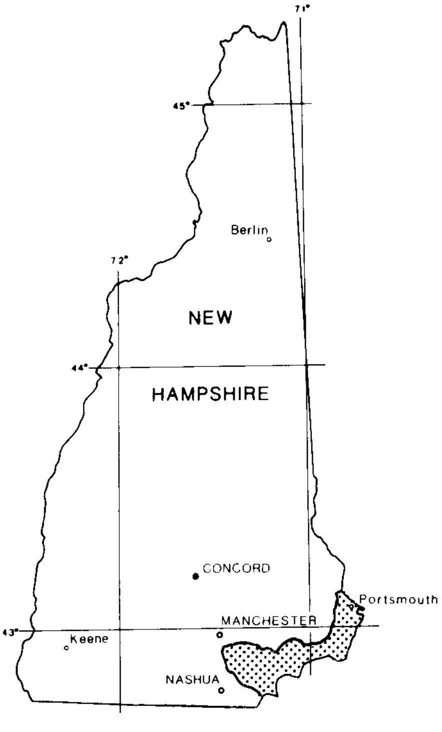
Geohydrology and Water Quality of Stratified-Drift Aquifers in the Lower Merrimack and Coastal River Basins, Southeastern New Hampshire

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4025



Prepared in cooperation with the

NEW HAMPSHIRE DEPARTMENT OF ENVIRONMENTAL SERVICES
WATER RESOURCES DIVISION

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

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By Peter J. Stekl and Sarah M. Flanagan

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MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	3.7854	liter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day per square mile [$(Mgal/d)/mi^2$]	1,460	cubic meter per second per square kilometer
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity	
square foot per day (ft^2/d)	0.09290	square meter per day

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

Geohydrology and Water Quality of Stratified-Drift Aquifers in the Lower Merrimack and Coastal River Basins, Southeastern New Hampshire

By Peter J. Stekl and Sarah F. Flanagan

ABSTRACT

Communities in the lower Merrimack River basin and coastal river basins of southeastern New Hampshire are experiencing increased demands for water because of a rapid increase in population. The population in 1987 was 228,495 and is expected to increase by 30 percent during the next decade. As of 1987, five towns used the stratified-drift aquifers for municipal supply and withdrew an estimated 6 million gallons per day. Four towns used the bedrock aquifer for municipal supply and withdrew an average of 1.6 million gallons per day.

Stratified-drift deposits cover 78 of the 327 square miles of the study area. These deposits are generally less than 10 square miles in areal extent, and their saturated thickness ranges from less than 20 feet to as much as 100 feet. Transmissivity exceeds 4,000 square feet per day in several locations. Stratified-drift aquifers in the eastern part are predominantly small ice-contact deposits surrounded by marine sediments or till of low hydraulic conductivity. Stratified-drift aquifers in the western part consist of ice-contact and proglacial deposits that are large in areal extent and are commonly in contact with surface-water bodies.

Five stratified-drift aquifers, in the towns of Derry, Windham, Kingston, North Hampton, and Greenland, have the greatest potential to supply additional amounts of water. Potential yields and contributing areas of hypothetical supply wells were estimated for an aquifer in Windham near Cobbetts Pond and for an aquifer in Kingston along the Powwow River by use of a method analogous to superposition in conjunction with a numerical ground-water-flow model. The potential yield is estimated to be 0.6 million gallons per day for the Windham-Cobbetts Pond aquifer and 4.0 million gallons per day for the Kingston-Powwow River aquifer. Contributing recharge area for supply wells is estimated to be 1.6 square miles in the Windham-Cobbetts Pond aquifer and 4.9 square miles in the Kingston-Powwow River aquifer.

Analyses of water samples from 30 wells indicate that the water quality in the basins studied is generally suitable for drinking and other domestic purposes. Concentrations of iron and manganese exceeded the U.S. Environmental Protection Agency's (USEPA) and the New Hampshire Water Supply Engineering Bureau's secondary maximum contaminant levels for drinking water in 20 samples. With one exception, concentrations of volatile organic compounds at all wells sampled met New Hampshire Water Supply and Engineering Bureau's drinking-water standards. At one well, trichloroethylene was detected at a concentration of 5.7 micrograms per liter.

Ground-water contamination has been detected at several hazardous-waste sites in the study area. Currently, 5 sites are on the USEPA's National Priority List of superfund sites, 10 sites are Resource Conservation and Recovery Act of 1976 sites, and 1 site is a Department of Defense hazardous-waste site.

INTRODUCTION

Southeastern New Hampshire has undergone a rapid increase in population in the past few decades. Population in the region increased by more than 39 percent from 1970 through 1987, when it reached 228,495. The population is projected to increase at an average annual rate of 3.32 percent by the end of the century (New Hampshire Office of State Planning, written commun., 1989). Economic development has increased in southeastern New Hampshire because of its proximity to metropolitan Boston. This growth, accompanied by industrial expansion, increased energy needs, and changes in land use, has steadily increased the demands for potable water and has stressed existing municipal water supplies. Currently, this area depends on ground water as its primary source of water. The increased stress on this resource from a growing population has created occasional shortages in water quantity and deterioration of water quality.

Extensive ground-water contamination has occurred at five hazardous-waste sites, and the migration of contaminants has prevented development of productive aquifers in some areas. Water quality in the shallow stratified-drift aquifers is of a concern because depth to water is typically 20 ft or less, and the highly permeable surficial materials above the water table offer little protection from seepage of contaminants into ground water. Development of new public water supplies is needed to satisfy current and future demands. Additional ground-water data are needed to facilitate development of water supplies and protection of water quality.

To meet this need for ground-water data, the U.S. Geological Survey (USGS), in cooperation with the New Hampshire Department of Environmental Services, Water Resources Division, began a 10-year program in 1983 to provide detailed maps of stratified-drift aquifers statewide. Maps that show aquifer boundaries, water-table altitudes, general directions of ground-water flow, saturated thickness, and aquifer transmissivity are being compiled on a scale of 1 in. equals 2,000 ft. The study also provides statewide data on background water quality in stratified-drift aquifers. Detailed geohydrologic information is provided in the reports for use by regional and local planners in making maximum use of existing ground-water resources and in locating and developing new resources. This report describes stratified-drift aquifers for the Beaver Brook, Spicket River, Powwow River, and Little River subbasins of the lower Merrimack River basin and the coastal rivers basin, which include Berry Brook, Winnicut River, Taylor River, and Hampton Falls River that flow directly into Great Bay or the Atlantic ocean (fig. 1).

Purpose and Scope

The purpose of this report is to (1) describe the hydrologic and geologic characteristics of the stratified-drift aquifers--areal extent, saturated thickness, and transmissivity; ground-water levels; general directions of ground-water flow and yield of stratified drift and contributing areas for selected aquifers after prolonged pumping; (2) describe general geohydrology of till and bedrock and water use and water-yielding characteristics of the bedrock aquifer; and (3) document ground-water quality in the stratified-drift aquifers.

This investigation focused on but was not limited to collection, compilation, and evaluation of data from stratified-drift aquifers. Some water yield data was also collected and evaluated for the bedrock aquifer. Two stratified-drift aquifers, in Windham near Cobbetts Pond and in Kingston along the Powwow River, have the greatest potential to supply additional ground water. A superposition modeling technique was used to estimate yields of these two aquifers and to delineate the size of the contributing areas after 180 days of pumping.

