A PLAN FOR THE STUDY OF THE HYDROGEOLOGY OF BEDROCK OF NEW ENGLAND

By Wayne W. Lapham

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Flow	
gallon per minute (gal/min)	0.06308	liter per second (L/s)

A Plan for the Study of the Hydrogeology of Bedrock of New England

By Wayne W. Lapham

ABSTRACT

Uses of bedrock in the six-State New England region of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont are diverse. Bedrock is used as building material, for construction of roads, in many industrial and commercial applications, as a source of water supply, and as a repository for waste. Although bedrock in New England is an important multiple-use water resource, there has been no coordinated investigation of the hydrogeology of bedrock in the region. There is a critical need for coordinated, systematic, and comprehensive study of all aspects of the hydrogeology of bedrock of New England to aid Federal, State, and local agencies in managing and protecting this valuable water resource.

This report presents a plan for the coordinated, systematic, and comprehensive study of the hydrogeology of bedrock in New England. Included as part of this plan are brief summaries of previous and current investigations in New England; a summary of the current understanding of the hydrogeology of bedrock on a regional basis; a statement of long-term objectives for study; and a proposed initial study. The initial study is designed to provide a description of the physical framework of the bedrock needed for subsequent studies that will address the many complex and diverse aspects of the hydrogeology of bedrock of New England.

Several of the most important interrelated objectives required for a comprehensive study of the hydrogeology of bedrock of New England are to (1) characterize the physical framework of bedrock in relation to scale and to identify factors that control the framework, such as rock lithology, bedding, foliation and geologic stress-strain history; (2) develop methods for identifying and characterizing the areal and vertical distributions of porosity and fractures in bedrock and describe the relation between fracture systems and the hydraulic properties of the rock; (3) describe the occurrence of water and characterize the flow system in bedrock on regional and local scales; (4) determine the sources of water to bedrock wells; (5) develop testing procedures for evaluating the performance of bedrock wells; (6) determine the water-yielding characteristics of bedrock and describe the relation between well yield and factors that affect well yield; (7) describe the background quality of ground water in the bedrock and relate water chemistry to rock chemistry; (8) describe the relation between bedrock ground-water quality and land use; (9) relate the nature of contaminant transport in bedrock to the bedrock framework; and (10) determine the nature of the fate and transport of contaminants in the various bedrock types.

These interrelated studies need to be based on a sound understanding, which is presently lacking, of the physical framework of bedrock in New England. Therefore, characterization of this framework is the proposed focus of the initial study.

INTRODUCTION

Background

Uses of bedrock in the six-State New England region of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont (fig. 1) are diverse. Bedrock is used as building material, for construction of roads, in many industrial and commercial applications, as a source of water supply, and as a repository for waste. These diverse uses generally are incompatible. For example, water withdrawn from bedrock aquifers commonly is used for water supply, but these aquifers commonly are hydraulically connected to areas that contain septic systems, buried storage tanks, road-salt storage piles, landfills, hazardous-waste storage and disposal sites, waste-injection wells, and disposal lagoons. As a result, contamination of water in bedrock aquifers is common, and many domestic, industrial, and municipal wells completed in bedrock have been shut down following degradation of water quality.

Historically, most large municipal water supplies in New England have been derived from stratified-drift aquifers, whereas most domestic supplies have been derived from bedrock aquifers. In recent years, however, development of industrial and municipal water supplies from bedrock has increased in many areas of New England as demand for water has grown beyond that available from the overlying unconsolidated deposits. The need to locate high-yield wells completed in bedrock simply, quickly, and economically has increased as demand for water supply has increased relative to available supply. There also is a need to develop methods by which these aquifers can be managed and protected by State and local agencies. One critical aspect of this management and protection is the delineation of recharge areas to wells completed in bedrock.

It is increasingly clear that water in bedrock aquifers is highly vulnerable to contamination from human sources. Under the U.S. Environmental Protection Agency's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) programs and companion State programs, new cases of contamination of water in bedrock aquifers are being discovered continuously. Cleanup of contaminated water in bedrock aquifers is costly and extremely difficult, and requires an understanding of the hydrogeology of the aquifers in the vicinity of the site, which generally is unavailable. This knowledge is based on data describing the physical properties and geologic and hydrologic characteristics of the bedrock, and the geochemical characteristics of water in the bedrock. Physical properties include the fracture characteristics and the primary and secondary porosities of the rock. Geologic characteristics include lithology and geologic history. Hydrologic characteristics include the degree of hydraulic connection between fractures, the rate and direction of ground-water flow, and the rates and locations of recharge and discharge. Geochemical characteristics include background water quality and the sources and types of chemical constituents in the bedrock.

Crystalline rocks in New England also have been considered as possible deep repositories for the long-term containment and isolation of high-level radioactive waste and spent fuel (U.S. Department of Energy, 1986). Selection of sites for long-term containment of these wastes implies that, beyond a synoptic understanding of the hydrogeology of these repositories, there is an understanding of probable long-term changes in the hydrogeology in the vicinity of the sites and the effects these changes could have on the safe containment of these wastes. Given the current state of knowledge of hydrogeology of bedrock in New England, and other factors, such as climatic change, it is questionable to predict these long-term changes or their effect on the safe containment of wastes.

