GLACIAL AQUIFER SYSTEMS IN THE NORTHEASTERN UNITED STATES--

A STUDY PLAN

By Forest P. Lyford, Joel E. Dysart, Allan D. Randall, and Angelo L. Kontis

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CONVERSION FACTORS AND ABBREVIATIONS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
degrees Fahrenheit (°F)	°C = 5/9(°F-32)	degrees Celsius (°C)
gallons per minute (gal/min)	0.00378544	cubic meters per minute (m^3/min)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
micromho per centimeter at 25°C (μmho/cm)	1.000	microsiemens per centimeter at 25°C (μS/cm)

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ABSTRACT

The U.S. Geological Survey in 1982 designed a study of the availability and quality of water in glacial aquifers in the States of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and Ohio. The study is one of several being conducted nationwide to assemble information on major aquifer systems. The work, scheduled for completion in 1986, focuses on general principles that define aquifer geometry, hydraulic properties, recharge, and discharge; physical-chemical properties of water, interactions between water and rock; and mechanisms for mixing of water from multiple sources.

Planned project activities include compilation and analysis of available data for a regional summary of glacial-aquifer systems, studies of selected system components such as recharge and chemical processes, classification of aquifers with regard to water-supply potential, and construction of generalized ground-water models to predict responses of several types of aquifer systems to pumping and climatic stress. This report describes the general characteristics of glacial aquifer systems in the northeastern United States and the planned work elements of the study.

INTRODUCTION

Nationwide concern about the availability of water, especially during periods of drought, prompted the U.S. Geological Survey in 1978 to begin a program of ground-water studies that would provide knowledge for evaluating and managing major aquifer systems. The program, referred to as the Regional Aquifer-System Analysis (RASA) program (Bennett, 1979), has identified 28 aquifer systems nationwide for regional studies.

The study described herein is referred to as the Northeast Glacial Aquifers RASA. Begun in 1982 and scheduled for completion in 1986, the study will concentrate on sand and gravel aquifers that were formed during advances and retreats of continental glaciers in the northeastern United States.

Glacial aquifers in the Northeast, though consisting of many independent systems geographically (fig. 1), form a regional group in that most consist of glacially derived materials and thus share many geologic, hydrologic, and geochemical characteristics. Although most glacial aquifers are less than 150 ft thick and of limited areal extent, many contain large quantities of ground water in storage and are naturally replenished by precipitation and streams. Many of these aquifers, however, are also vulnerable to contamination by man's activities on the land surface. For this reason, the use of glacial aquifers as a source of water may be limited in many areas.

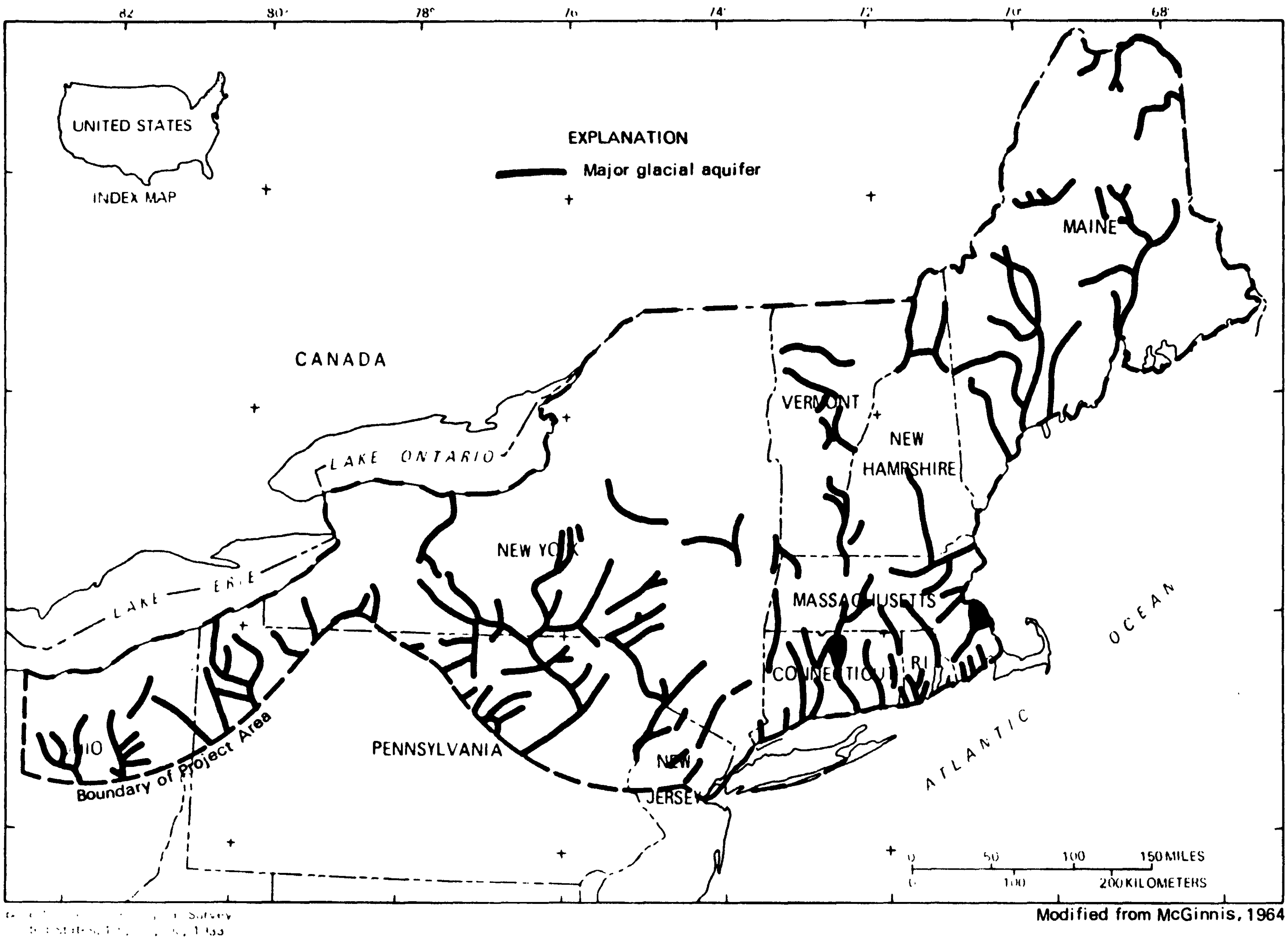


Figure 1.--Location of project area and of major glacial aquifers.

Effective ground-water management requires a knowledge of many components of the aquifer systems, including geometry, hydraulic properties, recharge, streamflow, and water chemistry. These system components must be known in order to accurately predict the effects of pumping and climatic stress on water supply and water quality. This project will document the water-supply characteristics of glacial aquifers in the Northeast through study of the variations in magnitude and areal distribution of key components of the systems and through evaluation of the response of systems to simulated pumping and to climatic stresses. The large number of glacial aquifers in the Northeast precludes detailed definition of the key components of even the largest aquifer systems within the allotted time, but the principles and concepts of ground-water occurrence and quality in glacial aquifers throughout the Northeast can be explored through use of the large data bases available. The main emphasis of this study will therefore be to describe these concepts and provide information that will be applicable to aquifers throughout the Northeast.

Purpose and Scope

This report gives an overview of the characteristics of glacial aquifer systems in the project area (fig. 1) and outlines work elements that are planned for 1984-86. It also lists the subjects of planned reports that will document the results. The work plan described in this report is subject to change as the study progresses.

Data Management

The project will use the U.S. Geological Survey's National Water-Data Storage and Retrieval System (WATSTORE) data-base format for storage and retrieval of most data. A separate system will be devised to facilitate the processing and analysis of data for model simulations. This system will consist of a suitable method of data storage, data-editing capability, and computer software to perform the data processing and analysis.

Acknowledgments

This plan of study is a product of contributions from many sources. Discussions with staff of U.S. Geological Survey offices within the project area identified problems relating to ground-water resources. Members of a liaison committee of State representatives provided information about ground-water-related problems and information needs in their States. Several Geological Survey offices are participating in parts of the study; the following Survey staff are gratefully acknowledged for coordinating or performing literature searches: Thomas Maloney, David Mazzaferro, John Cotton, Michael Frimpter, Roger Waller, Allen Razem, G. Allan Brown, and John Williams. Denise Wiltshire performed literature searches of special topics.

