HYDROGEOLOGY OF STRATIFIED-DRIFT AQUIFERS AND WATER QUALITY IN THE NASHUA REGIONAL PLANNING COMMISSION AREA SOUTH-CENTRAL NEW HAMPSHIRE

By Kenneth W. Toppin

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per seccond per square mile [$(ft^3/s)/mi^2$]	10.93	liter per second per kilometer [$(L/s)/km^2$]
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
inch (in.)	25.4	millimeter (mm)
	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
square mile (mi^2)	2.59	square kilometer (km^2)

National Geodetic Vertical Datum (NGVD) of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

Chemical concentrations are given as International System Units, in milligrams per liter.

Hydrogeology of Stratified-Drift Aquifers and Water Quality in the Nashua Regional Planning Commission Area, South-Central New Hampshire

By Kenneth W. Toppin

ABSTRACT

The Nashua Regional Planning Commission area in south-central New Hampshire is a 12-community area that is experiencing increased demands for water supply because of increases in population. The study area is underlain by 129 square miles (40 percent of the area) of stratified drift which, where sufficiently saturated and permeable, form the most productive aquifers in the area. At present, eight towns use the stratified-drift aquifers for municipal water supply.

The saturated thickness of stratified drift in the study area ranges from 0 or less than 20 feet near aquifer boundaries to more than 100 feet in the Souhegan and Merrimack River valleys. The transmissivity of stratified drift ranges from less than 2,000 ft^2/d (feet squared per day) throughout much of the area to more than 8,000 ft^2/d in the communities of Amherst, Brookline, Hollis, Hudson, Litchfield, Merrimack, Milford, Nashua, and Pelham. Directions of ground-water flow are generally from valley walls to surface waters, which act as drains for the stratified-drift aquifers.

At present, the estimated total yield of community water-supply systems in the study area (surface and ground water combined) is 22 Mgal/d (million gallons per day). Analytical modeling indicates that an additional 12 Mgal/d could be obtained from six aquifers located in the communities of Amherst, Litchfield, Merrimack, Milford, and Pelham. Other aquifers in the area, not modeled in this study, also could provide increased amounts of water especially where yields could be augmented by induced recharge of surface water.

Ground-water quality in the study area is characterized by naturally elevated levels of iron and manganese. Of 32 wells sampled, 7 exceeded USEPA (U.S. Environmental Protection Agency) recommended drinking-water limits for both iron and manganese, and 3 wells exceeded the manganese limit only. The average total dissolved-solids concentration for 32 samples was 121 mg/L (milligrams per liter). Ground water in the area is slightly corrosive; pH's ranged from 5.0-7.3.

Ground-water contamination has been detected at two USEPA "superfund" sites in the study area located in Milford and Nashua. At both sites, contamination of ground water has caused shutdown of municipal and private water-supply wells. The widespread effect of application of highway deicing chemicals on ground-water quality is reflected by sodium concentrations that average 24 mg/L throughout the study area. At 11 of 32 sites sampled, the USEPA recommended limit for sodium (20 mg/L) was exceeded.

INTRODUCTION

This report describes the hydrogeology of the Nashua Regional Planning Commission area (fig.1)--one of the most rapidly growing areas in New Hampshire and New England. The 12 communities in the Nashua planning area experienced a 37 percent growth rate from the 1970 to 1980 (U.S. Bureau of the Census, 1980). Part of the reason for this growth is that the F. E. Everett Turnpike, which provides a quick and easy access to points in eastern and central Massachusetts, passes through the center of the region.

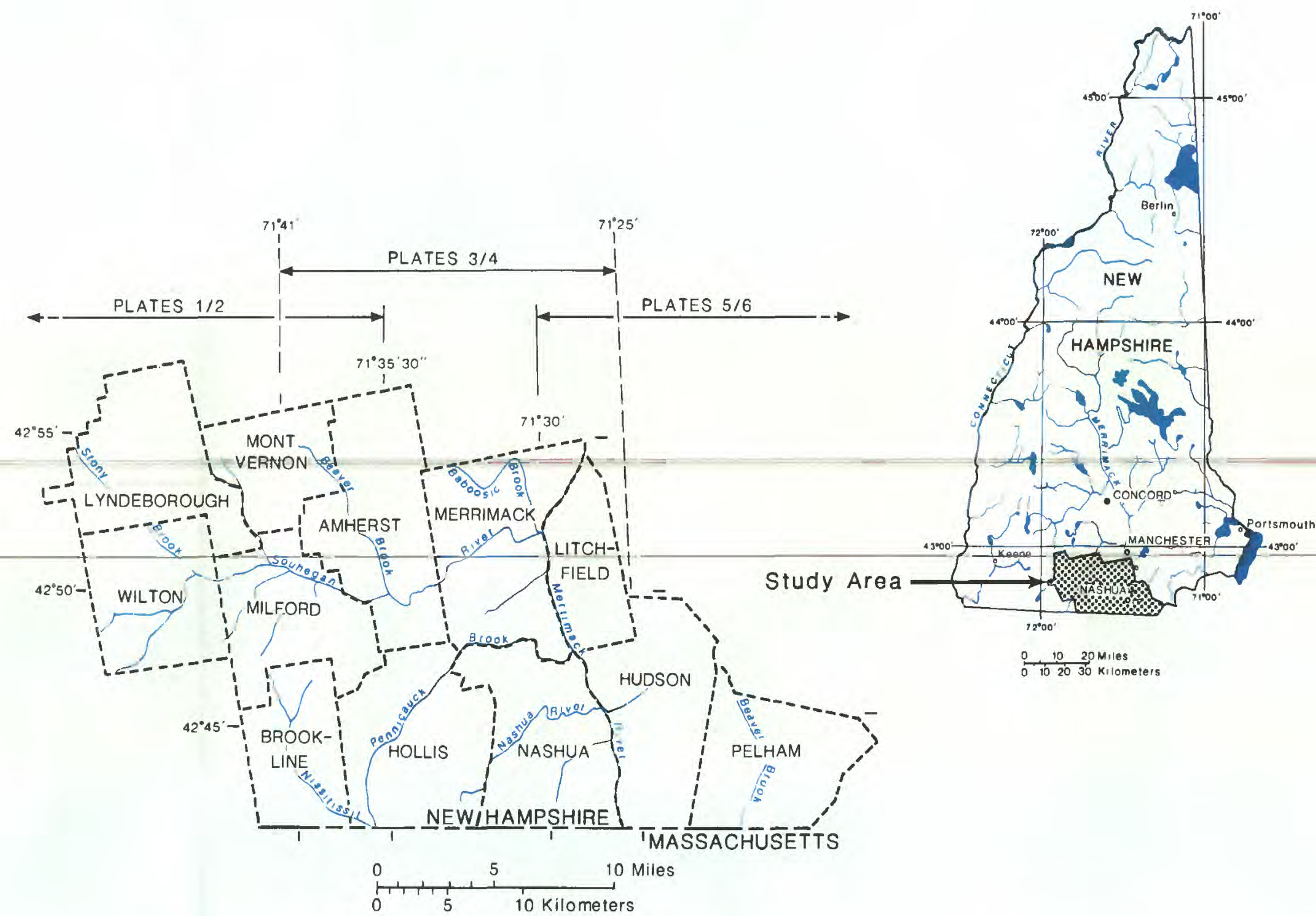

Figure 1.--Location of the Nashua Regional Planning Commission area in south-central New Hampshire.

Since the mid 1970's, the predominant water use in the area has changed from industrial to residential. Additionally, the present transition from heavy to light industry (computers and electronics) requires much less water than did the large industrial users of the past. However, a few large-volume industrial water users still remain.

Summary water-use information for community systems in the Nashua region (Nashua Regional Planning Commission, 1980) indicates daily water usage of 14 Mgal/d in 1980 as opposed to 12 Mgal/d in 1971. The estimated total yield of community systems after the 1980 national census was 22 Mgal/d, as opposed to 21 Mgal/d in 1970. Although industrial use during this 10-year period was down slightly, domestic use was up. Increased population, settling largely in areas beyond existing water systems, relies primarily on private wells for water. Projected total water-use figures for 1985 and 2000 are, respectively, 26.5 and 53.7 Mgal/d (Nashua Regional Planning Commission, 1980).

Approximately 40 percent of the total Nashua Regional Planning Commission area population lives in the city of Nashua. Nashua is the second largest city in New Hampshire and is areally the fourth largest community within the project area (Howard and others, 1973). The most populated part of the city is clustered along the Merrimack and the Nashua Rivers, immediately above an extensive sand and gravel aquifer.

Ground water comprises 70 percent of the total water used in the area and 50 percent of the water used for industrial purposes (Nashua Regional Planning Commission, 1982). The city of Nashua and the town of Wilton depend primarily upon surface water for their municipal supplies. Wilton recently has conducted a detailed assessment of part of its ground-water resources to augment the capacity of the existing surface-water supply.

Communities in the study area with public-supply wells completed in stratified-drift aquifers include Amherst, Hollis, Hudson, Litchfield, Merrimack, Milford, Nashua, and Pelham. The towns of Brookline, Lyndeborough, and Mont Vernon, have no municipal systems and are served by privately owned dug, driven, or drilled wells. Communities with municipal supply systems that are operating at or close to current system capacity are Amherst, Litchfield, Milford, and Wilton.

Tremendous increases in residential and industrial development in the Nashua region in the last 10 years have caused a large increase in the demand for water; this development also threatens ground-water quality. Contamination of aquifers from organic chemicals and subsequent shutdown of several municipal water wells have made the public more aware of the need to identify and protect the water resources of the area. To adequately protect the ground-water resources of the area, local and State planning officials need up-to-date information on the location and extent of aquifers in the region.

Purpose and Scope

This report describes the results of a study to define the hydrogeologic characteristics of the stratified-drift aquifers of the Nashua area by (1) identifying the areal extent, saturated thickness and transmissivity of the aquifers, (2) indicating general directions of ground water flow within the aquifers, and (3) predicting aquifer yields for selected aquifers under long-term pumping conditions. The report also describes the general quality of surface and ground waters in the area. The scope of this investigation is limited to the study of stratified-drift aquifers. Emphasis is placed on aquifers that have not been heavily developed, consist of highly permeable materials, are of large areal extent, and are thickly saturated. Future large-scale municipal water supplies could potentially be obtained from this type of aquifer. Lesser emphasis is placed upon the thinly saturated, less permeable, more heavily developed aquifers of small areal extent, although many of these areas are adequate sources of water to individual households. Selected aquifers were modeled to illustrate how the geohydrologic data from this study can be used to predict aquifer yields under long-term pumping conditions.

Study Area

The Nashua Regional Planning Commission area encompasses 322 mi^2 in south-central New Hampshire and includes Amherst, Brookline, Hollis, Lyndeborough, Merrimack, Milford, Mont Vernon, Nashua, and Wilton to the west of the Merrimack River and Hudson, Litchfield, and Pelham to the east.

Surface-water drainage is to the Merrimack River, which flows generally southward through the center of the region; major tributaries are the Souhegan River, which flows eastward into the

Merrimack River; and the Nashua River, which flows northeastward into the Merrimack River. Other significant streams in the study area include Beaver Brook in Amherst; Nissitissit River in Brookline and Hollis; Pennichuck Brook bounding Hollis, Nashua, and Merrimack; Baboosic Brook in Merrimack; and Beaver Brook in Pelham.

The Nashua region is predominantly hilly, the broadest valleys are primarily along the trunk of the Merrimack, Souhegan, and Nashua Rivers. The sand and gravel aquifers of the area are typically long and narrow valley-fill-type deposits, except for the broad outwash-plain deposits along the Merrimack River in the towns of Merrimack, Litchfield, Hudson, and Nashua.

Previous Investigations

Surficial geology of the area was mapped by Koteff (1970, 1976) for the Milford 15-minute and the Nashua North 7.5-minute quadrangles. Koteff and Volckmann (1973) mapped the surficial geology of the Pepperell 7.5-minute quadrangle. B. D. Stone (U.S. Geological Survey, written commun., 1971) mapped the surficial geology of the Manchester South 7.5-minute quadrangle east of the Merrimack River. Weigle (1963, 1968) and Cotton (1977) identified aquifers within the surficial deposits of the Nashua area favorable for ground-water development. Weigle and Kranes (1966) summarized records of selected wells, test holes, springs, physical and hydrologic tests on samples of unconsolidated materials, and chemical analysis of ground water in the lower Merrimack River Valley of New Hampshire. The U.S. Army Corps of Engineers (Anderson-Nichols and Co., Inc., 1980) evaluated safe yields of four stratified-drift aquifers in the towns of Pelham and Hudson.

Soil surveys of Hillsborough County were done by the U.S. Soil Conservation Service (1953; 1981; 1985). These surveys were utilized in the delineation of contacts between stratified drift and till/bedrock and for estimates of transmissivity in areas where there was little subsurface information.

Approach and Methods

The first phase of the investigation involved compilation of all available subsurface data. Information was obtained from well-drilling contractors, towns, the New Hampshire Water Supply and Pollution Control Commission, and the New Hampshire Department of Public Works and Highways. Data points were plotted on base maps, and all pertinent information (approximately 1,200 site entries) were added to the U.S. Geological Survey computerized GWSI (Ground Water Site Inventory) data base.

Test drilling was completed at 52 locations to define subsurface lithology and stratigraphy. Test holes were drilled with a 6-inch-diameter hollow-stem auger. Split-spoon samples of materials were collected at various depth intervals to identify the stratigraphic sequences of materials comprising the various aquifers. Test holes were cased with 2-inch-diameter polyvinyl chloride pipe and slotted screen to obtain water-level measurements and water-quality samples. Water-level measurements were obtained at all wells at least twice--once during late summer or early fall, when the water table was at or near the yearly low, and in the spring, when the water table was near the annual high.

Seismic-refraction geophysical profiling was completed at 22 locations within the study area, along traverses totaling 7.4 miles in length to map the depths to the water table and bedrock and to determine aquifer saturated thickness. The locations where seismic-refraction profiles were run are shown on plates 1, 3, and 5. A 12-channel, signal-enhancement seismograph was used to record arrival times of refracted waves. A two-component explosive was used for the sound source. Altitudes of geophones and shot points on each seismic line were leveled to a common datum. The seismic data were interpreted with a computer program developed by Scott and others (1972) that uses time delay and ray-tracing methods. Data from nearby test holes were used, where available, to verify the results of the seismic-profile interpretation.

The stratigraphic boundaries of the sand and gravel deposits and till or bedrock were determined in the field from mapping, test drilling and seismic-refraction profiling. Aquifer boundaries were defined on the basis of several studies, including those by Weigle (1968), Koteff (1970; 1976), Koteff and Volckmann (1973), and from Soil Conservation Service (1953; 1981; 1985) maps. The locations of the stratified-drift aquifer boundaries are shown on plates 1, 3, and 5.

Surface-water-discharge measurements were made at 43 sites throughout the study area during base-flow conditions when surface water is made up entirely of ground-water discharge. The low-flow measurements indicate quantities of water potentially available for induced recharge to pumping wells, as well as the natural discharge of ground water from aquifers.

Mathematical analytical models, based on the Theis nonequilibrium formula (1935), as modified by image-well theory (Ferris and others, 1962), were used to estimate long-term aquifer yields. The model used takes into account the effects of dewatering of the aquifer and well-construction characteristics (Mazzaferro and others, 1978). The model was applied to specific aquifers within the study area in which information on long-term aquifer yield was needed.

As part of this investigation, 32 ground-water and 14 surface-water samples were collected and analyzed for priority pollutants, volatile organics, acid extractables, base/neutral extractables, pesticides, polychlorinated biphenyls metals, iron, manganese, barium, sodium, chloride, total dissolved solids, chemical oxygen demand, nitrates, total organic carbon, and conductivity. A summary of the results of this water-quality sampling is included in a report by Metcalf and Eddy (1983).

Numbering System for Wells, Borings, and Springs

Local numbers assigned to wells, test wells, borings, and springs consist of (1) a two-letter town designation, (2) a letter designation ("A" is for borings done for hydrologic or hydrogeologic purposes with no casing set, "B" is for borings done primarily for construction purposes, "S" is for springs, and "W" is for wells completed for all purposes and in which a casing was set), and (3) a sequential number within each town. Therefore, the local number for cased well number 1 in the town of Merrimack is MKW-1. On plates 1, 3, and 5, the wells, borings, and springs are shown without the preceding town letters to conserve space.

The location number is a 15-digit latitude-longitude number followed by a decimal point and a sequential number for wells and borings in a 1-second grid. Each well entered into the GWSI data base is cross referenced to the original driller, owner, well-identification number, and other pertinent information.

Geologic Setting

Unconsolidated Deposits

The Nashua area was covered by continental glaciers at various times from about 1 million years ago to about 14,000 years ago. Approximately 20,000 years ago, the ice sheet covering New Hampshire began to melt and its southern margin retreated northward (Chapman, 1974). The last remnants of the glacier in New Hampshire were believed to have disappeared 14,000 years ago.

Rock and loose material beneath the glacial ice sheet were eroded and incorporated into the ice mass as the ice advanced. This material, which was deposited as till on the bedrock surface during advancing and retreating stages of glaciation, is the most widespread glacial deposit in the study area. Till is characterized by an unsorted mixture of clay, silt, sand, gravel, and rock fragments and generally is nonstratified. A discontinuous layer of till, typically less than about 10 feet thick, called lodgement till, is the older of the till deposits in the Nashua area and is sometimes referred to as the lower till (Koteff, 1970). This type of till is more compact than the upper till and has an olive to yellow-brown appearance. Lower till forms the bulk of drumlins in the area and can be as much as 100 feet thick. The upper till or ablation till, was probably deposited by a later ice advance (Koteff, 1970). Ablation till, has a less compact light to dark-grey mixture of materials that accumulated in places as the surface ice was removed by ablation. Ablation till is found as a discontinuous layer, probably averaging less than 10 feet thick, throughout the study area.

As the glaciers melted and receded, meltwaters carried away sediments incorporated in the ice. Sediments were differentially deposited by glacial meltwaters in areas where the velocity of the meltwater decreased enough for sediment particles to be deposited. Deposits of sediment formed distinct layers of differing grain sizes that were sorted according to the fluvial environment at the time; these deposits are termed stratified drift. Sediments deposited in channels under or within the ice, adjacent to the ice, against valley walls, and at the margins of melting ice, are called ice-contact, stratified drift. Ice-contact stratified drift consists primarily of sand and gravel because the flow of streams under and next to the melting ice was too fast for the silts and clays to be deposited.

Typical ice-contact deposits include eskers (tunnel fillings within the ice), crevasse fillings (fillings in cracks in the ice), kames (irregularly shaped hills formed when sediment filled holes in the ice), kame terraces (flat topped terraces formed by water flowing between ice and a valley wall), and kame deltas (irregularly shaped mounds that once were deltas built inward against ice or outward from ice). A typical ice contact feature of the region is the kame delta to the northeast of Naticook Lake along Camp Sargent Road in Merrimack (pls. 3 and 4). Outwash deposits are stratified drift deposited by meltwater streams away from the melting ice margin as they flowed across the valley bottoms. Outwash deposits consist of sand, gravel, silt and clay that are better sorted than ice-contact deposits; sorting generally increases with the distance travelled by the sediments. The coarser grained components generally are found in deposits closest to the location of the melting ice where streamflow velocities were greatest.

Deltaic deposits were formed where glacial meltwaters flowed into a glacial lake. Deltas that were deposited into ancient glacial Lake Merrimack, generally consist of well-sorted sand in topset and foreset beds; however, coarse sand and gravel deposits are also found in topset and foreset beds presumed to be close to the meltwater source. Bottomset beds generally consist of fine-grained lake-bottom deposits.

Stratified lake-bottom deposits are found in areas where glacial lakes once existed. The grain size of the stratified lake-bottom material ranges from a clayey silt to gravel, depending on such factors as the depth of the lake, hydraulic retention time, and distance from the meltwater source. The large glacial lake-bottom deposits (glacial Lake Merrimack) generally contain more fine-grained components (silt, and clay) than the smaller glacial-lake-bottom (glacial Lake Nashua) deposits, which consist primarily of sand and gravel with minor amounts of silt and clay.

Glacial Lake Merrimack (Koteff, 1970), the largest in the study area, extended up the Merrimack Valley from south of the New Hampshire-Massachusetts border to about Milford center to the west. It also extended up into many tributary valleys such as Beaver Brook in Amherst and Baboosic Brook in Merrimack (pls. 3 and 4). On the east side of the present-day Merrimack River in the Hudson and Litchfield areas (pls. 5 and 6), glacial Lake Merrimack extended eastward as far as Londonderry Road and Route 102, beyond Greeley Road, and into the Litchfield State Forest. Small glacial lakes in the study area included glacial Lake Nashua, extending throughout parts of Nashua and Hollis (pls. 3 and 4); glacial Lake Nissitissit, in Hollis and Brookline (pls. 1-4); and glacial Lake Tyngsboro, extending from south of the New Hampshire-Massachusetts border northward into Pelham (Koteff and Volckmann, 1973). Stratified drift covers approximately 40 percent or 129 mi^2 of the study area (pls. 1-6). Till or bedrock cover the remaining 60 percent or 193 mi^2 of the area. General stratigraphic relations between different material types are shown in selected geologic sections of the study area (fig. A-1). The location of geologic sections is shown on plates 1, 3, and 5.

Bedrock

The bedrock structure of the Nashua area trends northeast-southwest and is subdivided into three general areas (J. B. Lyons, W. A. Bothner, R. H. Moench, and J. B. Thompson, Jr., U.S. Geological Survey, written commun., 1983). These areas, from east to west consist of metasedimentary rocks of the Early Devonian Berwick Formation of Merrimack Group, Precambrian- to Ordovician-age plutonic rocks, and metasedimentary rocks of the Rangeley, Perry Mountain, and Smalls Falls Formations of Silurian age. The pre-Silurian Early Devonian Berwick Formation that trends southwest-northeast underlies the eastern part of the study area; it consists of metasedimentary phyllites, granulites, gneisses, and schists that are intruded by granodiorite and binary granite. To the west, plutonic rocks of Precambrian to Ordovician age include Massabesic Gneiss, granitic migmatite, granite, and binary granite. The western part of the study area is underlain by metasedimentary rocks of the Rangeley, Perry Mountain, and Smalls Falls Formations, which consist of quartzite, sandstone, siltstone, shale, and mica schist locally intruded in places by granite. Major northeasterly trending fault zones of the area include Naticook fault, Bower Pond fault, Nashua fault, Chase Brook fault (Smith and Barosh, 1981) and Campbell Hill-Hall Mountain fault, Flint Hill fault, and Silver Lake fault (Lyons and others, 1982).

Acknowledgments

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HYDROGEOLOGY OF STRATIFIED-DRIFT AQUIFERS

Ground Water

Occurrence

Ground water is present beneath the surface of the earth in the zone of saturation where connected voids between rock fragments contain water. In unconsolidated materials, the openings or pores between rock particles are called primary openings, as opposed to secondary openings such as fractures or caverns in consolidated rock. Pores within unconsolidated rock provide space for the storage and movement of ground water. The ratio of the total volume of pore space to the total volume of sediments or rock is termed total porosity which is expressed as a percentage. The effective porosity of sediments or rock is the ratio of the volume of water that can be drained by gravity to the total volume of the material. For most rock or sediment the effective porosity is much less than the total porosity. Effective porosity also is referred to as specific yield (Todd, 1980).

Stratified drift

Factors that determine the quantity of water an unconsolidated deposit can contain include the shape, arrangement, and uniformity of rock particles. Deposits consisting of uniformly sized particles are termed well sorted and generally provide the greatest storage space for water. Well-sorted sand and well-sorted gravel have total porosities of about 25 and 20 percent, respectively (Heath, 1983). In coarse-grained sediments the total porosity is essentially equivalent to specific yield. A well-sorted glacial lake-bottom deposit, consisting mostly of silt, sampled in Litchfield, has a total porosity of about 44 percent (Weigle and Kranes, 1966). Despite the fact that silt usually has a higher total porosity than sand or gravel, it has a much lower specific yield because of the smaller size of the pore spaces and attendant increased molecular attraction between water molecules and sediments which can hinder the drainage of water from the material. The fine-grained matrix also is much less permeable and transmits less water.

Outwash deposits consist predominantly of well-sorted sand with small amounts of gravel, silt, and clay. The average total porosity for three outwash samples collected in the study area is 34 percent (Weigle and Kranes, 1966). Where outwash deposits have enough saturated thickness, they can provide large quantities of water to properly constructed gravel-packed wells.

Ice-contact deposits are more poorly sorted and coarser grained than outwash deposits. Ice-contact deposits consist predominantly of sand and gravel, with minor amounts of silt and clay. The average total porosity of five samples of ice-contact deposits in the study area is 32 percent (Weigle and Kranes, 1966). Because of high permeability and porosity, ice-contact deposits are favorable for development of large-capacity production wells.

Till

Till is a mixture of all grain sizes ranging from clay to boulders. Basal or lodgement till is very compact and much more dense than ablation till because it is deposited underneath the weight of overlying ice. Two ablation-till samples in the study area had an average total porosity of about 25 percent (Weigle, 1968). Dug wells in till can usually provide adequate amounts of water for individual household needs (1 to 5 gal/min). However, water-level fluctuations in till can be quite large, which can make the dug well in till much less reliable during the dry seasons of the year.

Bedrock

Water obtained from bedrock in the study area is primarily from secondary openings--namely, fractures and cracks in the rock. The storage capacity of fractures generally is limited and depends on the number, size, and degree of interconnection of the fractures. The number and size of fractures tends to decrease with depth be-

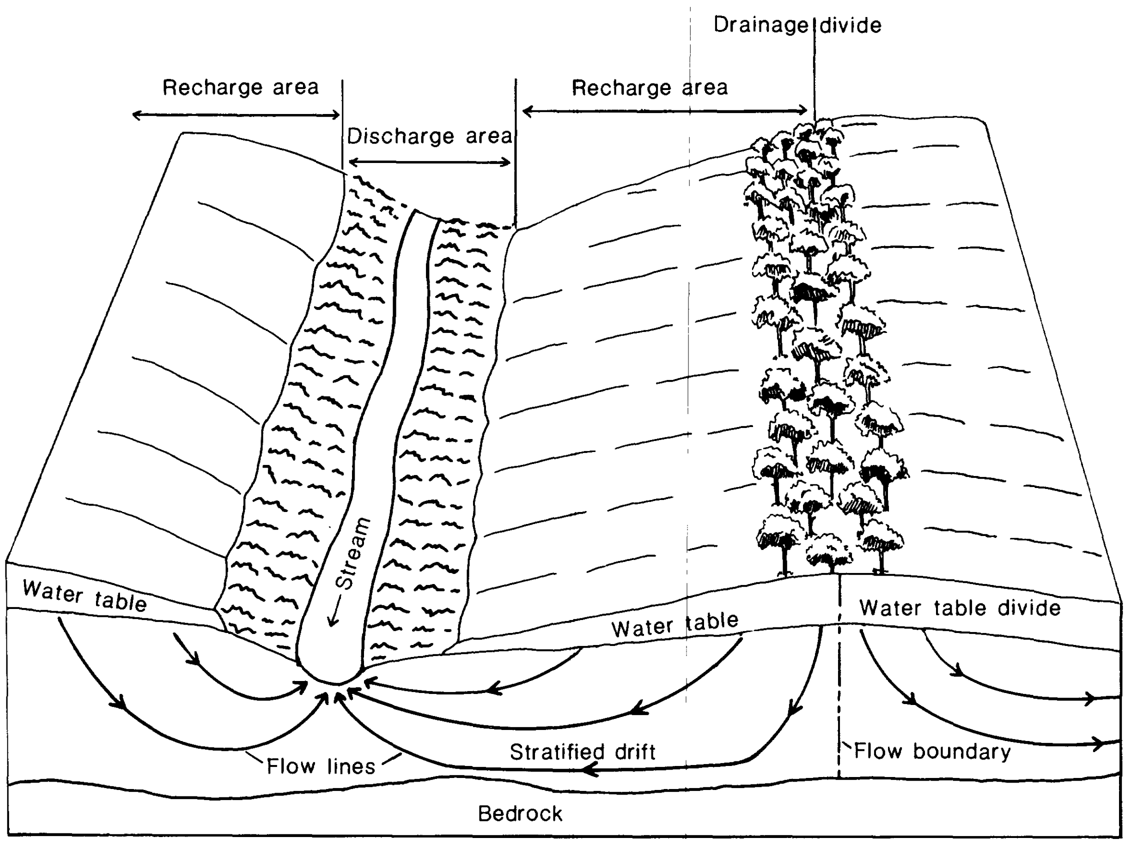


Figure 2.--Idealized pattern of ground-water flow from recharge to discharge areas.

cause of loading and, therefore, so does the storage capacity (Goldthwait, 1949). A typical rock type in the study area, granite, may only have a specific yield of about 10 percent (Heath, 1983). The largest stored quantities of water in bedrock are usually in fault zones in the region, as described by Billings (1956), Smith and Barosh (1981), and Lyons and others (1982). Bedrock may be capable of yielding large quantities of water (greater than 100 gal/min) to wells within fault zones throughout the area. Bedrock well MKW-147 (pl. 3), located along the Naticook fault zone in Merrimack, has a reported yield of more than 100 gal/min. Typical private bedrock wells only yield a few gallons per minute. Determination of the areal extent and expected yields from fault zones in bedrock was considered to be beyond the scope of this study.

Movement

All ground water in the study area originates as precipitation that infiltrates the land surface and percolates through the zone of aeration to the water table, which is the upper surface of the zone of saturation. The water contained within the zone of saturation moves from areas of recharge to areas of ground-water discharge (fig. 2) in the direction of decreasing total head. Its rate of movement depends on the hydraulic conductivity of the aquifer and the hydraulic gradient, which is defined as the change in head per unit of distance, generally in the direction of maximum decrease in head. Hydraulic conductivity, which is discussed later in the report, is a measure of the capacity of a rock to transmit water and is, in part, related to the size and number of interconnected pore space in the rock matrix. Generalized ground-water-flow directions, perpendicular to water table contours, are shown on plates 1, 3, and 5. In unconsolidated materials, ground water generally flows in a uniform manner in discrete flow lines (laminar flow) in which there is little mixing of water from one flow line to the next.

Recharge

Recharge is the process by which water is added to the zone of saturation of an aquifer. Recharge to unconfined stratified-drift aquifers results from infiltration of precipitation that ultimately reaches the water table. For the 1982-84 water years (October 1 through September 30 of each year), precipitation totals were 48.6, 48.1 and 55.4 inches, respectively, at the Nashua 2 NWW weather station (National Oceanic and Atmospheric Administration, 1982; 1983; 1984; 1985). Long-term average precipitation (1951-80) for this station is 43.3 inches per year (National Oceanic and Atmospheric Administration, 1980).

Average annual recharge in the study area was estimated from work done by others. MacNish and Randall (1982) estimate that where sand and gravel is present at land surface about half of total annual precipitation reaches the water table as recharge. Pluhowski and Kantrowitz (1964) reached the same conclusion on Long Island, an area covered almost entirely with stratified drift. Therefore, assuming similar conditions in the Nashua area, the average annual recharge to stratified drift is about 22 inches per year.

Runoff from till and bedrock uplands can provide large amounts of recharge to adjacent stratified-drift deposits. Morrissey (1983) estimates that lateral inflow from ground-water runoff in upland till areas to a stratified-drift aquifer in Maine averages about 0.5 $(ft^3/s)/mi^2$ of upland area. Where upland areas are drained by streams that cross stratified-drift aquifers, ground-water recharge occurs through permeable streambeds (Randall, 1978). Statistics from several small till covered drainage areas in southern New Hampshire show that average basin runoff is 0.07 $(ft^3/s)/mi^2$ at the 90-percent flow duration.

Although the magnitude of ground-water recharge is variable with time, the distribution of recharge generally follows a seasonal pattern, as shown by the hydrographs in figure 3. Recorded monthly water-levels in two wells (fig. 3) show that recharge occurs during March and April and again in November and December of each year. Most recharge occurs in the spring and is usually associated with a combination of snowmelt and rainfall. During the summer, little or no recharge occurs because evapotranspiration depletes most water that infiltrates the land surface before it can reach the water table. In the fall, after plants die and deciduous trees lose their leaves, substantial amounts of rainfall can again percolate to the water table. Precipitation again may be restricted from reaching the water table when the ground freezes (January and February).

The permeability of land cover and soils also affects the quantity of recharge to aquifers. Mature forests on sandy soil can absorb up to about 1 in./hr (inch per hour) of rainfall, but silty, clayey soil may absorb less than 0.1 in./hr (Heath, 1983). Ground frost can completely restrict recharge through some soils in the winter months. Artificial recharge of aquifers in the Nashua region is not a common practice, but does occur to a limited extent in the summertime as farmlands and turf farms are irrigated. Also, the subsurface disposal of household wastes in leach fields can be considered a type of artificial recharge. In communities that have sewage-collection and treatment facilities, this type of recharge does not occur, because the collected and treated wastewater is typically discharged to surface-water bodies. Thus, this water is lost downstream and is not available to replenish the aquifer.

Induced recharge to an aquifer from surface-water bodies occurs where pumping wells reverse natural flow directions and induce flow into the aquifer. The amount of induced infiltration depends on the difference in head between the ground water and overlying surface water and on the hydraulic conductivity of aquifer and streambed materials. Induced infiltration is an important source of water for pumping wells in this area, especially where high-yield municipal wells are located close to bodies of surface water, such as in the towns of Milford, Amherst, and Merrimack. In some instances, induced infiltration controls the long-term yield of wells, especially in small river-valley aquifers of limited storage capacity.

Discharge

The majority of ground water discharge from stratified drift aquifers is to surface waters such as lakes, streams or rivers. This discharge maintains surface flows through extended dry periods when there is little or no surface runoff. The amount of streamflow from ground-water discharge depends, in part, on the geology of the basin. Cervione and others (1972) showed that the amount of streamflow from ground-water discharge was directly proportional to the amount of stratified drift within a drainage basin.

Streamflow was measured at several locations within the study area during the period August 27-31, 1984, during a period when there was little or no surface runoff. The measurements, called base flow or low-flow measurements, are summarized in table 1 and locations of measurements are shown on plates 1, 3, and 5. At several locations signifi-

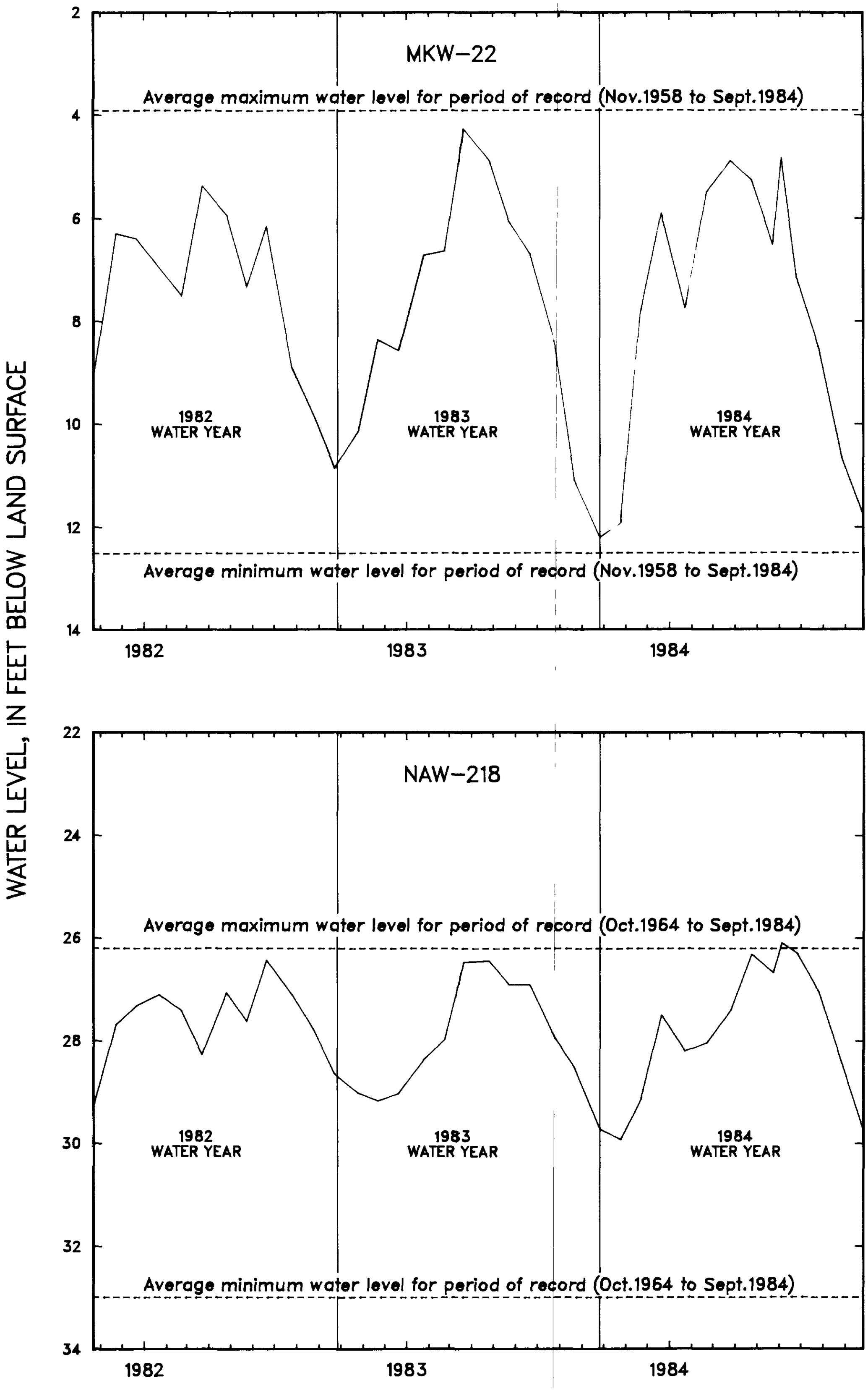


Figure 3.--Observation wells MKW-22 and NAW-218.

Table 1.--*Summary of base-flow measurements*

[Informal numbers are shown on plates 1, 3, and 5.]

Informal No.	USGS station No.	Stream	Date (August 1984)	Discharge, in cubic feet per second
--	01092000	Merrimack River	27	[1]1,040
01	01093720	Souhegan River	27	5.38
02	01093740	do.	27	11.4
03	01093850	do.	27	20.9
06	01093930	do.	27	26.4
09	01093950	Beaver Brook	24	.01
14	01093980	Souhegan River	28	26.5
07	01094000	do.	28	27.1
28	01094003	Baboosic Brook	30	.38
30	01094005	do.	30	.56
31	01094010	Naticook Brook	31	.03
32	01094020	do.	31	0
33	01094024	do.	31	.21
46	01094046	Chase Brook tributary	31	0
45	01094050	Chase Brook	31	2.52
15	01094070	Pennichuck Brook	28	.64
16	01094080	do.	28	.71
22	01094100	Muddy Brook	31	0
23	01094120	do.	31	.39
13	01094130	Witches Brook	31	.45
12	01094140	do.	31	.86
11	01094150	do.	31	1.70
17	01094155	do.	31	4.45
29	01094157	Pennichuck Brook	28	14.5
04	01096501.5	Scab Mill Brook	29	.20
05	01096501.7	Nissitissit River	29	.77
18	01096502	do.	29	5.86
20	01096502.1	Beaver Brook	31	.06
19	01096502.2	do.	29	.12
21	01096502.8	Nissitssit River	29	7.51
27	01096506	Nashua River	30	84.9
24	01096506.2	Flints Pond tributary	31	0
25	01096506.3	Flints Brook	31	.04
26	01096506.4	do.	31	.88
34	01096507	Nashua River	30	126
35	01096510	Glover Brook	29	0
38	01096510.6	Second Brook	31	.08
39	01096529.6	Limit Brook	29	0
40	01096529.8	do.	29	.34
10	01096530.3	do.	29	1.70
42	01096585.4	Beaver Brook	30	5.72
43	01096585.8	do.	30	7.85
44	01096593.5	do.	30	11.5

[1]Mean daily discharge.

cant gains in streamflow occurred when surface waters crossed stratified-drift aquifers.

Along the Souhegan River in Milford, a gain in streamflow of 5.5 ft^3/s was observed between measuring sites 3 and 6 (pl. 1), where the Souhegan River crosses a large stratified-drift aquifer that serves as a source of water for the town of Milford. Other significant gains in streamflow from ground-water discharge were observed along Witches, Baboosic, Beaver, Chase, Pennichuck, Limit, and Flints Brook and along the Nissitissit River (pls. 1, 3, and 5).

Ground water also can discharge by evapotranspiration, especially where the water table is near land surface. Such locations include wetlands or other riparian areas along lakes or rivers. The U.S. Army Corps of Engineers (1980) estimates that ground-water evapotranspiration in southeastern New Hampshire is 5 percent of total annual precipitation or about 2 in./yr (inches per year).

Water Levels

Seasonal changes in the altitude of the water table occur as a result of seasonal changes in aquifer storage. Water-level fluctuations are usually greater in till uplands than in outwash and ice-contact deposits located in valley bottoms.

Water-level hydrographs for a shallow dug well (MKW-22) completed in ice-contact sand and gravel and a deep well (NAW-218) screened in outwash sand show monthly water-level fluctuations during the 1982-84 water years (fig. 3). Recharge occurs from approximately March through June as rainfall and snowmelt infiltrate the ground. During the summer growing season, very little recharge occurs. As a result, the water level declines from June through September. Recharge begins again in the late fall after the growing season, continues into December, and ends when the ground freezes. After the ground thaws in March, the annual recharge cycle begins again. The general pattern of annual recharge and discharge and associated water-level fluctuations discussed in the section of the report titled "Recharge" is evident in the hydrographs shown in figure 3. The separate fall and spring peaks are visible for the 1982 and 1984 water years, although only one peak occurred during the 1983 water year. This could be due to incomplete ground freezing that allowed recharge to occur throughout the winter months.

The maximum annual water-level fluctuation for the period of record at MKW-22 (27 years of record) and NAW-218 (21 years of record) was 8.6 ft and 7 ft, respectively. Minimum water levels occurred in 1964 at both observation wells during an extended drought period. Because the effects of evapotranspiration are greater in the shallow well (MKW-22) the water level fluctuations are greater than those in the deep well (NAW-218).

Thirty-nine U.S. Geological Survey observation wells (table A-1) were measured at least twice during this study. The measurements were taken during September and June, times when extremely low and high water levels (as indicated by monthly observation wells NAW-218, NAW-143, MKW-22, and MOW-36) typically occur. Water-table fluctuations observed in these wells ranged from 1.5 to 7.5 ft and averaged 3.5 ft.

Generalized water-level altitudes for aquifers are shown in the water-table maps (pls. 1, 3, and 5) that were constructed from water-level data collected from 1982 through 1984 at all existing observation wells and from surface-water elevations on existing topographic maps. Because topographic maps were used for vertical control, the accuracy of water levels shown on the plates is approximately one-half of the contour interval shown on the map. Water-level contours are shown at 10- or 20-ft intervals, depending on the contour interval of the base map.

Arrows indicating generalized flow directions of ground water in the aquifers are also shown on plates 1, 3, and 5. Assuming that the aquifers are isotropic the flow directions are drawn perpendicular to water-table contours shown on the plates. Because of the scale of these maps, localized flow patterns at a given site could differ from those shown on the plates. Introduction of high-yield pumped wells can also affect the flow direction shown on the plates.

Description of Aquifers

Lithology

Generalized lithology of the stratified-drift aquifers (pls. 2, 4, and 6 and table A-2) include coarse-grained stratified drift overlying till and bedrock; fine-grained stratified drift overlying till and bedrock; coarse-grained stratified drift overlying fine-grained stratified drift that overlies till and bedrock; and fine-grained stratified drift overlying coarse-grained stratified drift that overlies till and bedrock.

