fine to medium quartzose sand with layers and lenses of clay, silt, and coarse sand and gravel. The coarsest material is present in the lower 50 to 100 feet of the formation. The Magothy was extensively eroded prior to glaciation and is missing in the northwestern part of the island. The depth to the top of the Magothy Formation ranges from land surface in isolated outcrop areas on the north shore to about 600 feet below land surface on the south shore. The Magothy Formation comprises the Magothy aquifer, which ranges in thickness from a featheredge in places on the north side of the island to about 1,000 feet in an area of southwestern Suffolk County on the south shore (**fig. 68**).

Pre-Pleistocene streams eroded several deep channels in the Magothy surface, two of which extend southeastward across the entire island (**fig. 68**). The channel in Queens County was probably eroded by the ancestral Hudson River. The other channel, which extends from the eastern end of the North Fork of the island southeastward across the South Fork, was probably eroded by the ancestral Connecticut River.

Two other significant channels were eroded in the Magothy Formation surface in Suffolk County. The Huntington buried valley extends northwestward toward Long Island Sound about 5 miles east of the Nassau–Suffolk County line (**fig. 68**). The other valley, which forms the Ronkonkoma Basin, also extends northwestward toward Long Island Sound about 15 miles east of the Nassau–Suffolk County line.

The Monmouth Group (**fig. 64**) on Long Island is represented by the Monmouth greensand, which is a clayey, glauconitic unit of Cretaceous age similar in hydraulic character to the Raritan confining unit. The Monmouth greensand unconformably overlies the Magothy aquifer along the southern edge of the island (**figs. 69, 70**) and dips and thickens to the south. The greensand ranges in thickness from a featheredge to about 150 feet (**fig. 70**). The greensand mostly underlies the bays between the barrier islands and the main part of Long Island and extends from near the Nassau–Suffolk County line eastward to the western part of the South Fork. The Monmouth greensand is a confining unit where it overlies the Magothy aquifer.

The Jameco Gravel is the basal deposit of Pleistocene age (**fig. 64**) and underlies parts of Kings and Queens Counties on the western end of Long Island (**fig. 69**). The Jameco ranges from a fine sand to gravel with some lenses of clay and silt and, for the most part, fills valleys eroded into the underlying Magothy Formation (**fig. 71**). The Jameco Gravel ranges in thickness from a featheredge to about 200 feet in south-central Queens County (**fig. 69**) and forms the local Jameco aquifer.

The Jameco Gravel is overlain by the Gardiners Clay, which is a marine deposit of Pleistocene age that underlies most of Kings County and the southern one-half of Queens County and extends eastward along the south shore area to the middle of the South Fork. The Gardiners Clay ranges in thickness from a featheredge to about 100 feet. The clay is thickest in Queens County and thins to about 50 feet in the remainder of its extent. The Gardiners Clay is clayey and silty in the western one-half of its extent but becomes increasingly sandy to the east. Where present, the clay forms a confining unit that separates the upper glacial aquifer from the Magothy and Jameco aquifers.

Pleistocene glacial deposits blanket Long Island and range in thickness from a featheredge to about 600 feet in the Ronkonkoma Basin. Till, which is composed of unsorted and unstratified clay, silt, sand, gravel, cobbles, and boulders, forms the Harbor Hill and Ronkonkoma Terminal Moraines (**fig. 62**). Outwash deposits that consist primarily of fine to coarse quartzose sand and gravel are exposed at land surface between and south of the two moraines. Outwash deposits also are interbedded with till in and north of the moraines. Outwash and other coarse-grained materials form the upper glacial aquifer.

Glacial-lake deposits that consist of clay, silt, and some sand and gravel layers are present within the upper glacial aquifer in central and eastern Long Island. Marine clay of Pleistocene age also is present within the upper glacial aquifer in Queens and southern Nassau Counties. These glacial-lake deposits and marine sediments, along with unsorted and unstratified till, form local confining units where they overlie permeable outwash deposits.

Holocene deposits, which are as much as 50 feet thick and consist of salt-marsh deposits, stream alluvium, and beach sands, occur locally throughout the island. Holocene deposits consist of sand, clay, silt, organic muck, and shells. They are at land surface and generally overlie Pleistocene deposits. They are either unsaturated or too thin and discontinuous to form aquifers. In some areas, they form local confining units.

Figure 70. *The upper glacial aquifer is in contact with the Magothy aquifer in most places and with the Lloyd aquifer under Long Island Sound. The Monmouth greensand and Gardiners confining units overlie the Magothy aquifer in the area of Great South Bay. The line of the section is shown in figure 69.*

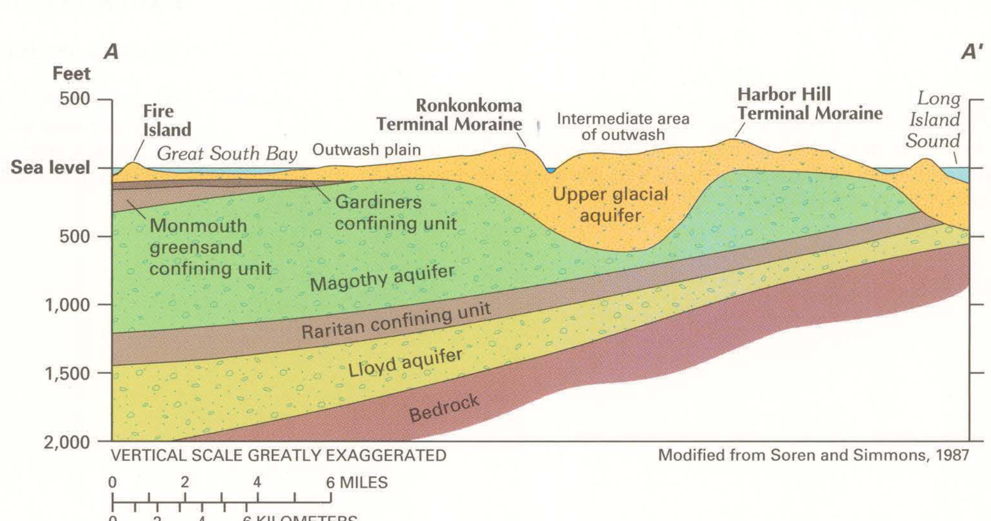


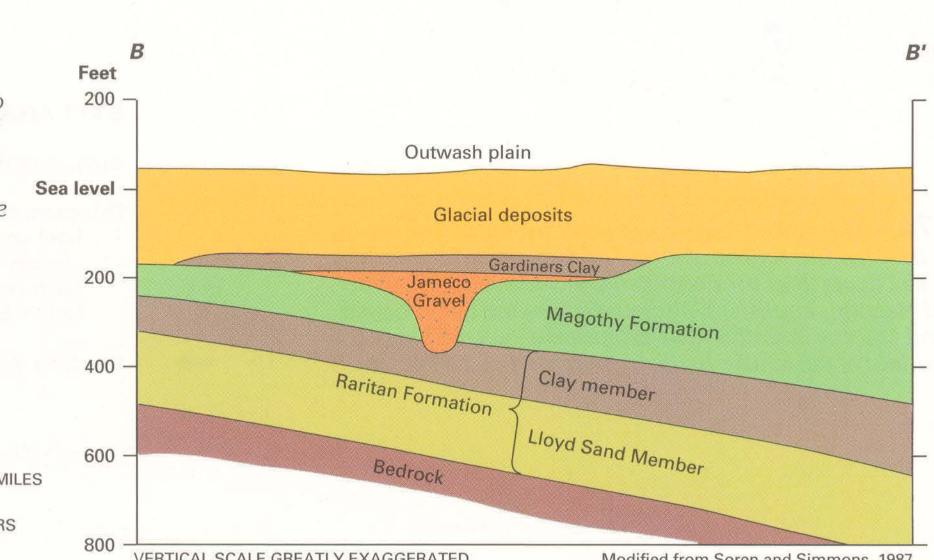
Figure 71. *The Jameco aquifer consists primarily of glacial sand and gravel that fill valleys eroded into the Magothy Formation. The line of the section is shown in figure 69.*

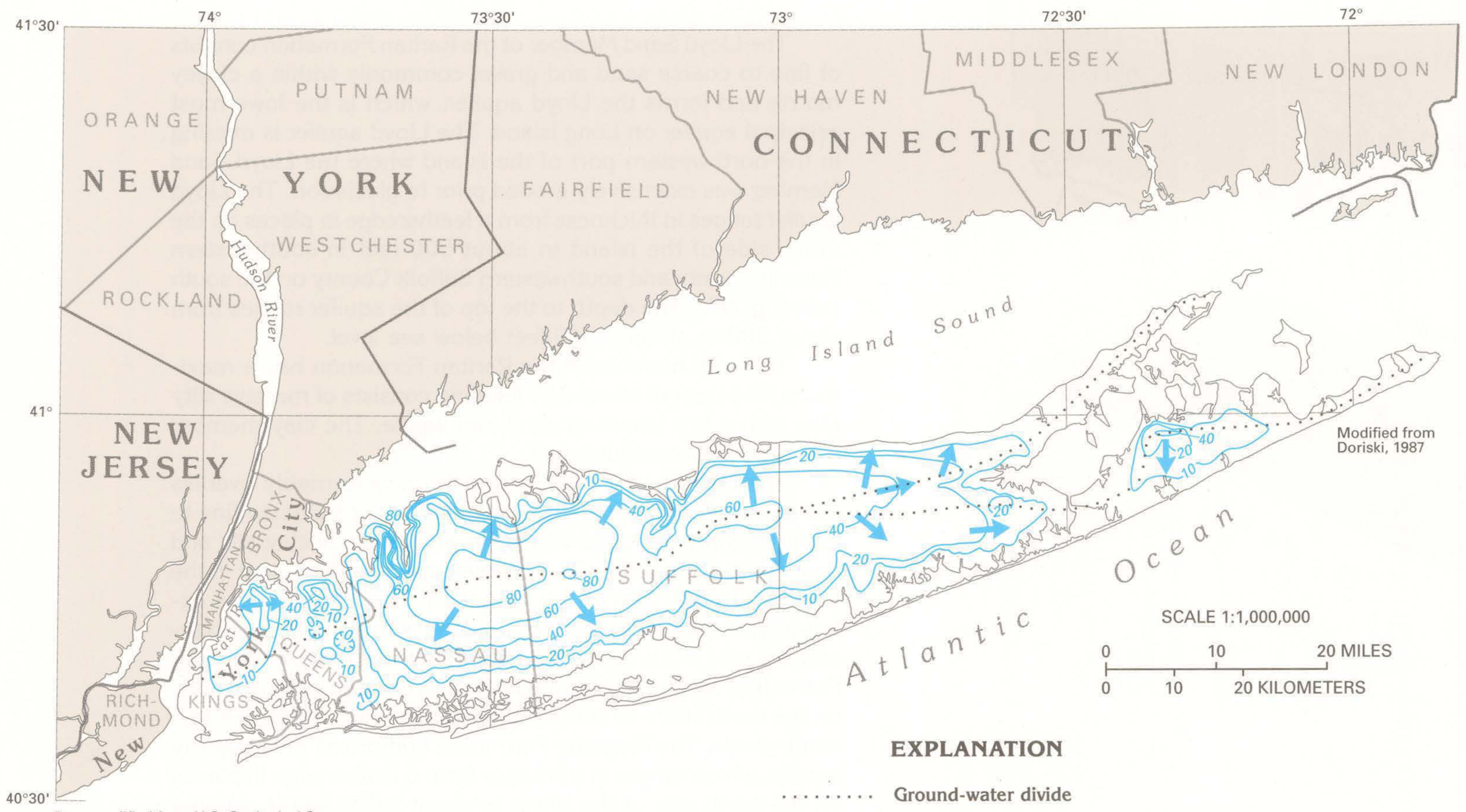
EXPLANATION

Jameco aquifer

0 1 2 MILES

0 1 2 KILOMETERS





Base modified from U.S. Geological Survey
New York State base map, 1:500,000, 1974

Figure 72. *The potentiometric surface of the upper glacial aquifer slopes gently to the north and south from a central high, except in the western part of the island where ground-water withdrawals have lowered the water table and created cones of depression.*

EXPLANATION

Ground-water divide

20 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells during March–April 1984. Hachures indicate depression. Contour intervals 10 and 20 feet. Datum is sea level

Direction of ground-water movement

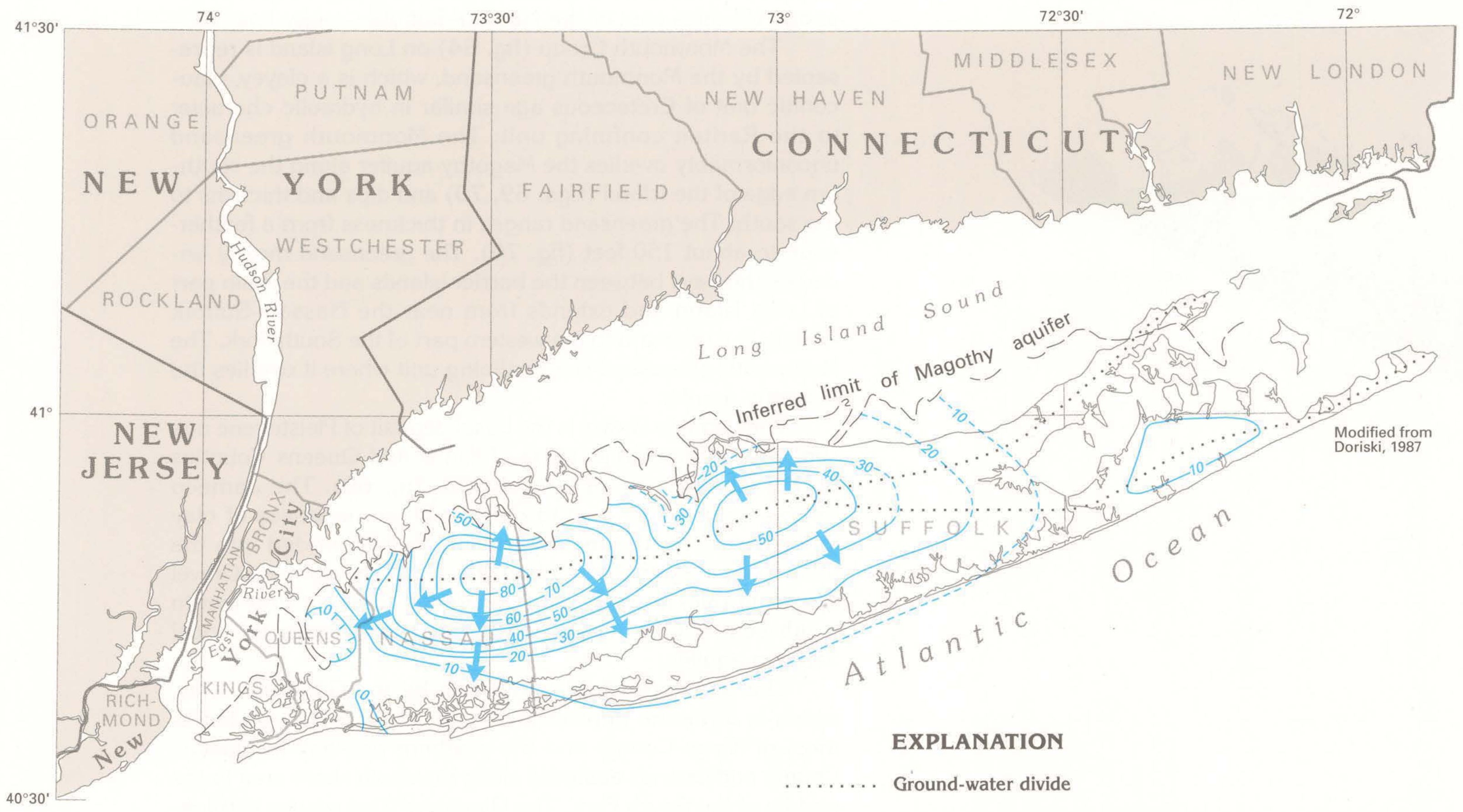


Figure 73. *The potentiometric surface of the Magothy aquifer has a configuration similar to that of the upper glacial aquifer, but the surface in the Magothy is more subdued and slightly lower in altitude.*

EXPLANATION

Ground-water divide

20 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells during March–April 1984. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is sea level

Direction of ground-water movement

GROUND-WATER FLOW

On Long Island, water from precipitation that is not evapotranspired or that does not run off in storm drains or streams infiltrates the permeable soil and moves both downward and horizontally through the porous rocks in response to gravitational or withdrawal-induced gradients. A map of the potentiometric surface of each of the principal aquifers represents the pressure surface to which water will rise in tightly cased wells open to the aquifer and indicates the general direction of ground-water movement, which is down the hydraulic gradient and generally perpendicular to the potentiometric contours.

The potentiometric surfaces of the upper glacial and Magothy aquifers in March and April 1984 and of the Lloyd aquifer in January 1984 are shown in **figures 72 through 74**. The potentiometric surface of the unconfined upper glacial aquifer (**fig. 72**) is the water table, which is the top of the saturated zone. Ground-water divides separate the movement of ground water northward to Long Island Sound and southward to Great South Bay and the Atlantic Ocean.

The estimated configuration of the potentiometric surface of the upper glacial aquifer in Kings and Queens Counties under natural (predevelopment) conditions is shown in **figure 75**. Ground-water withdrawals in these counties have lowered the potentiometric surface, changed its configuration, and produced characteristic circular cones of depression centered around the areas of withdrawal as shown in **figure 72**.

The potentiometric surface of the Magothy aquifer (**fig. 73**) has a configuration similar to that of the upper glacial aquifer, but is more subdued and slightly lower in altitude. The ground-water divide on the Magothy potentiometric surface nearly coincides with that on the potentiometric surface of the upper glacial aquifer. Ground-water withdrawals from the Magothy aquifer in Kings and Queens Counties also have lowered water levels in the aquifer below natural levels.

The Magothy aquifer is mostly unconfined, as is the upper glacial aquifer, and the two aquifers function hydraulically as one aquifer. However, because the potentiometric surface of the Magothy is slightly lower than that of the upper glacial aquifer, the vertical gradient is downward, and water moves downward from the upper glacial aquifer to recharge the Magothy.

The Lloyd aquifer is confined by the Raritan confining unit (**fig. 64**), and the potentiometric surface of the aquifer is shown in **figure 74**. The potentiometric surface is above the base of the confining unit and rises to an altitude of 20 to 50 feet below that of the Magothy potentiometric surface (**figs. 76, 77**) in Nassau and Suffolk Counties. Thus, the vertical gradient is downward from the Magothy aquifer to the Lloyd aquifer, and water moves downward from the Magothy aquifer to recharge the Lloyd aquifer.

Ground-water withdrawals from the Lloyd aquifer in Kings and Queens Counties have lowered water levels in those two counties and in much of Nassau County. A large cone of depression dominates the potentiometric surface of the Lloyd aquifer in the western part of Long Island (**fig. 74**); water levels are more than 20 feet below sea level in an area that extends from Kings and Queens Counties into the western and southern parts of Nassau County. The large-scale withdrawals have shifted the ground-water divide in the Lloyd aquifer northward in much of the western part of the island. Elsewhere, the divide is unaffected and is nearly coincident with that of the upper glacial and the Magothy aquifers.

Movement of water through the unconsolidated deposits that underlie Long Island is a function of the hydraulic conductivity (the capacity of the deposits to transmit water). The estimated average hydraulic conductivity in the horizontal and vertical directions of the major hydrogeologic units on Long Island is presented in **table 10**. The horizontal hydraulic conductivity of the Lloyd and the Magothy aquifers is of a similar magnitude but that of the upper glacial aquifer is about six times greater. The horizontal hydraulic conductivity of the Gardiners and the Raritan confining units is several orders of magnitude less than that of the aquifers, and the vertical hydraulic conductivity of the upper two aquifers and both confining units is an order of magnitude less than their horizontal hydraulic conductivity. The horizontal hydraulic conductivity of the upper two aquifers is 10 to about 36 times that of their vertical hydraulic conductivity. Thus, under an equal hydraulic gradient, ground water moves more rapidly horizontally than vertically through these units, more rapidly horizontally through aquifers than through the confining units, and more rapidly through the upper glacial aquifer than through the Magothy and the Lloyd aquifers.