PROJECT AREA

The project area includes most of the glaciated part of the northeastern United States and extends as far west as the edge of the glaciated Appalachian Plateau in Ohio (fig. 2). Long Island and Cape Cod are excluded because extensive work has already been done there. The project area includes several physiographic provinces, which range from high relief in the White Mountains of New Hampshire and Maine, the Green Mountains of Vermont, and the Adirondack and Catskill Mountains of New York, to low relief along the Great Lakes, the St. Lawrence River valley, the Hudson and Mohawk River valleys, and lowland areas along the Atlantic Coast (fig. 2).

Climate and Runoff

Normal annual precipitation in the project area, based on 1931-60 records, ranges from 32 inches along the St. Lawrence valley of New York to as much as 74 inches in the White Mountains of New Hampshire (fig. 3) (U.S. Environmental Data Service, 1968). Normal annual snowfall varies significantly with latitude and altitude and ranges from 36 inches in northern New Jersey to 100 inches or more in northern Maine, in mountainous areas, and on the margins of the Great Lakes (U.S. Environmental Data Service, 1968). (See fig. 4.)

Temperature also varies with latitude and altitude. Normal January temperatures in the project area, based on 1931-60 records, range from 30°F in northern New Jersey to 10°F or less in northern Maine and in mountainous areas. Normal July temperatures range from 75°F in northern New Jersey to 65°F in northern Maine and in mountainous parts of the project area (U.S. Environmental Data Service, 1968).

Runoff in the project area is equal to precipitation minus the amount lost to evapotranspiration. As shown in figure 5, the greatest annual runoff value (30 inches or more) is in mountainous areas, where precipitation is relatively high. Elsewhere, annual runoff generally ranges from 15 to 25 inches. Annual evapotranspiration ranges from about 15 inches in northern New York and northern Vermont to about 25 inches in New Jersey (Knox and Nordenson, 1955).

Bedrock

Bedrock in most of New England, southeastern New York, northern New Jersey, and the Adirondack Mountains of New York consists largely of highly deformed metamorphosed sedimentary and igneous rocks (fig. 6). Exceptions are in the Connecticut River valley in Massachusetts and Connecticut and parts of northern New Jersey and southern New York, where a variety of sedimentary rocks are found with volcanic rocks. Sedimentary rocks are also present in eastern Massachusetts, Rhode Island, and northeastern Maine.

Sedimentary rocks consisting mostly of shale, sandstone, dolomite, and limestone underlie much of New York, Pennsylvania, and Ohio. In addition, evaporites of bedded gypsum and halite are present at or near the surface in west-central New York. Some sandstone and carbonate rock units in parts of Pennsylvania, Ohio, and New York form important aquifers. However, most rock units in the study area yield only small quantities of water to wells.

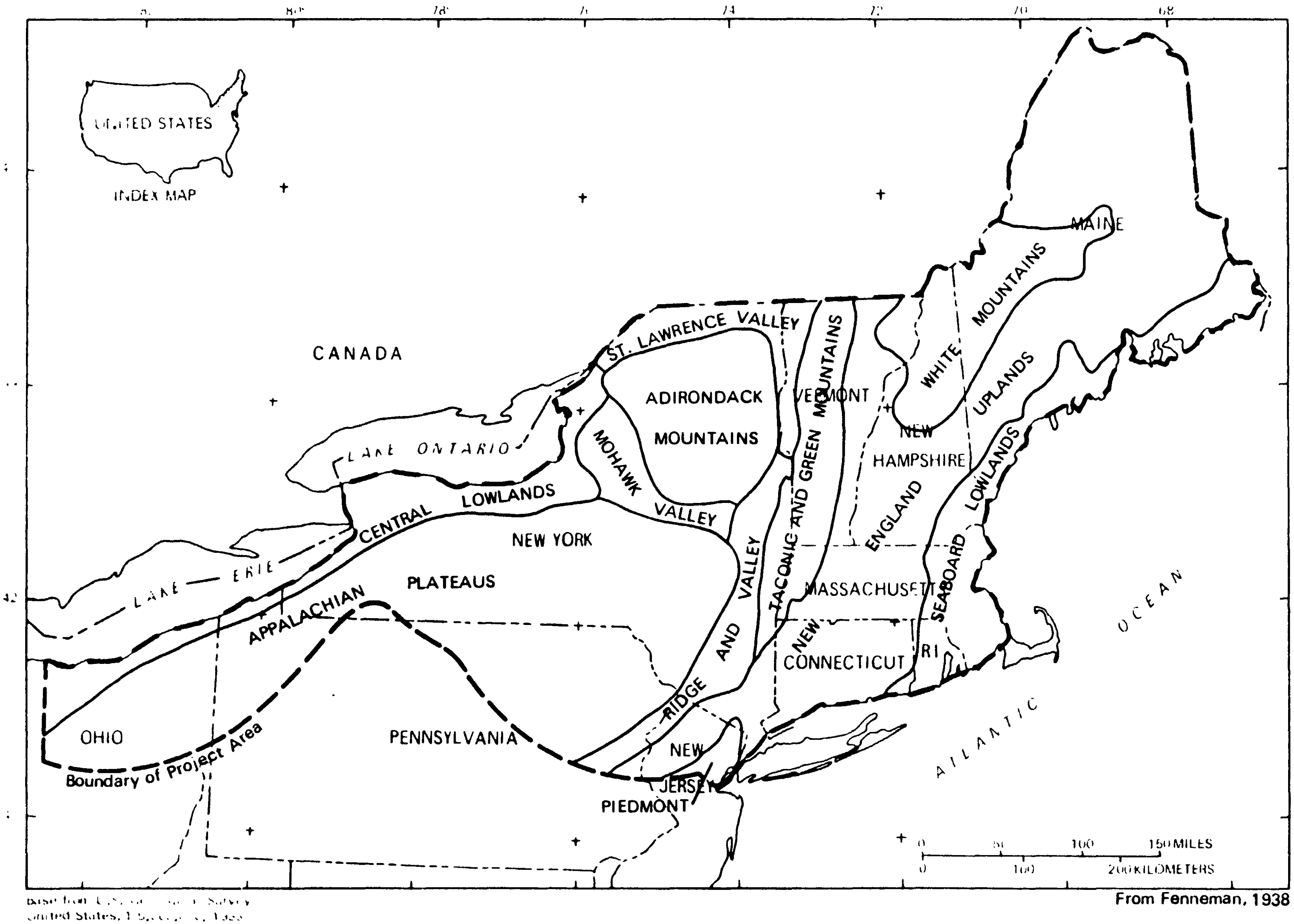


Figure 2.--Physiographic divisions of the northeastern United States.