Coarse-grained stratified-drift units consist of material ranging from medium sand to cobble gravel, that have been sorted by glacial meltwater. When saturated, these materials produce enough ground water to sustain yields for large municipal and industrial supply wells. The greatest yields are provided by wells located in coarse materials in the most thickly saturated part of aquifers or by wells located adjacent to a surface-water body from which infiltration to the aquifer can be induced by pumping. The coarse-grained units throughout the study area generally are located at the upstream ends of tributary valleys (pls. 2, 4, and 6) above fine materials deposited in former glacial Lake Merrimack. However, some coarse-grained sand and gravels are located in deltaic deposits along the trunk of the Merrimack River (pl. 4).

Fine-grained stratified-drift units consist of clayey silt to fine sand. Dug wells or driven well points located in fine sands usually produce 5 to 10 gal/min, which is enough water for individual households. The very fine sand, silt, and clay do not yield appreciable amounts of water. Fine-grained sand, silt, and clay, that form bottom sediments of former glacial Lake Merrimack, border the trunk of the Merrimack River and extend into parts of central Merrimack, Nashua, Litchfield, and Hudson (pls. 4 and 6). Fine-grained deposits of glacial Lake Merrimack also extend along State Route 101A into northern Nashua and Hollis, southern Merrimack, Amherst (pl. 4) and eastern Milford (pl. 2) as shown by Koteff (1970; 1976).

The lithologic unit in which coarse-grained stratified drift overlies fine-grained stratified drift generally consists of 10 to 50 ft of predominantly medium sand to gravel overlying a significant thickness of fine- to very fine-grained sand, silt, and clay. The fine-grained materials at the bottom of this unit are generally unproductive. Wells within this unit are screened in the thickest, most transmissive parts of the upper coarse-grained materials and are often located adjacent to surface-water bodies from which infiltration can be induced. The coarse-grained over fine-grained stratified unit is found in many places throughout the study area, mainly in places where glacial stream deltas, or other outwash materials, build out onto glacial-lake deposits.

The buried, coarse-grained stratified-drift units generally consist of 10 or more feet of medium sand to gravel overlain by a significant thickness of fine-grained material. Buried coarse materials are found in a few isolated places throughout the study area and are not areally extensive. Because they are deeply buried and usually thin, locating this type of aquifer is difficult.

Hydraulic Properties

Saturated thickness, transmissivity, and storage coefficient are the hydraulic properties of an aquifer that define its capability to transmit and store water. These hydraulic properties must be known to predict the effects that pumping will have on an aquifer and to determine aquifer yield.

Saturated thickness

The saturated thickness of an unconfined, stratified-drift aquifer is the distance between the water table and the base of the aquifer. For many stratified-drift systems, the base of the aquifer is at the contact with relatively impermeable till or bedrock. The saturated thickness of an aquifer is an indication of the total amount of stored water and the head available for aquifer development. Variations in the saturated thickness of stratified drift are shown by lines of equal saturated thickness in figure 4.

The saturated thickness of stratified-drift aquifers in this study is shown on plates 2, 4, and 6. Saturated thickness was determined by plotting the difference between the water table and depth to bedrock or till at all well or test-boring locations. Saturated thickness was also determined from seismic-refraction profiles run in the area (fig. A-2). Dashed lines are used to show saturated thickness where data are sparse.

Saturated thickness maps can be used to locate the best sites for wells, such as large-capacity production wells, which are ideally located in the most thickly saturated part of an aquifer. The total drawdown available for any proposed well installation can be determined from the saturated thickness maps, if the aquifer materials are suitable for well construction.

Several aquifers in the study area consist of coarse-grained material over finer grained silt and clay. In aquifers of this type, the usable saturated thickness is limited to the area between the water table and the bottom of the coarse-grained layer. However, saturated thicknesses shown on the

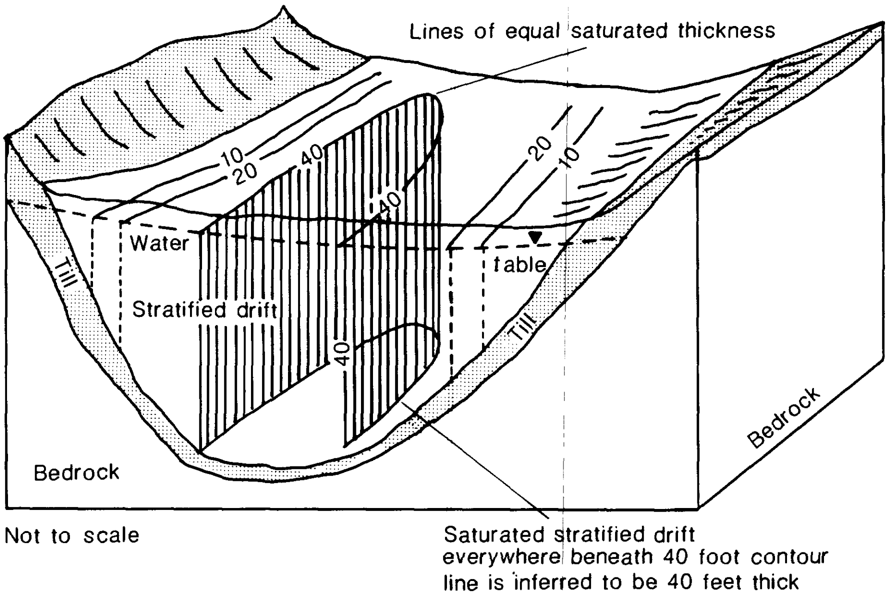


Figure 4.--Lines of equal saturated thickness in a stratified-drift aquifer.

plates in this report include the entire saturated thicknesses of all stratified-drift materials, whether coarse or fine.

Saturated thickness contours, at 10-, 20- and 40-ft intervals, are shown on plates 2, 4, and 6 for the stratified-drift aquifers throughout the study area. The range of saturated thickness is from 0 near many of the till/bedrock boundaries to greater than 100 ft, but less than 120 ft, in the deepest valleys. Saturated thicknesses of 60 ft or more are areally most extensive along the Souhegan River valley in Milford and Amherst, south of the Souhegan River in Amherst, along State Route 101A extending into central Nashua and in the Beaver Brook valley in central Pelham (pl. 2, 4, and 6). These areas contain the largest stored volumes of water within stratified-drift aquifers of the study area.

Less extensive areas of stratified drift having a saturated thickness greater than 60 ft are found within many of the narrow river valleys. These aquifers are in the upper Souhegan River valley in Wilton, the Nissitissit River valley in central Brookline, Beaver Brook in Hollis, Naticook Brook in Merrimack, Beaver Brook in Amherst, and Beaver Brook in Pelham. Aquifers in which saturated thickness exceeds 100 ft can be found in parts of Amherst, Hollis, Litchfield, Merrimack, and Pelham (pls. 4 and 6); however, these aquifers are not areally extensive. Other deposits of stratified drift having significant saturated thickness are located in buried valleys or deepened areas of the bedrock surface (pls. 4 and 6), along the Merrimack River in Merrimack, Hudson, and South Nashua, and in central Litchfield south of Darrah Pond.

Transmissivity

Transmissivity is defined as the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Heath, 1983). The transmissivity (T) of an aquifer is equal to the hydraulic conductivity (K) of the aquifer multiplied by the saturated thickness (b) of the aquifer; thus, $T = Kb$. Transmissivity is expressed in units of feet squared per day.

Aquifer transmissivity was determined from specific-capacity data from aquifer tests or estimated from stratigraphic logs of aquifer materials. The large majority of test wells installed in the

Table 2.--*Example of the estimation of transmissivity from logs of wells and test holes*

[Test hole HSW-43. Drilled with hollow stem auger by U.S. Geological Survey, 1983. Depth to water 4.6 feet below land surface.]

Material description	Depth interval below land surface, in feet	Saturated thickness, in feet (A)	Assigned hydraulic conductivity, in feet per day (B)	Calculated transmissivity, in feet squared per day (A X B)
Sand, medium to very coarse	0 - 15	10	300	3,000
Sand, fine to coarse	15 - 15	10	100	1,000
Sand, coarse to very coarse	25 - 30	5	500	2,500
Sand, fine to medium	30 - 35	5	50	250
Sand, medium to very coarse	35 - 40	5	300	1,500
Sand, fine to medium	40 - 45	5	50	250
Sand, very fine to medium	45 - 55	10	25	250
Sand, fine to coarse	55 - 60	5	100	500
Silt to fine sand, some gray clay	60 - 65	5	1	5
Sand, very fine to medium	65 - 70	5	25	125
Silt to fine sand	70 - 75	5	1	5
Sand, very fine to medium	75 - 85	10	25	250
Refusal[1]	at 85	--	--	
			Total	9,635

[1]Refusal may be bedrock, a boulder, a hard or cemented layer, or till.

area either were not tested or the aquifer tests are not adequate to evaluate the specific capacity of an aquifer; therefore, estimates of hydraulic conductivity were made by evaluating drillers' logs.

Hydraulic conductivity (K) is a measure of the capacity of an aquifer to transmit water. It is defined as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area of aquifer. Hydraulic conductivity depends on the size and arrangement of pore spaces, the viscosity and density of water within the pore spaces, and the strength of the gravitational field. The method of estimating transmissivity from a well log is shown in table 2. Each lithologic unit of a driller's log is assigned a value of hydraulic conductivity based on a description of materials. These values are then multiplied by the saturated thickness of each unit and totalled to give the estimated transmissivity of the entire section. Hydraulic conductivities for various materials that were used for estimating the transmissivity of aquifers in this study are shown in table 3.

Descriptions of materials from well logs that can be used to estimate hydraulic conductivity and transmissivity differ from driller to driller, from one method of drilling to another, and from job to job, depending on the purpose of the drilling. Domestic wells in New Hampshire are most commonly completed in bedrock with cable tool or rotary-drilling methods. As a result, well-drilling contractors pay little attention to the unconsolidated materials above bedrock and describe them in only a cursory manner. The use of such logs to estimate transmissivity can be misleading. Records of dug wells may include reasonably good descriptions of material, but because they commonly are completed in till, their use is limited.

Descriptions of aquifer materials obtained from the wash-and-drive method of drilling are usually accurate; however, many of the fines may

Table 3.--*Estimated hydraulic conductivity for various materials*

[Modified from tables by Lohman, 1972, p. 53; and Ryder and others, 1970, p. 21.]

Material	Estimated hydraulic conductivity, in feet per day
Clay	1
Till	1
Silt	1
Silt and very fine sand	1
Silt and clay	1
Silt and gravel	2
Fine sand, very fine sand and silt	2
Clayey fine sand to fine gravel	5
Fine sand with clay layers	5
Fine sand, some clay and gravel	10
Fine sand	15
Fine and medium sand with clay layers	20
Fine sand and medium sand	25
Sandy till	25
Fine sand to fine gravel	30
Medium and coarse sand, clay layers	40
Alluvium	50
Sand and gravel, some clay	60
Medium sand	100
Medium sand and coarse sand	125
Medium sand, some fine sand to fine gravel	300
Sand and gravel	500
Fine gravel and sand	600
Medium and coarse sand, some gravel and silt	700
Fine gravel	800
Medium and coarse sand and gravel	900
Coarse sand to gravel, some fine to medium sand	900
Coarse sand and cobbles	1,000
Gravel	1,000
Cobbles and gravel	1,000

be washed out of the sample and not observed and, accordingly, the material description indicates coarser material than was actually present. In addition, cobble and boulders in stratified drift and till can limit penetration with the wash-and-drive method. Relatively undisturbed samples of aquifer material can be obtained by hollow-stem auger drilling and split-spoon sampling. However, coarse-grained stratified drift, especially cobbles or boulders and till, can limit the penetration of a hollow-stem auger.

The transmissivity maps (pls. 2, 4 and 6) provide information that allows users to locate the highest yielding, most productive part of an aquifer system. Users of transmissivity maps should be aware that two aquifers with the same transmissivity values commonly have entirely different materials and thickness. For example, 100 ft of fine sand with a hydraulic conductivity of 50 ft/d and 10 ft of sand and gravel with a hydraulic conductivity of 500 ft/d can both have a transmissivity of 5,000 ft^2/d.

The accuracy of transmissivity maps depends on the number and distribution of data points in the area under consideration. The transmissivity of an aquifer can be extremely variable over very short distances because of the heterogeneous nature of stratified-drift deposits. Therefore, users must keep in mind that the contouring of transmissivities indicates an average value for the entire contour interval and that higher or lower transmissivities may be found within that same interval.

Storage coefficients

The storage coefficient of an aquifer is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Theis, 1938). For unconfined aquifers, storage coefficient is essentially equal to specific yield, where specific yield is the amount of water that can be obtained by gravity drainage of a unit volume of aquifer. Specific yields of unconfined aquifers range from about 10 to 30 percent (Lohman, 1972).

Laboratory tests done on 13 unconsolidated samples collected in southern New Hampshire indicate specific yields that range from 14 to 34 percent and average 26 percent (Weigle and Kranes, 1966). Material types used for the analysis ranged from fine-grained lacustrine deposits to coarse-grained sand and gravel. For estimating aquifer storage volumes and for predicting aquifer yields, an average value of 20 percent was assigned to aquifers of the region, although higher (30 percent) storage coefficients are commonly assigned to the coarse-grained materials and lower values (10 to 20 percent) to the fine-grained materials.

Aquifer Descriptions by Town

Amherst

The town of Amherst encompasses a land area of 34.2 mi^2. Stratified-drift deposits cover approximately 13.5 mi^2, or 40 percent of the town (fig. 1). Stratified-drift aquifers are widely scattered throughout the town and vary greatly in areal extent and saturated thickness (pls. 3 and 4).

The largest aquifer in Amherst is located along the Souhegan River, extending from Milford to Merrimack and southward to Witches Brook. The deep, central part of this aquifer consists of 25 ft of coarse-grained sand and gravel overlying 75 ft of fine-grained materials (wells W-62, W-63). Near the Milford line along its western edge, at the mouth of Beaver Brook and toward Witches Spring, the stratified drift is coarse grained. Although the saturated thickness exceeds 100 ft in the center of this aquifer, usable saturated thickness is limited to about one third to one half of that shown on plate 4 because of the low permeability, fine-grained stratified drift under the coarse-grained material. In the coarse-grained material near the aquifer boundaries, saturated thickness is less than 60 ft. Transmissivity is greater than 8,000 ft^2/d throughout most of this area. Municipal wells in Milford (wells W-73, W-74), which pump 400 and 700 gal/min, respectively, are at the western end of this aquifer near the Milford town line. Merrimack well W-146, which pumps in excess of 500 gal/min, is located in the southeastern part of this aquifer in South Merrimack.

The Amherst village district well (site W-11, 18) is located in the stratified-drift deposit south of the town center along Beaver Brook. The well yields 200 gal/min from coarse-grained sand and gravel that has a saturated thickness of about 70 ft. Saturated thickness decreases upstream from this point.

Transmissivity of the Beaver Brook aquifer generally is less than 8,000 ft^2/d, except near the mouth of the brook where it exceeds 8,000 ft^2/d. Additional municipal supply wells might be possible in the permeable material downstream of the current town well where the extent and saturated thickness of the aquifer are greatest and where supplemental induced recharge from Beaver Brook could be obtained.

East of the Beaver Brook watershed, the small aquifer that extends northwest to southeast from Baboosic Lake Road to Upham Road has less than 40 ft of saturated thickness. Coarse-grained material overlies fine-grained material, and transmissivity is greater than 8,000 ft^2/d in the central part of this aquifer.

Brookline

Stratified drift occupies 6.3 mi^2 or 31 percent of the total land area of Brookline. Continuous stratified-drift aquifers are in the river valleys throughout the center of town (pls. 1 and 2).

Aquifers along North Stream, Village Brook, and the upper Nissitissit River have a maximum saturated thickness of 50 ft or more. Near Pine Grove Cemetery in southern Brookline, the stratified drift consists of about 30 ft of permeable sand over 50 ft of relatively impermeable, fine-grained sand. The part of this aquifer that yields water freely, therefore, is limited to the top 30 ft. Other aquifers, located along lower Nissitissit River, Wallace Brook and Stickney Brook, Rocky Pond Brook, Spaulding Brook, and Scab Mill Brook, have saturated thicknesses that generally are less than 40 ft.

Stratified-drift aquifers with a transmissivity of at least 8,000 ft^2/d border the upper and lower Nissitissit River, Village Brook, and North Stream. These aquifers have the greatest potential for the development of municipal supplies. Within the lower Nissitissit River valley, the town of Pepperell, Mass., uses water from the aquifer near its boundary with Brookline, N. H. A 500-gal/min gravel-packed well is located in Hollis along the Nissitissit River near the Brookline town line.

Transmissivity throughout the remainder of Brookline generally is less than 8,000 ft^2/d. Large capacity wells, installed near streams in these lower transmissivity aquifers, could augment their yields by induced infiltration. The remainder of the aquifer is suitable for the development of wells that could yield 5 to 10 gal/min--a quantity that would be suitable for an individual household.

Hollis

Approximately 11.5 mi^2 or 36 percent of the area of the town of Hollis (fig. 1), is covered with stratified drift. These variable stratified-drift aquifers are widely scattered in relatively narrow river valleys (pls. 3 and 4). The large Flints Pond stratified-drift deposits broaden southeastward toward the Nashua River. Saturated thickness of the coarse sand and gravel generally is less than 40 ft; transmissivity exceeds 8,000 ft^2/d in a strip extending from Flints Pond to Nashua River. Two high-yield (100-gal/min) wells tap this aquifer--one south of Flints Pond (W-53) and the other near Nashua River at the southern end of the aquifer (W-52). This aquifer has the requisite permeable material, covers a large area, and has the potential for induced infiltration from Nashua River--properties that make it suitable for high-yield wells.

The lower Witches Brook/Pennichuck Brook stratified-drift deposits, located mostly east of State Route 122 along the Amherst/Hollis border of Pennichuck Pond, also have large areal extent and high permeability and are near sources of induced infiltration (Witches Brook and Pennichuck Pond). Saturated thickness generally is less than 40 ft, but reaches a maximum of more than 80 ft near the northeastern corner of Hollis, and transmissivity is 8,000 ft^2/d. This area has a high production potential, as indicated by a 500-gal/min well (MKW-46) located in Merrimack in the northeast corner of Hollis. The stratified drift upstream, along Pennichuck and Witches Brook, has a saturated thickness greater than 40 ft in places. Transmissivity is less than 8,000 ft^2/d along Pennichuck Brook and greater than 8,000 ft^2/d along the Witches Brook.

South of Silver Lake, an aquifer of limited areal extent is located along Beaver Brook. This aquifer is very deep, having a saturated thickness more than 100 ft in the center; it consists of 40 to 50 ft of coarse-grained sand and gravel on 50 to 60 ft of fine-grained material. The usable saturated thickness thus is limited to about one half that shown on plate 4 or about 40 ft, but transmissivity exceeds 8,000 ft^2/d. The Hollis school system well (W-51) is located near the eastern aquifer boundary and yields about 100 gal/min. The best potential for additional production is from the northern end of the aquifer near Silver Lake, where there also is potential for induced recharge.

The Nissitissit River valley aquifer, in the southwestern corner of Hollis, has a saturated thickness of only 20 ft. However, this aquifer has a transmissivity greater than 8,000 ft^2/d and potential for induced infiltration from the Nissitissit River. A 500 gal/min well near W-46 provided water for a former campground in this area.

Hudson

The town of Hudson has a nearly continuous aquifer along the Merrimack River (pl. 5 and 6) that comprises 10 mi^2 or 36 percent of the town area. The most productive aquifer is located around Ottarnic Pond and extends northeastward along Glover Brook and southwestward to the Merrimack River. The aquifer consists of coarse-grained pebble-to-boulder gravel in the northeast that grades to mixed sand and gravel and to sand in the southwest (Koteff, 1976). This aquifer contains the largest volume of recoverable stored ground water within Hudson. Saturated thickness is greater than 60 ft; the greatest thickness occurs between Ottarnic Pond and the Merrimack River. Several wells (W-1 to 3, W-69, W-112), with capacities ranging from 100 to 400 gal/min, are located in this aquifer near Ottarnic Pond and Melendys Pond. Other areas favorable for ground-water development are located near the Merrimack River; however, because the land is built up and has a high population density, ground-water quality considerations might limit this favorability.

Most of the other stratified-drift aquifers of Hudson are composed of fine-grained, glacial-lake-bottom sediments with low permeability. Saturated thickness generally is less than 40 ft throughout, and transmissivity is less than 4,000 ft^2/d. There are two areas of greater transmissivity and saturated thickness in southern Hudson. They have limited areal extent and are remote from sources of induced recharge. They are probably best suited for wells that yield 5 to 10 gal/min. here

Along Route 102 near Alvirne High School in northern Hudson, permeable kame delta deposits supply water to individual households. Other permeable stratified drift, localized in north-central Hudson near the Londonderry and Litchfield borders are of limited areal extent and have small saturated thickness. These deposits do not seem to be capable of supporting large-capacity municipal water systems that require more than 100 gal/min.

Litchfield

Located on the eastern side of the Merrimack River (fig. 1), the town of Litchfield has 14 mi^2 or 93 percent of its area underlain by stratified drift (pls. 5 and 6). The predominant stratified material is fine-grained glacial sediment of Glacial Lake Merrimack (Koteff, 1976). Several good aquifers, in northern and central Litchfield are of permeable, coarse sand and gravel with a saturated thickness greater than 100 ft in some places.

Large quantities of water are pumped from the coarse-grained sand and gravel aquifer centered about Darrah Pond. This aquifer is in a segment of a buried valley occupied by Darrah Pond delta deposits (Koteff, 1976); the deposits are more than 100 ft thick southeast of Darrah Pond, and their transmissivity is greater than 8,000 ft^2/d. The coarse-grained deposits of the aquifer are bounded on the west by fine-grained materials. The Darrah Pond well (W-59) has a capacity of 100 gal/min and serves part of central Litchfield. Darrah Pond is the only significant source of water available for induced infiltration into this area.

Northwest of Darrah Pond, two wells (W-56, W-57) are located in the coarse-grained sand and gravel along Nesenkeag Brook, and they each yield less than 100 gal/min. The aquifer along the brook is not as extensive as the Darrah Pond aquifer; its saturated thickness is less than 40 ft, and its transmissivity is less than 8,000 ft^2/d.

South of the Darrah Pond aquifer, another coarse sand and gravel aquifer, located near Cutler Road, also is within the same buried valley that follows a north-south course through central Litchfield. The saturated thickness is greater than 60 ft and transmissivity is greater than 8,000 ft^2/d. The Weinstein production well (W-36) in this area yields more than 500 gal/min. Additional production capacity from this area probably is limited by potential interference with well W-36 that taps from this small aquifer.

Saturated thickness of the coarse sand and gravel aquifer along Colby Brook exceeds 40 ft, and transmissivity is less than 8,000 ft^2/d. Based on the extent and saturated thickness of the permeable material at wells W-1 to W-6, W-34, and W-35 (transmissivity averages 7,000 ft^2/d), the yield of this aquifer potentially is as large as that from aquifers near Darrah Pond and Nesenkeag Brook.

Lyndeborough

Lyndeborough is in the upland region of the northwestern corner of the study area (fig. 1) along the eastern base of the Monadnock Mountain Range. Only 2.4 mi^2 or 8 percent of the town is underlain by permeable stratified drift (pls. 1 and 2). In a few places, the saturated thickness of stratified drift exceeds 10 ft; therefore, most deposits seem to be incapable of yielding more water than may be required for residential use.

The small, thin aquifers in Lyndeborough are widely scattered and discontinuous. In the Piscataquog River, Curtis Brook, and Stony Brook valleys, the stratified drift in kame terraces and eskers is thick, but the saturated thickness is too small to support large well yields; possible exceptions are stratified-drift deposits along the Piscataquog River east of Piscataquog Mountain and those northeast of Piscataquog Mountain near Wilton Road, where the saturated thickness is less than 20 ft and the transmissivity is less than 4,000 ft^2/d. However, exploration to determine if sites for large yielding wells are possible would be desirable.

The limited extent and saturated thickness of the stratified-drift aquifers in Lyndeborough (pls. 1 and 2) indicates that a large-capacity municipal water-supply system is not likely to be located in the town. Use of the small, isolated stratified-drift aquifers, which generally have transmissivities less than 2,000 ft^2/d, is suited for individual household water supplies.

Merrimack

The town of Merrimack, on the western side of the Merrimack River (fig. 1), has stratified drift beneath about 19 mi^2 or 57 percent of its area (pls. 3 and 4). Like Litchfield across the river, much of the stratified drift in Merrimack is fine-grained bottom sediment of Glacial Lake Merrimack (Koteff, 1970; 1976). Highly permeable, coarse stratified drift is interspersed with fine-grained materials in local areas along the Merrimack River and Naticook Brook. The deposits along the brook northeast of Naticook Lake and the South Merrimack deposits in the southwestern corner of town form the most important aquifers in Merrimack. Saturated thickness of these two permeable stratified-drift deposits are greater than 80 ft and 60 ft, respectively, and their transmissivity exceeds 8,000 ft²/d. The very large South Merrimack deposits extend northeastward toward Naticook Lake and southwestward into the broad outwash plain in Nashua, Amherst, and Hollis.

Induced recharge potential is greatest in South Merrimack from Pennichuck Pond and Pennichuck Brook and in the Naticook Valley from Naticook Lake and Greens Pond. Three municipal wells (W-15, W-23, and W-148), located in the Naticook Valley aquifer east and northeast of Greens Pond and one in South Merrimack, each yield more than 300 gal/min. These aquifers have the potential to yield additional quantities of water for expanding the municipal-supply system.

Elsewhere in Merrimack, permeable, coarse-grained deposits capable of yielding large quantities of water to wells are located along the Merrimack River. These deposits extend from 1 mile south of the Thorntons Ferry toll gate of the F. E. Everett Turnpike northward to the Bedford town line. However, these discontinuous aquifers are surrounded by finer grained materials. At least three high-yielding production wells, including a Merrimack Village district well (W-30) are screened in coarse-grained deltaic deposits adjacent to the Merrimack River. The transmissivity of aquifers along the river varies from less than 2,000 ft²/d to more than 8,000 ft²/d. Saturated thickness ranges from about 20 to 100 ft; the greatest saturated thickness is between Horseshoe Pond and the Souhegan River. This aquifer has potential for additional high-yield wells, especially north of the Souhegan River because of the large area and saturated thickness of the aquifer and its potential for induced recharge.

Stratified drift in the valleys of Baboosic Brook and Souhegan River west of the F. E. Everett Turnpike, is predominantly fine grained, and its transmissivity is less than 4,000 ft²/d. These deposits are not suited for high-yield production wells, but probably would provide 5 to 10 gal/min, which would be sufficient for individual households.

Milford

Thirty-eight percent of the town of Milford, or about 10 mi², is underlain by permeable stratified drift. These deposits are in two adjoining valleys west of State Route 13 (pls. 1 and 2). One, the Souhegan River valley, contains the largest, most productive aquifer in the town. The other, Great Brook valley, in South Milford, also has a large area underlain by permeable stratified drift.

The Great Brook and Souhegan Valley deposits are generally sand and gravel, overlying glaciolacustrine bottom deposits of fine sand, silt, and clay especially in the deeper parts of each valley. Throughout Great Brook valley are ice-contact sand and gravel (Koteff, 1970) deposits; however, in the lower part of the valley, fine-grained lake-bottom sediments predominate. Saturated thickness within both valleys is less than 80 ft. The greatest saturated thickness in the Souhegan Valley (60 ft) is just south of or directly beneath Souhegan River. The area of saturated thickness in the Great Brook area is around Osgood Pond. Transmissivity greater than 8,000 ft²/d is present at only a few locations within the town. The main Souhegan River valley has an extensive zone of transmissivity of more than 8,000 ft²/d and lesser zones around Osgood Pond and east of State Route 13 along the Souhegan River.

The main Souhegan River valley aquifer consists of six high-capacity production wells having sustained yields of from 200 to 500 gal/min. The wells include the town of Milford's municipal Savage (W-21) and Keyes (W-73) wells, Milford fish hatchery well (W-65), and three industrial wells. To the east of State Route 13 are the town of Milford's Curtis wells (W-72 and W-73), which yield 400 and 700 gal/min, respectively. Sites for additional withdrawals may be located in the high-transmissivity aquifer area south of the Souhegan River.

In the Osgood Pond area of the Great Brook valley, is the town of Milford's well (W-71), which yields approximately 500 gal/min. This aquifer is not as extensive as the Souhegan Valley aquifer. The capacity for induced recharge is greatest along Osgood Pond and Great Brook.

The town of Milford has many areas in which only a few feet of the highly permeable stratified drift is saturated. Large quantities of water induced to flow from surface-water bodies to wells are important, especially where thin aquifers provide limited ground-water storage, such as along Route 13 and near West Milford. In places where the stratified materials are mostly fine grained, such as in the lower Great Brook area, this type of development is not possible.

Mont Vernon

Mont Vernon, in the hilly northwestern part of the study area (fig. 1), has about 0.4 mi² of stratified drift that covers 2 percent of the town's area. Most of the sand and gravel is located between Salisbury Road and the tributary to Lords Brook (pls. 1 and 2). Transmissivity is estimated to be less than 2,000 ft^2/d because to the saturated thickness is less than 10 ft.

Several other discontinuous patches of sand and gravel in Mont Vernon may be stratified, but are not areally extensive and have very little saturated thickness. These areas were field checked and were not considered important enough to be placed on the maps. Transmissivities range from 0 to less than 2,000 ft^2/d. Mont Vernon does not seem to have any stratified-drift aquifers that could be developed into a municipal water supply. Individual users in Mont Vernon rely mostly on water in the till or bedrock aquifer for household needs.

Nashua

The city of Nashua, located on the western side of the Merrimack River (fig. 1) is underlain by approximately 21 mi^2 of stratified drift (pls. 3 and 4) or 67 percent of the area of the city. The stratified drift along the Merrimack and Nashua Rivers is nearly continuous in extent but has variable saturated thickness and transmissivity.

The most extensive aquifer is beneath the city and extends southward along the Nashua River and northward towards Pennichuck Pond. The area east of the F. E. Everett Turnpike is underlain by deltaic deposits (Koteff, 1976). Saturated thickness of the deltaic deposits is typically less than 60 ft, and transmissivity is less than 8,000 ft^2/d; however, some deposits having higher transmissivity are located along the Nashua River and Salmon Brook. Pennichuck Water Company wells W-126, W-127, and W-128 each yield approximately 500 gal/min in the Salmon Brook area of central Nashua. Sites for new public-supply wells may be difficult to locate in Nashua because a protection zone of at least 400 ft in radius around the well is required by State law; most of the city is too densely populated to provide this protection. Therefore, the aquifer beneath Nashua is probably useful only for industrial use.

West of the F. E. Everett Turnpike, the aquifer extending towards Pennichuck Pond consists of coarse-grained material buried beneath fine-grained deposits. Near Pennichuck Pond, the fine-grained deposits pinch out and the entire section of stratified drift is coarse grained (NAA-213). Saturated thickness of these deposits is generally less than 60 ft and transmissivity of the coarse material is greater than 8,000 ft^2/d. Transmissivity of the remainder of the stratified-drift is less than 8,000 ft^2/d. The aquifer having the greatest potential for high-yield wells extends from near Pennichuck Pond northward to Pennichuck Brook. Potential yield may be augmented by induced recharge from Pennichuck Brook or Pennichuck Pond; however, resulting streamflow losses due to induced recharge may significantly reduce surface-water inflow to the Pennichuck water supply, which serves Nashua and adjacent towns. The saturated deltaic deposits between Boire Field and the F. E. Everett Turnpike is another potential water source, although the area is thickly settled and heavily developed. The U.S. Fish and Wildlife Service has two wells that yield 100 and 600 gal/min (W-187 and W-188), respectively, west of the F. E. Everett Turnpike and Route 101 interchange.

Other permeable sand and gravel aquifers are located along the Nashua River in the southwestern part of Nashua. This area is underlain by coarse-grained deposits of Glacial Lake Nashua (Koteff and others, 1973). Thickness of these deposits generally is less than 60 ft, and transmissivity is less than 8,000 ft^2/d. Three production wells (W-157, W-158, and W-220) yield from 50 to more than 600 gal/min in this area of Nashua. High-yield wells may be developed in this area, but the density of development and water-quality problems in the Nashua River and at the Gilson Road hazardous-waste site may eliminate this aquifer from consideration as a public-water supply.

Along the Merrimack River, north and south of urban Nashua, the saturated thickness of permeable material is less than 60 ft. The most favorable area for ground-water development is in south Nashua near the mouth of Spit Brook where transmissivity exceeds 8,000 ft^2/d, where the yield of the aquifer can be augmented by induced recharge from Merrimack River. However, dense industrial development may cause water-quality problems. Elsewhere, large-capacity ground-water development from the stratified drift is limited by fine-grained materials and (or) thin saturated thickness.

Pelham

The town of Pelham in the southeastern corner of the study area (fig. 1) is underlain by 10.7

mi² (40 percent of the area of the town) of stratified drift (pls. 5 and 6). The most extensive and thickest deposits are in the center of the town along Golden and Beaver Brooks. Other outlying deposits are mostly thin, discontinuous pockets of sand and gravel of limited areal extent and saturated thickness (pls. 5 and 6).

Saturated thickness is less than 80 ft along Beaver Brook above the mouth of Golden Brook. In lower Beaver Brook valley, saturated thickness is greater than 100 ft near Nashua Road in central Pelham, but generally less than 60 ft throughout the remainder of the watershed. In the lower valleys of Golden Brook and Island Pond Brook, saturated thickness generally is less than 40 to 60 ft.

The largest stratified-drift aquifer extends from the mouth of Golden Brook southward along Beaver Brook. This aquifer consists primarily of coarse sand and gravel locally overlain by fine material and extends southwestward past Willow Street. Saturated thickness as much as 100 ft and a transmissivity of more than 8,000 ft²/d make this area of central Pelham the best available location for developing ground-water supplies for the town. The school-system well (W-63) yields more than 400 gal/min from this aquifer.

Along Beaver Brook to a point northwest of its confluence with Golden Brook, the stratified drift consists of coarse sand and gravel. This aquifer is not as extensive and does not have as great a storage capacity as the lower Beaver Brook area; however, it does have a transmissivity greater than 6,000 ft²/d. Wells could be located in the permeable materials of this area and designed to induce recharge from Beaver Brook.

Other stratified-drift deposits of limited areal extent, saturated thickness, and transmissivity of less than 4,000 ft²/d are within the valleys of Gumpas Pond Brook, Island Pond Brook, Harris Pond, upper Golden Brook, and the northwestern corner of Beaver Brook. The deposits in these areas are not capable of supplying water at pumping rates that would be sufficient to supply municipal wells.

Wilton

Permeable stratified drift covers 5.2 mi² or about 20 percent of Wilton. These stratified-drift deposits are found in continuous bands along Stony Brook, Blood Brook, a Stony Brook tributary, and the Souhegan River (pls. 1 and 2).

The most important aquifer available for additional development is along the Souhegan River near New Hampshire State Routes 101 and 31 (pls. 1 and 2). This aquifer extends from the Massachusetts border northward toward Wilton Center and westward up the valley of Blood Brook. Seismic-refraction and test-well data indicate the presence of about 80 ft of saturated sand and gravel in this area. Well W-6 in this aquifer has a yield of 500 gal/min. Transmissivity in the most thickly saturated part of this aquifer is greater than 8,000 ft²/d.

The aquifer along Stony Brook south of the Wilton-Lyndeborough town line is of limited areal extent but contains at least 40 ft of saturated sand and gravel. Potential exists for induced recharge from Stony Brook to supplement the yield of this aquifer. Although the transmissivity of this aquifer is less than 8,000 ft²/d, the aquifer may, upon testing, have the capacity to sustain one large-yielding well.

All other stratified-drift aquifers in Wilton, including those in the valleys of upper Blood Brook, Stony Brook tributary and lower Souhegan River contain stratified drift with transmissivity generally less than 2,000 ft²/d; this stratified drift is best suited for supplying water to individual households or other small users.

Estimates of Sustained Yield of Selected Aquifers

To meet the increasing water needs of consumers, wells within several aquifers currently are being pumped at maximum rate. However, many of these aquifers may still be capable of yielding additional quantities of water to wells. This section of the report describes the use of mathematical models for estimating potential yields of six aquifers within the study area. These aquifers were selected because of their importance and to demonstrate model use in various hydrogeological settings. It was considered beyond the scope of this report to assess the yield of each aquifer in the study area. In addition, consideration has not been given to low-flow maintenance or to water-quality ramifications caused by induced recharge in this analysis.

Computations of sustained yield were made with an analytical-mathematical model based on the Theis nonequilibrium equation (Theis, 1935), as modified by image well theory (Ferris and others, 1962) to account for boundary conditions.

These estimates take into account the effects of hydraulic boundaries of aquifers, aquifer hydraulic properties, well-construction characteristics, and possible well interferences (Mazzaferro and others, 1978). Calculation of sustained yield from hypothetical wells involves four basic steps: (1) determination of aquifer and well characteristics, (2) determination of an initial discharge rate, (3) determination of total drawdown in wells from information obtained in steps 1 and 2, and (4) determination of adjusted discharge rate so that total drawdown is at least 1 ft above the screened interval of each pumping well.

Aquifer characteristics incorporated into the models include saturated thickness, transmissivity, and storage coefficient. Using plates 2, 4, and 6, saturated thicknesses are determined for each real or hypothetical well site. Transmissivity (pls. 2, 4, and 6) assigned to each modeled area represents the average transmissivity over the entire model area. Storage coefficients used in model simulations ranged from 15 percent to 20 percent.

Construction characteristics of the real and hypothetical wells are incorporated in model simulations by assigning well-diameter values and the ratio of well-screen length to total saturated thickness. For hypothetical wells, the diameter was assumed to be 1 ft and screened intervals were assumed to be 30 percent of total aquifer saturated thickness; therefore, the total available drawdown at each well is assumed to be 70 percent of saturated thickness. Sustained yield of selected aquifers was determined for 180-day periods with no ground-water recharge; this is assumed to be the maximum no-recharge period in this study area.

The total drawdown at each pumping well is equal to drawdown produced by six basic components: (1) drawdown due to aquifer and well characteristics, (2) drawdown due to dewatering of the aquifer, (3) drawdown due to partial penetration of the aquifer by the pumping well, (4) drawdown due to well loss caused by flow into the screen, (5) drawdown caused by nearby pumping wells, and (6) drawdown (or buildup) caused by hydraulic boundaries.

Hydraulic boundaries that can be simulated with the Theis image-well model are line-source recharge boundaries, barrier (no-flow) boundaries, and open or infinite boundaries. Recharge boundaries represent unlimited sources of water that may be available to aquifers from surface-water bodies such as rivers, ponds, and lakes. Because recharge boundaries act as an unlimited source of water, they limit the cone of depression caused by a pumped well (fig. 5). Impermeable-barrier boundaries can be used to represent the contact between materials that have a large difference in permeability, such as the contact between stratified drift and till/bedrock. Drawdown caused by a pumped well is amplified along a barrier boundary (fig. 6) because there is no flow across this boundary.

Recharging or discharging image wells (Ferris and others, 1962) are used to simulate the effects of hydraulic boundaries. In this particular model, the above-mentioned aquifer boundaries must be idealized as straight lines that enclose a rectangular area in which one of the boundaries remains "open" (figs. 7 through 12).

The model determines the maximum discharge rate for a well such that total drawdown at the well is at least 1 ft above the well screen. In addition, drawdown caused by aquifer and well characteristics must be less than or equal to only 30 percent of saturated thickness at each well site. If drawdown for any well falls outside these limits, an adjustment to the discharge rate is made and drawdown is recalculated. This adjustment process is done iteratively until the above criteria are met.

The adjusted discharge for each pumping well within the modeled aquifer is then totalled to provide an estimate of sustained yield for the aquifer. The reliability of the estimated total sustained yield depends on how closely assumed conditions match actual field conditions in a given aquifer. Consideration also should be given to the actual amount of ground water available by comparing computed yields with low flow in nearby surface waters. Comparison of predicted yields with low flows will indicate if enough ground water is actually available to sustain the predicted yield.

Amherst-Beaver Brook Aquifer

This aquifer is located along Beaver Brook in Amherst from about Thorntons Ferry Road to Merrimack Road (fig. 7). The existing Amherst town well (W-18) is located at the northern end of this aquifer to the west of Beaver Brook. Pumping was simulated at the Amherst well (W-18) and at two additional locations within this aquifer in the model (fig. 7). The two additional locations were selected based upon exploratory drilling done in the area that indicated favorable conditions for well installation.

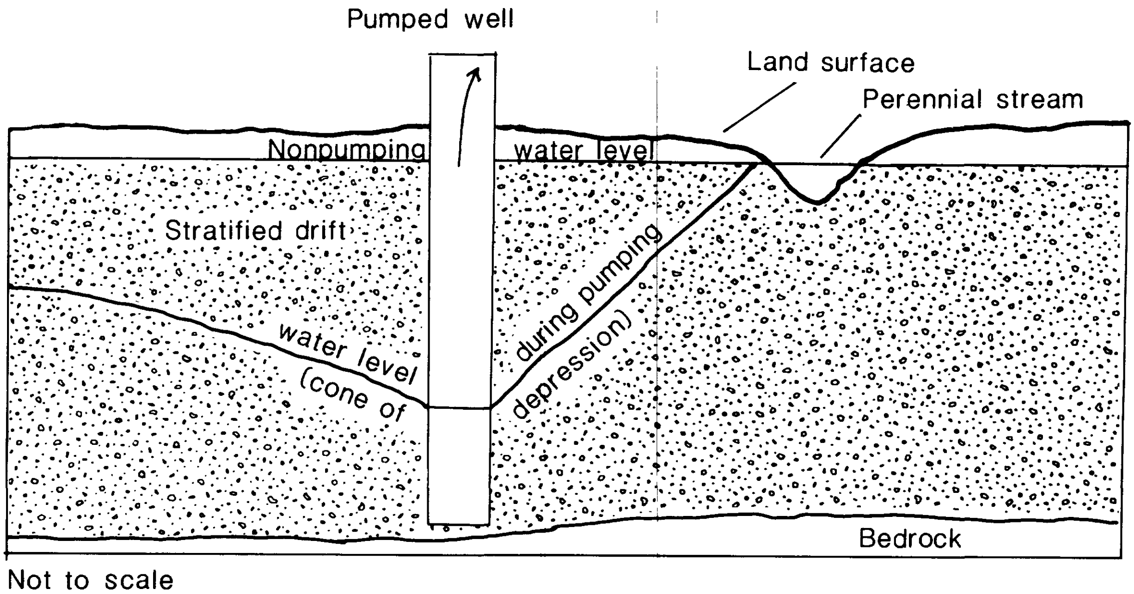


Figure 5.--Effects of a recharge boundary on the cone of depression of a pumped well.