Although bedrock of New England is a multiple-use resource and some of the uses are incompatible, and, although bedrock is an important water resource, there has been no coordinated investigation of the hydrogeology of bedrock in the region. Consequently, the hydrogeology of bedrock of New England remains poorly understood. There is a critical need for coordinated, systematic, and comprehensive study of all aspects of the hydrogeology of bedrock of New England to aid Federal, State, and local agencies in managing and protecting this valuable water resource.

Purpose and scope

This report presents a general plan for the coordinated, systematic, and comprehensive study of the hydrogeology of bedrock of New England. Included are brief summaries of previous and current investigations in New England; a summary of the current understanding of the hydrogeology of bedrock of New England; a statement of long-term objectives for the

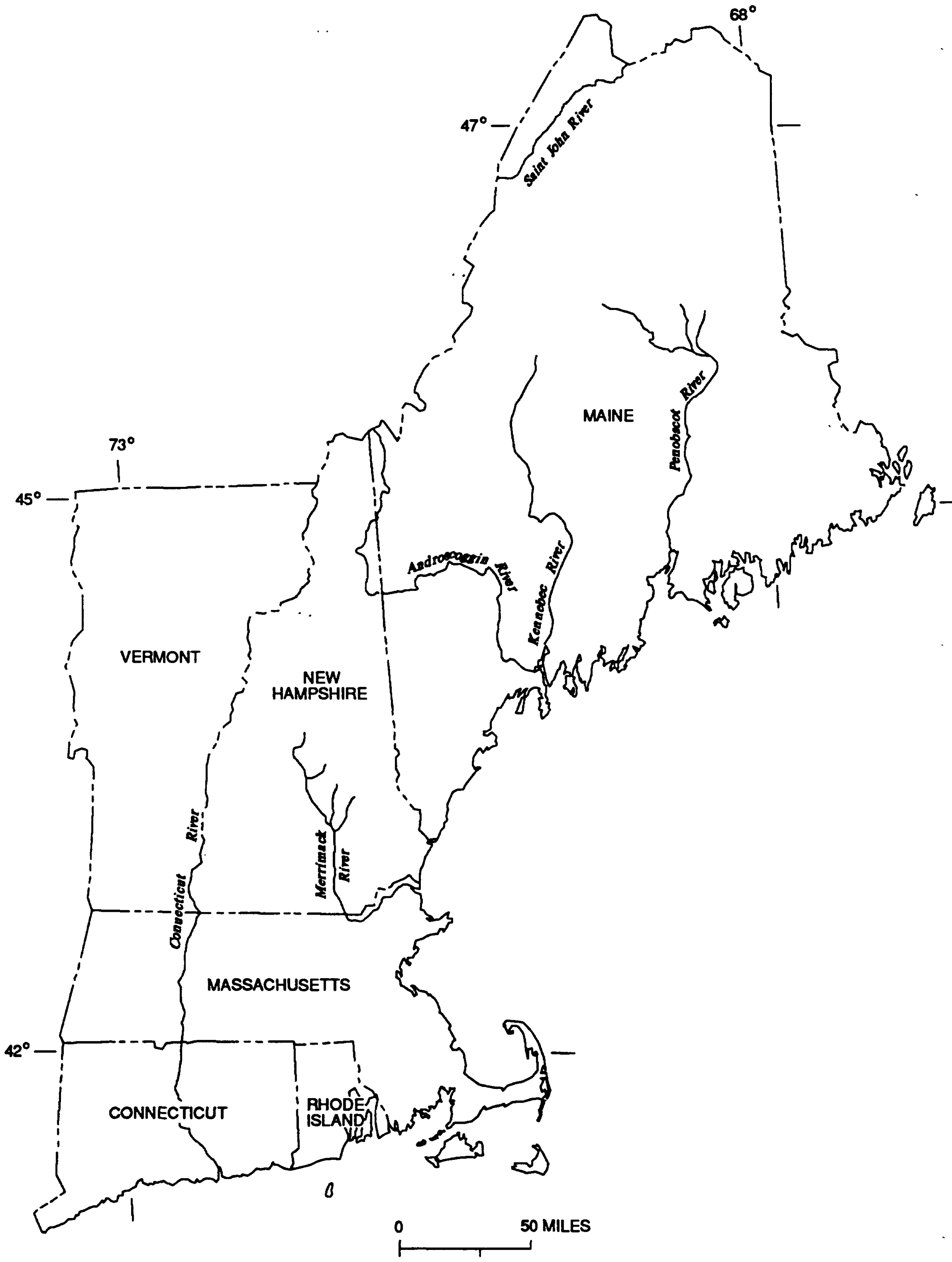

Figure 1.--The six-State New England Region.

study of the region's bedrock hydrogeology; and a proposed initial study. The initial study is designed to provide a description of the physical framework of the bedrock needed for subsequent studies that will address the many complex and diverse aspects of the hydrogeology of bedrock of New England.