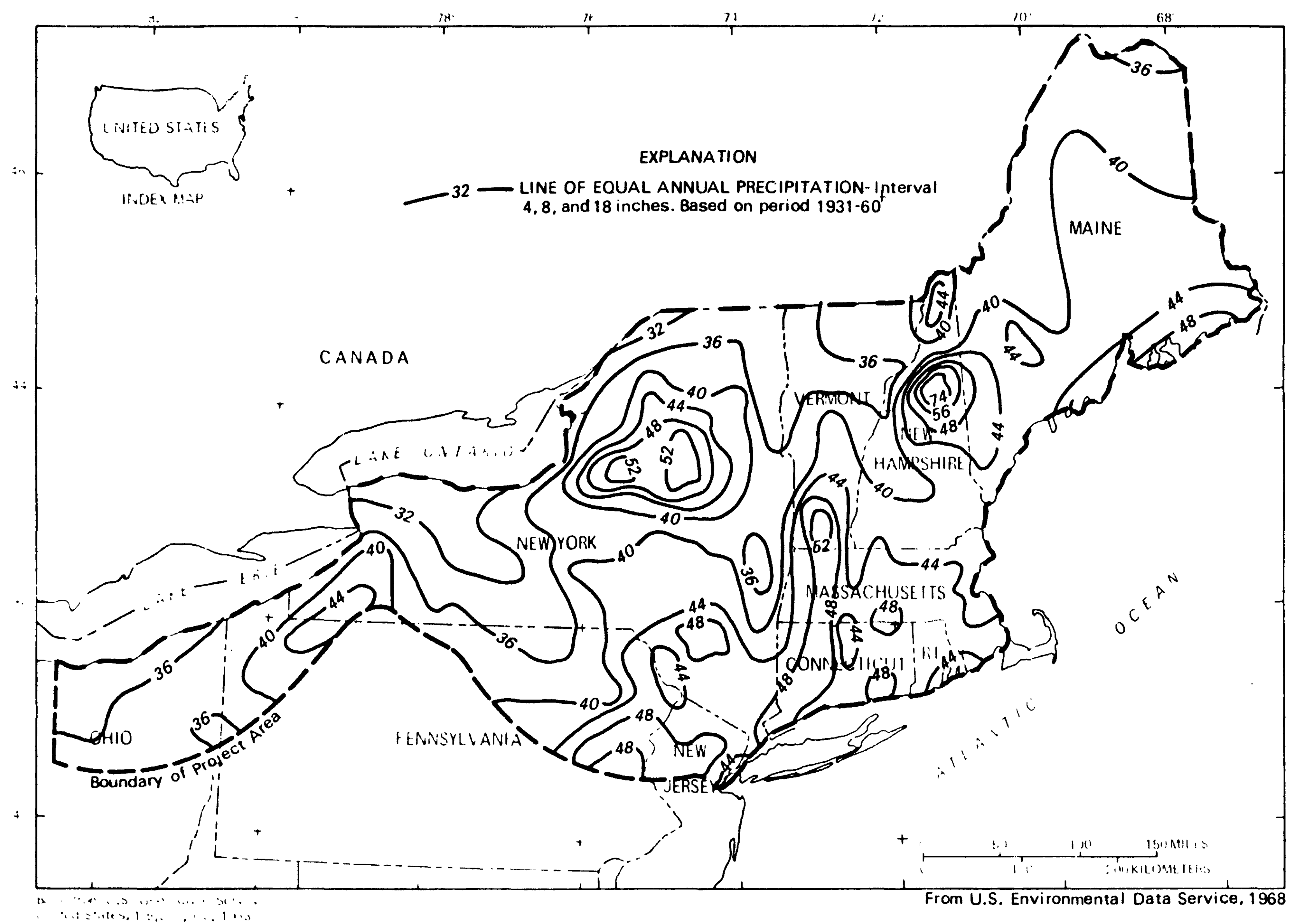


Figure 3.--Normal annual precipitation in the northeastern United States.

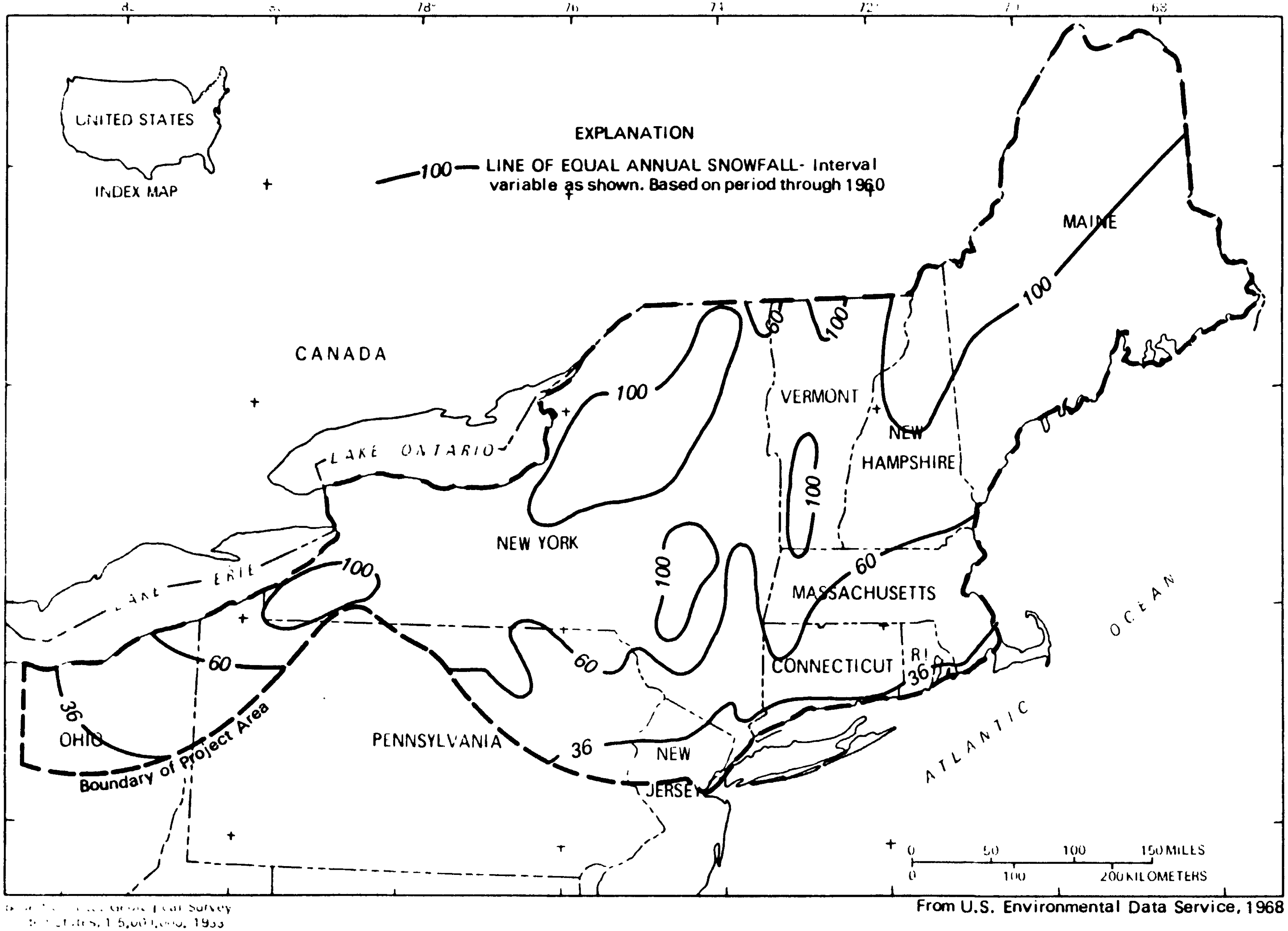


Figure 4.--Normal annual snowfall in the northeastern United States.