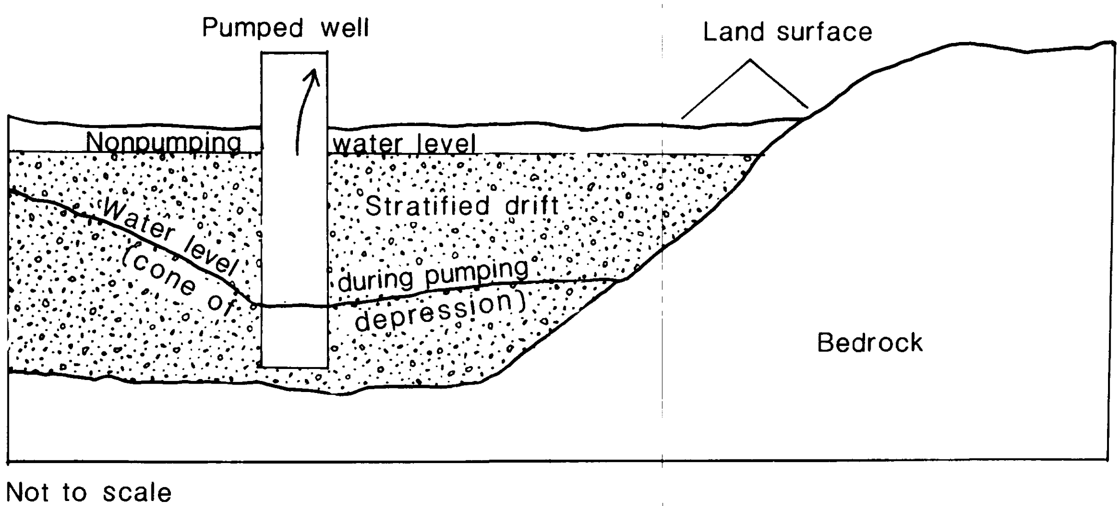


Figure 6.--Effects of a barrier boundary on the cone of depression of a pumped well.

0 1000 2000 3000 FEET
0 400 800 METERS

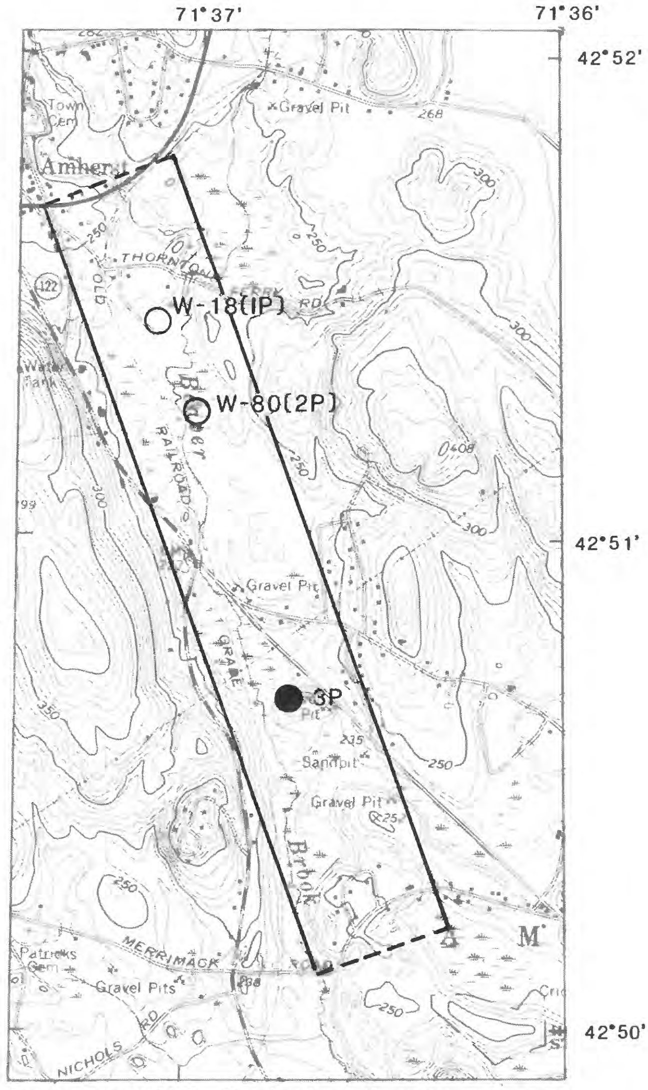
EXPLANATION

○ W-18 EXISTING WELL AND NUMBER

1P WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL

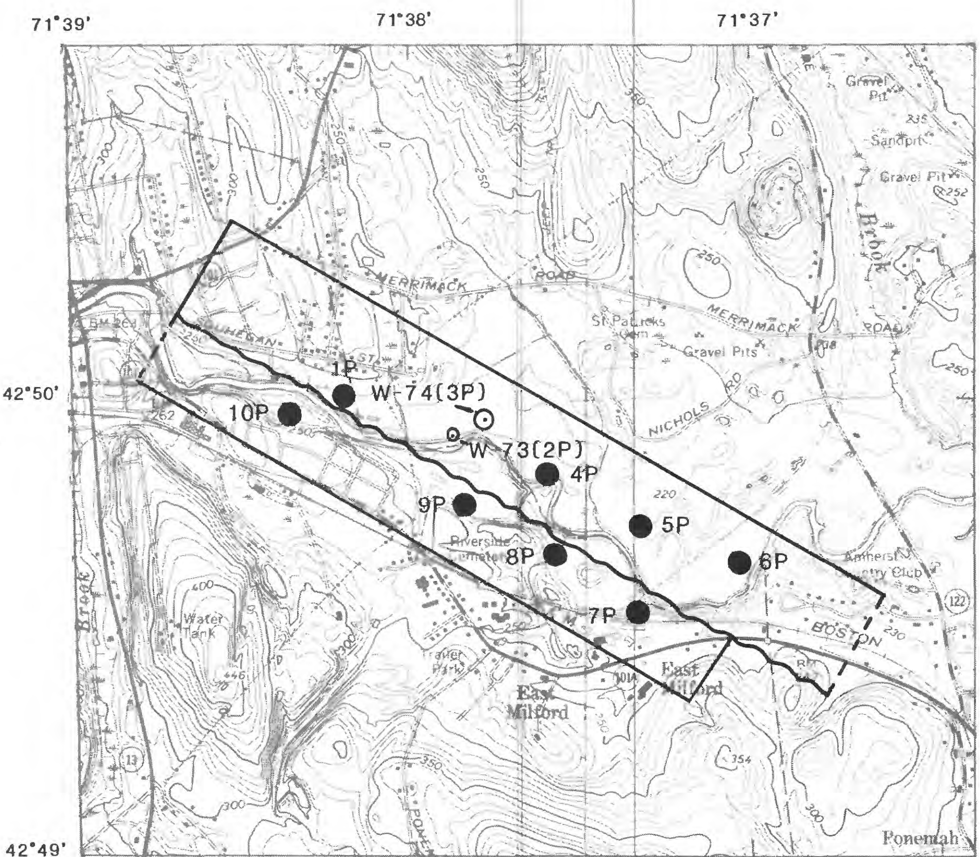
—— BARRIER BOUNDARY

- - - - OPEN BOUNDARY



Base From U.S. Geological Survey 1:24,000
South Merrimack, 1968, Photorevised 1985

Figure 7.--Boundaries and well placement for sustained-yield estimate of the Amherst-Beaver Brook aquifer.



Base From U.S. Geological Survey 1:24,000
Milford 1968, Photoinspected 1974,
South Merrimack 1968, Photorevised 1985.

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

W-73 EXISTING WELL AND NUMBER

HYPOTHETICAL WELL SITE

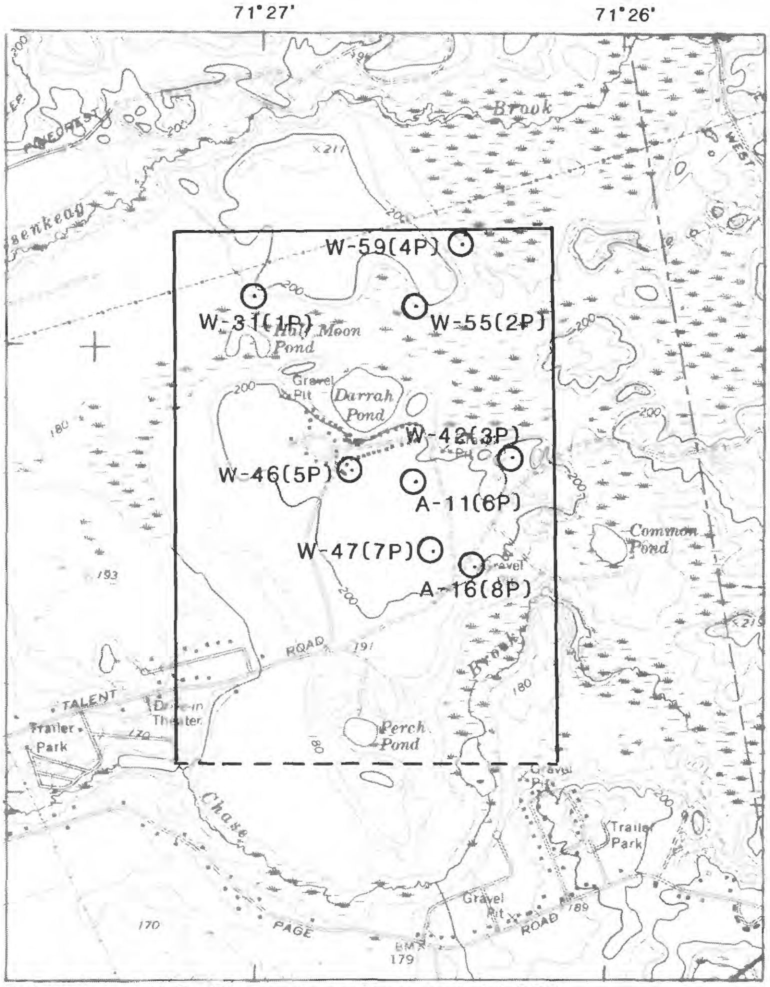
1P WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL

RECHARGE BOUNDARY

BARRIER BOUNDARY

OPEN BOUNDARY

Figure 8.--Boundaries and well placement for sustained-yield estimate of the Amherst-Milford Souhegan River aquifer.



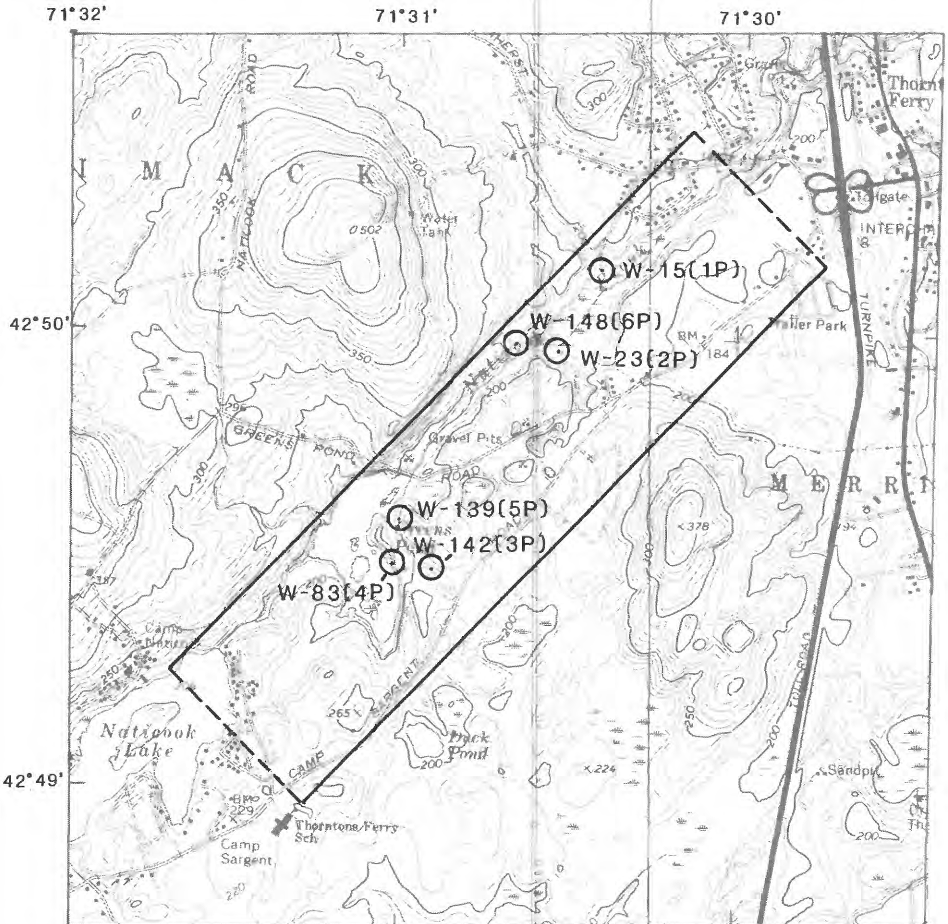
Base From U.S. Geological Survey 1:24,000
Nashua North, 1968, Photorevised 1974

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

⊙ W-59	EXISTING WELL AND NUMBER
⊙ A-11	AUGER BORING SITE AND NUMBER
1P	WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL
——	BARRIER BOUNDARY
- - - -	OPEN BOUNDARY

Figure 9.--Boundaries and well placement for sustained-yield estimate of the Litchfield-Darrah Pond aquifer.



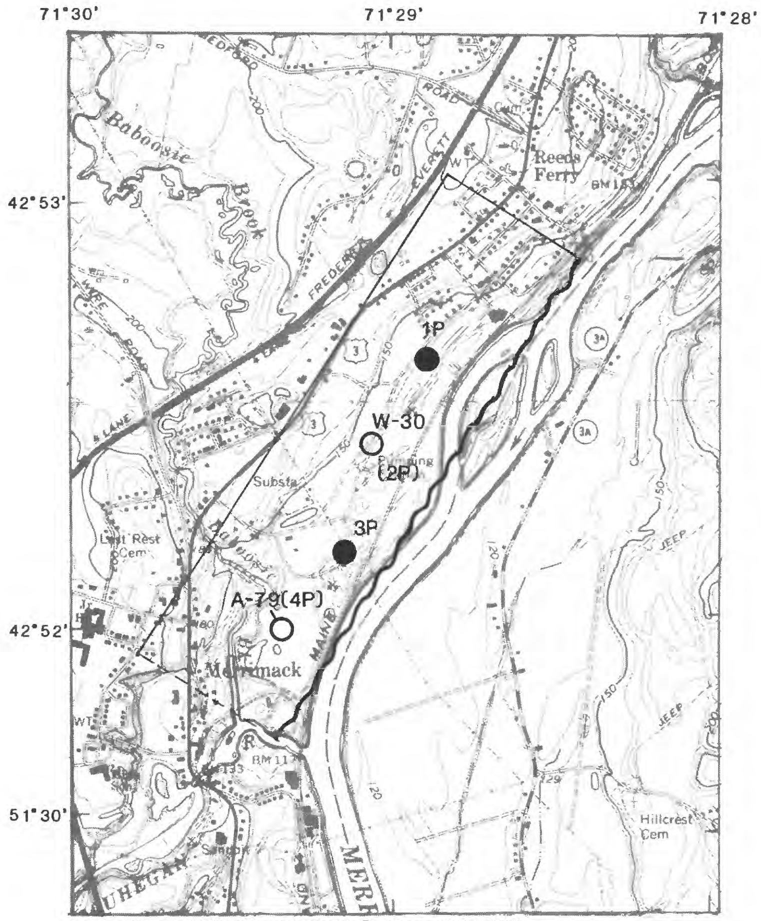
Base From U.S. Geological Survey 1:24,000
South Merrimack, 1968, Photorevised 1985
Nashua North, 1968, Photorevised 1974

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

⊙ W-15	EXISTING WELL AND NUMBER
1P	WELLS WHERE PUMPING WAS SIMULATED IN THE MODEL
———	BARRIER BOUNDARY
- - - -	OPEN BOUNDARY

Figure 10.--Boundaries and well placement for sustained-yield estimate of the Merrimack-Naticook Brook aquifer.



Base From U.S. Geological Survey 1:24,000
Nashua North 1968, Photorevised 1974,
Manchester South 1968.

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

○ W-30 EXISTING WELL AND NUMBER

○ A-79 AUGER BORING SITE AND NUMBER

● HYPOTHETICAL WELL SITE

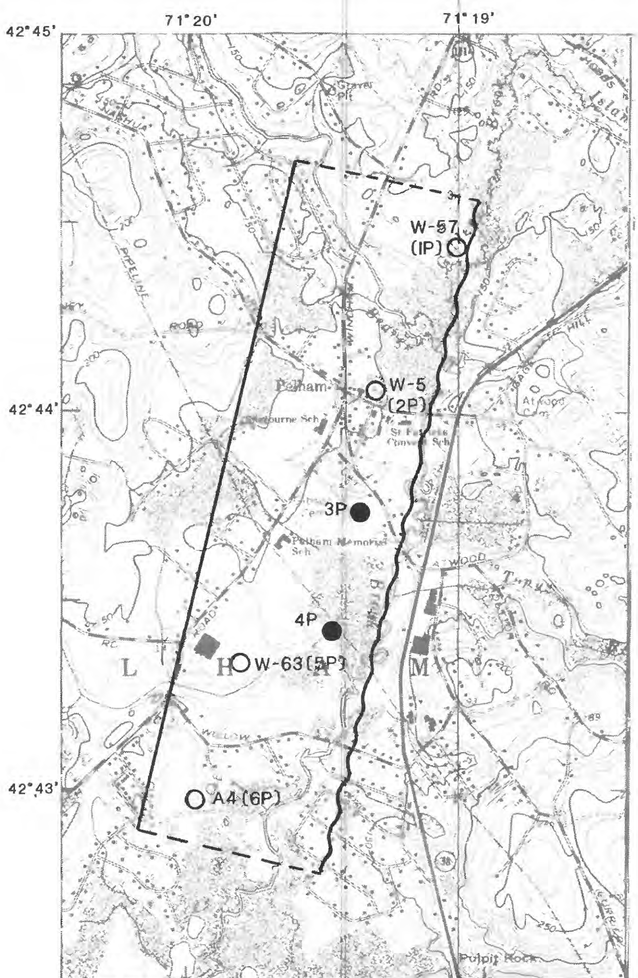
1P WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL

RECHARGE BOUNDARY

BARRIER BOUNDARY

OPEN BOUNDARY

Figure 11.--Boundaries and well placement for sustained-yield estimate of the Merrimack-Merrimack River aquifer.



Base From U.S. Geological Survey 1:24,000
Lowell-Mass.-N.H., 1966

0 1000 2000 3000 FEET
0 400 800 METERS

EXPLANATION

○ W-57	EXISTING WELL AND NUMBER
○ A-4	AUGER BORING SITE AND NUMBER
●	HYPOTHETICAL WELL SITE
1P	WELL OR AUGER BORING SITES WHERE PUMPING WAS SIMULATED IN THE MODEL
∿∿	RECHARGE BOUNDARY
——	BARRIER BOUNDARY
- - - -	OPEN BOUNDARY

Figure 12.--Boundaries and well placement for sustained-yield estimate of the Pelham-Beaver Brook aquifer.

In the model, the contacts between the stratified-drift aquifer and till along the edges of the valley were simulated as two barrier boundaries and because the aquifer continues beyond the modeled area the north and south ends were treated as "open" or infinite boundaries. Beaver Brook was not simulated as a recharge boundary because it has very little flow during summer periods (site 09, table 1). Therefore, the model simulates flow of ground water derived entirely from storage within the aquifer. Saturated thickness ranged from 25 to 50 ft, and transmissivity averaged 5,000 ft^2/d in the modeled area (pls. 2, 4, and 6).

Model results indicate that potential sustained yield of 0.6 Mgal/d could be derived from the three wells shown in figure 7. The existing production well (W-18) pumps 0.2 Mgal/d; therefore, under the hydrologic conditions specified above, an additional 0.4 Mgal/d could be pumped from this aquifer. The total estimated yield of 0.6 Mgal/d is probably conservative, because induced recharge from Beaver Brook could occur during periods of increased surface-water runoff in the spring and early summer.

Amherst-Milford Souhegan River Aquifer

This aquifer is situated along the Souhegan River in western Amherst and extends east of Milford center (fig. 8). Two existing Milford town wells (W-73 and W-74) are located in the central part of this model area north of the Souhegan River. Eight additional hypothetical pumping wells were simulated in the model--four to the north and four to the south of the river (fig. 8).

The contacts between the aquifer and till valley walls were simulated as barrier boundaries in the model; the Souhegan River was simulated as a line-source recharge boundary. Because the aquifer is continuous along the valley beyond the modeled area, the end boundaries were left open. The modeled area was assumed to have an average transmissivity of 8,500 ft^2/d.

Model results indicate that the aquifer would provide a total sustained yield of 7.6 Mgal/d to the eight wells shown in figure 8. Wells W-73 (2P) and W-74 (3P), have a combined yield of 1.6 Mgal/d. An additional 6.0 Mgal/d could be obtained from the six additional wells simulated in the model (fig. 8). The discharge of the Souhegan River during base-flow conditions, downstream from the aquifer, was measured at 26.5 ft^3/s on August 28, 1984 (site 14, table 1, pl. 3). Under the modeled pumping scenario, the discharge of the Souhegan River downstream of this aquifer would be reduced by 9.0 ft^3/s (6.0 Mgal/d) if all pumped water were used consumptively.

Litchfield-Darrah Pond Aquifer

The Darrah Pond aquifer is located in central Litchfield and is approximately centered about Darrah Pond (fig. 9). Seismic-refraction profiling and test drilling indicate the presence of a buried valley running north-south through this area. The Darrah Pond well (W-59) is located in the northern part of this aquifer and yields 100 gal/min to residences in central Litchfield. In the model, seven additional wells were simulated at locations where test drilling showed favorable conditions (fig. 9).

The modeled area was simulated as having barrier boundaries to the north, east, and west where saturated thickness of the aquifer is 20 ft or less. The southern boundary of the model was left open to simulate the continuous aquifer deposit in that direction. Average transmissivity was modeled as 5,000 ft^2/d.

Model results show that the total sustained yield from this aquifer could be approximately 2.3 Mgal/d. This probably is a conservative estimate of potential yield because the model assumes no significant sources of induced recharge and withdrawal of water is obtained only from storage.

Merrimack-Naticook Brook Aquifer

The Naticook Brook aquifer is located along Naticook Brook northeast of Naticook Lake (fig. 10) in Merrimack. At present, three municipal wells (W-15, W-23, and W-148) located along Naticook Brook in the central part of this aquifer yield 1.3 Mgal/d. Additional pumping was simulated at three locations (W-142, W-83, and W-139) where test drilling showed sites that were favorable for ground-water withdrawal.

The model boundaries were simulated as no flow along the contact of the stratified-drift aquifer and till/bedrock valley walls. The continuous aquifer deposits were simulated with open boundaries on the northeastern and southwestern edges of the model. Because low flow in Naticook Brook was observed to be 0.2 ft^3/s or less (table 1), the surface water was not simulated as a recharge boundary. Transmissivity in the modeled area was assumed to average 10,000 ft^2/d.

Model results show that a total yield of approximately 3.4 Mgal/d could be obtained from the three existing and three proposed wells, or an increase of 2.0 Mgal/d above the existing pumping rate. This total yield is considered to be conservative, because some recharge could probably be obtained from Naticook Brook at high flows or from Naticook Lake and because some flow of water would probably occur across the till/stratified-drift boundary.

Merrimack-Merrimack River Aquifer

This aquifer is located along the Merrimack River north of the Souhegan River in Merrimack (fig. 11). The Reeds Ferry municipal well (W-30), located in the center of aquifer area, pumps 0.8 Mgal/d. Additional pumping was simulated at three additional sites where drilling showed conditions were favorable for well construction (fig. 11).

In the model, the Merrimack River was simulated as a line-source recharge boundary. The northern and western edges of the model were treated as barrier boundaries to simulate thin saturated thickness and low transmissivity. The southern boundary of the model was left "open" to simulate continuous aquifer material beyond the modeled area. Transmissivity within the model area was assumed to average 7,000 ft^2/d.

Model results indicate that the four wells have a total potential yield of 1.9 Mgal/d. At this site, total well yield depends on recharge from the Merrimack River. Flow in the river is sufficient to sustain much greater yields than those simulated with the model.

Pelham-Beaver Brook Aquifer

The aquifer, located along Beaver Brook in central Pelham (fig. 12), extends from the mouth of Golden Brook on the north, to Willow Street on the south. Well W-63 pumps approximately 400 gal/min from the central part of this aquifer. The logs of several test borings (W-57, W-55, W-62, and A-4) in the central part of the valley west of Beaver Brook indicate favorable conditions for well construction. Additional pumping from six locations in the aquifer was simulated.

The model area has a recharge boundary on the east to simulate Beaver Brook and a barrier boundary on the west to simulate the stratified-drift till contact. The northern and southern boundaries were left "open" to simulate continuous aquifer deposits beyond the model area. Saturated thickness ranges from 30 to 100 ft and transmissivity averages 9,000 ft^2/d (pl. 6) in the modeled area.

Modeled results indicate a potential total yield of 3.8 Mgal/d from six wells within this aquifer; this represents an increase of 2.3 Mgal/d over the current yield. The measured streamflow in Beaver Brook during base-flow conditions at the downstream end of the modeled area was 11.5 ft^3/s (site 44, table 1). Under the modeled pumping scenario, discharge at Beaver Brook would be reduced by about 3.5 ft^3/s, if all pumped water is used consumptively.

WATER QUALITY

Stratified-drift aquifers are particularly susceptible to contamination from human activities, because they have thin, highly permeable, unsaturated zones. Contaminants can readily travel from the land surface to the water table with little or no filtration. Land-use activities that can adversely affect ground-water quality include, but are not limited to, underground petroleum storage, fertilizer application, underground waste disposal, and road salting.

Two CERCLA "superfund" sites are within the study area, at Gilson Road in Nashua and Savage well in Milford. More than 1,300 55-gallon drums and 900,000 gallons of hazardous waste were disposed of at the 7-acre Gilson Road site. At present, contaminated ground water at the Gilson site is being collected and treated. At the Savage well site, municipal wells for the town of Milford were contaminated with organic chemicals. Four companies have been working on a plan to address the problem.

The New Hampshire Water Supply and Pollution Control Commission (1982) has identified other land-use activities that could have an adverse effect on the water quality of surface water and ground water in the Nashua region. Discussed in that report are: nonpoint potential pollution sources, such as agricultural, industrial, and domestic waste disposal; and point sources, including landfills, dumps, hazardous-waste sites, and salt-storage areas. Sources of information on point sources of contamination are listed in a report by Metcalf and Eddy, Inc. (1983).

Water-quality samples were collected at 14 surface-water and 32 ground-water locations during November 1-7, 1983, to characterize background water quality in the study area. Water-quality sampling and analytical work was done by the U.S. Geological Survey and by Metcalf and Eddy, Inc., (consultants) according to standard procedures developed by the U.S. Geological Survey (Goerlitz and Brown, 1972) and the American Public Health Association (1980). The water-quality results summarized in subsequent sections of this report have been published by Metcalf and Eddy, Inc., (1983).

Ground Water

The natural chemical composition of ground water derived from unconsolidated aquifers depends on several factors, including precipitation chemistry; subsurface physical, chemical, and biological reactions; and the mineralogy of the aquifer materials. Residence time of water in an aquifer, which depends on the distance and rate that ground water travels from recharge to discharge areas, also is an important factor in natural ground-water geochemistry. Ground water in natural discharge areas generally is higher in dissolved solids than water obtained from recharge areas because of the longer contact time with aquifer materials.

Ground-water quality sampling was conducted on November 1-3 and 7, 1983, at 32 locations throughout the Nashua region including: 15 domestic wells, 11 municipal wells, 6 U.S. Geological Survey observation wells. Sampling locations were specifically selected to avoid any known point sources of contamination to obtain information on background water quality. A summary of results of chemical analysis is shown in table 4, and sampling locations are shown on plates 1, 3, and 5.

Physical and Chemical Properties

Dissolved solids

The dissolved-solids content of natural waters consists mainly of inorganic chemicals such as bicarbonates, carbonates, chlorides, sulfates, and phosphates. Elevated concentrations of dissolved solids can be used as an indicator of human-introduced contamination in areas where concentrations are normally low. The USEPA-recommended drinking-water limits for total dissolved solids are set at a maximum of 500 mg/L, based primarily on taste considerations (U.S. Environmental Protection Agency, 1976).

Concentration of total dissolved solids was typically less than 200 mg/L and did not vary greatly across the region (fig. 13). The highest concentrations, 470 and 580 mg/L, were found in shallow dug wells in Mont Vernon and Nashua (Metcalf and Eddy, Inc., 1983), respectively. The high levels of dissolved solids observed in both wells are due to high levels of sodium and chloride that originated from road-deicing operations. Thirty other wells had a concentration of total dissolved solids that averaged 115 mg/L and ranged from 50 to 210 mg/L (table 4), indicating that background concentrations are relatively low as compared to the USEPA drinking-water recommended limit.

pH

The pH of water is a measure of the hydrogen-ion activity and is used in expressing the acidity or alkalinity of water on a scale of 0 to 14. At pH 7.0, water is considered neutral, increasingly acidic at values less than 7.0, and increasingly alkaline at values greater than 7.0. Natural water generally has a pH range of from 6.5 to 8.5 (Hem, 1970), which is also the range of USEPA drinking-water recommended limit (U.S. Environmental Protection Agency, 1976). The pH of ground water is primarily controlled by interaction with carbon-dioxide gas and with carbonate and bicarbonate ions. The hydrogen-ion activity is important in that it affects taste and corrosivity of drinking water. At a pH of less than 6.5, metals from plumbing and water-distribution systems, such as copper, zinc, cadmium, and lead, can dissolve in water and cause health problems.

The average pH of 32 samples was 6.2 and ranged from 5.0 to 7.3 (table 4). Water from 28 wells had a pH below that of the USEPA drinking-water recommended limit of 6.5 to 8.5.

Chloride

Recommended limits for chloride concentrations in drinking water are based on taste rather than on health considerations. The USEPA recommended maximum limit for chloride is 250 mg/L (U.S. Environmental Protection Agency,

Table 4.--*Summary of ground-water quality*

[Modified from Metcalf and Eddy, Inc., 1983.]

Constituent or property	Number of samples	Average concentration, in milligrams per liter	Range, in milligrams per liter		
Chloride (Cl)	32	37.97	230.0	-	2.0
Chemical oxygen demand (COD)	22	13.0	82.0	-	5.3
Specific conductance (microsiemens per centimeter at 25 °C)	29	217	880	-	47.0
Nitrate (NO_3 as N)	31	1.59	6.0	-	.018
pH	32	6.17	7.3	-	*5.0
Total dissolved solids	32	140.25	*580.0	-	50.0
Total organic carbon (TOC)	23	6.3	90.0	-	.37
Barium (Ba)	33	.018	.097	-	.001
Silver (Ag)	8	.002	.006	-	.001
Arsenic (As)	1	.05	--		--
Copper (Cu)	27	.059	.642	-	.001
Cadmium (Cd)	5	.00068	.001	-	.001
Chromium (Cr)	2	.029	.045	-	.012
Iron (Fe)	28	*3.63	*78.2	-	.006
Manganese (Mn)	32	*.20	2.01	-	.001
Sodium (Na)	32	*23.9	*119.0	-	1.7
Nickel (Ni)	6	.008	.024	-	.003
Zinc (Zn)	25	.021	.076	-	.001
Lead (Pb)	6	.015	.02	-	.01

*Exceeds maximum drinking water limit set by the U.S. Environmental Protection Agency, 1976.

1976). Chloride is not readily absorbed by rock and soil particles and is, therefore, highly mobile in water. Elevated concentrations of chloride may indicate contamination from highway deicing chemicals, salt-storage piles, landfills, and municipal and domestic sewage-disposal systems.

All chloride concentrations in the samples analyzed were below the USEPA drinking-water recommended limit of 250 mg/L. The highest concentrations, 180 and 230 mg/L, were detected in shallow dug wells in Mont Vernon and Nashua, respectively. Water from these two wells were far above the average concentration of 33 mg/L detected at 30 additional wells (table 4).

Sodium

A maximum sodium concentration of 20 mg/L has been recommended by USEPA for drinking-water supplies to help regulate sodium in the diet, which, in excess amounts, can lead to cardiac disease, renal disease, and cirrhosis of the liver (U.S. Environmental Protection Agency, 1976). As much as 40 percent of the public-water supplies of the United States had natural or added sodium concentrations above the 20-mg/L limit. Sodium is one of the most common cations in nature, but the natural sodium content is augmented in many areas by stored and spread highway-deicing salts, sewage-disposal systems, and industrial and agricultural waste.

Sodium concentrations averaged 24 mg/L across the study area, ranging from 1.7 to 119 mg/L (table 4). The USEPA drinking-water recommended limit of 20 mg/L (U.S. Environmental Protection Agency, 1976) for sodium was exceeded at 11 of the sampling sites. The maximum value of 119 mg/L was observed in water from a shallow dug well in Mont Vernon in an area where the water in many wells is affected by highway salting.

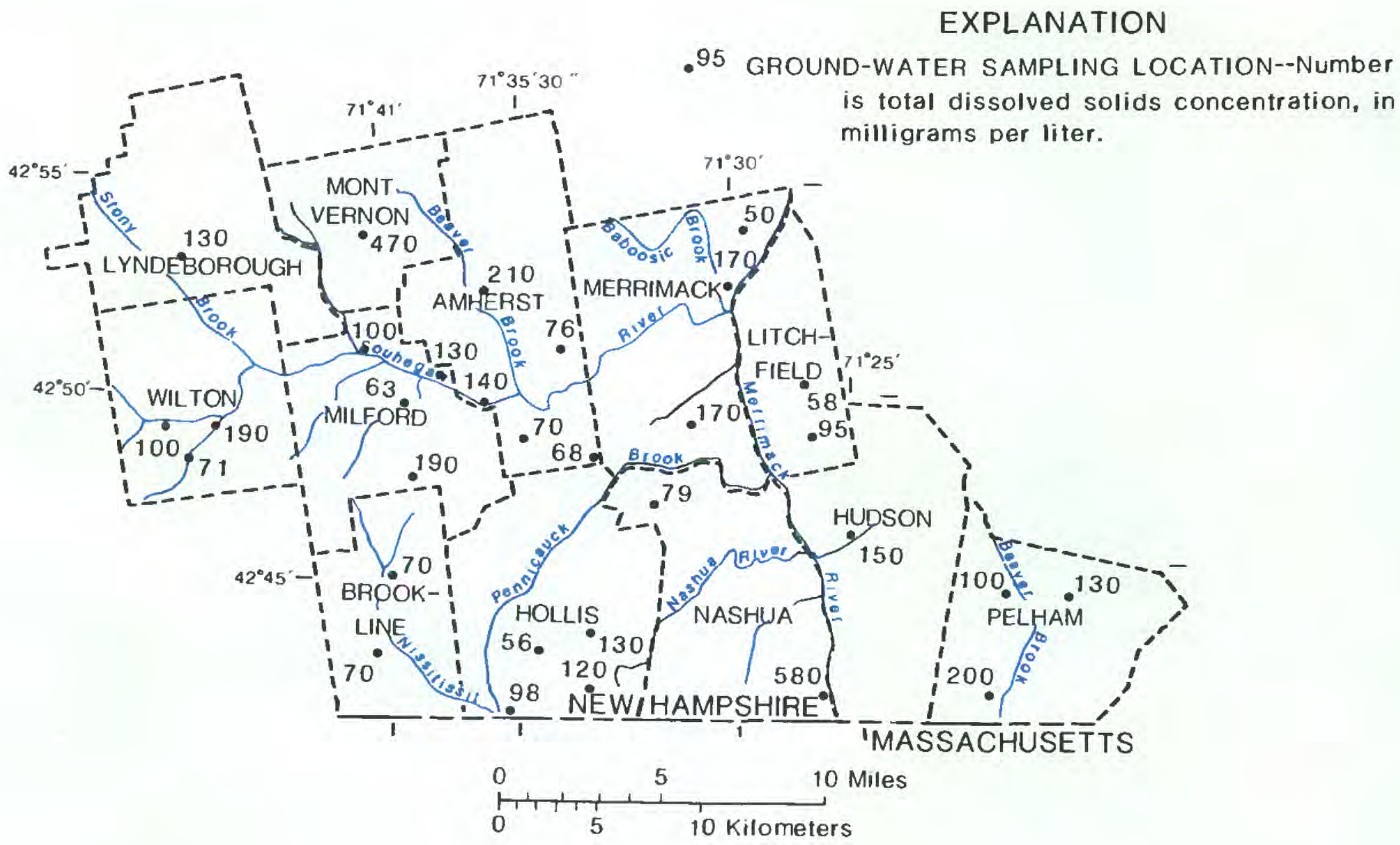


Figure 13.--Distribution of total dissolved solids at ground-water-sampling sites.

Nitrate

The predominant form of inorganic nitrogen found in natural waters is nitrate nitrogen, which results from oxidation of nitrogenous compounds. The USEPA drinking-water recommended limit for nitrate as nitrogen is set at 10 mg/L (U.S. Environmental Protection Agency, 1976) primarily because greater concentrations can cause or contribute to methemoglobinemia or "blue baby" disease. Concentrations greater than the standard may indicate contamination by excess application of fertilizer, leachate from domestic waste disposal from animal feedlots, and municipal sewage effluent. Nitrate concentrations in the study area were below USEPA drinking-water recommended limits, averaged 1.6 mg/L, and ranged from 0.02 to 6.0 mg/L (table 4).

Iron and manganese

Elevated levels of iron and manganese are common in ground water from stratified-drift aquifers. Chemically reducing conditions in ground water promote solution of iron and manganese, which, when exposed to the atmosphere, precipitate out as iron and manganese oxides. The USEPA maximum recommended limits for iron and manganese in drinking water are 0.3 and 0.05 mg/L, respectively (U.S. Environmental Protection Agency, 1976). The standards are based on aesthetic considerations because high levels of iron and manganese can cause unpleasant tastes, staining of laundry and plumbing fixtures, and growth of iron bacteria in water-distribution systems.

Iron and manganese concentrations averaged 3.6 and 0.20 mg/L (table 4), respectively, in samples from 32 wells, 7 wells exceeded both standards and 3 wells exceeding the manganese standard only. Iron concentrations ranged from 0.01 to 78 mg/L, and manganese concentrations ranged from 0.001 to 2.0 mg/L. Three out of the 11 public-water supplies sampled also exceeded either the iron or manganese standard. Treatment to remove elevated concentrations of iron and manganese may be necessary in areas where water is otherwise acceptable for drinking. Removal of iron and manganese from ground water currently is being practiced on water that supplies the Milford

Fish Hatchery, because high levels of these constituents are harmful to trout and salmon fry.

Trace elements

Water samples were analyzed for the following trace elements: Arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, silver, and zinc. Natural waters usually contain most of these elements in trace quantities, and many are essential for metabolism. Water from Pelham well W-55 had an arsenic concentration of 0.05 mg/L, which is the USEPA recommended drinking-water limit for arsenic (U.S. Environmental Protection Agency, 1976). Water from all other wells had concentrations of arsenic and other trace elements below USEPA drinking-water limits throughout the region.

Organic chemicals

The TOC (total organic carbon) determination is useful in assessing the degree of organic loading of natural waters. Organic substances generally are found in low concentrations in ground water, and excess amounts may indicate human-introduced pollutants. TOC is a measure of suspended and dissolved organic materials. Natural waters are known to have TOC concentrations ranging from 1 to 30 mg/L (Hem, 1970); and, although there are no specific regulatory criteria established for TOC, waters containing less than 3.0 mg/L TOC have been described as relatively clean (Environment Canada, 1977).

The highest concentration of TOC (90 mg/L) was from a shallow dug well in Nashua (Metcalf & Eddy, Inc., 1983), which also had water with elevated concentrations of total dissolved solids, sodium, and chloride. The average concentration of TOC for all wells (except the shallow dug well in Nashua) was 2.5 mg/L, ranging from 0.37 to 15 mg/L (table 4).

Specific organic analysis conducted on all water samples included the following groups of organic compounds: Volatile organics, acid extractables, base/neutral extractables, pesticides, and polychlorinated biphenyls. In none of the samples were organics found above the detection limit for each compound listed in the report by Metcalf & Eddy, Inc. (1983). This was determined after resampling several wells that originally contained organic contaminants which later were determined to be laboratory contaminants.

Surface Water

Rivers and streams across the Nashua region generally are classified as Class B (New Hampshire Water Supply and Pollution Control Commission, 1982). Class B waters are acceptable for bathing and recreation, fish habitat, and public-water supply after adequate treatment. Disposal of sewage or wastes is not allowed unless adequately treated.

Class A waters include the Witches Brook and Pennichuck Brook drainages, which are the watershed lands for the Pennichuck Water Company surface-water-supply system. The Stony Brook tributary in Wilton is the only other Class A system and supplies water to the Wilton Reservoir. Class A waters are potentially acceptable for public-water supply after disinfection and if they receive no discharges of sewage or other wastes.

Class C waters include the mouths of Pennichuck Brook and Salmon Brook, the entire reach of the Nashua River from the Massachusetts State line to the Merrimack River, and the Merrimack River from the confluence with the Nashua River to the Massachusetts State line. Class C waters are acceptable only for recreational boating, fishing, and industrial water supply with or without treatment.

These classifications are based on regulations set by the New Hampshire Water Supply and Pollution Control Commission and the U.S. Environmental Protection Agency (1971). Where induced infiltration of Class A or Class B surface water occurs, the overall quality of ground water is considered to be unaffected. Induced infiltration of Class C water is considered to degrade the quality of ground water from that suitable for public supply to that suitable only for industrial water supply.

Surface-water samples were collected at 14 locations in most of the major drainage basins within the study area. The sampling was conducted on November 1-3, 1983, when flow in rivers of the study area was at a rate that was equalled or exceeded 90 percent of the time (Blackey and others, 1984). The dissolved-solids concentration of surface water is inversely related to streamflow; the highest concentration is at low flow when streamflow is largely derived from ground-water discharge.

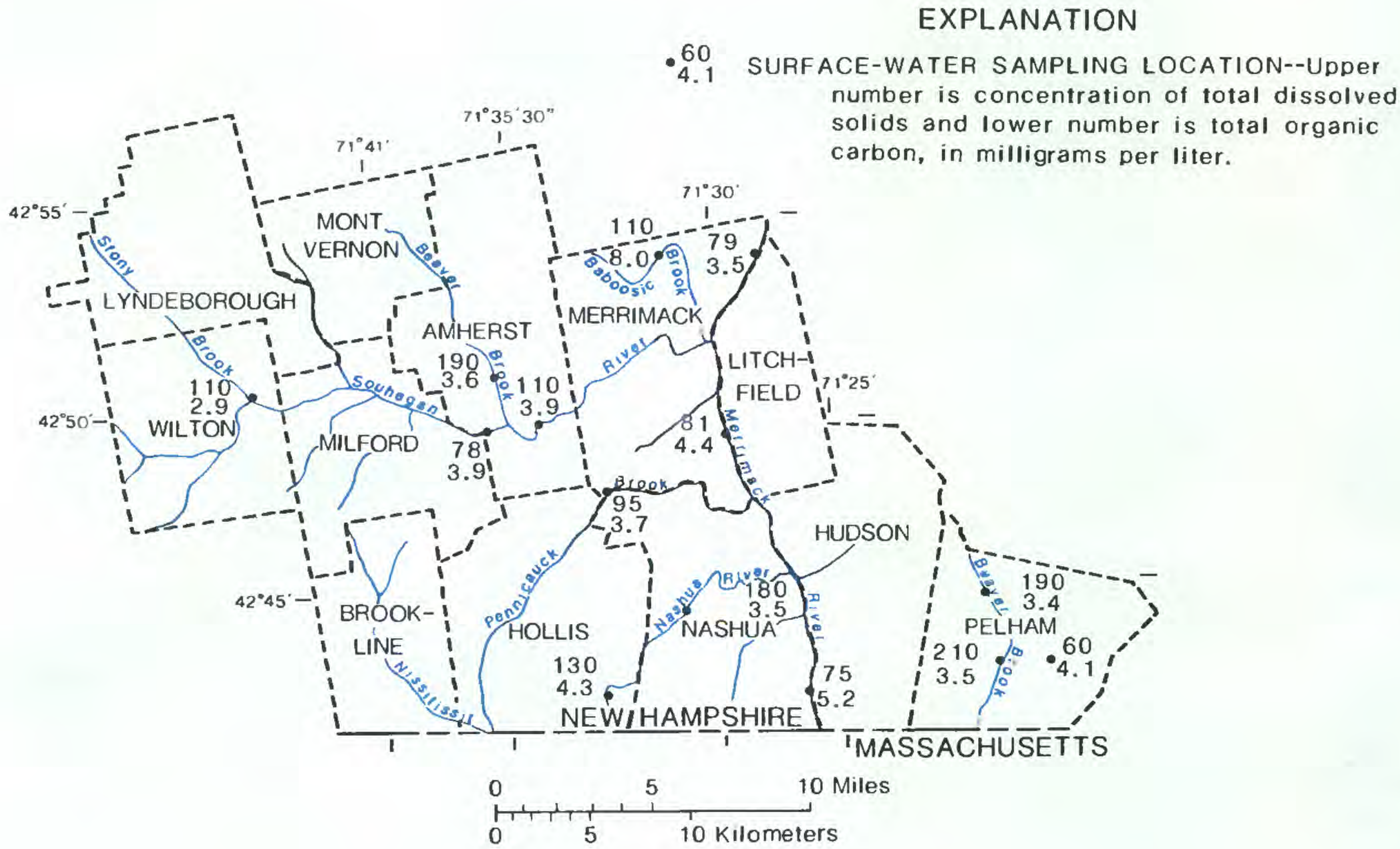


Figure 14.--Distribution of total dissolved solids and total organic carbon at 14 surface-water-sampling sites.