Table 10. *The horizontal hydraulic conductivity of the Magothy and Lloyd aquifers is of similar magnitude, but that of the upper glacial aquifer is about six times greater. The hydraulic conductivity of the Gardiners and Raritan confining units is several orders of magnitude less than that of the aquifers*

[Modified from Franke and Cohen, 1972; —, no data available]

Hydrogeologic unit	Approximate maximum thickness (feet)	Estimated average hydraulic conductivity (feet per day)	
		Horizontal	Vertical
Upper glacial aquifer	600	270	27
Gardiners confining unit	100	.01	.001
Magothy aquifer	1,000	50	1.4
Raritan confining unit	300	.01	.001
Lloyd aquifer	500	40	—

The general pattern of water movement in each of the aquifers, as indicated in **figures 72–74**, is from the ground-water divides northward to Long Island Sound and southward to Great South Bay and the Atlantic Ocean. The character of the flow system at depth is shown by hydrogeologic sections through northern Nassau (**fig. 76**) and southwestern Suffolk Counties (**fig. 77**). The distribution of hydraulic heads in the three aquifers is shown in **figures 76 and 77** by hydraulic-head contours. Water movement is perpendicular to the lines and from the highest to the lowest hydraulic head. Water enters the system as recharge at the ground-water divides where the hydraulic head is highest, then moves northward, southward, and downward, all directions of decreasing hydraulic head. Thus, some of the water from precipitation that percolates downward into the upper glacial aquifer continues to move downward into the Magothy aquifer, through the Raritan confining unit, and into the Lloyd aquifer. The ground-water divide of the upper glacial aquifer is reflected in the Magothy and the Lloyd aquifers in **figures 76 and 77** along the lines of section that represent natural, predevelopment conditions. Under actual withdrawal conditions, the divide of the Lloyd aquifer would be shifted northward.

The water that reaches each of the aquifers moves horizontally away from the divide toward discharge areas, but there also is a downward component that moves water into the underlying aquifers (**figs. 76, 77**). At discharge areas, water at depth moves nearly vertically upward either through overlying aquifers and confining units or directly to aquifer subcrop areas where the water is discharged to the peripheral saltwater bodies. Note that hydraulic-head contours are deflected by the Raritan confining unit because its low permeability retards the downward movement of the water. Even though the clay has very low permeability, water does move through this confining unit.

This flow system is present throughout Long Island where natural conditions prevail. Fresh ground water is discharged along most of the periphery of the island. The discharge of freshwater, which is less dense than saltwater, prevents the saltwater from entering the aquifers. A transition zone between freshwater and saltwater is maintained, under equilibrium conditions at the periphery of the island, that parallels the upward

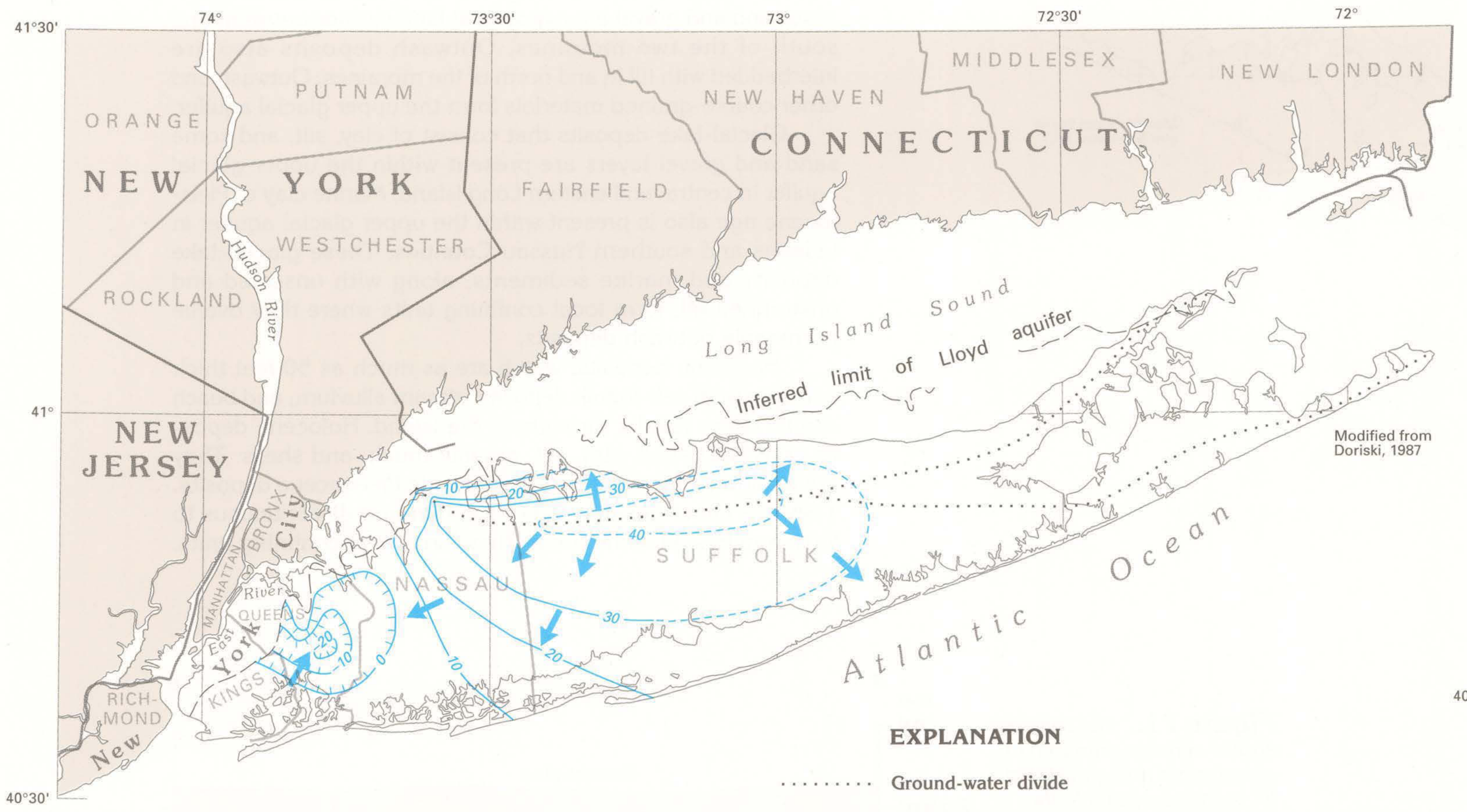


Figure 74. *The potentiometric surface of the Lloyd aquifer represents the pressure surface of a confined aquifer and generally is 20 to 50 feet lower than the potentiometric surfaces of the upper glacial and Magothy aquifers. Withdrawals from the Lloyd aquifer in Kings and Queens Counties have extensively lowered the potentiometric surface of the aquifer in the western part of the island.*

EXPLANATION

Ground-water divide

20 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells in January 1984. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is sea level

Direction of ground-water movement

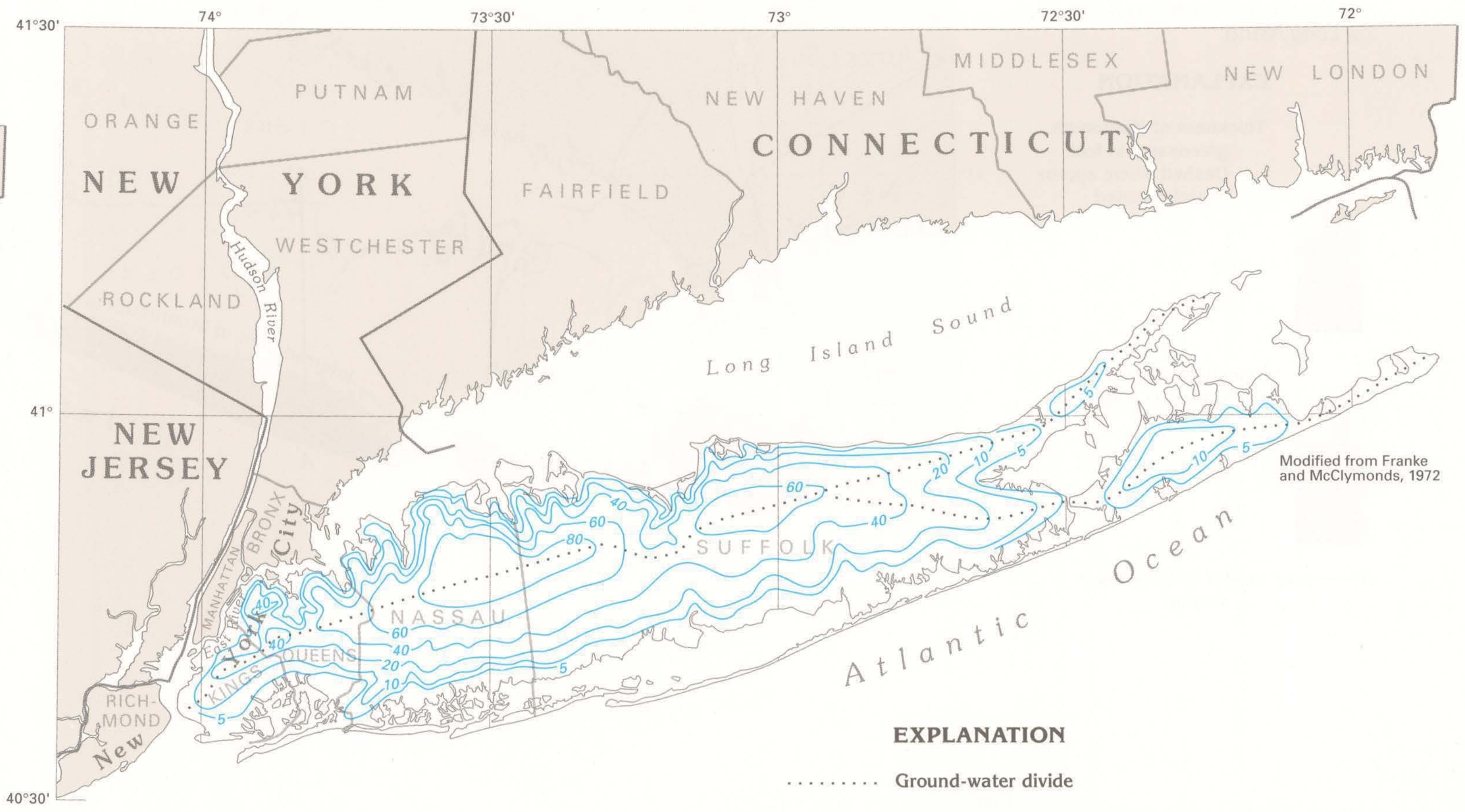


Figure 75. *The estimated configuration of the potentiometric surface of the upper glacial aquifer, prior to any large-scale withdrawals, shows a smoothly sloping surface to the north and south in the western part of the island.*

EXPLANATION

Ground-water divide

20 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells. Contour interval, in feet, is variable. Datum is sea level

curve of the discharging freshwater (**fig. 78**). Equilibrium conditions, however, have been disturbed in Kings, Queens, and part of Nassau Counties where ground-water withdrawals have lowered hydraulic heads in each of the aquifers (**figs. 72–74**) and, in some cases, reversed the direction of flow so that water moves toward the pumping wells. As a consequence, wedge-shaped bodies of saltwater have entered the upper glacial, the Jameco, and the Magothy aquifers in the southwestern part of the island, as shown in **figure 79**. Saltwater also has undoubtedly moved inland in the Lloyd aquifer, but data are not available to locate the present position of the saltwater wedge.

The character of the regional ground-water flow system might be better visualized with a comparative time scale. The estimated time required for water to move through parts of the system is shown in **figure 80**. Water that moves into the upper glacial aquifer at the ground-water divide will move downward through the upper glacial and the Magothy aquifers to the Raritan confining unit in about 100 years. An additional 100 years is required for the water to move through the confining unit. Movement about 15 miles downdip to the south in the Lloyd aquifer requires as much as 3,000 years.

The rate of water moving into, through, and out of the ground-water flow system of Long Island has been estimated for parts of Nassau and Suffolk Counties as indicated on **figure 81**. The estimated rates at which water moves through the principal parts of the system in that area, in million gallons per day, are listed in **table 11**. An average of about 1,600 million gallons per day of precipitation falls on Long Island; of that, only about 1.3 percent, or about 20 million gallons per day, runs off directly to streams. Of the remaining water, about 50 percent, or nearly 795 million gallons per day, is returned to the atmosphere by evapotranspiration, and about 49 percent, or nearly 785 million gallons per day, infiltrates the ground as recharge. About 2 percent of the water that enters the ground, or 15 million gallons per day, is returned to the atmosphere as ground-water evapotranspiration. The remaining 770 million gallons per day moves downward to recharge the aquifers. The aquifers discharge freshwater back to the land surface as discharge to streams and to the peripheral saltwater bodies by underflow. Ground-water discharge to streams is about 41 percent of recharge, or about 320 million gallons per day. Underflow accounts for the remaining 57 percent of recharge, or about 450 million gallons per day.

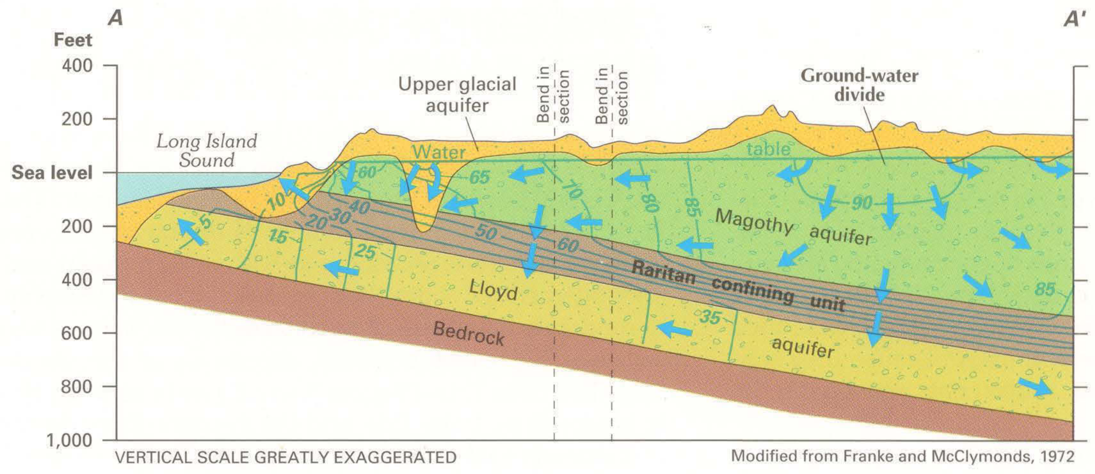


Figure 76. *Water enters the upper glacial aquifer as recharge at the ground-water divide where the hydraulic head is highest. It moves downward to recharge the Magothy and Lloyd aquifers, where it moves horizontally to the north to discharge to Long Island Sound after moving upward through the several aquifers. The line of the section is shown in figure 81.*

0 2 4 MILES
0 2 4 KILOMETERS

EXPLANATION

—70— Hydraulic-head contour—Contour intervals 5 and 10 feet. Datum is sea level

→ Direction of ground-water movement

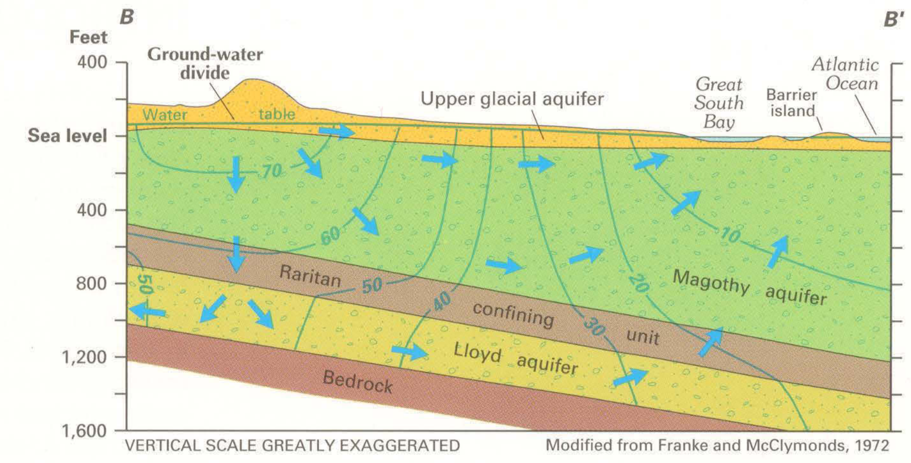


Figure 77. *The ground-water flow system south of the ground-water divide is similar to that north of the divide; water moves downward and then horizontally in the aquifers and finally moves upward to discharge into either Great South Bay or the Atlantic Ocean. The line of the section is shown in figure 81.*

0 2 4 MILES
0 2 4 KILOMETERS

EXPLANATION

—30— Hydraulic-head contour—Contour interval 10 feet. Datum is sea level

→ Direction of ground-water movement

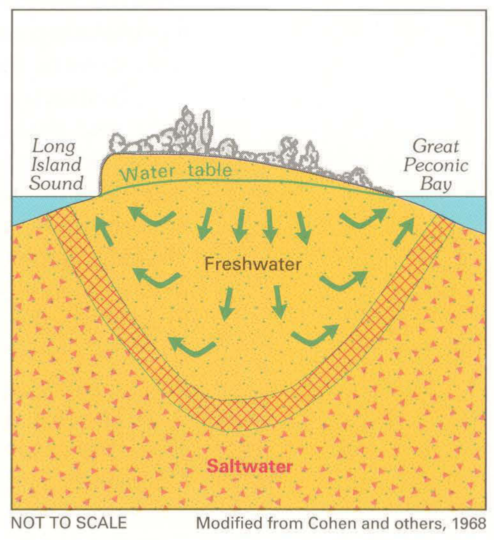
Figure 78. *A transition zone between freshwater and saltwater parallels the upward path of discharging freshwater. This transition zone is maintained at near-equilibrium conditions at the periphery of the island.*

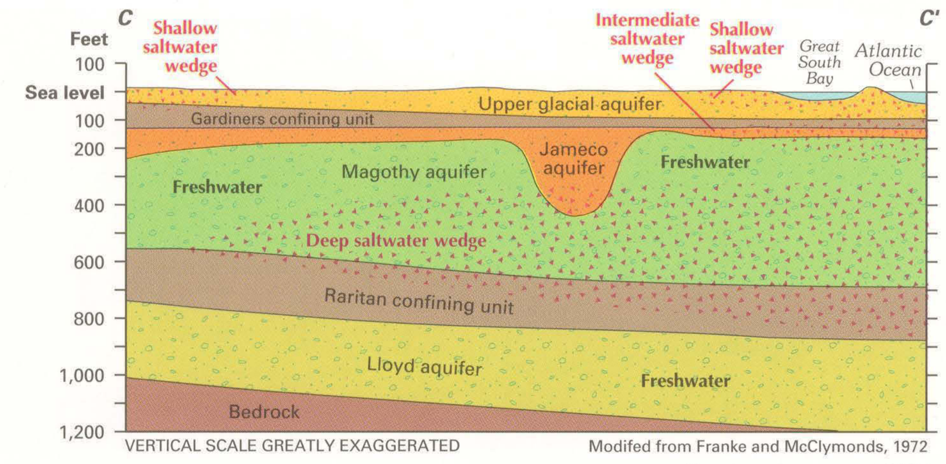
EXPLANATION

Upper glacial aquifer

Transition zone

→ Direction of ground-water movement





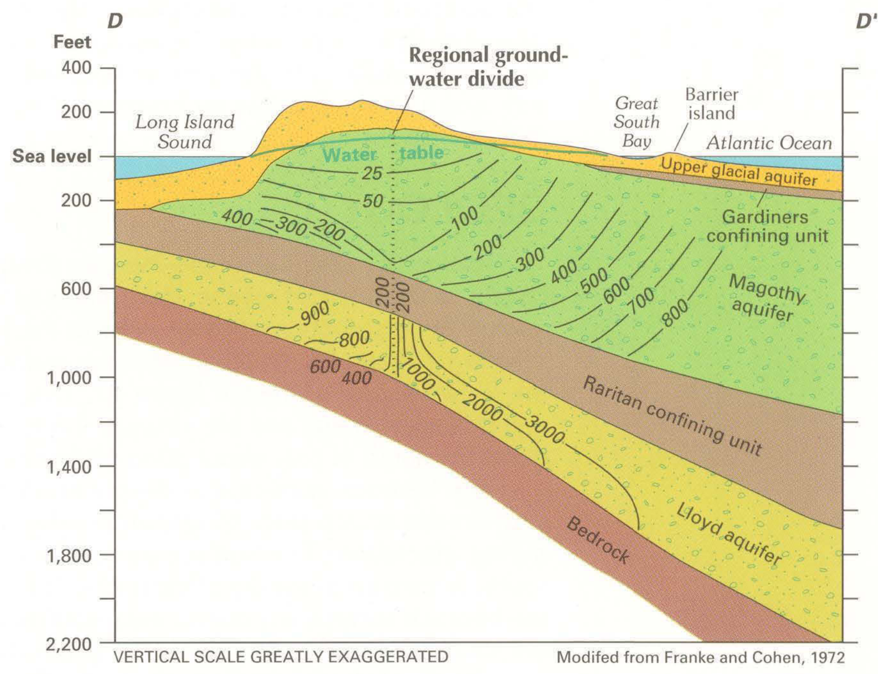
0 .5 1 MILE
0 .5 1 KILOMETER

Figure 79. *Saltwater has entered the upper glacial, Jameco, and Magothy aquifers in the southwestern part of Long Island as a result of large ground-water withdrawals that have disturbed equilibrium conditions. The line of the section is shown in figure 81.*