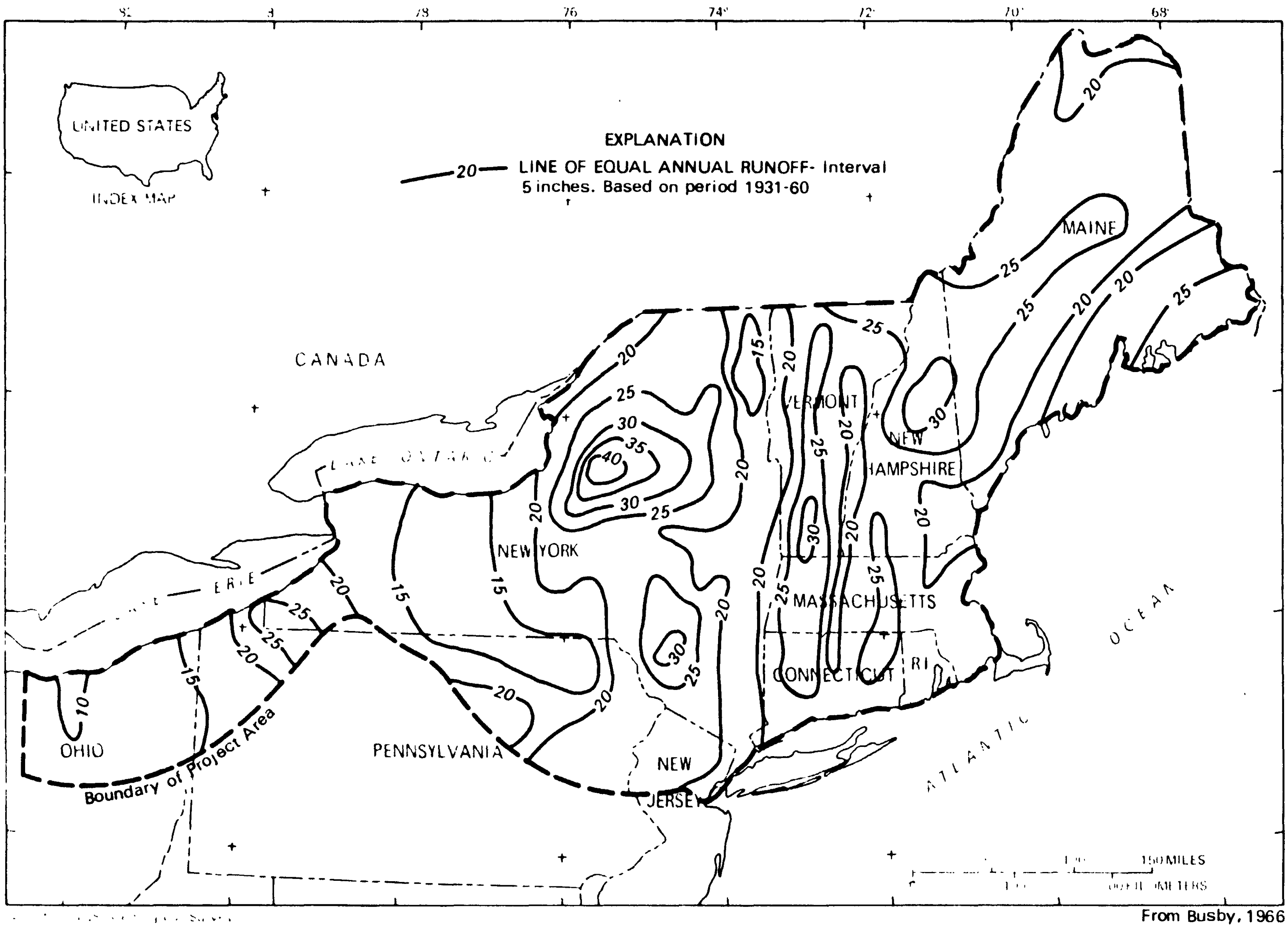
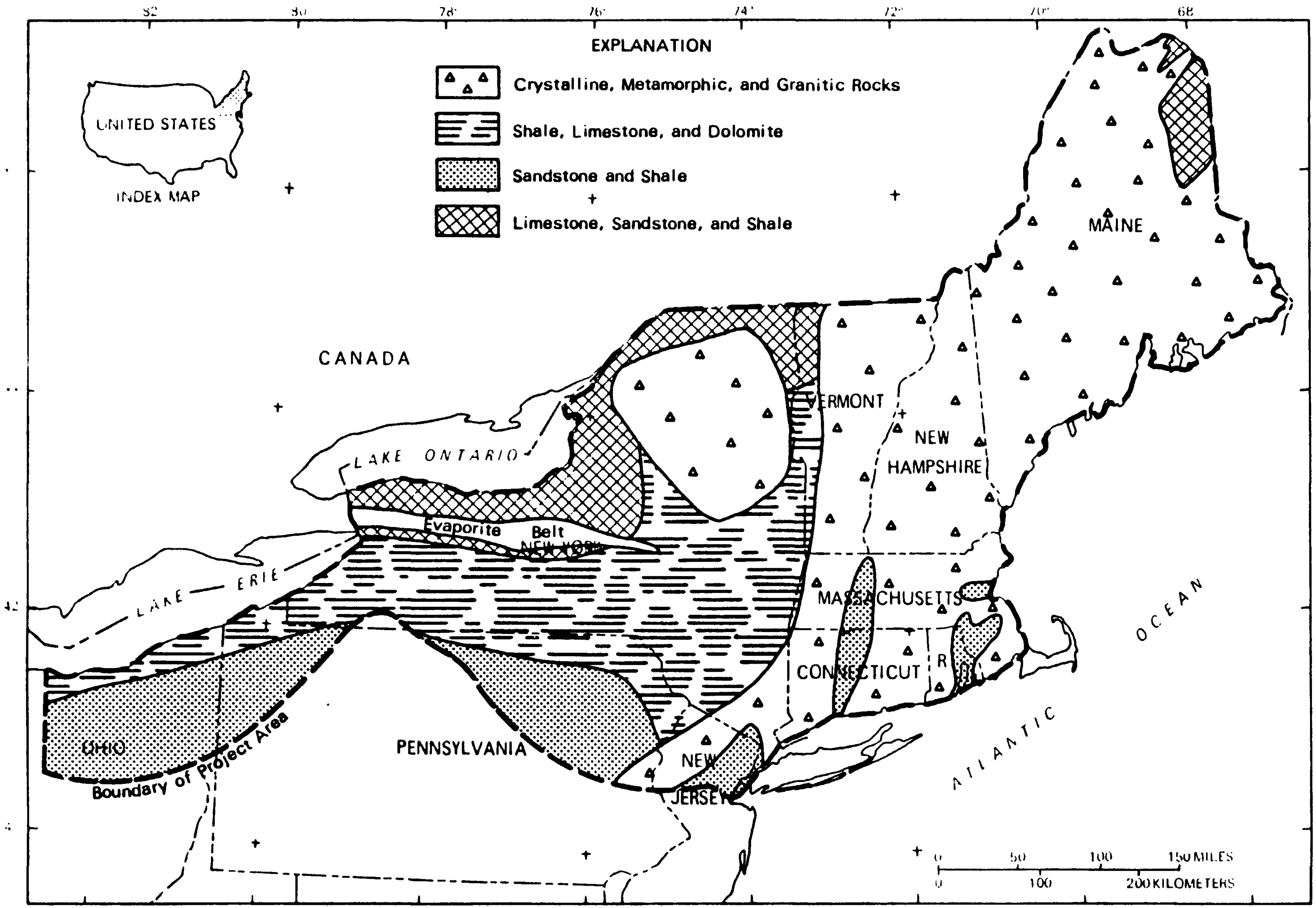


Figure 5.--Annual runoff in the northeastern United States.



Base from U.S. Geological Survey United States, 1:5,000,000, 1933

Compiled with modifications from King and Beikman, 1974; U.S. Geological Survey, 1970, p. 75, and Denny, 1982, fig. 4

Figure 6.--Distribution of major bedrock types in the northeastern United States.

GENERAL CHARACTERISTICS OF GLACIAL AQUIFERS

Physical Properties

Glacial deposits consist of fine to coarse rock materials deposited by glacial meltwater. Most of the glacial materials in the project area were deposited during the most recent (Wisconsinan) glacial stage.

Glacial material may be sorted or unsorted, depending on the mode of deposition. The deposits that have the largest water-yielding properties are well sorted and consist mostly of sand and gravel. Unsorted deposits, known as till, consist of a heterogeneous mixture of clay to boulder-sized material, deposited either at the base of the glacier by moving ice or as a residue left by melting ice. Till does not yield substantial quantities of water to wells.

Sorted materials consist of uniformly sized particles that were deposited by glacial meltwater along stream channels or in lakes or the ocean. Sorted materials are known as stratified drift and can be grouped into three broad categories according to the mode of deposition, as described below.

Fluvial deposits.--These consist of sand and gravel that was either deposited at the side or the terminus of a melting glacier by water flowing along or under the ice, or was deposited further downstream by meltwater. Deposits that formed next to or beneath the glacier are called ice-contact deposits; those that formed further downstream are called outwash. Fluvial deposits form productive stratified drift aquifers owing to their coarse texture and high transmissivity.

Lacustrine (lake-bottom) deposits.--These consist of sediment that settled to the bottom of former lakes. The deltas of streams entering these lakes contain silt, sand, and gravel; material that settled in the deeper parts formed silt and clay. The deltaic sand and gravel deposits form productive aquifers, but the silts and clays are nearly impermeable. In some areas, silt and clay layers overlie and confine sand and gravel aquifers.

Marine Deposits.--These materials consist of silt, sand, and gravel that was deposited in deltas along the seacoast, and silt and clay that were deposited in deeper water. During deglaciation, the sea level rose and inundated the coastal area, which had been depressed by the weight of glacial ice. The land later rebounded slowly and exposed the newly formed marine deposits. Marine deposits are found along parts of the Seaboard Lowland north of Boston, Mass. and in parts of the St. Lawrence River Valley physiographic province. Deltaic marine deposits form productive aquifers in some areas.

In most of the project area, glacial aquifers lie within valleys that are bounded by till-covered bedrock hillsides. In areas of low relief, however, such as on the western edge of the Appalachian Plateau in Ohio, western Pennsylvania, and the Seaboard Lowland of New England (fig. 2), the aquifers may overlie and obscure the valleys beneath. Some aquifers consisting of coarse materials that were deposited within large lakes are bounded by streams that have cut through the coarse material into the underlying fine-grained sediment.

The thickest glacial deposits are in valleys that were downcut by streams before glaciation and later became scoured deeper by glaciers. The deepest valleys and thickest deposits of the region are in western New York, northwestern Pennsylvania, and northeastern Ohio, where thicknesses commonly exceed 400 ft, although much of the fill in these valleys consists of fine-grained lacustrine materials. Elsewhere, the thickness of glacial deposits is generally less than 200 ft.