Concentration of total dissolved solids in surface-water samples averaged 121 mg/L (fig. 14) and ranged from 60 to 210 mg/L (table 5), indicating that under low-flow conditions, the overall chemical quality of streams is good. Components of the total dissolved-solids determination, sodium and chloride, average 15.0 mg/L and 27.3 mg/L, respectively, which are well below the USEPA drinking-water limit.

Concentrations of TOC ranged from 2.9 mg/L to 8.0 mg/L (fig. 14), averaging 4.2 mg/L across the region. Concentration is relatively low and evenly distributed throughout the region except for the sample from Baboosic Brook in northern Merrimack, which had the highest concentration of TOC (8.0 mg/L).

The COD (chemical oxygen demand) of surface water averaged 20.5 mg/L and ranged from 7.3 to 50.0 mg/L. The highest COD's observed were 34.0 mg/L at the Souhegan River in Wilton and 50.0 mg/L at the Nashua River in Nashua. Historical data from U.S. Geological Survey gaging stations on the Nashua and Merrimack Rivers show COD concentration of 35 mg/L and 18 mg/L, respectively. Other COD's of miscellaneous streams in southern New Hampshire generally ranged from about 10 to 50 mg/L.

The pH of surface-water samples was slightly on the acidic side, ranging from 5.9 to 6.7 and averaging 6.4.

Trace metals were generally within USEPA recommended limit for drinking-water supplies except for iron and manganese. Iron averaged 0.33 mg/L and ranged from 0.07 to 0.71 mg/L; manganese averaged 0.045 mg/L and ranged from 0.022 to 0.094 mg/L. These data show the wide distribution of naturally occurring iron and manganese throughout the Nashua region.

No widespread organic compounds or polychlorinated biphenyls were detected in surface-water samples from across the region. The pesticide endrin aldehyde was found at the Nashua River in Hollis at a concentration of 0.394 mg/L.

Table 5--*Summary of surface-water quality*

[Modified from Metcalf and Eddy, Inc. 1983.]

Constituent or property	Number of samples	Average concentration, in milligrams per liter	Range, in milligrams per liter		
Chloride (Cl)	14	27.3	60.0	-	14.0
Chemical oxygen demand (COD)	14	20.5	50.0	-	7.3
Specific conductance (microsiemens per centimeter at 25 °C)	14	155	270	-	77.0
Nitrate (NO_3 as N)	14	.29	.92	-	.02
Nitrite (NO_2)	2	.02	.024	-	.02
pH	12	6.37	6.7	-	5.9
Total dissolved solids	14	121	210	-	60.0
Total organic carbon (TOC)	13	4.23	8.0	-	2.9
Barium (Ba)	14	.012	.029	-	.007
Iron (Fe)	14	*.333	*.714	-	.071
Copper (Cu)	8	.006	.020	-	.001
Manganese (Mn)	14	.045	.094	-	.0223
Sodium (Na)	14	15.01	30.1	-	7.5
Zinc (Zn)	7	.006	.009	-	.002
Nickel (Ni)	1	.004	--		--
Antimony (Sb)	1	.02	--		--

*Exceeds maximum drinking water limit set by the U.S. Environmental Protection Agency, 1976.

SUMMARY AND CONCLUSIONS

Stratified-drift deposits cover about 129 mi² or 40 percent of the land area in the 12-community Nashua Regional Planning Commission area in south-central New Hampshire. The stratified-drift deposits are important aquifers where they have sufficient saturated thickness and permeability to yield large quantities of water to wells. The saturated thickness of stratified drift in the study area ranges from less than 20 ft near valley walls to more than 100 ft in the Souhegan River valley in the town of Amherst and in the Merrimack River valley in the towns of Merrimack and Litchfield. The transmissivity of stratified drift ranges from less than 2,000 ft²/d throughout much of the study area to more than 8,000 ft²/d in the communities of Amherst, Brookline, Hollis, Hudson, Litchfield, Merrimack, Milford, Nashua, and Pelham.

At present, the estimated total yield of all community water-supply systems in the study area is 22 Mgal/d. Analytical modeling indicates that an additional 12 Mgal/d could be obtained from six aquifers located in the communities of Amherst, Litchfield, Merrimack, Milford, and Pelham. Other aquifers in the area, not modeled in this study, also could provide increased amounts of water, especially where yields could be augmented by induced recharge from surface water.

The quality of ground water in the study area is suitable for most uses, except for locally elevated concentrations of iron and manganese. Elevated levels of sodium and chloride in shallow dug wells probably reflect the use of highway deicing chemicals in the area. Surface-water quality in major rivers of the study area is suitable for most uses with appropriate treatment. Endrin aldehyde was the only organic compound detected in a surface-water sample from the Nashua River in Hollis.

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GLOSSARY

Aquifer. A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield significant quantities of water to wells and springs.

Aquifer test. An analysis of change in water levels in an aquifer caused by withdrawals through wells.

Bedrock. Solid rock, commonly called "ledge," that forms the earth's crust. It is locally exposed at the surface but more commonly is buried beneath a few inches to more than 150 ft of unconsolidated deposits.

Cone of depression. A depression produced in a water table or other potentiometric surface by the withdrawal of water from an aquifer; in cross section, shaped like an inverted cone with its apex at the pumped well.

Contact. A plane or irregular surface between two different types or ages of rocks.

Cubic feet per second. A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream 1 ft wide and 1 ft deep flowing at an average velocity of 1 foot per second.

Dissolved solids. The residue from a clear sample of water after evaporation and drying for 1 hour at 180 °C; consists primarily of dissolved mineral constituents, but may also contain organic matter and water of crystallization.

Drainage area. The area or tract of land, measured in a horizontal plane, that gathers water and contributes it ultimately to some point on a stream channel, lake, reservoir, or other water body.

Drawdown. The lowering of the water table or potentiometric surface caused by the withdrawal of water from an aquifer by pumping; equal to the difference between the static water level and the pumping water level.

Drumlin. An elongated oval shaped hill consisting of glacial till.

Esker. Long ridges of sand and gravel that were deposited by running water in tunnels within or beneath stagnant glacial ice.

Evapotranspiration. Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil combined with transpiration from living plants.

Flow duration, of a stream. The percentage of time during which specified daily discharges have been equaled or exceeded in magnitude during a given time period.

Fracture. A break or opening in bedrock along which water may move.

Gneiss. A coarse-grained metamorphic rock with alternating bands of granular and micaceous minerals.

Granite. A coarse-grained, light colored, igneous rock.

Gravel. Unconsolidated rock debris composed principally of particles larger than 2 millimeters in diameter.

Gravel pack. A lining, or envelope of gravel placed around the outside of a well screen to increase well efficiency and yield.

Ground water. Water in the saturated zone.

Ground-water discharge. The discharge of water from the saturated zone by (1) natural processes such as ground-water runoff and ground-water evapotranspiration and (2) discharge through wells and other manmade structures.

Ground-water divide. A hypothetical line on a water table on each side of which the water table slopes downward in a direction away from the line. In the vertical dimension, a plane across which ground water does not flow.

Ground-water evapotranspiration. Ground water discharged into the atmosphere in the gaseous state, either by direct evaporation or by the transpiration of plants.

Ground-water outflow. The sum of ground-water runoff and underflow; it includes all natural ground-water discharge from a drainage area exclusive of ground-water evapotranspiration.

Ground-water recharge. The amount of water that is added to the saturated zone.

Ground-water runoff. Ground water that has discharged into stream channels by seepage from saturated earth materials.

Head, static. The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

Hydraulic boundary. A physical feature that limits the areal extent of an aquifer. The two types of boundaries are termed impermeable-barrier boundaries and line-source boundaries.

Hydraulic conductivity (K). A measure of the ability of a porous medium to transmit a fluid. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient, of unit change in head over unit length of flow path.

Hydraulic gradient. The change in static head per unit of distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decrease in head.

Hydrograph. A graph showing stage (height), flow velocity, or other property of water with respect to time.

Ice-contact deposits. Well- to poorly stratified deposits of sand, gravel and cobbles that were emplaced within or adjacent to stagnant glacial ice. Landforms include eskers, kame deltas, kame fields, and kame terraces.

Igneous. Descriptive rocks formed by solidification of molten or partially molten magma, such as basalt or granite.

Image well. An imaginary well so placed with respect to a real well and hydrologic boundary that by discharging or recharging it produces a ground-water divide or condition of no drawdown along the boundary position.

Impermeable-barrier boundary. The contact between an aquifer and adjacent impermeable material that limits the areal extent of the aquifer--for example, the termination of permeable valley-fill deposits of sand and gravel against the bedrock valley walls. Its significant hydraulic feature is that, ideally, no ground water flows across it.

Induced infiltration. The process by which water infiltrates or percolates to an aquifer from an adjacent surface-water body in response to pumping.

Induced recharge. The amount of water entering an aquifer from an adjacent surface-water body by the process of induced infiltration.

Land-surface datum (lsd). A datum plane that is at land surface at each ground-water observation well.

Line-source boundary. A boundary formed by a surface-water body that is hydraulically connected to an adjacent aquifer. Ideally there is no drawdown along such a boundary.

Mean (arithmetic). The sum of the individual values of a set, divided by their total number. Also referred to as the "average."

Metamorphic. Descriptive term for rocks such as gneiss and schist which have formed, in the solid state, from other rocks.

Milligrams per liter (mg/L). A unit for expressing the concentration of chemical constituents in solution by weight per unit volume of water.

Outwash deposits. Stratified deposits of sand and gravel carried beyond the glacier margin by meltwater streams, usually present in flat or gently sloping outwash plains.

pH. The negative logarithm of the hydrogen-ion concentration. A pH of 7.0 indicates neutrality; values below 7.0 denote acidity, those above 7.0 denote alkalinity.

Phyllite. A fine-grained, metamorphic rock, similar to schist, commonly having a silky luster.

Porosity. The property of a rock or unconsolidated material that contains voids or open spaces; it may be expressed quantitatively as the ratio of the volume of its open spaces to its total volume.

Precipitation. The discharge of water from the atmosphere, either in a liquid or solid state.

Primary porosity. Porosity which is due to the sediment or rock matrix.

Runoff. That part of the precipitation that appears in streams. It is streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Saturated thickness. Thickness of an aquifer between the water table and the bedrock surface or till.

Saturated zone. The subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone. Water in the saturated zone is under pressure greater than atmospheric.

Schist. A metamorphic rock with subparallel orientation of the visible micaceous minerals which dominate its composition.

Secondary porosity. Porosity which may be due to such phenomena as secondary solution or structurally controlled regional fracturing.

Sediment. Fragmental material that originates from weathering of rocks. It can be transported by, suspended in, or deposited by water.

Specific capacity, of a well. The rate of discharge of water divided by the corresponding drawdown of the water level in the well in gallons per minute per foot.

Specific yield. The ratio of the volume of water that a rock or soil will yield by gravity after being saturated to its own volume.

Storage coefficient. The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Stratified drift. A predominantly sorted sediment laid down by or in meltwater from a glacier; it includes sand and gravel and minor amounts of silt and clay arranged in layers.

Sustained yield. The rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is harmful to the aquifer itself, or to the quality of the water, or is no longer economically feasible.

Till. A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt and clay mixed in various proportions.

Transmissivity. The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. Equal to the average hydraulic conductivity times the saturated thickness.

Unconfined aquifer (water-table aquifer). One in which the upper surface of the saturated zone, the water table, is at atmospheric pressure and is free to rise and fall.

Unconsolidated. Loose, not firmly cemented or interlocked; for example, sand in contrast to sandstone.

Unsaturated zone. The zone between the water table and the land surface in which the open spaces are not all filled with water except temporarily during recharge events.

Water table. The upper surface of the saturated zone.

Water year. A continuous 12-month period, October 1 through September 30, during which a complete hydrographic streamflow cycle takes place. It is designated by the calendar year in which it ends.

APPENDIX

Table A-1.--*Water-level measurements at observation wells*

[Water levels are given in feet below land-surface datum.]

Date	Water level	Date	Water level	Date	Water level
		AMW-62			
7-12-83	19.32	9-13-83	21.45	6- 5-84	17.72
		AMW-63			
7-13-83	12.77	9-13-83	12.17		
		AMW-64			
7-13-83	11.56	9-13-83	12.52	6- 5-84	5.06
		AMW-65			
7-13-83	12.06	9-13-83	13.94	6- 5-84	9.68
		AMW-66			
7-14-83	4.32	9-13-83	5.14	6- 5-84	2.33
		AMW-67			
9-13-83	3.97	6- 6-84	1.86		
		B4W-32			
7-20-83	13.20	9-13-83	13.54	6- 6-84	11.33
		B4W-33			
8-10-83	18.16	9-13-83	19.14	6- 6-84	15.70
		B4W-34			
8-11-83	5.98	9-13-83	6.05	6- 6-84	4.10
		B4W-35			
8-15-83	18.90	9-13-83	18.28	6- 6-84	15.92
		HSW-39			
7- 6-83	1.47	9-12-83	2.44	6- 5-84	0.76
		HSW-40			
7- 6-83	2.70	9-12-83	5.49		
		HSW-41			
7-11-83	11.40	9-12-83	13.93	6- 5-84	8.72
		HSW-42			
7-11-83	3.44				
		HSW-43			
9-12-83	4.60	6- 5-84	1.88		
		HSW-44			
9-12-83	18.04	6- 5-84	12.62		
		HSW-45			
9-12-83	6.55	6- 5-84	4.11		
		HSW-46			
7-20-83	7.94	9-13-83	8.81	6- 6-84	4.49
		HSW-47			
7-21-83	7.45	9-12-83	8.48	6- 5-84	4.67
		HSW-48			
7-21-83	14.63				
		HSW-49			
7-22-83	4.38	9-12-83	6.30		
		HSW-50			
8-11-83	9.80	9-12-83	10.16	6- 6-84	8.27
		HVW-119			
8-26-83	5.00	9-14-83	6.40	6- 7-84	2.66
		LMW-30			
9-13-83	4.84	6- 7-84	0.70		
		LMW-31			
8-23-83	12.71	9-14-83	13.04	6- 7-84	9.95
		LMW-32			
8-24-83	10.57	9-14-83	5.60	6- 7-84	1.68
		LMW-33			
8-24-83	11.05	9-14-83	9.79	6- 7-84	4.97
		LMW-34			
8-24-83	18.80	9-14-83	19.46	6- 7-84	15.28
		LMW-35			
9-14-83	33.15	6- 7-84	30.93		

Table A-1.--*Water-level measurements at observation wells (continued)*

Date	Water level	Date	Water level	Date	Water level
MKW-22					
10-22-81	8.98	11-22-82	8.35	11-22-83	7.80
11-23-81	6.28	12-21-82	8.57	12-21-83	5.90
12-21-81	6.39	1-25-83	6.71	1-23-84	7.75
1-22-82	6.93	2-23-83	6.62	2-22-84	5.48
2-22-82	7.50	3-22-83	4.26	3-26-84	4.88
3-23-82	5.34	4-26-83	4.87	4-24-84	5.26
4-26-82	5.92	5-23-83	6.05	5-24-84	6.52
5-24-82	7.33	6-21-83	6.67	6- 5-84	4.83
6-21-82	6.13	7-25-83	8.39	6-26-84	7.18
7-26-82	8.92	8-22-83	11.09	7-26-84	8.50
8-24-82	9.80	9-26-83	12.20	8-27-84	10.63
9-23-82	10.86	10-25-83	11.91	9-26-84	11.76
10-25-82	10.15				
MKW-90					
7-15-83	6.31	9-13-83	10.20	6- 5-84	6.21
MKW-36					
10-22-81	29.31	11-21-82	8.19	11-23-83	7.56
11-23-81	27.68	12-22-82	8.25	12-24-83	7.13
12-21-81	27.32	1-21-83	7.80	1-24-84	7.72
1-22-82	27.10	2-22-83	7.62	2-25-84	6.46
2-22-82	27.41	3-22-83	5.98	3-23-84	6.49
3-23-82	28.27	4-23-83	6.80	4-25-84	6.96
4-26-82	27.06	5-24-83	7.13	5-24-84	7.54
5-24-82	27.62	6-24-83	7.78	6- 6-84	6.36
6-21-82	26.43	7-28-83	8.75	6-23-84	7.67
7-26-82	27.10	8-24-83	9.58	7-24-84	7.73
8-24-82	27.76	9-24-83	9.63	8-24-84	8.72
9-23-82	28.64	10-24-83	9.21	9-24-84	9.48
10-21-82	8.60				
NAW-143					
10-25-82	8.51	7-25-83	7.57	3-26-84	6.75
11-22-82	8.52	8-22-83	8.22	4-24-84	6.33
12-21-82	8.81	9-26-83	8.77	5-24-84	6.79
1-25-83	8.24	10-25-83	8.88	6- 5-84	5.89
2-23-83	7.96	11-22-83	8.29	6-26-84	6.42
3-22-83	6.18	12-21-83	7.26	7-26-84	6.94
4-26-83	6.11	1-23-84	7.79	8-27-84	7.71
5-23-83	6.53	2-22-84	7.27	9-26-84	9.08
6-21-83	6.88				

Date	Water level	Date	Water level	Date	Water level
NAW-218					
10-25-82	29.01	7-25-83	27.93	3-26-84	27.40
11-22-82	29.17	8-22-83	28.52	4-24-84	26.31
12-21-82	29.02	9-26-83	29.72	5-24-84	26.68
1-25-83	28.37	10-25-83	29.93	6- 5-84	26.10
2-23-83	27.96	11-22-83	29.15	6-26-84	26.30
3-22-83	26.47	12-21-83	27.49	7-26-84	27.04
4-26-83	26.44	1-23-84	28.20	8-27-84	28.41
5-23-83	26.90	2-22-84	28.03	9-26-84	29.74
6-21-83	26.90				
PAW-52					
8-16-83	3.45	9-14-83	4.59		
PAW-53					
8-17-83	8.00	9-14-83	8.63	6- 7-84	3.14
PAW-54					
8-17-83	8.45	9-14-83	8.99	6- 7-84	3.94
PAW-55					
8-16-83	6.50	9-14-83	6.89	6- 7-84	4.00
PAW-56					
8-18-83	23.00	9-14-83	21.41	6-7-84	17.27
PAW-57					
8-19-83	5.15	9-14-83	4.83	6- 7-84	1.94
PAW-58					
8-19-83	13.5	9-14-83	14.07	6- 7-84	9.88

Table A-2.--*Logs of selected wells and test holes*

[Depth is given in feet below land surface; thickness is given in feet.]

Identification number: Exploratory holes were numbered sequentially in the order in which they were drilled.

Location: A 15-digit site-identification number that shows latitude, longitude, and sequence number.

Description of materials: Logs of observation wells, based on the Wentworth scale. Wentworth scale is given below.

Wentworth size class	Range of grain sizes, in millimeters	General category, in millimeters
Clay	<0.004	
Silt	.004 - <0.062	Clay
Very fine sand	.062 - <.125	Silt
Fine sand	.125 - <.25	
Medium sand	.25 - <.50	Sand
Coarse sand	.50 - <1.0	
Very coarse sand	1.0 - <2.0	
Granule	2.0 - <4.0	
Pebble	4.0 - <64	Gravel
Cobble	64 - <256	
Boulder	>256	

Terms used in logs of exploration holes:

Sand and gravel--sorted sediment varying in size from boulder to very fine sand.
Till--A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay.
End of hole--Depth of bottom of exploration hole in which bedrock or refusal was not reached.
Refusal--Depth at which drilling equipment could not penetrate further.

	Depth	Thickness
AMA-1. 4250340713407.01		
Sand, fine to coarse	0 - 12	12
Sand, very fine to coarse	12 - 21	9
Sand, fine to medium	21 - 26	5
Sand, medium to coarse	26 - 31	5
Sand, very fine to coarse	31 - 88	57
Refusal	at 88	
AMW-62. 4249000713533.01		
Sand, medium to very coarse	0 - 25	25
Silt to fine sand	25 - 35	10
Sand, very fine to medium	35 - 65	30
Sand, very fine to coarse	65 - 75	10
Sand, very fine to medium	75 - 85	10
Refusal	at 85	
AMW-63. 4249200712516.01		
Sand, fine to very coarse, predominantly coarse	0 - 20	20
Sand, very fine to medium	20 - 55	35
Sand, very fine to fine	55 - 75	20
Sand, very fine to medium	75 - 100.5	25.5
Refusal	at 100.5	
AMW-64. 4249410713502.01		
Sand, very fine to fine	0 - 6	6
Sand, fine to very coarse	6 - 12	6
Sand, medium to very coarse	12 - 25	13
Gravel, medium	25 - 35	10
Sand, medium to very coarse	35 - 44	9
Sand, medium to coarse	44 - 45	1
Refusal	at 45	
AMW-65. 4250240713417.01		
Sand, fine to very coarse, topsoil	0 - 6	6
Sand, medium to very coarse	6 - 11	5
Sand, fine to very coarse	11 - 15	4
Sand, fine to coarse	15 - 60	45
Sand, very fine to medium coarse	60 - 75	15
Silt; sand, very fine to fine	75 - 89	14
Refusal	at 89	
AMW-66. 4251340713542.01		
Sand, fine to very coarse	0 - 18	18
Sand, silt to fine	18 - 31	13
Boulder	31 - 32	1
Sand, fine to very coarse	32 - 35	3
Refusal	at 35	

Table A-2.--*Logs of selected wells and test holes (continued)*

	Depth	Thickness
AMW-67. 4254050713608.01		
Sand, very fine to coarse	0 - 6	6
Sand, fine to very coarse	6 - 21.5	15.5
Refusal	at 21.5	
B4W-32. 4242320713820.01		
Sand, fine to medium, well sorted	0 - 5	5
Sand, fine to very coarse	5 - 15	10
Sand, medium to very coarse	15 - 25	10
Till	25 - 38	13
Refusal	at 38	
B4W-33. 4243310713927.01		
Sand, fine to very coarse	0 - 20	20
Sand, fine to coarse	20 - 40	20
Sand, very fine to medium	40 - 50	10
Sand, very fine to fine	50 - 70	20
Sand, very fine to fine, some silt and clay	70 - 91	21
Refusal	at 91	
B4W-34. 4243580713949.01		
Sand, fine to very coarse	0 - 7	7
Sand, coarse to very coarse	7 - 30	23
Sand, fine to very coarse, poorly sorted	30 - 34	4
Refusal	at 34	
B4W-35. 4245330714036.01		
Sand, fine to very coarse	0 - 11	11
Sand, medium to very coarse	11 - 30	19
Gravel, compacted	30 - 31	1
Refusal	at 31	
HSA-1. 4245000713608.01		
Sand, coarse to very coarse	0 - 5	5
Cobbles	5 - 14	9
Refusal	at 14	
HSA-2. 4246010713510.01		
Sand, fine to very coarse, light brown, some large cobbles	0 - 6	6
Sand, fine to very coarse some pebbles and cobbles	6 - 20	14
Sand and gravel	20 - 21	1
Sand, fine to very coarse	21 - 25	4
HSA-2 (continued).		
Sand, coarse to very coarse	25 - 30	5
Sand, very fine to coarse; silt clay, gray	30 - 33	3
End of hole	at 33	
HSW-39. 4244310713313.01		
Silt; some gravel, organic	0 - 5	5
Sand and gravel	5 - 15	10
Sand, coarse sand to gravel	15 - 25	10
Gravel	25 - 30	5
Sand, medium sand to gravel	30 - 35	5
Refusal	at 35	
HSW-40. 4243490713318.01		
Gravel, some large cobbles	0 - 15	15
Gravel, some very coarse sand	15 - 20	5
Sand, very coarse to gravel, red	20 - 25	5
Gravel	25 - 30	5
Sand, medium to coarse; gravel	30 - 33	3
End of hole	at 33	
HSW-41. 4246180713609.01		
Sand, medium; gravel	0 - 6	6
Sand, medium to coarse, tan	6 - 11	5
Sand, fine to medium, light tan	21 - 30	9
Sand, silt to very fine	30 - 32	2
Sand, medium to very coarse	32 - 34	2
Sand, medium to very coarse; gravel, gray	34 - 35	1
Silt to sand, medium, gray	35 - 45	10
Silt to sand, fine, gray some granite chips	45 - 47	2
Silt to very coarse sand, gray	47 - 47.5	.5
Refusal	at 47.5	
HSW-42. 424802071335901		
Sand, silt to very coarse, dark brown	0 - 10	10
Sand, fine to very coarse, light brown	10 - 66	56
Sand, fine to very coarse; gravel, small	66 - 68	2
Refusal	at 68	

Table A-2.--*Logs of selected wells and test holes (continued)*

	Depth	Thick-ness
HSW-43. 424443071361401		
Sand, medium to very coarse, light brown	0 - 15	15
Sand, fine to coarse	15 - 25	10
Sand, coarse to very coarse	25 - 30	5
Sand, fine to medium	30 - 35	5
Sand, medium to very coarse	35 - 40	5
Sand, fine to medium	40 - 45	5
Sand, very fine to medium	45 - 55	10
Sand, fine to coarse, brown	55 - 60	5
Silt to fine sand, some gray clay	60 - 65	5
Sand, very fine to medium, brown	65 - 70	5
Silt to fine sand, gray	70 - 75	5
Sand, very fine to medium, gray	75 - 85	10
Refusal	at 85	
HSW-44. 424257071331801		
Sand, fine to very coarse, some topsoil	0 - 6	6
Sand, fine to coarse, light brown	6 - 15	9
Sand, medium to very coarse	15 - 25	10
Sand, fine to coarse, some clay	25 - 35	10
Sand, silt to fine	35 - 40	5
Refusal	at 40	
HSW-45. 4244230713625.01		
Sand, medium to very coarse	0 - 6	6
Sand, coarse to very coarse, well sorted	6 - 15	9
Sand, medium to very coarse, well sorted	15 - 25	10
Sand, fine to coarse, gray	25 - 35	10
Sand, fine to medium, very well sorted	35 - 45	10
Sand, fine to medium, well sorted	45 - 50	5
Sand, very fine to fine, well sorted	50 - 75	25
HSW-45 (continued).		
Sand, very fine to medium, dark gray	75 - 80	5
Sand, silt to very fine, light gray	80 - 85	5
Sand, very fine to medium	85 - 95	10
Sand, very fine to fine, some gray clay	95 - 105	10
Till	105 - 108	3
End of hole	at 108	
HSW-46. 4242200713701.01		
Sand, medium to very coarse	0 - 25	25
Shale, dark gray	25 - 28	3
HSW-47. 4245420713539.01		
Sand, fine to coarse	0 - 6	6
Sand, fine to very coarse some pebbles	6 - 15	9
Sand, very fine to medium	15 - 21	6
Refusal, till	at 21	
HSW-48. 4246100713452.01		
Sand, fine to very coarse, some cobbles and pebbles	0 - 30	30
Sand, very fine to medium	30 - 38	8
Till	38 - 43	5
End of hole	at 43	
HSW-49. 4246510713608.01		
Sand, medium to very coarse	0 - 30	30
Sand, very coarse; gravel, small	30 - 40	10
Sand, coarse to very coarse; gravel	40 - 47	7
Sand, silt to medium	47 - 50	3
Refusal	at 50	
HSW-50. 4243190713743.01		
Sand, fine to very coarse	0 - 15	15
Sand, medium to very coarse	15 - 20	5
Till	20 - 21	1
Refusal	at 21	

Table A-2.--*Logs of selected wells and test holes (continued)*

	Depth	Thickness
HVA-1. 4242190712443.01		
Sandy silt	0 - 3	3
Sand, medium to very coarse	3 - 8	5
Silt, sandy, soft	8 - 18	10
Silt, light brown	18 - 22	4
Silt; sand, very fine to very coarse, some pebbles	22 - 33	11
Till	33 - 35	
Refusal	at 35	
HVW-119. 4247150712659.01		
Silt, gray	0 - 1	1
Sand, very fine to fine, light brown	1 - 7	6
Sand, fine to coarse, reddish brown	7 - 25	18
Silt, brown	25 - 27	2
Till, gray-brown	27 - 38	11
LMA-38. 4250120712607.01		
Sand, very fine to medium, light brown	0 - 12	12
Sand, very fine to fine, light gray	12 - 36	24
Silt to very fine sand, some broken up mica schist, till	36 - 41.5	5.5
Refusal	at 41.5	
LMA-39. 4250140712547.01		
Sand, medium to very coarse	0 - 20	20
Sand, very fine to medium, light gray	16 - 31.5	15.5
Till, silty sand	31.5 - 36	4.5
Refusal	at 36	
LMA-41. 4249410712636.01		
Sand, very fine to fine	0 - 6	6
Gravel, cobbly	6 - 10	4
Till, silty	10 - 18	8
Refusal	at 18	
LMA-42. 4249410712638.01		
Silt, red-brown	0 - 16	16
Silty clay, gray	16 - 36	20
Till, compacted	36 - 40.5	4.5
Refusal	at 40.5	

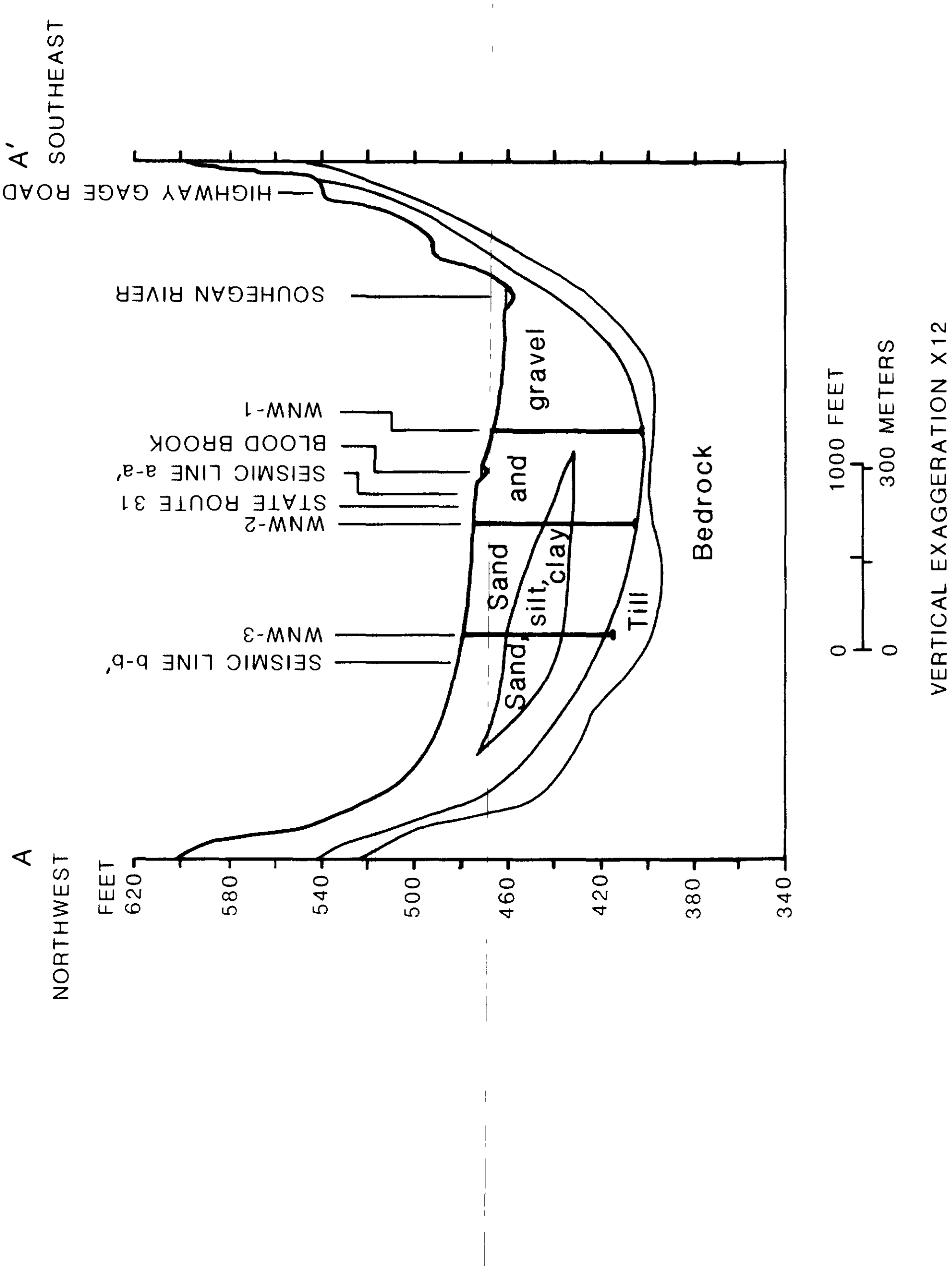
	Depth	Thickness
LMW-30. 4249130712659.01		
Sand, very fine to coarse	0 - 25	25
Silt, light gray; clay, dark gray	25 - 63	38
Sand, very fine, some silt	63 - 90	27
Sand, very fine, light gray	90 - 98	8
Refusal	at 98	
LMW-31. 4250060712701.01		
Sand, medium to very coarse	0 - 46	46
Sand, very fine, some silt	46 - 51	5
Sand, very fine to very coarse, some pebbles	51 - 62	11
Sand, very fine to very coarse, tilly, some silt	62 - 65.5	3.5
Refusal	at 65.5	
LMW-32. 4248100712619.01		
Sand, medium to very coarse	0 - 11	11
Sand, very fine to fine	11 - 33	22
Till, silty	33 - 40	7
Refusal	at 40	
LMW-33. 4248040712636.01		
Sand, very fine to fine	0 - 16	16
Sand, very fine to fine, some silt	16 - 33	17
Sand, coarse to fine gravel	33 - 50	17
Till, poorly sorted, dark gray	50 - 53	3
End of hole	at 53	
LMW-34. 4251590712852.01		
Sand, fine to very coarse, some pebbles and cobbles	0 - 13	13
Sand, fine to very coarse	13 - 26	13
Sand, fine to very fine, light gray	26 - 55	29
Sand and gravel	55 - 62	7
Till, clayey, silty, gravelly	62 - 64	2
End of hole	at 64	
LMW-35. 4252500712737.01		
Sand, very fine to coarse	0 - 21	21
Silt; sand, very fine	21 - 37	16
Clay, varved, dark gray	37 - 47	10
Sand, fine to very coarse poorly sorted at 50-59 ft.	47 - 59	12
Silty sand	59 - 61	2
End of hole	at 61	

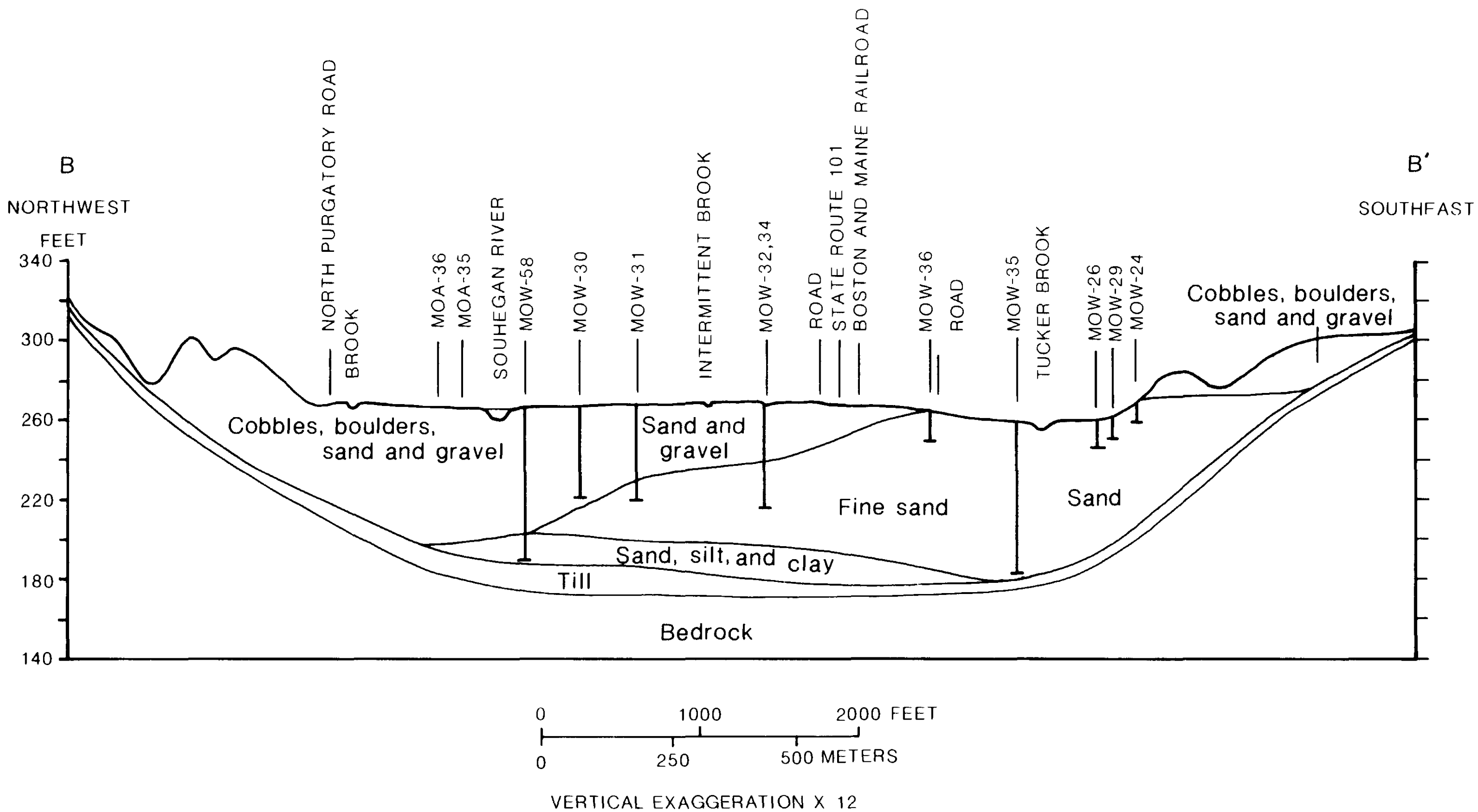
Table A-2.--*Logs of selected wells and test holes (continued)*

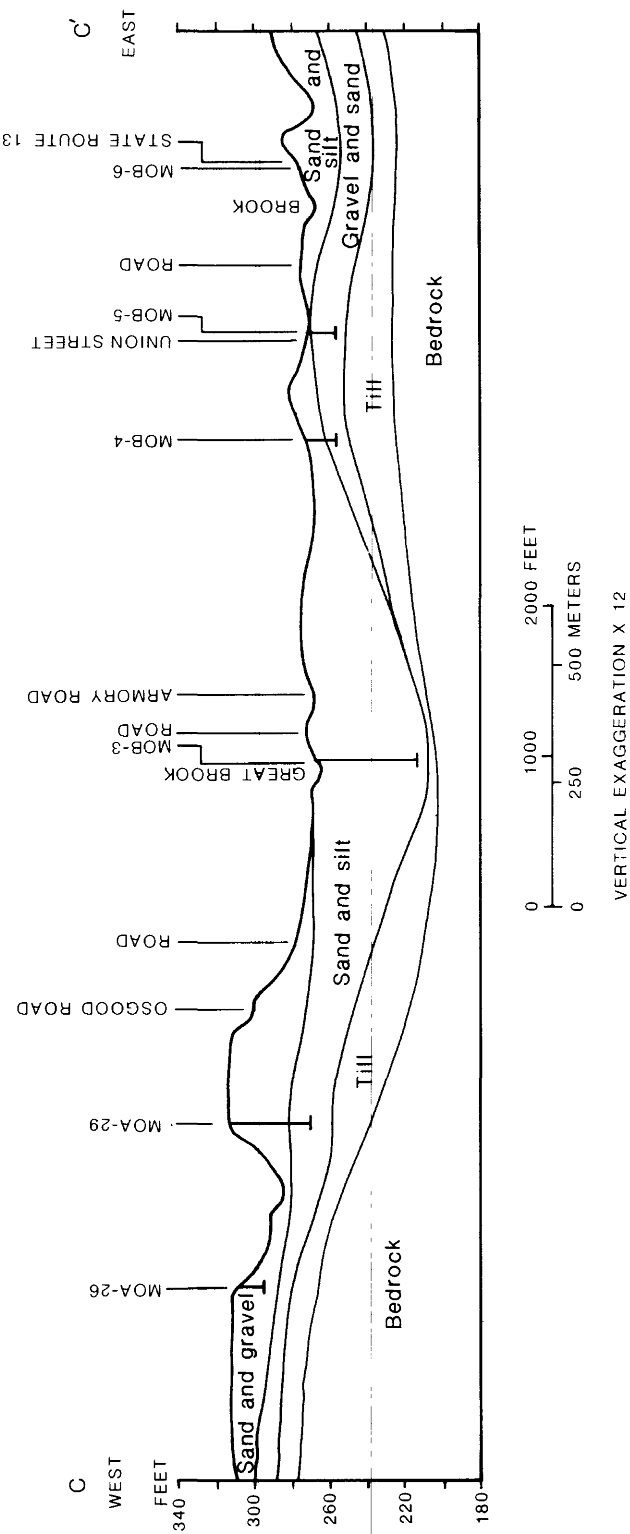
	Depth	Thick-ness
PAA-4. 4242580711957.01		
Sand, very fine to medium, some pebbles	0 - 9	9
Sand, coarse to very coarse	9 - 12	3
Gravel	12 - 14	2
Sand, coarse to very coarse	14 - 21	7
Till	21 - 21.5	.5
Refusal	at 21.5	
PAA-5. 4243100711942.01		
Sand, fine to coarse	0 - 16	16
Sand, very fine to medium	16 - 20	4
Sand, very fine to fine some pebbles and cobbles	20 - 23.5	3.5
Refusal	at 23.5	
PAA-6. 4245000711931.01		
Soil, silty, black-brown	0 - 6	6
Sand, medium to very coarse, some gravel	6 - 11	5
Sand, medium to very coarse, clean	11 - 15	4
Sand, very fine to medium	15 - 20	5
Weathered rock	20 - 21	1
Refusal	at 21	
PAA-7. 4245350711930.01		
Silty soil, black	0 - 2	2
Sand, very fine to coarse, some gravel	2 - 10	8
Silt	10 - 13	3
Till, sandy, light gray	13 - 15.5	2.5
Refusal	at 15.5	
PAW-52. 4242500711942.01		
Sand, silty, black	0 - 8	8
Sand, coarse to very coarse, clean	8 - 21	13
Sand, fine to coarse, gray	21 - 29	8
Till, sandy, light gray	29 - 32	3
Refusal	at 32	
PAW-53. 4243230712014.01		
Sand, fine to coarse	0 - 6	6
Sand, very fine to medium	6 - 15	9
Silty clay	15 - 16	1
Sand, medium to very coarse	16 - 25	9
PAW-53 (continued).		
Till, sandy, light gray-brown	25 - 29	4
Refusal	at 29	
PAW-54. 4243580711939.01		
Sand, fine to coarse	0 - 21	21
Sand, very fine to medium	21 - 39	18
Silt to very fine sand, light gray	39 - 45.5	6.5
Sand, very fine to coarse, some gravel	45.5 - 55	9.5
Rock, weathered	55 - 55.5	.5
Refusal	at 55.5	
PAW-55. 4243250711931.01		
Sand, fine to coarse	0 - 6	6
Sand, coarse to very coarse	6 - 16	10
Sand, medium to very coarse, red	16 - 26	10
Sand, fine to very coarse, red	26 - 36	10
Sand, fine to medium, light gray	36 - 38	2
Sand, fine to silty, gray	38 - 41	3
Refusal	at 41	
PAW-56. 4245000712015.01		
Sand, very fine to coarse	0 - 6	6
Sand, very fine to very coarse	6 - 28	22
Sand, very fine to fine	28 - 66	38
Sand, fine to very coarse, light gray	66 - 70	4
Sand, fine to very coarse, light brown	70 - 84	14
Clay, silt, sand, gravel, layered	84 - 94	10
Refusal	at 94	
PAW-57. 4244270711900.01		
Sand, medium to very coarse	0 - 33	33
Sand, silt to very fine	33 - 56	23
Till	56 - 62.5	6.5
Refusal	at 62.5	
PAW-58. 4244330711911.01		
Sandy silt	0 - 1	1
Sand, fine to very coarse	1 - 27	26
Sand, very fine to very coarse, some gravel	27 - 33	6
Refusal	at 33	