Table 11. *Estimates of the rate at which water moves into, through, and out of the ground-water flow system in the central part of Long Island indicate that about one-half the precipitation falling on the island becomes ground-water recharge*

[Modified from Franke and McClymonds, 1972]

Water movement	Rate of movement (million gallons per day)
Into ground-water flow system	
Precipitation	1,600
Minus evapotranspiration	795
Minus direct runoff	20
Subtotal	785
Through ground-water flow system	
Ground-water recharge	785
Out of ground-water flow system	
Ground-water discharge to streams	320
Underflow to saltwater bodies	450
Evapotranspiration of ground water	15
Subtotal	785

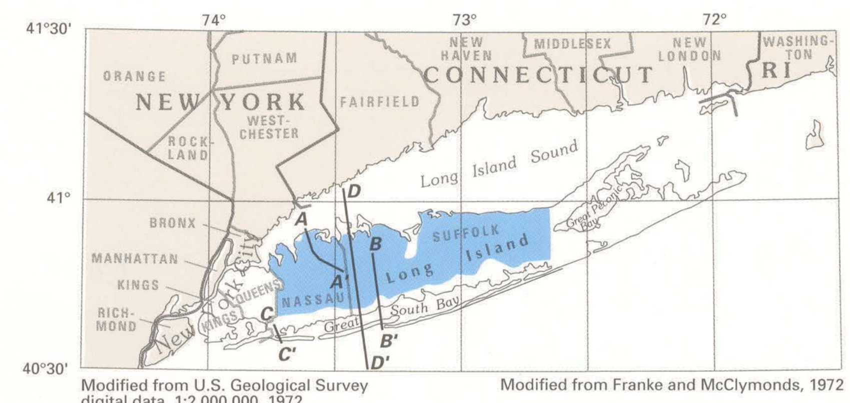


EXPLANATION

—300— Line of equal age of water—Interval, in years, is variable

0 5 10 MILES
0 5 10 KILOMETERS

Figure 80. *Some of the water that enters the upper glacial aquifer as recharge moves downward through the upper glacial and Magothy aquifers to the Raritan confining unit in about 100 years. Movement through the confining unit requires about another 100 years, and movement about 15 miles downdip in the Lloyd aquifer takes as much as 3,000 years. The line of the section is shown in figure 81.*



SCALE 1:2,500,000

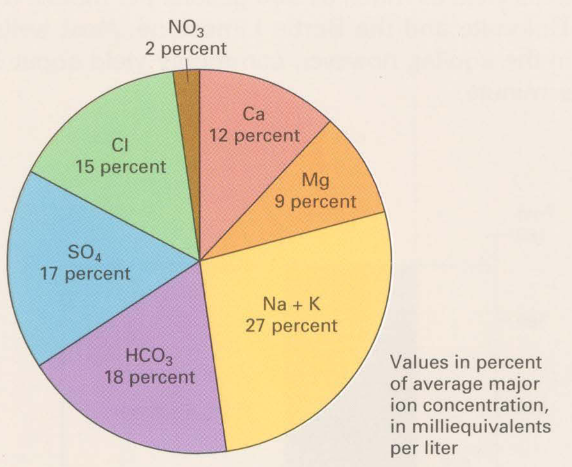
0 25 50 MILES
0 25 50 KILOMETERS

EXPLANATION

Area used in estimating rates of water movement

A——A' Line of hydrogeologic section

Figure 81. *Estimates of the rates of water moving into, through, and out of the ground-water flow system presented in table 11 were calculated for the area shown, which consists of parts of Nassau and Suffolk Counties.*



Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	5.3 to 6.5	6.1 (median)	6
Calcium (Ca)	0.5 to 4.0	1.6	6
Magnesium (Mg)	0.1 to 1.6	0.77	6
Sodium (Na)	2.4 to 6.2	3.7	6
Potassium (K)	0.3 to 2.2	0.92	6
Bicarbonate (HCO_3)	3.0 to 16.0	7.2	6
Sulfate (SO_4)	1.0 to 14.0	5.5	6
Chloride (Cl)	2.0 to 5.0	3.6	6
Dissolved solids	15 to 36	30	6
Nitrate (NO_3)	0.1 to 1.9	0.6	6
Iron (Fe)	0.01 to 3.3	1.12	6

Data from Franke and McClymonds, 1972

Figure 82. *Concentrations of all constituents in each of the aquifers on Long Island are minimal. Calcium, bicarbonate, chloride, and sulfate make up similar percentages of dissolved constituents, and sodium makes up a slightly higher percentage.*

GROUND-WATER QUALITY

Generally, the chemical quality of water in the aquifers of Long Island is suitable for most uses, including human consumption (**fig. 82**). Concentrations of dissolved solids in water from each of the aquifers are exceptionally small—less than 40 milligrams per liter. Stream and lake water, which is largely derived from ground-water discharge, reflects these small concentrations, having similar dissolved-solids concentrations of less than 50 milligrams per liter. In places, larger concentrations of dissolved solids indicate mixing of freshwater with saltwater or contamination from sources at the land surface. Iron concentrations are locally excessive, and the pH of the water commonly is less than 6.0, which causes the water to be very corrosive to transmission pipes, pumps, and plumbing.

The changes in quality of water as it moves through the hydrologic system on Long Island are described in **figure 83**. Moisture-laden air that moves over the ocean picks up salty spray. Precipitation removes salt, dust, and gases from the atmosphere as it falls to Earth; the average dissolved-solids concentration of precipitation has been reported to be about 10 milligrams per liter. Evapotranspiration concentrates and increases the dissolved-solids concentration of the water. Natural processes, especially oxidation, modify dissolved-solids concentrations and the chemical character of the water in the zone of aeration. Flow through the saturated zone tends to increase the dissolved-solids concentration in the water but, because aquifer materials are virtually chemically inert, little change occurs.

Thus, the salient features of the natural water chemistry of the island are (1) natural freshwater has a remarkably small dissolved-solids concentration, (2) the chemically inert materials that form the aquifer cause little change in the dissolved-solids concentration of the water as it moves through the ground-water flow system, (3) mixing of freshwater and saltwater in the transition zone results in a sodium-chloride-type water with large concentrations of dissolved solids, and (4) the pH of ground water is commonly less than 6.0, which causes the water to be corrosive.

Ground-water contamination from various sources is a problem of long standing on Long Island. Saltwater encroachment from excessive ground-water withdrawals has rendered much of the ground water in Kings and Queens Counties unpotable. In Nassau and western Suffolk Counties, septic systems, oil and gas spills, and pesticide use have contaminated much of the upper glacial aquifer and forced most users to withdraw water from the Magothy aquifer. In the remainder of Suffolk County, which is not densely populated, contamination generally is not a serious problem. On the eastern end of the island, however, truck farming has introduced some pesticide contaminants into the upper glacial aquifer.

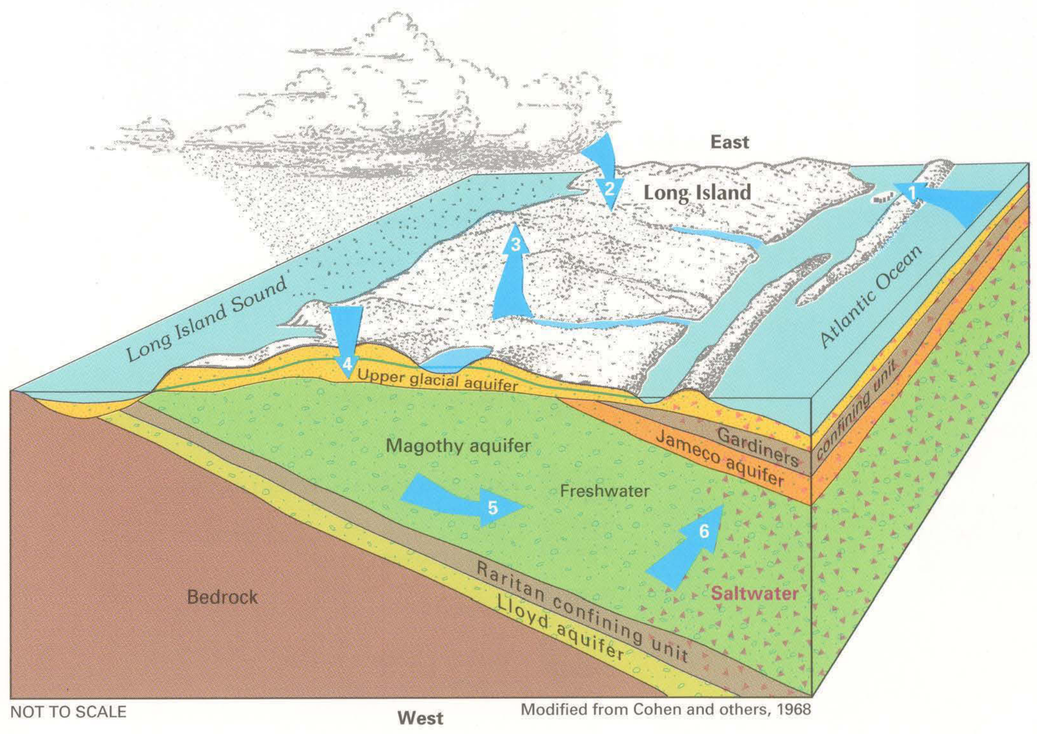
FRESH GROUND-WATER WITHDRAWALS

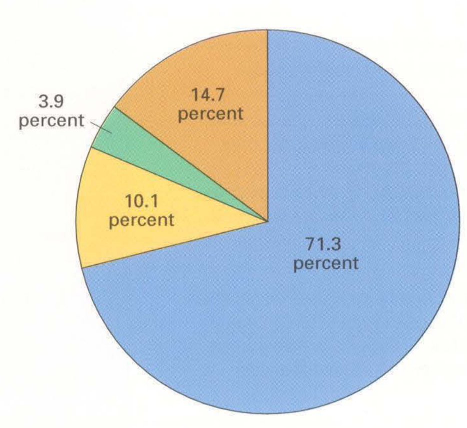
Fresh ground-water withdrawals on this densely populated and urbanized island were about 469 million gallons per day during 1985. Public supply accounted for about 71 percent of the withdrawals (**fig. 84**), and withdrawals for industrial, mining, and thermoelectric power were estimated to be about 15 percent. Combined domestic, commercial, and agricultural uses accounted for the remaining 14 percent of total withdrawals.

Figure 83. *A number of processes affect water quality as the water moves through the ground-water flow system.*

EXPLANATION

1. Air moving over ocean picks up salt spray
2. Precipitation removes dust and gases from atmosphere
3. Evaporation and transpiration of precipitation from land surface and from soil zone increase dissolved-solids concentration of ground water
4. Physical, chemical, and biological processes modify dissolved-solids concentration of water that percolates through unsaturated zone
5. Flow through glacial deposits and coastal plain sediments in saturated zone modifies dissolved-solids concentration of ground water only slightly
6. Fresh ground water and salty ground water mix in transition zone





Total withdrawals
469.3 million gallons per day

Data from U.S. Geological Survey, 1990

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent

71.3	Public supply
10.1	Domestic and commercial
3.9	Agricultural
14.7	Industrial, mining, and thermoelectric power

Figure 84. *Public supply accounted for about 71 percent of total withdrawals of fresh ground water during 1985 in this densely populated area.*

Carbonate-rock aquifers

INTRODUCTION

Aquifers are present in consolidated rocks in the Central Lowland, the St. Lawrence Valley, the Adirondack, and the New England Physiographic Provinces in Segment 12. These aquifers are in three principal types of rocks: carbonate rocks (**fig. 85**), sandstone, and crystalline rocks of igneous or metamorphic origin. No regional study has been conducted for aquifers in any of the three principal rock types in the segment; accordingly, examples of smaller scale studies are described in this report. The examples were chosen because they represent ground-water occurrence, movement, and quality for each principal rock type.

Consolidated-rock, or bedrock, aquifers also are present in the Appalachian Plateaus, the Valley and Ridge, and the Piedmont Physiographic Provinces in Segment 12. The bedrock aquifers in these provinces are carbonate-rock and sandstone aquifers that generally yield only small volumes of water and are of local extent. The bedrock aquifers in the Appalachian Plateaus, the Valley and Ridge, and Piedmont Provinces are not described in this report.

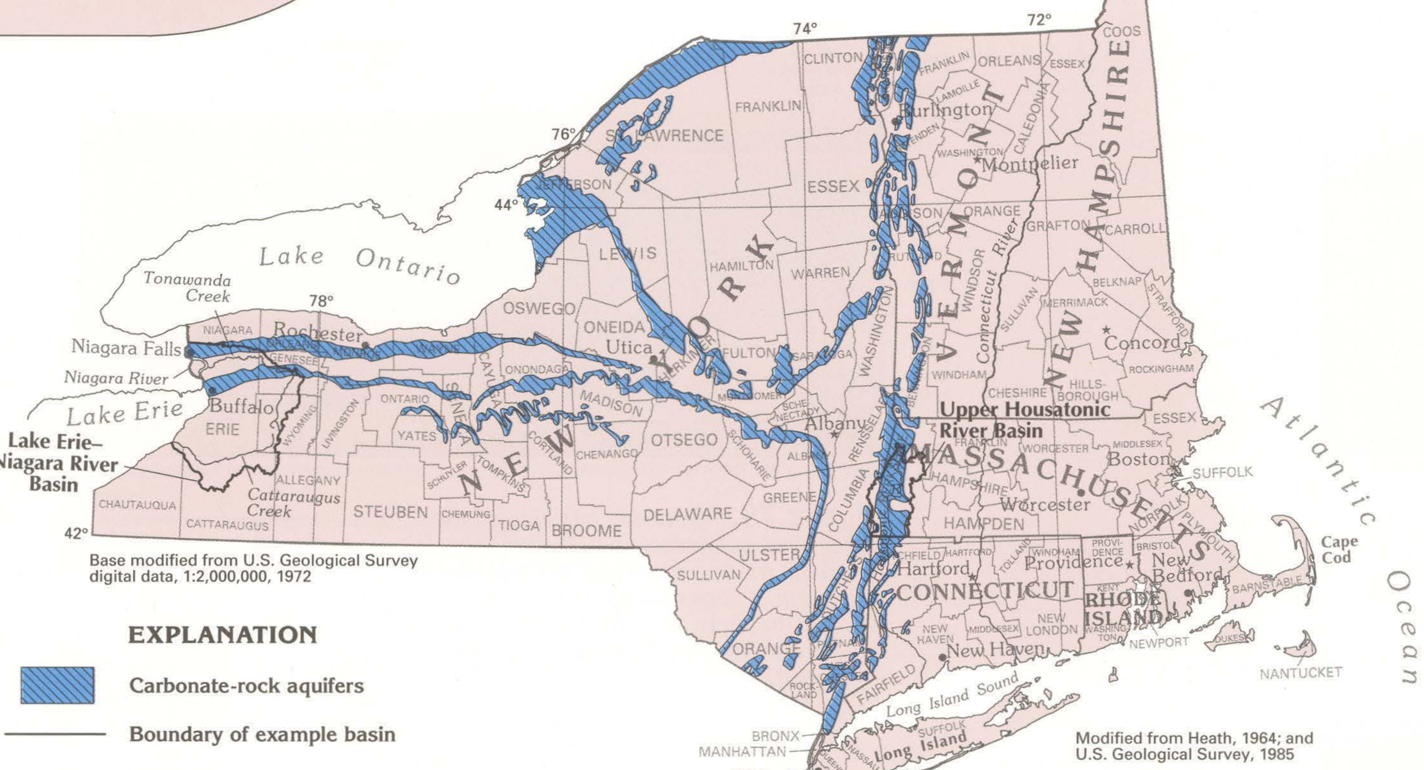


Figure 85. *Carbonate-rock aquifers underlie several areas of New York, Vermont, Massachusetts, and Connecticut.*

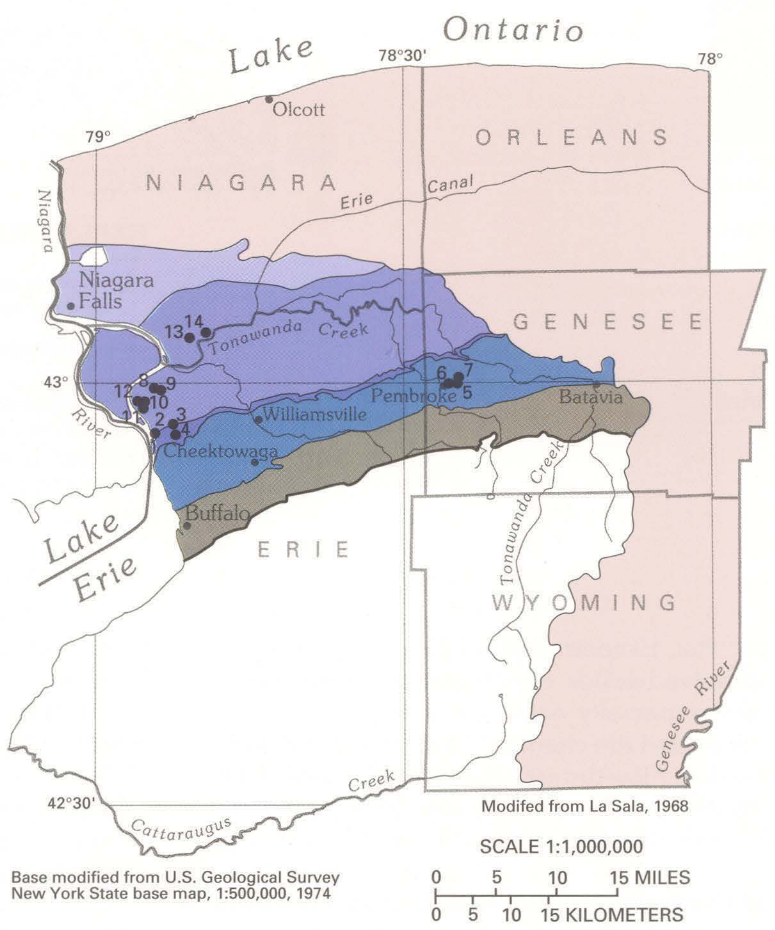


Figure 86. *The Lake Erie–Niagara River Basin is located in western New York. The northern part of the basin is underlain by numerous geologic units, which are mostly limestone, dolomite, and shale of Silurian and Devonian ages.*

System	Formation	Principal lithology	Hydrogeologic unit
Devonian	Skaneateles Shale	Fissile shale. Some calcareous beds and pyrite. Ten-foot, gray limestone at base	Confining unit. Shales yield small quantities of water
	Marcellus Shale	Dense, fissile shale	
	Onondaga Limestone	Limestone; cherty limestone; and crinoidal limestone	**Limestone aquifer.** Wells completed in Akron and Bertie yield as much as 300 gallons per minute. Yields commonly are about 30 gallons per minute; yields are larger in outcrop areas
Silurian	Akron Dolomite	Fine-grained dolomite	
	Bertie Limestone	Dolomite and dolomitic limestone. Some interbedded shale	
	Camillus Shale Syracuse Formation Vernon Shale	Shale and massive mudstone. Interbedded limestone and dolomite prominent. Gypsum beds, lenses, and veins common. Some salt beds in subsurface	**Camillus aquifer.** Wells yield as much as 1,200 gallons per minute, but commonly yield about 50 gallons per minute
	Lockport Dolomite: Gasport Limestone Member; Decew Dolomite Member	Fine- to coarse-grained dolomite. Local algal reefs and gypsum nodules. Gasport is limestone. Decew is shaly dolomite	**Lockport aquifer.** Wells yield as much as 100 gallons per minute, but commonly yield about 30 gallons per minute
	Rochester Shale	Calcareous shale	Confining unit

Modified from La Sala, 1968

Figure 87. *The basin contains three aquifers that consist of limestone, dolomite, and gypsiferous shale. The aquifers are bounded above and below by confining units of shale.*

LAKE ERIE–NIAGARA RIVER BASIN

The aquifers in the Lake Erie–Niagara River Basin are an example of carbonate-rock aquifers that are characteristic of the Central Lowland Province of western New York. The aquifers are in the northern one-third of the basin and consist of flat-lying limestone and dolomite with some gypsum and abundant interbedded shale. The aquifers typically yield only small to moderate quantities of water to wells; the water is hard, and saltwater is present in places, commonly at shallow depths.