Most water-producing sand and gravel units are less than 150 ft thick. Many underlie thick, fine-grained lacustrine or marine sediments or till. The origin and areal extent of many of these buried aquifers are poorly defined.

Hydraulic Properties

Hydraulic properties of aquifers include hydraulic conductivity, storage coefficient, specific yield, and transmissivity. Reported ranges of hydraulic properties for aquifer systems in the Northeast, and the principal sources of data, are given in table 1.

Many productive aquifers are capable of yielding 500 gallons per minute or more to individual wells. These aquifers generally have transmissivities exceeding 10,000 ft^2/d. Transmissivities exceeding 100,000 ft^2/d have been reported from some of the larger drainages such as the Mohawk River valley (Winslow and others, 1965) and Susquehanna River valley (Randall, 1977). Few data are available on the hydraulic properties of stratified fine-grained deposits (lake silts and clays), however.

Bedrock units in the project area yield water to wells mostly through fractures or solution openings. A few studies have reported hydraulic data for bedrock (table 1). Several reports give data on yield, and some include drawdown data (Ellis, 1909; Prescott, 1963; Hollyday, 1969; Cederstrom, 1972).

Data on streambed hydraulic conductivity, an important property needed to evaluate the interaction between an aquifer and an adjacent stream, are scant. Gonthier and others (1974), Johnston and Dickerman (1974), and Randall (1978a) suggest that in many places it is similar to that of underlying aquifer materials. Further studies are needed, however, to define the range of streambed hydraulic conductivity. This property is of great importance in predicting the response of aquifers and streams to pumping stresses.

Recharge

Glacial aquifers are recharged by infiltration of rainfall and snowmelt, infiltration from streams, and inflow of ground water from adjacent and underlying till and bedrock. Annual recharge rates for some glacial aquifers may exceed 30 inches. (See table 1.)

Recharge to glacial aquifers from losing streams is controlled by river stage, streambed hydraulic conductivity, hydraulic conductivity of glacial deposits under the streambed, and the head in the underlying aquifer. Seepage

Table 1.--Reported ranges of selected hydrologic characteristics of northeastern glacial-aquifer systems

Characteristic	Range	Selected sources of information*
Hydraulic conductivity:		
Aquifer material.	1-13,300 ft/d	1-5, 7-25, 28, 32, 35
Silt and clay	10^{-4} - 1 ft/d	1, 13, 18, 19, 21, 28, 34
Till.	10^{-5} - 30 ft/d	1, 2, 19, 23, 26, 27
Streambed materials . . .	.03 - 120 ft/d	4, 6, 8, 9, 16, 20, 23, 35
Fractured bedrock . . .	<.5-710 ft/d	13, 19, 33, 34
Storage coefficient		
Confined sand and gravel	10^{-4} - 10^{-2}	5, 10, 12, 13, 18, 22
Unconfined sand and gravel	.05 - .35	1-4, 10, 12, 13, 15, 19-21, 24
Fractured bedrock . .	1 x 10^{-5} - .12	13, 19, 33, 34
Recharge from precipitation	0.2 - 31 in/yr	2, 3, 6, 9, 12, 15, 17, 19,
Ground-water evapotranspiration	1 - 9 in/yr	1, 6, 9, 12, 29

* Numbers refer to the following publications. This list is from a preliminary search and is not all inclusive.

1. Allen, Hahn, and Brackley, 1966
2. Baker, Healy, and Hackett, 1964
3. Cervione, Mazzaferro, and Melvin, 1972
4. Cosner and Harsh, 1978
5. Crain, 1966
6. Frimpter, 1974
7. Gay and Delaney, 1980
8. Gonthier, Johnston, and Malmberg, 1974
9. Haeni, 1978
10. Lang, Bierschenk, and Allen, 1960
11. Lloyd and Carswell, 1981
12. Meinzer and Stearns, 1928
13. Meisler, 1976
14. Perlmutter, 1962
15. Randall, 1977
16. Randall, 1978a
17. Randall, 1978b
18. Randall, 1979
19. Randall, Thomas, Thomas, and Baker, 1966
20. Rosenshein, Gonthier, and Allen, 1968
21. Sammel, Baker, and Brackley, 1966
22. Schiner and Gallaher, 1979
23. Wilson, Burke, and Thomas, 1974
24. Thomas and others, 1967
25. McClymonds and Franke, 1972
26. Prudic, 1982
27. Norris, 1963
28. Silvey and Johnston, 1977
29. Pluhowski and Kantrowitz, 1964
30. Crain, 1974
31. Heath, 1964
32. Winslow and others, 1965
33. Randall, 1964
34. Johnston, 1964
35. Johnston and Dickerman, 1974

losses occur continuously from some perennial streams where they enter or cross valleys filled with stratified drift (Ku and others, 1975; Randall, 1978a). In the Susquehanna River basin of New York, seepage losses from small streams average 1 ft^3/s per 1,000 ft of channel (Randall, 1978a). Recharge to some valley aquifers from tributary streams and adjacent hillsides may approach or exceed areal recharge from precipitation (MacNish and Randall, 1982). Infiltration induced from large streams by nearby pumping is commonly the largest potential source of recharge (MacNish and others, 1969). Few if any studies in the project area have quantified the seasonal variation in recharge or the response to climatic fluctuations.

Discharge

Natural discharge of ground water from an aquifer occurs by evapotranspiration and by flow to wetlands and surface-water bodies. Evapotranspiration from the saturated zone is difficult to measure, but estimates based on streamflow records range from 1 to 9 in/yr (Olmsted and Hely, 1962; Pluhowski and Kantrowitz, 1964; Allen and others, 1966; Frimpter, 1974). Evapotranspiration may be significant only where the water table is at or very close to the land surface, such as in wetland areas or along streambanks. Variations in evapotranspiration in response to climatic variations are not known.

Ground-water discharge to streams sustains streamflow between storms and snowmelt-runoff periods. Cervione and others (1972), using results of studies in the Northeast, related ground-water discharge to streams to the percentage of drainage area underlain by stratified drift. In areas of little or no stratified drift, ground-water discharge to streams ranges from 30 to 40 percent of the total streamflow; but where glacial sand and gravel covers most of a drainage area, ground-water discharges to streams may account for as much as 98 percent of the streamflow (Pluhowski and Kantrowitz, 1964).

The influence of stratified drift in a drainage basin on streamflow has been demonstrated by flow-duration and low-flow frequency studies in Connecticut (Thomas, 1966; Cervione and others, 1982) and New York (Ku and others, 1975). Techniques developed in Connecticut and New York for predicting low-flow frequency in streams from the percentage of drainage area underlain by stratified drift may be applicable to other parts of the project area. Other factors such as land use, soil type, bedrock geology, vegetation, pumpage, and extent of wetlands may also affect low flow, but the relative importance of these factors has not been studied.

Changes in Storage

Glacial aquifers undergo seasonal changes in storage as a result of fluctuations in recharge and discharge. Water levels in wells tapping glacial aquifers in Massachusetts normally fluctuate annually within a range of about 6 ft (Frimpter, 1981). Greater fluctuations of 15 to 20 ft often occur in wells completed in till and bedrock in uplands and near losing reaches of tributaries on the sides of major valleys. Highest ground-water levels usually occur during and after the spring snowmelt. In many aquifers that have little or no pumping stress, water levels near streams respond quickly to changes in river stage and never drop appreciably below the stream bed. In areas of stratified drift that are remote from streams, long-term water-level fluctuations reflecting wet and dry climate cycles over several years are commonly greater than annual fluctuations.

Chemical Characteristics

Dissolved-solids concentrations of water in glacial aquifers generally do not exceed 500 mg/L. Water in glacial aquifers is generally similar to that in shallow bedrock units. A summary of the ground-water quality data available from WATSTORE shows that the geometric means of dissolved-solids concentration in glacial aquifers is 150 mg/L and in bedrock units 180 mg/L (table 2). The

Table 2.--Statistical summary of selected chemical characteristics of ground water in the glaciated Northeast

[Based on samples collected through September 30, 1981. Data from WATSTORE. Concentrations in milligrams per liter unless otherwise indicated.]