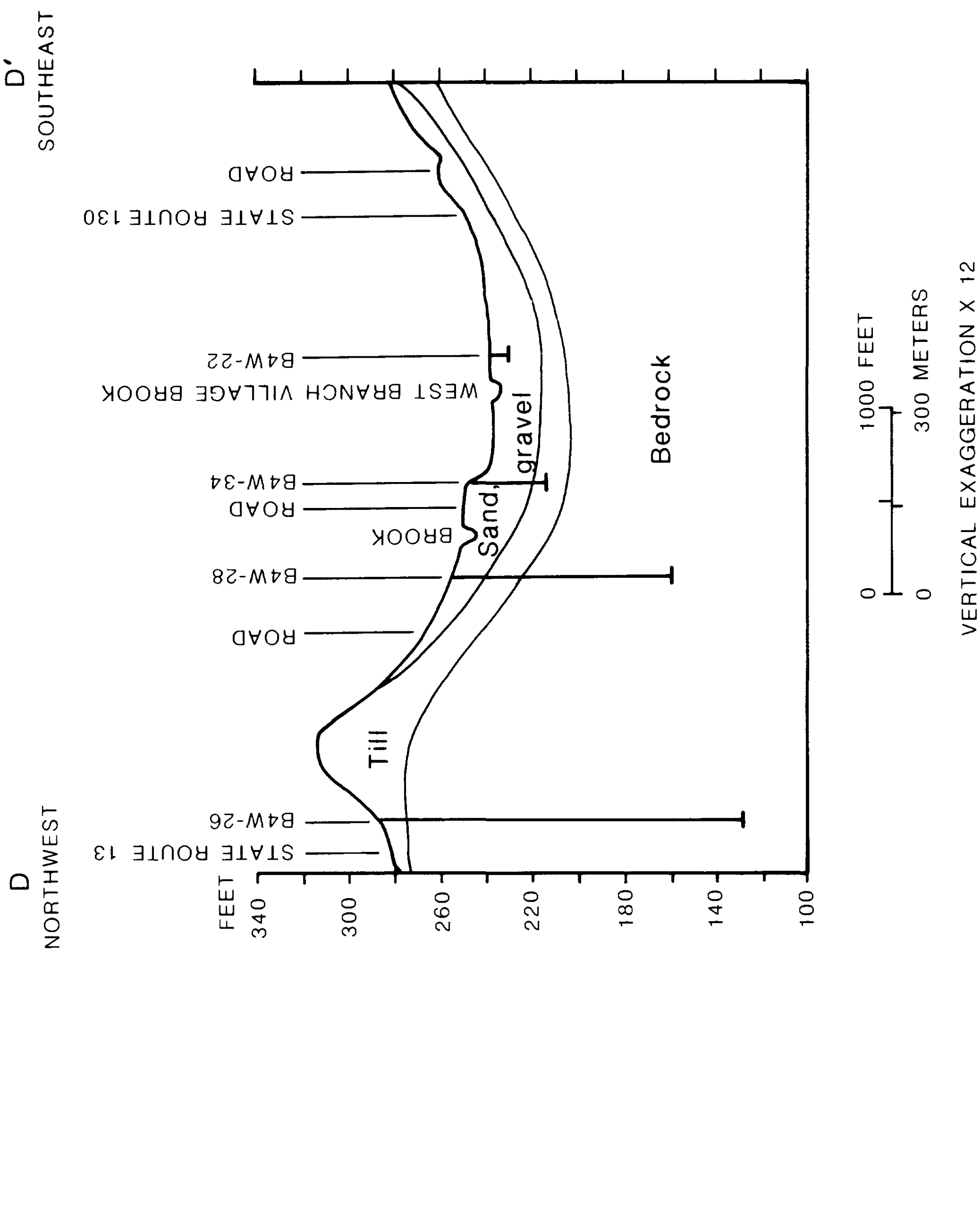
Figure A-1.--*Geologic sections*

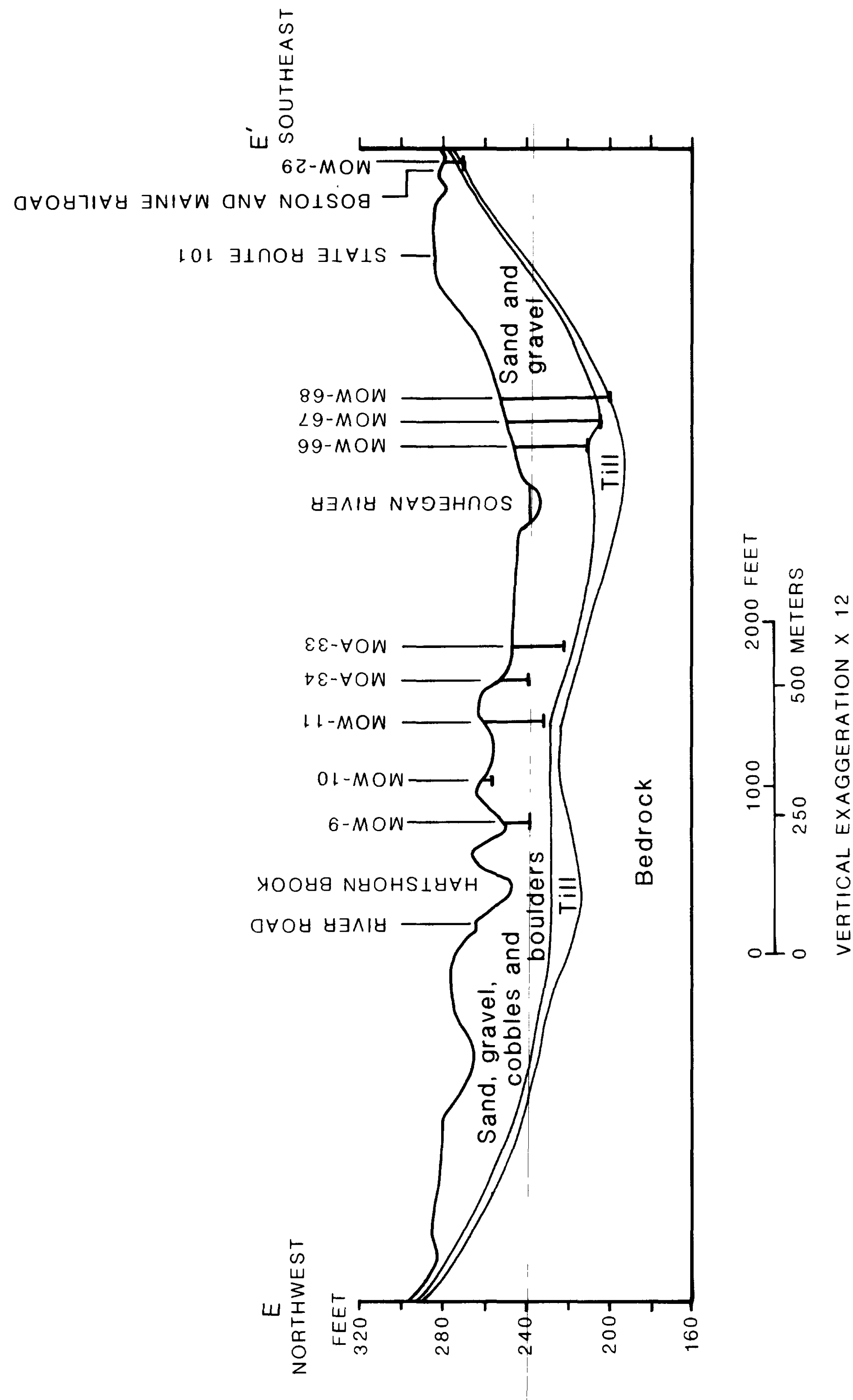
Section line	Plate	Description
A-A'	1	Wilton Center, near State Routes 101 and 31, Souhegan River
B-B'	1	Milford, Souhegan River, State Route 101
C-C'	1	Milford, Osgood and Armory Roads, State Route 13
D-D'	1	Brookline, State Routes 13 and 130
E-E'	1	Milford, River Road, Souhegan River, State Route 101
F-F'	1 and 3	Brookline-Hollis, Nissitissit River
G-G'	1 and 3	Milford-Amherst, State Route 101A, Souhegan River
H-H'	3	Amherst, Beaver Brook, State Route 122
I-I'	3	Amherst, Souhegan River, State Route 101A, Thorntons Ferry Road
J-J'	3	Amherst, Joe English Brook, Horace Greeley Road
K-K'	3	Hollis-Amherst, Witches Brook, State Route 101A
L-L'	3	Amherst-Merrimack, County Road, Thorntons Ferry Road, Souhegan River
M-M'	3	Hollis, Witches Brook, State Route 122, Truell Hill Road
N-N'	3	Merrimack, Souhegan River, Meeting House Road
O-O'	3	Merrimack, Souhegan River, Meeting House Road
P-P'	3	Nashua-Merrimack, Pennichuck Pond to State Route 101A
Q-Q'	3	Merrimack, Baboosic Lake Road, Souhegan River
R-R'	3	Nashua, Boire Field, State Route 101A
S-S'	3 and 5	Merrimack-Litchfield, Everett Turnpike, Merrimack River
T-T'	3	Nashua, Salmon Brook, Everett Turnpike
U-U'	3 and 5	Nashua-Hudson, U.S. Route 3, Merrimack River, State Route 3A
V-V'	3	Hollis, State Route 130, Silver Lake
W-W'	3 and 5	Hudson, Merrimack River, Limit Brook, State Route 3A
X-X'	5	Hudson, Highland Street, State Route 111, Ottarnic Pond area
Y-Y'	3	Hollis, Flints Brook, Depot Road, State Route 130
Z-Z'	5	Hudson-Litchfield, Merrimack River, State Route 102
AA-AA'	5	Litchfield, Merrimack River, State Route 3A, Nesenkeag Brook
BB-BB'	5	Litchfield, between Nesenkeag and Chase Brooks, Talent Road
CC-CC'	5	Litchfield, between Watts and Colby Brooks, State Route 3A
DD-DD'	5	Pelham, Beaver Brook, State Route 128
EE-EE'	3	Merrimack, Patten Road
FF-FF'	5	Pelham, Beaver Brook, State Route 111A
GG-GG'	3	Merrimack, Baboosic Brook, Patten Road
HH-HH'	5	Pelham, Golden Brook, State Route 111A and 38
II-II'	5	Pelham, Beaver Brook, State Route 111A

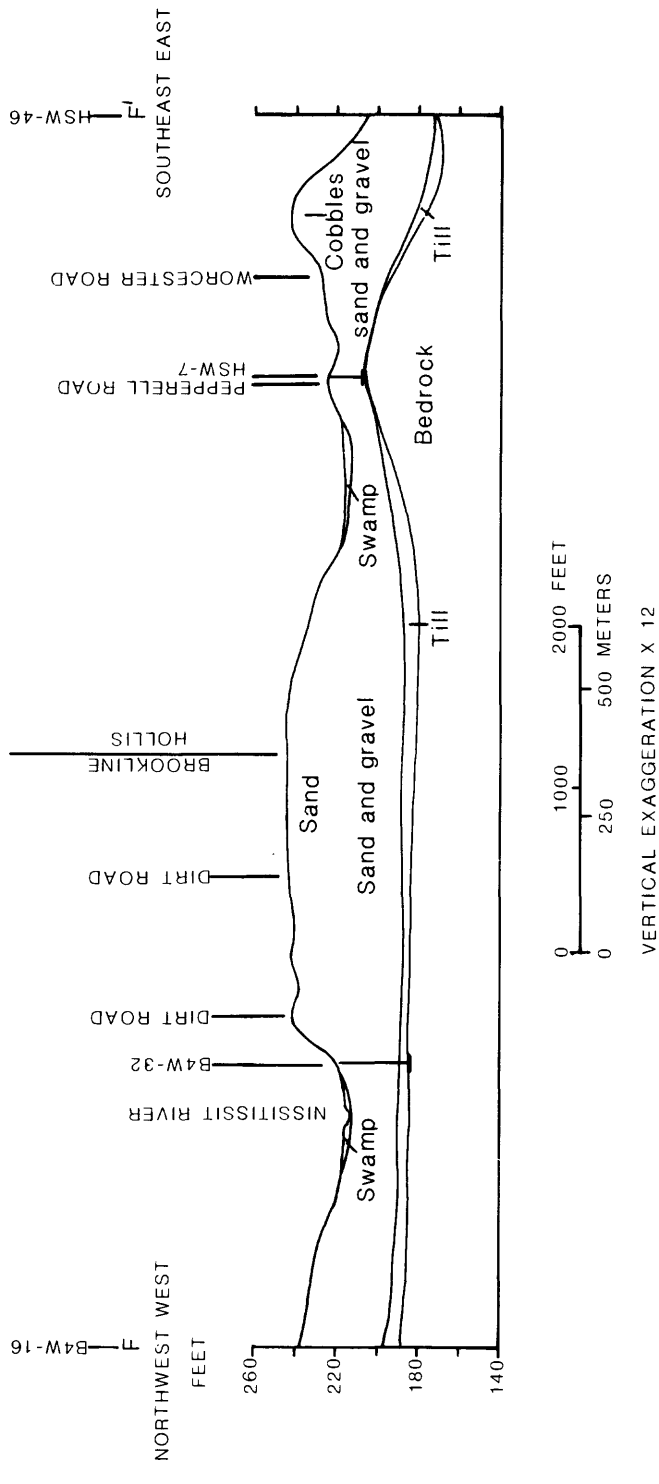

A
NORTHWEST
A'
SOUTHEAST
HIGHWAY GAGE ROAD
SOUHEGAN RIVER
WNW-1
BLOOD BROOK
SEISMIC LINE a-a'
STATE ROUTE 31
WNW-2
WNW-3
SEISMIC LINE b-b'
FEET
620
580
540
500
460
420
380
340
Sand and gravel
Sand, silt, clay
Till
Bedrock
0
1000 FEET
0
300 METERS
VERTICAL EXAGGERATION X12

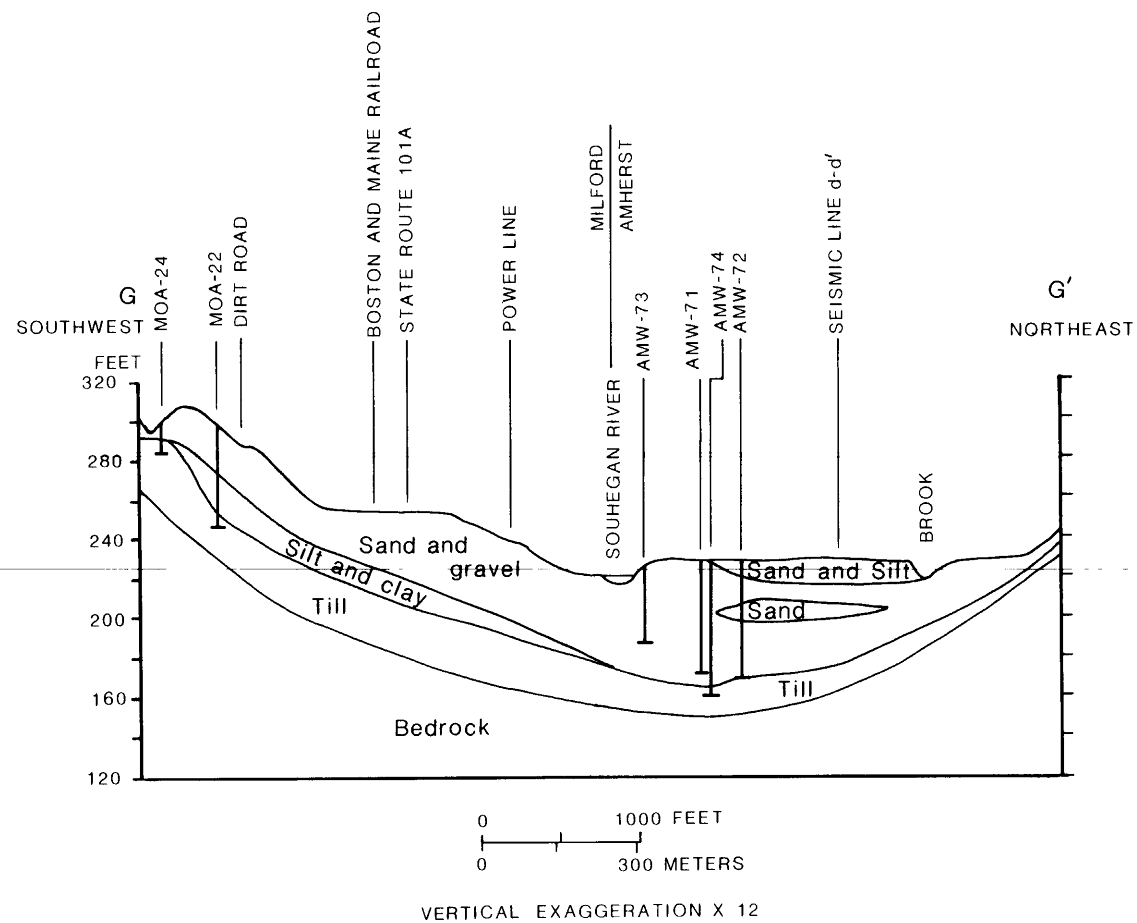

B
NORTHWEST
FEET
340
300
260
220
180
140
NORTH PURGATORY ROAD
BROOK
MOA-36
MOA-35
SOUHEGAN RIVER
MOW-58
MOW-30
MOW-31
INTERMITTENT BROOK
MOW-32,34
ROAD
STATE ROUTE 101
BOSTON AND MAINE RAILROAD
MOW-36
ROAD
MOW-35
TUCKER BROOK
MOW-26
MOW-29
MOW-24
B′
SOUTHEAST
Cobbles, boulders, sand and gravel
Sand and gravel
Fine sand
Sand
Cobbles, boulders, sand and gravel
Sand, silt, and clay
Till
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

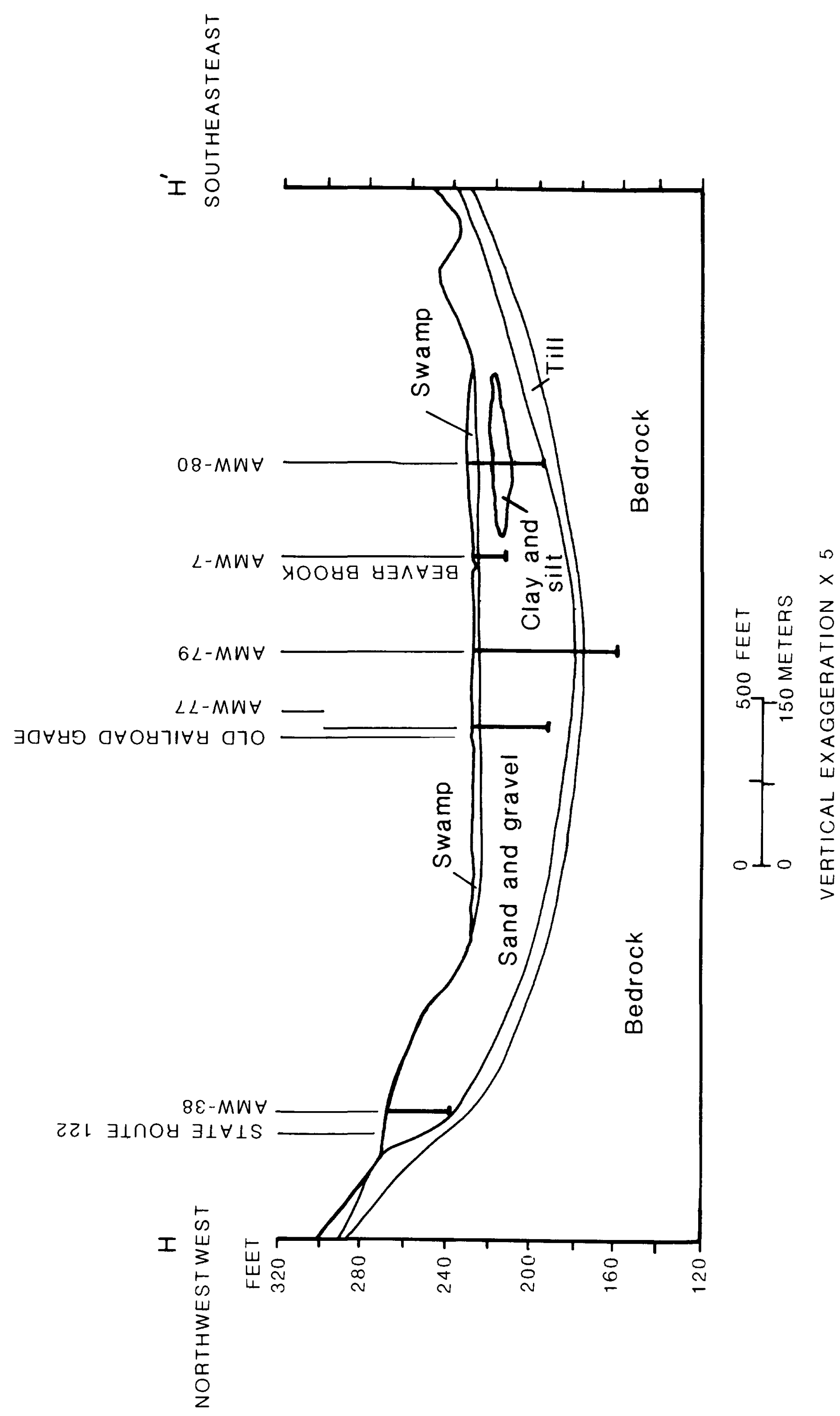

C
WEST
C′
EAST
FEET
340
300
260
220
180
MOA-26
MOA-29
OSGOOD ROAD
ROAD
GREAT BROOK
MOB-3
ROAD
ARMORY ROAD
MOB-4
UNION STREET
MOB-5
ROAD
BROOK
MOB-6
STATE ROUTE 13
Sand and gravel
Bedrock
Till
Sand and silt
Till
Bedrock
Sand and silt
Gravel and sand
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

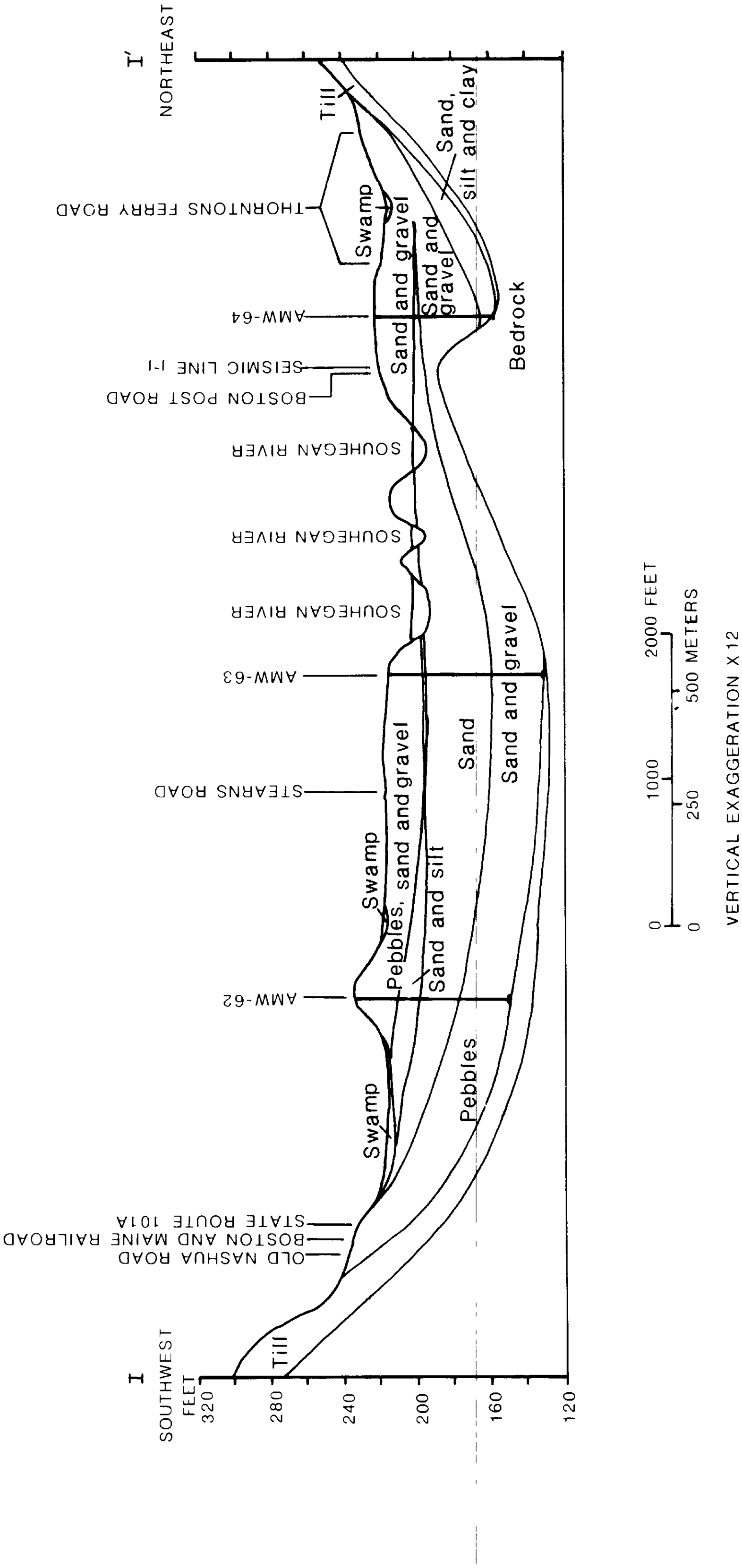

D
NORTHWEST
D′
SOUTHEAST
FEET
340
300
260
220
180
140
100
STATE ROUTE 13
B4W-26
Till
ROAD
B4W-28
BROOK
Sand, gravel
ROAD
B4W-34
WEST BRANCH VILLAGE BROOK
B4W-22
Bedrock
STATE ROUTE 130
ROAD
0
1000 FEET
0
300 METERS
VERTICAL EXAGGERATION X 12

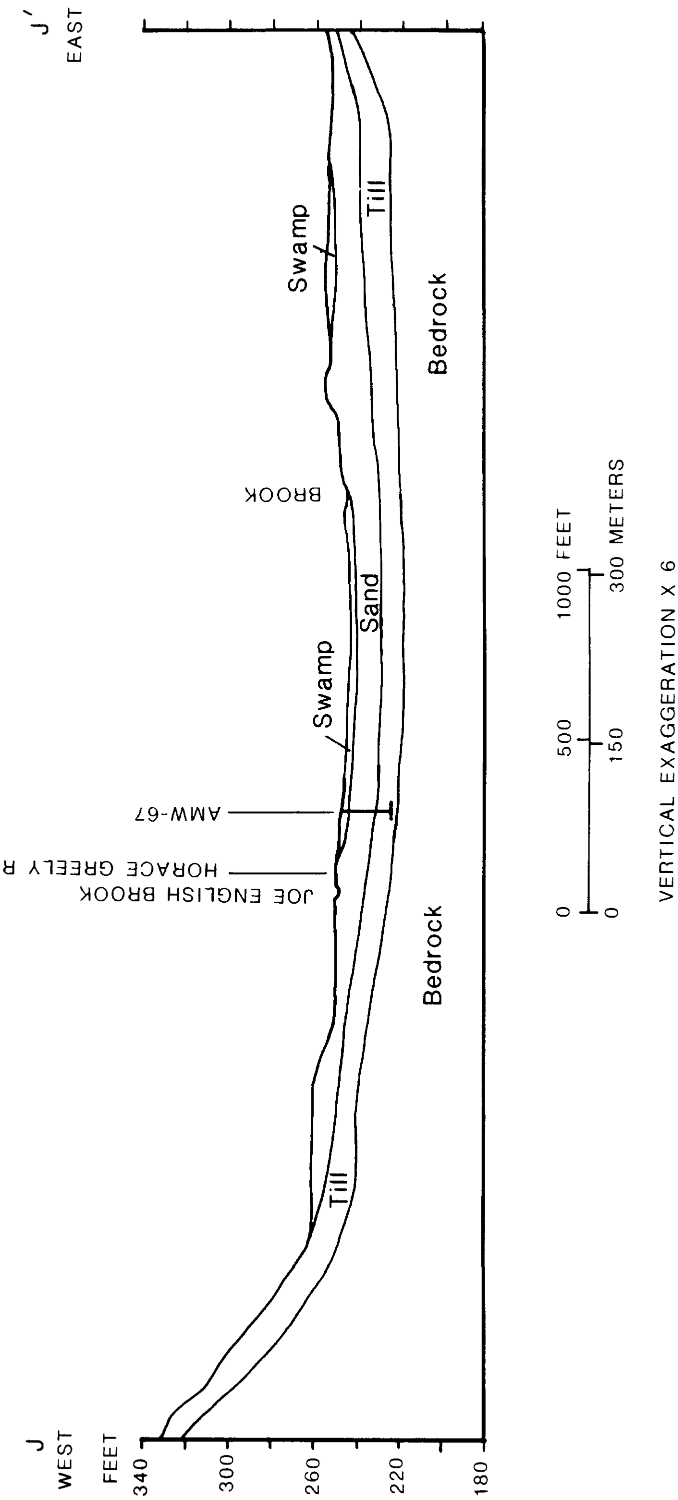

E
NORTHWEST
E′
SOUTHEAST
FEET
320
280
240
200
160
MOW-29
BOSTON AND MAINE RAILROAD
STATE ROUTE 101
MOW-68
MOW-67
MOW-66
SOUHEGAN RIVER
MOA-33
MOA-34
MOW-11
MOW-10
MOW-9
HARTSHORN BROOK
RIVER ROAD
Sand and gravel
Till
Sand, gravel, cobbles and boulders
Till
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12


F
B4W-16
NORTHWEST WEST
FEET
260
220
180
140
Swamp
NISSITISSIT RIVER
B4W-32
DIRT ROAD
DIRT ROAD
Sand
Sand and gravel
BROOKLINE
HOLLIS
Till
Swamp
PEPPERELL ROAD
HSW-7
Bedrock
WORCESTER ROAD
Cobbles sand and gravel
Till
F'
HSW-46
SOUTHEAST EAST
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

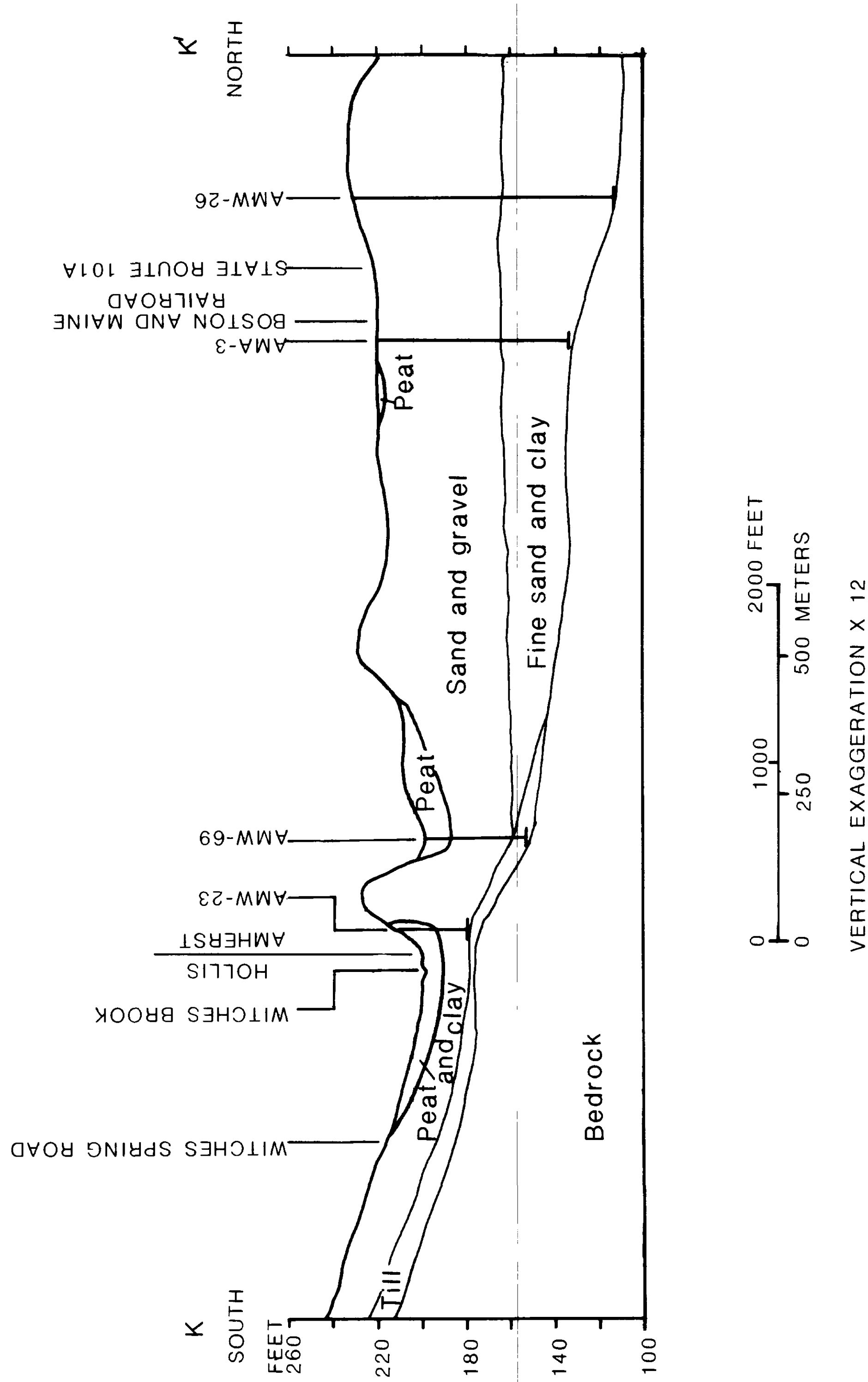

G
SOUTHWEST
G′
NORTHEAST
FEET
320
280
240
200
160
120
MOA-24
MOA-22
DIRT ROAD
BOSTON AND MAINE RAILROAD
STATE ROUTE 101A
POWER LINE
MILFORD
AMHERST
SOUHEGAN RIVER
AMW-73
AMW-71
AMW-74
AMW-72
SEISMIC LINE d-d′
BROOK
Sand and gravel
Silt and clay
Till
Sand and Silt
Sand
Till
Bedrock
0
1000 FEET
0
300 METERS
VERTICAL EXAGGERATION X 12

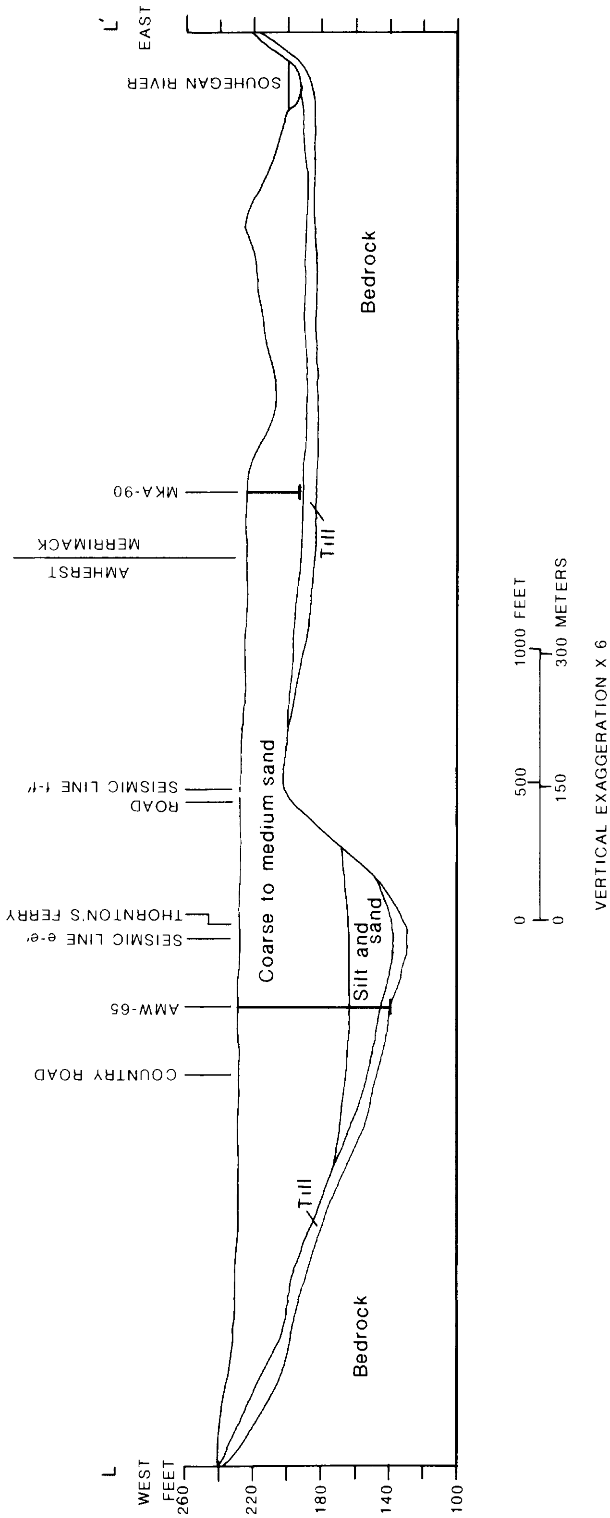

H
NORTHWESTWEST
FEET
320
280
240
200
160
120
STATE ROUTE 122
AMW-38
Bedrock
Sand and gravel
Swamp
OLD RAILROAD GRADE
AMW-77
AMW-79
BEAVER BROOK
AMW-7
Clay and silt
AMW-80
Bedrock
Swamp
Till
H′
SOUTHEASTEAST
0
500 FEET
0
150 METERS
VERTICAL EXAGGERATION X 5


I
SOUTHWEST
I′
NORTHEAST
FEET
320
280
240
200
160
120
OLD NASHUA ROAD
BOSTON AND MAINE RAILROAD
STATE ROUTE 101A
AMW-62
STEARNS ROAD
AMW-63
SOUHEGAN RIVER
SOUHEGAN RIVER
SOUHEGAN RIVER
BOSTON POST ROAD
SEISMIC LINE I-1
AMW-64
THORNTONS FERRY ROAD
Till
Swamp
Swamp
Pebbles
Pebbles, sand and gravel
Sand and silt
Sand
Sand and gravel
Sand and gravel
Sand and gravel
Bedrock
Swamp
Till
Sand, silt and clay
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