Description of the Study Area

The study area, in southeastern New Hampshire (fig. 2), is east of the Merrimack River and extends from the towns of Londonderry to New Castle. Beaver Brook, Little River, Spicket River, and Powwow River are the largest drainage subbasins (fig. 1). For the purpose of discussion in this report, the area has been divided into three subareas (western, central, and eastern), and two map plates (at the back of the report) are used to present geohydrologic information on each subarea (fig. 2). The study area of 327 mi^2, is underlain by stratified-drift aquifers (78 mi^2), marine deposits (69 mi^2), and till deposits (180 mi^2). Many towns with a municipal water supply rely completely or partly on ground water for that supply.

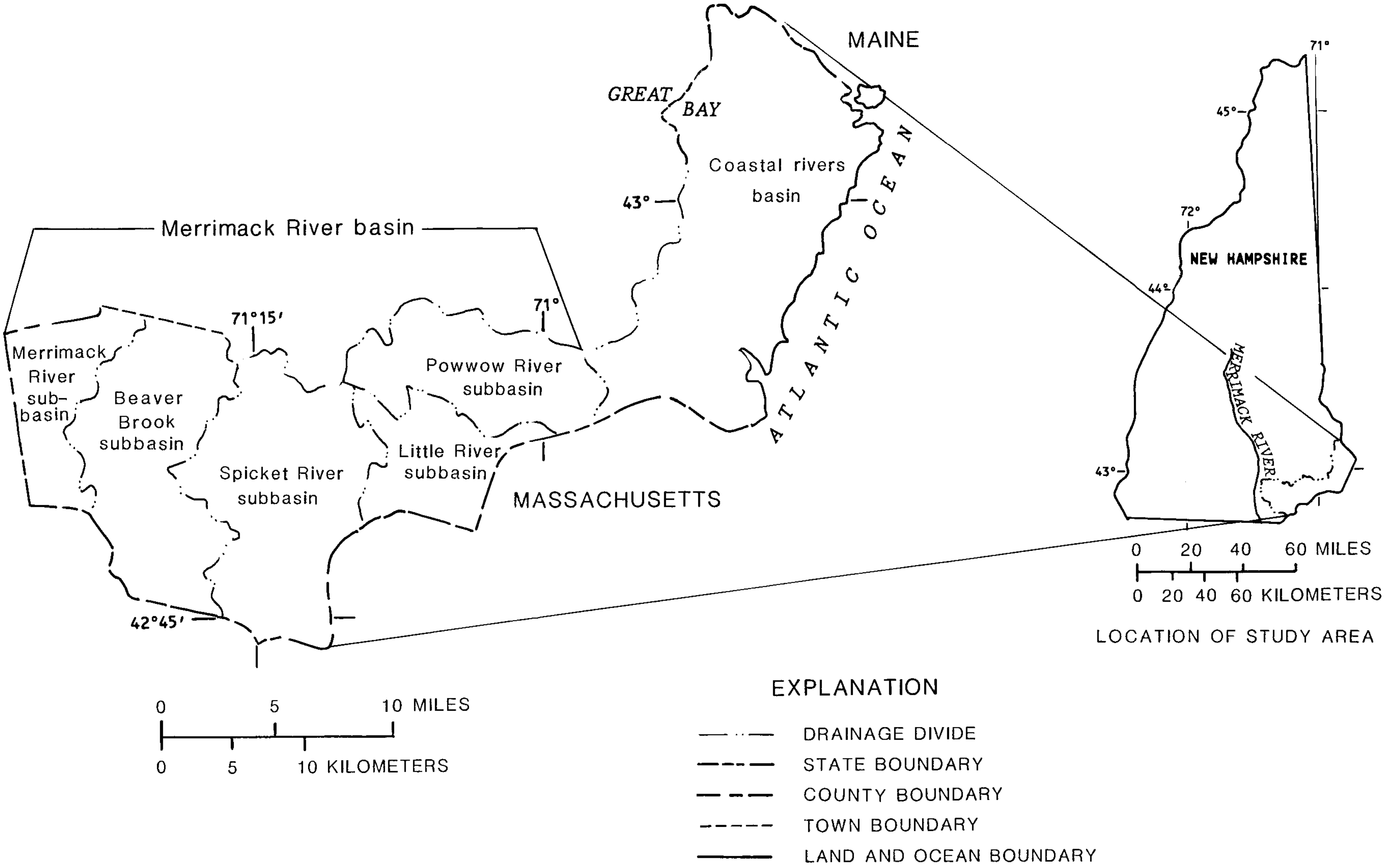


Figure 1.--Location of the lower Merrimack and coastal rivers basins, southeastern New Hampshire.