REGIONAL GEOLOGY AND HYDROGEOLOGY OF BEDROCK

Geology

Bedrock in New England is composed of crystalline igneous, crystalline metamorphic, and sedimentary rocks (fig. 2). There has been extensive mapping of bedrock units and interpretation of the structural and geologic history of the region (Billings, 1955; Doll and others, 1961; Goldsmith, 1964; Hussey and others, 1967; Thompson and Norton, 1968; White, 1968; Quinn, 1971; Kane and others, 1972; Zen, 1972; Weed and others, 1974; Cameron and Naylor, 1976; Harwood and Zietz, 1976; Osberg, Hussey, and Boone, 1985; Hatch, 1988; among others). From a regional hydrogeologic perspective, bedrock in New England can be divided into Proterozoic and Paleozoic igneous and metamorphic rocks; partly metamorphosed lower Paleozoic sedimentary rocks; Cambrian and Ordovician sedimentary carbonate rocks; and upper Paleozoic, Triassic, Jurassic, and Cretaceous sedimentary rocks.

Proterozoic and Paleozoic igneous and metamorphic rocks are the most widespread in New England. These rocks cover large areas of Maine, New Hampshire, Rhode Island, Vermont, Connecticut, and nearly all of Massachusetts except the Connecticut Valley, Nantucket, and possibly Martha's Vineyard. The most common crystalline igneous rocks are granite, rhyolite, diabase, pegmatite, and basalt (Sinnott, 1982). The most common metamorphic rocks are gneiss, schist, phyllite, slate, marble, quartzite, and argillite.

Lower Paleozoic metasedimentary rocks, including quartzitic conglomerate, slate, phyllite, argillite, and marble, occur throughout Maine, in several areas in New Hampshire, and in western and southeastern Massachusetts, Rhode Island and Connecticut (Sinnott, 1982).

Cambrian and Ordovician sedimentary carbonate rocks, consisting largely of limestone, dolomite, and calcareous shale, and some metamorphosed sedimentary carbonate rocks consisting largely of marble, underlie western Vermont and the Housatonic River valley in western Massachusetts and Connecticut. Triassic and Jurassic sedimentary sandstone, conglomerate, and shale underlie the Connecticut Valley lowland in west-central Massachusetts and central Connecticut and the Aroostook valley in northern Maine along the border between the United States and Canada. Carboniferous conglomerate, sandstone, siltstone, and shale with some coal underlie the Boston and Narragansett basins of eastern and southeastern Massachusetts and southeastern Rhode Island. Igneous and metamorphic rocks underlie Cape Cod. Nantucket Island and Martha's Vineyard are underlain by partly indurated Tertiary coastal plain sediments, which overlie basalt of Triassic or Jurassic age at Nantucket.

Hydrogeology

Although the geology of bedrock in New England has been studied extensively and is reasonably well understood, there has been no comprehensive companion study of the hydrogeology of bedrock of New England. Most previous investigations of the hydrogeology of bedrock of New England (Ellis, 1909; Cushman and others, 1953; Heald, 1956; Stewart, 1965?; Hodges, 1968; Frimpter and Maevsky, 1979; Sinnott, 1982; Emery and Cook, 1984; Hoag, 1985; Paillet, 1985a; Caswell, 1987; Randall, 1988; among others) have focused on bedrock as an aquifer and, therefore, as a source of water for supply; therefore, the following discussion of the regional hydrogeology of bedrock of New England is from the supply perspective.

General relations between average well yield and rock type have been determined in New England. However, these relations may or may not apply at particular sites. The same rock unit can exhibit substantial areal and vertical variation in hydraulic characteristics, depending on the areal and vertical variation in primary and secondary permeability of the rock, and, therefore, large variation in yield. Conversely, rock units that are different lithologically can have similar hydrologic characteristics because of similar fracture characteristics, and, therefore, similar yields.