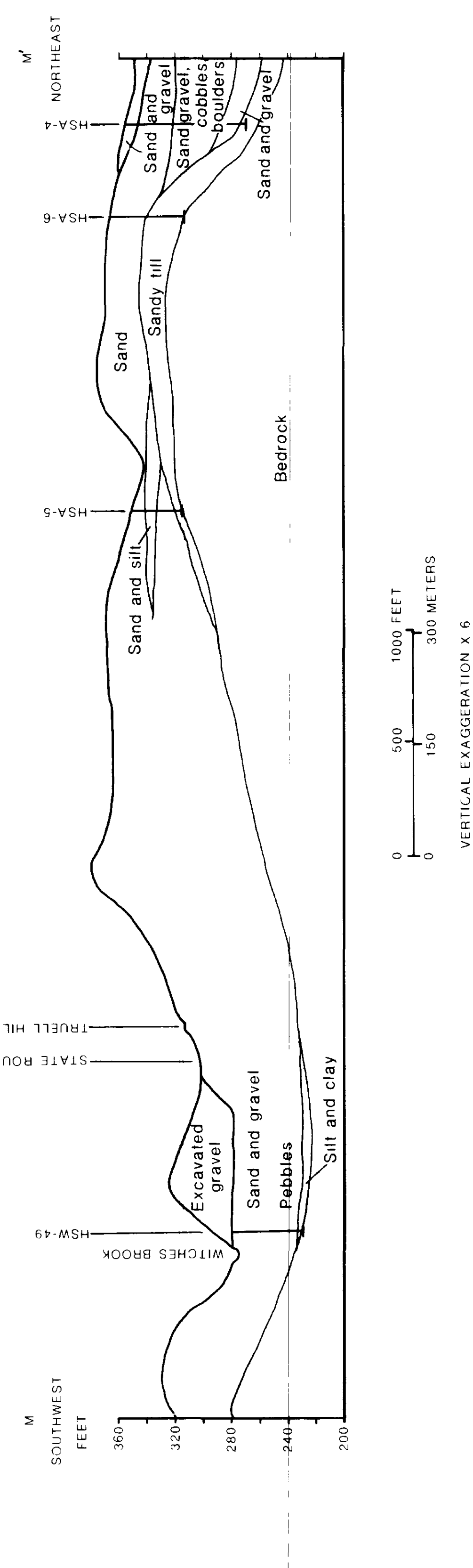


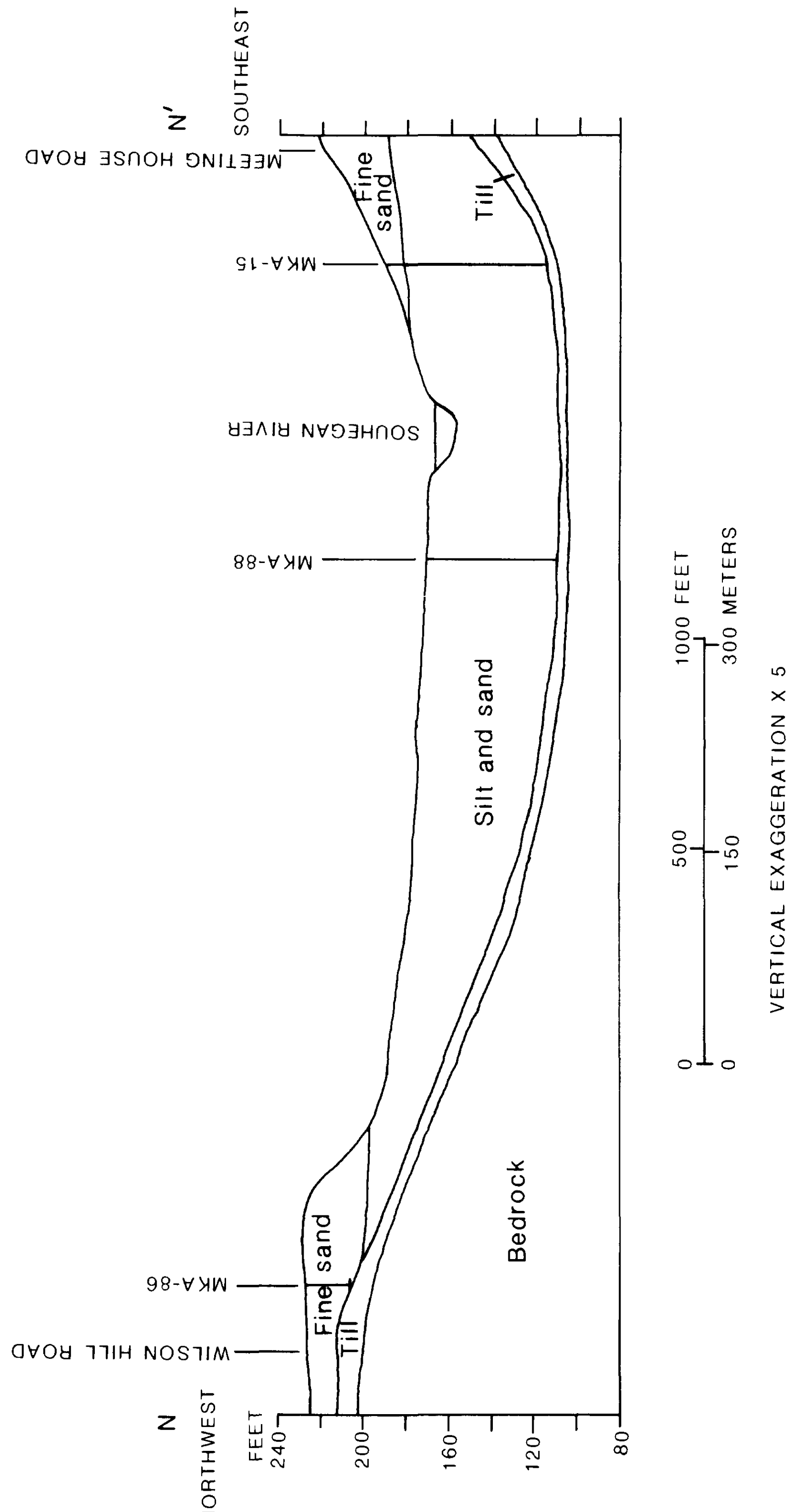
J
WEST
FEET
340
300
260
220
180
J'
EAST
Swamp
Till
Bedrock
BROOK
Sand
Swamp
AMW-67
HORACE GREELY ROAD
JOE ENGLISH BROOK
Bedrock
Till
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

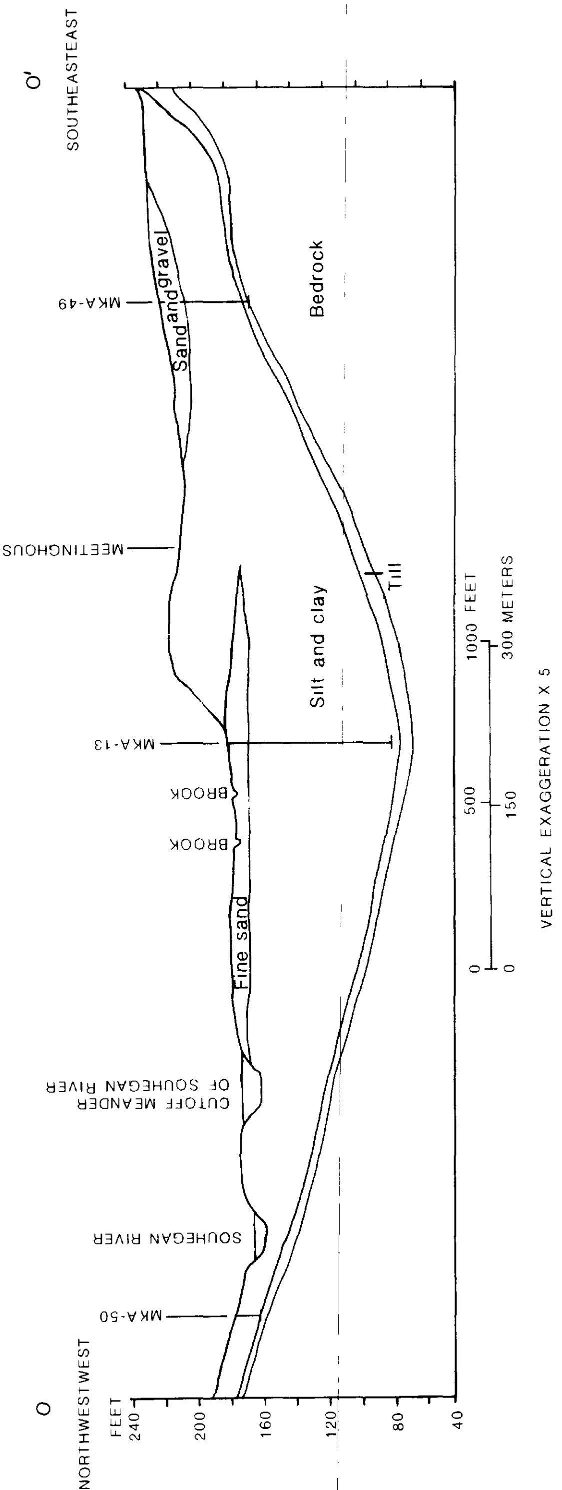

K
SOUTH
K'
NORTH
FEET
260
220
180
140
100
WITCHES SPRING ROAD
WITCHES BROOK
HOLLIS
AMHERST
AMW-23
AMW-69
AMA-3
BOSTON AND MAINE
RAILROAD
STATE ROUTE 101A
AMW-26
Till
Peat
and clay
Peat
Sand and gravel
Fine sand and clay
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

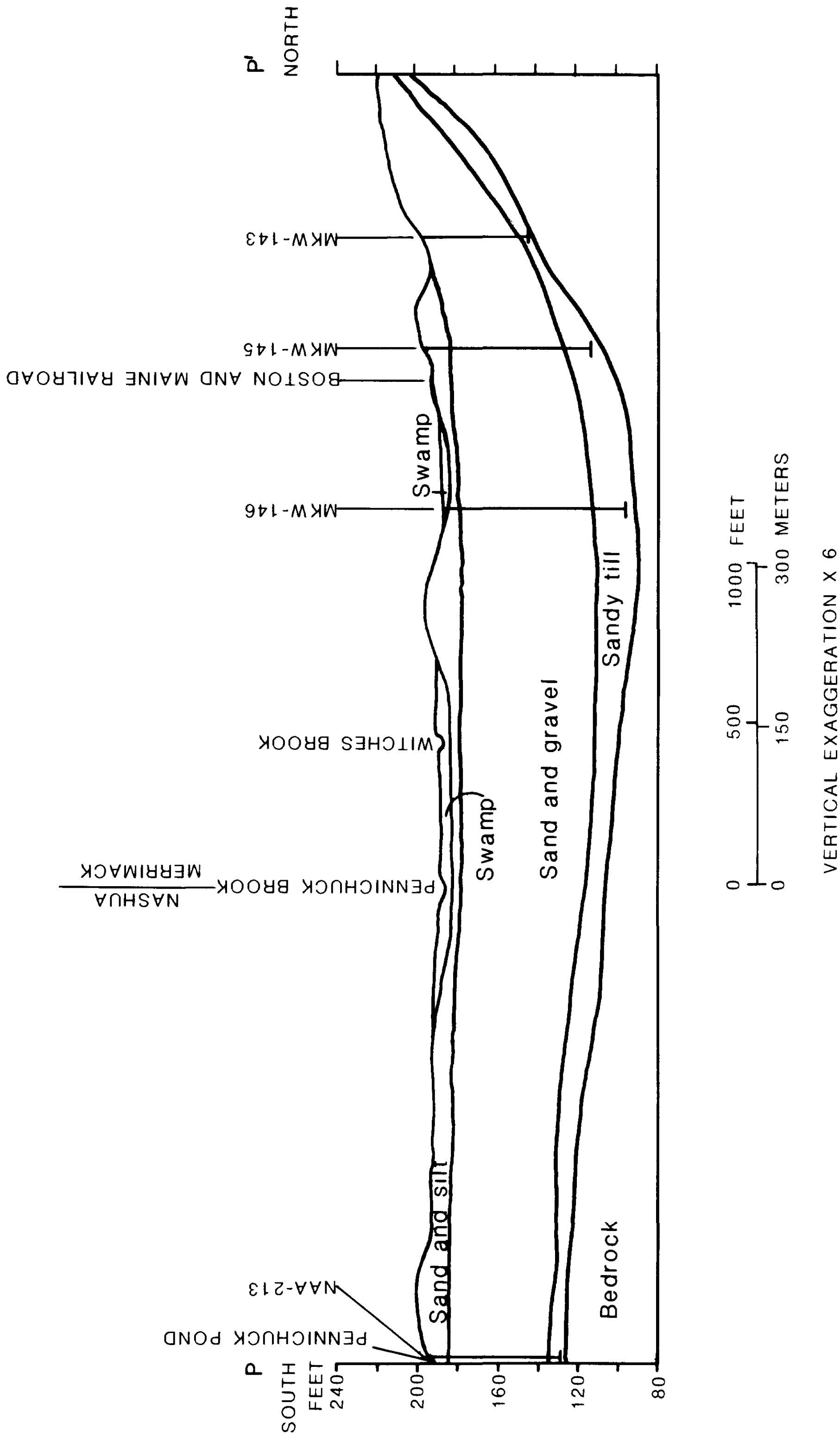


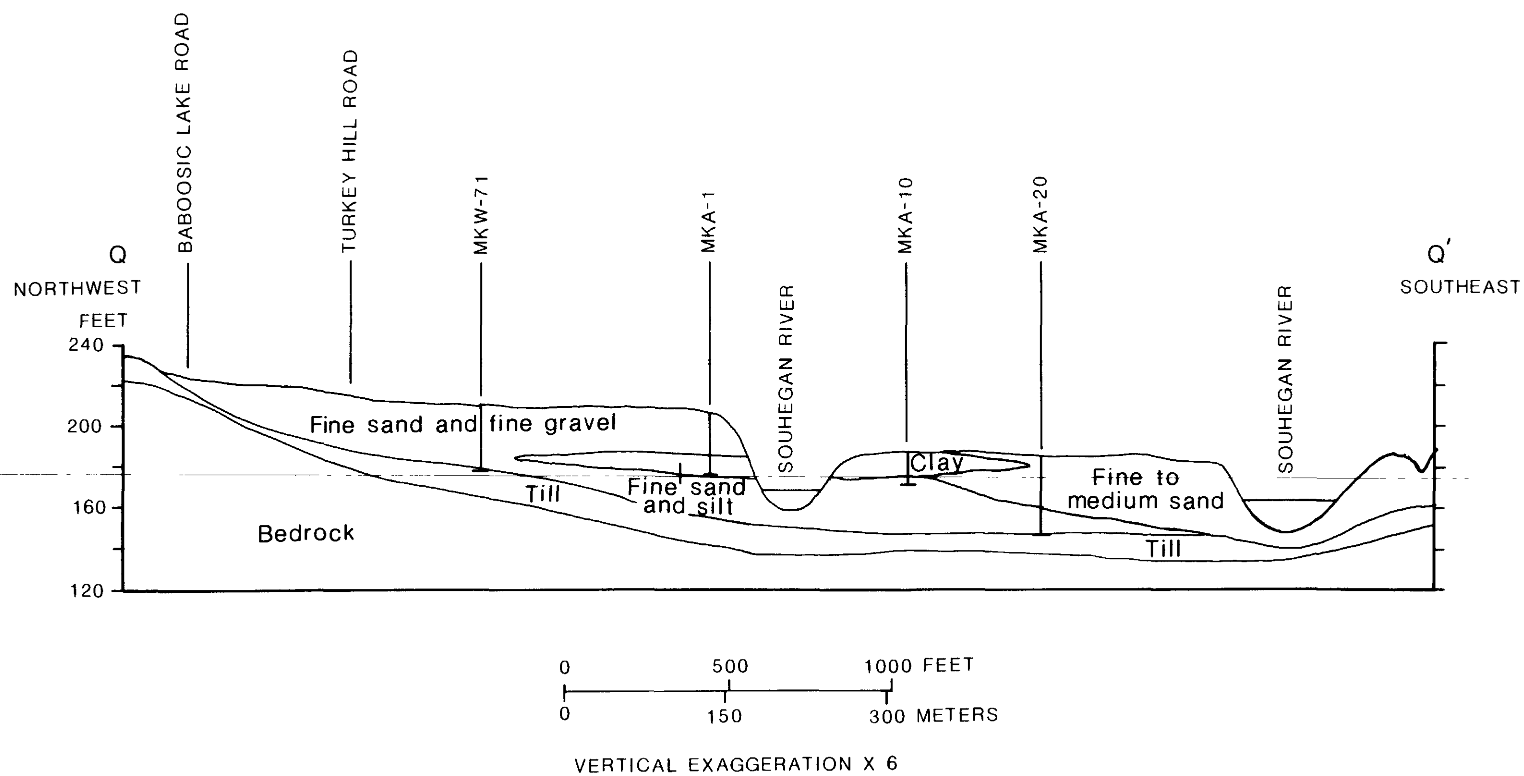
L
WEST
FEET
260
220
180
140
100
L′
EAST
SOUHEGAN RIVER
MKA-90
MERRIMACK
AMHERST
SEISMIC LINE f-f′
ROAD
THORNTON'S FERRY ROAD
SEISMIC LINE e-e′
AMW-65
COUNTRY ROAD
Bedrock
Till
Coarse to medium sand
Silt and sand
Till
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

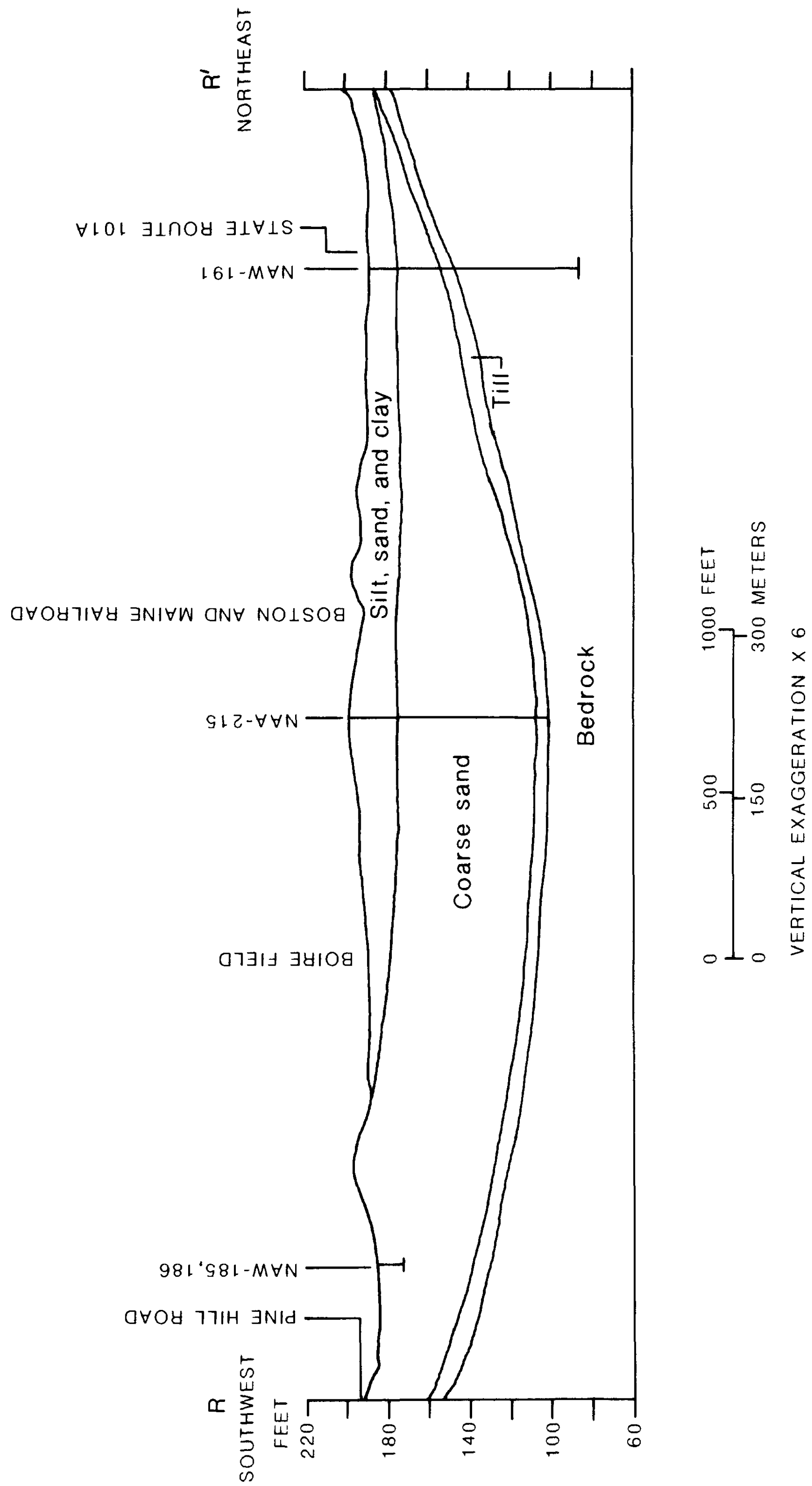

M
SOUTHWEST
FEET
360
320
280
240
200
M′
NORTHEAST
HSA-4
HSA-6
HSA-5
HSW-49
WITCHES BROOK
STATE ROUTE 122
TRUELL HILL ROAD
Sand and gravel
Sand
Sand
gravel,
cobbles,
boulders
Sand and gravel
Sand
Sandy till
Bedrock
Sand and silt
Excavated gravel
Sand and gravel
Pebbles
Silt and clay
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

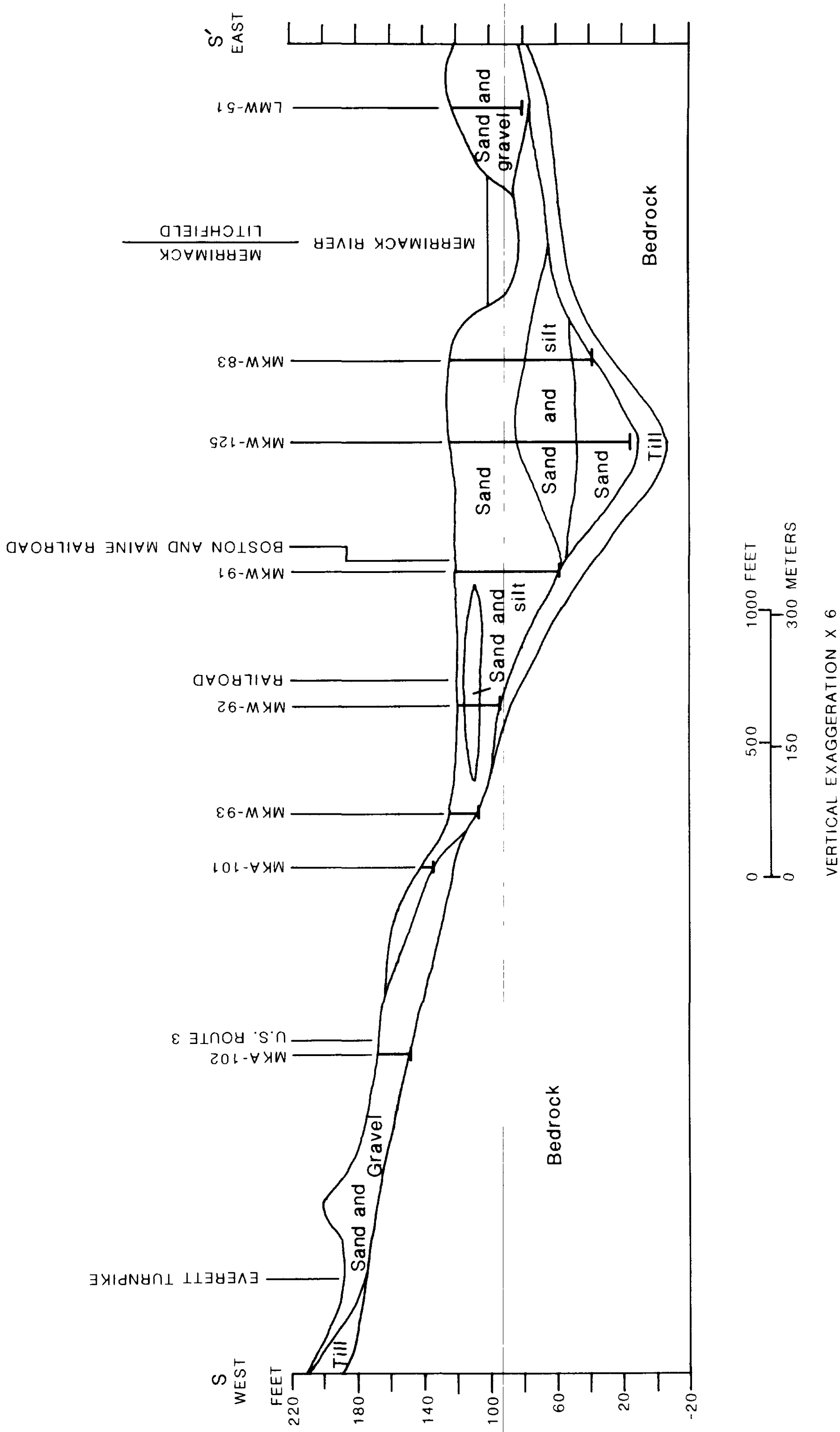

N
NORTHWEST
N′
SOUTHEAST
FEET
240
200
160
120
80
WILSON HILL ROAD
MKA-86
SOUHEGAN RIVER
MKA-88
MKA-15
MEETING HOUSE ROAD
Fine sand
Till
Fine sand
Silt and sand
Bedrock
Fine sand
Till
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 5

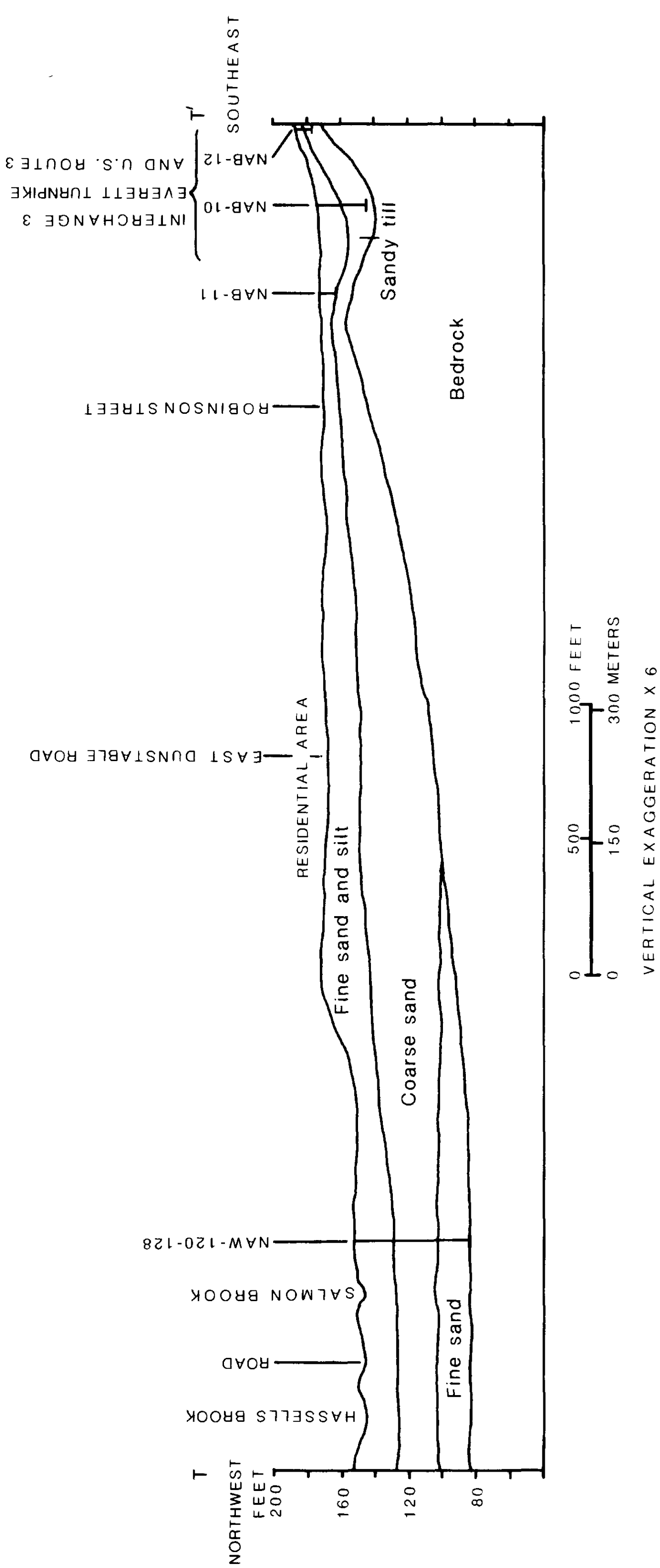

O
NORTHWESTWEST
O'
SOUTHEASTEAST
FEET
240
200
160
120
80
40
MKA-50
SOUHEGAN RIVER
CUTOFF MEANDER
OF SOUHEGAN RIVER
Fine sand
BROOK
BROOK
MKA-13
Silt and clay
MEETINGHOUSE ROAD
Till
Sand and gravel
MKA-49
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 5


P
SOUTH
FEET
240
200
160
120
80
P'
NORTH
PENNICHUCK POND
NAA-213
PENNICHUCK BROOK
NASHUA
MERRIMACK
Swamp
WITCHES BROOK
MKW-146
Swamp
BOSTON AND MAINE RAILROAD
MKW-145
MKW-143
Sand and silt
Sand and gravel
Sandy till
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

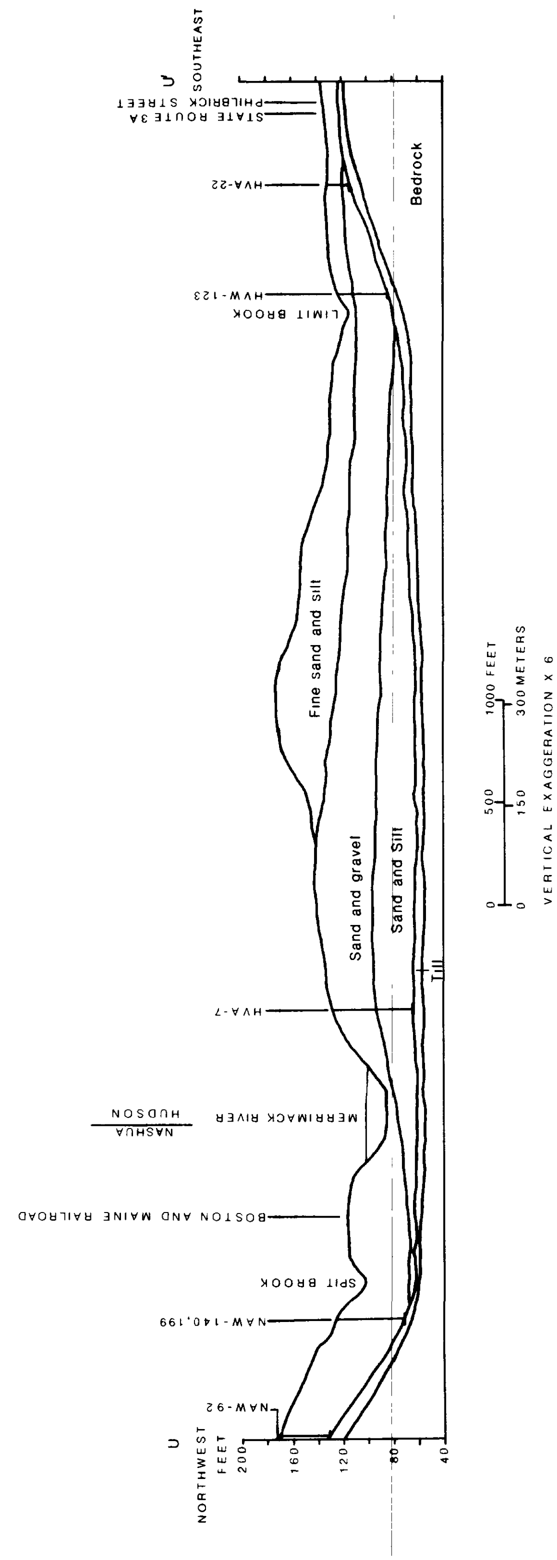

Q
NORTHWEST
Q′
SOUTHEAST
FEET
240
200
160
120
BABOOSIC LAKE ROAD
TURKEY HILL ROAD
MKW-71
MKA-1
SOUHEGAN RIVER
MKA-10
MKA-20
SOUHEGAN RIVER
Fine sand and fine gravel
Fine sand
and silt
Clay
Fine to
medium sand
Till
Till
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

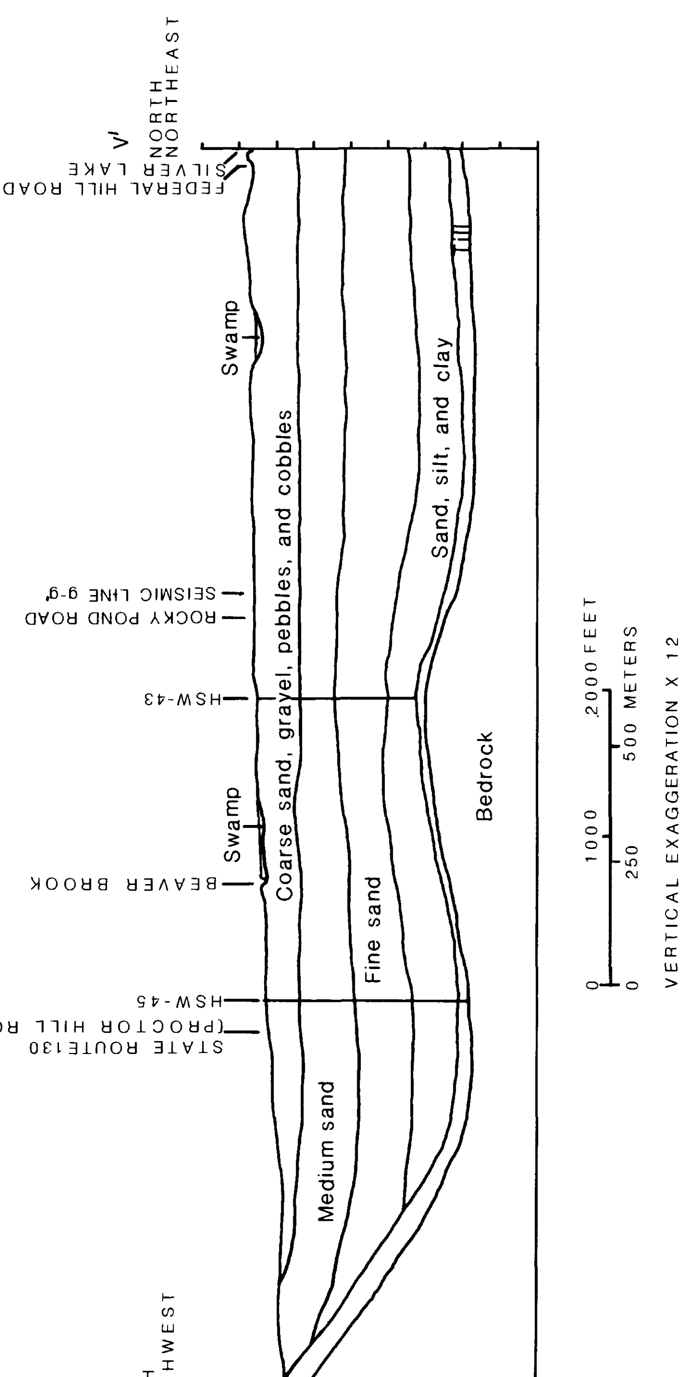

R
SOUTHWEST
R′
NORTHEAST
FEET
220
180
140
100
60
PINE HILL ROAD
NAW-185,186
BOIRE FIELD
NAA-215
BOSTON AND MAINE RAILROAD
NAW-191
STATE ROUTE 101A
Silt, sand, and clay
Coarse sand
Till
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6


S
WEST
S'
EAST
FEET
220
180
140
100
60
20
-20
EVERETT TURNPIKE
MKA-102
U.S. ROUTE 3
MKA-101
MKW-93
MKW-92
RAILROAD
MKW-91
BOSTON AND MAINE RAILROAD
MKW-125
MKW-83
MERRIMACK RIVER
MERRIMACK
LITCHFIELD
LMW-51
Till
Sand and Gravel
Bedrock
Sand and silt
Sand
Sand and silt
Sand
Till
Sand and gravel
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

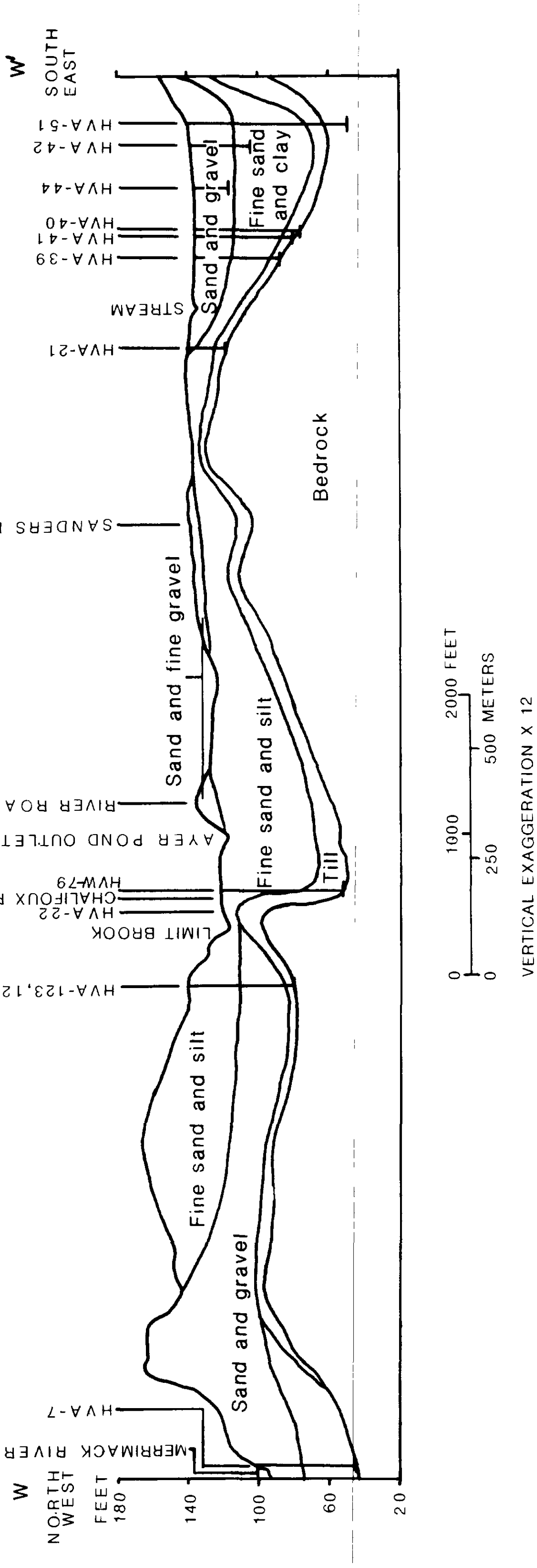


T
T'
NORTHWEST
SOUTHEAST
FEET
200
160
120
80
HASSELLS BROOK
ROAD
SALMON BROOK
NAW-120-128
EAST DUNSTABLE ROAD
RESIDENTIAL AREA
ROBINSON STREET
NAB-11
NAB-10
NAB-12
INTERCHANGE 3
EVERETT TURNPIKE
AND U.S. ROUTE 3
Fine sand and silt
Coarse sand
Fine sand
Sandy till
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

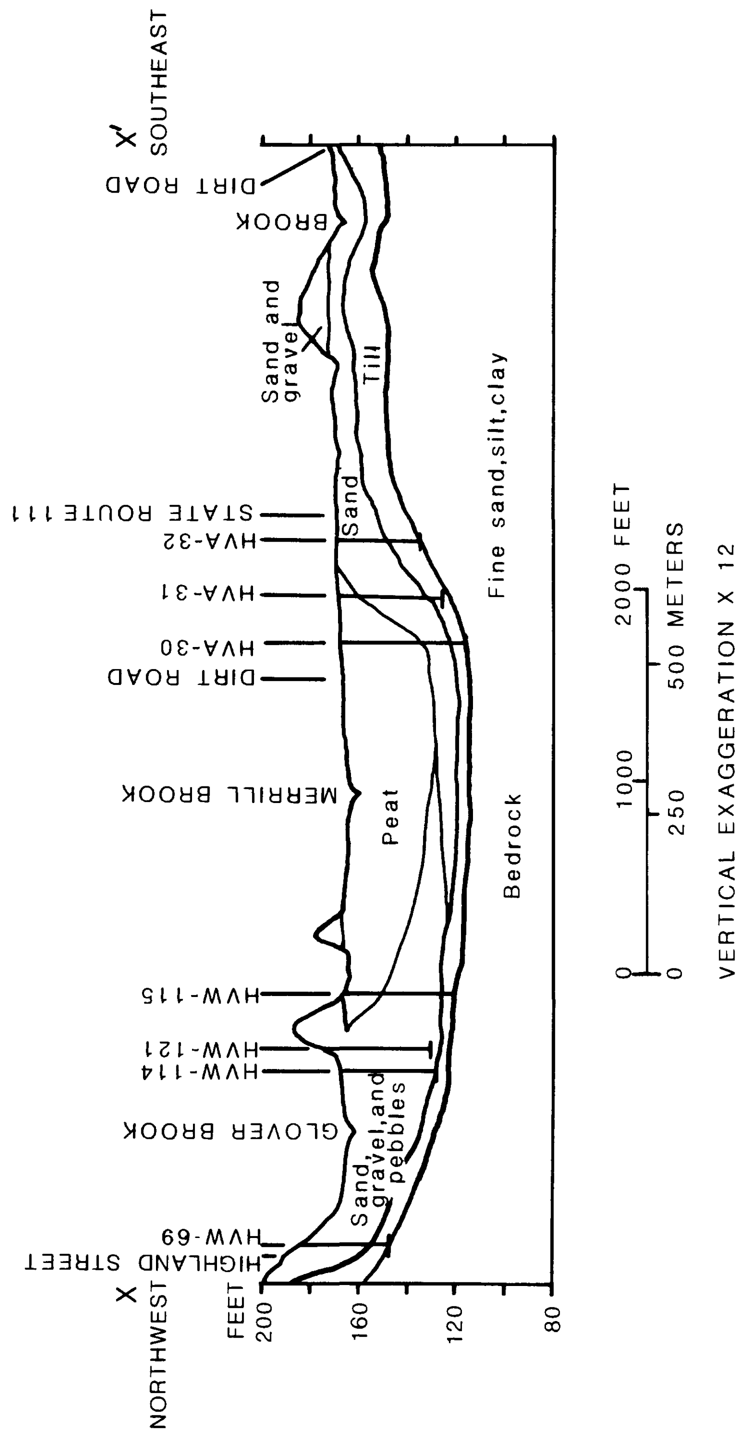

U
NORTHWEST
FEET
200
160
120
80
40
NAW-92
NAW-140,199
SPIT BROOK
BOSTON AND MAINE RAILROAD
NASHUA
HUDSON
MERRIMACK RIVER
HVA-7
Till
Sand and gravel
Sand and Silt
Fine sand and silt
LIMIT BROOK
HVW-123
HVA-22
Bedrock
STATE ROUTE 3A
PHILBRICK STREET
U'
SOUTHEAST
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 6