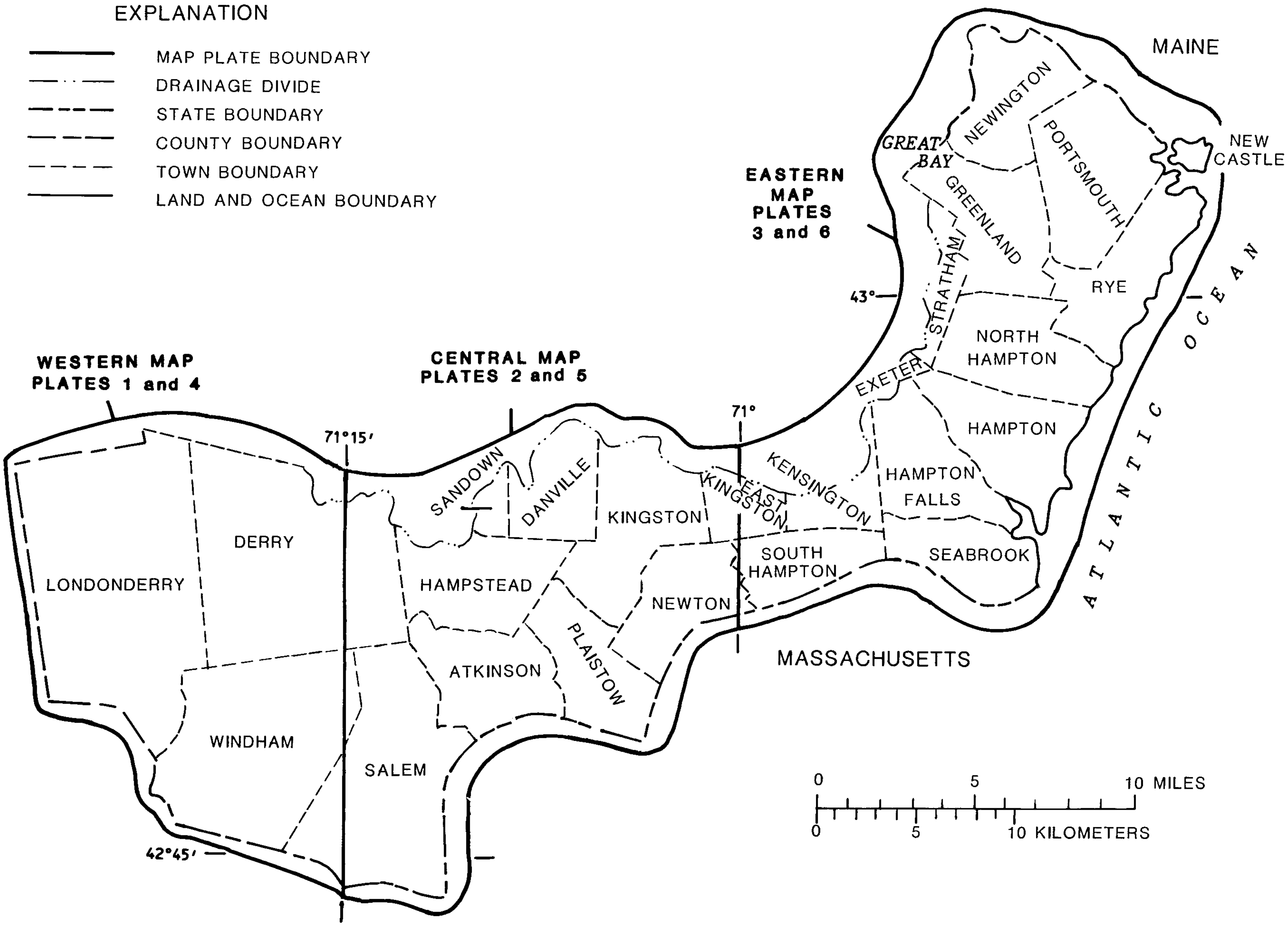


Figure 2.--Western, central, and eastern map plates of the lower Merrimack and coastal rivers basins.

Previous Investigations

Regional investigations include two basic-data reports for wells and springs in southeastern New Hampshire (Bradley and Peterson, 1962; Weigle and Kranes, 1966), an interpretive report on ground-water resources (Bradley, 1964), and an evaluation of water resources and the extent of ground-water contamination at a stratified-drift aquifer underlying Pease Air Force Base (Bradley, 1982).

Other studies on water resources and hazardous-waste sites from several towns have been done by private consultants and a State agency. Camp Dresser & McKee, Inc. (1966, 1973) assessed water resources in the town of Derry. NUS Corporation (1985, 1986) investigated ground-water contamination at a commercial repair garage in Londonderry and ground-water contamination at the Auburn Road Landfill in Londonderry. New Hampshire Water Supply and Pollution Control Division (NHWSPC) (1985a, 1985b) investigated ground-water contamination at the Coakley Landfill in North Hampton and ground-water contamination at the Duston Road area in Salem. Goldberg-Zoino and Associates (1986) investigated ground-water contamination at the Ottati and Goss site in Kingston. Roy F. Weston, Inc. (1986) investigated ground-water contamination at Pease Air Force Base in Portsmouth. Leggette, Brashears, & Graham, Inc. (1987) evaluated recharge areas to water-supply wells owned by the Hampton Water Works Company that service the towns of Hampton and North Hampton.

Previous maps of stratified-drift aquifers in southeastern New Hampshire by the USGS include reconnaissance maps at a scale of 1:125,000 for the lower Merrimack River basin (Cotton, 1977a) and the Piscataqua and other coastal river basins (Cotton, 1977b). Surficial-geology maps for parts of the study area are available through the Cooperative Geologic Mapping Program (COGEOMAP)--a cooperative program between various states and the Geologic Division of the USGS. For New Hampshire, the New Hampshire Department of Environmental Services, Office of the State Geologist, is the cooperator in this program.

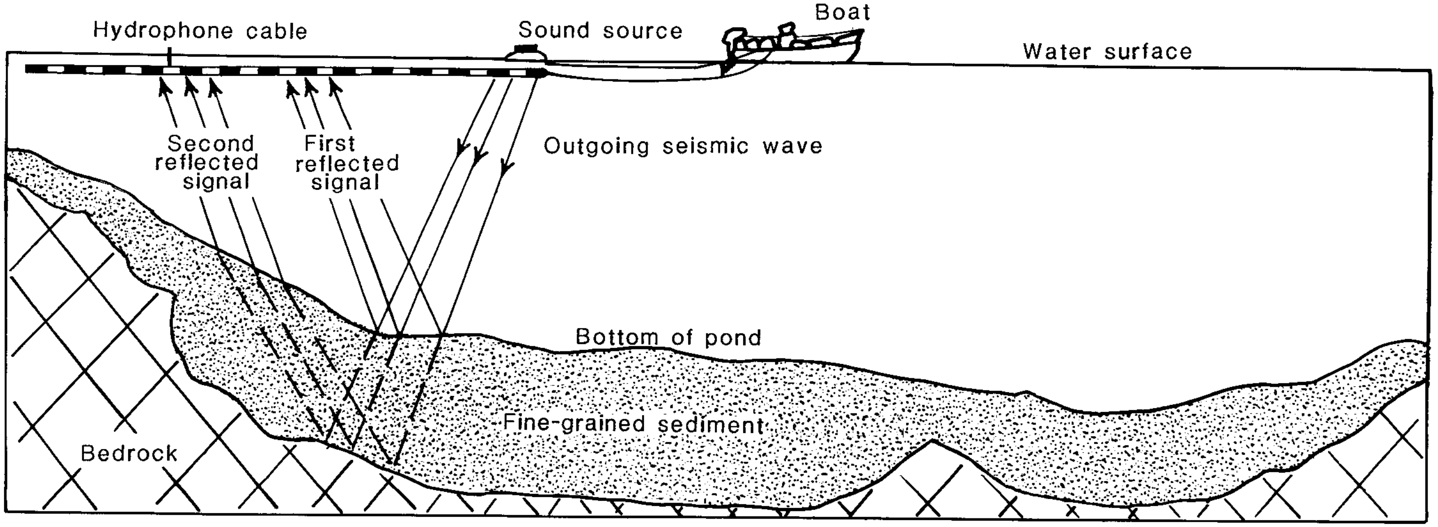
Approach and Methods

The areal extent of stratified-drift aquifers was delineated from published and unpublished surficial-geology maps provided by the COGEOMAP program and from lithologic data collected from auger holes. Available subsurface data on stratigraphy, saturated thickness, ground-water levels, and aquifer-test results were compiled. Data were obtained from published and unpublished sources of the U.S. Geological Survey, New Hampshire Department of Environmental Services, New Hampshire Department of Transportation, well-drilling contractors, towns, and local residents. Flanagan and Stekl (1990) have summarized data collected for this study.

Data points were plotted on base maps, and about 1,400 site entries were added to the Geological Survey's computerized Ground-Water Site Inventory (GWSI) data base. The GWSI data base allows retrievals for specific data requirements. For example, retrievals can be restricted to data for wells finished in a particular type of aquifer or wells from a specific geographical area. Each well is cross referenced to a well-identification number, latitude and longitude, original driller, and owner.

Seismic-refraction profiling, a surface geophysical method for subsurface exploration, was done at 49 sites (pls. 1-4) for a total distance of 10.0 mi to map depths to water table and bedrock and to estimate saturated thickness of aquifers. A 12-channel, signal-enhancement seismograph was used to record arrival times of refracted waves generated from the ignition of a two-component explosive (Haeni, 1986a). Altitudes of geophones and shot points on each seismic line were determined by leveling to a common datum. Seismic data were interpreted with a computer program (Scott and others, 1972) that incorporates time delay and ray-tracing methods. Data from nearby test holes were used to verify the results of the computer-generated profiles.