The Lake Erie–Niagara River Basin in western New York is bordered by Lake Erie and the Niagara River on the west and extends eastward to about the middle of Genesee County (**fig. 86**). The basin includes the area near the city of Niagara Falls in which streams drain to the Niagara River. A strip of land bordering Lake Erie is part of the Eastern Lake Section of the Central Lowland Physiographic Province, which is a region of low relief. The remainder of the basin is in the rugged Appalachian Plateaus Physiographic Province, which has considerable relief, but all the aquifers described are in the Central Lowland Province.

The basin has been glaciated, a process that scoured the bedrock surface and left a veneer of till in the upland areas and thick, complex valley-fill deposits that consist of ice-contact, outwash, and glacial-lake deposits in the deeply eroded bedrock valleys. The valley-fill deposits form principal aquifers that are hydraulically connected with bedrock aquifers and with streams that traverse the surface of the valley fill.

Bedrock in the basin consists chiefly of limestone, dolomite, and shale. The carbonate rocks and the shale are virtually impermeable as homogeneous rock. These rocks, however, have been subjected to regional tectonic stresses and are vertically and horizontally fractured. The fractures provide openings for the storage and transmission of water. Fracture permeability is enhanced in limestone and, to a lesser extent, in dolomite by dissolution of the rock by ground water. A similar enhancement of permeability is produced by dissolution of interbedded gypsum in some rock units.

The principal bedrock aquifers in the Lake Erie–Niagara River Basin are (1) a limestone aquifer that consists of the Onondaga Limestone, the Akron Dolomite, and the Bertie Limestone; (2) the Camillus aquifer, which consists of the Camillus Shale, the Syracuse Formation, and the Vernon Shale; and (3) the Lockport aquifer, which consists of the Lockport Dolomite. These aquifers differ considerably in water-yielding characteristics but generally yield only small to moderate quantities of water to wells. The aquifers, however, are typical of bedrock aquifers in the Central Lowland Province of New York and are presented as an example of aquifers in that hydrologic environment.

GEOLOGY

Bedrock in the Lake Erie–Niagara River Basin consists chiefly of stratified limestone, dolomite, and shale of marine origin. The distribution of these units at the bedrock surface is shown in **figure 86**, and their lithology and vertical sequence are shown and described in **figure 87**. The units are Silurian and Devonian in age and are virtually flat lying, with a gentle dip to the south of only about 30 to 40 feet per mile (**fig. 88**).

The bedrock surface was deeply eroded by weathering and stream action prior to glaciation and by glacial scour during glaciation. The surface increases in altitude to the south, in contrast to the dip of the rocks. Thus, rocks that form the bedrock surface in parallel, east-northeast-trending belts are successively younger toward the south (**fig. 86**).

Much of the bedrock in the Lake Erie–Niagara River Basin consists of black to gray carbonaceous shale with minor calcareous beds and limestone layers (**fig. 87**). The exceptions are the five formations, which form the three aquifers, that consist of limestone, dolomite, and gypsiferous shale primarily of Silurian age.

The Lockport Dolomite is the lowermost carbonate-rock unit and overlies the Rochester Shale. The Lockport forms the bedrock surface in the northern part of the basin (**fig. 86**) and consists mainly of fine- to coarse-grained dolomite. Gypsum is present as nodules along some bedding-plane surfaces in the Lockport. The maximum thickness of the Lockport is about 150 feet. Near the base of the Lockport, the formation is divided into the Decew Dolomite Member and the overlying Gasport Limestone Member.

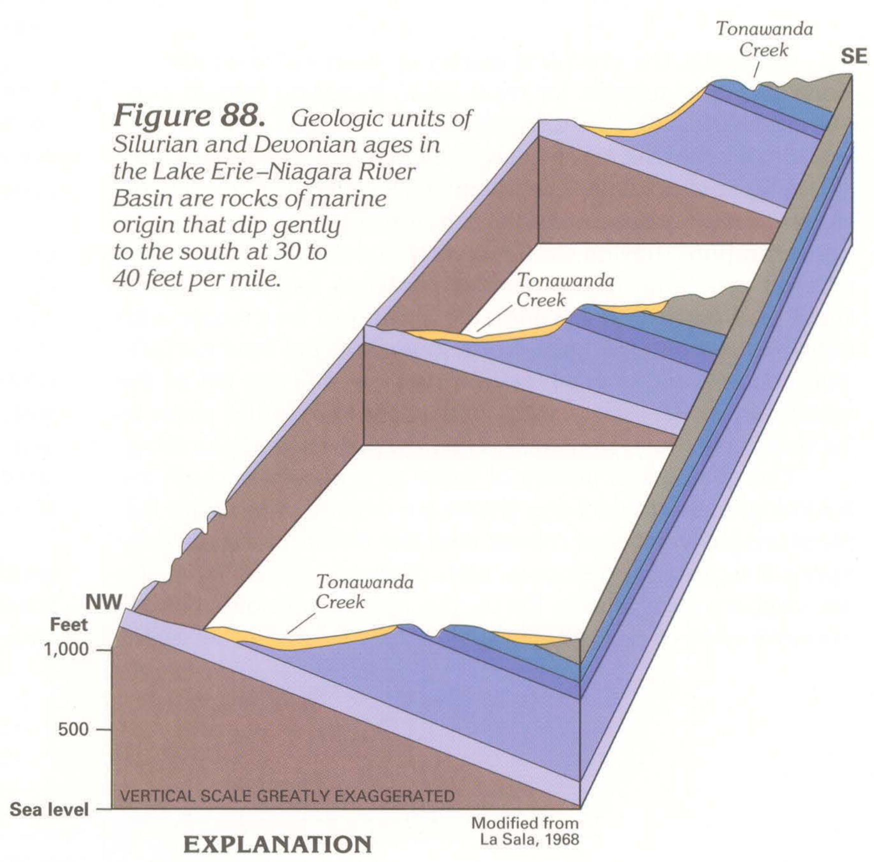


Figure 88. *Geologic units of Silurian and Devonian ages in the Lake Erie–Niagara River Basin are rocks of marine origin that dip gently to the south at 30 to 40 feet per mile.*

EXPLANATION

Holocene deposits
- Glacial and alluvial deposits

Devonian rocks
- Skaneateles and Marcellus Shales
- Onondaga Limestone

Silurian rocks
- Akron Dolomite and Bertie Limestone
- Camillus Shale, Syracuse Formation, and Vernon Shale
- Lockport Dolomite
- Rochester Shale and older rocks

The Vernon Shale, the Syracuse Formation, and the Camillus Shale overlie the Lockport Dolomite and form the bedrock surface to the south of the Lockport (**fig. 86**). Outcrops of these formations are rare because of the low relief of the area and the cover of glacial deposits. The three formations consist chiefly of shale; however, considerable massive mudstone, limestone, and dolomite are interbedded with the shale (**fig. 87**). Gypsum is present in beds as much as 5 feet thick, as well as in thin lenses and veins.

A sequence of limestone units—the Bertie Limestone, the Akron Dolomite, and the Onondaga Limestone (**fig. 87**)—overlies the Camillus Shale. The Bertie Limestone and the Akron Dolomite are of Silurian age and are separated from the overlying Onondaga Limestone of Devonian age by an unconformity or erosional contact.

The Bertie Limestone consists mostly of dolomite and dolomitic limestone with interbedded shale particularly in the lower parts (**fig. 89**). The middle part of the Bertie is a massive dolomite and dolomitic limestone. The upper part is gray dolomite and shale with beds of variable thickness. Its maximum thickness is about 55 feet.

The Akron Dolomite is a fine-grained dolomite with beds that vary in thickness from a few inches to about 1 foot. The upper contact of the Akron is erosional and generally is marked by remnants of shallow stream channels that contain sandy lenses. The thickness of the Akron generally is between 7 and 9 feet.

The Onondaga Limestone, which has a maximum thickness of about 110 feet, forms the upper two-thirds of the carbonate-rock sequence. The Onondaga consists of three lithologies: a lower coarse-textured, crinoidal limestone that is about 10 feet thick; a middle cherty limestone that is about 45 feet thick; and an upper limestone that is about 55 feet thick.

The carbonate-rock sequence is overlain by the Marcellus Shale (**fig. 87**), which is a gray to black fissile shale with a basal, 10-foot-thick limestone sequence; the thickness of the formation ranges from 30 to 50 feet. The Marcellus Shale is, in turn, overlain by the Skaneateles Shale.

AQUIFERS AND THEIR CHARACTERISTICS

The bedrock units in the northern part of Lake Erie–Niagara River Basin have been divided into three aquifers. In descending order they are the limestone, the Camillus, and the Lockport aquifers. The aquifers are not separated by confining units, but can be distinguished by their contrasting water-yielding characteristics. Except where they form the bedrock surface and are mostly covered by glacial deposits, the three aquifers are overlain and underlain by thick sequences of shale that form effective confining units.

The limestone aquifer, which consists of the Onondaga Limestone, the Akron Dolomite, and the Bertie Limestone (**fig. 89**), yields water mostly from solutionally enlarged fractures, bedding planes, and other openings in the rock. Bedding planes or horizontal fractures typically are the most enlarged and important water conduits; however, vertical fractures conduct some water between horizontal openings.

The area where the limestone aquifer forms the bedrock surface is drained by Tonawanda Creek and its major tributaries (**fig. 86**). Water enters the aquifer in the interstream areas by infiltration into joints and fractures. Some of the water is discharged laterally to the streams, and some percolates downward into the Camillus Shale.

The transmissivity of the limestone aquifer ranges from 535 to 3,340 feet squared per day. Transmissivity and specific capacity data are summarized in **table 12**. A number of large-yield wells in Buffalo, Cheektowaga, Williamsville, Pembroke, and Batavia are completed in the limestone aquifer. These wells yield as much as 300 gallons per minute from the Akron Dolomite and the Bertie Limestone. Most wells completed in the aquifer, however, commonly yield about 30 gallons per minute.

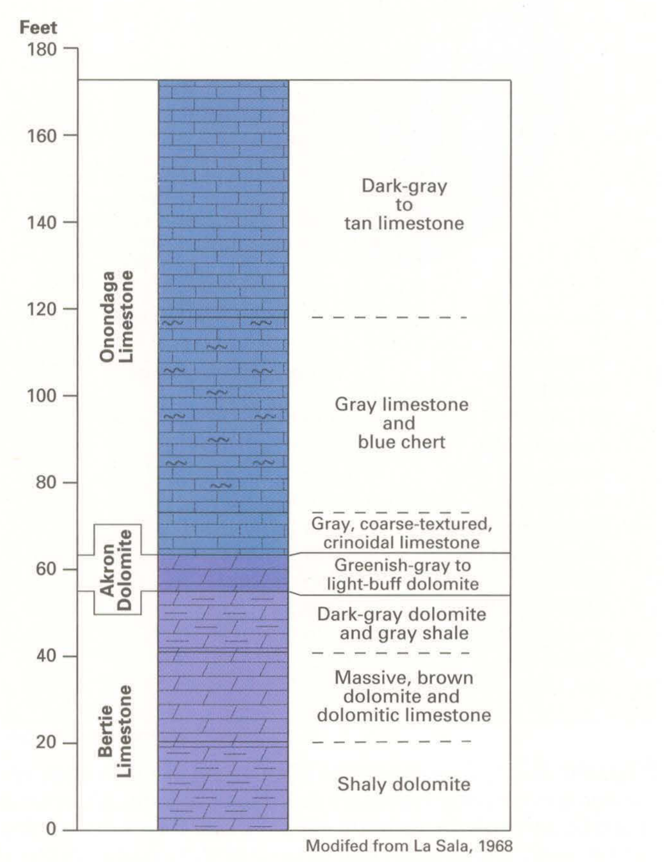


Figure 89. *The limestone aquifer, which consists of the Bertie Limestone, the Akron Dolomite, and the Onondaga Limestone, forms the uppermost bedrock aquifer in the basin.*

Table 12. *The transmissivity of the limestone aquifer ranges from about 500 to 3,300 feet squared per day*

[Modified from La Sala, 1968; —, no data]

Well number (fig. 86)	Pumping rate (gallons per minute)	Duration of pumping (hours)	Drawdown (feet)	Specific capacity (gallons per minute per foot)	Transmissivity (feet squared per day)
2	30	—	17	2	535
3	130	—	10	13	3,340
4	180	6	45	4	1,070
5	100	8	30	3.3	800
6	100	8	12	8.3	2,005
7	104	8	28	3.7	935

AQUIFERS AND THEIR CHARACTERISTICS—Continued

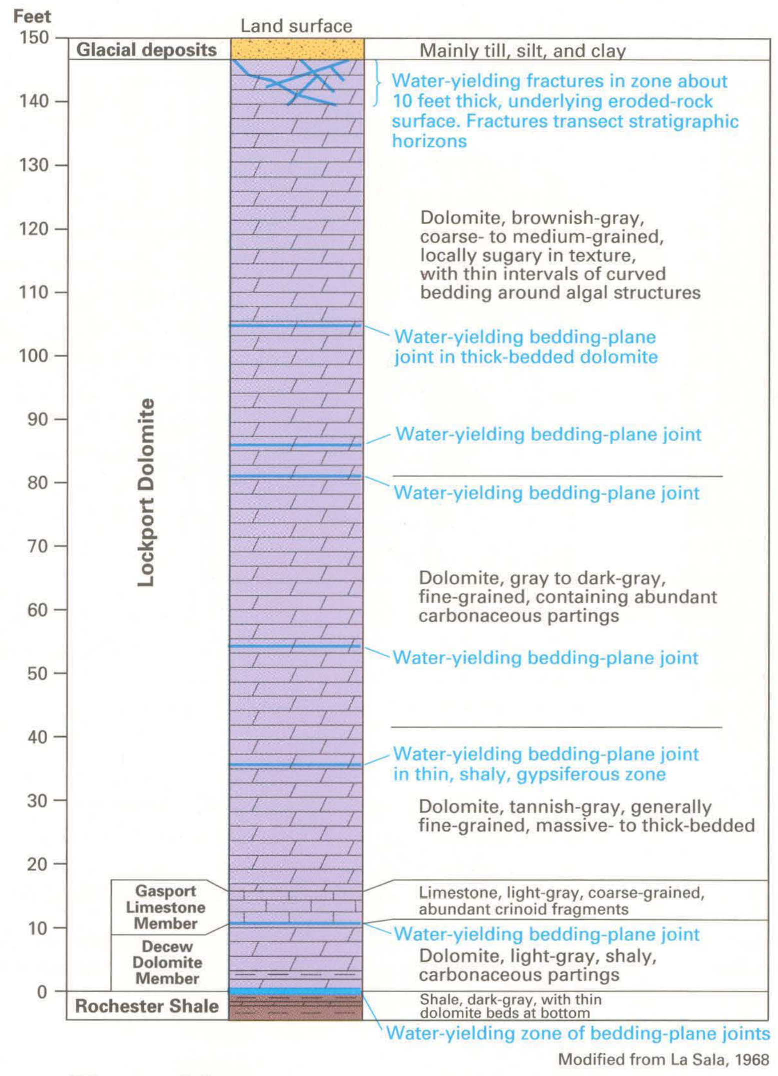
The Camillus aquifer is by far the most productive aquifer in the basin. Industrial wells completed in the aquifer in the vicinity of Buffalo and Tonawanda yield from 300 to 1,200 gallons per minute, and large volumes of water from the aquifer entering mines elsewhere in the basin indicate that large well yields are possible locally. The Camillus Shale contains extensive interbedded gypsum, which is more soluble than the surrounding shale, limestone, or dolomite. Therefore, as the gypsum dissolves, openings remain that enhance the storage and transport of water. As a result of these openings, the Camillus aquifer has transmissivity values that range from 935 to 9,350 feet squared per day (**table 13**). The transmissivity, however, is variable vertically and horizontally within the aquifer because of the variability of occurrence of the gypsum and the extent of dissolution.

Table 13. *The transmissivity of the Camillus aquifer ranges from about 900 to 9,300 feet squared per day*

[Modified from La Sala, 1968; e, estimated; — no data]

Well number (fig. 86)	Pumping rate (gallons per minute)	Duration of pumping (hours)	Drawdown (feet)	Specific capacity (gallons per minute per foot)	Transmissivity (feet squared per day)
8[1]	1,090	8e	53	21	5,350
9	90	—	22	4	935
10	500	8e	17	29	7,350
11	1,000	8e	26	36	9,350
12	1,500	8e	38	39	9,350
13	700	24	10	70	—
14	660	8e	8	83	—

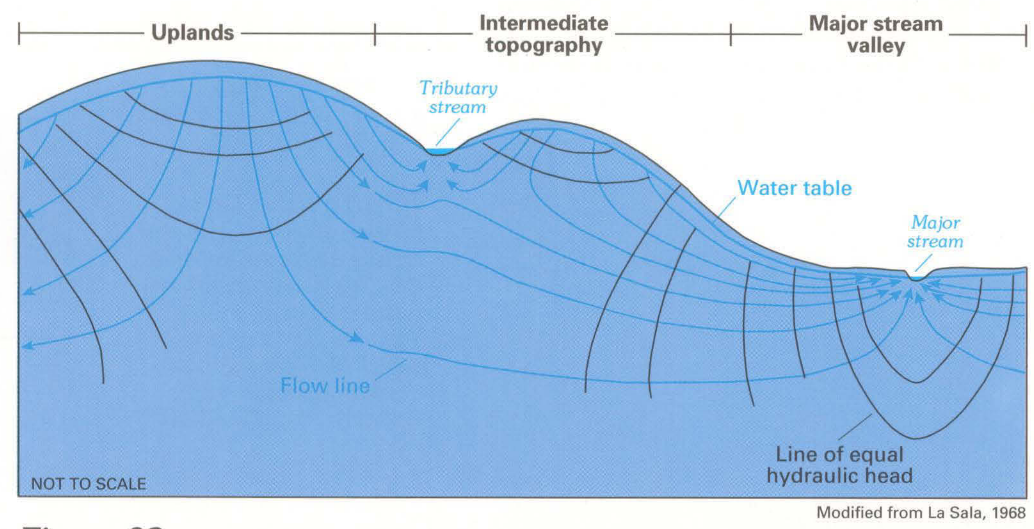
[1] Well also penetrates a water-yielding zone in Lockport Dolomite



Modified from La Sala, 1968

Figure 91. *The Lockport Dolomite (Lockport aquifer) in the area of Niagara Falls yields water from eight zones of openings, most of which are horizontal bedding-plane joints.*

Figure 90. *The Lockport aquifer is the lowermost bedrock aquifer in the basin. It crops out in the northern part of the basin and consists of fine- to coarse-grained dolomite.*



Modified from La Sala, 1968

Figure 92. *In upland areas, hydraulic heads decrease with depth, and ground-water flow is downward. In areas of intermediate topography, hydraulic heads are approximately equal in the vertical plane, and flow is primarily horizontal. In major stream valleys, hydraulic heads increase with depth, and flow is upward toward the stream where ground water discharges.*

The Camillus aquifer forms a low topographic trough on its outcrop area, which is traversed by Tonawanda Creek. Water that enters the aquifer discharges mainly to Tonawanda Creek. Other streams that traverse the aquifer, however, are not well incised, and discharge from the Camillus aquifer to these streams is small.