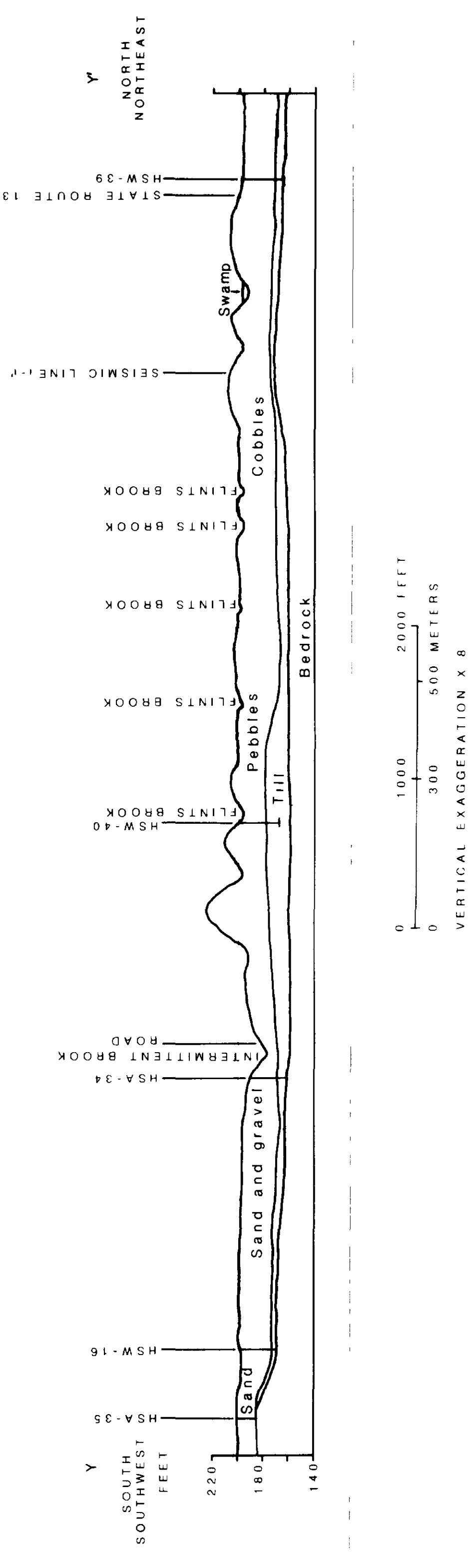


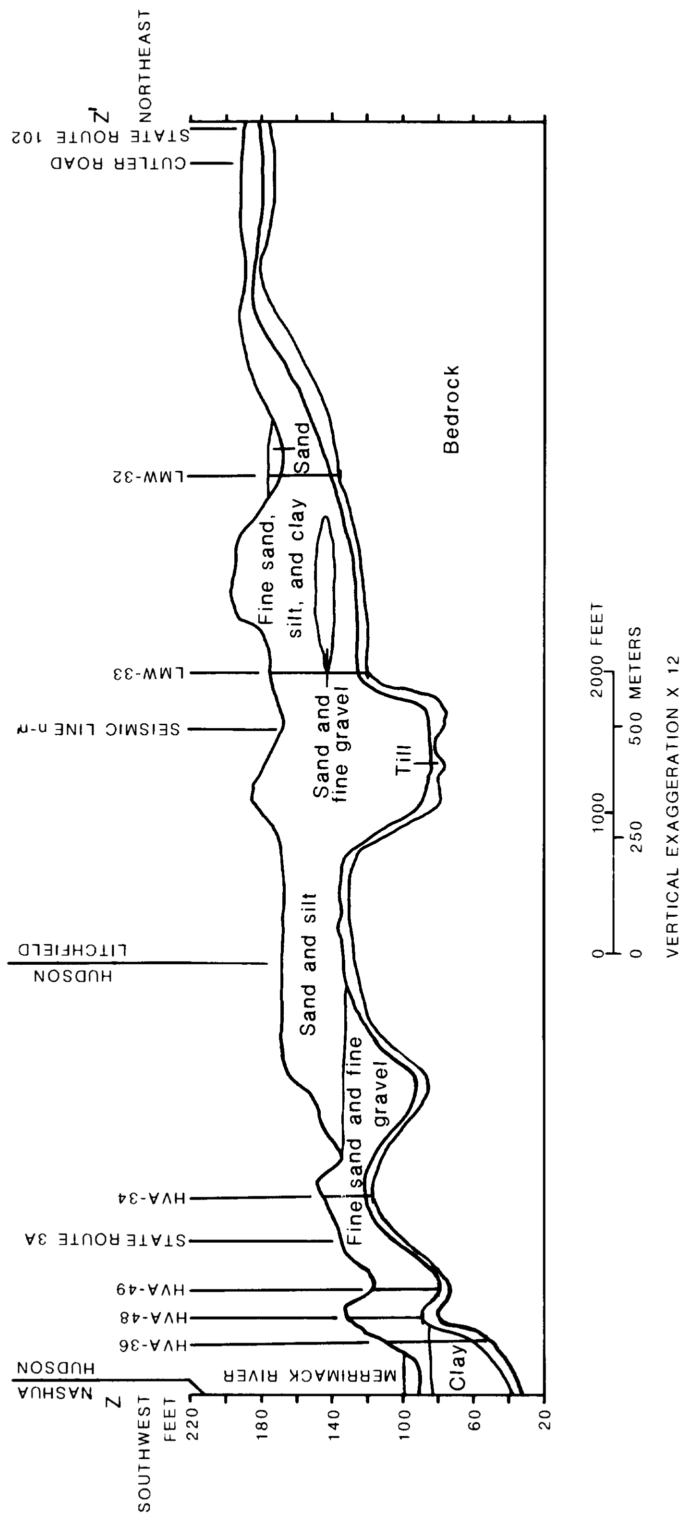
V
SOUTH
SOUTHWEST
V'
NORTH
NORTHEAST
FEET
280
240
200
160
120
STATE ROUTE130
(PROCTOR HILL ROAD)
HSW-45
BEAVER BROOK
Swamp
HSW-43
ROCKY POND ROAD
SEISMIC LINE g-g'
Swamp
FEDERAL HILL ROAD
SILVER LAKE
Medium sand
Coarse sand, gravel, pebbles, and cobbles
Fine sand
Sand, silt, and clay
Till
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

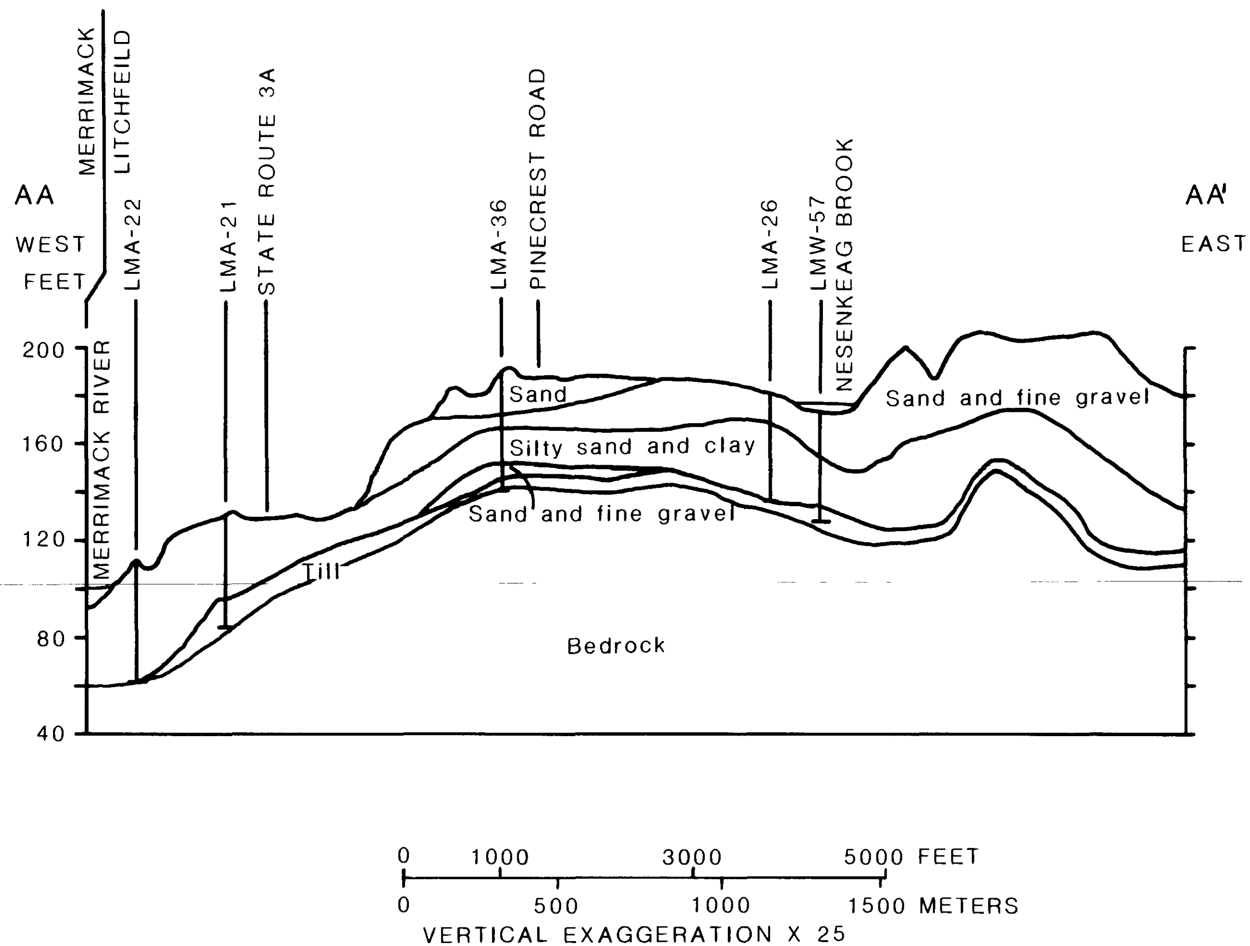


W
NORTH WEST
W'
SOUTH EAST
FEET
180
140
100
60
20
MERRIMACK RIVER
HVA-7
HVA-123,124
LIMIT BROOK
HVA-22
CHALIFOUX ROAD
HVW-79
AYER POND OUTLET
RIVER ROAD
SANDERS ROAD
HVA-21
STREAM
HVA-39
HVA-41
HVA-40
HVA-44
HVA-42
HVA-51
Sand and gravel
Fine sand and silt
Sand and fine gravel
Sand and silt
Fine sand and silt
Till
Bedrock
Sand and gravel
Fine sand and clay
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

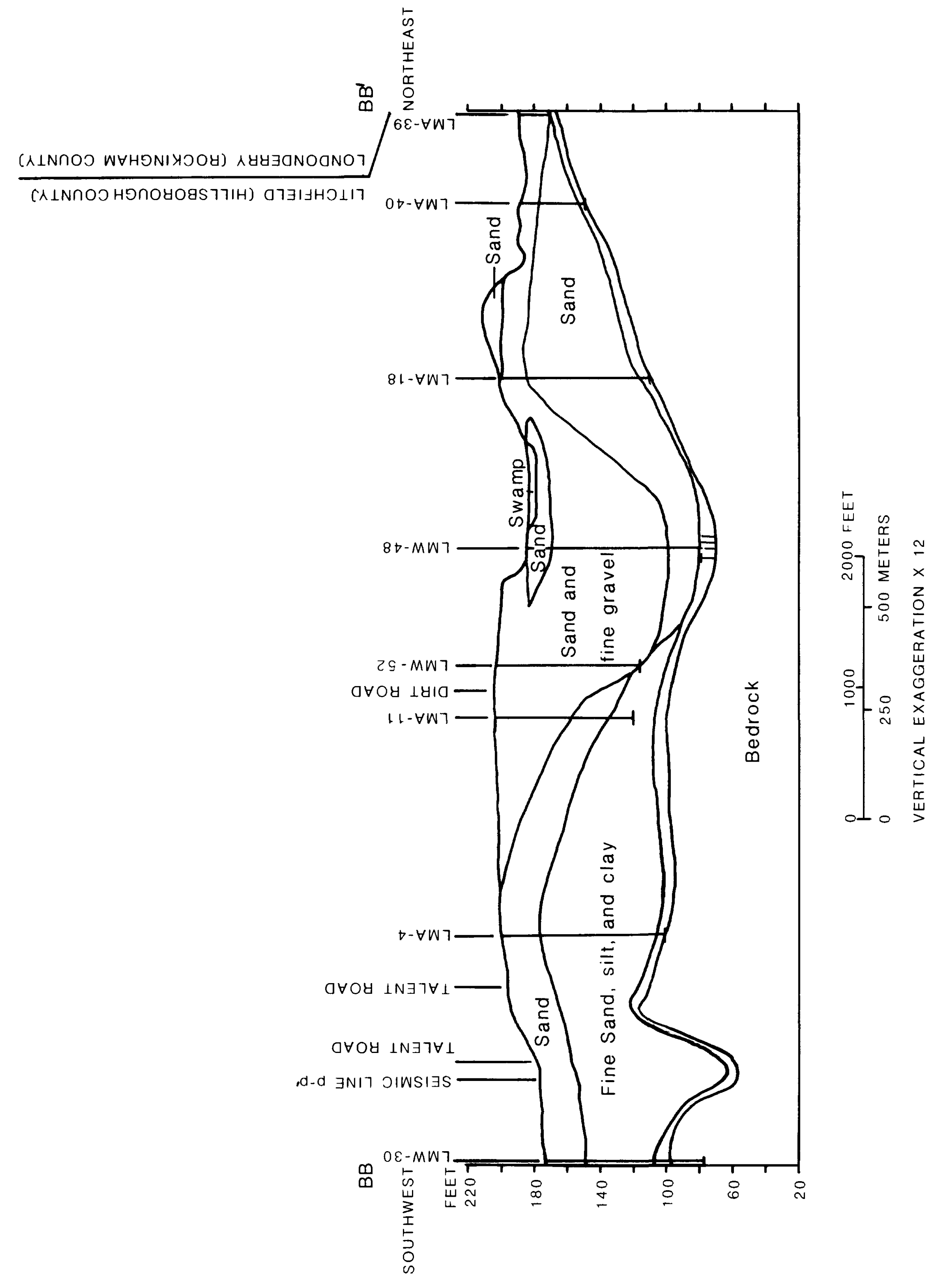

X
NORTHWEST
X'
SOUTHEAST
FEET
200
160
120
80
HIGHLAND STREET
HVW-69
GLOVER BROOK
HVW-114
HVW-121
HVW-115
MERRILL BROOK
DIRT ROAD
HVA-30
HVA-31
HVA-32
STATE ROUTE 111
BROOK
DIRT ROAD
Sand, gravel, and pebbles
Peat
Sand
Sand and gravel
Till
Fine sand, silt, clay
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

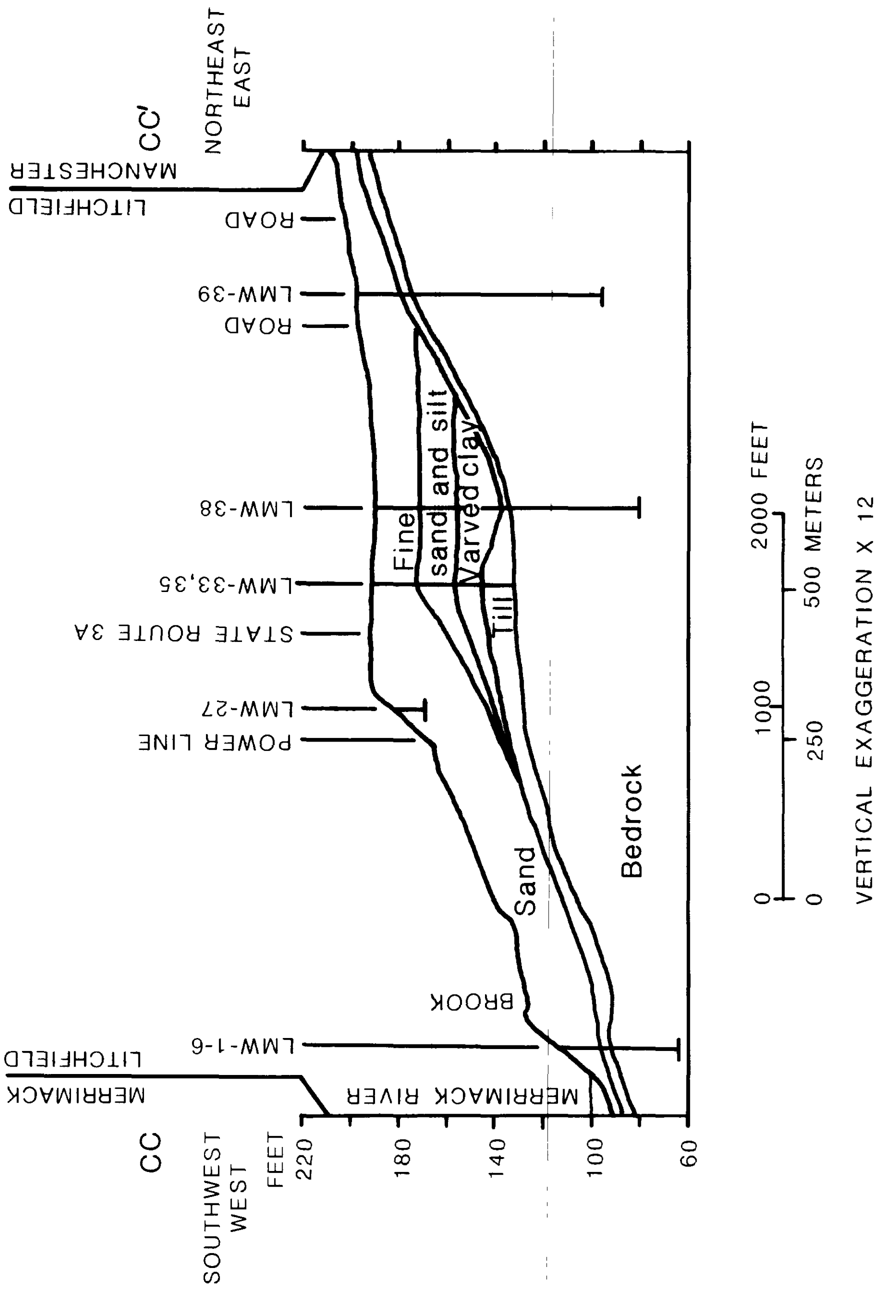

Y
SOUTH
SOUTHWEST
FEET
220
180
140
HSA-35
HSW-16
HSA-34
INTERMITTENT BROOK
ROAD
HSW-40
FLINTS BROOK
FLINTS BROOK
FLINTS BROOK
FLINTS BROOK
FLINTS BROOK
SEISMIC LINE I-I'
Swamp
STATE ROUTE 130
HSW-39
Y'
NORTH
NORTHEAST
Sand
Sand and gravel
Pebbles
Till
Cobbles
Bedrock
0 1000 2000 FEET
0 300 500 METERS
VERTICAL EXAGGERATION X 8

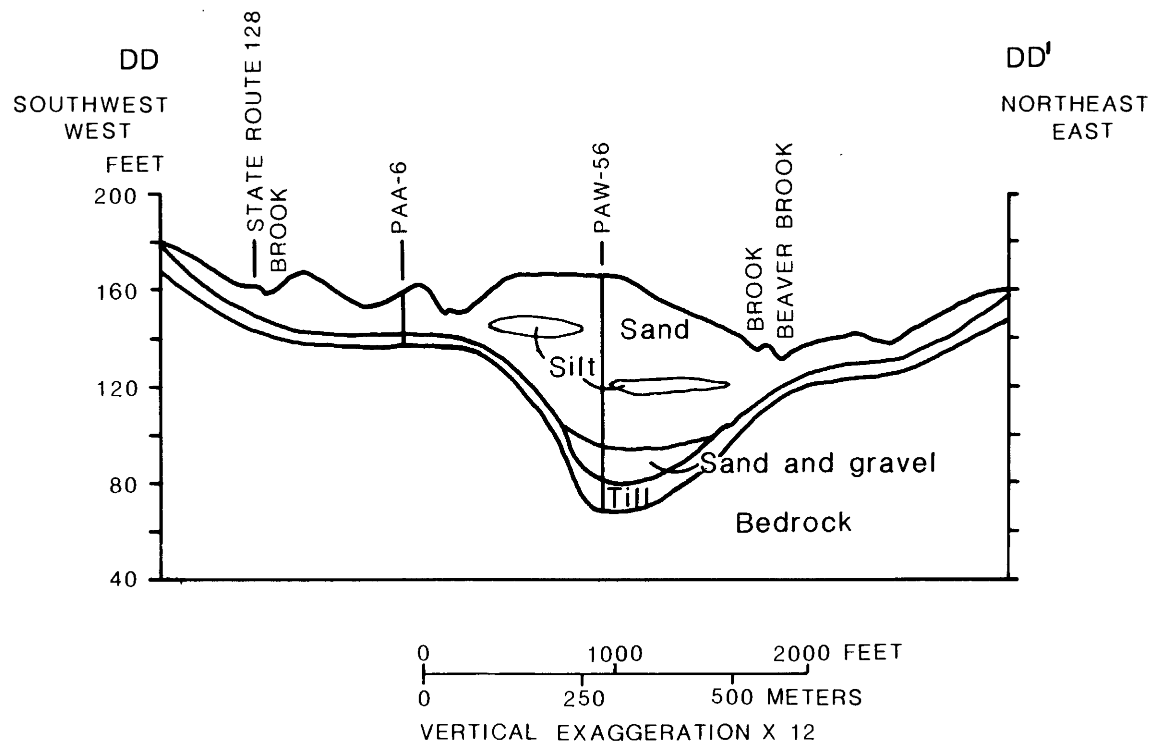

SOUTHWEST
FEET
220
180
140
100
60
20
Z
NASHUA
HUDSON
MERRIMACK RIVER
HVA-36
HVA-48
HVA-49
STATE ROUTE 3A
HVA-34
Clay
Fine sand and fine gravel
Sand and silt
HUDSON
LITCHFIELD
Sand and fine gravel
Till
SEISMIC LINE n-n'
LMW-33
Fine sand, silt, and clay
LMW-32
Sand
Bedrock
CUTLER ROAD
STATE ROUTE 102
Z'
NORTHEAST
0 1000 2000 FEET
0 250 500 METERS
VERTICAL EXAGGERATION X 12

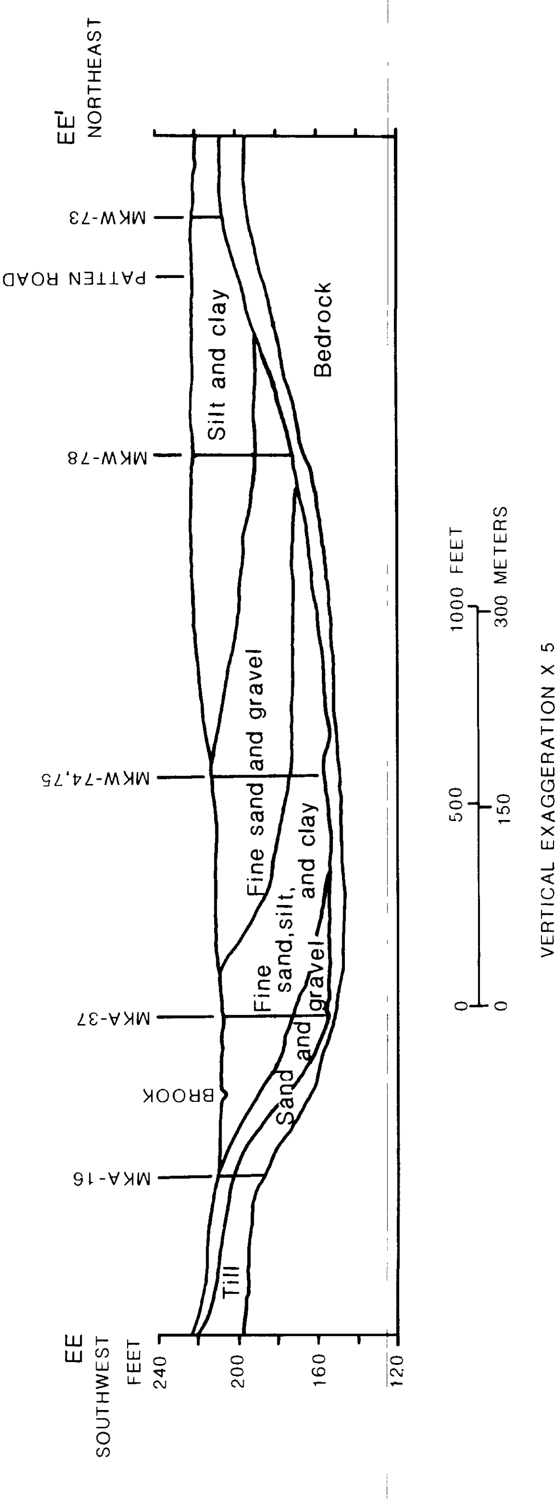


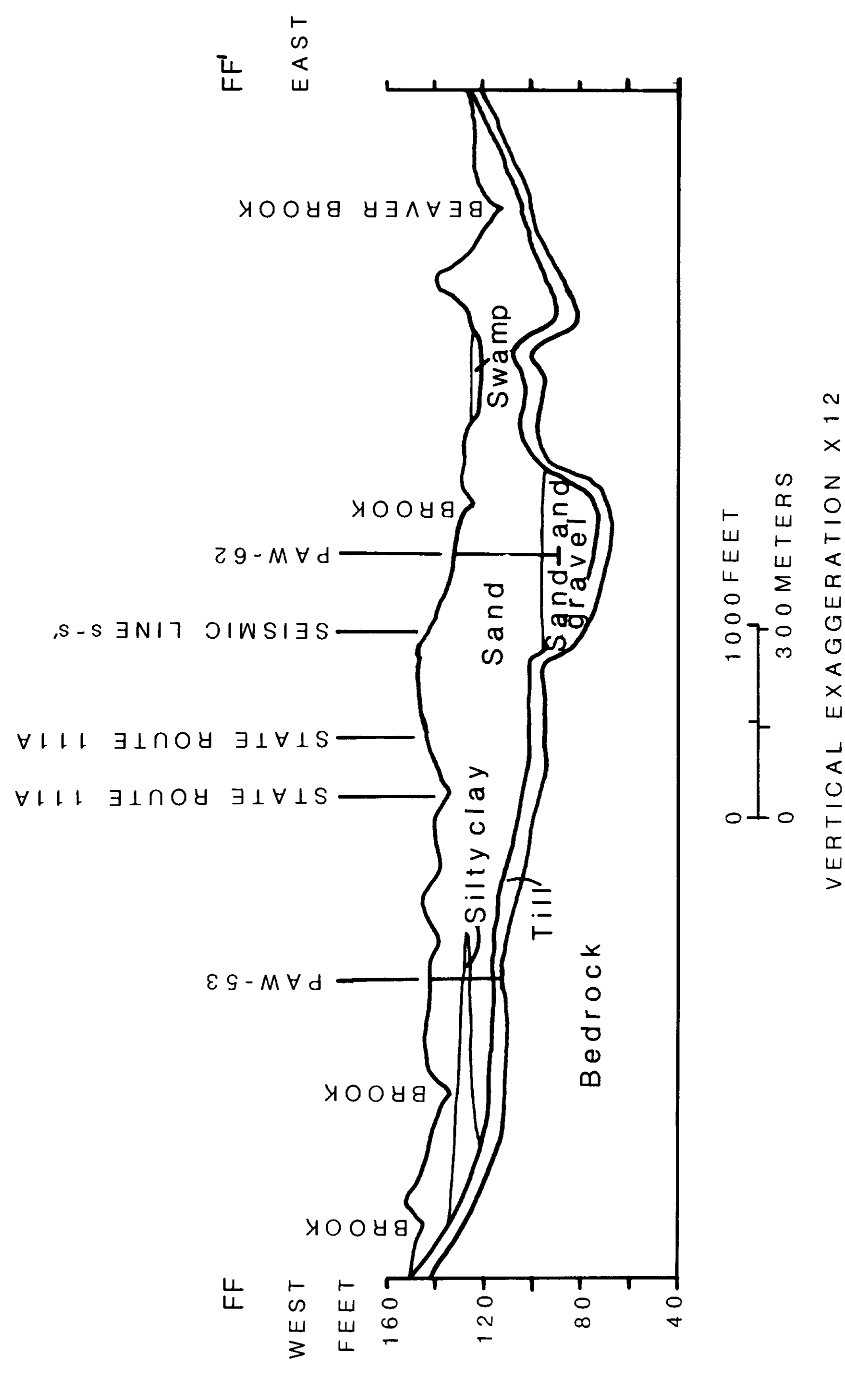
AA
WEST
FEET
MERRIMACK
LITCHFEILD
LMA-22
LMA-21
STATE ROUTE 3A
LMA-36
PINECREST ROAD
LMA-26
LMW-57
NESENKEAG BROOK
AA'
EAST
200
160
120
80
40
MERRIMACK RIVER
Sand
Silty sand and clay
Sand and fine gravel
Sand and fine gravel
Till
Bedrock
0
1000
3000
5000 FEET
0
500
1000
1500 METERS
VERTICAL EXAGGERATION X 25

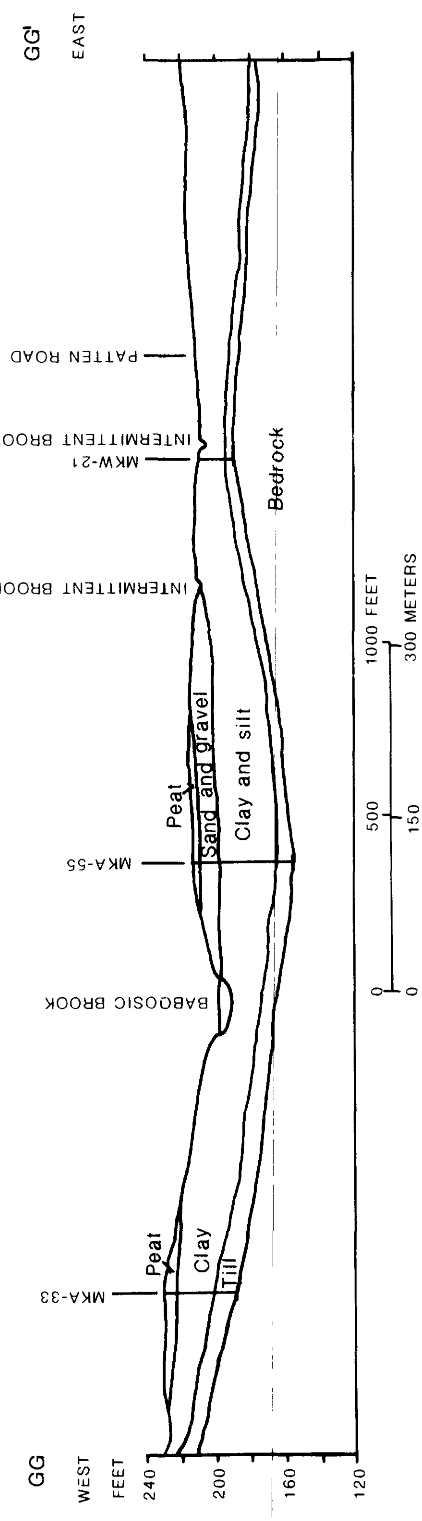

BB
BB'
SOUTHWEST
NORTHEAST
FEET
220
180
140
100
60
20
LONDONDERRY (ROCKINGHAM COUNTY)
LITCHFIELD (HILLSBOROUGH COUNTY)
LMW-30
SEISMIC LINE p-p'
TALENT ROAD
TALENT ROAD
LMA-4
LMA-11
DIRT ROAD
LMW-52
LMW-48
LMA-18
LMA-40
LMA-39
Sand
Fine Sand, silt, and clay
Sand and fine gravel
Swamp
Sand
Sand
Sand
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12

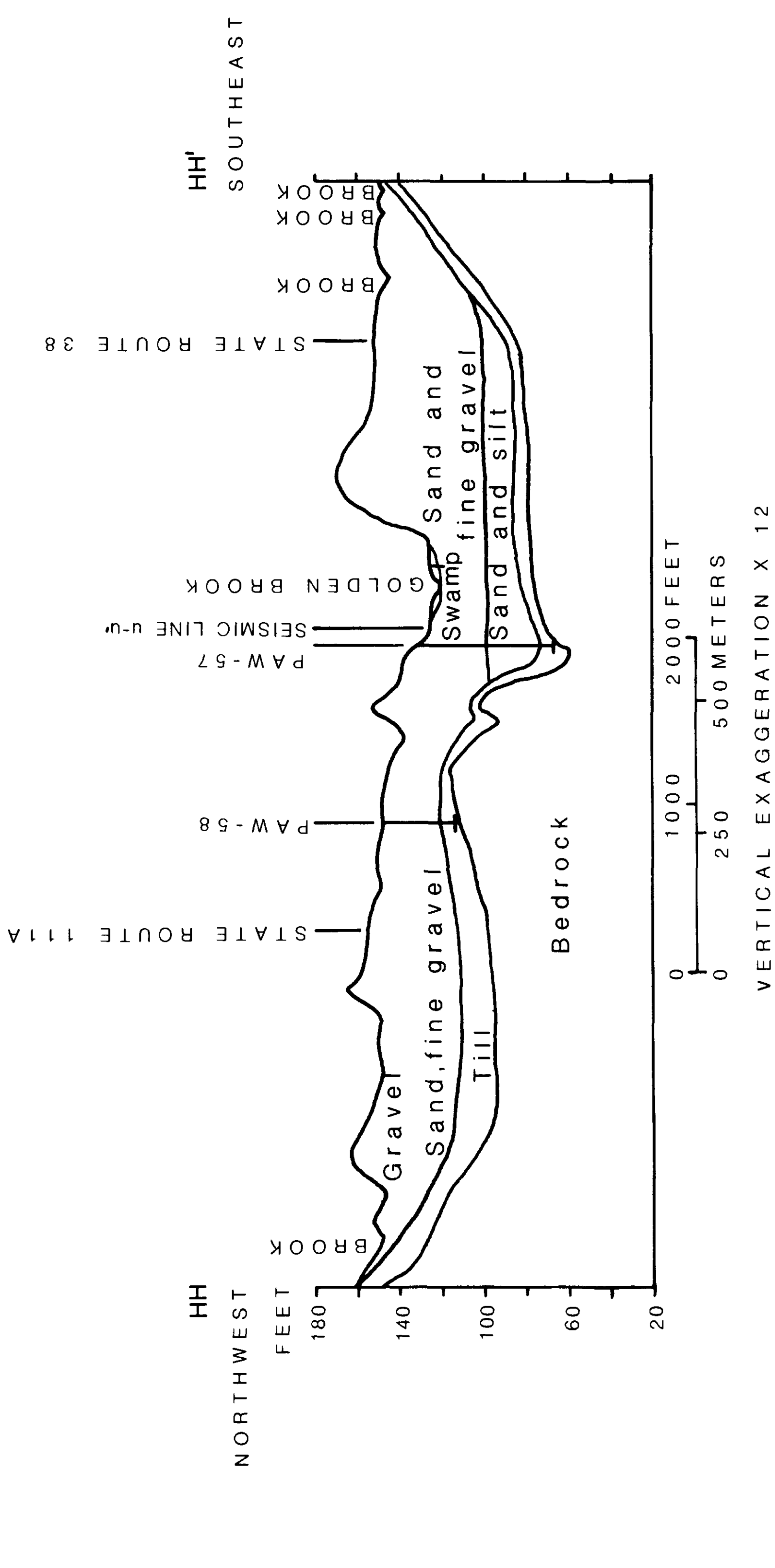

CC
CC'
SOUTHWEST
WEST
NORTHEAST
EAST
FEET
220
180
140
100
60
MERRIMACK
LITCHFIELD
MANCHESTER
LITCHFIELD
MERRIMACK RIVER
LMW-1-6
BROOK
POWER LINE
LMW-27
STATE ROUTE 3A
LMW-33,35
LMW-38
ROAD
LMW-39
ROAD
Fine sand and silt
Varved clay
Till
Sand
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12


DD
SOUTHWEST
WEST
FEET
200
160
120
80
40
STATE ROUTE 128
BROOK
PAA-6
PAW-56
BROOK
BEAVER BROOK
DD'
NORTHEAST
EAST
Sand
Silt
Sand and gravel
Till
Bedrock
0
1000
2000 FEET
0
250
500 METERS
VERTICAL EXAGGERATION X 12


EE
SOUTHWEST
FEET
240
200
160
120
EE'
NORTHEAST
MKA-16
BROOK
MKA-37
MKW-74,75
MKW-78
PATTEN ROAD
MKW-73
Till
Sand and gravel
Fine sand,silt, and clay
gravel
Fine sand and gravel
Silt and clay
Bedrock
0
500
1000 FEET
0
150
300 METERS
VERTICAL EXAGGERATION X 5


FF
WEST
FEET
160
120
80
40
FF'
EAST
BEAVER BROOK
Swamp
BROOK
PAW-62
Sand and gravel
SEISMIC LINE s-s'
Sand
STATE ROUTE 111A
STATE ROUTE 111A
Silty clay
Till
PAW-53
Bedrock
BROOK
BROOK
0 1000 FEET
0 300 METERS
VERTICAL EXAGGERATION X 12


GG
WEST
GG'
EAST
FEET
240
200
160
120
MKA-33
BABOOSIC BROOK
MKA-55
INTERMITTENT BROOK
MKW-21
INTERMITTENT BROOK
PATTEN ROAD
Peat
Clay
Till
Peat
Sand and gravel
Clay and silt
Bedrock
0
500
1000 FEET
0
150
300 METERS


HH
NORTHWEST
HH'
SOUTHEAST
FEET
180
140
100
60
20
BROOK
BROOK
BROOK
BROOK
STATE ROUTE 111A
PAW-58
PAW-57
SEISMIC LINE u-u'
GOLDEN BROOK
STATE ROUTE 38
Gravel
Sand, fine gravel
Till
Bedrock
Swamp
Sand and fine gravel
Sand and silt
Sand and silt
0 1000 2000 FEET
0 250 500 METERS
VERTICAL EXAGGERATION X 12

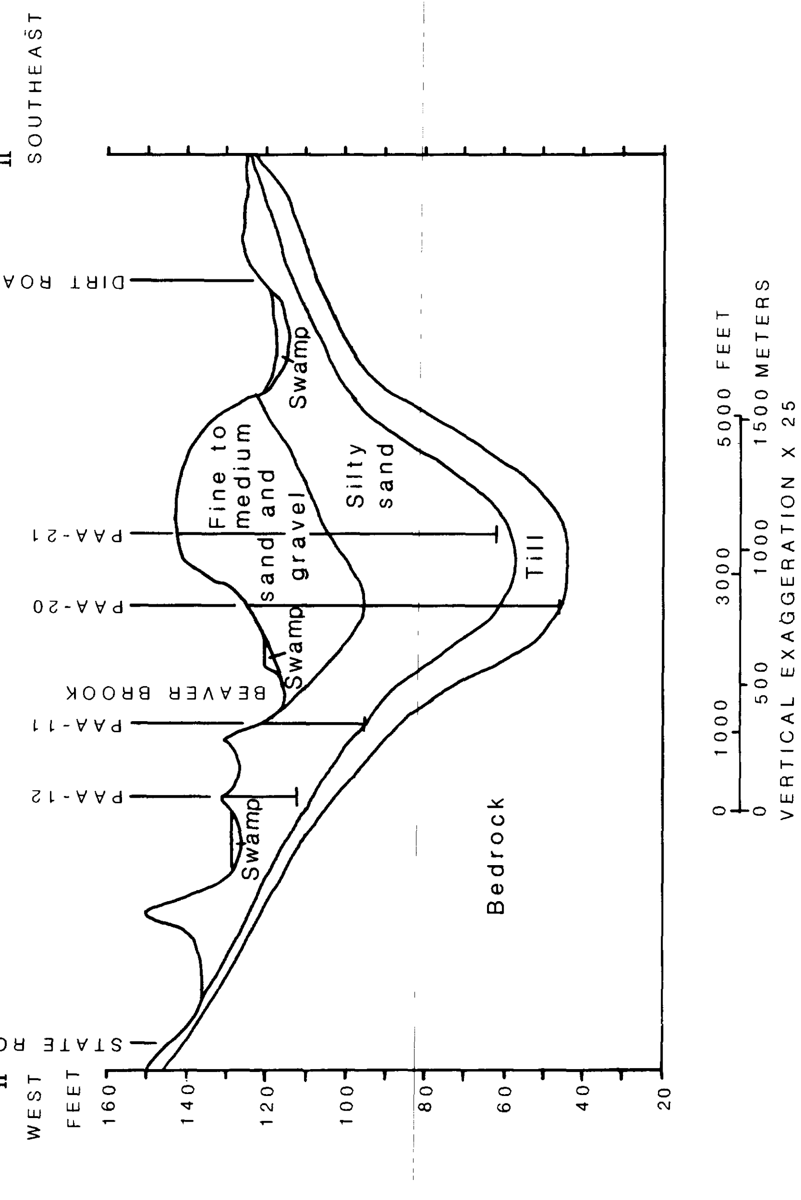
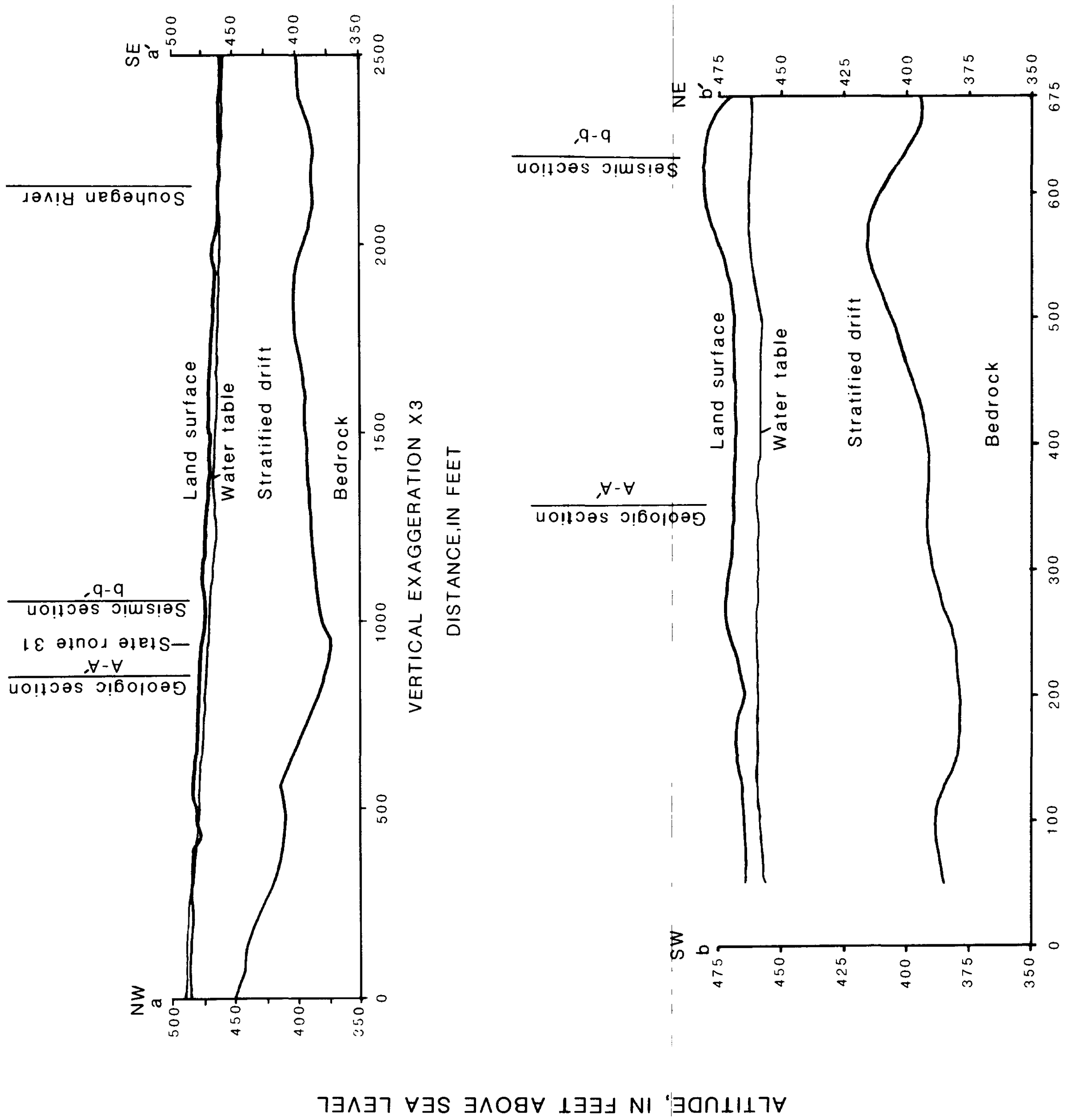
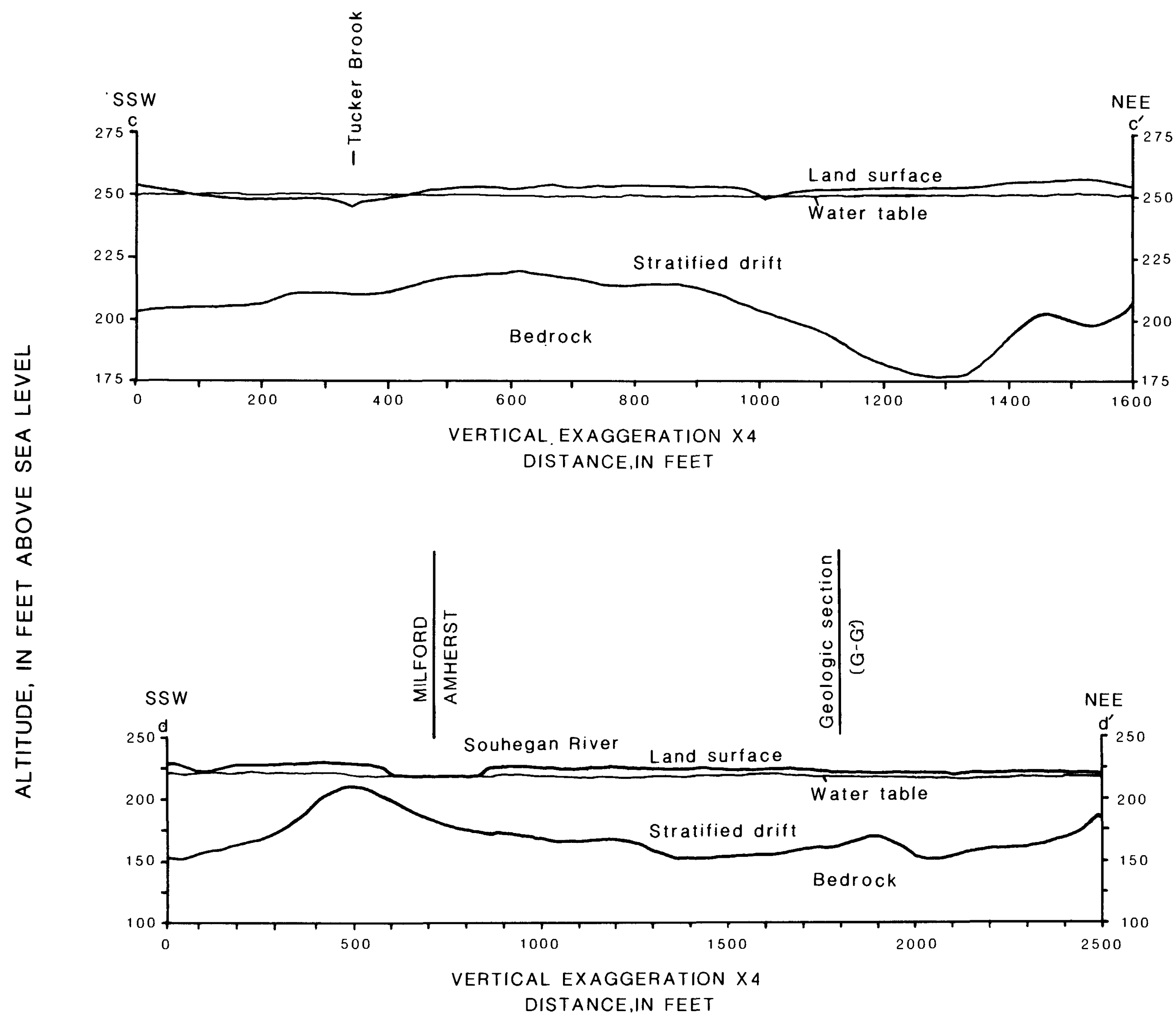
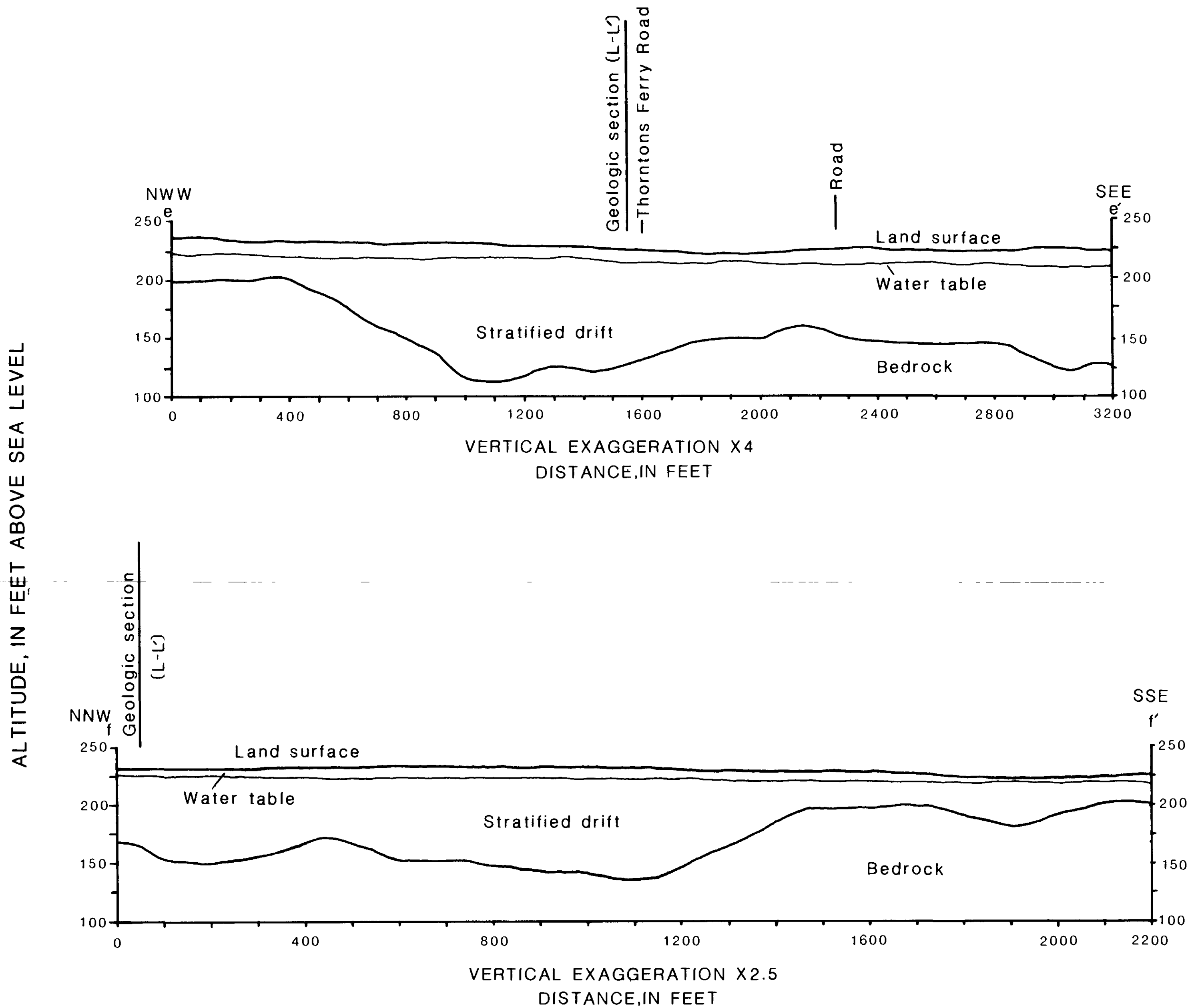