Continuous seismic-reflection profiling--a geophysical method for investigating stratigraphy below surface-water bodies--was done at Cobbetts and Island Ponds (pls. 1 and 2). The profiles aid in mapping fine and coarse-grained layers in the aquifer, the continuity of the aquifer, and depth to bedrock (Haeni, 1986b). Seismic-reflection profiles are generated by towing a displacement-type sound source and a hydrophone streamer across the water surface at a constant speed and monitoring the reflected signal (fig. 3). Sound energy generated from the sound source travels through the water column as outgoing seismic waves and into the subbottom materials. This energy or seismic wave is sensitive to changes in the acoustic impedance of the underlying stratigraphic units and is reflected back to the surface (Haeni, 1986b). Acoustic impedance



Not to scale

Figure 3.--High-resolution, continuous seismic-reflection-profiling system.

of stratigraphic layers is a product of a material's density and the velocity at which sound travels through that material. The reflected signals return to the hydrophones at the water surface and are then filtered, amplified, and displayed graphically on the chart recorder to allow interpretation of aquifer stratigraphy and bedrock depths. Lithologic data from nearby wells and test holes were used as control points to check the interpretation of the reflection profiles.

Test drilling was done at 66 locations (pls. 1-3) to determine sediment grain size, stratigraphy, depth to water table, depth to bedrock, and ground-water quality. A 6-inch-diameter, hollow-stem auger was used for test drilling. Split-spoon samples of subsurface materials collected at specific depths were used to evaluate the grain-size characteristics and identify the stratigraphic sequence of materials comprising the aquifers. Thirty-eight test holes cased with a 2-inch-diameter polyvinyl-chloride (PVC) pipe and slotted screens were used to make ground-water-level measurements and collect ground-water-quality samples.

Surface-water-discharge measurements were made at 16 sites during low flow when the surface water is primarily ground-water discharge. These low-flow measurements indicate quantities of ground water potentially available from aquifers.

Hydraulic conductivities of aquifer materials were estimated from grain-size-distribution data from 61 samples of stratified drift. Transmissivity was estimated from well logs by assigning hydraulic conductivity to specific well-log intervals, multiplying by the saturated thickness of the interval, and summing the results. Additional transmissivity values were obtained from an analysis of specific-capacity and aquifer-test data.

Long-term aquifer yields and contributing areas to hypothetical supply wells were estimated by application of a method that is analogous to superposition and incorporates a ground-water-flow model developed by McDonald and Harbaugh (1988). This method was applied to two aquifers judged to have the best potential for providing additional ground-water supplies.

Samples of ground water from 26 test wells and 4 municipal wells were collected in March and August 1987 for analysis of common inorganic, organic, and volatile organic constituents. Methods for collecting and analyzing the samples are described by Fishman and Freidman (1989). The water-quality results from the well samples were used to characterize background water quality in the stratified-drift aquifers.

Numbering System for Wells, Test Holes, and Springs

Numbers assigned by the USGS to wells, test holes, and springs consist of a two-character town designation (table 1), a supplemental letter designation ("A" for test holes done for geohydrologic purposes with no casing set, "B" for test holes done primarily for constructional purposes, "S" for springs, and "W" for all wells with a casing set), and a sequential number within each town. For example, the first well in the town of Atkinson is ARW-1.

Acknowledgments

The authors wish to express appreciation to State and municipal officials, well drillers, consulting engineers, and residents of the area who provided useful information and granted access to their properties. The authors gratefully acknowledge the interest and support extended by the staff of the Rockingham Planning Commission.

GEOLOGIC SETTING

Bedrock

Metamorphic rocks of sedimentary and volcanic origin underlie the lower Merrimack River basin at depths of 0 to 120 ft. The regional structural pattern has a northeast-southwest trend and is defined by three major tectonic features: the Massabesic anticlinorium along the western boundary; the Merrimack trough, which occupies most of the basin; and the Rye anticlinorium, which extends along the coastal boundary and includes towns from Portsmouth to Hampton (Lyons and others, 1982).

The Rye Gneiss of Precambrian age contains the oldest rocks in southeastern New Hampshire and most commonly consists of coarse-grained gneiss, quartzites, and schists. The metamorphic rocks of these formations are intruded by small lenticular bodies of granite, pegmatite, and diabase aligned parallel to the regional structural trend (Billings, 1956). The Merrimack Group of pre-Silurian age underlies most of the study area and is divided into the

Table 1.--*Two-character town codes used as prefixes in the numbering system for wells, test holes, and springs*

Town	Code	Town	Code
		New Hampshire	
Atkinson	AR	Newington	NI
Danville	DC	Newton	NQ
Derry	DF	North Hampton	NS
East Kingston	EA	Plaistow	PW
Exeter	EX	Portsmouth	PX
Greenland	GT	Rye	RY
Hampton	HE	Salem	SA
Hampton Falls	HF	Sandown	SD
Hampstead	HD	Seabrook	SG
Kensington	KF	South Hampton	SL
Kingston	KT	Stratham	SS
Londonderry	LR	Windham	WP
New Castle	NE		
		Massachusetts	
Merrimac	MR	Salisbury	SB

Kittery, Eliot, and Berwick Formations[1] (Lyons and others, 1986). The Merrimack Group consists of schists, calc-silicate rocks, and quartzites, and the grade of metamorphism increases irregularly from east to west toward the Massabesic anticlinorium, which extends from about the western town border of Londonderry to the Seacoast (Lyons and others, 1982).

All formations are folded and faulted. Large faults are oriented parallel to the regional northeast-southwest strike of the bedrock. The Portsmouth fault is one of the large faults and forms the Rye-Gneiss Kittery-Formation contact for about 9 mi (Novotny, 1969). Smaller faults strike northwesterly, cut across the regional structural grain, and do not dislocate rocks more than a few tens of feet.

Surficial Deposits

The surficial deposits are characteristic of the two physiographic provinces in the study area: the coastal lowlands, which include the area east of the Spicket River drainage basin, and the southeastern New Hampshire uplands, which include the Spicket basin and areas farther west. Topography east of the Spicket River drainage basin is generally less than 200 ft above sea level; the area is largely a broad flat coastal plain underlain by unconsolidated glacial and marine deposits. Except in some high hills, surficial deposits in this area were affected by marine inundation and beach processes that reworked older glacial deposits. Unique to this region are zones of coarse-grained glacial drift that underlie fine-

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[1] The stratigraphic nomenclature of bedrock units used in this report is that of the New Hampshire Geological Survey (Lyons and others, 1986) and does not necessarily follow usage of the U.S. Geological Survey.

grained marine deposits in some localities. Where this stratigraphic relation is present and the underlying coarse-grained deposits are thick, confined aquifers have the potential to supply large quantities of ground water. In contrast, the uplands to the west have high ridges, steep slopes, and distinct valley walls incised in bedrock. Marine deposits are absent, and the shape of the bedrock surface is the primary control on the distribution of glacial sediments.

Till, stratified drift, and marine deposits primarily comprise the surficial deposits in the study area. These deposits, which control the storage and movement of ground water in the subbasins of the study, are discussed in the context of their geologic origin (fig. 4).