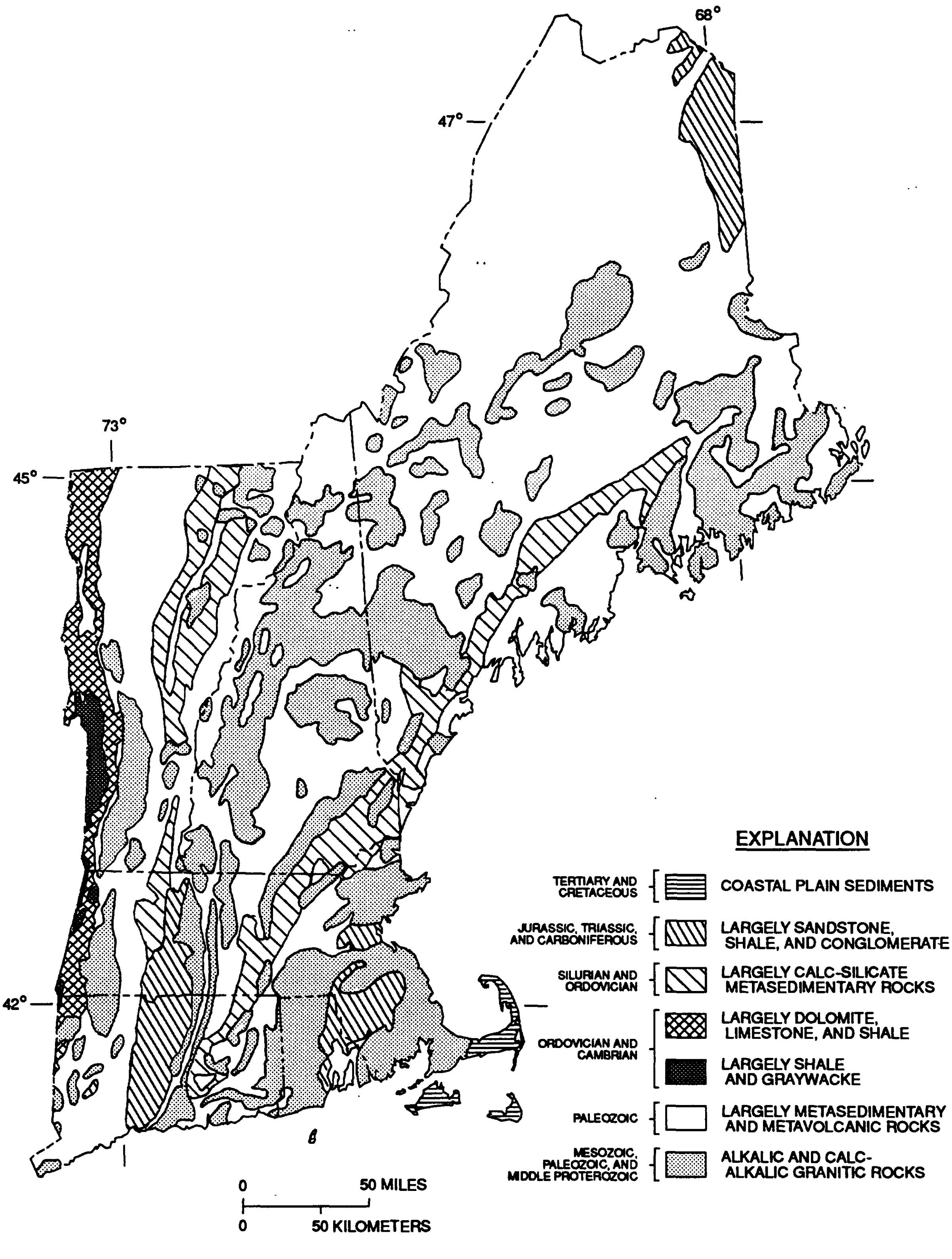

Figure 2.--Distribution of major types of bedrock in New England (Modified from Denny, 1982)

Wells in igneous rocks (granite, rhyolite, diabase, pegmatite and basalt) and metamorphic rocks (gneiss, schist, phyllite, slate, marble, quartzite and argillite) in New England derive nearly all their water from secondary permeability resulting from fractures in the rock (Sinnott, 1982). Similarly, wells in less intensely metamorphosed zones of quartzite, slate, phyllite, argillite and marble derive ground water from fractures in the vicinity of the well. Water to wells from the Cambrian and Ordovician carbonate limestone, dolomite, and calcareous shale is also derived from fractures. Some wells in these carbonate rocks are highly productive, particularly where solution along fractures has enlarged the openings and created zones of high secondary permeability. Water from wells from the Triassic, Jurassic, and Cretaceous sandstones, conglomerates, and shales is derived from interconnected pores (primary permeability) in the rock matrix, from faults and joints, and from fractures along bedding planes (secondary permeability).

Yields of bedrock wells in New England range from a fraction of a gallon per minute (gal/min) to more than 1,000 gal/min (Hodges, 1968; Cushman and others, 1953; U.S. Geological Survey, 1984). Cushman and others (1953) determined that the yield of a bedrock well in New England depends primarily on four factors: the number of fractures intersected by the well, the water-bearing capacity of the fractures, the ability of the fractures to transmit water, and the rate of recharge to bedrock in the vicinity of the well. Yields can be high where wells intersect major faults and in areas where the bedrock is overlain by saturated stratified drift (U.S. Geological Survey, 1984). Cushman and others (1953) summarized the yields from 1,952 wells from 7 rock types. Results of this summary indicated that wells in limestone produced the highest average yield, 177 gal/min, and that wells in gneiss produced the lowest average yield, 9.0 gal/min. Between these two extremes, the average well yield was 37.7 gal/min in granite, 32.7 gal/min in Carboniferous sedimentary rocks, 19.8 gal/min in Triassic sedimentary rocks, 11.7 gal/min in granite gneiss, and 10.3 gal/min in schist. Cushman and others (1953) also concluded that the topographic setting of the well is related to yield. Wells located in valleys had an average yield of 91.9 gal/min, and wells located on plains, slopes, and hills had average yields of 57.5, 18.8, and 7.7 gal/min, respectively. Average yield may be a poor index for evaluating well yield, however, because a few very high yielding wells can have a significant effect on the average.

Sinnott (1982) and the U.S. Geological Survey (1984) provide recent summaries of bedrock characteristics in New England with respect to well yield. The U.S. Geological Survey (1984) reports that well depths generally range from 100 to 300 ft in sedimentary rock aquifers, and from 20 to 800 ft in noncarbonate crystalline and carbonate rock aquifers (table 1). The range of yields is from 1 to 100 gal/min from the sedimentary rock aquifers, from 1 to 25 gal/min from the noncarbonate crystalline rock aquifers, and from 1 to 50 gal/min from the carbonate rock aquifers.