Constituent or Characteristic	Glacial Aquifers			Bedrock Aquifers		
	Geometric Mean	Median	No. sites sampled	Geometric Mean	Median	No. sites sampled
Total dissolved solids, sum of constituents	150	150	660	180	170	1,246
Calcium	22	25	808	27	28	1,584
Magnesium	5.0	5.2	788	6.6	6.6	1,531
Sodium	11	9.1	706	11	8.5	1,254
Potassium	1.6	1.6	674	1.5	1.5	1,142
Chloride	14	12	981	11	9.0	1,992
Fluoride	0.1	0.1	446	0.2	0.1	938
Sulfate	19	19	870	21	19	1,806
Bicarbonate	69	71	753	90	100	1,726
Silica	11	12	670	11	12	1,292
Iron (micrograms per liter)	150	90	641	140	100	1,596
Manganese (micrograms per liter)	80	50	410	50	40	977
pH (standard units)	---	7.3	792	---	7.5	1,816
Specific conductance (micromhos per centimeter at 25°C)	275	290	918	321	305	1,788

similarity between chemical characteristics of water in glacial aquifers to those in underlying bedrock suggests that the water in glacial aquifers is influenced by the bedrock. Inflow of ground water from bedrock is known to increase the dissolved-solids concentrations in glacial aquifers and streams in parts of western New York, especially where evaporite rocks are present (LaSala, 1968; Crain, 1975). The range of values of chemical characteristics in the Northeast is summarized in table 3.

Because of their closeness to land surface, glacial aquifers are vulnerable to contamination by substances introduced at or near land surface, and many incidents of ground-water contamination have been reported. For example, aquifers may be affected by waste disposal, road-deicing salts, agricultural practices, natural or induced infiltration from streams, industrial spills, highway runoff, and many other activities.

Table 3.--Range in values of selected chemical characteristics of ground water in the glaciated Northeast

[Based on samples collected through September 1981; data from WATSTORE. Concentrations are in milligrams per liter unless otherwise indicated.]

Constituent or Characteristic	Glacial Aquifers [1]	Bedrock Aquifers [1]
Total dissolved solids, sum of constituents	47 - 470	71 - 520
Calcium	5.6 - 75	7.2 - 84
Magnesium	1.2 - 20	1.6 - 28
Sodium	3.1 - 57	2.7 - 77
Potassium	0.6 - 4.4	0.5 - 4.6
Chloride	2.5 - 90	1.8 - 81
Fluoride	0.1 - 0.3	0.1 - 0.6
Sulfate	5.0 - 76	4.8 - 110
Bicarbonate	18 - 250	25 - 260
Silica	6.6 - 18	6.6 - 20
Iron (micrograms per liter)	20 - 3310	20 - 1500
Manganese (micrograms per liter)	10 - 1390	10 - 400
pH (units)	6.2 - 8.0	6.4 - 8.1

1 Ten percent of samples have values above given range, and 10 percent have values below it.

PLANNED WORK ELEMENTS

The work that is planned as a part of the Northeast Glacial Aquifers RASA will support the objective of defining and understanding the flow characteristics of glacial aquifers of the Northeast. Studies will be done to obtain data on the aquifer-system components that are needed to evaluate ground-water flow. Although evaluation of the key components of all aquifers would be impossible, certain principles and concepts and an information base will be developed for regionwide applications. The regional appraisal of ground-water resources in the glacial aquifers will involve grouping or classifying the aquifers by characteristics relating to their water-supply potential. Results of the studies of system components will be used in conjunction with generalized flow models to characterize the flow systems and water-supply potential of each glacial-aquifer type.

This plan of study outlines work elements that concentrate on particular system components or aspects of system analysis. The work elements will be modified as knowledge and understanding of the glacial-aquifer systems in the Northeast grows during the project. Some of the work elements will be extended in scope and time after the feasibility and applicability of techniques have been analyzed.

Results of some work elements will be given in individual reports. The expected topics and the publication series are listed in table 4 with the schedule for completion of work elements, described below.

Work Element 1: Geometry of Glacial Aquifers

Glacial aquifers in the project area may be grouped by geometry, which controls well yields and flow characteristics. Aquifer geometry includes the distribution and thickness of coarse and fine-grained sediments within straified drift and the nature of bedrock valley walls. The principal types of aquifer geometry will be defined and correlated with geomorphologic features, glacial history, and valley and basin size. Such a conceptual framework would be useful to hydrologists in interpreting data related to ground-water flow in glacial aquifers.

Approach

1. Review available geologic and hydrologic literature of the Northeast.

2. Compile examples of selected aquifer-geometry types. List and describe these examples in reports. (See table 4.)

3. Perform detailed studies of aquifer geometry in selected areas in conjunction with other studies. This activity may include testing and application of some surface geophysical techniques that have not been widely applied in glaciated terranes.

4. Prepare descriptions of each aquifer-geometry type or concept. Present a map showing generalized distribution of aquifer-geometry types.

Table 4. Schedule for work elements and reports

[A, report submitted for review; P, preliminary report; dashed line indicates that study may be extended depending on applicability of techniques.]

Work elements	Publication series[1]	Work schedule[2] 1982	1983	1984	1985	1986
Project study plan	OF	—	— A			
Work Elements						
1. Aquifer geometry	HA	—	— AP	—	— A	
2. Streamflow duration and low flow	HA		— AP	—	— A	
3. Recharge estimates from water budgets	Jour		—	— AP - -	- - - A	
4. Streamflow-recession analysis	Jour	—	— AP	- - - A		
5. Water-quality data base (aquifers)	HA	—	—	— A		
6. Water-quality data base (streams)	HA		—	— A		
7. Iron and manganese, general	Jour		—	—	— A	
8. Flow from uplands	WRI		—	—	— A	
9. Hydraulic conductivity near streams	WRI		—	—	— A	
10. Chemical processes	WRI		—	— A - -	- - - A	
11. Surface-water/ground-water mixing	Jour		—	— A —	— A	
12. Iron-manganese, site study	WRI			—	— A - - A	
13. Generalized flow modeling	WRI	—	—	— AP —	— A	
14. Classification of aquifers	HA	—	—	— AP —	— A	
Summary Reports	PP			—	—	— A

[1] U.S. Geological Survey series: OF = Open File; HA = Hydrologic Investigations Atlas; WRI = Water Resources Investigations Series; PP = Professional Paper
Jour. = journal article (non-survey)

[2] Dates represent Federal fiscal year beginning October 1.

Product

Report on geometry and distribution of glacial aquifers of the Northeast. (Hydrologic Investigations Atlas.)

Work Element 2: Relation of Flow Duration and Low Flow to Basin Characteristics

Flow duration and low-flow frequency observed at surface-water stations are important indicators of the interaction between ground-water flow and flow in streams. Regional comparison of selected surface-water flow statistics will indicate patterns of ground-water flow that may relate to aquifer geometry, hydraulic conductivity of surficial-aquifer and streambed materials, physiography, climate, or other basin characteristics.

Previous work in Connecticut and south-central New York has shown that the percentage of a drainage basin that is covered by stratified drift is the most significant factor controlling the low flow of streams. Refinement of this work and extension to areas of differing topography and surficial geology may enable this principle to be quantified. Results of this effort will help define the principles of flow between glacial aquifers and streams.

Approach

1. Compute flow-duration and low-flow frequency statistics for stations on unregulated streams in the Northeast.
2. Plot selected statistics such as 90 percentile flow or 7-day 10-year low flow on maps of the study area.
3. Rework low-flow analyses for south-central New York and Connecticut to test the relative importance of a few basin characteristics not previously considered, such as lake and swamp areas, precipitation, and underflow.
4. Describe variations in flow duration and low flow in streams throughout the project area.

Product

Report on regional analysis of flow-duration and low-flow characteristics of streams. (Hydrologic Investigations Atlas.)

Work Element 3: Recharge Estimates from Water Budgets

Recharge to glacial aquifers varies in response to precipitation. Streamflow hydrographs in conjunction with water-level and precipitation data may be used to estimate ground-water evapotranspiration and recharge.

Approach

1. Select a dozen or more unregulated streams in the project area having diverse aquifer geometries and climatic settings and at least 20 years of record, and, if possible, observation wells to evaluate storage changes.

2. Use standard methods of separating ground-water runoff from the streamflow hydrograph.

3. Use historical water-level records and measurements of water-level fluctuations in additional wells over 1 or 2 years to compute annual recharge for each year of record. Analyze as a frequency distribution or as a function of precipitation.

Product

Report on variations of recharge in selected glacial aquifers of the Northeast. (Journal article.)