Unconsolidated deposits of Pleistocene and Holocene age cover the bedrock throughout most of southeastern New Hampshire. During late Wisconsin time in the Pleistocene Epoch (approximately 13,000 to 20,000 years ago) the entire region was covered by a vast continental glacier (Boudette, 1990). As the glacier advanced and its front melted, a fairly continuous blanket of unsorted material, called till, was spread over the bedrock.

Proglacial stratified-drift deposits were formed when meltwater flowing in channels or tunnels, next to or under the ice, transported sediment derived from till or from melting ice to sites of deposition near or beyond the ice margin. Stratified drift deposited against or on top of melting ice formed ice-contact deposits. As the ice sheet melted, sea level rose in relation to the land surface and flooded part of the present coastal area. Sand, silt, and clay were deposited in large estuaries or bays similar to present-day Great Bay and the Piscataqua River. Since deglaciation, the land uplifted and sea level retreated to its current position. The sand, silt, and clay sediments are marine deposits as indicated by marine fossils found in sediment exposures. The fine-grained marine deposits partly cover ice-contact deposits, till, or bedrock.

Ice was probably near the coast when the sea flooded part of coastal New Hampshire. The ice continued to melt and supplied outwash, which graded to the level of shore deposits in the flooded areas.

Till is the predominant surficial material and covers 55 percent of the study area. Till--an unsorted, unstratified mixture of rock fragments--consists of particles ranging in size from clay to boulders and is present either as basal till (debris deposited beneath the ice and compressed by its weight) or as ablation till (debris entrained within the ice and, as the ice melted, deposited by processes that involve repeated mudflows and sorting by meltwater). Most basal till has an oriented fabric and is fine-grained, compact, and fissile. The thickness of basal till ranges from 0 to 15 ft, but is much thicker in streamlined elongate ridges, termed drumlins. Examples of drumlins are found in Kensington and South Hampton. The thickness of till in one drumlin in Kensington exceeds 220 ft. Ablation till has more sand and is less compact than basal till, lacks fissility or consistent fabric, and contains lenses of silt, sand, or gravel. This till is found everywhere in the upland areas and coastal lowland ridges and probably averages about 40 ft in thickness.

Glaciofluvial and glaciolacustrine stratified drift cover 24 percent of the study area. Glaciofluvial stratified drift consists of sorted, stratified sand and gravel deposited by glacial meltwater streams. Glaciolacustrine drift is also found and consists of well-sorted, stratified, and commonly laminated fine sand, silt, and clay deposits formed in the standing water of lakes and ponds. An example of these glaciolacustrine deposits are the laminated couplets of silt and clay, as much as 60 ft thick, beneath the bottom of Island Pond in the town of Derry.

Glaciofluvial and glaciolacustrine stratified drift can be grouped into two broad genetic types--ice-contact and proglacial stratified drift--which are distinguished by the abundance of stagnant or detached ice in the original depositional environment. Ice-contact stratified drift consists of sediment deposited on or against decaying ice. Proglacial stratified drift is deposited by or in meltwater beyond the margin of a glacier. Generally, sorting and texture among sands and gravels is more uniform in a proglacial environment than in an ice-contact environment. Sand and gravel deposited in an ice-contact position commonly contains interbedded thick lenses of silt and fine sand, which were deposited in quiet parts of the temporary lakes near stagnant ice. The thickness of ice-contact deposits in the study area ranges from 0 to 80 ft.

Many prominent topographic features among the lowlands of the basin are composed of ice-contact and proglacial stratified drift that can be further classified on the basis of the landform in which they occur. Landforms composed of ice-contact glaciofluvial stratified drift include ice-channel fillings, kame plains, kame terraces, and kame deltas. Characteristic features are ice-contact slopes, collapsed surfaces, and kettles that formed in the deposits as the supporting ice melted away.

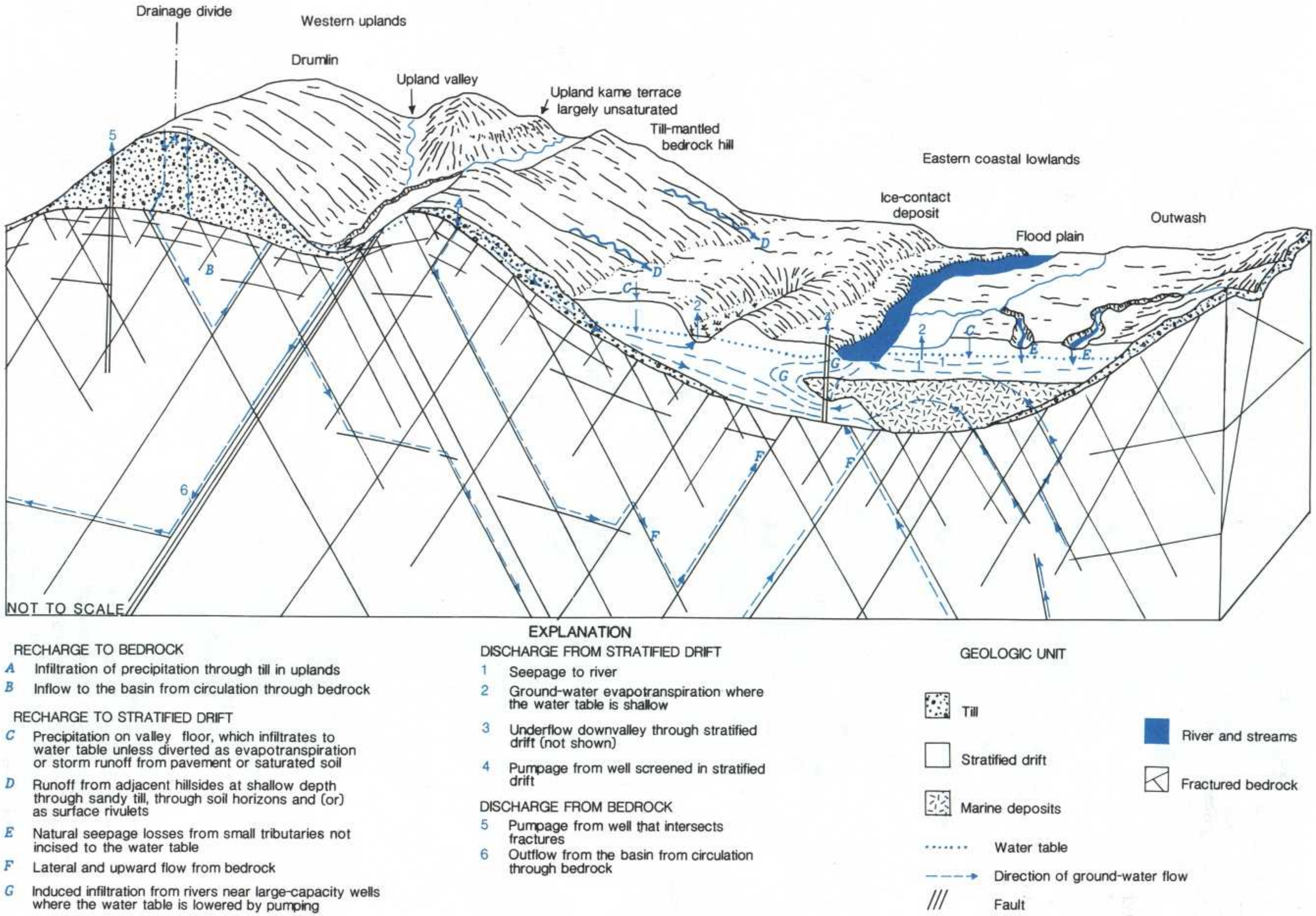

Figure 4.--Idealized geohydrologic block diagram showing distribution of geologic units and ground-water flow (Modified from Randall and others, 1988a, fig. 1).