II
WEST
FEET
160
140
120
100
80
60
40
20
STATE ROUTE 111A
PAA-12
PAA-11
BEAVER BROOK
PAA-20
PAA-21
DIRT ROAD
II'
SOUTHEAST
Swamp
Swamp
Swamp
Fine to medium sand and gravel
Silty sand
Till
Bedrock
0 1000 3000 5000 FEET
0 500 1000 1500 METERS
VERTICAL EXAGGERATION X 25

Figure A-2.--*Seismic sections*

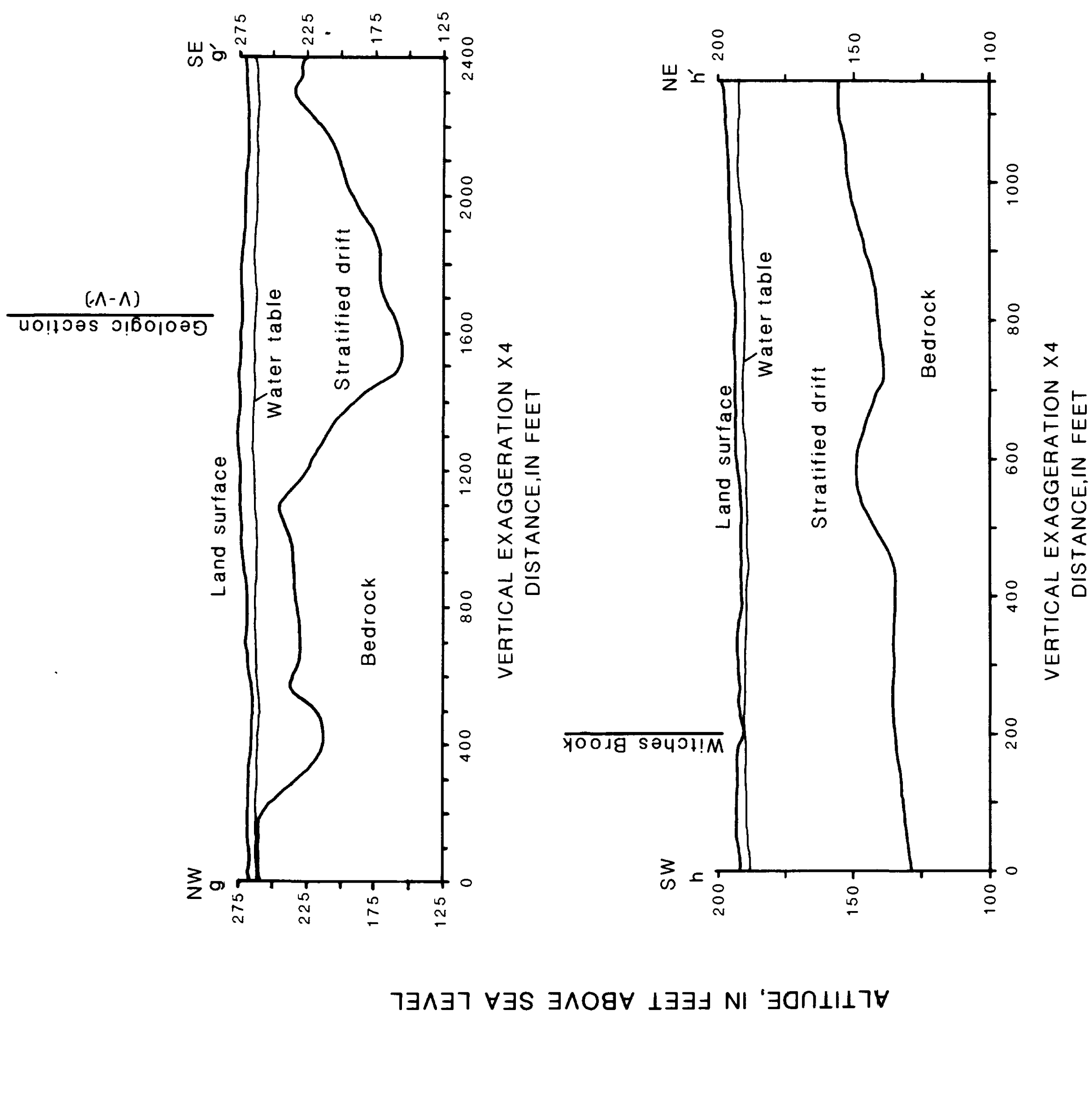
Section line	Plate	Description
a-a'	1	Wilton, line 1, spreads 1-4, Souhegan River, State Route 31
b-b'	1	Wilton, line 2, spread 1, southeast of Wilton Center
c-c'	1	Milford, line 1, spreads 1-3, State Route 31, Souhegan River
d-d'	1 and 3	Milford-Amherst, line 5, spreads 1-4, Souhegan River
e-e'	3	Amherst, line 2, spreads 1, 3-6, north of County Road
f-f'	3	Amherst, line 3A, spreads 1-4, Thorntons Ferry Road
g-g'	3	Hollis, line 3, spreads 1-4, Rocky Pond Road
h-h'	3	Hollis, line 1, spreads 1-2, South Merrimack Road
i-i'	3	Hollis, line 2, spreads 1-3, south of Flints Pond, Wright Road
j-j'	3	Amherst, line 1, spread 1, Boston Post Road
k-k'	3	Amherst, line 4, spread 1, parallels State Route 122
l-l'	3	Merrimack, line 1, spreads 1-4, Wire Road
m-m'	3	Amherst, line 6, spreads 1-2, Beaver Brook, Thorntons Ferry Road
n-n'	5	Litchfield, line 3, spreads 1-6, near Cutler Road
o-o'	5	Litchfield, line 1, spreads 1-5, Talent Road extension
p-p'	5	Litchfield, line 2, spreads 1-2, Talent Road
q-q'	5	Litchfield, line 4, spreads 1-3, north of Half Moon Pond
r-r'	5	Pelham, line 1, spreads 1-2, north of Willow Street
s-s'	5	Pelham, line 2, spreads 1-3, Marsh Road toward Willow Street
t-t'	5	Pelham, line 3, spreads 1-3, State Route 128
u-u'	5	Pelham, line 5, spreads 1-3, Golden Brook between State Routes 111A and 38
v-v'	5	Pelham, line 4, spreads 1-3, south of Willow Street


NW
a
SE
a'
Geologic section
A-A'
State route 31
Seismic section
b-b'
Souhegan River
Land surface
Water table
Stratified drift
Bedrock
VERTICAL EXAGGERATION X3
DISTANCE, IN FEET
SW
b
NE
b'
Geologic section
A-A'
Seismic section
b-b'
Land surface
Water table
Stratified drift
Bedrock
VERTICAL EXAGGERATION X2
DISTANCE, IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL

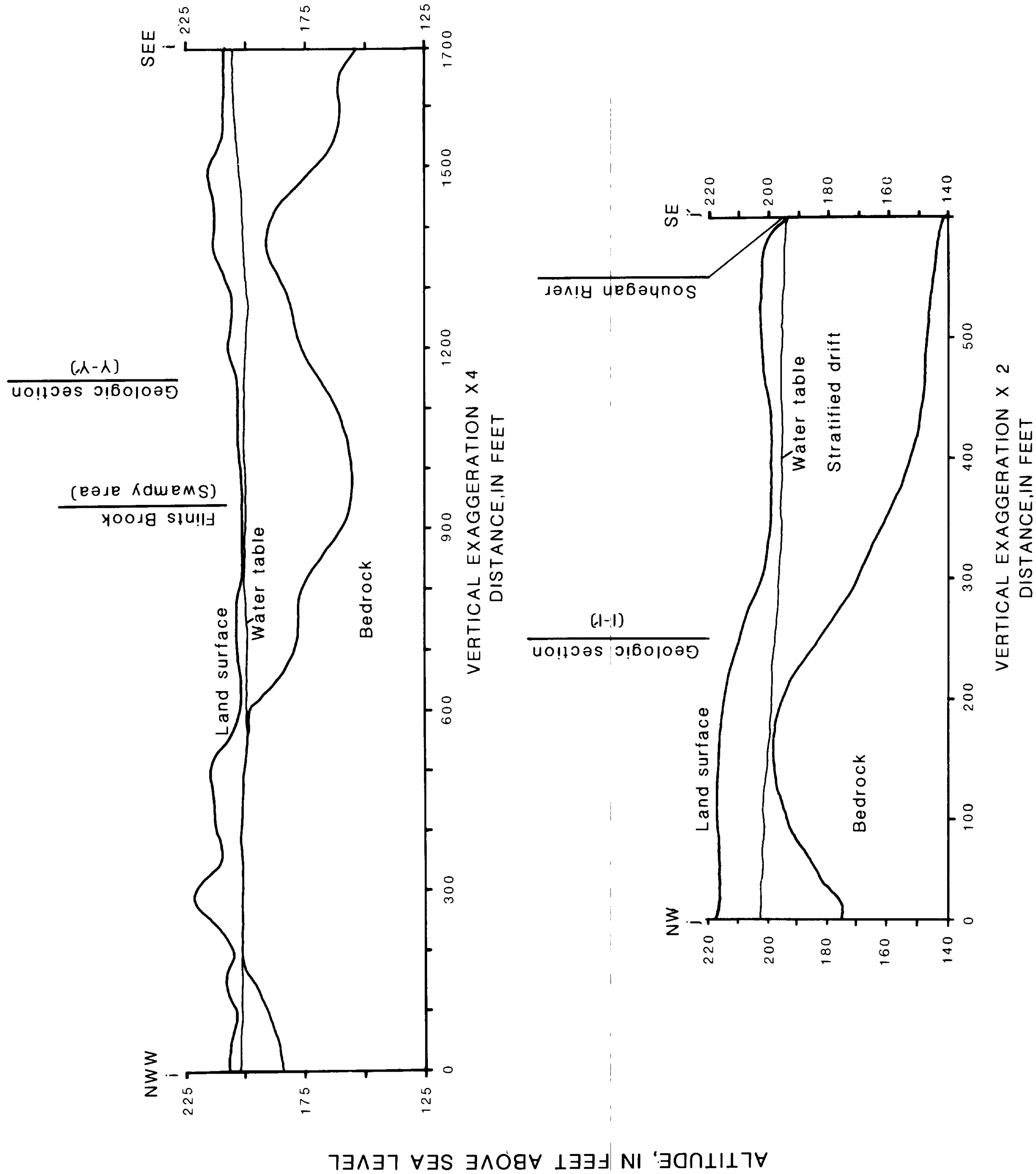

ALTITUDE, IN FEET ABOVE SEA LEVEL
SSW
c
NEE
c′
Tucker Brook
Land surface
Water table
Stratified drift
Bedrock
275
250
225
200
175
0
200
400
600
800
1000
1200
1400
1600
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
SSW
d
NEE
d′
MILFORD
AMHERST
Geologic section
(G-G′)
Souhegan River
Land surface
Water table
Stratified drift
Bedrock
250
200
150
100
0
500
1000
1500
2000
2500
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET



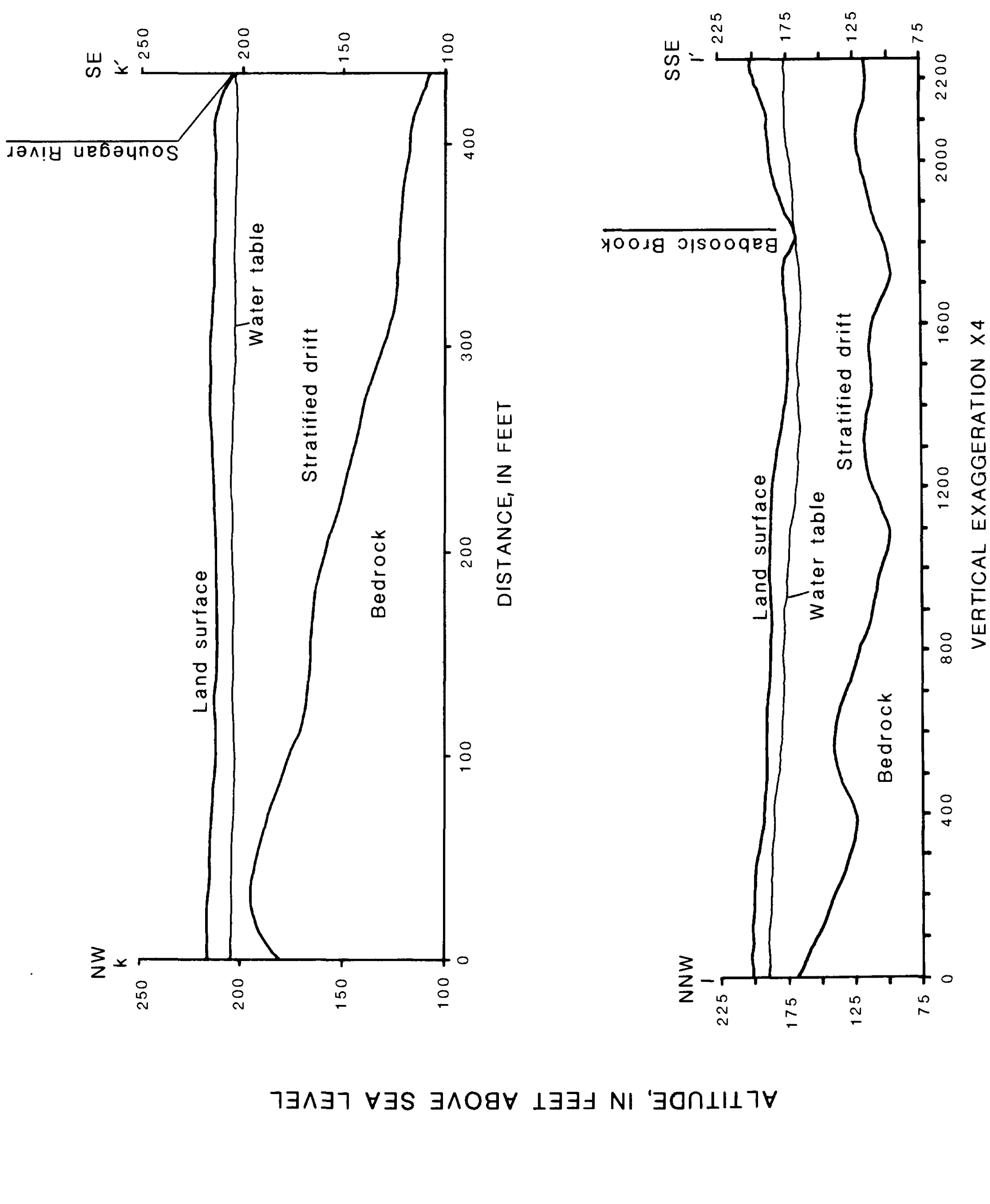
ALTITUDE, IN FEET ABOVE SEA LEVEL
NWW
e
SEE
e′
Geologic section (L-L′)
Thorntons Ferry Road
Road
Land surface
Water table
Stratified drift
Bedrock
250
200
150
100
0
400
800
1200
1600
2000
2400
2800
3200
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
NNW
f
SSE
f′
Geologic section (L-L′)
Land surface
Water table
Stratified drift
Bedrock
250
200
150
100
0
400
800
1200
1600
2000
2200
VERTICAL EXAGGERATION X2.5
DISTANCE,IN FEET

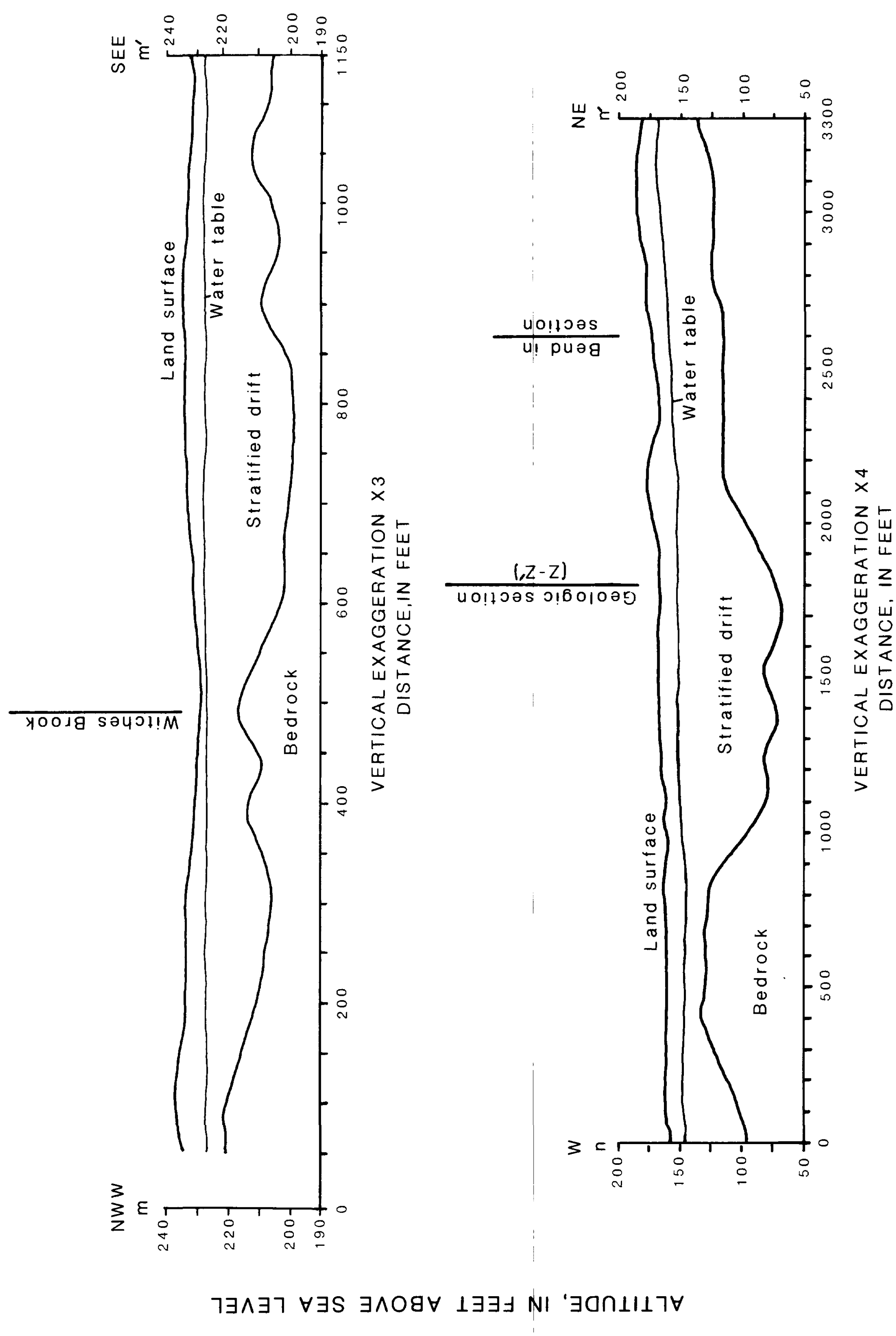


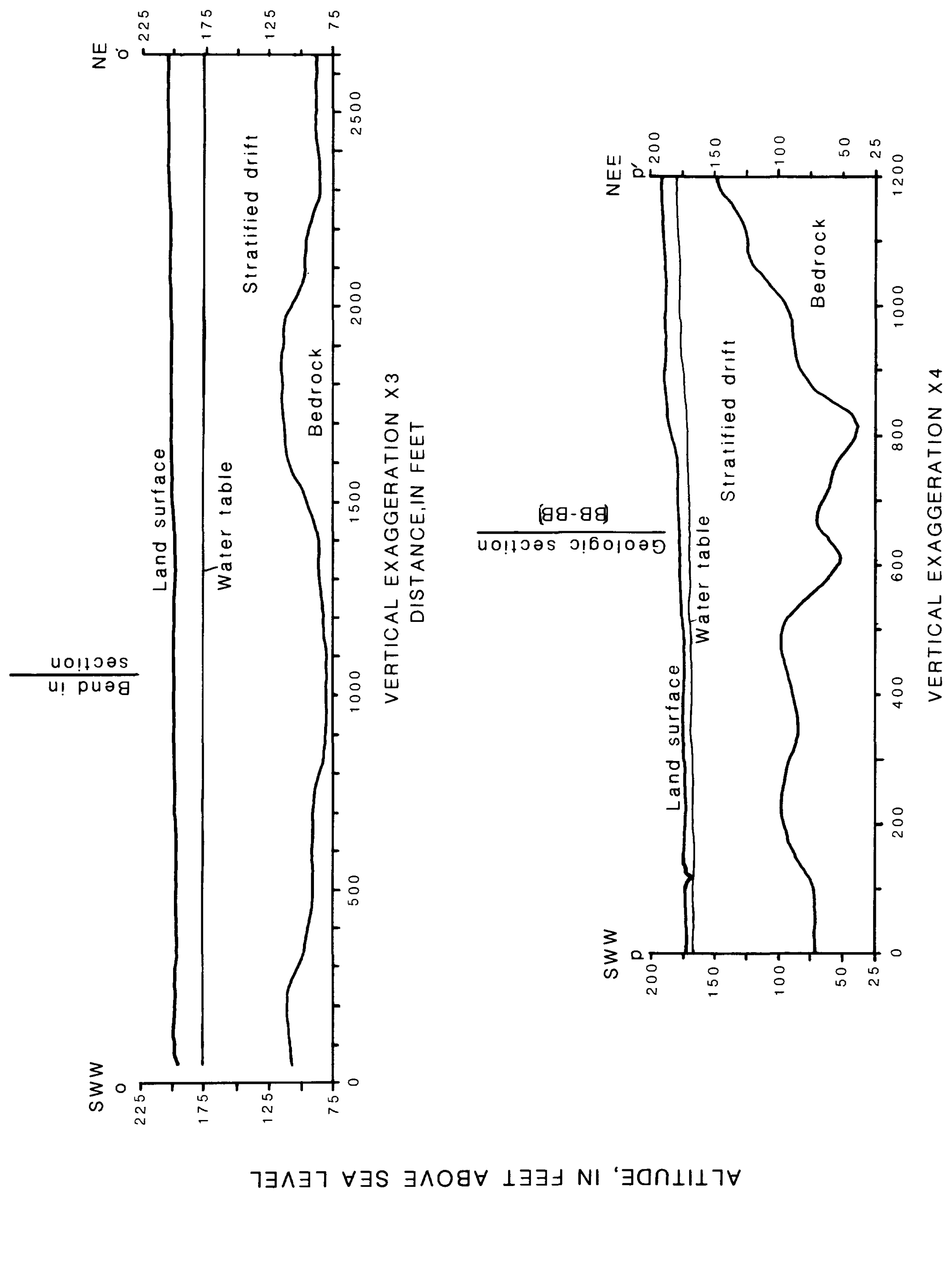
NW
g
SE
g′
Land surface
Water table
Stratified drift
Bedrock
Geologic section
(V-V′)
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
SW
h
NE
h′
Witches Brook
Land surface
Water table
Stratified drift
Bedrock
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL

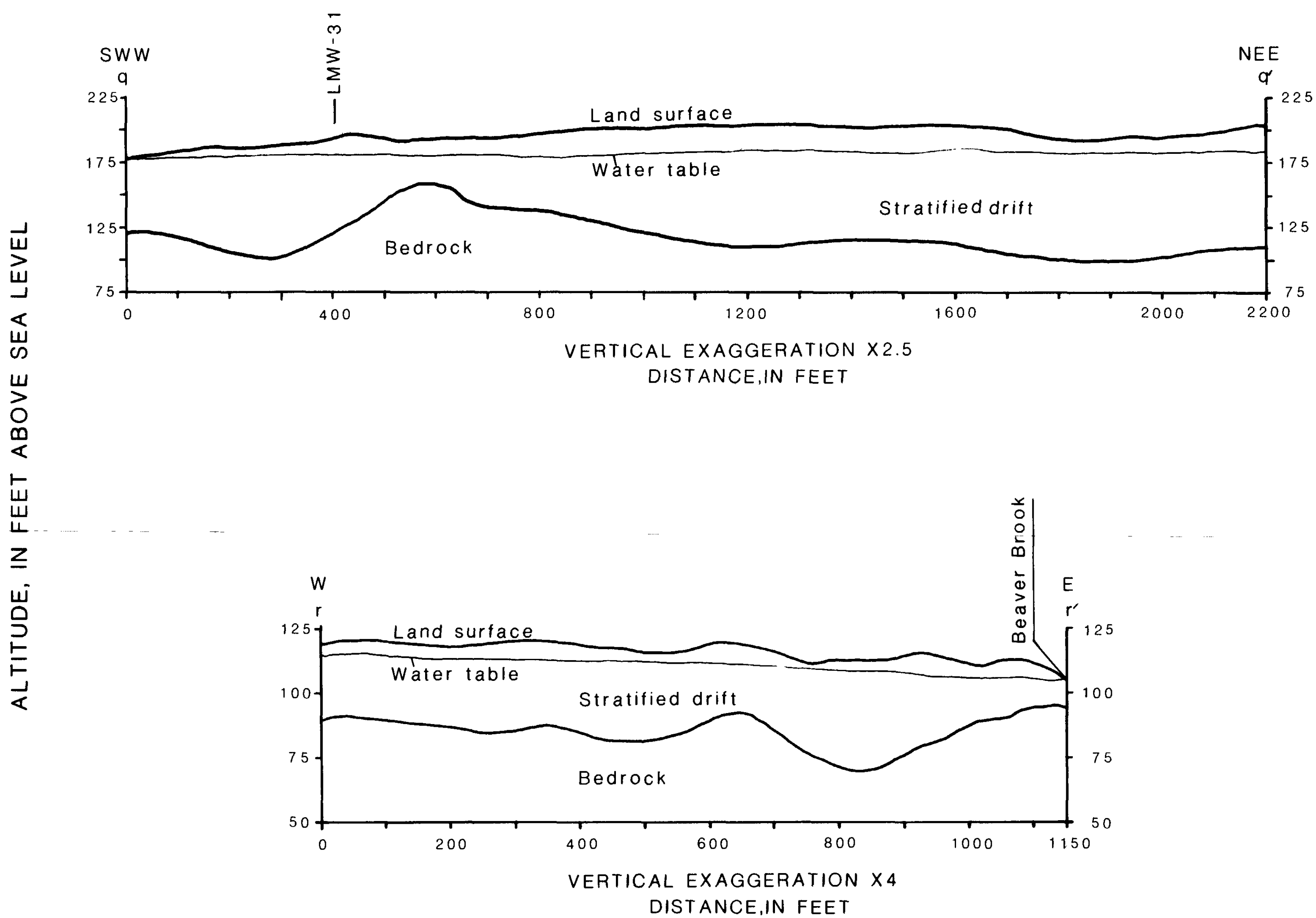


NWW
i
SEE
i′
Land surface
Water table
Bedrock
Flints Brook
(Swampy area)
Geologic section
(Y-Y′)
225
175
125
0
300
600
900
1200
1500
1700
VERTICAL EXAGGERATION X 4
DISTANCE, IN FEET
NW
j
SE
j′
Land surface
Water table
Stratified drift
Bedrock
Souhegan River
Geologic section
(I-I′)
220
200
180
160
140
0
100
200
300
400
500
VERTICAL EXAGGERATION X 2
DISTANCE, IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL

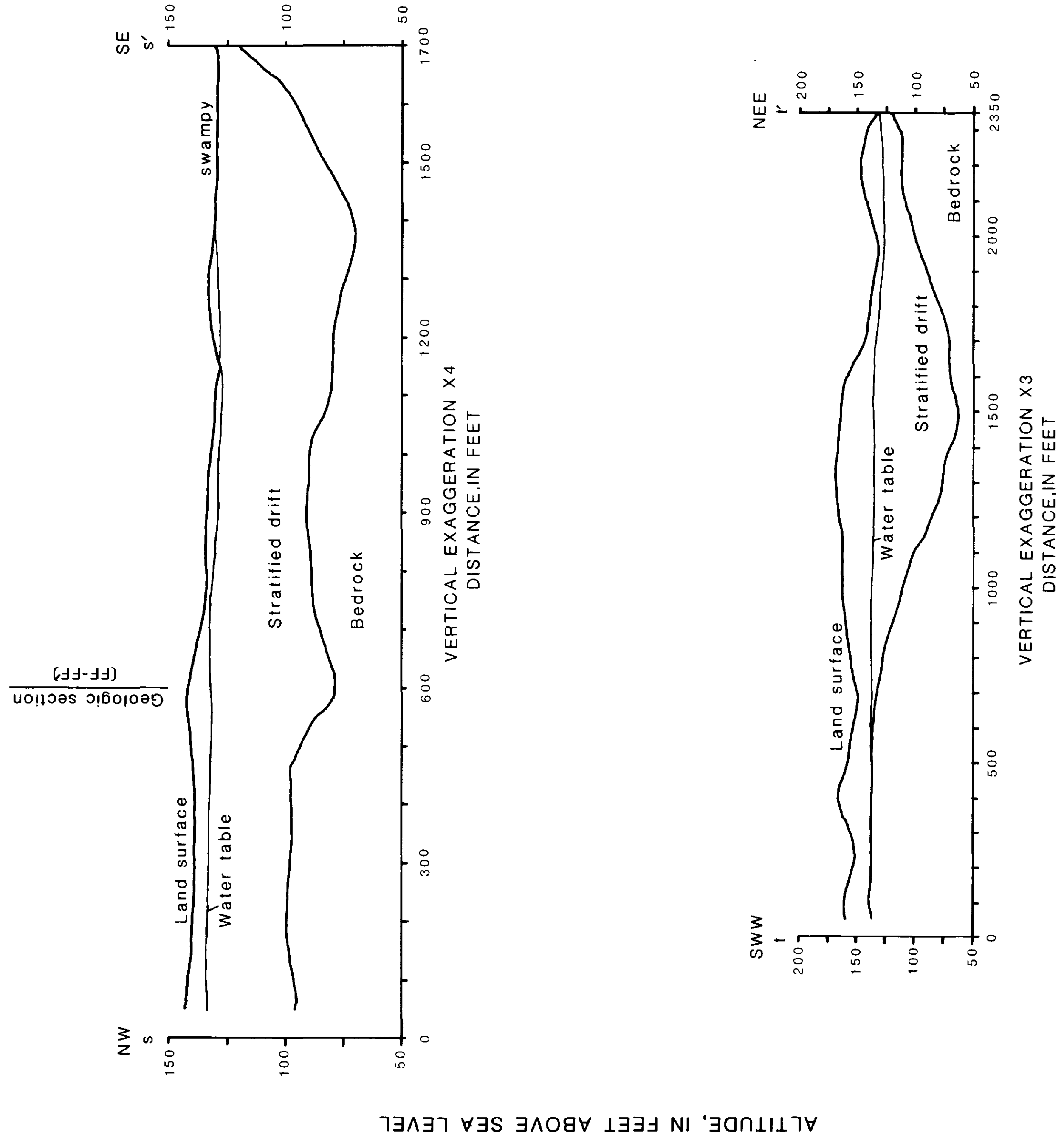

NW
k
SE
k′
Souhegan River
Land surface
Water table
Stratified drift
Bedrock
250
200
150
100
0
100
200
300
400
DISTANCE, IN FEET
NNW
l
SSE
l′
Baboosic Brook
225
175
125
75
0
400
800
1200
1600
2000
2200
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL

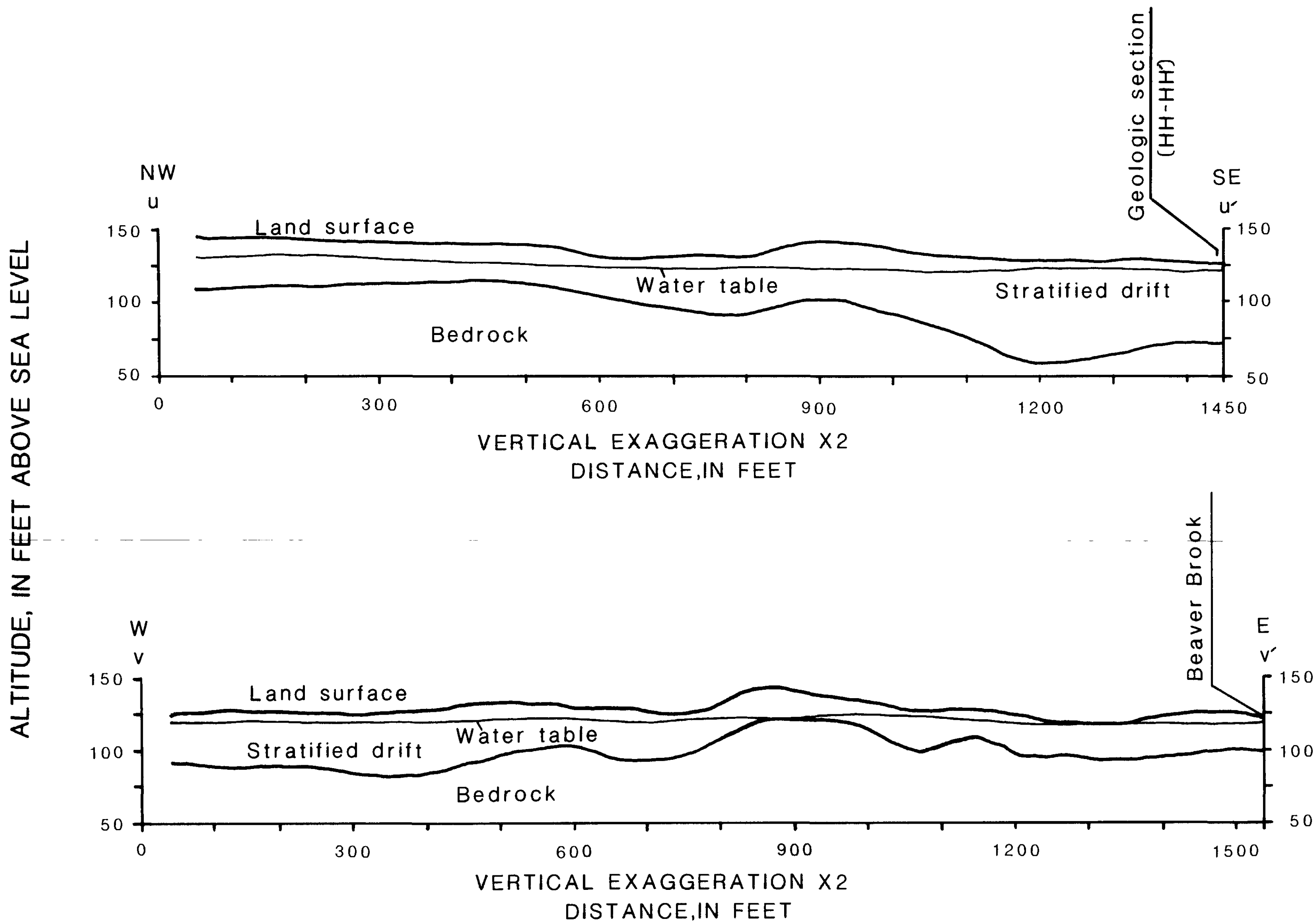

NWW
m
SEE
m′
240
220
200
190
Land surface
Water table
Stratified drift
Bedrock
Witches Brook
0
200
400
600
800
1000
1150
VERTICAL EXAGGERATION X3
DISTANCE, IN FEET
W
n
NE
n′
200
150
100
50
Land surface
Water table
Stratified drift
Bedrock
Geologic section
(Z-Z′)
Bend in
section
0
500
1000
1500
2000
2500
3000
3300
VERTICAL EXAGGERATION X4
DISTANCE, IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL


SWW
o
NE
o′
Land surface
Water table
Stratified drift
Bedrock
Bend in section
VERTICAL EXAGGERATION X3
DISTANCE, IN FEET
0
500
1000
1500
2000
2500
225
175
125
75
SWW
p
NEE
p′
Land surface
Water table
Stratified drift
Bedrock
Geologic section (BB-BB)
VERTICAL EXAGGERATION X4
DISTANCE, IN FEET
0
200
400
600
800
1000
1200
200
150
100
50
25
ALTITUDE, IN FEET ABOVE SEA LEVEL



ALTITUDE, IN FEET ABOVE SEA LEVEL
SWW
q
NEE
q′
LMW-31
Land surface
Water table
Stratified drift
Bedrock
225
175
125
75
0
400
800
1200
1600
2000
2200
VERTICAL EXAGGERATION X2.5
DISTANCE,IN FEET
W
r
E
r′
Beaver Brook
Land surface
Water table
Stratified drift
Bedrock
125
100
75
50
0
200
400
600
800
1000
1150
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET


NW
s
SE
s′
150
100
50
0
300
600
900
1200
1500
1700
Land surface
Water table
Stratified drift
Bedrock
swampy
Geologic section
(FF-FF′)
VERTICAL EXAGGERATION X4
DISTANCE,IN FEET
SWW
t
NEE
t′
200
150
100
50
0
500
1000
1500
2000
2350
Land surface
Water table
Stratified drift
Bedrock
VERTICAL EXAGGERATION X3
DISTANCE,IN FEET
ALTITUDE, IN FEET ABOVE SEA LEVEL


ALTITUDE, IN FEET ABOVE SEA LEVEL
NW
u
SE
u′
Geologic section
(HH-HH′)
Land surface
Water table
Stratified drift
Bedrock
150
100
50
0
300
600
900
1200
1450
VERTICAL EXAGGERATION X2
DISTANCE,IN FEET
W
v
E
v′
Beaver Brook
Land surface
Water table
Stratified drift
Bedrock
150
100
50
0
300
600
900
1200
1500
VERTICAL EXAGGERATION X2
DISTANCE,IN FEET