Work Element 4: Streamflow-Recession Curves for Hydrologic-Systems Analysis

The slopes of streamflow-recession curves reflect the hydraulic characteristics of aquifers adjacent to streams. Analytical techniques are available for calculating aquifer diffusivity from the slope of the streamflow-recession curve. Other techniques may be used to obtain estimates of ground-water evapotranspiration, leakage, and recharge from streamflow hydrographs. Unfortunately, the many simplifying assumptions of these analytical techniques may limit the use of hydrographs for hydrologic analysis. The techniques will be tested to evaluate their applicability in glaciated terranes.

Approach

1. Review methods of using streamflow-recession curves for hydrologic analysis.

2. Use generalized cross-section models and simple areal digital models to evaluate the effects of various hydrologic factors on recession characteristics. Modeling techniques may be used to prepare type curves for various hydrologic conditions.

3. Select a few areas in diverse geologic terranes to apply available methods of analysis. Explore the use of streamflow-recession analysis to discern differences in aquifer properties among basins.

4. If the above techniques are applicable, design a regionwide analysis from the available streamflow records.

5. Establish temporary discharge-measurement stations or make miscellaneous measurements upstream and downstream from selected valley reaches of known uniform aquifer geometry to study recession characteristics of the different aquifer types.

Product

Report on use of streamflow-recession curves for hydrologic analysis in glaciated terranes. (Journal article.)

Work Element 5: Statistical Analysis of Ground-Water-Quality Data Base

Chemical analyses for common ions are available in the WATSTORE data base for approximately 5,000 sites in or immediately adjacent to the project area. Additional analytical data are also available but have not been produced in machine-readable format. This analysis may (1) delineate water-quality zones for a regional appraisal, (2) help define geochemical processes such as water and rock interactions and mixing from multiple sources, and (3) identify chemical characteristics for special study.

Approach

1. Compile water-quality data from wells tapping glacial aquifers, till, and bedrock. Also update missing major ion and site data in the WATSTORE data base and compile selected data from other sources.

2. Screen the data base to exclude samples from known contaminated sources.

3. Use statistical methods to compute the spatial and depth distribution of selected chemical constituents.

4. Prepare maps showing ion ratios and selected saturation indices for glacial aquifers and bedrock.

Product

Report on ground-water quality in Northeast glacial aquifers. (Hydrologic Investigations Atlas.)

Work Element 6: Statistical Analysis of Surface-Water-Quality Data Base

Many chemical analyses of surface water in the project area are available. During periods of low flow, surface water probably reflects the quality of ground water discharging to the streams. A summary of water quality in streams during low flow will complement a summary of ground-water quality.

Approach

1. Compile water-quality data on streams that have data on water-quality in the associated aquifer. Update the U.S. Geological Survey data base if necessary and compile data from other sources.

2. Prepare maps showing (1) locations of surface-water sampling sites, (2) areal distribution of selected constituents during periods of low flow, and (3) variations in water quality at selected sites during low-flow periods. Also compile a table of ion ratios and selected saturation indices for selected sites.

Product

Report on chemical quality of water in selected streams at low flow. (Hydrologic Investigations Atlas.)

Work Element 7: Vulnerability of Glacial Aquifers to Iron and Manganese Contamination

High concentrations of iron and manganese are common in glacial aquifers. At present, the distribution of these ions is difficult to delineate because the geochemical and hydrologic data are inadequate. A review of available iron and manganese data may reveal some relationship to geology, hydrology, or other factors.

Approach

1. Identify areas where high iron and manganese concentrations are reported.

2. Establish correlations between iron and manganese concentrations and (a) physical-chemical characteristics, including dissolved oxygen, Eh, and pH; (b) proximity to streams, lakes, bogs, and swamps; (c) degree of saturation of selected mineral species; (d) pumping stress; (e) grain size and mineralogy of glacial aquifers; and (f) ground-water flow paths.

3. Identify data needs and collect additional data as needed.

Product

Report on distribution of iron and manganese in glacial aquifers. (Journal Article.)

Work Element 8: Recharge to Stratified-Drift Aquifers From Uplands

Inflow to glacial aquifers from adjacent till-covered bedrock uplands in the Northeast is poorly defined. Recharge from uplands occurs by three mechanisms--overland and shallow subsurface flow from hillsides immediately adjacent to aquifers, subsurface flow from till and bedrock, and infiltration from tributary streams that drain uplands. Each of these is described briefly below.

Overland and shallow subsurface flow from till hillsides.--Presumably, all runoff from hillsides recharges the bordering aquifer. The magnitude and time distribution of surface runoff from hillsides lacking channels should be similar to runoff from upland basins.

Lateral subsurface flow through bedrock.--Ground-water flow through bedrock contributes water to glacial aquifers. No reliable methods for estimating lateral subsurface flow through bedrock have been developed because of uncertainty as to hydraulic gradients and hydraulic conductivity in bedrock. However, rough estimates could be obtained from published values of hydraulic properties for till and bedrock and an analysis of water-level fluctuations in bedrock wells.

Infiltration from tributary streams.--Small streams crossing stratified drift or alluvial fans in a large valley lose water by seepage to underlying sediment (Ku and others, 1975). Randall (1978a) measured seepage losses in a region of shale-siltstone bedrock and clay-silt upland till. He recommended a simple average loss rate per unit length of channel to estimate recharge from tributary streams. Comparable studies in areas of crystalline, sandstone, and carbonate bedrock, where the alluvium and till might be appreciably less silty, would enlarge understanding of recharge from tributary streams in the project area.

Approach

1. Review literature for hydraulic properties of till and bedrock in the project area and for descriptions of hydrologic processes on hillslopes.

2. Use water-level fluctuations in observation wells completed in bedrock and water-level recession analysis or flow models to calculate hydraulic properties of the bedrock.

3. Use the hydraulic properties obtained above and Darcy's Law to calculate possible ranges of subsurface contributions from uplands.

4. Use chemical mixing models to estimate the magnitude of contributions from bedrock in selected areas.

5. Construct generalized cross sectional and areal digital models to evaluate volumes and time variations of flow from uplands under various hydrologic conditions.

6. Review literature for studies of water loss in tributary streams.

7. Monitor flow of selected tributary streams in diverse physiographic and geologic settings to provide seepage-loss data.

8. Refine analytical or other approaches for estimating seepage loses in the project area.

Products

1. Report on model simulation of flow from bedrock to glacial aquifers of the Northeast. (Water Resources Investigations series.)

2. Report on methods of estimating recharge to glacial aquifers from tributary streams draining uplands. (Water-Resources Investigations series.)

Work Element 9: Vertical Hydraulic Conductivity Near Streams

Induced infiltration from large streams is the largest potential source of recharge to most glacial aquifers during pumping. Some information suggests that even though the type of aquifer material is the principal constraint on infiltration, the vertical hydraulic conductivity of the streambed material may be critical in areas of generally permeable aquifer material. Many pumping centers in the Northeast are known to induce recharge from streams. Measurement of stream losses near these streams and concurrent water-level data in wells can be used to calculate the vertical hydraulic conductivity. Aquifer pumping tests may also be used to calculate vertical hydraulic conductivity.

Approach

1. Review water-use data on selected glacial aquifers and identify areas where pumpage is at least 20 percent of streamflow during low-flow periods.

2. Conduct seepage runs and simultaneous water-level measurements in wells during low-flow periods. Install temporary piezometers if necessary to measure hydraulic-head differences across the streambed.

3. Analyze results by analytical methods or finite-difference models.

4. Perform aquifer tests in wells near streams to determine vertical hydraulic conductivity.

5. Relate computed values of streambed hydraulic conductivity to the composition of streambed materials. Laboratory tests of hydraulic conductivity may be included.

Product

Report on hydraulic conductivity of streambeds in the Northeast. (Journal article.)

Work Element 10: Geochemical Processes in Glacial Aquifers

The chemistry of ground water is a result of both geochemical and hydrologic processes. These include, for example, the composition of the aquifer material, chemical reactions between the water and the aquifer material, and flow rates and flow paths of water in the system. In the past 20 years, several advances have been made in understanding the geochemistry of ground water (saturated) systems. Experimental and theoretical studies have provided a basis for the interpretation of natural systems. Field studies have concentrated on ground waters from igneous, carbonate, and, to a lesser extent, clastic rocks.

Glacial aquifers present a set of geochemical conditions different from those of other types of aquifers. The mineralogy of glacial aquifers is more complex than that of many other types. For example, glacial materials may have a relatively high percentage of silt and clay, which can affect the kinetics of chemical reactions. The main objective of studying the geochemistry of selected glacial aquifers is to develop capabilities for evaluation of the water chemistry of such aquifers for which data are lacking.