Ice-channel fillings are linear ridges of sand and gravel deposited in meltwater streams confined by stagnant ice. Eskers are generally a curvilinear type of ice-channel filling deposited in confined tunnels in or under the ice. The largest ice-channel filling, in the town of Plaistow, is a linear southeast-trending ridge about 5.5 mi long with occasional breaks caused by sand and gravel mining and postglacial erosion. The shape and orientation of the ridge indicates deposition between stagnating tongues of ice or in a large fracture in the ice (crevasse). Kame terraces--flat-topped masses of sand and gravel deposited by meltwater between a receding or stagnant ice tongue and the valley wall--are present in the western section. The entire thickness of many kame terraces is above the grade of modern streams; therefore, the bulk of the sand and gravel is unsaturated. Kame deltas typically have a flat-topped triangular shape and were built onto or against glacial ice. These deltas are the most widespread landforms of stratified drift in the eastern section. Most of the deltas in the area graded to estuaries or open marine waters. Foreset beds of the deltas are commonly well-sorted sands that are transitional downslope to silts and clays of marine origin. Locally, these deposits have been modified by beach processes.

Landforms composed of proglacial stratified drift in the area include valley trains and outwash plains. A valley train consists of stratified drift that fills a valley from wall to wall and was formed by the deposition of sediment-laden meltwater draining from a glacier upvalley (Flint, 1971). The most extensive valley train is in the Beaver Brook valley. Although large in area, this valley train is less than 40 ft thick, and numerous interbedded layers of silt interrupt the vertical continuity of sand and gravel.

Outwash plains are similar to valley trains but are not confined by valley walls. They are the largest landforms of stratified drift in the study area and are generally thicker and more extensive inland than on the coast. Outwash deposits are finer textured and better sorted, as a result of their distance of transport, than ice-contact deposits. Outwash deposits consist primarily of loose medium- or fine-grained sand but include some fine and coarse materials. The deposits become fine grained downward, often grading into marine and estuarine deposits. An extensive outwash plain locally reworked by beach processes is found in Kingston and Newton where thick deposits of sand and gravel exceed 120 ft in places.

Marine deposits cover 21 percent of the surface and are found only in the eastern section. (This percentage refers to those parts where marine deposits are actually at the surface or overlain by outwash or beach deposits too thin to map or analyze.) They consist of fine-grained sand, silt, and clay deposited in shallow estuaries and tidal areas during the later stages of deglaciation when sea level rose and much of the valleys and lowlands was inundated. Thin outwash and beach deposits typically overlie the fine-grained marine deposits in the eastern part. In some areas, marine deposits, up to 90 ft thick, overlie permeable ice-contact deposits and act as confining layers.

GEOHYDROLOGIC SETTING

Occurrence of Ground Water

Water occurs beneath the land surface in two different zones. In the upper or unsaturated zone, which usually extends from a few inches to several tens of feet below the land surface, the openings are filled with air and water. In the lower or saturated zone, the interconnected openings contain only water. The surface that divides these two zones is the water table. The water table rises when recharge exceeds the sum of withdrawal, discharge to streams, and evapotranspiration from the saturated zone, and declines when the converse is true. In general, the water table is a subdued replica of the land surface; however, it commonly is deepest beneath hills and is at or near the surface in the lowlands.

Lithology also controls the configuration and fluctuation of the water table. For example, in upland or lowland till, the water table is at or within a few feet of the land surface every spring but declines considerably during dry summers. In coarse-grained stratified drift, the water table slopes gently toward streams regardless of the season or topographic irregularities and tends to be slightly above the grade of the nearest perennial stream. At many eskers, kame terraces, and kame deltas that form ridges, depths to water can be several tens of feet. In areas where outwash overlies lacustrine or marine deposits, the topography is low and flat, the water table is typically several feet above the top of the fine-grained sediments if they are above stream grade.

Ground water is present in unconfined and confined aquifers in the study area. Where water partially fills the aquifer and the upper surface of the saturated zone is at atmospheric pressure, ground water is unconfined. The most extensive aquifers in the study area are unconfined. Ground water is commonly confined under hydrostatic pressure in the eastern part where stratified-drift and bedrock aquifers are locally buried beneath relatively impermeable silt and clay. Examples of high-yield wells that produce water from confined aquifers are the Sherburne well in Portsmouth (PXW-4) and gravel-pack wells 3 (SGW-44) and 4 (SGW-65) in Seabrook (table 2).

Water levels in wells finished in the unconfined aquifers will rise to the water table and fluctuate slowly as the volume of stored water changes. In contrast, ground water in confined aquifers is under hydrostatic pressure and water levels in wells will rise above the top of the aquifer (fig. 5).

General Description and Water-Yielding Characteristics of the Lithologic Units

The lower Merrimack and Coastal River basins are underlain by three general types of geologic units that can yield useable quantities of water to properly constructed wells and, therefore, can be considered aquifers: stratified drift, till, and crystalline bedrock. These geologic units, however, differ greatly in their ability to store and transmit water.

Stratified Drift

Stratified-drift deposits constitute the most extensive and productive aquifer in the region. Currently, 79 percent of ground water withdrawn from high-capacity wells in the basin is pumped from wells screened in the stratified-drift aquifer. Towns served by high-yield, gravel-packed wells finished in the stratified-drift aquifer include Hampton, North Hampton, Portsmouth, Rye, and Seabrook (table 2). The maximum well yield from 19 gravel-packed wells averages 377 gal/min and ranges from 125 to 900 gal/min. The yield from gravel-packed wells represents maximum yield for the well technology used at each site; therefore, the yields of these wells (table 2) are useful approximations of the withdrawal rates that can be expected from the aquifers.

The most productive high-yield stratified-drift deposits are ice-contact and proglacial (valley train and outwash) deposits. Ice-contact deposits exhibit abrupt changes in stratification and grain size that cause large variations in the water-bearing characteristics of the deposits. Ice-contact sediments are deposited in sequences that are graded to a particular base level--generally thickest near the ice-contact slope, and thinnest and interrupted by bedrock outcrops near the till contact. The proximal end of a sequence is characterized by poorly sorted and poorly stratified deposits containing lenses of till (flow till) that form the ice-contact faces of kame terraces, kame deltas, and heads of outwash. These features commonly supply small amounts of water to wells because of the poorly sorted materials and the absence of thick saturated intervals.