LONG-TERM STUDY OBJECTIVES

A thorough understanding of the hydrogeology of bedrock in the region requires a number of studies. Each of these studies would focus on a specific aspect of the hydrogeology of bedrock; therefore, each study will have different objectives and scope from the other studies. All are interrelated, however, and studies will be best conducted concurrently. Most of these studies need to be based on a sound understanding, presently lacking, of the physical framework of bedrock in New England. For example, all of the States in New England are faced with the problem of ground-water contamination in bedrock--a problem that requires immediate and intensive study. However, the first step in the study of the fate and transport of contaminants in bedrock at a site is to understand the physical framework of the rock in the vicinity of the site and the relation between the framework and the hydraulic properties of the bedrock. For this reason, a study that focuses on the physical framework of the bedrock is viewed as a necessary first step toward understanding the fate and transport of contaminants in bedrock. Therefore, characterization of this framework is the proposed focus of the initial study.

Over the long term, concurrent studies of the hydrogeology of bedrock of New England should be designed to:

(1) Characterize the physical framework of bedrock in relation to scale and identify factors which control the framework, such as rock lithology, bedding, foliation and geologic stress-strain history.

(2) Develop methods for identifying and characterizing the areal and vertical distributions of

Table 1.--*Summary of well characteristics in bedrock aquifers in New England by State.*
[From U.S. Geological Survey, 1985; --, no information; ft, feet; gal/min, gallons per minute]

Bedrock aquifer	State	Well characteristics			
		Depth (ft)		Yield (gal/min)	
		Common range	May exceed	Common range	May exceed
Sedimentary	Conn.	100-300	500	2-50	500
	Maine	--	--	--	--
	Mass.	100-250	500	10-100	500
	New Hampshire	--	--	--	--
	Rhode Island	100-300	500	1-20	50
	Vermont	--	--	--	--
Crystalline (noncarbonate)	Conn.	100-300	500	1-25	200
	Maine	20-800	--	2-10	500
	Mass.	100-400	1,000	1-20	300
	New Hampshire	100-600	800	1-10	100
	Rhode Island	100-300	500	1-20	50
	Vermont	100-600	800	1-10	100
Carbonate	Conn.	100-300	500	1-50	200
	Maine	20-800	--	10-30	600
	Mass.	100-300	1,000	1-50	1,000
	New Hampshire	--	--	--	--
	Rhode Island	--	--	--	--
	Vermont	100-300	500	5-20	300

porosity and fractures in bedrock and describe the relation between fracture systems and the hydraulic properties of the rock.

(3) Describe the occurrence of water and characterize the flow system in bedrock on regional and local scales.

(4) Determine the sources of water to bedrock wells.

(5) Develop testing procedures for evaluating the performance of bedrock wells.

(6) Determine the water-yielding characteristics of bedrock and describe the relations among well yield and factors that affect well yield.

(7) Describe the background quality of water in the bedrock and relate water chemistry to rock chemistry.

(8 Describe the relations among bedrock ground-water quality and land use.

(9) Relate the nature of contaminant transport in bedrock to the physical framework of the bedrock.

(10) Determine the nature of the fate and transport of contaminants in the various types of bedrock.

A diagram that summarizes these objectives is shown in figure 3.

Investigations that partly address several of these objectives currently are ongoing in New England. These investigations include a study of the hydrogeologic characteristics of fractured rock near Mirror Lake, Thornton, New Hampshire (Paillet, 1985a) as part of the U.S. Geological Survey's National Research Program; development of surface-geophysical methods to detect bedrock fractures (F.P. Haeni, U.S. Geological Survey, oral commun., 1989); studies of the hydraulic characteristics of fractured rock, ground-water flow and the fate and transport of contaminants in bedrock as part of remedial investigations at Superfund sites; a study of the occurrence of water in bedrock by the Massachusetts Office of the U.S. Geological Survey (B.P. Hansen, U.S. Geological Survey, oral commun., 1989); and several State programs of bedrock data collection, compilation and analysis. Fracture-trace analysis and surface geophysics currently is being applied by some firms in the water-well industry to locate the most likely locations for high-yield bedrock wells.

Accurate and standardized reporting of data describing physical, geologic and hydraulic characteristics of bedrock collected throughout the six New England States, the storage of these data in common data bases, and the ability to easily retrieve, manipulate, and display these data are critical for a regional approach to the investigation of the hydrogeology of bedrock. These data include the locations of test holes and wells, lithologic and water yield logs, pumping rates and time-drawdown data from aquifer tests and other hydraulic tests, borehole- and surface-geophysical surveys, lineament and fracture-trace analyses, and chemical analyses of water from bedrock. Currently, the methods by which these data are collected, reported, stored, and retrieved in State data bases differ in content and accuracy from State to State. Therefore, one important first step toward the regional study of hydrogeology of bedrock of New England is to establish and maintain standardized State bedrock data bases or one New England-wide data base. Utilization of a Geographic Information System (GIS) for data storage-and-retrieval system is one possible approach for management of these data.