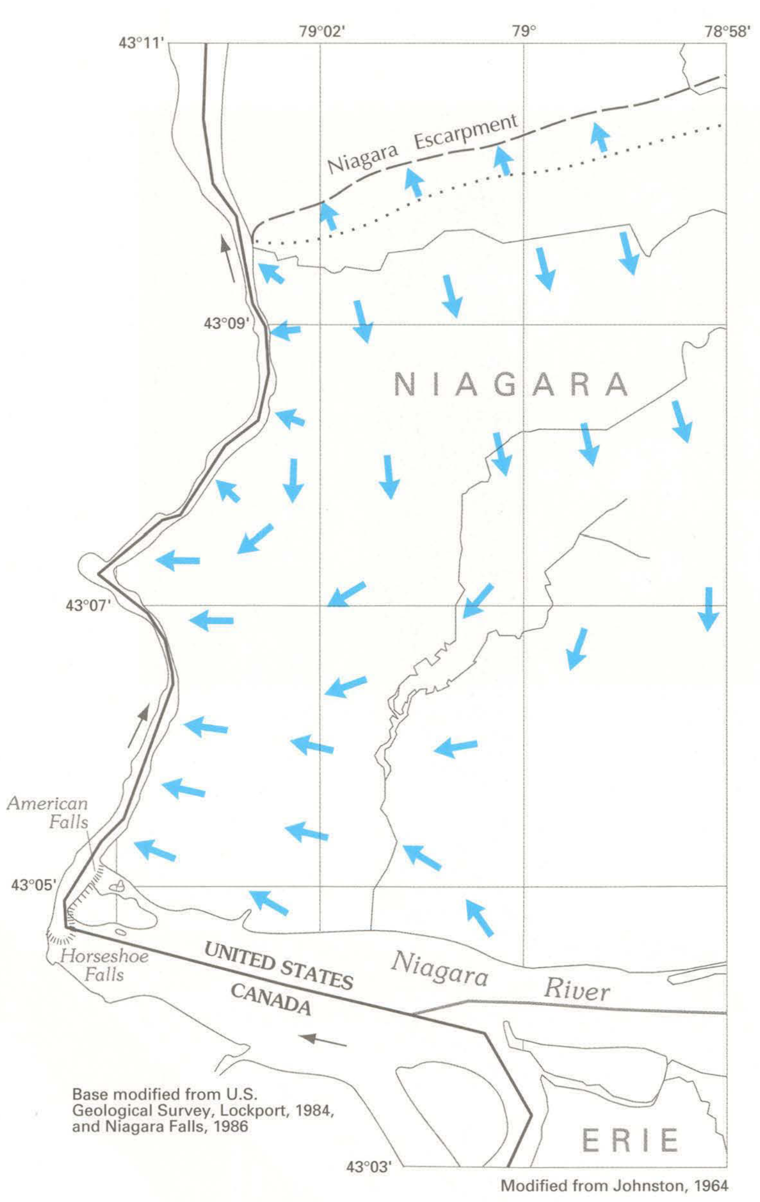
The Lockport aquifer forms the bedrock surface on the north side of the basin. The Lockport Dolomite (**fig. 90**) forms the Niagara Escarpment and the lip of Niagara Falls. Water-yielding characteristics of the aquifer have been studied in detail in the vicinity of the Robert Moses Niagara Powerplant; this area is characteristic of the aquifer.

Horizontal bedding-plane joints or zones of such joints are the principal water-yielding openings in the Lockport aquifer in the Niagara Falls area. Although some water moves through vertical joints and solution cavities from which gypsum has been dissolved, these openings are minor conduits. Water-yielding bedding joints might be present in any stratigraphic horizon; however, those that are areally persistent commonly are in zones of thin beds overlain by thick or massive beds. Seven such areally extensive water-yielding zones have been identified in the Lockport aquifer in the Niagara Falls area (**fig. 91**). The bedding-plane joints appear to be continuous for miles, but they are not water-yielding everywhere. For example, the water-yielding bedding-plane joint that is about 35 feet above the base of the Lockport aquifer is located in a zone where gypsum nodules along bedding planes have been dissolved, thus providing openings for flow and storage of water. This bedding-plane joint yields some water but is not laterally persistent because of the differential dissolution of gypsum. Outcrop and well log data indicate that similar horizontal conduits are present in other parts of the basin. Where they contain water, they have been widened by dissolution of the dolomite. Some joints stand open as much as one-eighth of an inch. Locally, dissolution along the bedding planes has been sufficient to cause the overlying rock to settle.

An eighth widespread water-yielding zone in the Lockport is a weathered zone in the upper 10 feet of the formation which is extensively fractured (**fig. 91**). This zone is present only in outcrop areas and is hydraulically connected to the overlying glacial deposits.

A transmissivity of 305 feet squared per day was calculated for the Lockport aquifer on the basis of data collected during dewatering of an 18,000-foot-long powerplant intake conduit near Niagara Falls. This probably is a representative transmissivity value for the aquifer because of the extent of the aquifer involved. Aquifer tests were conducted in the Niagara Falls area by using four wells completed in the aquifer. Transmissivity values of 40 to 135 feet squared per day and coefficients of storage of 0.00001 to 0.0003 were calculated. The smallest values of transmissivity and the smallest coefficients of storage were obtained from wells completed in the lower part of the Lockport aquifer.

The Lockport aquifer is the least productive of the three bedrock aquifers. Yields of wells completed in this aquifer within the Lake Erie–Niagara River Basin range from less than 1 to about 100 gallons per minute. In the Niagara Falls area, yields of wells completed in the lower 40 feet of the Lockport aquifer range from 0.5 to 20 gallons per minute with an average yield of 7 gallons per minute. Wells completed in the upper part of the aquifer yield from 2 to 110 gallons per minute and have an average yield of 31 gallons per minute. Well yields from the Lockport are areally and vertically variable but generally are about 30 gallons per minute.



Modified from Johnston, 1964

SCALE 1:100,000

0 1 2 MILES

0 1 2 KILOMETERS

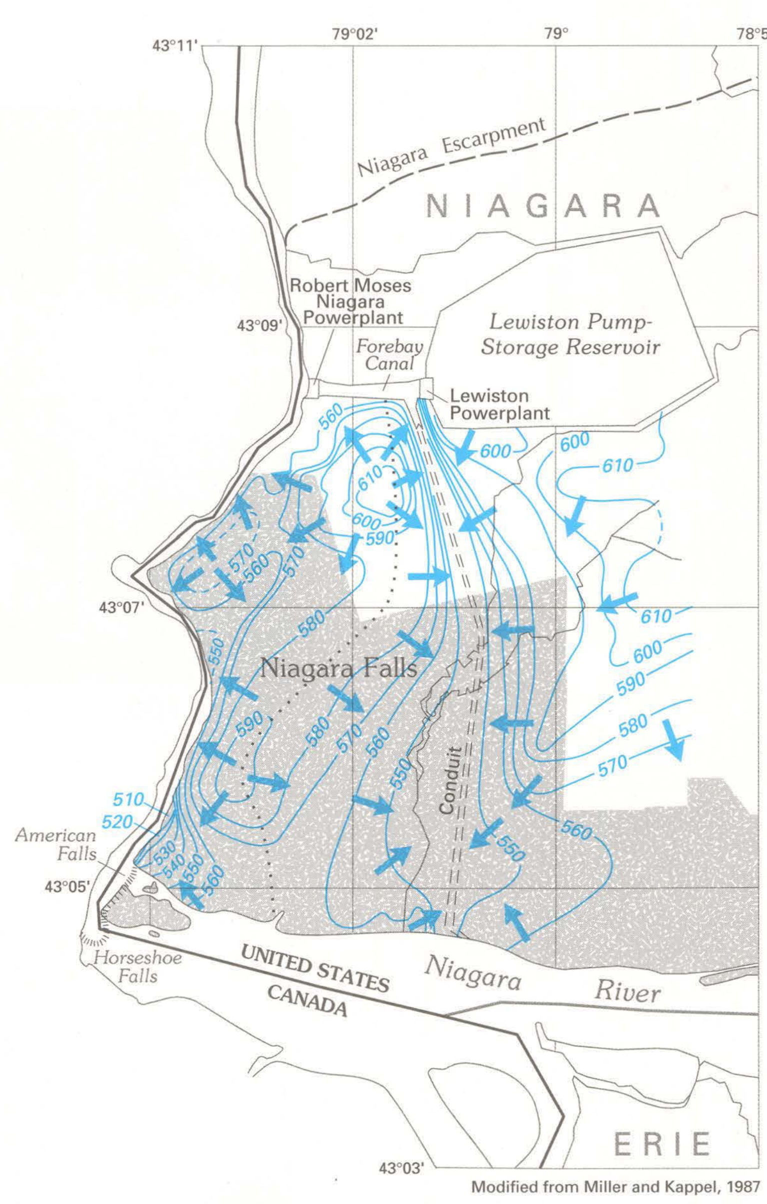
EXPLANATION

········ Ground-water divide

→ Direction of ground-water movement

→ Direction of surface-water movement

Figure 93. *Prior to ground-water development, a simple flow system existed. Water moved from a divide just south of the Niagara Escarpment through the Lockport aquifer toward the Niagara River and the escarpment.*



Modified from Miller and Kappel, 1987

EXPLANATION

········ Ground-water divide

—550— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells in March 1985. Dashed where approximately located. Contour interval 10 feet. Datum is sea level

→ Direction of ground-water movement

Figure 94. *Construction of the Lewiston Pump-Storage Reservoir and associated structures that supply two powerplants greatly affected the ground-water flow system in the Lockport Dolomite. The structures that have the most profound effect are the unlined intake conduit and the Lewiston Pump-Storage Reservoir.*

GROUND-WATER FLOW

Ground water is stored in and moves through secondary openings (joints and fractures) in the predominantly carbonate and shale rocks of the Lake Erie–Niagara River Basin. On a regional scale, the rocks can be considered as a single ground-water system with a continuous water table. Water moves through this system under a hydraulic gradient from areas of recharge to areas of discharge.

An idealized diagram that shows ground-water movement in bedrock aquifers of the basin is shown in **figure 92**. The flow lines describe the theoretical movement of water through the system. The lines of equal hydraulic head, which are at right angles to the flow lines, represent the hydraulic gradient in the aquifer. Hydraulic heads are highest in the upland areas, which are principal areas of recharge, and decrease to a minimum in major stream valleys, which are principal areas of discharge. Thus, in upland areas, hydraulic heads decrease with depth, and flow is downward. In intermediate areas, hydraulic heads are approximately equal in the vertical plane, and flow becomes primarily horizontal. At major stream valleys, hydraulic heads increase with depth, and ground-water flow is upward toward the stream, where it is discharged. The depth of the regional flow system is unknown, but it probably is no more than 300 to 500 feet below land surface because openings in the rocks below those depths are minimal.

Superimposed on the regional flow system are small local flow systems that discharge to secondary (tributary) streams (**fig. 92**). These systems operate in the same way as the regional flow system, but they are shallow and generally exist entirely within the drainage basin of a tributary stream. Local flow systems are sensitive to droughts during which the water table might decline enough to partly or completely obliterate the flow system and cause the tributary stream to cease flowing.

Inferred ground-water circulation in the Lake Erie–Niagara River Basin is through regional flow systems that have recharge areas in the Appalachian Plateaus Province; the water subsequently moves through the Central Lowland Province and discharges to Tonawanda Creek. The deepest circulating water moves upward toward Tonawanda Creek through joints and fractures in the Camillus Shale and the Lockport Dolomite.

Water movement in the bedrock aquifers has been affected by withdrawals through wells and engineering developments, such as hydroelectric power at Niagara Falls. The movement of water through the upper part of the Lockport aquifer prior to ground-water development is shown in **figure 93**. Ground water moved from topographically high areas mostly toward the Niagara River downstream from Horseshoe and American Falls. Ground water moved northward along a thin strip adjacent to the Niagara Escarpment. A ground-water divide separated movement toward the escarpment and the Niagara River. Water also moved into the Lockport from the Niagara River upstream from the falls, bypassed the falls, and discharged into the downstream reaches of the river.

The potentiometric surface of the Lockport aquifer changed (**fig. 94**) after construction of the Lewiston Pump-Storage Reservoir and the Forebay Canal, which conveys water westward from the reservoir through two powerplants to the Niagara River downstream from the falls. An unlined intake conduit also was constructed that trends northward from the Niagara River upstream from the falls to the Forebay Canal. The bottom of the intake conduit is below the water table, and the conduit functions as a line of discharge for the aquifer. The water level in the Lewiston Pump-Storage Reservoir is higher than the water table, and the reservoir functions as an imposed recharge area for the aquifer. These three structures have profoundly rearranged the ground-water flow system of the area.

The intake conduit provides a principal drain for the Lockport aquifer, and water is moving toward the conduit from the east and west for its entire length. Discharge from the reservoir moves into the aquifer and westward toward the conduit. A ground-water divide, which separates the eastward and westward movement, has been established between the conduit and the downstream reaches of the Niagara River because of discharge to the conduit. Water continues to enter the aquifer from the upstream reach of the Niagara River, but some now moves toward the conduit. Some water continues to move through the aquifer and around the falls to the downstream reaches of the Niagara River.

GROUND-WATER QUALITY

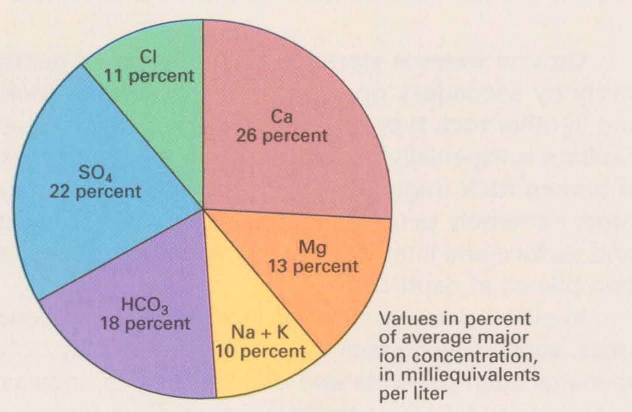
Dissolved constituents in the ground water in the northern part of the Lake Erie–Niagara River Basin are derived primarily from dissolution of the rocks through which the water moves. Water-yielding rocks in the basin contain four soluble minerals: calcite, which is the major constituent of limestone; dolomite; gypsum; and halite, or rock salt. Calcite and dolomite are present throughout the basin especially in the Lockport aquifer and in the limestone aquifer. Most shale formations in the basin, including those of the Camillus aquifer, are calcareous. Calcium, magnesium, and bicarbonate ions are dissolved from the aquifer minerals and contribute to the hardness of the water.

Gypsum is present in the Camillus aquifer and, to a lesser extent, in the Lockport aquifer. The principal dissolution products of gypsum are sulfate and calcium. Halite is present in the Camillus aquifer in the southern one-half of the basin. Dissolution of halite produces sodium and chloride in ground water.

Each of the soluble minerals in the basin also is present in varying quantities in the glacial drift, which was derived largely from the rocks that it overlies. Recharge to bedrock aquifers by water that moves through the surficial aquifer system also might contribute ions to the water in the bedrock aquifers.

Other minerals present in the rocks of the basin are silicates, which have minimal solubility. These minerals contribute only small quantities of dissolved ions to the ground water.

A summary of 21 representative chemical analyses of water from the limestone, Camillus, and Lockport aquifers is shown in **figure 95**, along with a diagram that shows the average percentage of principal constituents in the water. The water generally is very hard and of the calcium magnesium bicarbonate sulfate type. The large concentrations of sulfate indicate that the water has been in contact with gypsum. Similarly, the large concentrations of chloride indicate the presence of halite in the aquifer.



Concentrations in milligrams per liter unless otherwise specified

Property or constituent	Range	Average	Number of samples
pH (standard units)	6.6 to 7.8	7.1 (median)	21
Calcium (Ca)	17 to 520	170	21
Magnesium (Mg)	4 to 165	55	21
Sodium (Na) and potassium (K)	9.4 to 447	75	21
Bicarbonate (HCO_3)	102 to 501	353	21
Sulfate (SO_4)	0.2 to 840	348	21
Chloride (Cl)	12 to 860	125	21
Dissolved solids	193 to 3,990	993	21
Nitrate (NO_3)	0.01 to 4.0	0.8	21
Iron (Fe)	0.07 to 8.4	1.3	21

Data from La Sala, 1968

Figure 95. *Ground water in the northern part of the Lake Erie–Niagara River Basin is a calcium magnesium bicarbonate sulfate type. Concentrations of sulfate are large because of interbedded gypsum in the carbonate rocks.*

GROUND-WATER QUALITY—
Continued

The distribution of sulfate, chloride, and hardness in water from bedrock aquifers in the Lake Erie–Niagara River Basin is shown in **figures 96–98**. Concentrations of sulfate and chloride ions, as well as the hardness of the water, are greatest in the northern part of the basin and near the area where the Camillus aquifer forms the bedrock surface, especially along Tonawanda Creek. The larger concentrations and hardness values in this area probably result partly from dissolution of gypsum and halite in the Camillus aquifer and partly because Tonawanda Creek is a principal discharge area for the regional ground-water flow system. The concentrations of all constituents in ground water tend to be larger in this discharge area, which is the end point of long flow paths.

Because much of the ground water contains sulfate and chloride in excess of 250 milligrams per liter, the quality of the water places a definite limitation on its usefulness. Similarly, excessive hardness requires that the water be treated for most uses.

In addition to the general unsuitable quality of water from shallow wells in areas where the three aquifers form the bedrock surface, the quality of water from aquifers throughout the Central Lowland and the Appalachian Plateaus Provinces generally deteriorates with depth because of limited ground-water circulation and the widespread presence of salt and gypsum beds.

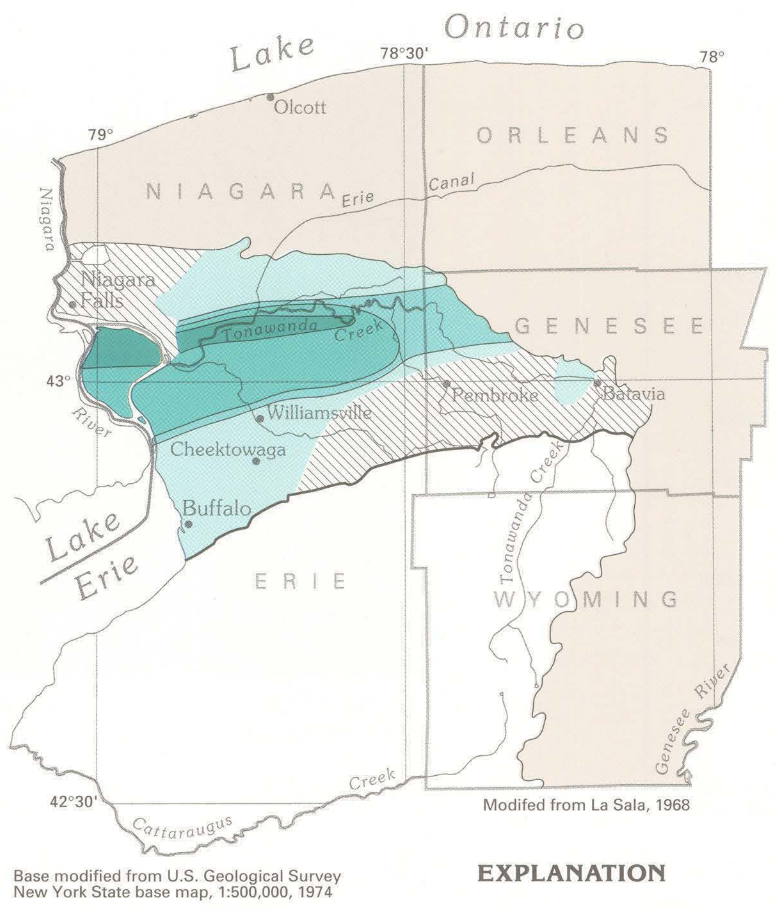


Figure 96. Sulfate content of ground water in carbonate-rock aquifers of the Lake Erie–Niagara River Basin is greatest in the Tonawanda Creek area, which is a ground-water discharge area in the northern part of the basin.