An example of the head of outwash is found between 140 and 150 ft elevation, in the town of Newton less than 1,000 ft southeast of the intersection between Amesbury and Bear Hill Roads (pl. 2). Much of this ridge of stratified drift is unsaturated and consists of very poorly sorted pebble-cobble-gravel material that has a low water-bearing capacity. The distal end of the sequences is characterized by well-stratified, moderately well-sorted deposits that comprise most of the ice contact and (or) proglacial landform. These deposits of well-sorted sand and gravel allow rapid flow of ground water and are capable of large well yields where the saturated interval is sufficiently thick. Examples of these deposits are the kame plain near Route 1 north of the town of Hampton (pl. 3) and the kame delta that underlies Pease Air Force Base in the town of Newington (pl. 3). Both aquifers serve as primary sources of the public water supply.

In some areas, fine-grained marine deposits overlie ice-contact deposits or overlap the perimeters of such deposits. For example, the Sherburne well in Portsmouth is drilled to a depth of 50 ft into a confined aquifer. The top 20 ft consists of silt and clay of marine origin that form a confining layer and the bottom 30 ft consists of highly permeable sand and gravel that forms the productive zone in a confined aquifer. Because of the confinement by marine deposits, recharge to the ice-contact deposits from precipitation and runoff is greatly reduced.

Maximum thickness of ice-contact deposits inferred from seismic data is 100 ft and from well logs is 78 ft; well yields range from 3 to 900 gal/min.

Proglacial deposits comprising valley trains and outwash plains are generally finer grained, more homogeneous, and better sorted than ice-contact deposits, and consist primarily of sand with small amounts of gravel and silt. Many of the valley trains, in the western part of the study area, have well-sorted sand interbedded with layers of silt and clay that formed from temporary glacial ponds that occupied the valleys. Gravel-packed wells developed

Table 2.--Maximum well yields for major water-supply wells

[ft, feet; gal/min, gallons per minute; --, no data available; User: SNHWC, Southern New Hampshire Water Company; DPW, Department of Public Works; HWWC, Hampton Water Works Company; AFB, Air Force Base. Type of well: DVN, driven; GPW, gravel-packed well; BrW, open-hole bedrock well.]

Well identifier	Latitude	Longitude	User or owner	Other identifier	Type of well	Depth of well (ft)	Maximum well yield (gal/min)
DERRY							
DFW-79	42 52'19"	71 18'35"	SNHWC	Maple Hills	BrW	200-825	270 (3 wells)
GREENLAND							
GTW- 1	43 01'50"	70 49'46"	Portsmouth DPW	Greenland well #5	GPW	60	450
HAMPTON							
HEW- 3	42 57'27"	70 49'35"	HWWC	White's Field	GPW	50	400
HEW- 6	42 57'12"	70 49'38"	HWWC	Scammon	GPW	50	490
HEW- 7	42 56'30"	70 48'56"	HWWC	Ryder	GPW	45	350
HEW-24	42 57'21"	70 49'30"	HWWC	Sicard	GPW	63	625
LONDONDERRY							
LRW-144	42 53'03"	71 21'38"	SNHWC	Birchville	BrW	250-788	33.5 (5 wells)
LRW-145	42 53'54"	71 25'54"	SNHWC	Brook Park	BrW	150-620	29.6 (4 wells)
NEWINGTON							
NiW- 8	43 05'08"	70 50'45"	Pease AFB	MMS No. 2	BrW	170	29
NiW- 9	43 05'13"	70 50'41"	Pease AFB	MMS No. 1	BrW	130	28
NiW- 50	43 04'43"	70 51'29"	Pease AFB	Loomis well	BrW	300	15
NiW- 51	43 06'42"	70 49'01"	C.H.Sprague & Sons Co.	--	BrW	--	20.8 (2 wells)
NORTH HAMPTON							
NSW- 8	42 57'31"	70 49'24"	HWWC	Marston Springs	GPW	44	150
NSW- 27	43 00'05"	70 51'48"	HWWC	BRW #13	BrW	318	350
NSW- 31	43 00'09"	70 51'55"	HWWC	Coakley	GPW	55	200
NSW- 70	43 00'01"	70 51'43"	HWWC	Crenshaw	GPW	46	350
PORTSMOUTH							
PXW- 2	43 04'34"	70 49'13"	Pease AFB	Haven	GPW	66	900
PXW- 4	43 03'34"	70 47'22"	Portsmouth DPW	Sherburne	GPW	45	450
PXW- 5	43 03'26"	70 47'53"	Portsmouth DPW	Portsmouth well #1	GPW	63	350
PXW- 47	43 03'56"	70 48'19"	Pease AFB	Harrison	GPW	46.3	150
PXW- 49	43 03'34"	70 48'24"	Pease AFB	Smith	GPW	67	430

Table 2.--Maximum well yields for major water-supply wells--Continued

Well no.	Latitude	Longitude	User or owner	Other identifier	Type of well	Depth of well (ft)	Maximum well yield (gal/min)
				RYE			
RYW- 12	42 59′27″	70 46′23″	HWWC	Jeness Beach	GPW	21	125
RYW- 38	42 59′53″	70 47′17″	Rye Water Dist.	Garland	GPW	49	400
RYW- 45	42 59′41″	70 47′18″	Rye Water Dist.	BRW #5A	BrW	500	260
				SALEM			
SAW-207	42 45′34″	71 14′43″	BCI Inc., Salem DPW	Turner	BrW	460	416
SAW-208	42 46′23″	71 15′29″	BCI Inc., Salem DPW	Donigan	BrW	250	240
				SEABROOK			
SGW- 1	42 53′37″	70 54′47″	Seabrook DPW	GPW #1	GPW	54	350
SGW- 2	42 53′37″	70 54′51″	Seabrook DPW	GPW #2	GPW	49	250
SGW- 44	42 53′15″	70 54′07″	Seabrook DPW	GPW #3	GPW	98	350
SGW- 65	42 53′12″	70 53′59″	Seabrook DPW	GPW #4	GPW	83	400
SGW- 89	42 54′17″	70 54′59″	Seabrook DPW	Brw #1	BrW	500	200
SGW- 90	42 54′20″	70 54′53″	Seabrook DPW	BrW #2	BrW	500	350
SGW- 91	42 54′21″	70 54′59″	Seabrook DPW	BrW #3	BrW	500	500
SGW- 92	42 53′59″	70 54′54″	Seabrook DPW	BrW #4	BrW	400	305
				WINDHAM			
WPW-273	42 48′00″	71 16′01″	SNHWC	W.& E.	BrW	345-941	90 (2 wells)
WPW-274	42 46′20″	71 18′39″	SNHWC	Golden Brook	DVN	46	100 (2 wells)