Approach

1. Aquifers will be selected for study on the basis of geologic and hydrologic information. Availability of water-quality information will play a key role in the selection of the aquifers.

2. Water-quality data for the selected areas will be compiled from all sources, such as U.S. Geological Survey, State, and public water-supply agencies. Major ion concentrations, alkalinity, and temperature will be required, and several silica and aluminum concentrations, not routinely determined in water-quality studies, may be done, which will require the collection and analysis of additional samples. All water-chemistry data will be compiled in a computerized data base.

3. Information on the mineralogy and hydrologic characteristics of the aquifers and adjacent bedrock units will be compiled.

4. The water chemistry of the aquifers will be characterized in a variety of ways, such as ion ratios and correlation coefficients between ions and other variables.

5. Relative transfer rates of species into solution and mass balance calculations will be used to identify reactions occurring in the aquifers.

6. Water-chemistry data will be plotted on stability field diagrams, and saturation indices will be calculated. Both techniques will provide information about chemical equilibria in the systems.

7. The spatial variation of the water chemistry will be investigated through use of three-dimensional plots where the data are sufficient. This information, when combined with hydrologic data, will provide preliminary information about the evolution of chemical character of water in glacial aquifers.

8. Data will be analyzed to discern correlations between water chemistry and the geology of the aquifers.

Product

Report on geochemical processes in glacial aquifers. (Journal article.)

Work Element 11: Relationship Between Surface-Water Quality and Ground-Water Quality

Most streams and lakes gain water from ground-water sources. Simple mixing models have been used to distinguish ground-water contributions to streamflow from water from other sources. These mixing models provide a check on techniques of identifying ground-water discharge on the streamflow hydrograph. Conversely, induced infiltration from rivers near pumping centers has been shown to alter the physiochemical characteristics of the pumped water. In such areas, mixing models may be used to quantify induced infiltration from streams and lakes.

Approach

1. Select areas where ground-water quality data, surface-water quality data, and streamflow data are available.

2. Use water levels in wells and concurrent stream or lake stage to delineate flow directions.

3. Use streamflow hydrographs to calculate ground-water discharge to the streams.

4. Use mixing models as an alternative means of estimating ground-water contributions to streams and lakes.

5. Use models to simulate observed changes in physiochemical properties of ground water near selected pumping centers.

6. Use flow models and mixing models to evaluate possible effects of river water on quality of the pumped waters.

Product

Report on relationship between surface-water quality and ground-water quality in glacial aquifers. (Journal article.)

Work Element 12: Manganese Enrichment of Water From Heavily Pumped Wells in a Stratified-Drift Aquifer in Rhode Island

An understanding of the causes of iron and manganese enrichment in wells in Rhode Island may help determine whether these constituents could reach troublesome levels elsewhere. Criteria may be formulated for locating wells and limiting withdrawals to minimize iron and manganese concentrations.

Previous studies in a well field near South Kingston, R.I., have shown that manganese in water from wells may be attributed to induced flow from streams through bottom sediments (Silvey and Johnston, 1977). Patterns of manganese concentrations in the well field can probably be explained by an analysis of flow paths. Preliminary three-dimensional modeling has supported concepts of manganese enrichment, including apparent changes in dissolved oxygen and pH along the flow paths, but results have not been thoroughly tested and documented.

Approach

1. Review the water-quality data and collect additional data if necessary.

2. Review the existing three-dimensional model of the well field and surrounding area. Modify, refine, and update the model if necessary.

3. Relate water quality, particularly the concentration of manganese, to flow patterns.

4. Stress the three-dimensional model to evaluate pumping schemes that would affect the induced infiltration and the distribution of manganese.

Product

Report on manganese in water from wells near Kingston, R.I. (Water-Resources Investigations series.)

Work Element 13: Generalized Flow Modeling

Potential yields and flow patterns in glacial aquifers can be studied through digital models. With generalized models it is possible to evaluate the water-supply potential of aquifer systems representing a variety of geologic and hydrologic conditions in the models. Identification of the information needed for evaluation of aquifer yields will guide efforts for data collection in future detailed studies.

Approach

1. Construct flow models for several classes of aquifers representing a variety of geologic and hydrologic conditions that are common in glacial-aquifer systems of the project area.

2. Vary the most significant factors over a plausible range to determine the variation in model results.

3. Present the results either as (1) a single index value of aquifer yield for an aquifer having average values of all factors, (2) graphs of multiplication factors to be applied to that index yield to account for deviations in yields from the average values, or (3) other relationships that may be developed during model construction and testing.

Product

Report on preliminary analysis of glacial aquifer flow systems through generalized flow models. (Water-Resources Investigations series.)

Work Element 14: Classification of Aquifers

Results of the work elements described above will provide the basis for classification of glacial aquifers by potential yield and water-quality characteristics. The resulting maps and description of aquifer types can be used by water managers to identify the type of aquifer in the area of interest and assess the water-supply potential or determine the data needed for further studies.

Approach

1. Design a scheme for aquifer classification that defines the characteristics needed for evaluation of potential water supplies. Factors such as geology, streamflow characteristics, physiography and water quality will be considered.

2. Describe the yield potential of each aquifer type on the basis of modeling.

3. Prepare a map, probably at a scale of 1:1,000,000, showing the distribution of such classified aquifers.

Product

Report on the classification of glacial aquifers of the Northeast. (Hydrologic Investigations Atlas.)

SUMMARY REPORTS

Several summary reports are planned for publication, either as separate U.S. Geological Survey Professional Papers or as a single Professional Paper with several chapters. The summary report(s) will discuss the general hydrology of glacial aquifers, the water chemistry of glacial aquifers, and the response of aquifer models to simulated stresses. Each of these is outlined in detail below.

General Hydrology of Glacial Aquifers

Climatology.--This section will include a discussion of seasonal and long-term spatial variations in precipitation and evapotranspiration. The information will be presented on small-scale maps or in tables and graphs. Most of the information will be compiled from published sources.

Geology.--This section will discuss the bedrock geology and physiography, Pleistocene history, and modes of sediment deposition.

Streamflow characteristics.--This section will discuss the spatial and time distribution of streamflow and geologic and other controls on ground-water discharge to streams, especially for low-flow periods.

Hydraulic properties of aquifer materials.--This section will present reported ranges and commonly observed or described values of hydraulic properties for till, bedrock, and stratified drift. Physiographic, geologic, and other controls on distribution and variability of the hydraulic properties will also be discussed.

Hydrologic budget.--This section will relate the quantities of recharge from various sources, including direct infiltration, flow from bedrock, and infiltration from tributaries, to climatology, physiography, glacial geology, and other controlling factors. The principles and magnitudes of induced infiltration will be discussed, and ground-water discharge to streams and evapotranspiration in various hydrologic settings will be explained. Seasonal and long-term variations in storage as reflected in water-level fluctuations and streamflow recession will be related to variations in precipitation, stream stage, hydraulic properties, and location in relation to streams.

Availability of ground water.--This section will discuss the availability of ground water in relation to glacial geology, aquifer geometry, and streamflow. Aquifers may be grouped on a small-scale regional map by potential for sustained water supply.

Chemistry of Water in Glacial Aquifers

General characteristics of water chemistry in the project area.--Maps and graphs will be prepared showing the chemical character of water in bedrock, till, and stratified drift and in streams during low-flow periods.

Mixing of water from multiple sources.--This section will discuss the magnitude and importance of chemical contributions from precipitation, stream infiltration, and of minerals in bedrock and till.

Chemical reactions.--This section will discuss some reactions that influence water chemistry within glacial aquifers.

Iron and manganese.--This section will discuss the distribution and possible causes of iron and manganese in water in glacial aquifers and possible actions to avoid increases in their concentration.

Contamination.--This section will be a brief discussion based on the literature search and observations.

Responses of Model Aquifer Systems to Simulated Stress

Steady-state analysis of aquifer types.--This section will discuss the nature of steady-state flow systems in various types of aquifers. It will relate flow patterns to aquifer characteristics and present results of sensitivity analyses to identify and evaluate the aquifer properties most important to definition of the steady-state flow conditions.

Nonsteady-state analysis of aquifer types.--This section will describe tests of various patterns of pumping and climatic stresses and summarize results of sensitivity analyses.

Water-supply potential of various aquifer types.--This section will summarize results of nonsteady-state simulations and emphasize the water-supply potential of major aquifer types.

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