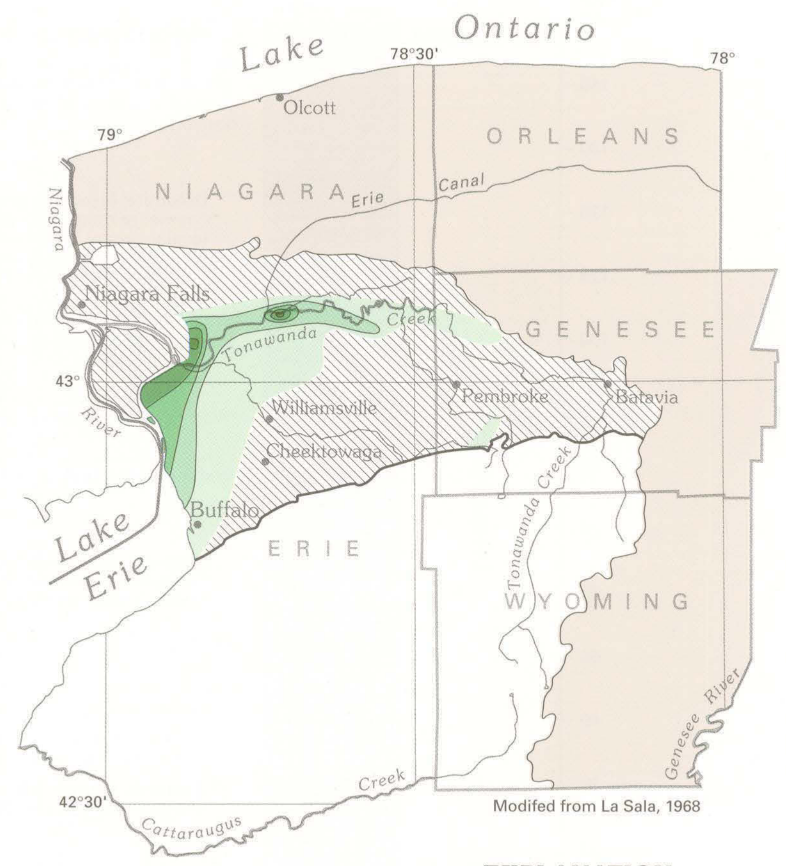


Figure 97. Chloride concentrations in water from the carbonate-rock aquifers of the Lake Erie–Niagara River Basin are greatest where ground water discharges near Tonawanda Creek.

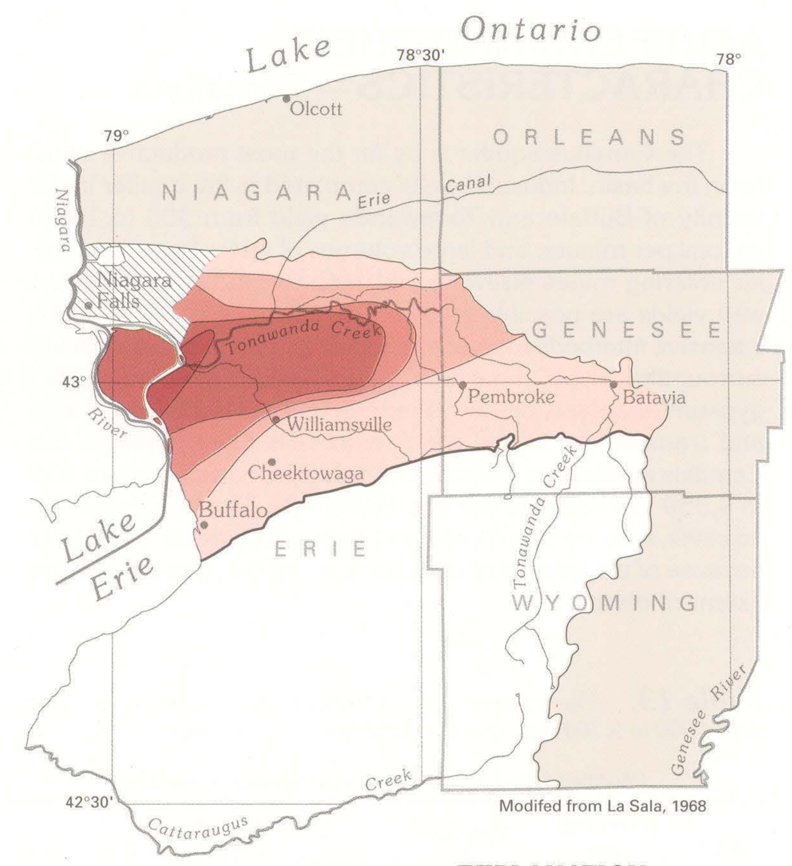


Figure 98. Hardness of ground water in carbonate-rock aquifers of the Lake Erie–Niagara River Basin is greatest in the Tonawanda Creek area, which is in the northern part of the basin.

UPPER HOUSATONIC RIVER BASIN

The upper Housatonic River Basin is located mostly in Berkshire County in western Massachusetts (**figs. 99, 85**), and in a small area in Columbia County, N.Y. The basin is bounded by the drainage divide of the Housatonic River. The river drains southward through Connecticut to Long Island Sound. The basin straddles a part of a discontinuous outcrop of carbonate rocks that extends from southeastern New York and southwestern Connecticut northward along the borders of New York, Connecticut, Massachusetts, and Vermont to the Canadian border. The carbonate rocks are exposed in valleys of the Taconic and the Green Mountains and consist largely of limestone, dolomite, and marble (**fig. 100**). The carbonate rocks exposed in the upper Housatonic River Basin generally are geologically and hydrologically typical of the entire belt of carbonate rocks in eastern New York and western Vermont, Massachusetts, and Conncecticut, and are presented here as an example of the more extensive area.

GEOLOGY

Bedrock in the upper Housatonic River Basin consists of limestone, dolomite, and marble, as well as schist, quartzite, and gneiss (**fig. 99**). During various periods of geologic history, these rocks have been deformed by tilting, folding, and faulting to such a degree that their overall formation attitudes can be determined only by detailed geologic mapping. The deformation processes have caused partings along bedding planes and have created many joints, fractures, and faults, which now constitute the major water-yielding openings in the rocks.

Carbonate rocks are present in the low central part of the upper Housatonic River Valley. They consist of limestone, dolomite, and marble of Cambrian and Ordovician ages and limestone of Precambrian age (thin beds in the eastern part of the basin). As shown in **figure 101**, the carbonate rocks are faulted and slightly folded and are in fault contact with other rock types in several areas. The carbonate rocks are bounded on the west by quartz-mica schist with some garnetiferous schist.

The carbonate rocks are bounded on the east by quartzitic rocks that consist of quartzite, quartzite conglomerate, and feldspathic quartzite with some mica schist, and by gneissic rocks that are mostly granite-biotite gneiss with some micaceous schist and quartzite. There are numerous faults in these quartzitic and gneissic rocks.

GROUND-WATER HYDROLOGY

Ground water is stored in and transmitted nearly exclusively by secondary openings in the carbonate-rock aquifer and in other rock types in the upper Housatonic River Basin. Faulting is especially important where the fault zones consist of broken rock fragments. Such zones commonly provide a large, extremely permeable conduit for water that extends to land surface and interconnects with fractures, joints, and bedding planes at depth.

In places where water circulates freely in carbonate-rock areas, such as along fault zones, dissolution may occur along openings such as joints and bedding planes, increasing and enlarging conduits for water movement. Thus, wells completed in a fault zone or solution cavity might yield large quantities of water, whereas wells a short distance away that penetrate undissolved carbonate rocks might yield virtually no water. Wells in fractured carbonate or crystalline rocks generally yield small to moderate quantities of water, depending on the number and interconnection of fractures penetrated by the well.

Ground-water movement in the basin is not well documented. However, numerous studies indicate that the size and number of openings in fractured rocks decrease with depth; this is assumed to be true in the upper Housatonic River Basin. Therefore, the ground-water flow system extends to a finite depth, possibly between 300 and 500 feet, below which fractures are sealed or sparse and flow is minimal.

Regional ground-water flow originates in the uplands (divide areas) where recharge from precipitation enters the aquifer either directly or percolates downward into the aquifer through a thin cover of glacial drift. The water then moves in response to a hydraulic gradient downward and laterally toward the Housatonic River, where it finally moves upward to be discharged into the river. Superimposed on this regional flow system are local, shallow flow systems that discharge to smaller tributary streams.

The actual flow system may differ somewhat from the theoretical flow system. Movement of ground water is subject to the random size and distribution of openings in the rocks. The water might follow irregular paths as it flows downward and laterally through the carbonate rocks. The flow system is generally unconfined; however, artesian (confined) conditions can occur. Wells that penetrate fractures filled with water under sufficient pressure to force the water upward to an altitude above that of the top of the well will flow. Similarly, a network of solution-enlarged openings in carbonate rocks might contain water under confined conditions and produce flowing wells, as well as springs where water under hydraulic pressure flows upward or laterally to the land surface. Unconsolidated glacial deposits that are thick or have minimal permeability also might confine the water in the carbonate rocks.

Yields of carbonate rocks and other rock types shown in **figure 99** are comparable because each rock type represents a fractured-rock aquifer. Wells completed in carbonate rocks, with a median yield of about 9 gallons per minute, have yields that are approximately one-half the median yields of wells completed in gneissic rocks. Yields of wells completed in carbonate rocks, however, range from less than 1 to about 1,400 gallons per minute, which is a much greater range than that reported for the other rock types because yields of wells completed in carbonate-rock aquifers generally are a function of the degree of dissolution that has occurred. In some areas of extreme dissolution, yields of nearly all wells are large, but in other areas where dissolution apparently has not occurred, yields of most wells are minimal.

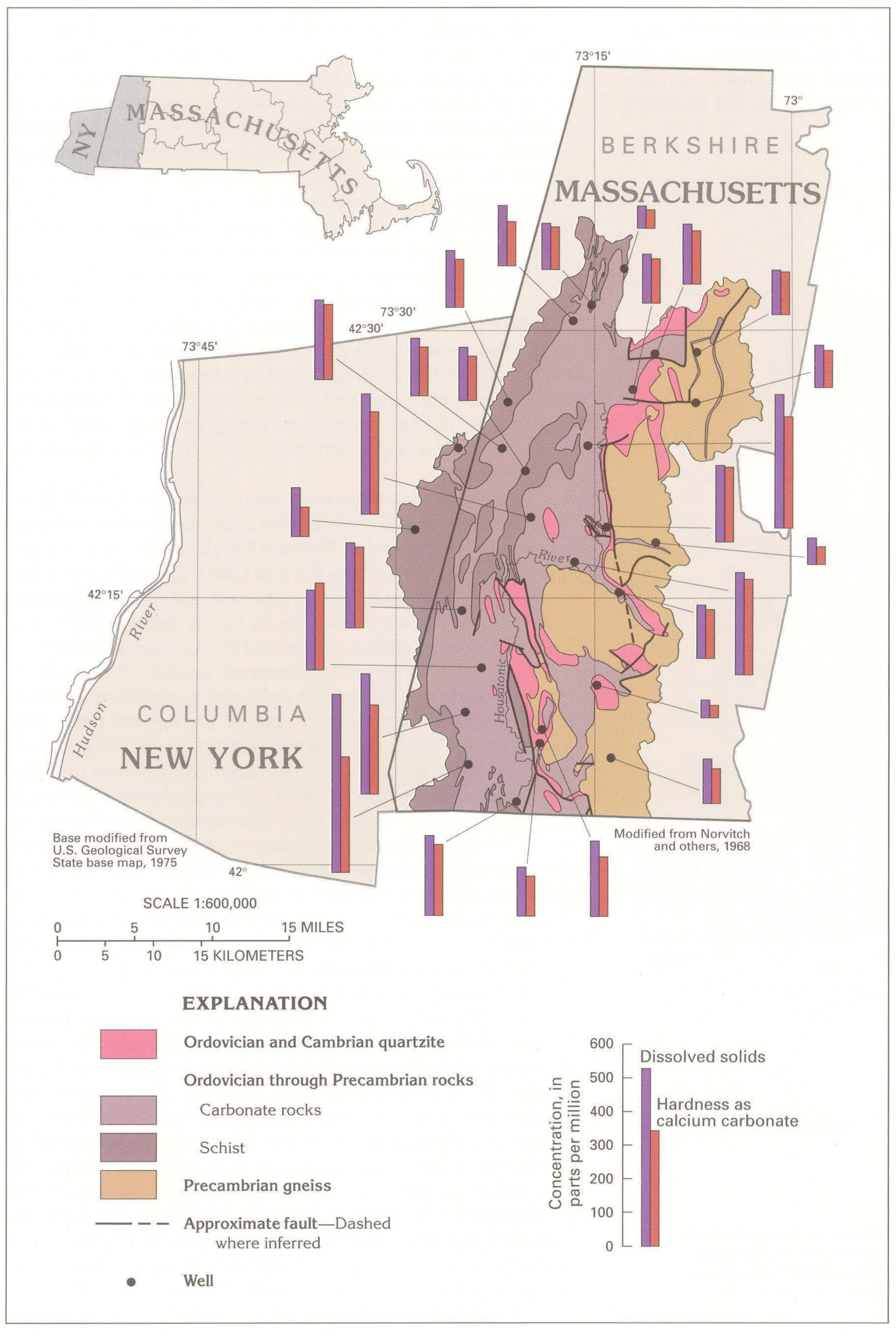


Figure 99. Carbonate rocks in the upper Housatonic River Basin of western Massachusetts and eastern New York consist of limestone, dolomite, and marble in the central lowland. Schist underlies the western side of the basin, and quartzite and gneiss underlie the eastern side of the basin. The least mineralized and softest water is obtained from wells in recharge areas that are completed in schist, quartzite, and gneiss. As the water moves into carbonate rocks toward the center of the basin and then southward, mineralization increases.

GROUND-WATER QUALITY

Water in the carbonate-rock aquifer in the upper Housatonic River Basin generally is suitable for most uses but contains large concentrations of calcium and magnesium compared to water in other rock types. This results in a moderately hard to very hard water. Bicarbonate concentrations also are large in water from the carbonate-rock aquifer. Each of these factors contributes to large concentrations of dissolved solids, which is reflected by a large specific conductance of the water. Other dissolved constituents in water from the carbonate-rock aquifer generally are in the same range as constituents in water from other rock types. This is because of the slightly mineralized precipitation that recharges all the bedrock aquifers and the similar mineralogy of the glacial deposits through which the recharge percolates before entering the aquifers.

The distribution of dissolved-solids concentrations and hardness in ground water of the upper Housatonic River Basin is shown in **figure 99** and is an indication of water quality. The least mineralized and softest ground water is present around the periphery of the basin, which is in the recharge areas that generally are underlain by schist, quartzite, and gneiss that are only slightly soluble. As the water moves through these rocks toward carbonate rocks in the center of the basin and then southward, mineralization increases. The most mineralized water obtained from the carbonate-rock aquifer was from a well near the Massachusetts–Connecticut State line.

Figure 100. Marble is a principal lithology for carbonate-rock aquifers.

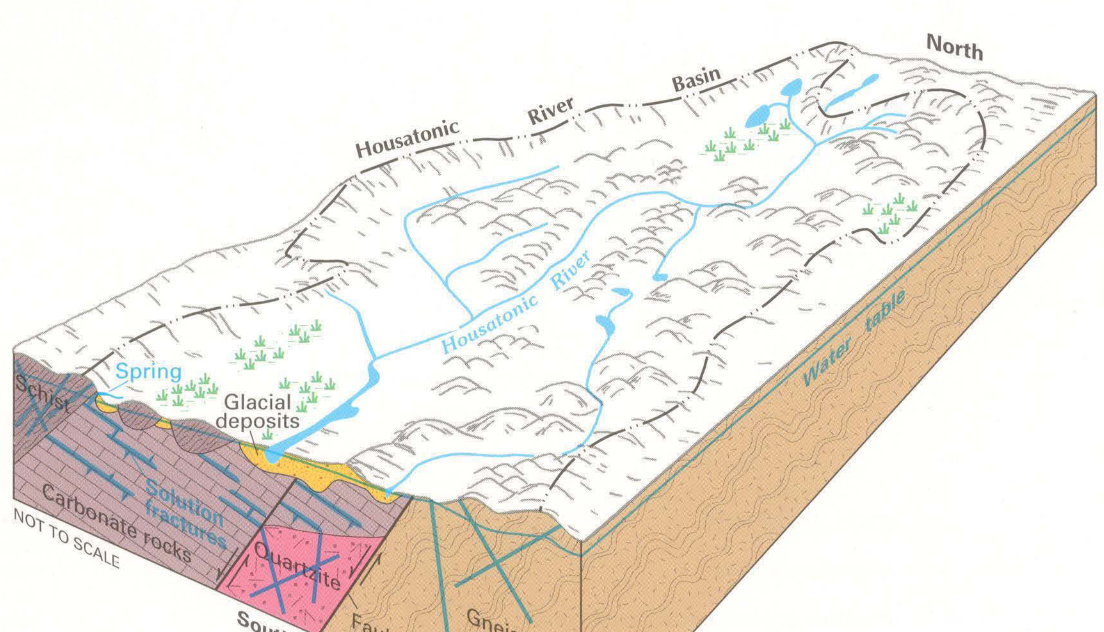


Figure 101. The central lowland of the upper Housatonic River Basin is underlain by faulted and fractured carbonate rocks that have been subjected to dissolution.

Sandstone aquifers

INTRODUCTION

Sedimentary rocks that consist primarily of sandstone form aquifers in several areas of New York, Massachusetts, and Connecticut (**fig. 102**). The Potsdam Sandstone of Cambrian age in parts of northern New York together with the overlying Theresa Formation, also of Cambrian age, is an aquifer that yields small to moderate quantities of water to wells. Small quantities of water also are obtained from sandstones of the Silurian Medina Group in the Mohawk River Valley and along the south shore of Lake Ontario. In the Connecticut River Valley of Connecticut and Massachusetts, sandstones in the Newark Supergroup of early Mesozoic age form a significant aquifer. These rocks also are present in an early Mesozoic basin in New Jersey that extends into southeastern New York. Although sandstone aquifers generally are limited in areal extent and yield small to moderate quantities of water, they are significant sources of water for rural, domestic, industrial, and small-community supplies in their area of occurrence where the surficial aquifer system is not present.

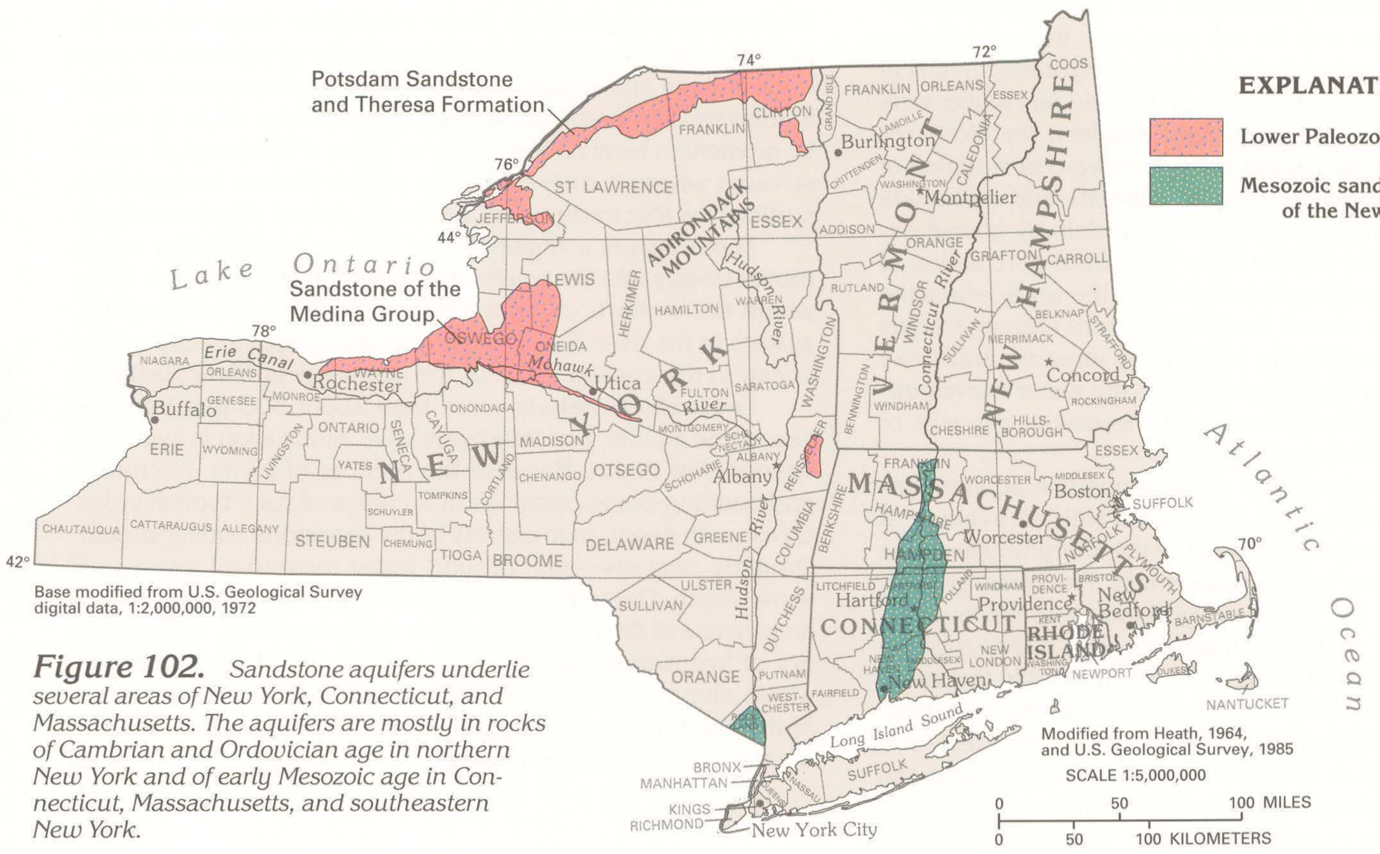


Figure 102. Sandstone aquifers underlie several areas of New York, Connecticut, and Massachusetts. The aquifers are mostly in rocks of Cambrian and Ordovician age in northern New York and of early Mesozoic age in Connecticut, Massachusetts, and southeastern New York.