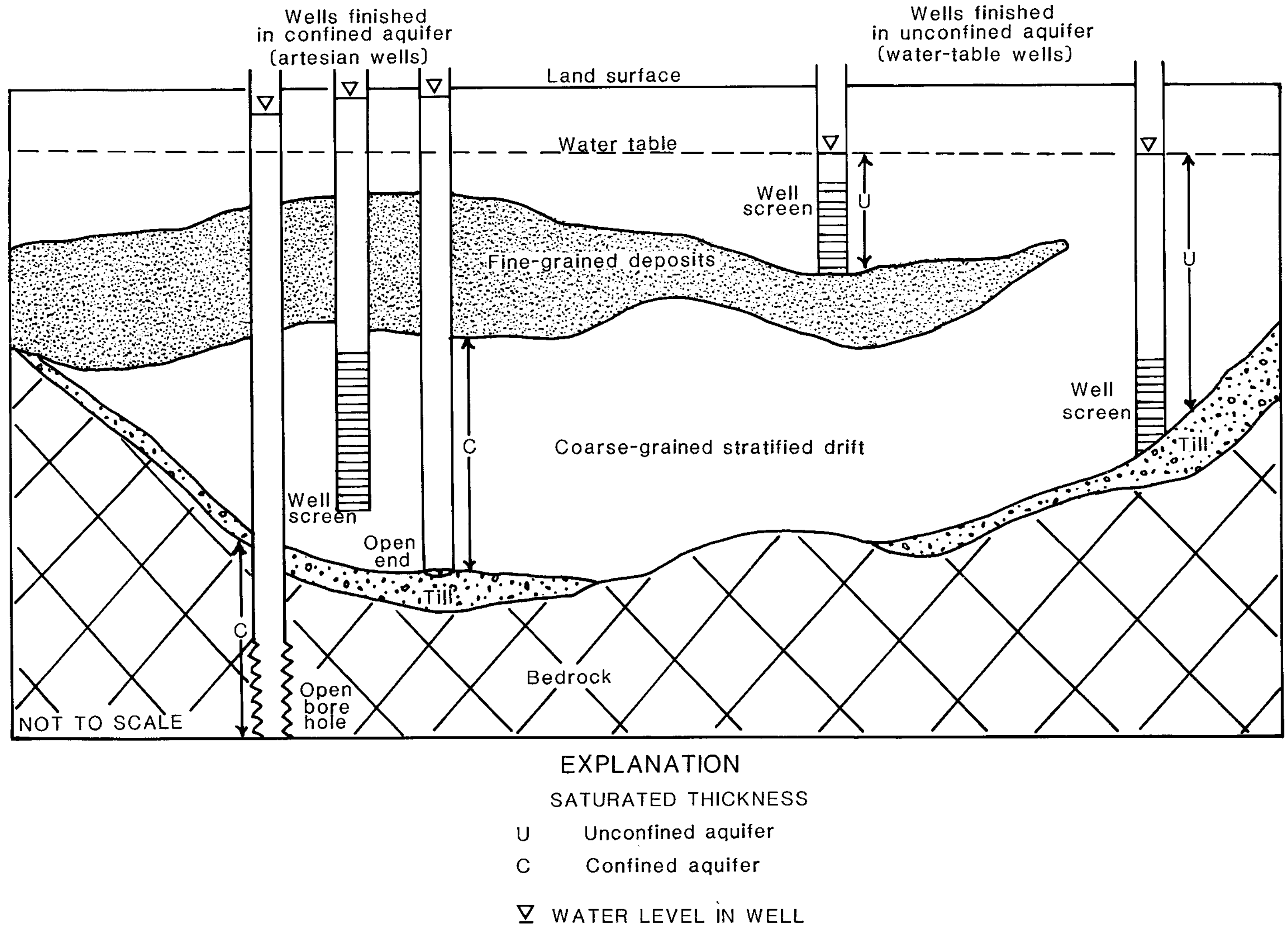

Figure 5.--Idealized geohydrologic section showing unconfined and confined aquifers.

in these deposits yield as much as 300 gal/min; however, where coarse sand and gravel overlie thicker deposits of fine-grained sand, silt, and clay, less than 300 gal/min is expected. Toward the coast, proglacial deposits thin, probably because the marine waters they were deposited in became progressively shallower as relative sea level declined and marine sediments accumulated. Thinning of deposits also occurred with the retreat of the ice sheet northward.

Outwash in the basin contains generally well-sorted, coarse-grained deposits with large pore spaces. In many places, a veneer of outwash deposits overlies thick marine deposits; these outwash deposits form a thin aquifer with small storage capacity. Where outwash deposits have a large saturated thickness, properly constructed, gravel-packed wells have large yields. Maximum thickness of these deposits is in the outwash plain at Kingston. Maximum depth to bedrock, determined by seismic-refraction, is about 120 ft and, from well logs, is 90 ft. Currently, high-capacity production wells have not been drilled in this deposit.

Till

Till consists of a mixture of grain sizes ranging from clay to boulders. Because it is dense and contains a large proportion of fine-grained particles, till is considered a poor aquifer and normally will not yield enough water to meet municipal, industrial, or commercial needs. Historically, large-diameter wells dug in till have provided water for domestic and agricultural use, but these wells are shallow (less than 30 ft deep) and generally yield only a few gallons per minute. Many wells fail to meet current demands during dry summers when the water table lowers and water storage decreases. Layers or lenses of stratified sand and gravel are present at places in ablation till and, where these layers are saturated, more reliable long-term well yields can be expected. In contrast, basal till is more compact and denser than ablation till and produces a smaller water yield. Because the yield from the till aquifer is seasonally inadequate to meet modern domestic demands, the trend is toward the drilling of bedrock wells.

Bedrock

All rocks in the study area have been subjected to uplift, weathering, and erosion, which have resulted in the widening of fractures and the formation of new openings, such as stress-relief fractures. These breaks in the otherwise solid rock are the conduits for ground-water flow and control both the movement and storage capacity of water in bedrock. Storage capacity is generally small because the fractures are narrow and widely spaced. The orientation, width, and number of water-bearing fractures also differs from place to place, making systematic exploration for large production wells difficult. If two wells are adjacent to each other, different fractures may be intersected. As a result, one well may yield an ample supply of water at depth, whereas the other, even though drilled to a lesser depth than the first, may yield a comparatively small supply. For the most part, however, crystalline bedrock is a reliable source of water for both domestic and municipal supplies.

Information from 94 bedrock wells drilled in the towns of Greenland, Newington, and Portsmouth (Stewart, 1968) indicate that the average well drilled is a domestic well 118 ft deep, up to 6 in. in diameter, and yielding 13 gal/min. On the basis of these and similar data collected from drillings in New England, the following assumptions were made: crystalline rocks generally yield only small amounts of water to wells and water is obtained from vertical fractures that typically pinch out at a depth of 300 ft because of lithostatic pressure (Hodges, 1969).

Data collected for this study from recent drillings of bedrock municipal wells, however, indicate that the crystalline bedrock aquifer beneath the region can sustain high yields to properly located wells. The maximum yield from eight bedrock municipal water-supply wells ranges from 200 to 500 gal/min and averages 328 gal/min (table 2). All but one of these high-capacity bedrock wells exceeds 300 ft in depth, and all exceed 8 in. in diameter. In each of these wells, maximum yields were obtained by drilling to greater depths than previously thought necessary. The rate of ground-water withdrawal from bedrock municipal wells is estimated to be 1.6 Mgal/d--a rate equal to 21 percent of the ground water pumped from all public-water-supply wells in the study area. The largest quantities of recoverable water are found where the bedrock is extensively fractured or brecciated as a result of the intersection of several fractures and (or) faults (Daniel, 1987).

The brecciated zones associated with the northeast- and northwest-trending faults are potential areas for providing above-average well yields. Although the locations of several large northeast-trending faults have been shown on bedrock geology maps (Billings, 1956; Novotny, 1969; Lyons and others, 1986), additional information on the structural fabric of the bedrock is necessary to prospect for large yields from bedrock aquifers.