PROPOSED PLAN OF INITIAL STUDY

Achieving a thorough understanding of the hydrogeology of bedrock of New England will require a number of studies designed to address the several interrelated objectives discussed in the section "Long-term objectives". The first of these objectives is to characterize the physical framework of bedrock in New England. The proposed initial study will provide a description of the physical framework of bedrock in New England at regional and local scales and relate that framework to factors that control the framework, such as rock lithology and geologic history. Characterization of the framework will provide fundamental information necessary for subsequent investigations of water supply, the fate and transport of contaminants, and remediation of contaminated ground water in bedrock systems.

A rock unit can have substantial areal and vertical variation in hydraulic characteristics, depending on the areal and vertical variation in primary and secondary porosity and permeability of the rock. Conversely, rock units with differing lithologies may have

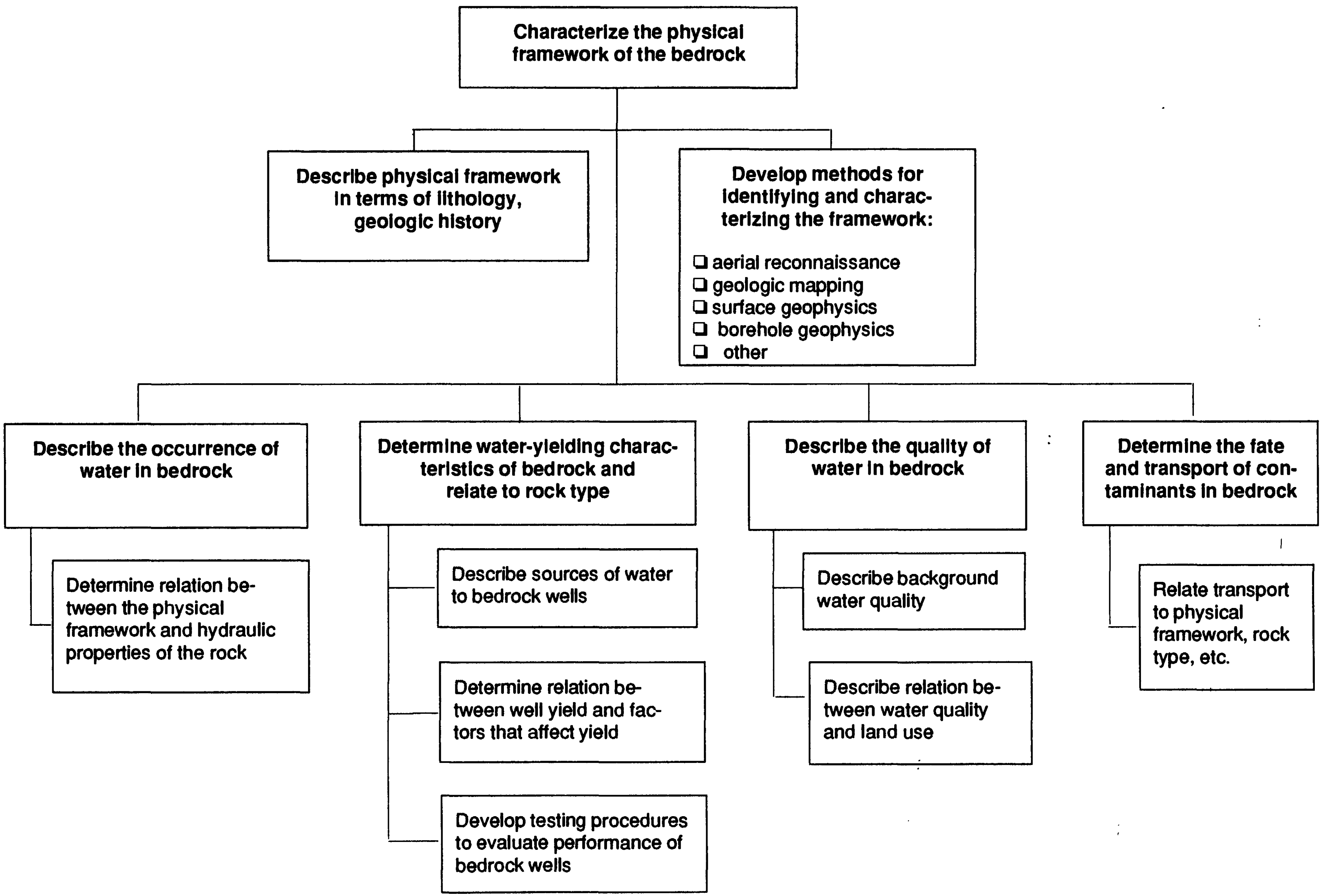

Figure 3.--Objectives for the study of the hydrogeology of bedrock of New England.

similar hydraulic characteristics because of similar porosity characteristics. Therefore, knowledge of the brittle deformation and resulting fracture characteristics of bedrock (the physical framework of the bedrock) is fundamental information required for studies of the occurrence of water, yields of water from bedrock wells, and the fate and transport of contaminants in bedrock aquifers. Characterization of the bedrock framework consists of a description of the following physical properties of the rock: (1) the primary porosity of the rock; (2) the types of rock fracture systems (joints, faults, shear zones) that contribute to the rock's secondary porosity; and (3) the characteristics of these fracture systems, including the areal and vertical geometry, orientation, size of openings, spacing, density, and fracture interconnection. Fracture systems are the physical features of brittle deformation of rock in response to stress. An understanding of the stress-strain relationships is a key to transfer of fracture system patterns from one geographic area and from one lithologic terrane to another. A large body of knowledge of rock mechanics already exists in the literature and structural geology studies provide a strong foundation for development of hydrologic analysis of secondary bedrock porosity and permeability.