GEOLOGY

The Cambrian Potsdam Sandstone forms a discontinuous fringe around the northern and western borders of the Adirondack Mountains in New York. The Potsdam generally consists of tan to grayish-white quartz sandstone with siliceous and cal-careous cement. Locally, some of the basal sandstone beds are either red from hematitic cementation or green from chloritic cementation. Basal beds of coarse conglomerate are present in some places.

The Potsdam Sandstone overlies granite and hornblende-syenite gneiss of Precambrian age (**fig. 103**); its thickness ranges from a featheredge to about 200 feet. The Potsdam might have formed originally as a beach deposit. It grades upward into the Theresa Formation of marine origin, which consists of hard, bluish-gray, thinly bedded, sandy dolomite with calcareous sandstone layers in the basal part. The upper beds of the Theresa Formation range from calcareous and dolomitic sandstones to sandy dolomite, which is characterized by numerous fossils. The thickness of the Theresa Formation ranges from a featheredge to about 70 feet. Dolomite and limestone of the Black River Group of Ordovician age overlie Cambrian rocks.

The sedimentary rocks of central Connecticut and Massachusetts have been assigned to the Newark Supergroup of early Mesozoic age (**fig. 102**). They are lithologically similar to the Newark Supergroup, which consists of red sandstone, shale, and conglomerate and fills a number of fault-block basins that extend from New Jersey to South Carolina. These basins are discussed in Chapter L of this Atlas. In Connecticut and Massachusetts, these sedimentary rocks unconformably overlie pre-Mesozoic igneous and metamorphic rocks in the lowland trough of the Connecticut River Valley. The sedimentary rocks are bounded on the east by a major fault with several thousand feet of vertical displacement (**fig. 104**). The fault formed an eastward-tilting trough that became filled with sandstone and interbedded lava flows, which are in contact with pre-Mesozoic crystalline rocks beneath and across the fault. The rocks in the trough dip eastward at about 15 degrees. They feather out to the west to expose the underlying pre-Mesozoic bedrock. Glacial deposits overlie the early Mesozoic rocks.

The Newark Supergroup consists of continental deposits of reddish arkosic sandstone (**fig. 105**), feldspathic sandstone, conglomerate, and shale, with some limestone and siltstone. The sandstone is interbedded with at least three thick basaltic lava flows (**fig. 106**) that also dip eastward at about 15 degrees. Because they are hard and resistant to erosion, the lava flows typically form topographic ridges. The softer sandstone, which is easily eroded, typically forms lowlands and rarely crops out.

The Newark Supergroup has been subdivided into three formations: the New Haven Arkose, the Meriden Formation, and the Portland Arkose. The New Haven Arkose is the lowermost formation and consists of all sedimentary rocks below the lowermost lava flow. The Meriden Formation consists of the three lava flows and interbedded sandstone. The Portland Arkose is the uppermost formation and includes all sedimentary rocks above the uppermost lava flow. Maximum thickness of the Meriden Formation is about 800 feet. The maximum thickness of the Newark Supergroup is estimated to be about 4,000 feet.

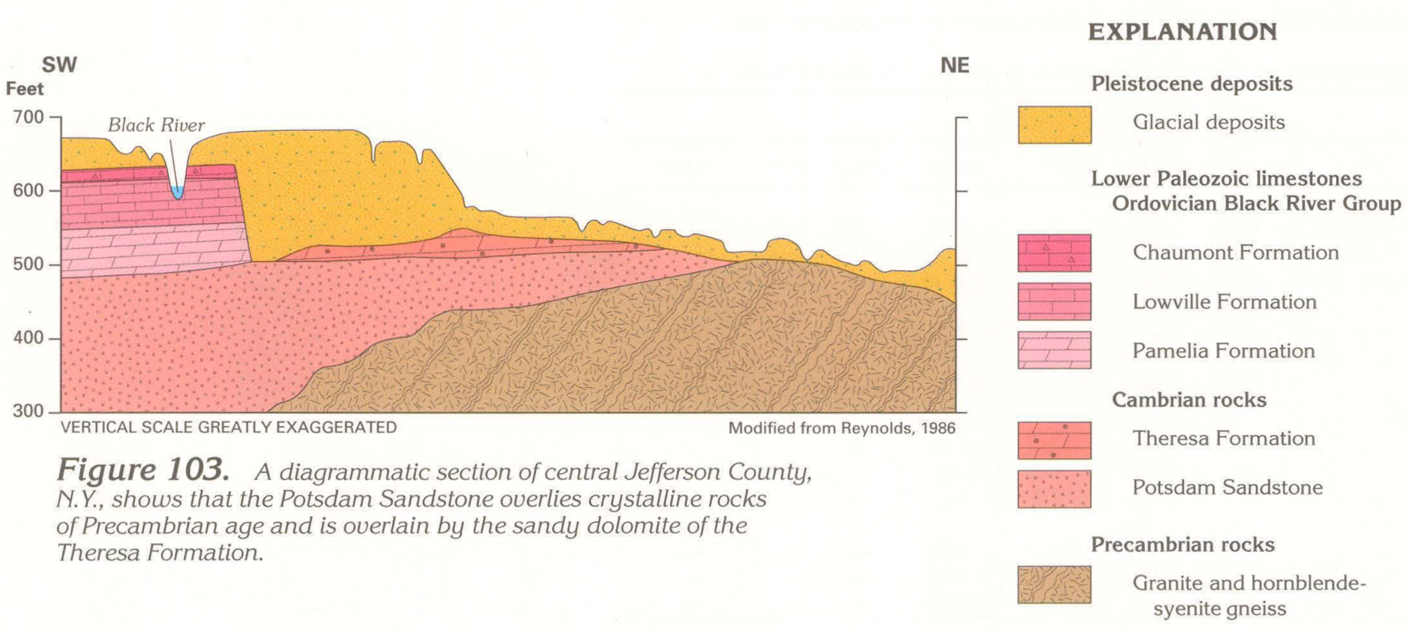


Figure 103. A diagrammatic section of central Jefferson County, N.Y., shows that the Potsdam Sandstone overlies crystalline rocks of Precambrian age and is overlain by the sandy dolomite of the Theresa Formation.

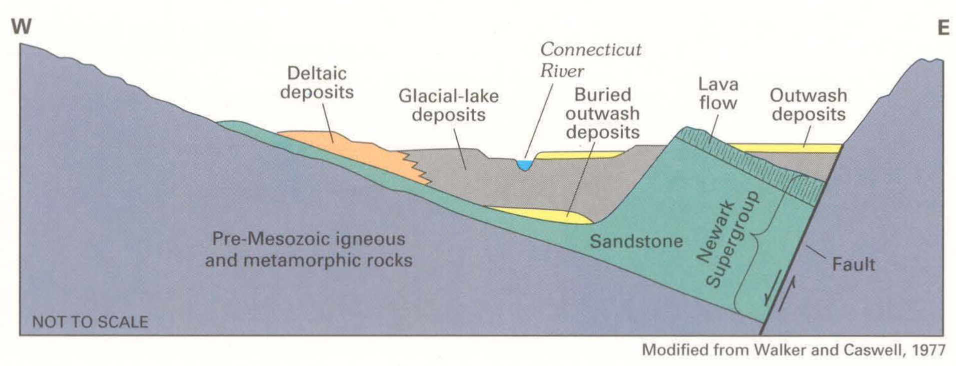


Figure 104. Red sandstones and lava flows of the Newark Supergroup unconformably overlie pre-Mesozoic igneous and metamorphic rocks in the lowland trough of the Connecticut River Valley. The rocks are bounded on the east by a major fault with several thousand feet of vertical displacement.

Figure 105. The Newark Supergroup largely consists of continental deposits of reddish arkosic sandstone. The supergroup also includes feldspathic sandstone, conglomerate shale, and minor limestone and siltstone. Lava flows also are interbedded with the sedimentary rocks.

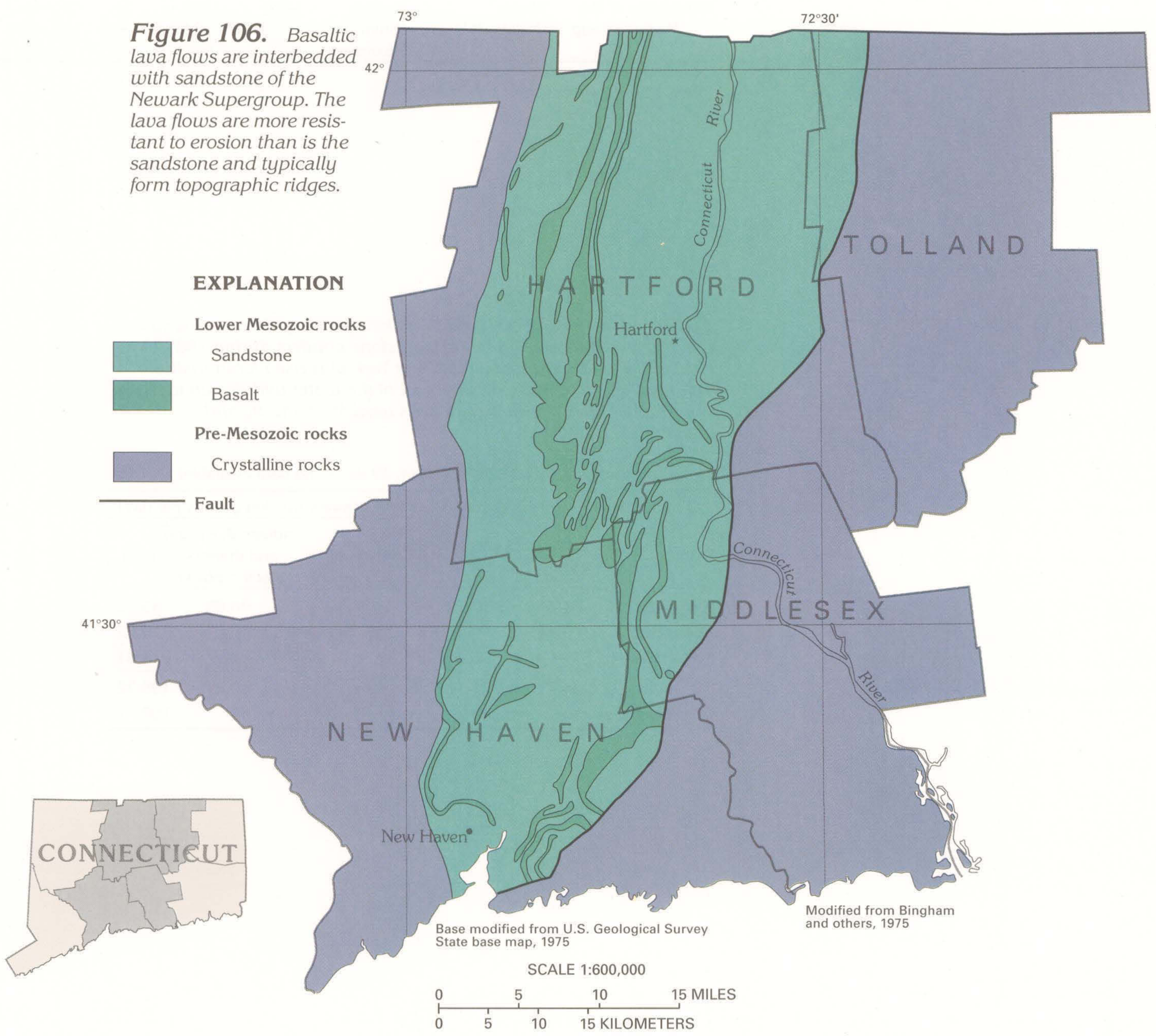


Figure 106. Basaltic lava flows are interbedded with sandstone of the Newark Supergroup. The lava flows are more resistant to erosion than is the sandstone and typically form topographic ridges.

GROUND-WATER HYDROLOGY

The sandstone aquifer in northern New York (**fig. 102**) generally is hydraulically connected with the aquifer in overlying carbonate rocks and, for the most part, the two aquifers are confined by overlying glacial deposits. Hydraulic heads in the glacial deposits generally are from 30 to 40 feet higher than the potentiometric surface of the two aquifers; therefore, recharge to the sandstone aquifer is by downward percolation of water through the overlying glacial deposits and carbonate rocks. Where the sandstone aquifer is overlain by glacial deposits, recharge to the aquifer is by downward percolation of water through the overlying deposits. After the water enters the sandstone aquifer, it moves horizontally from recharge areas in the interstream highlands toward the streams and Lake Ontario. At these surface-water bodies, the water moves upward through the carbonate rocks or the glacial deposits or both into the surface-water bodies.

The intergranular porosity of the sandstone aquifer generally ranges from about 4 to 30 percent with an average of only about 10 percent because most of the intergranular space is filled with siliceous or calcareous cement. Therefore, groundwater movement in the aquifer is primarily through secondary openings, such as joints, fractures, and bedding-plane openings. Data for 12 domestic wells completed in the sandstone aquifer in northern New York indicate that the wells penetrated from 16 to 55 feet of sandstone (average 32.5 feet) and yielded from 3 to about 30 gallons per minute. Wells with the largest yields were completed only in the Theresa Formation, thus indicating that it might be more fractured than the Potsdam Sandstone.

The sandstone of the Newark Supergroup also is well cemented by carbonate cement that has filled many of the intergranular openings; porosity is estimated to be about 7 percent. Thus, water in the aquifer in the lower Mesozoic sandstone primarily is contained in and moves through secondary openings, such as joints, fractures, and bedding planes. Bedding-plane openings probably transfer the greatest quantity of water.

Yields from 688 wells completed in the sandstone aquifer of the Newark Supergroup ranged from 0.5 to 578 gallons per minute; the average yield was 34 gallons per minute. The depths of these wells range from 40 to 973 feet with an average depth of 203 feet.

Yields from the interbedded basaltic lava flows, which have only fracture permeability, generally are smaller than those from the sandstone aquifer. The average yield of 53 wells completed in the basalt ranged from 1.5 to about 50 gallons per minute with an average yield of 13 gallons per minute. The depths of these wells range from 60 to 500 feet.

Yields to wells completed in either the sandstone aquifer or the basalt tend to be larger in areas where these aquifers are overlain by the surficial aquifer system rather than in areas where they are overlain by till. This indicates that the surficial aquifer system provides storage for water that subsequently moves downward into the aquifers as water is withdrawn from them.

Ground-water movement through the sandstone aquifer of the Newark Supergroup is not well defined; however, the presence of freshwater at depths of several hundred feet in the aquifer indicates that regional ground-water movement occurs. Recharge occurs in areas where the aquifer crops out and in upland areas where the sandstone aquifer is overlain by permeable sand and gravel of the surficial aquifer system. Water in the sandstone aquifer mostly moves down a slight hydraulic gradient in local flow systems to areas of discharge at small streams where it moves upward to the stream through the surficial aquifer system and becomes part of the streamflow.

There also is a regional flow system in which the water moves deeply into the aquifer and toward the Connecticut River where the water is discharged through the surficial aquifer system to the river. Some water also discharges directly to the ocean in the coastal areas of the Connecticut River Basin.

Few wells penetrate more than about 500 feet into the sandstone aquifer, and little hydrologic information is available beyond that depth. Because the number of joints, fractures, and bedding-plane openings in all types of rock typically decrease with depth, permeability of the sandstone aquifer should similarly decrease until ground-water movement ceases at some depth. Decreased circulation of ground water results in an increase of dissolved minerals in the water. Thus, the boundary of freshwater is lower in the sandstone aquifer, probably within about 1,000 feet of the land surface, below which use of the aquifer is limited by a decrease in permeability and by a deterioration in water quality.

GROUND-WATER QUALITY

The chemical quality of water in sandstone aquifers of the Newark Supergroup and in Lower Paleozoic rocks generally is suitable for drinking, as well as most other uses. A summary of water-quality data for water from the aquifers in the Newark Supergroup in Connecticut and southeastern New York and from the Potsdam Sandstone and sandstone of the Medina Group in north-central New York is shown in **table 14**. Median, maximum, and minimum values of each chemical constituent for about 100 chemical analyses are listed.

Median values of calcium, sulfate, hardness, and dissolved solids shown in **table 14** indicate that excessive concentrations of dissolved minerals generally are not a problem. Locally, large maximum values indicate that highly mineralized water exists, particularly at depth in the sandstone aquifers of the Newark Supergroup and in sandstone of the Medina Group. Large sulfate concentrations may result from dissolution of gypsum that is disseminated in places in the sandstone of the Newark Supergroup. The calcium from the gypsum contributes to excessive hardness and large concentrations of calcium. Both ions contribute to increased concentrations of dissolved solids.

Large chloride concentrations in water from aquifers in the Newark Supergroup of Rockland County, N.Y. (**table 14**), may indicate local contamination from road-deicing chemicals or some other source of chloride on the land surface. Locally, large chloride and calcium concentrations in water from sandstone of the Medina Group in Wayne County, N.Y., contribute to dissolved-solids concentrations in excess of 8,000 milligrams per liter. In general, water from sandstone of the Medina Group appears to be more mineralized than that in the sandstone aquifers in the Newark Supergroup.

FRESH GROUND-WATER WITHDRAWALS

Aquifers in the Cambrian sandstone of New York and the lower Mesozoic sandstone of Connecticut and Massachusetts generally yield only small quantities of water to wells. Therefore, they are used primarily as a source of supply for households, commercial establishments, and small communities and industries that require only modest quantities of water. About 28 percent, or 29 million gallons per day, of the total water withdrawn from the sandstone aquifers in Segment 12 during 1985 was withdrawn for domestic and commercial use (**table 15**). In Connecticut and Massachusetts, 74 percent (**fig. 107**), or about 16 million gallons per day, of the water withdrawn from these aquifers was used for domestic and commercial purposes.

Water from sandstone aquifers also is used for industrial and mining purposes, especially in New York. Withdrawals for these use categories accounted for about 38 percent, or about 40 million gallons per day, of total withdrawals from the sandstone aquifers in the three States during 1985 but accounted for about 46 percent, or about 39 million gallons per day, of the total water withdrawn in New York. Water was withdrawn for industrial and mining uses, primarily for inplant domestic uses, gravel pit or quarry dewatering, boiler makeup water, and gravel washing rather than for use as industrial process water.

Agricultural use accounted for only about 1 percent, or about 1.3 million gallons per day, of total withdrawals from the sandstone aquifers during 1985. This water was used largely for stock watering and milk processing.

In New York and Connecticut, about 33 percent, or about 35 million gallons per day, of the total water withdrawn from the sandstone aquifers was used for public supply (**table 15**). This use, however, generally was in small communities or as a supplemental supply to surface water in larger communities because of the generally limited yields of wells completed in the sandstone aquifers.

Total withdrawals from the sandstone aquifers in the three States were about 106 million gallons per day during 1985 (**fig. 107**). The largest withdrawals, which were about 85 million gallons per day, were in New York. Connecticut and Massachusetts withdrew about 21 million gallons per day.

Table 14. *Freshwater and saltwater are present in the sandstone aquifers in most areas. The most mineralized water is present in the sandstone of the Medina Group in Wayne County, New York. Large chloride and sulfate concentrations are the primary causes of the local, excessive mineralization of the ground water*

[Modified from Griswald, 1951; Heath,1964; and Ryder and others, 1981. Concentrations are in milligrams per liter unless otherwise specified; —, no data available]

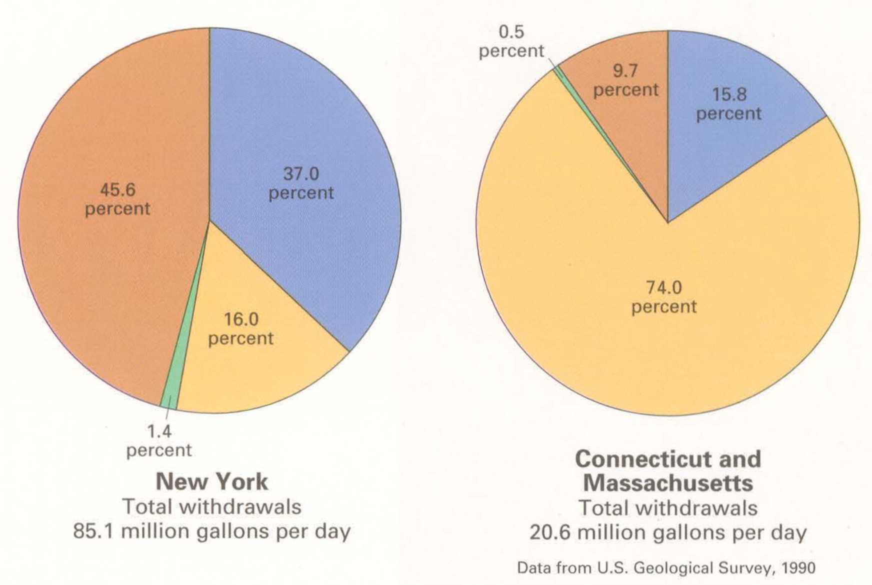
Water-yielding unit	Basin or county		pH (standard units)	Hardness (as $CaCO_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (C1)	Dissolved solids[1]	Nitrate (NO_3)	Iron (Fe)[2]	Manganese (Mn)[2]
Newark Supergroup	Upper Connecticut River Basin, Conn.	Median	7.7	107	39	7.9	11	0.8	96	37	8.4	202	3.8	0.08	0.02
		Minimum	6.5	26	8.8	.9	2.3	.2	14	3.4	1.1	—	0	0	0
		Maximum	8.5	1,328	508	59	239	6.6	430	1,500	245	2,060	171	2.4	6.4
	Rockland County, N.Y.	Median	—	112	—	—	—	—	110	21	18.2	170	—	—	—
		Minimum	—	18	—	—	—	—	21	5.9	2.2	52	—	—	—
		Maximum	—	256	—	—	—	—	198	64	2,000	2,276	—	—	—
Potsdam Sandstone	St. Lawrence County, N.Y.	Median	—	378	—	—	—	—	299	78	22	—	—	—	—
		Minimum	—	—	—	—	—	—	—	—	—	—	—	—	—
		Maximum	—	—	—	—	—	—	—	—	—	—	—	—	—
Sandstone of the Medina Group	Wayne County, N.Y	Median	—	280	—	—	—	—	217	43	34	420	—	—	—
		Minimum	—	84	—	—	—	—	116	19	1.8	128	—	—	—
		Maximum	—	960	—	—	—	—	394	255	3,500	8,830	—	—	—

[1] Residue on evaporation at 180° Celsius.
[2] Concentrations in micrograms per liter.

Table 15. *About 106 million gallons per day of fresh ground water was withdrawn from the sandstone aquifers during 1985. Most of the water withdrawn in New York was used for industrial and mining purposes, whereas most of the water withdrawn in Connecticut and Massachusetts was used for domestic and commercial purposes*

[Source: U.S. Geological Survey, 1990; —, no data available]

State	Fresh ground-water withdrawals (million gallons per day): Public supply	Domestic and commercial	Agricultural	Industrial, mining and thermoelectric power	Total
New York	31.45	13.60	1.19	38.85	85.09
Connecticut	3.34	6.50	.11	.07	10.02
Massachusetts	—	9.24	—	1.37	10.61
Total	34.79	29.34	1.30	40.29	105.72
Percentage	33	28	1	38	100



EXPLANATION

Use of fresh ground-water withdrawals during 1985

- Public supply
- Domestic and commercial
- Agricultural
- Industrial, mining, and thermoelectric power

Figure 107. *Industrial, mining, and thermoelectric power uses, along with public supply, accounted for about 83 percent of all withdrawals from the sandstone aquifers. In Connecticut and Massachusetts, domestic and commercial uses accounted for 74 percent of total use.*

Crystalline-rock aquifers

INTRODUCTION

The bedrock surface of about 65 percent of the area of Segment 12 is crystalline rock of igneous or metamorphic origin (**fig. 108**). Glacial deposits of outwash, ice contact, and lacustrine sand and gravel fill ancient valleys cut into the bedrock surface and form the principal aquifers of the segment. However, in uplands and other areas where thin or barely permeable deposits of till blanket the bedrock, surficial aquifers are not readily available, and the bedrock itself is an important source of water.

GEOHYDROLOGY

Igneous and metamorphic rocks that form crystalline-rock aquifers are described by State in **table 16**. Well-indurated sedimentary rocks that exist in a few places are mapped with the crystalline rocks in this chapter because they have similar hydraulic characteristics. Although the crystalline rocks are geologically complex with a structural fabric that generally trends northeast, movement of water through the rocks is totally dependent on the presence of secondary openings; rock type has little or no effect on ground-water flow. Examples of granitic igneous rocks and metavolcanic metamorphic rocks are shown in **figures 109 and 110**.

Spaces between the individual mineral crystals of the crystalline rocks are few, microscopically small, and generally unconnected. Consequently, the intergranular porosity of crystalline rocks is so small as to be insignificant. Samples of several types of crystalline rocks were tested in the laboratory and found to range in hydraulic conductivity from 0.000003 to 0.0001 foot per day (**table 17**). A well that penetrates 200 feet of these crystalline rocks would have a yield of only 0.007 gallon per minute if all the water had to enter the well through intergranular pore spaces. Virtually all wells completed in crystalline rocks yield considerably more water; therefore, water reaches the wells through conduits other than intergranular pore spaces. Many studies have determined that virtually all movement of water in crystalline rocks is through fractures or joints in the rocks. Fractures are readily visible in most outcrops in roadcuts, and, after a rainstorm, water can occasionally be observed seeping from these fractures; for example, seepage from a metavolcanic-rock outcrop, frozen into icicles, is shown in **figure 110**.

Fracture permeability in crystalline rocks is the result of the cooling of igneous rocks, deformation of igneous and metamorphic rocks, faulting, jointing and weathering. Openings commonly are present along relict bedding planes, cleavage planes, foliation, and other zones of weakness in the rocks; these openings typically are heterogeneous in spacing, orientation, size, and degree of interconnection. Generally, openings in the rocks are most prevalent near land surface and decrease in number and size with depth. Thus, wells commonly are not drilled past depths of 300 to 600 feet (**table 16**), but exceptions indicate that deep water-yielding fractures are present. The specific capacity of wells, or the yield of the well divided by the distance the water level is drawn down by pumping, is one way to compare well performance. Data from 147 wells completed in crystalline rocks in Connecticut show that yields per foot of saturated crystalline rock decrease as well depth increases.

Fracture permeability in the upper part of most crystalline rocks in Segment 12 appears to be adequate to support a ground-water flow system. Thus, water from precipitation recharges the fracture system either directly at outcrop areas or indirectly through overlying glacial deposits. Recharge occurs primarily in the uplands, and the water moves down a hydraulic gradient to stream valleys where it is discharged either to the valley fill or to streams or other surface-water bodies.

Although the crystalline rocks in Segment 12 transmit water, the volume of water in storage in the fracture system of these rocks generally is small, and drawdown is large in pumped wells that produce only small quantities of water. Water that is stored in overlying glacial deposits or water in nearby streams or other surface-water bodies, however, commonly is hydraulically connected with the bedrock fracture system and might provide large quantities of water as recharge induced by pumping the wells completed in the crystalline rocks. Thus, although the common range of well yields is only a few gallons per minute (**table 16**), yields from some wells may exceed 100 to 500 gallons per minute.

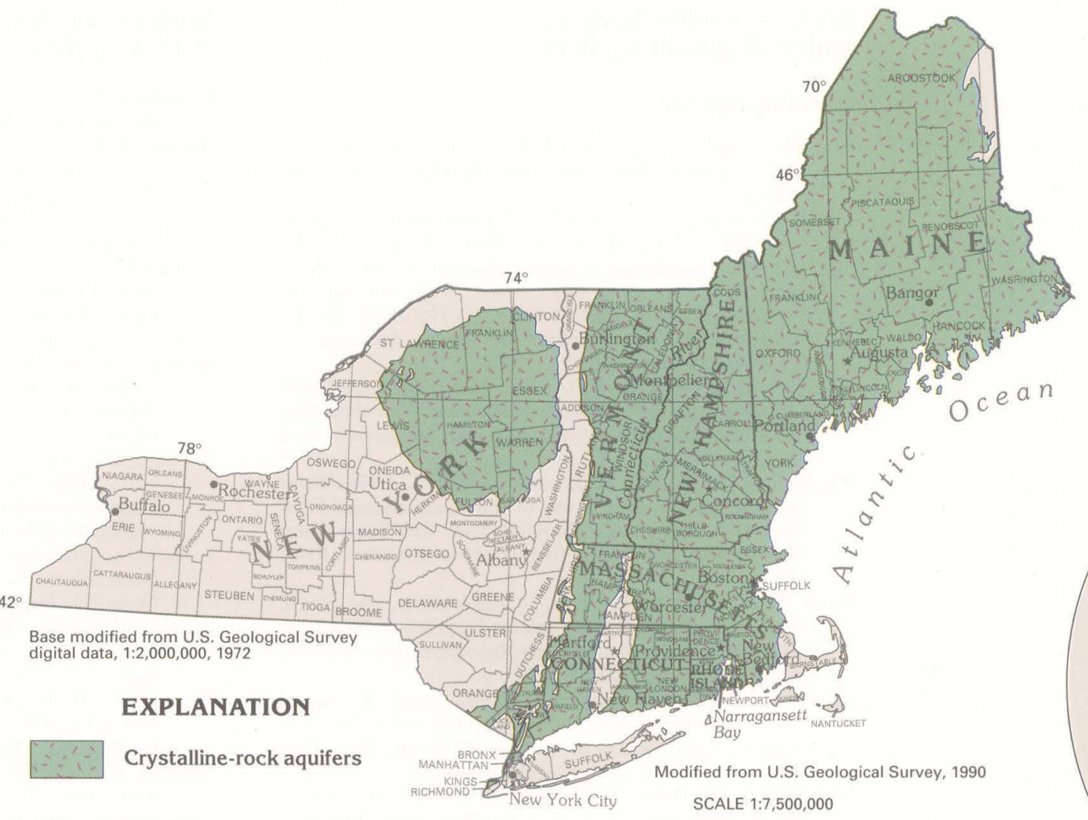


Figure 108. *About 65 percent of the bedrock surface in Segment 12 consists of crystalline rocks of igneous or metamorphic origin which comprise aquifers.*

Table 17. *Laboratory determinations of the hydraulic conductivity of several types of nonfractured crystalline rocks ranged from 0.000003 to 0.0001 foot per day*

[Modified from Randall and others, 1966]

Rock type	Porosity (percent)	Specific yield (percent)	Hydraulic conductivity (foot per day)
Granitic gneiss	1.5	0.7	0.0001
Mica schist	2.8	1.7	.000005
Hornblende–feldspar gneiss	.7	.0	.000005
Quartzite	2.2	1.2	.000004
Amphibolite	2.0	1.7	.000003

Figure 109. *Granitic igneous rocks form a large part of the bedrock surface in Segment 12.*

Table 16. *Wells completed in crystalline-rock aquifers in each of the States of Segment 12 generally yield less than 20 gallons per minute and usually are less than 600 feet deep. The chemical quality of the water is variable, but generally is suitable for most uses*

[Source: U.S. Geological Survey, 1985]

State	Aquifer description	Well characteristics: Depth (feet) Common range	Depth (feet) Might exceed	Yield (gallons per minute) Common range	Yield (gallons per minute) Might exceed	Chemical characteristics
New York	Igneous and metamorphic rocks. Generally confined.	25 – 400	600	1 – 120	180	Water generally suitable for most uses. Locally, large iron concentrations.
Connecticut	Gneiss and schist with some other metamorphic- and igneous-rock types. Generally unconfined in upper 200 feet, might be confined at depth.	10 – 300	500	1 – 25	200	Water generally suitable for most uses. Dissolved-solids concentrations range from 20 to about 1,600 milligrams per liter. Iron and manganese concentrations might exceed 0.3 and 0.05 milligram per liter, respectively.
Maine	Igneous rocks include granite, gabbro, diorite, granodiorite, and pegmatite. Metamorphic rocks include schist, gneiss, quartzite, slate, and agrillite. Locally, confined at depth.	20 – 500	800	2 – 10	500	Water generally suitable for most uses. Large concentrations of iron and manganese in water from some wells.
Massachusetts	Igneous and metamorphic rocks, predominantly gneiss and schist. Confined.	100 – 400	1,000	1 – 20	300	Water generally suitable for most uses. Water might cause corrosion of pipes and appliances.
New Hampshire	Igneous and metamorphic rocks. Generally confined.	100 – 600	800	1 – 10	100	Water generally suitable for most uses.
Rhode Island	Indurated to metamorphosed sedimentary rocks in the vicinity of Narragansett Bay; igneous and metamorphic rocks, chiefly granite and granite gneiss, elsewhere. Unconfined.	100 – 300	500	1 – 20	50	Water generally suitable for most uses, but locally contains large concentrations of iron.
Vermont	Igneous, metasedimentary, and metavolcanic rocks. Generally confined.	100 – 600	800	1 – 10	100	Water generally suitable for most uses.

Figure 110. *Frozen seepage from joints and other fractures in metamorphosed volcanic rocks (metavolcanic rocks) indicates how water moves through secondary openings in the rocks.*

James A. Miller, U.S. Geological Survey, 1990

Table 18. *Small median concentrations of most constituents characterize the quality of water in crystalline-rock aquifers. The water typically is alkaline and soft to moderately hard*

[Modified from Weiss and others, 1982. Concentrations in milligrams per liter unless otherwise specified; μg/L, micrograms per liter]

Property or constituent	Range	Median	Number of analyses
pH (standard units)	5.7 to 8.2	7.7	43
Hardness as $CaCO_3$	14 to 186	68	42
Calcium (Ca)	4.0 to 66	23	36
Magnesium (Mg)	.9 to 15	2.8	36
Sodium (Na)	2.7 to 40	8.4	37
Potassium (K)	0 to 5.3	2.6	36
Bicarbonate (HCO_3)	4 to 205	62	41
Sulfate (SO_4)	4.1 to 46	15	36
Chloride (Cl)	.4 to 140	6.5	41
Fluoride (F)	0 to .6	.1	37
Silica (SiO_2)	8.1 to 28	18	37
Dissolved solids	31 to 286	116	37
Nitrate (NO_3)	0 to 16	.2	59
Iron (Fe)	.04 to 5.2	.17	61
Manganese (Mn)	0 to .58	.03	56

GROUND-WATER QUALITY

Water in the crystalline-rock aquifers generally is suitable for most uses because crystalline rocks generally are composed of virtually insoluble minerals, water is in contact with a relatively small surface area in the joints and fractures, and water movement through the joints and fractures generally is rapid and along short flow paths. Consequently, only small quantities of minerals are dissolved by the water. Recharge to the crystalline-rock aquifers, however, is at least partly derived from water percolating downward through the overlying surficial aquifer system. This water has its own unique chemical characteristics. Thus, the chemical quality of water in the crystalline-rock aquifers generally is a composite of the chemical quality of water from both sources. Locally, water in the crystalline-rock aquifers contains excessive concentrations of iron, manganese, sulfate, or radon.

The chemical and physical properties of water in the crystalline-rock aquifers of Segment 12 are exemplified by the median values and ranges of constituents or properties of samples collected from 36 to 61 wells in the lower Connecticut River basin in Connecticut (**table 18**). The median dissolved-solids concentration in water from 37 different wells completed in the crystalline-rock aquifer was only 116 milligrams per liter. The water typically is soft to moderately hard and alkaline and generally contains only moderate concentrations of most constituents except iron, which is a problem in some areas.

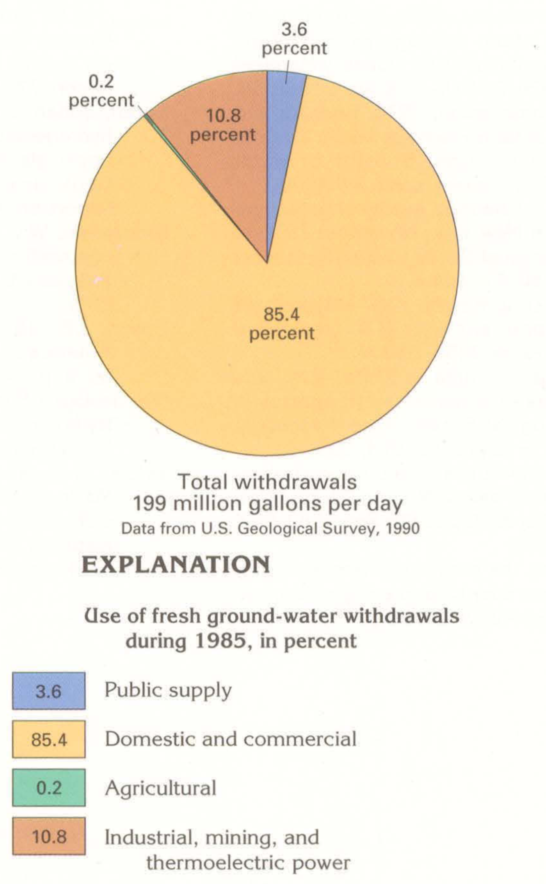


Figure 111. *Fresh ground-water withdrawals from the crystalline-rock aquifers are used primarily for domestic and commercial supply.*

FRESH GROUND-WATER WITHDRAWALS

Fresh ground-water withdrawals from the crystalline-rock aquifers in Segment 12 during 1985 totaled nearly 200 million gallons per day (**table 19**). Water was withdrawn from the aquifer primarily for domestic and commercial uses, which accounted for about 85 percent of the total withdrawals (**fig. 111**) or about 170 million gallons per day. Industrial, mining, and thermoelectric power withdrawals accounted for about 11 percent of the total withdrawals or about 21.5 million gallons per day. Agricultural and public-supply uses accounted for only about 4 percent of the total withdrawals or about 7.5 million gallons per day, most of which was withdrawn for public supply.

Table 19. *Fresh ground-water withdrawals from the crystalline-rock aquifers in Segment 12 totaled nearly 200 million gallons per day during 1985. The largest withdrawals were in Massachusetts. Domestic and commercial uses accounted for about 85 percent of total withdrawals*

[Source: U.S. Geological Survey, 1990; <, less than]

State	Fresh ground-water withdrawals (million gallons per day): Public supply	Domestic and commercial	Agricultural	Industrial, mining, and thermoelectric power	Total
New York	6.79	36.9	0.23	1.08	45
Maine	0	12.75	0	4.25	17
Massachusetts	0	83.77	0	13.12	96.89
New Hampshire	0	22.0	0	0	22
Rhode Island	.31	4.81	.15	.84	6.11
Vermont	0	9.84	0	2.16	12.0
Total	7.1	170.07	.38	21.45	199.00
Percentage	4	85	<1	11	100

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