Hydraulic properties of the rock, such as the primary and secondary permeability, storage coefficient, and degree of heterogeneity and anisotropy, are related to the physical properties. The central problem associated with the characterization of flow and transport in fractured rock is one of heterogeneity and scale (Shapiro and Hsieh, U.S. Geological Survey, written commun., 1989). Characterization of the physical framework of the rock unit or units under investigation at a specified scale provides direct information on this heterogeneity and indirect information on the hydraulic properties. For example, characterization of the framework at a regional scale may indicate that flow in the rock on a regional scale can be described using porous-media models, whereas characteristics of the framework on a local scale may indicate that flow in the rock on a local scale only can be described with models that simulate flow in discrete fractures that are separated by solid rock. The characterization of the framework at different scales, therefore, will direct the focus of future studies. Assessment of bedrock as a regional water supply probably will require characterization of the physical framework of bedrock on a regional scale, whereas determination of the fate and transport of contaminants in bedrock probably will require characterization of the physical framework on a local scale. Characterization of the physical framework of bedrock at different scales, therefore, is fundamental information required for studies of issues related to water supply and ground-water contamination and is the proposed focus of the initial study.

The primary objective of the initial study is to characterize the physical framework of bedrock in New England at a regional scale, and, where possible, at a local scale, and to relate that framework to controlling factors, such as lithology, bedding, foliation and geologic stress-strain history. A secondary objective is to relate this framework to the hydraulic properties of the rock.

The physical framework of the bedrock will be characterized at regional and local scales by describing the primary porosity of the rock, identifying the types of fracture systems (joints, faults, bedding-plane fractures, shear zones), and the physical characteristics of the fractures (areal and vertical geometry, orientation, size of openings, spacing, density, and interconnection). This physical framework then will be related to factors that might affect or control these properties. Comparison of the characteristics of the physical framework among sites with similar controls, such as rock type or stress history, will provide information on the transferability of these frameworks to other areas of New England where data are not available. Available hydrogeologic data, such as the primary and secondary permeability, heterogeneity, anisotropy, and storage capacity of bedrock, will be related to this physical framework.

The framework on a regional scale will be characterized using available data, aerial-photograph and/or satelite-imagery interpretation, and field investigations. It is anticipated that a large body of data already exists that indirectly describes the framework. These data have been collected during studies of the geology of New England, particularly studies of structural geology. Other data from geophysical and hydrologic studies also may be available. Therefore, the first phase of the study will be a comprehensive review of the geologic, geophysical, and hydrologic literature, and interpretation of data that describe the nature of gross rock porosity (primary, secondary, or both) and the physical characteristics of fractures (the areal and vertical geometry, size of openings, spacing, and fracture density). Much of the data available will describe the physical framework indirectly because these data were collected for other reasons. For example, structural mapping of a rock unit commonly includes rose diagrams and stereo plots of measurements of the strike and dip and other characteristics of major joints and faults. Data on these characteristics of fractures, such as strike and dip, lengths, widths, degree of surface weathering, and spacings of these fractures will provide important information describing the brittle deformation of the rock. Available data may be sufficient that a significant part of the study will be spent reviewing and reinterpreting these data. Additionally, aerial-photograph and/or satelite-imagery interpretation may aid the characterization of the framework on a regional basis. Field investigation also may further refine and verify the in-office characterization of the framework. Field investigations include measurements of surface-fracture characteristics on exposed rock surfaces, measurements of fracture characteristics at outcrops, road cuts, and quarries, and surface-geophysical surveys. Contractural services for mapping fracture systems using aerial-photograph and/or satelite-imagery interpretation, and for characterization of the framework is possible.

The physical framework will be characterized on a local scale using existing data and on-site field investigation. Existing data from wells completed in bedrock, such as those collected during remedial investigations at Superfund sites are available for analysis and interpretation. These data include borehole-geophysical surveys of boreholes completed in bedrock to delineate the vertical distributions of fractures, and surface-geophysical surveys to map areal fracture patterns. Some borehole-geophysical surveys in recently drilled domestic and municipal bedrock wells also may be run. These wells usually are available only for a brief time after completion of drilling--pumps are installed in the bedrock wells drilled for water supply soon after completion of drilling. In addition, bedrock test holes at Superfund sites are commonly left as open holes for only a short time after completion of drilling and water-quality sampling, to prevent cross contamination of ground-water caused by vertical flow in the borehole. Geophysical logging of these boreholes soon after completion of drilling will provide information on the size and vertical distribution of fractures in the boreholes.

Extensive, detailed characterization of the framework on a local scale is beyond the scope of this study. Detailed characterization on a local scale requires long-term access to boreholes completed in bedrock for borehole-geophysical logging, aquifer and slug tests using packers, and cross-hole pumping and tracer tests. With the constraint of long-term access to boreholes, the best approach for study of the bedrock framework at a local scale is the establishment of fractured-rock field research sites. These sites should be located in a variety of fractured rock environments with different degrees of fracturing and complexity, that are identified as important hydrogeologic terranes for water supply or disposal of waste. Installation, instrumentation, and detailed investigation of fractured-rock field-research sites is expensive and manpower intensive. Also, until understanding of the physical framework of bedrock in New England is improved, selection of sites for detailed study of small-scale bedrock hydrogeology that are representative of large areas of the Region would be difficult.

Some data on the bedrock framework at a local scale currently is being collected and can be included in this study. One site is located near Mirror Lake, West Thorton, New Hampshire. Comparisons of results of studies at Mirror Lake and at other sites in future studies ultimately are expected to enable characterization of local frameworks in different rock lithologies in New England and provide evidence for or against transferability of these results to other sites where data are not available.

An example of how the physical framework of the bedrock might be characterized at regional and local scales and how the framework will be related to factors that might affect or control these properties, such as rock lithology and geologic history, is illustrated in table 2 (R. Melvin, U.S. Geological Survey, written commun., 1989).

SUMMARY

Uses of bedrock in the six-State New England region of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont are diverse. Water is commonly withdrawn from bedrock for water supply, but bedrock is commonly hydraulically connected to areas that contain septic systems, buried storage tanks, road-salt storage piles, landfills, hazardous-waste storage and disposal sites, waste-injection wells, and disposal lagoons. Although bedrock in New England is an important multiple-use water resource, there has been no coordinated investigation of the hydrogeology of bedrock in the region. Consequently, the hydrogeology of bedrock of New England remains poorly understood. There is a critical need for coordinated, systematic, and comprehensive study of all aspects of the hydrogeology of bedrock of New

Table 2.--*Hypothetical example of an approach to characterizing the physical framework of a rock type in New England.*

I. ROCK LITHOLOGY

Granite

A. SUMMARY OF GENERAL HYDROGEOLOGIC CHARACTERISTICS

No primary porosity.
Significant secondary porosity.
Fractures are concentrated in discrete zones in the upper 100 meters.
Jointing between fractures is irregular.
Areal fracture density is highly variable (cite range).
Vertical fracture density is highly variable (cite range)

1. HYDROGEOLOGIC CHARACTERISTICS ON A REGIONAL SCALE

a. Shallow joint sets
    orientation
    spacing
    areal fracture density
    vertical fracture density
    etc.

b. Deep joint sets
    orientation
    spacing
    areal fracture density
    vertical fracture density
    etc.

2. HYDROGEOLOGIC CHARACTERISTICS ON A LOCAL SCALE

a. Shallow joint sets
    orientation
    spacing
    areal fracture density
    vertical fracture density
    etc.

b. Deep joint sets
    orientation
    spacing
    areal fracture density
    vertical fracture density
    etc.

England to aid Federal, State, and local agencies in managing and protecting this valuable water resource.

This report presents a general plan for the coordinated, systematic, and comprehensive study of the hydrogeology of bedrock in New England. Included are brief summaries of previous and current investigations in New England; a summary of the current understanding of the hydrogeology of bedrock of New England; a statement of long-term objectives for the study of the region's bedrock hydrogeology; and a proposed initial study. The initial study is designed to provide a description of the physical framework of the bedrock needed for subsequent studies that will address the many complex and diverse aspects of the hydrogeology of bedrock of New England.

Achieving a thorough understanding of the hydrogeology of bedrock in the region will require a number of studies. Each of these studies should focus on a specific aspect of the hydrogeology, and, therefore, each study will have different objectives and scope from the other studies. All are interrelated, however, and studies will be best conducted concurrently. These concurrent studies should be designed to (1) characterize the physical framework of bedrock of New England in relation to scale and identify factors that control the framework, such as rock lithology and geologic history; (2) develop methods for identifying and characterizing the areal and vertical distributions of porosity and fractures in bedrock and describe the relation between fracture systems and the hydraulic properties of the rock; (3) describe the occurrence of water and characterize the flow system in the bedrock on regional and local scales; (4) determine the sources of water to bedrock wells; (5) develop testing procedures for evaluating the performance of bedrock wells; (6) determine the water-yielding characteristics of bedrock and describe the relation between well yield and factors that affect well yield; (7) describe the background quality of ground water in the bedrock and relate water chemistry to rock chemistry; (8) describe the relation between bedrock ground-water quality and land use; (9) relate the nature of contaminant transport in bedrock to the bedrock framework; and (10) determine the nature of the fate and transport of contaminants in the various bedrock types.

Most of these interrelated studies need to be based on a sound understanding, which is presently lacking, of the physical framework of bedrock in New England. Therefore, the characterization of this framework is the proposed focus of the initial study.

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